Assessing the Active Transportation Potential of Neighbourhood Models Using GIS

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

The last hundred years have seen tremendous changes in how Canadians move. As car use has grown, so too have the many health, social, and environmental impacts caused by motorized transport. Now, in a renewed effort to address these problems, planners are turning to alternative models of neighbourhood layout and design that promise to not only reduce car use but also to encourage active transportation, creating greener, healthier cities and towns for residents. Several such neighbourhood models exist, but which is best able to support active transportation is a regular matter of debate. To help address this problem, this study sought to answer the following question:

"How do neighbourhood models compare in terms of the characteristics known to affect active transportation rates, and which model is most likely to be able to facilitate active transportation as a result?"

Active transportation in this study considered two active modes: walking and biking. Five models were selected for inclusion in the study: two traditional models (the Grid and the Loop and Cul-de-Sac) and three alternative ones (the Fused Grid, New Urbanist, and the Greenway). Model principles and the design characteristics of case study neighbourhoods were described and design specifications for each model were developed. These specifications were then used to develop a GIS ("Geographic Information System")-based representation of an example neighbourhood for each model, which included the transportation network, lots of different land use types and densities, homes and destinations.

GIS, statistical and graph-based techniques were then used to assess and compare the models in terms of their potential to facilitate walking and biking through the built environment correlates identified in the literature review (such as connectivity and modal separation). The models were ranked on each variable, and then an overall comparison was made on the basis diversity (land use mix), density and design - the three dimensions identified by Cervero and Kockelman (1997) as being the key ways through which the built environment can contribute to creating walkable neighbourhoods. In order to ensure that these measures of the built environment would have a real effect on the walking or biking experience, a set of origins and destinations was created for each and the various aspects of possible trips between them (such as trip length) were calculated. Finally, several variables of importance to the

development community (such as total buildable area) were also included in order to make these results as useful as possible for decision-makers.

The results illustrated how each model's unique approach to facilitating walking and/or biking was reflected in the built environment characteristics assessed. While a model that was strong in one category was often weaker in another (a finding which echoes that of Filion and Hammond, 2003), the three alternative models (Fused Grid, New Urbanist and Greenway) consistently fared better than the more traditional Grid and Loop and Cul-de-Sac designs, with the New Urbanist scoring the highest on the overall evaluation of walkability and bikeability and the Greenway the best on network design for cyclists.

In practice, however, while knowing the active transportation potential of these models is useful for its ability to provide general direction for neighbourhood designs, it is not as useful for evaluating proposed plans, as these often deviate from model specifications, whether as the result of local topography, developer preference, municipal policies or street standards. As such, it is important for planners to be able to evaluate proposed designs. Their efforts are stymied, however, by a lack of tools for doing so. Most attempts to evaluate walk- or bikeability make use of indices, the majority of which are designed to assess only specific routes (rather than whole neighbourhoods) and which can only be used in pre-existing developments (at which point it is often too difficult and costly to make significant improvements to a design). An additional result of this study, then, is the model construction and analysis methodology itself, which can allow planners to use GIS to quickly and cost-effectively assess any design's inherent walk- and bikeability *prior* to plan approval. This study also provided an opportunity to explore and make recommendations concerning certain problems related to model design and analysis, including issues surrounding frame choice, the treatment of alleys, lot vs. density-based approaches to trip measurement, the alpha index and the effects of using the road network as a proxy for the active transportation network.

Research has shown that a latent demand for active transportation exists: that is, if neighbourhoods are designed to be more walkable and bikeable, people will walk and bike more (Lee and Moudon, 2004). The results of this study show that it is possible to create more walkable and bikeable neighbourhoods; that alternative models can consistently out-perform more conventional ones (though the means by which they do so varies); and that the use of a comprehensive set of well-developed built environment measures will enhance our ability evaluate proposed developments and to create neighbourhood designs which are more responsive to the needs of our changing society.

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Any errors are solely my own.

DEDICATION

CB

To my mother Annette and sister Courtney for years of unwavering faith, encouragement and support:
I could never have finished this without you.

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TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

The last hundred years have seen tremendous changes in how Canadians move. Since mass production of the automobile began in the early 1900s, much of the focus in urban planning has been on how to better accommodate vehicular traffic, leading to the severe degradation of the pedestrian environment and the creation of barriers to travel on foot and bike throughout urban areas around the world (NAHB et al., 2001; Southworth and Ben-Joseph, 2003; Forsyth and Southworth, 2008). Not surprisingly, car use has grown dramatically over the past hundred years, and as a result so too have the many health, social, and environmental impacts caused by motorized transport. Now, in a renewed effort to address these problems, planners are turning to alternative models of neighbourhood layout and design that promise to not only reduce car use but also to encourage active transportation, creating greener, healthier cities and towns for their residents.

Background

The benefits of active transportation modes such as walking or biking are well established. Regular exercise like walking or biking can help meet suggested minimum weekly levels of physical activity (Brownson et al., 2000; Brownson et al., 2001; Sharpe et al., 2004; Frank and Engelke, 2005) and has been shown to be reduce the risk of several different health problems such as obesity, heart attacks, diabetes, high blood pressure, osteoporosis, cancer, while promoting psychological well-being (OMOH, 1975; Klonoff, 1994; PHAC, 2004; Bassett et al., 2008). In addition to health benefits, walking and biking are both environmentally benign, especially compared to motorized vehicles (Olde Kalter, 2007). They are also less likely to cause fatal accidents (unless a motorized vehicle is also involved): it is easy to imagine that a collision between a cyclist and a pedestrian, a pedestrian and a pedestrian, or a cyclist and a cyclist is not likely to be deadly. Once a car is added into the mix, however, the results can easily prove to be fatal. Active transportation modes (and in particular walking) are also more equitable forms of transportation than driving, and the past emphasis on designing cities for cars has ignored the needs of the young (who cannot drive), the old (who often either cannot drive, or would prefer not to), the poor (who cannot afford to) and individuals with certain disabilities (who may be unable to).

In light of public health, safety and environmental challenges related to motorized transportation and the benefits offered by active transportation, many governments, public health organizations, community groups and members of the research community have been looking for ways to change travel behaviour in favour of active modes. Despite past efforts, however, active transportation rates in Canada remain quite low – only 6.4% of working Canadians walk to work, while a mere 1.3% bike (Statistics Canada, 2008a). Clearly, the failure to significantly reduce car use suggests that efforts to date have been inadequate, and that there is a need for a better understanding of how people can be encouraged to walk and bike.

Research has shown that a latent demand for active transportation exists: that is, if neighbourhoods are designed to be more walkable and bikeable, people will walk and bike more (Lee and Moudon, 2004). Developers, planners and municipal governments are limited, however, in which characteristics they can manipulate in order to create more walkable and bikeable neighbourhoods. These characteristics are often grouped into the three broad categories of ***density, diversity*** (land-use mix) and ***design***, also known as the "3 Ds" (Cervero and Kockelman, 1997). While density and diversity can be fairly narrowly defined and (to some extent) established through zoning and other tools, "design" is more ambiguous and can cover a wide range of neighbourhood elements, not all of which can be directly affected by a municipality (for instance, aspects such as cleanliness, good landscaping in yards, etc.). The most important aspect of "design" that cities have control over is the design of its transportation networks, which have an obvious connection to travel behaviour, are mostly publicly owned (Frank and Engelke, 2005), occupy a considerable portion of urban land (Mumford, 1961; Southworth and Ben-Joseph, 1997), are generally more or less evenly distributed and accessible to all residents of a city and which, once built, will be around for a long time (Hess, 2008). Thus, for municipal planners, the "3Ds" usually mean "diversity, density, and network design", and it is through these variables that walkability and bikeability are achieved.

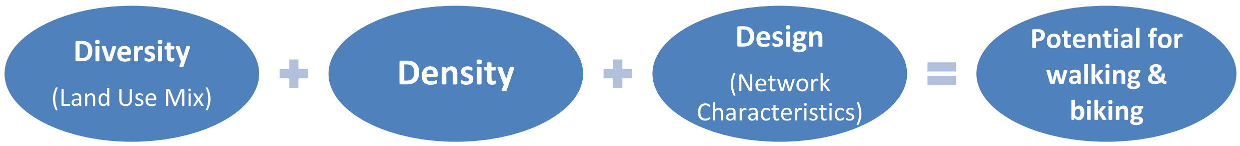
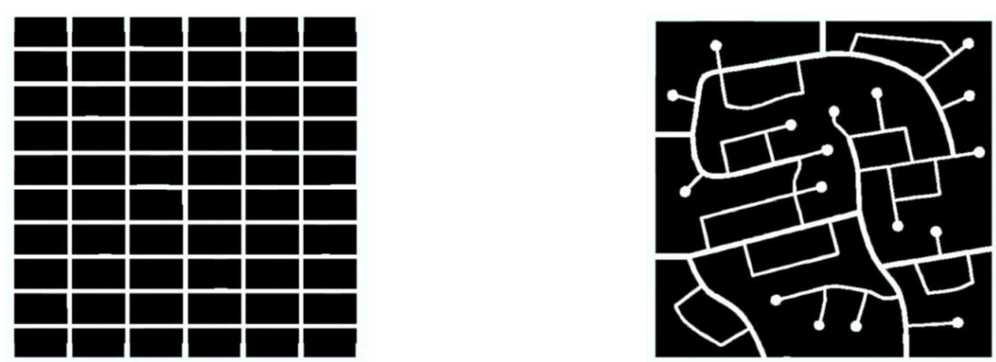


Fig. 1: The 3Ds

It is widely accepted that it is a combination of the 3Ds of "Diversity, Density and Design" which determine the walkability and bikeability of a neighbourhood. For municipal planners, the most important elements of design are those related to the transportation network.

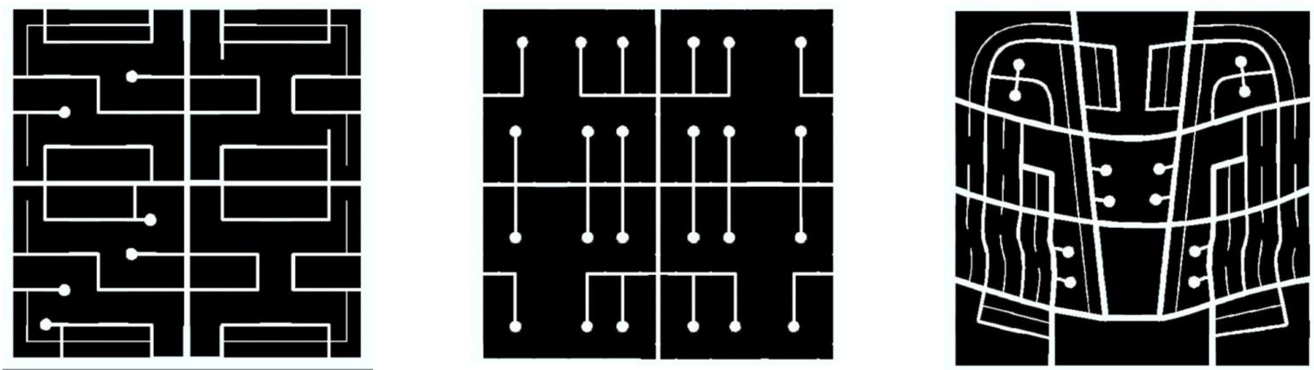
When coming up with designs for more walkable and/or bikeable neighbourhoods, planners are often guided by ***neighbourhood models***, which advocate for specific combinations of network layouts, density, and land use mix (the 3Ds). Historically, the most common of these models was the Grid (seen today in the downtown of most North American major cities) with its frequent, well-connected roads, however, this model has given way over the past several decades to the more disconnected Loop and Cul-de-Sac model, which has been blamed for much of the reduction in walking and biking rates (see Fig. 2 below). As a result, there has been a great deal of work done to develop new, alternative neighbourhood models that will better support active transportation. These models generally aim to do so by trying to improve upon or combine various aspects of the Grid and Loop and Cul-de-Sac models.



The Grid *Loop and Cul-de-Sac*

Fig. 2: Traditional models – the Grid (pre-1960s) and Loop and Cul-de-Sac (1960s on)

Three promising alternative models include the Fused Grid (which uses small parks to connect otherwise disconnected roads with trails), the New Urbanist (which put alleys and driveways behind homes in order to make a more continuous sidewalk network at the front) and the Greenway model (which moves roads behind homes and places a shared community trail in front of them) (CMHC, 2002; JLAF, 2010; Grammenos, 2008; Hess, 2008) (see Fig. 3 below).



The Fused Grid *Greenway* *New Urbanist*

Fig. 3: Alternative designs

A variety of research has been done to assess how different models affect active transportation rates (see, for instance, Lansing and Marans, 1970; CMHC, 2002, 2010; Lee and Ahn, 2003; Hawkins, 2007), and most have shown a positive relationship with either travel behaviour or the built environment characteristics known to be related to travel behaviour.

The research to date into these models has important limitations, however. Most past studies have tended to compare only two or three models at a time (for instance, see CMHC, 2002 and Lee and Ahn, 2003), and as such, it is difficult to compare the results of different models to one another across several studies, as different measurements may have been used. As well, the case study neighbourhoods often studied may be incomplete examples of the models that they were developed from, or may combine aspects of a couple of different models into one neighbourhood, making results difficult to interpret (see, for instance, Hawkins, 2007; Hess, 2008). While using case study neighbourhoods has the advantage of being able to study real transportation behaviours, the results can be confounded by individual characteristics of those making the trips (e.g., age, income, etc.) and residential self-selection (e.g., that people choose to live in a walkable community because they prefer to walk, and walking rates may appear higher as a result) (Kulkarni, 1996, as cited in Crane, 2000). Therefore, it is important to be able to evaluate the *inherent* potential walk- and/or bikeability of proposed neighbourhood models before they are translated into new developments, especially given that once developments are complete they are difficult and costly to retrofit.

Purpose & Research Question

Models are valuable tools in that they provide a useful way of communicating key ideas about design concepts. When it comes to designing a neighbourhood, planners have a number of models to choose from, including the conventional Loop and Cul-de-Sac, the older Grid and the more recent alternative New Urbanist, Fused Grid and Greenway models. All these models claim to support active transportation, despite considerable differences in their form and the approach they take to doing so. While these models are limited in that they do not *ensure* change in human behaviour, it is nevertheless important to understand what is possible in terms of creating the potential for active transportation within a neighbourhood design, before personal characteristics and residential self-selection come into play. In order to do so, this study will sought to answer the following research question:

"How do neighbourhood models compare in terms of the characteristics known to affect active transportation rates, and which model is most likely to be able to facilitate active transportation as a result?"

Research Objectives

In order to effectively address the research question, five research objectives were established:

1. Identify the characteristics known to be correlated with active transportation use
2. Identify and describe neighbourhood models aimed at facilitating active transportation and create a GIS-based model neighbourhood of each
3. Quantitatively and qualitatively assess the extent to which the built environment characteristics known to be correlated with active transportation use are incorporated (or not incorporated) into the models under consideration
4. Compare these models in terms of their potential to facilitate active transportation and identify the model most likely to be successful in this regard
5. Make recommendations regarding the use of these models in planning new neighbourhoods which are informed by the results concerning their active transportation potential and a comparison of additional built environment characteristics known to be of importance to the development community

Intended Audience

The questions addressed by this research will be of use to municipal governments and planners, developers, public health officials, environmental organizations and walking and cycling advocates.

CHAPTER 2: LITERATURE REVIEW

In order to assess the potential of a neighbourhood model to promote active transportation certain things must be known: what factors may affect travel behaviour, how they can be measured, the extent to which they are incorporated into the model and by what means.

This review is therefore broken into two parts: the first, an overview of common considerations in active transportation research which are relevant to this study (including theoretical frameworks, types of measurement and issues of scale) and findings to date regarding correlates of active travel behaviour; the second, an overview of active transportation networks and neighbourhood models, and methods for their analysis (with an emphasis on morphological analysis and GIS). This chapter has been heavily guided by the work of several researchers who have done reviews into the effects of urban form on travel behaviour (Crane, 2000; Ewing and Cervero, 2001; Saelens et al., 2003; Badland and Schofield, 2005; Handy, 2005; McMillan, 2005; Saelens and Handy, 2008; Heinen et al. 2010), on safety (Retting et al., 2003; Loukaitou-Sideris, 2006) and on public health (Frank, 2000; Frank and Engelke, 2005).

PART I: ACTIVE TRANSPORTATION RESEARCH & CORRELATES

Walking and biking are the least understood and most understudied modes of travel, with research into active transportation only have become mainstream since the mid-1990s (Agrawal et al., 2008; Krizek et al., 2009). Active transportation is an inherently interdisciplinary field, with significant contributions from the public health, recreation, transportation planning, and urban design disciplines (Sallis, 2009). Much of the research has sought to explain people's travel decisions and how those decisions are affected by changes in the built environment. Studies into active transportation vary in their theoretical frameworks, the types of trips or populations being considered, their scale and their methodologies. Despite this diversity, many share similar methodological challenges, including the issues of residential self-selection (Krizek, 2003b; Handy et al., 2006), multicollinearity of urban form variables (Handy, 1996a; Saelens et al., 2003) and a lack of datasets related to active transportation networks (Ewing and Cervero, 2001; Hawkins, 2007).

Theoretical Frameworks

Utility maximization theory, which states that people seek to further their own self-interest, has historically been the most common theoretical framework used in transportation planning (McFadden, 2002; Moudon, 2005; Heinen et al., 2010). Even though utility maximization deals with "cost" in a general sense, most research using this model has focused on easily quantifiable travel costs, such as time and the monetary cost of making trips, rather than more difficult to quantify costs such as "comfort" or "convenience" (Handy, 2005). While the theory recognizes the contribution of personal choices and characteristics, these factors are not typically included in the resulting models due to the difficulty of measuring them (Handy, 2005). Thus, in most studies, the cost of a trip is measured as distance, time, or by a dollar value (see, for instance, Crane, 1996b; Agrawal and Schimek, 2007; McMillan, 2007). Travel is seen only as a means to an end (Greenwald, 2003). This has led to critique of the framework insofar as it relates to active transportation, as walking and biking are often seen as having utility (by providing an opportunity for exercise or recreation), and therefore, can act as ends in and of themselves (see Salomon and Mokhtarian, 1998; Mokhtarian and Salomon, 2001; Mokhtarian et al., 2001). Utility maximization theory also accounts poorly for the effects of habits, constraints and beliefs on behaviour (Heinen et al., 2010; see also subsequent theories developed by Goodwin and Hensher, 1978, and Ajzen, 1991).

Consequently, there has been a steady shift over the past decade towards a greater use of socio-ecologic models, which had thus far been more commonly used in the public health field (Lee and Moudon, 2004; Handy, 2005). These models suggest that a combination of environmental and psychosocial variables will best explain physical activity (Sallis and Owen, 2002; see also Duhl and Sanchez, 1999), and therefore take into consideration a greater range of variables across multiple levels (such as individual/interpersonal, community, organizational and intercultural) that may affect an individual's travel decisions (McLeroy et al., 1988; Sallis and Owen, 1997; Sallis and Owen, 2002; Moudon, 2005). Reviewers have recommended the use of socio-ecological models in future transportation research (Lee and Moudon, 2004; Handy, 2005), and as such, this is the framework that will be used in this study.

Classifying and Measuring Travel Behaviour

Because of the interest in encouraging some modes of travel over others, travel is almost always classified according to mode (e.g., walking, biking, etc.). Travel behaviour is also often broken down by type of trip (usually utilitarian or recreational) (Buchanan, 1964; Frank and Engelke, 2005; Saelens and Handy, 2008), although this breakdown is not always so clear-cut (Mokhtarian et al., 2001). Utilitarian (and sometimes recreational) trips occur between distinct origin and destination pairs (OD pairs), and are therefore often also classified by the type of destination (work, non-work, school, retail, etc.). Active transportation is sometimes classified according to intensity of activity (light, moderate or vigorous), as there exists a dose-response relationship between intensity and health benefits (Frank and Engelke, 2005). Common measurements of travel include total distance traveled; trip frequency, trip length, route choice and modal share (Krizek et al., 2009). What is considered a trip and what trips are counted in a study can have important implications on research results (VTPI, 2008b).

Scale of Study

The appropriate scale at which to study study walk- and bikeability (here defined as the ability of the built environment to facilitate travel by the given mode) is dependent upon what constitutes a walk- or bikeable distance. Since Untermann (1984) found that the number of people willing to walk decreases dramatically after 0.5 miles, much research into walkability has limited itself to the study of short-distance or exclusively non-work trips, and thus focused on residential streets and areas (Mehta, 2007), schools (Niece, 2006) or shopping areas (Handy, 1996c). While it is almost certainly true that local trips are more likely to be influenced by the immediate neighbourhood than by more distant ones (Hawkins, 2007), and that smaller scales of analysis are better predictors of physical activity behaviour (Coutts, 2008), limiting research to the local neighbourhood ignores regional network patterns and their potential effect on active transportation. Boarnet and Greenwald (1999) found that regional factors can actually show dominant associations with travel patterns, further suggesting that their effect should not be underestimated (see also Handy, 1992; McNally, 1993; Cervero and Gorham, 1995). Some subsequent research has also indicated that some people may be willing to walk further than the oft-quoted 0.5 miles (see, for instance, Agrawal and Schimek, 2007; Agrawal et al., 2008) and that the distance people are willing to walk may vary considerably between cities (Zacharias, 2001). Thus, it would appear that much walkability research to date may have been too limited in its scope.

What constitutes a bikeable distance is even less-well established in the literature. Looking at cycling in the European Union, Hydén et al. (1998) suggested that trips shorter than 5 km could easily be covered by bicycle, while in their study of Austrian residents, Titze et al. (2008) found that the average cycling distance was 3.2 km. Howard and Burns (2001) found that distance varied with gender, with women biking 6.6 km to work while men would bike an average of 11.6 km. Because cyclists can travel longer distances at higher speeds than pedestrians, they require longer corridors (Krizek et al., 2009) which may not be effectively captured at the neighbourhood scale.

Studies have usually limited themselves to a “walkable” or “bikeable” distance by constraining the size of proposed neighbourhood models (Grammenos, 2008) or by creating buffers that contain an area believed to be walkable (usually a set distance or a distance based on travel time by a given mode) around the units of observation (most often households, but sometimes specific features such as trails or commercial centres) (see, for instance, Greenwald, 2003; Lee and Moudon, 2006; Hawkins, 2007;

Coutts, 2008; Saelens and Handy, 2008; Cho et al., 2009). Similarly, because of the interest in travel from home, a great deal of research has been done at the neighbourhood scale. This is complicated by the many definitions of a neighbourhood and the fact that "neighbourhoods" as a concept do not typically have fixed boundaries (Giles-Corti et al., 2005; Saelens and Handy, 2008). Some studies have defined neighbourhoods by using pre-existing transportation analysis zones or census tracts. Krizek (2003) warned that selecting too large an area can result in ecological fallacies, in which averaging the data from thousands of households may obscure the effect of the immediate locale. Creating artificial boundaries, on the other hand, can leave out some features which may actually be considered part of "the home range" for residents but fall just outside the border (Hawkins, 2007) or result in edge effects (Tresidder, 2005).

Correlates of Active Transportation

Knowing what factors are associated with travel behaviour is vital to determining what sort of policies and design interventions might help facilitate active transportation (Saelens and Handy, 2008; Heinen et al., 2010). The factors known to be related to (and generally believed to affect) active transportation can be broken down into two broad categories: internal characteristics (including personal and household) and external characteristics (including the built environment, safety, culture, the physical costs of travel, etc.)

Both built environment and socioeconomic factors show some relationship to travel mode choice (Craig et al., 2002; Frumkin et al., 2004). Socio-demographic characteristics typically have a greater influence on trip frequency, while urban form characteristics have a greater effect upon trip lengths (Ewing and Cervero, 2001).

The strength of an association (though rarely direction) varies by trip type (Cervero and Kockelman, 1997; Saelens and Handy, 2008); for instance, urban form has been found to be more important in utilitarian trips than recreational ones (Handy, 1996b, 1996c; Troped et al., 2003). Associations may also vary with personal characteristics (Agrawal et al., 2008; Bungum et al., 2009) and mode (Southworth, 2005; Zahran et al., 2008). This variability in the strength of relationships for different types of trips or populations makes broad statements about the precise importance of any given correlate difficult (if not, indeed, impossible).

Most studies looking at correlates have made use of statistical regression in addition to simple correlation (see, for instance, CMHC, 2010); the better ones controlling for various sociodemographic characteristics while doing so (Saelens and Handy, 2008). One of the limitations of these studies has been the almost exclusive use of linear regression models for testing variables, even though there is reason to believe that some variables (age being an excellent example) would exhibit a non-linear relationship with active transportation (Frank et al., 2008).

While there exists a substantial literature on the correlates of walking, studies into those of cycling have been rather scarce (Titze et al., 2008).

Personal and Household Characteristics

While urban form characteristics are generally of the greatest interest to planners because they fall within their direct influence or control, personal characteristics are often as important (if not more important) in their effect on travel behaviour (Black, 1990; Sorton and Walsh, 1994; Epperson et al., 1995; Cervero and Kockelman, 1997; Kockelman, 1997; Hess et al., 1999; Ross, 2000; Hawkins, 2007). Personal and household characteristics known to be tied to travel behaviour include age (GFG, 1998; NHTSA, 2003), gender (Bungum et al., 2009), income (Trost et al., 2002; Hanson and Chen, 2007), employment status (Ryley, 2006), ethnicity (Grieco et al., 1994), level of educational attainment (Rietveld and Daniel, 2004; Plaut, 2005; de Geus, 2007), household size and presence of children (Sternfeld et al., 1999; Dieleman et al., 2002), car ownership (Kain and Fauth, 1976; Kitamura et al., 1997; Crane and Crepeau, 1998; O'Regan and Quigley, 1998; Hawkins, 2007), having a disability (Blazey, 1992; Zimmer et al., 1995), social status (Moudon et al., 2005; Ryley, 2006) social support (Trost el al. 2002; De Bourdeaudhuij et al., 2005; Titze et al., 2007; de Geus et al., 2008), attitudes and social norms (Kitamura et al., 1997; Stinson and Bhat, 2005; Dill and Voros, 2007), self-perception, self-efficacy (Kendzierski and DeCarlo, 1991; McAuley, 1992; 1993; Sallis et al., 1992; Calfas et al., 1994; Moritz, 1997) and perception of an area's walkability (Handy, 1996c; Cho et al., 2009).

For cyclists, experience and comfort level riding in mixed traffic are important (Hunt and Abraham, 2007; see also Sorton and Walsh, 1994; Antonakos, 1994). Gender appears to play a more important role when it comes to biking than for walking, with men being far more likely to be cyclists than women (up to four times as likely in some studies) (Krizek and Roland, 2005; Krizek et al., 2005;

Heinen et al., 2010; see also Landis et al., 2003; Stinson and Bhat, 2003). This appears to have a strong relationship with women's perception of safety (Emond et al., 2009) and household responsibilities such as picking up children or shopping (Dickinson et al., 2003).

External Characteristics - Urban Form and the Built Environment

The built environment is defined as encompassing "all of the physical structures and elements of the human-made environments in which we live, work, travel and play" (Frank and Engelke, 2005, p. 194). The characteristics of the built environment are commonly broken down into the "3Ds" of density, diversity (land-use mix) and design, as first proposed by Cervero and Kockelman (1997) in their study of travel behaviours in the San Francisco Bay area.

As a part of their study, Cervero and Kockelman were able to use factor analysis to demonstrate that the 3Ds were all related, both individually and collectively, to travel behaviour (in their case, mode choice) in statistically significant ways. Their work was also notable because they able to show that the 3Ds could be used to effectively define the otherwise "somewhat obtuse concept of 'built environment'" (Cervero and Kockelman, 1997, p. 217) in terms of these three distinct dimensions. Since then, the 3Ds have gained wide acceptance as the principal dimensions through which the built environment affects travel behaviour. Many researchers studying the relationship between active transportation and the built environment have used the 3Ds as a means of framing their choice of built environment measures to include in their work (see, for example, Frank et al., 2005, 2009; Kuzmyak et al., 2006; and Sundquist et al., 2011) and even among those studies that have not explicitly done so, the vast majority include a measure of at least one (if not all three) of the Ds.

The majority of those studies have found weak to moderate associations between these three dimensions of the built environment and active transportation, but some findings have been inconclusive or shown no relationship at all (Boarnet and Sarmiento, 1996; Crane, 2000; Ewing and Cervero, 2001; Frank and Engelke, 2005; Lindsey et al., 2008). For instance, McMillan (2005, p. 442) found in her review of the literature that research "suggests that the accessibility of the pedestrian infrastructure (focusing on the presence, quality, travel distances, and route options) is associated with walking behavior" but that others remain skeptical, concluding that "little verifiable evidence supports the contention that changes in urban form will affect travel as intended at the scale proposed" (Crane, 2000, p. 3). Crane (2000) also noted, however, that in many cases there are methodological weaknesses in studies which have found no relationship, and so it is possible one may be present even where it has not been found. And even though many urban form characteristics show weaker relationships than other variables (such as car ownership), urban form will always define what travel is *possible* in the physical sense (regardless of, for instance, the price of gas or a person's age), and has a powerful influence over those factors often of greatest concern to pedestrians and cyclists, such as travel distances, times and safety.

The following section will review the correlates of active transportation related to the "three Ds" of density, diversity (land use mix) and design. For the purposes of this review, "design" will be restricted to those elements related to network design, as this is the design element likely to have the greatest impact on active transportation potential and because a full review of the "design" dimension (including such elements as architecture, street trees, etc.) is not possible within the scope and timelines of this study.

Built Environment Characteristics: Density and Land Use Mix

Density and land use mix are almost always found to be positively correlated with active transportation rates (Frank, 1994; Frank and Pivo, 1994, 1995; Handy, 1996b; Kockelman, 1997; Handy and Clifton, 2001; King et al., 2003; Lee and Moudon, 2006; Hawkins, 2007; Litman, 2007; Coutts, 2008; Parkin et al., 2008; Zahran et al., 2008; see also reviews by Steiner, 1994; Ewing and Cervero, 2001; Saelens et al., 2003; Saelens and Handy, 2008). There is some debate as to the strength of the associations, however, with some believing them to be moderate while others maintaining that they have only ambiguous, weak, or non-existent effects on auto use or walking, except in comparisons of communities on the extreme ends of either spectrum (e.g., Crane, 1996b, 2000; Gordon et al., 1991; Giuliano and Small, 1993; Badoe and Miller, 2000; Boarnet and Crane, 2001). For land use, in some cases a higher land use mix may not have much effect on trip lengths or mode choice if residents consistently choose more distant facilities (Handy and Clifton, 2001), even though it still provides residents the option to access local facilities, at least.

The benefits of density and land-use are essentially synergistic, and either, without the other, would likely have only a limited effect on travel (Lynch, 1981; Cervero, 1989; Krizek, 2003a; Coutts, 2008). While the connection between land use and active transportation is fairly intuitive (people will only walk if there is somewhere to go), the relationship with density is less clear and less direct (see

Frank and Pivo, 1994, 1995; Churchman, 1999; Forsyth et al., 2007). It seems unlikely that people value walking in dense areas for density's sake, so density is believed to contribute to active transportation by:

1) Enhancing the potential for public transportation (which in turn is necessary in order to reduce the need for car ownership) (Cervero and Gorham, 1995; CMHC, 2000; Newman and Kenworthy, 2006)

2) Reducing the ease of travel and parking by car (Hess, 2001; Taylor, 2002)

3) Increasing the number of active users potentially travelling through a space, which has been shown to encourage others to do the same (Zacharias, 1997) and to improve their safety from motorized traffic (Jacobsen, 2003)

It is noted that while density is correlated with the type of trip (e.g. purposeful travel vs. leisure), it has not always been found to be correlated with overall walking or total physical activity (Forsyth et al., 2007). However, since one of the main goals of promoting active transportation is to reduce the amount of pollution created by motorized modes, even shifting of the types of trips people walk or bike for can have important positive effects.

It may be that dense areas result in more walking because they also tend to have a greater variety of land uses and better connected street network (an example of spatial multicollinearity, a common problem in research), thereby increasing proximity to destinations (Saelens and Handy, 2008), because they value the presence of crowds (see, for instance, Zacharias, 1997), or because it makes travel by car more difficult (Ewing and Cervero, 2001). Recreational walking is not positively, or possibly not at all, related to density (Saelens and Handy, 2008). It is possible that residents in low-density neighbourhoods do a greater amount of recreational walking to make up for lower rates of utilitarian walking (Rodríguez et al., 2006; Oakes et al., 2007). More study is needed, but if this proves to be true, then it may be that the overall benefits of good urban form on public health may be negligible, in which case the biggest benefit of active transportation would be in its ability to decrease more polluting motorized travel.

Proximity

Proximity is defined as "how close different travel destinations are to one another in space" (Frank and Engelke, 2005, p. 198), and is a function of density and land-use mix (Saelens et al., 2003). In the context of this study it refers to the direct "as-the-crow-flies" (Euclidean) distance between two locations.

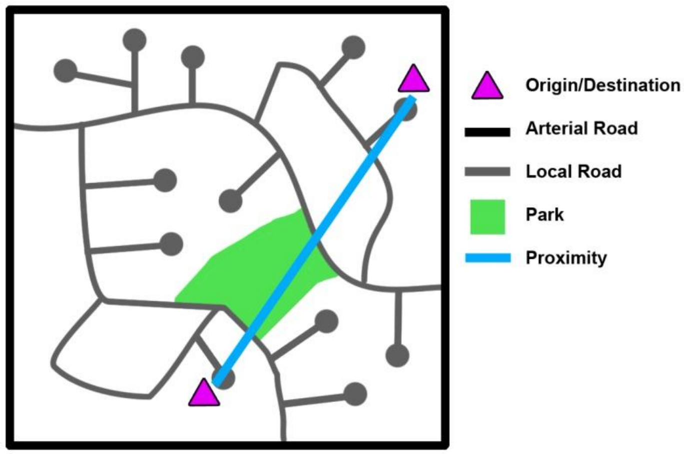


Fig. 4: Proximity is the direct distance between two locations

Travel distance (a proxy of travel time) is the urban form-dependent characteristic most consistently associated with travel behaviour, and is negatively associated with choosing active transportation modes (Moudon et al., 1997; Handy et al., 1998; Frank and Engelke, 2001; Greenwald and Boarnet, 2001; Troped et al., 2001; Saelens et al., 2003; Zacharias, 2005; Pucher and Buehler, 2006; Krizek and Johnson, 2006; Berke et al., 2007). Non-motorized modes of transportation are more sensitive to distance than motorized modes, as they are generally slower moving and therefore their travel times are more affected by changes in distance (Moudon et al., 1997; Marshall, 2005). It also likely has a disproportionate effect on active modes because of the physical effort required (van Wee et al., 2006). Not surprisingly, Agrawal et al. (2008) found that minimizing walking distance was the single most important factor influencing route choice for light rail commuters trying to get to the station.

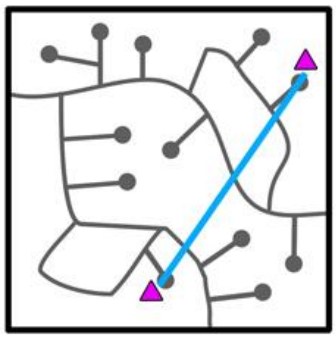
The proximity of a person to a transportation network can matter, much in the same way as proximity to a destination. Troped et al. (2001) found that the farther away a home was located from a rail-trail, the less likely the residents were to use the trail (see also King et al., 1992; Lindsey et al., 2001).

Built Environment Characteristics: Design Characteristics

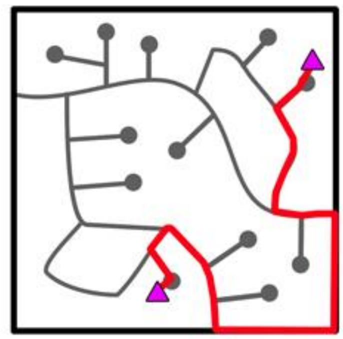
The relationships between design characteristics and active transportation have been far more variable and difficult to interpret than those of land use and density. Those that have shown the greatest connection to travel behaviour are those that affect travel times or improve safety. Aesthetics and amenities very rarely have anything more than a weak relationship with travel behaviour, while some network characteristics, such as modal separation and legibility, are believed to be important but have been studied too little to determine their effect. Those design characteristics believed to be most important to travel are described below.

Network Connectivity

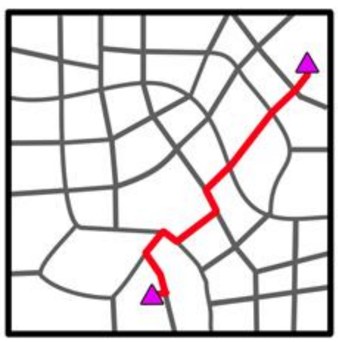
Connectivity refers to "the number and directness of transportation linkages between destinations" (Frank and Engelke, 2005, p. 198). If proximity is the absolute distance to a destination, connectivity is an attempt to measure how direct the trip to actually reach it is (network distance) and the number of route options available. High-connectivity networks provide more route options for travelers and (in most cases) shorten the trip distance between locations (Saelens et al., 2003; Frank and Engelke, 2005; Saelens and Handy, 2008). Connectivity is dependent upon network layout and design: fine-grain grid networks have high connectivity, whereas neighbourhoods made up of many loops and cul-de-sacs typically have low connectivity (Saelens et al., 2003).



Proximity (direct distance)



Network distance on a low connectivity network



Network distance on a higher connectivity network

Fig. 5: Proximity vs. connectivity

Given the importance of minimizing (utilitarian) trip lengths (Gärling and Gärling, 1988; Agrawal et al., 2008), it is not surprising that connectivity has been consistently found to be related to travel behaviour, although the strength of that relationship varies between studies (see, for instance Parajuli et al., 1996; Moudon et al., 2005; Hawkins, 2007; Hunt and Abraham, 2007; Lee and Moudon, 2008; Titze et al., 2008). If greater connectivity did not affect walking or biking trip frequency, then it could decrease total distance walked. Fortunately, there are significant positive associations between household walking trip rates and connectivity (Pierce et al., 2006; Moudon et al., 2007). Where pedestrians are offered a more direct route, there tends to be greater pedestrian travel, both in terms of total distance and modal share (Hawkins, 2007).

It is also possible for different networks (e.g., pedestrian vs. vehicular) to have different levels of connectivity. This is known as differential connectivity (see Fig. 6 below).

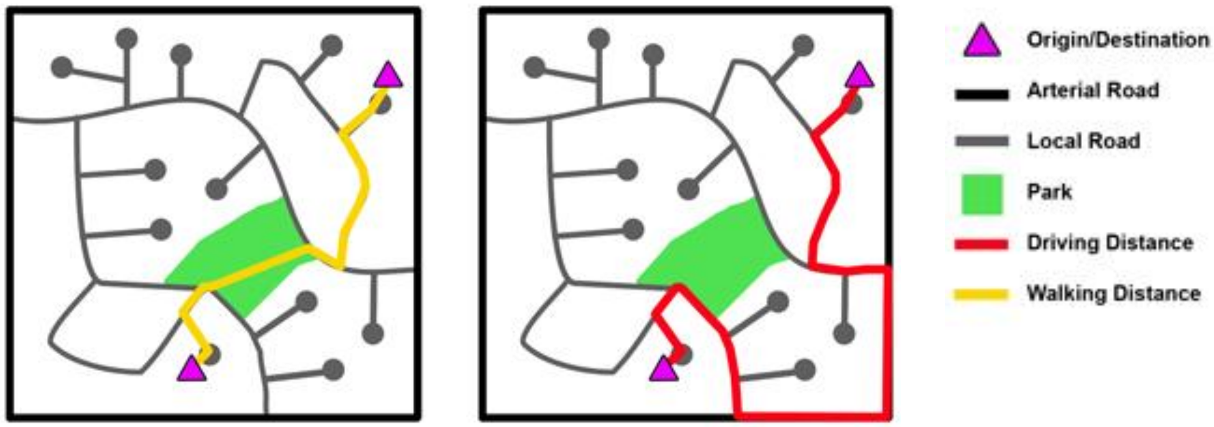


Fig. 6: Differential connectivity

Since pedestrians and cyclists can make use of park trails, their network has higher connectivity and the trip distance between the two locations becomes shorter (left). Cars, on the other hand, must take a longer way around to travel between the two points (right).

Hawkins (2007) found that street networks with differential connectivity encouraged travel by the favoured mode, and in some cases, *differences* in connectivity were found to be more important than connectivity in and of itself. Most neighbourhoods built in the past hundred years have had more or less identical parallel networks for pedestrians, cyclists and cars, and similar connectivities as a result.

Measuring connectivity

There are a number of different measures used to capture connectivity (see Table 1, below) (Randall and Baetz, 2001; Dill, 2004). Connectivity can be difficult to measure because the concept embodies trip length as well as route choice (Dill, 2004). As a result, some measures capture one of these two components better than the other (or not at all), and there is debate as to which measures are best.

Table 1: Connectivity measures used in active transportation research

Category	Measure	Definition	Used by	Captures (trip length or route choice)	Advantages/ Disadvantages	Optimal Values
Network feature density-based	Intersection density	Number of intersections per unit of area	Cervero and Radisch (1996); Cervero and Kockelman (1997); Reilly (2002) Dill (2004); Tresidder (2005); LUTAQH (2005); Cho et al. (2009)	Both	Easy to calculate and to use for standards; need to define what qualifies as an intersection	Higher is better
	Street density	Length of street per unit of area	Handy (1996); Mately et al. (2001); Dill (2004); Tresidder (2005)	Both	Easy to calculate and to use for standards	Higher is better
	Block density	Number of blocks per unit area	Cervero and Radisch (1996); Cervero and Kockelman (1997)	Both	Easy to calculate and to use for standards	Higher is better
Distance-based	Effective walking area	Lots within ¼ mile walking distance of origin point / lots within ¼ mile radius	INDEX model for Tampa Bay, Florida (described by Dill, 2004)	Trip length	Need to select origin point, making it difficult to use in policy Captures impact on trip distance better than density measures	Higher is better (max. value of 1)
	Network travel distance	Travel distance along the network (average, maximum, or percent above or below a threshold) between an origin (or origins) and a destination	Aultman Hall et al. (1997); Filion and Hammond (2003)	Trip length	Requires OD pairs; subject to neighbourhood boundary effects (closest grocery store may be in next neighbourhood over)	Lower is better (average, maximum, below threshold)
	Route directness	Ratio of actual travel distance to Euclidean distance between two points	Hess (1997); Moudon et al. (1997); Gauthier (1999); Engelke et al. (2000); Randall and Baetz (2001); Lee and Ahn (2003); Southworth (2005); Hawkins (2007); CMHC (2010)	Trip length	Need to establish logical origin/destination (OD) pairs Captures impact on trip distance better than density measures Same as "circuity factor" used in logistics (Ballou et al., 2002; Dill, 2004)	Lowest (and best) possible value is 1
	Metric reach	The length of street that can be reached travelling in all possible directions from a given point up to a set threshold distance	Peponis et al. (2007; 2008)	Route options	Innovative use of street midpoints to replace need for OD pairs	Higher is better

(Adapted from Dill, 2004; Tresidder, 2005)

Table 1: Connectivity measures used in active transportation research (continued)

Category	Measure	Definition	Used by	Captures (trip length or route choice)	Advantages/ Disadvantages	Optimal Values
Graph-based	Connected node ratio	# intersection nodes / total nodes	Allen (1997); Song (2003); Dill (2004); Tresidder (2005); Cho et al. (2009)	Route options	Would not differentiate between T- and X- intersections Does not consider distance between nodes	Higher is better (max. value of 1)
	Link-node ratio	# links / # nodes (including cul-de-sac nodes)	Ewing (1996); Dill (2004); Tresidder (2005)	Route options	Does not consider distance between nodes	Higher is better
	Gamma index	# links / 3*(#nodes – 2)	Tresidder (2005)	Route options	Essentially the number of links in the network relative to the maximum possible number of links (better representation of air, train networks) Does not consider distance between nodes	Higher is better (max. value of 1)
	Alpha index	(# links - # nodes) + 1 / [2*(# nodes) – 5]	Tresidder (2005)	Route options	Compares the number of circuits to the maximum possible number of circuits Dill (2004) recommended this as a good measure of route options	Higher is better (max. value of 1)
Pattern-based	"Gridiness"	% grid Or Grid-dummy variables	Boarnet and Crane (2001); Greenwald and Boarnet (2001) Crane and Crepeau (1998); Messenger and Ewing (1996)	Both (but poorly)	Does not differentiate between superblock vs. fine-grained grid	Higher is better "grid" better than "not-grid"
Dimensional	Average block length	Sum of link length per unit of area / # of nodes per unit of area	Cervero and Kockelman (1997); Tresidder (2005)	Both	Easy to calculate and to use for standards	Shorter is better
	Average block size	Mean or median area or perimeter	Hess et al. (1999); Reilly (2002); Song (2003)	Both	Easy to calculate, more flexible as a design standard	Smaller is better

(Adapted from Dill, 2004; Tresidder, 2005)

Dill (2004) and Peponis et al. (2007) found that several connectivity measures are strongly positively correlated (intersection density, street network density, metric reach, street density, intersection spacing, link-node ratio and connected node ratio). A notable exception was the link-node ratio, likely because, as a graph-based measure, it is not dependent upon the spacing or size of blocks and intersections.

Tresidder (2005) looked at the impacts of using buffers vs. census tract borders for eight connectivity measures in a GIS. The use of buffers for assessing connectivity proved challenging because the border would terminate road segments before they reached a node, changing some of the connectivity measures (and in particular intersection density) by as much as 36% (though Tresidder was able to make corrections for most of these problems).

Probably the single most common problem in assessing the effects of connectivity for walking and biking, though, is the lack of map data showing the locations of the active transportation networks. As a result, the majority of studies have had to use the street network as a substitute for the active transportation network, assuming that they share identical extent and positioning, even though, in many cases, this is not the case (Dill, 2004; Tresidder, 2005). How cul-de-sacs are handled also vary: in most studies, they are counted as contributing a single connected node (at the point where they intersect another road at their start), but in others (notably Southworth and Owens, 1993), they are treated as having no node at all because they do not actually provide any additional route choices (functionally being little more than an extra curve on the road to which they are attached). In some GIS-based studies (e.g.,Tresidder, 2005; Peponis et al., 2007), “noise” has also been an issue, wherein some nodes are counted or dropped from the network as a result of the use of artificial boundaries around a development.

Despite these challenges, the fact that connectivity can be easily measured using transportation networks makes it a useful characteristic when planning for walk- or bikeability. Some cities have even created connectivity standards so as to ensure networks are relatively direct (Dill, 2004; VTPI, 2010b).

Network Continuity, Completeness and Coverage

Continuity has been poorly conceptualized in most, if not all, active transportation literature to date. Depending on the study, “continuity” has been used to describe whether or not a network is present (e.g., do all roads have sidewalks?) (VTPI, 2011); the extent of network coverage (e.g., what is the total length of sidewalk relative to the total length of road?) (1000 Friends of Oregon, 1993; Ewing et al., 2004; Hawkins, 2007); the number of interruptions or breaks along a route (e.g., how often is a sidewalk or trail interrupted by intersections?) (Lee and Ahn, 2003; Lindsey et al., 2008) and the number of links that make up a route (Marshall, 2005). It is also sometimes used as a synonym for connectivity (see Cho et al., 2009; VTPI, 2010a). As a result of this ambiguity, there are no well-established measures of continuity. In order to address this problem within this review, the following terminology will be adopted:

Table 2: Proposed terminology for different continuity concepts

Conceptualization	Possible Measures	Term Used in This Study
Extent of network (i.e. the length of the network)	Linear length of the active transportation network per unit area	Coverage
Frequency of interruption from cross-way traffic (intersections) along a given path	Point of conflict density (by various types, such as road/road crossings; sidewalk/driveway crossings, etc.)	Continuity
Lack of gaps in the network; the presence of pathways where people would expect them to be	Proportion of roads with sidewalks on both sides; presence of trails in parks	Completeness (not measured in this study)

Coverage: The presence and extent of the active transportation network is, without a doubt, essential to creating walkable and bikeable communities, and has consistently been found to be positively correlated with higher rates of walking and biking (Corti et al., 1996; Kitamura et al., 1997; Moudon et al., 1997; Hess et al., 1999; Dill and Carr, 2003; Giles-Corti and Donovan, 2003; Saelens and Handy, 2008), although in some cases, their explanatory power may still be relatively weak. In his study of communities in Puget Sound, Hawkins (2007) found that the extent of the pedestrian network, relative to that of the road network (differential coverage) actually exhibited a *stronger* connection to travel behaviour (for both trip frequency and length) than connectivity, though more research is needed to confirm this finding (see also Rodríguez and Joo, 2004).

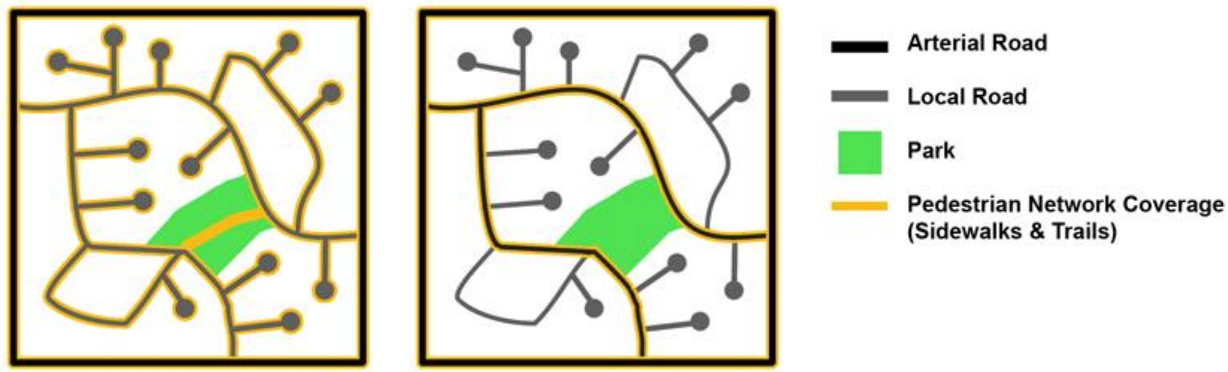


Fig. 7: Coverage
In a neighbourhood where all roads have sidewalks and trails are available, the dedicated pedestrian network may have relatively good coverage (left). Where trails are eliminated and sidewalks are only present on through roads, coverage decreases (right).

While good coverage often translates to good connectivity, this need not always be the case (see Fig. 8, below).

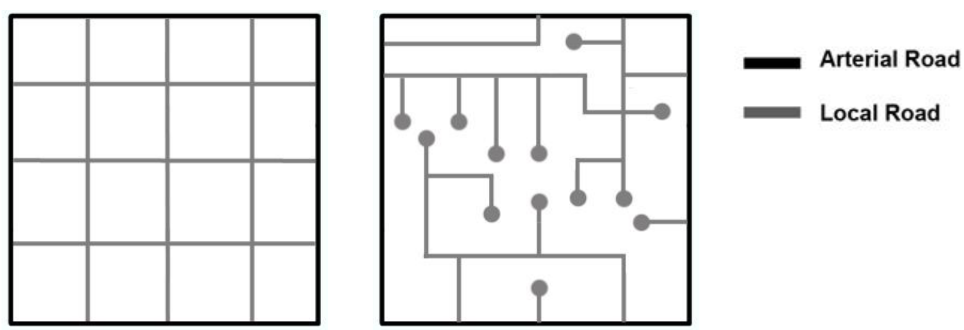


Fig. 8: Coverage vs. connectivity
These two examples have identical coverage (path length), but very different levels of connectivity – in the example on the left, it is easy to move from one part of the road network to another (high connectivity), but in the example on the left, it becomes very difficult (low connectivity).

Continuity: Network continuity is the extent to which a path continues uninterrupted by intersecting paths (see Fig. 9 below). For example, continuity is the main difference between sidewalks and trails in most neighbourhoods; trails offer high continuity, while sidewalks, which are regularly interrupted by driveways, have less.

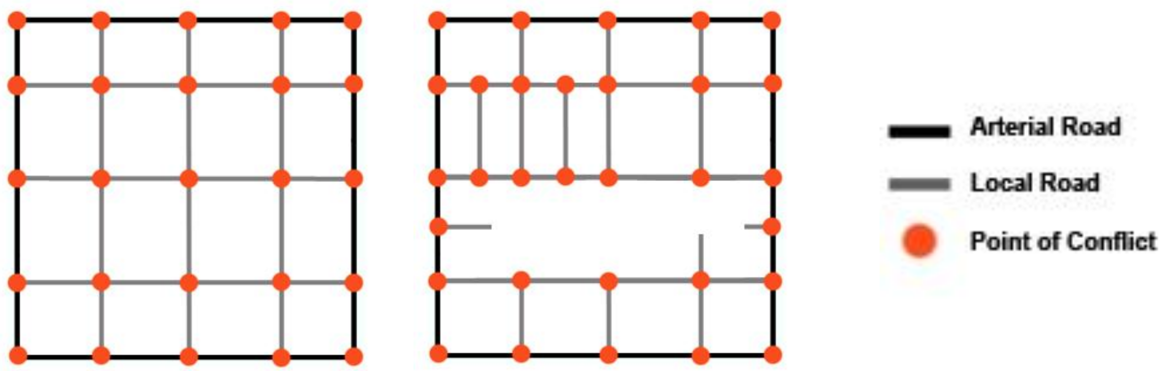


Fig. 9: Changes in continuity

While both these models have the same coverage, the model on the right has paths more frequently interrupted by other paths.

Two of the most common sources of conflicts are intersections and driveways. Several researchers have noted the conflicting functions of intersections for pedestrians and cyclists. While intersections provide a source of connectivity (Southworth, 1997), they inhibit continuity and serve as a potential source of conflict between vehicles, pedestrians and cyclists (NAHB et al., 2001; Lee and Ahn, 2003; Stinson and Bhat, 2003). Lee and Ahn (2003) assessed this source of conflict by calculating the mean number of street crossings made during a trip. (One weakness of that measure worth noting is that it treated all intersections as being equal, and therefore did not take into consideration how different intersection characteristics might cause one intersection to be seen as a greater challenge for pedestrians and cyclists than another). Nonetheless, they ultimately concluded that “finer street grids with more intersections would create less, rather than more, walkable environments” (p. 64), however, as this finding was based on morphological analysis and walking is consistently correlated with connectivity, such a conclusion may be somewhat premature. There is likely a trade-off between connectivity and continuity, and a point which most people consider ideal (which may vary between modes). For instance, intersections spaced 3000 feet apart would be so far apart as to substantially increase both trip lengths and time, while having intersections every 100 feet would create great annoyance due to the need for constant starting-and-stopping but only tiny reductions in trip length (and significant increases in trip time). However, the effect of such trade-offs has not yet been addressed in the literature, likely because good measures of continuity have been lacking. Dill (2004) has called for the development of measures separate from connectivity to help clarify the relationships and trade-offs between it and related factors, something which this research shall aim to do.

No research could be found on the effect of having driveways interrupting sidewalks or bike lanes, however, it is known that they affect cyclists' perception of hazard (Landis, 1994) and present a safety hazard for children (Roberts, 1995). Some studies have shown that New Urbanist developments, which improve continuity by removing driveway-sidewalk crossings, are likely to be associated with greater active transportation (Greenwald, 2003; Brown et al., 2008), but it is not known if this is due to improved continuity or other New Urbanist design principles, such as higher densities and land-use mix.

Modal Separation

Modal separation can be defined as the extent to which different modes of transportation are kept spatially separated from one another as a means of reducing the potential for conflict between them. Where multiple users can use the same path (such as in an alleyway), modal separation is low; where users are kept apart (for instance, by including sidewalks so as to prevent pedestrians from having to walk on the road), modal separation is high. Many attempts to create walkable and bikeable neighbourhoods have actively sought to incorporate different levels of modal separation than are seen in more conventional developments, but how modal separation affects transportation behaviour is still poorly understood.

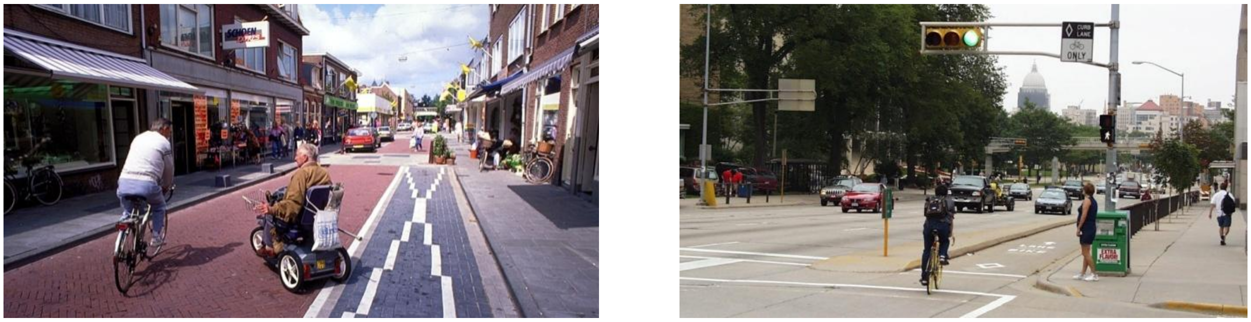


Fig. 10: Low vs. high modal separation

Woonerven (left) mix all types of traffic together and have no modal separation; roads with bike lanes and sidewalks (right) have higher modal separation

(Image sources: Burden, 2006a, 2006b)

On one end of the modal separation spectrum is the complete separation of motorized and non-motorized modes. Pedestrians and cyclists are provided their own paths and ways above or under roads so that even where the two are forced to cross motorized traffic, they need never come in contact with one another. In theory, this improves traffic safety and creates a more comfortable experience for all travel modes. How separation is achieved depends in part on mode – for pedestrians, this often means sidewalks and perhaps trails; for cyclists, it may include bike lanes (with some types providing more separation than others) or trails.

The debate over the separation of pedestrian and motorized traffic is an ongoing and contentious one. At some times in history, modal separation has been viewed very favourably for its ability to reduce conflict between cars, pedestrians and cyclists, while at others, it has been seen as taking away from the liveliness of streets (Woodward, 1997; Marshall, 2005). On the other end of the separation spectrum, some European designs strive for complete modal mixing (as seen in woonerven) as a means of improving traffic safety, with the rationale being that where drivers expect to regularly encounter pedestrians and cyclists they will drive more slowly and become more cautious.

The cyclist community is especially divided as to what level of separation is best. Some experienced cyclists prefer biking in mixed traffic, while others will not bike unless modally separated facilities are provided. Despite this, much of the emphasis in planning for cyclists has been on the creation of bike lanes. Pucher et al. (1999) argue that this has largely been the result of lobbying from “vehicular cyclists” who prefer that cyclists been given the same treatment as cars on the road, which may ultimately be at the expense of cyclists less inclined to bike in traffic.

Network Legibility

Legibility of transportation networks is regularly brought up as a design principle (Lynch, 1954; Buchanan, 1964; Marshall, 2005), although few objective measures of legibility have been developed to date. Osmond (2005) has used fractal analysis and space syntax to indirectly assess legibility between different areas of Sydney, Australia through measures of connectivity (the number of nodes connected to each node) and global integration (“the degree to which a node is integrated with or segregated from the system as a whole” (Osmond, 2005, p. 6). Since space syntax deals with axial lines (or lines which provide “maximum visual information” (Zimring and Dalton, 2003), it would seem to be a logical choice of technique for assessing legibility. Conceptually, however, it is not intuitively clear how connectivity or integration translate to legibility. Peponis et al. (2007; 2008) have come up with a more direct and easily conceptualized means of assessing legibility through a measure of “directional reach”, which is defined as “the average number of direction changes needed to cover the set of spaces that can be reached (...) from a particular point” (Peponis et al., 2007, p. 2). It is a parametric measure, so it is up to the researcher to set a threshold angle (e.g., 10 degrees) which will be considered a change in direction if the next road segment is that angle or greater relative to the current path of travel,. It also requires a “very small segment threshold”, so that that if the angle falls below a certain value (e.g., 0.1 degrees), it will start to add road segments together until it reaches the threshold value (and counts as a direction change), rather than treating each segment separately. In this way, it can capture both the gradual curving of streets as well as sharp changes in direction as potential confounders to wayfinding.

While it is generally held that grids are legible whereas conventional curvilinear road networks made up of loops and cul-de-sacs are not, the effect of legibility on active transportation behaviour remains largely untested.

Network Patterns & Walkability

Changes to network patterns (for instance, going from a grid to a layout that includes many cul-de-sacs) can have a significant effect on network characteristics such as coverage, connectivity and continuity. Consequently, many studies have been done to look at how overall pattern relates to active transportation (Cervero and Gorham, 1995; Cervero and Radisch, 1996; Friedman et al., 1994; Ewing et al., 1994; Handy, 1992, 1996b, 1996c; Handy and Clifton, 2001; McNally and Kulkarni, 1997; Kitamura et al., 1997). Some studies have used a walkability or bikeable index (Doyle et al., 2006; Frank et al., 2006; Sisson et al., 2006) or grid/not grid dummy variables (Messenger and Ewing, 1996; Crane and Crepeau, 1998) to classify each neighbourhood and then compare neighbourhood types with travel behavior. Some have used morphological analysis to simply describe the differences between a number of characteristics in each (Southworth and Owens, 1993; Southworth, 1997), while others have made use of factor analysis in order to produce statistically more significant results (Mehta, 2007; Bramley and Power, 2009).

Most of the research into the effects of network patterns on walking have been neighbourhood comparison studies (see, for instance, Ewing et al., 1994; Friedman et al., 1994; Cervero and Gorham, 1995; Cervero and Radisch, 1996; Handy, 1996b, 1996c; Kitamura et al., 1997; McNally and Kulkarni, 1997; Handy and Clifton, 2001). Research has consistently shown that people walk more in those neighbourhoods deemed "more walkable" (Ewing et al., 2003; McCann and Ewing, 2003; Saelens et al., 2003; Badland and Schofield, 2005; Handy, 2005), providing additional evidence that those variables believed to support active transportation do indeed do so, and that the use of models can have a positive impact on walking behaviour. Walking for exercise does *not* seem to be affected by neighbourhood type, however, and findings by Handy (1992; 1996c) and Handy and Clifton (2001) suggest that most differences are the result of changes in behaviour for utilitarian trips (Saelens et al. 2003; McMillan, 2005).

For cycling, two studies (Moudon et al., 2005 and Zacharias, 2005) did not find evidence of the influence of network layout on cycling, but such a result is at odds with other studies which have found that characteristics that are themselves dependent on network layout (such as connectivity, continuity and modal separation) have effects (Sacks, 1994; Copley and Pelz, 1995; Garrard et al., 2008; Krizek et al., 2005). This may be the result of the confounding relationship between network continuity and connectivity, which are both likely to be important to cyclists. At this time, the relationship between network layout and cycling remains unclear (Heinen et al., 2010), and more research needs to be done on this issue.

Residential self-selection (in which residents may move to neighbourhoods that support their travel behaviours) is a frequently cited concern in many of these studies, as it could mean that any differences in travel between neighbourhoods are not actually the result of design but simply people's pre-existing behaviours (Krizek, 2000, 2003b; Handy et al., 2006; Saelens and Handy, 2008). There is some evidence that self-selection does occur (Handy et al., 2006; Saelens and Handy, 2008). Levine et al. (2005) put forth another possibility, however - that there is *latent* demand for certain types of communities not already being met. (I.e., that people would walk more if they felt the neighbourhood design would support it). If true, then even with residential self-selection, developing more walkable and bikeable neighbourhoods would change behaviour, because it would meet an unmet demand. A recent review by Lee and Moudon (2004) concluded that evidence to date shows support for the presence of latent demand for walking (see also Krizek, 2000; Handy et al., 2006).

External Characteristics - Safety

While safety is affected by more than just network design, it is important enough to both pedestrians (Saelens and Handy, 2008) and cyclists (Heinen et al., 2010) to warrant some discussion here. These modes have been given only minimal consideration in the design of most road networks (Retting et al., 2003; Frumkin et al., 2004), and this, coupled with differences in the speed and mass of different modes, has likely contributed to the fact that both walking and biking are more dangerous than driving (Pucher and Dijkstra, 2000, Beck et al., 2007).

Safety is dependent on two types of factors – those related to people (crowds, traffic volume, crime rates, etc.) and those related to urban form (network design, lighting, natural surveillance, etc.). Both traffic safety and safety from crime are of concern to pedestrians and cyclists (Wilkinson et al., 1992; Loukaitou-Sideris, 2006; Agrawal et al., 2008). In a survey of light rail commuters, Agrawal et al. (2008) found that safety was often the second-most important factor for commuters when selecting a walking route (after distance/shortest route) (see also Hawthorne, 1989; USDT, 1994; Bauman et al., 1996). Parents regularly cite concern over neighbourhood traffic and safety and long travel distances as primary barriers to children using active transportation modes (Eichelberger et al., 1990; Bradshaw, 1995; DiGuiseppi et al., 1998; Dellinger and Staunton, 2002). Among adults, the effects of safety on travel are greatest for women, minorities, individuals with low incomes and seniors (CDC, 1999; Lohmann and Rölle, 2005; Johansson et al., 2005).

Few studies have attempted to look at how safety directly affects walking and biking rates (Saelens et al., 2003), but at least some studies have shown that the addition of new traffic safety measures and sidewalks has been shown to be effective in increasing them (Ogilvie et al., 2004).

Travel behaviour is affected by both real safety risks and perceived risks (Kononov et al., 2007). Cycling is widely perceived to be one of the riskiest modes of travel (Noland and Kunreuther, 1995) and is seen as being more dangerous than walking, taking public transit or driving (Lohmann and Rölle, 2005). It has been suggested that safety may be even more important to cycling than for walking or other modes of transport (Heinen et al., 2010). This may be in part due to some of their unique concerns, notably including the close proximity of motorized traffic going by (Krizek et al., 2009), which is itself the result of choices made concerning modal separation during network design.

While the following section describes some of the most common findings with regards to safety, it is important to note that knowledge of actual crash risk (as opposed to incidence) is extremely limited by a lack of exposure data in many studies (Hakkert and Braimaister, 2002; Beck et al., 2007). Assessing safety is also made difficult because crash data, while providing information about accident frequency and severity, generally provides little to no data on the nature of the safety problem, leaving planners and traffic engineers to infer the problem from what is known (Kononov et al., 2007).

FACTORS AFFECTING SAFETY (REAL & PERCEIVED)

Safety - Traffic Volume & Speed

The risk of fatal accidents or injuries increases with vehicular speed (Anderson et al., 1997; Leaf and Preusser, 1999; Wazana et al., 1997; Jacobsen et al., 2000). High traffic speeds are a significant deterrent to walking and biking (Roberts, 1995; Antonakos, 1994; Epperson, 1994; Sorton and Walsh, 1994; Davis, 1995; Landis and Vattikuti, 1997; Leaf and Preusser, 1999; Timperio et al., 2006). Heavy traffic volumes have also been found to discourage walking and biking (e.g. Hopkinson et al., 1987; Hoxie and Rubenstein, 1994; Shriver, 1997; Hess et al., 2004; Dill and Voros, 2007), although in some studies the researchers have concluded that its impact can be less significant (Shriver, 1997; King et al., 1999). For cyclists, the mix of vehicle types is relevant (Sorton and Walsh, 1994; Sorton, 1995), as larger vehicles are more likely to result in death or incapacitating injury in the event of a collision (Kim et al., 2007).

Traffic calming is increasingly being used in residential neighbourhoods as a means of slowing down traffic. Traffic calming measures can include changes to the roadway curvature, lane narrowing, bulb-outs, speed bumps, pedestrian refuge islands, etc. (Retting et al., 2003). Pucher and Dijkstra (2003) found that traffic calming could reduce accidents by 20-70%, depending on the area. In their review of counter-measures to improve traffic safety, Retting et al. (2003) concluded that in residential areas with many children, speed management appears to have the greatest potential for preventing injuries.

Safety - Roadway Width

Wider roads have been positively associated with pedestrian crashes, although this is likely due to corresponding vehicular speeds (Garder, 2004). Cyclists prefer roads and intersections with fewer lanes (Krizek and Roland, 2005; Petritsch et al., 2006; Shankwiler, 2006).

Road Crossings and Intersection Safety

The majority of pedestrian-vehicle and cyclist-vehicle accidents occur during road crossings, whether at an intersection or while jay-walking/biking (Hunter et al., 1995; Hunter et al., 1996; Campbell et al., 2004). This arguably makes intersections the most important aspect of the built environment when it comes to safety (see Chicago Department of Transportation, 2002; Campbell et al., 2004; Loukaitou-Sideris et al., 2007). A variety of intersection treatments and midblock features have been shown to affect pedestrian safety (JRA, 1969; Knoblauch et al., 1987; Stewart, 1988; Garder, 1989; Persuad et al., 1997; Brude and Larsson, 2000; Van Houten et al., 2000; Hughes et al., 2000; Zeeger et al., 2001; Koepsell et al., 2002; Retting et al., 2003), but a full discussion of these treatments is outside the scope of this review. It is generally held that four-way crossings (X-intersections) are more dangerous than three-way crossings (T-intersections) (Filion and Hammond, 2003), and that crossing higher-order roads (arterials, freeways, highways) is less safe than lower-order ones. David and Norman (1979), however, found that for low-volume urban roads there was very little difference in crash incidence between the X and T intersections, although at larger volumes (average daily traffic > 20,000), X-intersections were worse than T-intersections. Whether it is safer to have many crossings across lower order roads (grid network) or fewer crossings, but across higher order roads (hierarchical networks) is unclear.

Safety - Modal Separation

For cyclists, riding in mixed traffic is believed to be more dangerous (Kroll and Ramey, 1977; Lott et al., 1978; Guttenplan and Pratten, 1995), although there are still some who contend that there is not yet enough evidence to prove that modal separation is actually safer than biking with traffic (Forester, 2001). Although the effects of modal separation and bicycle infrastructure remain unclear, *perceived* safety is certainly higher where dedicated bicycle facilities (lanes, trails, etc.) are present (Klobucar and Fricker, 2007). Some researchers believe that complete modal mixing (where pedestrians, cyclists and cars share a road, as in a woonerf) can actually improve safety, by forcing drivers to be more aware and by greatly reducing vehicle speeds (Ben-Joseph, 1995; Southworth and Ben-Joseph, 2003).

Safety - Parking and Driveways

Parking (both on-street and off) and driveways create a safety risk for pedestrians and cyclists. Loukaitou-Sideris et al. (2007) found that almost 20 percent of collisions occurred someplace other than the road (e.g., in driveways, parking lots, sidewalks, etc.). Similarly, Campbell et al. (2004) found that while about 40% of crashes occur at intersections, the majority actually take place at other locations such as on sidewalks, parking lots, midblock connections, and so forth.

Driveways create “an invasion of the pedestrian space by cars” every time they cross sidewalks (Loukaitou-Sideris et al., 2007), and thus are believed to create a potential safety risk, particularly for children (Roberts, 1995; Loukaitou-Sideris et al., 2007). Having a large parking supply (including on-street parking and paid parking) discourages walking and biking (Epperson, 1994; Davis, 1995; Cervero and Kockelman, 1997; TRB, 2008). Roads with on-street parking are rated as more dangerous than roads without such parking by cyclists, as they run the risk of colliding with car doors or having vehicles parked on the bike lane (Stinson and Bhat, 2003, 2005). While most accidents involving adults occur at intersections, 69% of child pedestrian injuries occur along the midblock (Kraus et al., 1996). On-street parking is sometimes a cause of this, as it can prevent children from seeing on-coming traffic when running out from the road (Kraus et al., 1996; Zeedyk et al., 2002).

Safety - Density & Land Use Mix

Several researchers have found increases in crashes in areas with higher proportions of commercial, retail, and public service type land uses (Levine et al., 1995; Miles-Doan and Thompson, 1999; Loukaitou-Sideris et al., 2007; Cho et al., 2009), contrary to Ewing et al.'s (2003) hypothesis that crashes would be higher in residential neighbourhoods as a result of higher speeds. Ironically, the *perception* of crash risk has been negatively associated with land use mix and connectivity (Cervero and Kockelman, 1997; Frank et al., 2005; Leslie et al., 2005; Rodríguez et al., 2006; Cerin et al., 2006).

The effects of density on safety are mixed. LaScala et al. (2001), Clifton and Kreamer-Fults (2007) and Cho et al. (2009) found that density and land use mix increased risk, whereas others found a decrease in crash incidence with density (Clark, 2003; Ewing et al., 2003; Jacobsen, 2003; Lucy, 2003). Graham and Glaister (2003) found a decreased in expected collision rates in extremely dense areas, possibly because of the low traffic speeds (grid-lock) in congested areas. The findings with regards to the effect of density on perception of crash risk are similarly unclear (see Cho et al., 2009).

Safety from Crime

A lack of natural surveillance is believed to both reduce safety and increase the perception of risk (Jacobs, 1961; Newman, 1972), and can be affected by network layout (as in the Greenway model). The arrangement and maintenance of buildings and streets may create a sense of danger for pedestrians (Appleyard, 1981; Wilson and Kelling, 1982; Schweitzer et al., 1999), and it has been suggested that highly connected street systems with shorter blocks could help improve safety from crime (Newman, 1996). However, some studies have actually shown that less-connected streets such as cul-de-sacs actually have lower crime rates, likely because they offer criminals fewer chances to escape (Mayo, 1979).

Summary: Active Transportation Research & Correlates

Research into active transportation has been growing since the early 1990s. Most has made use of utility maximization theory, although there has been a recent shift towards more comprehensive socio-ecological models (see, for instance, Handy, 2005; de Geus et al., 2008). Research varies by trip type, travel outcomes under study (mode, trip distance, frequency, route choice, etc.) and scale.

An understanding of the correlates of active transportation is important in order to determine how design interventions are likely to affect travel behaviour. Both built form and non-built form variables play a role in active transportation behaviour. Research suggests that personal characteristics largely determine trip frequency, while urban form has a greater effect on trip length (Ewing and Cervero, 2001). Although non-urban form characteristics often have the strongest relationship with travel behaviour, the built environment still plays a key role in establishing travel networks (and their resulting opportunities and constraints) and determining trip lengths, times and safety (Handy, 2005). Evidence suggests that the strength of relationships (and possibly their direction) may sometimes differ between recreational vs. utilitarian travel, modes (e.g., cycling vs. walking) and populations.

Several reviews have attempted to summarize the findings in the literature with regard to active transportation correlates. All have concluded that various issues, including the number of studies, inconsistencies in data, differences in populations under study and methods of analysis make it difficult to reach definitive conclusions concerning the magnitude of effects (Saelens et al., 2003; Badland and Schofield, 2005; Saelens and Handy, 2008). This inability to determine the exact strength of relationships has considerable implications for any attempt to assess the active transportation potential of neighbourhoods, an issue discussed in greater detail on p. 69. Most reviews however “have provided tentative conclusions which are largely consistent with one another” (Saelens and Handy, 2008 p. S551), particularly with regards to which relationships are significant and what the direction of those relationships are.

Table 3 below provides a summary of those built environment characteristics known to have a statistically significant association with walking and biking, and the direction of their relationship with each mode. A few notes are necessary with regards to interpretation: first, while the built environment as a whole is believed to have only a weak-to-moderate effect on active transportation behaviours, some characteristics consistently come out as being stronger or more often statistically significant than others. These have been noted with a double symbol (++ or --) below. Second, the table outlines the strongest “likely strength” for any type of walking or population under study that was identified in a published review (for example, if connectivity had a moderate relationship with utilitarian trip-making but an indeterminate effect on recreational trips, the “moderate relationship” would be the one listed in the table). Finally, only one of the reviews considered (Ewing and Cervero, 2010) attempted a meta-analysis of findings with regards to the exact strength of these correlations (and then, only for walking): their conclusions concering the range of elasticities associated with these correlates have been noted where applicable.

Table 3: Summary of known built environment correlates of active transportation

Correlate	Walking		Biking	
	Direction	**Strength & Notes**	**Direction**	**Strength & Notes**
DENSITY CORRELATES				
Density	++	Relationship likely the result of making driving less appealing. "Elasticity of walk trips with respect to density" : 0.03 to 0.83 (Ewing and Cervero, 2010)	+ (++?)	Relationship likely the result of making driving less appealing.
DIVERSITY (LAND USE MIX) CORRELATES				
Land use mix	++	"Elasticity of walk trips with respect to diversity": 0.03 to 0.98 (Ewing and Cervero, 2010; noting that some of the studies they considered could be viewed as assessments of proximity rather than strict land use mix)	+ (++?)	
Parks & open space	+		+	
DESIGN CORRELATES				
Accessibility – physical & cognitive	? (++?)	(Includes accessibility features such as curb cuts, wheelchair ramps, wayfinding signage, etc.) Likely important for seniors and those with disabilities, but relatively unimportant to others.	? (++?)	(Includes accessibility features such as curb cuts, wheelchair ramps, wayfinding signage, etc.) Likely important for seniors and those with disabilities, but relatively unimportant to others.
Aesthetics	+	Usually quite weak, though possibly stronger for recreational trips	+	Usually quite weak, though possibly stronger for recreational trips
Amenities	~	Can include water fountains, benches, etc.	+	Can include bike racks, showers at the office, water fountains, etc.
Connectivity	++	Usually one of the strongest correlates; often the only network design characteristic included in research. "Elasticity of walk trips with respect to block and/or intersection density": 0.21 to 1.11 (Ewing and Cervero, 2010)	~	Likely not significant in many studies because of probable confounding relationship with continuity. Trip distance is a known correlate, however (having a positive relationship with cycling).
Continuity	? (+?)	Understudied in the literature to date.	++	Likely more important for cyclists than for pedestrians, given positive association betwen connectivity and walking for pedestrians but lack thereof for cyclists. Still relatively understudied in the literature to date.

++: Positive association – relatively strong   - -: Negative association – relatively strong   ~: Mixed results/no clear direction   (?): Suspected association
+: Positive association – relatively weak   -: Negative association – relatively weak   ?: Inadequate data/insignificant results

Table 3: Summary of known built environment correlates of active transportation (cont.)

Correlate	Walking		Biking	
	Direction	Strength & Notes	Direction	Strength & Notes
DESIGN CORRELATES (cont.)				
Coverage	+	Consistently associated with walking behaviour. “Elasticity of walk trips with respect to sidewalk coverage”: 1.23 (Ewing and Cervero 2010 on another study)	++	Closely tied to modal separation for cyclists; cyclists seem to be affected more by differences in network coverage than pedestrians.
Legibility	? (+?)	Understudied in the literature to date.	? (+?)	Understudied in the literature to date.
Modal separation	?	Understudied in the literature to date; usually confounded with the issue of network coverage.	++	User-dependant: less experienced cyclists or those uncomfortable with biking in mixed traffic find modal separation more important.
Neighbourhood pattern	+	Effect of neighbourhood type on walk trips: 0.35 to 3.06 (Ewing and Cervero, 2010)	~	Lack of a signficant relationship likely due to confounding relationship between connectivity and continuity.
Other path characteristics	+ or -	(Topography, greenery, trail smoothness, etc.) Direction of association dependent on variable under study.	+ or -	(Topography, greenery, trail smoothness, etc.) Direction of association dependent on variable under study. Topography (slope) likely more important for cyclists than pedestrians.
Width of roadway	-		-	
CORRELATES DEPENDANT ON MULTIPLE DIMENSIONS				
Accessibility – regional	+	Affected by network design and location of study area. Typically expressed in terms of proximity or trip time or length to CBD; sometimes tied to transit accessibility.	+	Affected by network design and location of study area. Typically expressed in terms of proximity or trip time or length to CBD; sometimes tied to transit accessibility.
Proximity & trip distances	++	Affected by network design and land use mix. “Elasticity of walk trips with respect to destination accessibility”: -0.32 to 0.49 (Ewing and Cervero, 2010)	++	Affected by network design and land use mix. Likely a non-linear relationship on the lower end (some trips are too short to bike).
Safety	+	Affected by land use mix, density, network design, population and traffic characteristics. Both real and perceived safety can have an affect on travel behaviour. “Safety” here relates both to safety from traffic and safety from crime.	+ (++?)	Affected by land use mix, density, network design, population and traffic characteristics. Both real and perceived safety can have an affect on travel behaviour. Cyclists seem to have greater safety concerns than pedestrians when it comes to safety from traffic; likely have less concern than pedestrians when it comes to safety from crime.

++: Positive association – relatively strong   - -: Negative association – relatively strong   ~: Mixed results/no clear direction   (?): Suspected association
+: Positive association – relatively weak   -: Negative association – relatively weak   ?: Inadequate data/insignificant results

Reviewers have concluded that the literature into correlates provides sufficient evidence to act "as a basis for advocating for changes in planning policies" (Saelens and Handy, 2008, p. S564). If so, then the question becomes "how can urban form be modified so as to take advantage of these relationships in order to facilitate increased active transportation?" The next two sections of this review will describe how networks and proposed neighbourhood models attempt to do so.

PART II: TRANSPORTATION NETWORKS & NEIGHBOURHOOD MODELS

Motorized Transportation Networks

Motorized transportation networks are comprised of all the pathways available to motorists for travel. These networks include both public pathways (roads) as well as private ones (such as driveways). While walking or biking may occur along the motorized transportation network, this is not always the case (for instance, highways). Because roads are often the best mapped public transportation network segments, they are often used as proxies for active transportation networks in active transportation research.

Active Transportation Networks

Active transportation takes place primarily on designated networks set within broader neighbourhoods which provide travel opportunities in the forms of places to go. Active transportation networks are places where active modes have priority over other modes. There are many different types of pathways upon which walking and biking may take place, each which serve a specific set of users, have a typical location within a residential development, and which are subject to different levels of continuity (Table 4, below).

Table 4: Common active transportation network path types

Path Type	Users (Modal Separation)	Location	Continuity
Sidewalks	Pedestrians	Along side roads	Usually interrupted by driveways
Trails and greenways	Pedestrians and cyclists	Away from roads, in parks and greenspaces	Usually uninterrupted except for intersections
Bike lanes	Cyclists	On edge of roads	Uninterrupted along their length, but subject to intereference from cars (parked or driving in the adjoining lane) and network discontinuities
Bike routes and roads	Cyclists and cars	Road lanes	Uninterrupted except for intersections
Woonerven	Pedestrians, cyclists and cars	Replacement for local roads	Same as for roads (interrupted by intersections), but less relevant where all three modes are sharing the same travel space anyways
Parking areas (alleys, driveways)	Pedestrians, cyclists and cars	Behind or in front of homes	Driveways are usually interrupted by sidewalks

A more complete discussion of these path types and other model components can be found in Appendix A. Active transportation networks can also include unique safety features (such as crosswalks) or amenities targeting pedestrians or cyclists (such as water fountains and bike racks), but these (with the exception of Greenway underpasses) will not be considered in this study.

Neighbourhood Models

The following section will review the use and history of neighbourhood models in planning North American neighbourhoods, provide an overview of the five models that will be considered in this study and then discuss how models have been evaluated in past research.

The Use of Models in Planning North American Neighbourhoods

Models of proposed neighbourhoods, cities, and even entire regions have a long history of use in urban planning to illustrate concepts about how to create better communities. Although these models typically emphasize roads and active transportation networks, many have also sought to integrate principles related to land use mix, density, housing mix and open space (Filion and Hammond, 2003).

Up until a few centuries ago, the majority of urban areas developed in an organic, unplanned fashion (Mumford, 1938; Kostof, 1991). Starting in the 1800s in North America, this type of development gave way to planned models, beginning with the most basic – the Grid. While efficient in terms of minimizing trip lengths, this model failed to address people's desires for privacy, tranquility and safer, low-traffic residential streets, and so over the past hundred years it has gradually given way to designs which have made use of increasingly disconnected, curvilinear and hierarchical networks, most recently culminating in the Loop and Cul-de-Sac models which have dominated new residential developments in North America for the past several decades (Southworth and Owens, 1993; Marshall, 2005) (see Fig. 11 below).

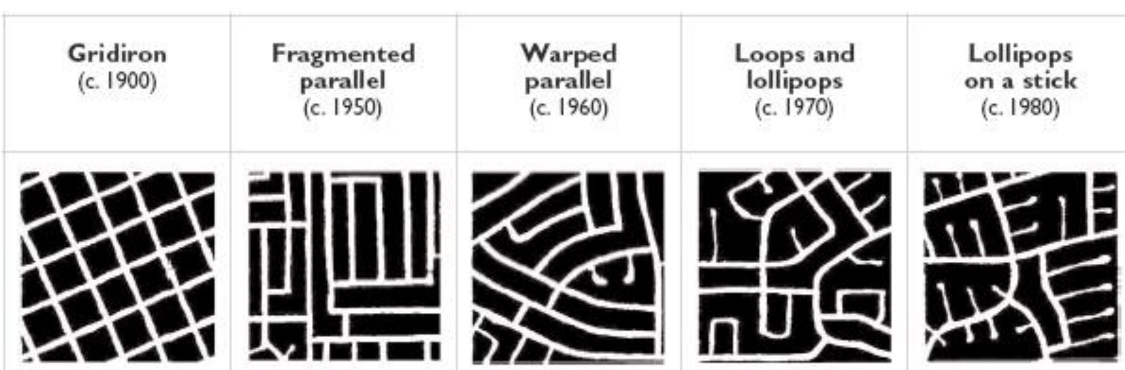


Fig. 11: Evolution of North American road patterns in the 1900s
The gradual evolution of road networks from grid into "lollipops on a stick"
(Figure source: Southworth and Owens, 1993, p. 280, Fig. 13)

Filion and Hammond (2003) described urban form and models as being like pendulums which swing in response to changing societal values, cultural preferences and transportation technologies. Since the invention of the automobile, the majority of the focus has been on how to better accommodate cars – both to make driving easier and to reduce the impacts of traffic on pedestrians and cyclists. The initial shift to the Loop and Cul-de-Sac's disconnected road system was made under the auspices of reducing traffic on local roads where people lived and children played (Kelly, 1974; Southworth and Ben-Joseph, 2003), and it was undoubtedly successful in this regard. The move to sprawling developments also allowed for more parks and trails, again aimed at creating a pleasant, car-free walking and biking environment.

Despite these laudable goals, the Loop and Cul-de-Sac model has many detractors, who point to the severe degradation of the pedestrian environment which has imposed barriers all across urban areas to travel on foot or by bike (Southworth and Ben-Joseph, 2003; Forsyth and Southworth, 2008). Under this model, block sizes grew, land uses became increasingly separated, and density (particularly in residential areas) declined (Filion and Hammond, 2003; Southworth and Ben-Joseph, 2003). Four-way "X" intersections gave way to three-way "T" intersections (Filion and Hammond, 2003). "Streets", former centres of public life and culture, were transformed into "roads", mere service lanes for traffic (Mehta, 2007; Forsyth and Southworth, 2008).

There is no doubt that with today's growing health and environmental problems, a rethinking of urban form is needed in order to come up with neighbourhoods that better respond to transportation needs through superior organization of network elements, buildings, and land uses (Buchanan, 1964; Marshall, 2005). Several alternative models have been developed in response to the problems created by the Grid and Loop and Cul-de-Sac models. These include the New Urbanist (which emphasizes highly connected streets and sidewalks free of intrusion from driveways), the Fused Grid (which emphasizes differential connectivity while still making use of a partially disconnected road network), and the Greenway (which emphasizes high levels of continuity and modal separation).

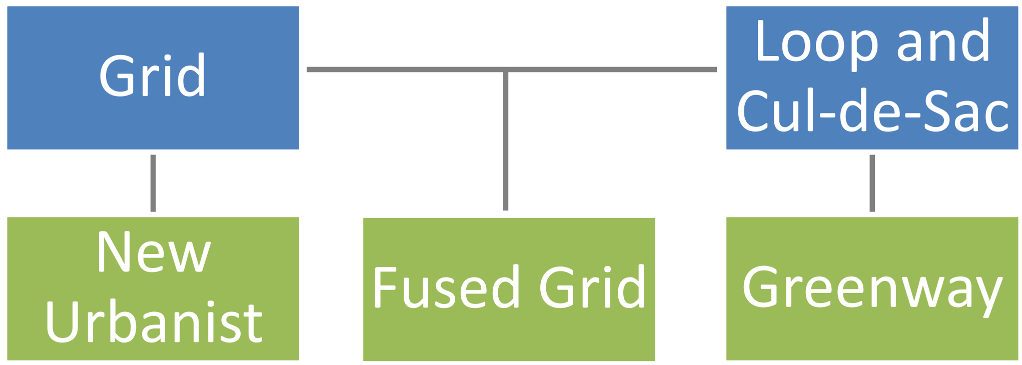


Fig. 12: The five study neighbourhood models

Each of the alternative models (shown in green) seek to improve on the basic premises of one or both of the traditional Grid and Loop and Cul-de-Sac models.

The following part of this literature review will provide an overview of each model under consideration in this study. These are by no means all the models that have been proposed to improve the walk- and bikeability of neighbourhoods, but are those identified as being common in the North American planning literature and appearing to have the greatest potential (both in terms of creating modal shift as well as in terms of feasibility of implementation) for improving active transportation rates in North America today.

About the Model Overviews

The following section aims to provide an overview of the guiding principles behind each of the study models, give case study examples where possible and describe some of their known (or suspected) advantages and disadvantages. A summary of these principals can be found in Appendix D, while more specific design specifications and case study information for each can be found in Appendix E.

Being able to describe pattern is critical in order to be able to compare structures across cases and to make recommendations based upon them (Marshall, 2005). Such description is challenging, however, because all urban form exists along a morphological continuum (Hanson, 1989). The goal for these model descriptions, then, is to carve a set of discrete types from the "morphological continuum" of possible designs while recognizing the possibility for various gradations between them. The primary focus in these descriptions is on each model's urban form, which here refers to "the physical characteristics that can be described or recorded for any section of street" (Marshall, 2005, p.54-56), as opposed to those specifications related to architectural features, lighting, landscaping, etc. While these models are meant to represent "standard types" for each concept, it is important to note that in practice, models are almost invariably modified to some degree when placed in a local context, whether in response to topography, existing transportation networks, municipal street standards, etc. (Hawkins, 2007; see also Moudon, 1992).

Model #1: The Grid

Description: Used since ancient times in many parts of the world, the Grid has been favoured for its ease of use and subdivision, short blocks, legibility, high connectivity, reduced trip distances and pedestrian scale (Crane, 1996b; Southworth and Ben-Joseph, 2003; Aurbach, 2006). It is commonly found in the downtown areas of major cities across North America. The model's unit/boundary is simply the block, and consequently, unlike later models, the Grid does not create distinguishable neighbourhood units by means of its layout (CMHC, 2000).

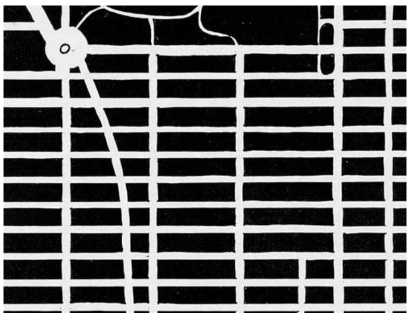


Fig. 13: Grid pattern

Manhattan Island, whose grid was first laid out in the Commissioner's Plan of 1811 (New York City, 2009) is a famous example of an area laid out using a grid network
(Image source: Jacobs, 1993, p. 232)

In the Grid model, roads are essentially designed such that "every street might be a traffic street" (Mumford, 1938). In theory, Grids can be hierarchical (Marshall, 2005), with some roads having extra lanes and higher speeds than others, but tend, in practice, to be relatively uniform. Block sizes depend on the fineness of the network grain, but are typically small compared to more recent "Loop and Cul-de-Sac" models. In principle, all intersections are X (four way)-intersections, though in practice there are often some T (three way)-intersections as well.

Advantages: The key benefit from an active transportation standpoint is that the Grid's network shortens trip *lengths* for all travel modes (Crane, 1996b), by virtue of all roads being through roads and offering a wider variety of route choice (Khisty, 1990), though the strength of this effect is dependent on the grid's grain (Krizek, 2003a). While the effect on trip length is easily seen, the effect on trip *time* is less clear, as grids have more intersections (and thus stops) than most other models (Southworth and Ben-Joseph, 2003). Grid neighbourhoods tend to have a high density and land use mix. This is not prescribed by the model itself, but is rather an example of co-variation, resulting from the fact that most grids were laid out prior to the advent of the automobile, making higher densities and lane use mix a necessity.

Disadvantages: Grids often result in "grid lock" (especially during peak hours) because intersections are spaced so closely together, keeping traffic speeds low (CMHC, 2000). Pollution exposure may be higher due to high traffic volumes (itself the result of density), trip speeds, frequent stops-and-stars, and the close proximity of homes (Frank, 1998; Pope et al., 2000; Peters et al., 2004; Frank and Engelke, 2005). Grid networks often leave little open space for parks or recreation (Southworth and Ben-Joseph, 2003). Grids also have relatively high infrastructure costs due primarily to the high street density – sometimes having up to 40% more land dedicated to roads than corresponding "Loop and Cul-de-Sac" neighbourhoods (IBI, 1995). For residents, considerable through traffic on residential roads makes grid networks less private, too loud and arguably too dangerous (Buchanan, 1964; CMHC, 2000; Southworth and Ben-Joseph, 2003). In an attempt to mitigate these effects, some communities have gone so far as to close off roads in existing Grid neighbourhoods in order to prevent them from acting as through streets (Newman, 1996), effectively transforming them into Fused Grid neighbourhoods (see p. 57).

Variations: The Grid model can vary in the size of blocks (which can be consistent throughout a neighbourhood, be derived from a set of standard sizes as seen in Savannah, Georgia, or vary thoughout a neighbourhood). In some cases, roads are warped to provide more of a rural/picturesque feel, while in others, the grid is interrupted so as to introduce more 3-way than 4-way intersections (see Southworth and Owens, 1993).

Model #2: Greenway Neighbourhoods (Radburn)

As the number of cars in Canada and the U.S. grew exponentially in the early 1900s, the Grid's shortcomings – and the need for a new model for residential developments – became clear. Architects Clarence Stein and Henry Wright's proposed solution – the design for the community of Radburn in Fairlawn, New Jersey (1929) - could be arguably called the most important neighbourhood model of the 1900s.

Description: Drawing from the American "Garden City" paradigm, Radburn was a direct response to the problems of the Grid model and the growing impacts of the automobile on daily life (Southworth and Parthasarathy, 1997; Lee and Ahn, 2003). Radburn incorporated three features that had rarely been used before: the superblock (a block several times the size of blocks found in most Grids), a hierarchical, disconnected, curvilinear road network that depended heavily on cul-de-sacs, and the relocation of the road network to the back of homes to allow the creation of a uninterrupted central shared greenway and trail system between the front of homes (Stein, 1957; Buchanan, 1964; Girling and Helphand, 1994; CMHC, 2000; JLAF, 2010; Nock, 2008).

Fig. 14: Homes facing the neighbourhood park and trail network is a key feature of Greenway designs (Image source: The Radburn Association, 2010)

The Radburn plan was one of the first to seek to create a distinct neighbourhood through the use of organized cells in the network layout (CMHC, 2000). The edge of each cell is made up of higher-order, wider, faster roads for motorized travel, off of which exist a series of cul-de-sacs to prevent through-traffic within the cell. Many of the streets in Radburn curve, but to nowhere near the extent that is seen in modern “Loop and Cul-de-Sac” surburbs (Lee and Ahn, 2003). The design for Radburn was one of the first in North America to clearly embody the principles of Clarence Perry’s “neighbourhood unit”, even though it preceded the publication of those ideas by a few years. Perry had suggested that neighbourhoods be planned such that they would be self-sufficient and yet still related to the greater community, and centred around a public facility like a school (Perry, 1929; CMHC, 2000). Every model since Radburn has incorporated some of Perry’s ideas – even if some have been far less successful than others in doing so. In terms of land use and density, the design for Radburn intentionally incorporated some mixed land use into the neighbourhood, but density was kept relatively low.

Fig. 15: Use of cells in Radburn

Whereas the Grid model used repeatable blocks, Radburn made us of a series of cells with similar design features (Source: Stein and Wright, 1929)

Advantages: Unlike most connectivity advocates, Stein and Wright recognized intersections as a key point of conflict between pedestrians and motorized vehicles and tried to develop a design which would minimize that conflict (Lee and Ahn, 2003). Radburn completely separates motorized and non-motorized traffic by providing a continuous trail network with underpasses at main roads (with the exception of some intersections). Having community trails in place of sidewalks makes travel (at least in theory) easier for cyclists, who no longer have to travel on the road with cars, as well as for pedestrians, who no longer have to worry about being hit by cars pulling out of driveways. The most dangerous feature of the urban landscape – motorized traffic – is located behind fenced-off backyards, rather than unfenced front yards, leaving the front of homes safe for children to walk and play (Lee and Ahn, 2003).

Cul-de-sacs reduce the majority of through traffic, making the area quieter and the residential roads (theoretically) safer (CMHC, 2000). Superblocks increase the distance between through roads, creating a cell size large enough to support a sizeable open space network and dramatically reducing the number of streets a pedestrian or cyclist needs to cross to reach a destination. It makes a cultural statement as well: rather than making roads and motorized traffic the central structure between homes, it makes walking and biking the focus of the community.

The design also eliminates the need for multiple parallel pedestrian and cyclist pathways, combining them into one and thereby likely reducing impermeable area (something this study will aim to test). Finally, the trail itself has high levels of natural surveillance, because it is overlooked by homes, rather than being located behind unsupervised backyards, as would be seen in later models (Nock, 2008; see also Frank and Engelke, 2005).

In this model, the active transportation network is laid out in a off-set grid, while the motorized vehicular network is laid out in loops and cul-de-sacs. As a result, the model has differing levels of connectivity between modes (see Fig. 16 below).

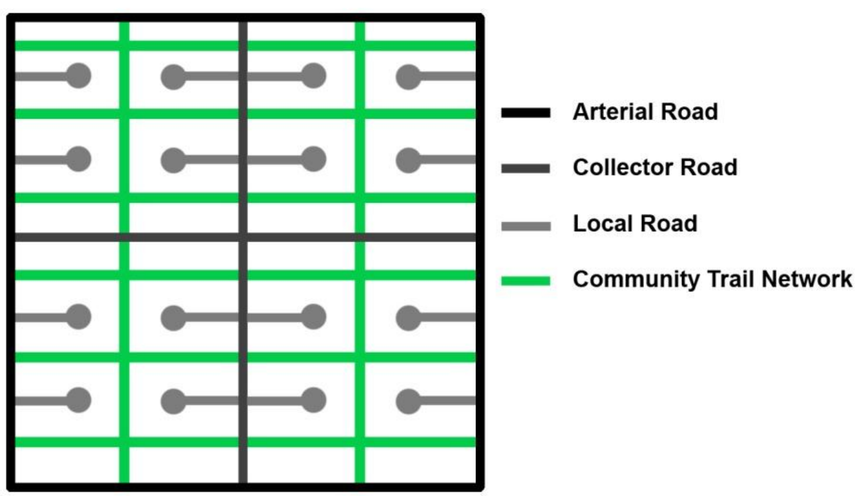


Fig. 16: Road vs. pedestrian network patterns in a Greenway neighbourhood

The differences in network layout result in differences in connectivity in a Greenway neighbourhood. Trips for pedestrians and cyclists are more direct for pedestrians and cyclists than for cars.

In terms of the success of the model, Lansing and Marans (1970) found that Radburn residents were much more likely to walk for groceries than people in nearby neighbourhoods. A study of 1990 census data revealed that public transit use (and therefore likely active transportation) is also significantly higher in Radburn than in its neighbouring areas (Lee and Stabin-Nesmith, 2001). Additional studies into the effects of this model on walking and biking would be beneficial (especially when compared to the number of studies looking at New Urbanist neighbourhoods, for instance), but are undoubtedly limited by the small number of such neighbourhoods that exist.

Disadvantages: Because there are fewer through roads, those that remain must be able to carry more traffic, which can be challenging for pedestrians and cyclists to cross. (This is a common problem to all models making use of a disconnected, hierarchical network – e.g., the Greenway, Fused Grid and Loop and Cul-de-Sac models). In Radburn, this was addressed through the use of underpasses at key intersections, however, these are not always appealing to pedestrians or cyclists who may perceive a (criminal) safety risk from them. Some have also suggested that separate pedestrian pathways decrease liveliness and security on streets (Calthrope, 1993), although empirical evidence of this appears to be lacking. In one public housing development in Australia, residents had enough concerns about high crime and vandalism rates to request that the New South Wales Department of Housing convert their neighbourhood back to a more traditional layout, with homes facing the street (Woodward, 1997). It is possible, then, that this model should only be used where crime rates are of less of a concern than problems associated with transportation. There is also debate as to the effects of this type of development on infrastructure costs, with some saying that increase them (Calthrope, 1993) and others saying they decrease them (Stein, 1957; CMHC, 2000). Additionally, the low density of these neighbourhoods would likely serve to decrease utilitarian walking trips.

Radburn Today: Greenway-Oriented Developments and Greenway Neighbourhoods

While none of the elements used in Radburn were entirely new, it was the development's seamless blending of them that made it unique, and from which stems its real merit (Lee & Stabin-Nesmith, 2001; Lee & Ahn, 2003). Although Radburn was considered a success (both when it was built and now), it has rarely been faithfully replicated, so much so that despite being one of the earliest models in this study, it has still be classified here as an "alternative", rather than "traditional" model. The majority of developments that followed often borrowed components of Radburn plan (Van der Ryn

& Calthorpe, 1986; CMHC, 2000), but dropped what is arguably its most important element – the central communal greenspace and active transportation system completely separated from the road network (Birch, 1980; Lee and Ahn, 2003). Without the active transportation network, the remaining elements of Radburn significantly hinder active transportation by creating substantially longer trip distances. Many authors describe this later type of development (termed the“Loop and Cul-de-Cac” model here) as “Radburn-style”, which is misleading. In order to avoid confusion, the Radburn-type developments are here referred to as “Greenway Neighbourhoods” (as used by JLAF, 2010) to emphasize that the greenways are the key and central elements in this design.

Variations: One variation on this basic model is called the “Greenways Interlaced with Cul-de-Sacs” model or “GICs” which includes pocket parks and special parking lots for guests (Nock, 2006; JLAF, 2010) (see Fig. 17 below). Further variations may also be possible, such as using a greenway orientation in combination with a grid road network.

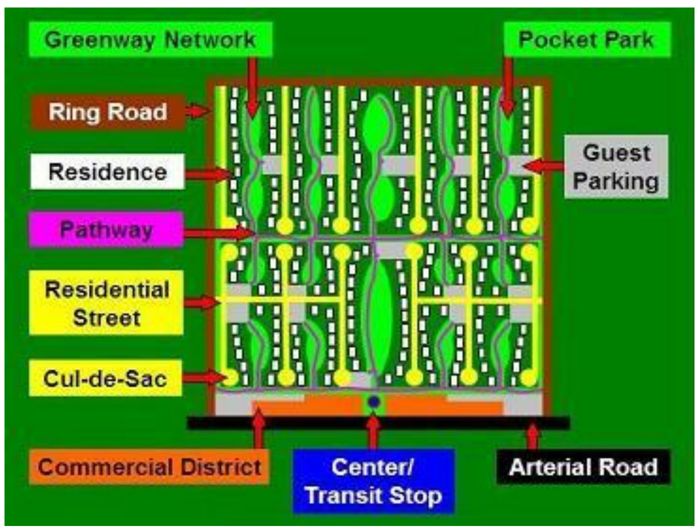


Fig. 17: One possible Greenway neighbourhood design
(Image source: JLAF, 2010)

Model #3: Loop & Cul-de-Sac

The most common model of the past 70 years – the "Loop and Cul-de-Sac" – has been heavily criticized for being detrimental to pedestrians and cyclists alike, through the lengthening of trip distances, reducing the viability of public transit, and creating higher traffic volumes and speeds along key corridors (CMHC, 2000; Southworth and Ben-Joseph, 2003; Forsyth and Southworth, 2008).

Description: Like Greenway Neighbourhoods, Loop and Cul-de-Sac models seeks to reduce the impacts of traffic seen in a grid network and create safer, quieter, private residential streets (Southworth and Owens, 1993; CMHC, 2000; Southworth and Ben-Joseph, 2003; Grammenos et al., 2005; Hawkins, 2007; VTPI, 2008a). It does so through the use of a disconnected road network made primarily up of cul-de-sacs and crescents which prevent through traffic on the majority of residential streets. However, where the design of Radburn clearly catered to pedestrians, this model all but ignores them (Lee and Ahn, 2003). The network itself is no longer systematically organized into cells, but rather laid out in a seemingly random fashion, in what is known as (somewhat ironically) "planned unit development" (PUD), creating major challenges in wayfinding for drivers and pedestrians alike (Kulash, 1991; CMHC, 2000; Duany et al., 2000). Superblocks are larger (although the block structure itself is no longer as clearly apparent), which forces even more traffic onto the arterial roads, which in turn have to be widened and their speed limits raised in order to accommodate increased loads, making them unsafe and inhospitable for pedestrians and cyclists (Duany et al., 2000; Grammenos et al., 2005; VTPI, 2008a).

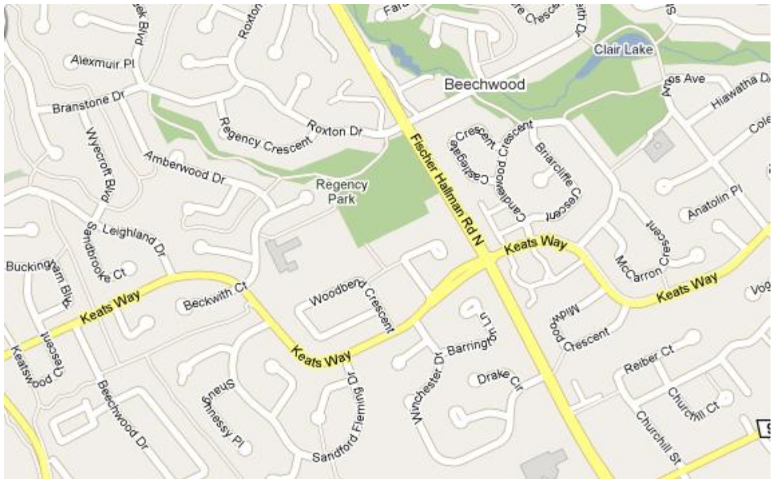


Fig. 18: A typical Loop and Cul-de-Sac neighbourhood

Note the large superblocks and curvilinear street system. (Image source: GoogleMaps, 2010)

The active transportation network is once more located alongside a road between the front of homes, leaving backyards to connect to one another and form a completely private space (Moudon, 1992). In some cases, sidewalks are only made available on one side of the road, or not at all (Forsyth and Southworth, 2008). Without any pedestrian connections between cul-de-sacs, trip lengths increased dramatically – in many cases to such an extent that many trips are no longer feasible by walking (CMHC, 2000). Some communities do incorporate trails beside or behind homes, but often these are also difficult to navigate, take longer to reach than the sidewalks and may feel unsafe due to a lack of surveillance.

In Radburn, all cul-de-sacs were directly connected to the higher order roads at one end, making main roads relatively accessible. In this model, it is not uncommon to have residential roads several "steps" (roads) away from the nearest main one. Neighbourhoods are often single-use (residential), as this has historically been felt to be safer from a traffic perspective (CMHC, 2000), and low density, in order, like Radburn, to cater to a preference for "country style" living.

Advantages: Loop and Cul-de-Sac models create private, quiet streets while responding to an apparent cultural preference for suburban living that seems closer to nature (CMHC, 2000; Day, 2000; Hellmund and Smith, 2006; Hawkins, 2007). Research has shown that there is increased child activity on streets which exclude through traffic (Wheway and Millward, 1997). It also reduces the infrastructure cost for development and increases the buildable area in a neighbourhood by devoting less land to the road network (IBI, 1995).

Disadvantages: The elimination of the greenways, the increased size of the superblocks and the extensive use of curvilinear, disconnected streets increases travel distance across all modes, while decreasing route choice and modal separation. Coupled with single-use zoning and low-density construction, walking to most destinations becomes all but impossible (CMHC, 2000; Forsyth and Southworth, 2008). Not surprisingly, Loop and Cul-de-Sac models have fallen heavily out of favour in most planning circles, and some communities such as Charlotte, North Carolina have gone so far as to ban cul-de-sacs entirely (VPTI, 2008).

Variations: An almost infinite number of permutations on the basic Loop and Cul-de-Sac design are possible. Over time, the trend has been towards an increasingly less disconnected network with a higher proportion of cul-de-sacs and fewer loops (Southworth and Owens, 1993; Southworth and Ben-Joseph, 2003).

Model #4: Fused Grid Neighbourhoods

A relatively new design, the Fused Grid emphasizes the use of differential connectivity as a means of achieving walkability and bikeability (Hawkins, 2007; Grammenos, 2008). The model arose out of the recognition that both Grid and Loop and Cul-de-Sac models have benefits and drawbacks, and that neither on its own fully meets quality of life and environmental needs (Grammenos, 2008; see also Southworth, 1997).

Description: The Fused Grid fuses an active transportation grid network overtop a regionally grid-like but locally disconnected cell made up of loops and cul-de-sacs (called a quadrant). The quadrants used in the Fused Grid model are quite similar to the cells used in the Radburn model, at least with regards to the layout of their road networks. Each quadrant is 400 m x 400 m ("a quarter mile square", or 40 acres), according to what the CMHC (2000, 2002) believes constitutes a walkable distance (a 5-minute walking radius). Each quadrant is framed on two sides by collector roads and on two sides by arterial roads, with disconnected loops and/or cul-de-sacs located on the interior. The layout of the residential streets can vary (as seen in Fig. 19 below), but the key element –small pocket parks with trails to link otherwise disconnected roads - is always present. Thus, the pedestrian and cyclist transportation network forms a grid, which generally overlaps with the vehicular movement network except in the park spaces (CMHC, 2000). (While the CMHC states that the network is a "continuous grid", an examination of the model diagrams show that the active transportation network contains several "T" intersections). The grain of the active transportation network is finer than that of the surrounding vehicular grid (CMHC, 2000). These connections between otherwise disconnected streets shorten travel distances for pedestrians and cyclists. The CMHC (2000) has developed seven variations on the basic Fused Grid model, four of which are illustrated in Fig. 19 below.

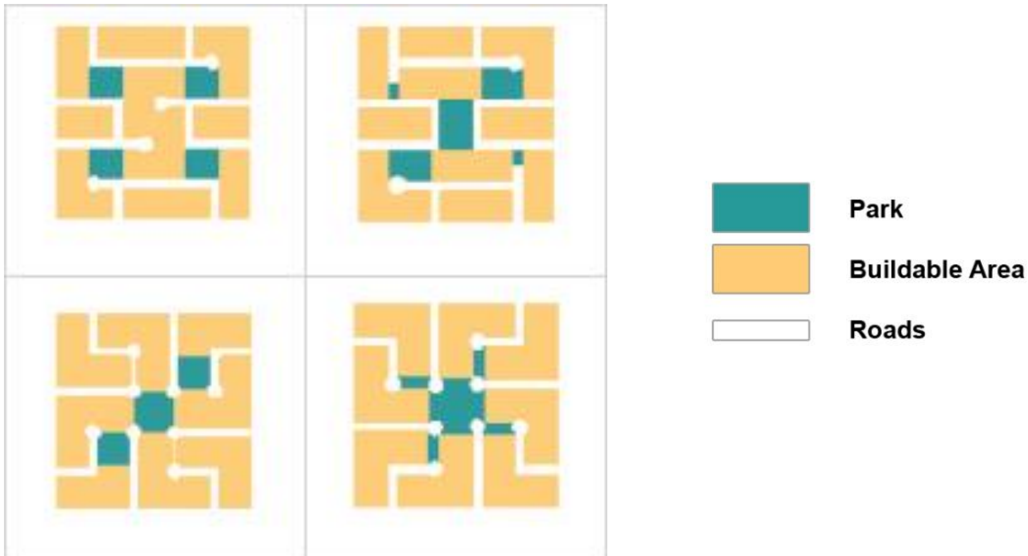


Fig. 19: Four variations on the Fused Grid quadrant (Image source: CMHC, 2002, p. 6, Fig. 7)

Advantages: Compared to the Loop and Cul-de-Sac model, the Fused Grid reduces travel distances (although the exact reduction has yet to be quantified in the literature, something which this study has helped to do – see p. 190) and improves the number of route choices and accessibility to public spaces while maintaining suburban lifestyle values such as privacy, safety and quiet (CMHC, 2000).

Proponents of the Fused Grid also attribute several other benefits to the design, including optimized use of land, streets, and infrastructure; reduced impermeable surface area; increased opportunities for social interaction; improved regional traffic flow; discouraging vehicular use for short-distance trips; and opportunities for stormwater management (Grammenos, 2008). However, as the Fused Grid is still a relatively new model, the amount of research done to support many of these claims is extremely limited. Hawkins' (2007) study of street networks suggests that the model can increase the odds of a person walking for at least some of their local travel by 13.5 – 42.5%, however, those estimates were the result of inference based off other networks, as no Fused Grids could be identified in the study area.

Disadvantages: No papers could be found critiquing the Fused Grid, likely because of the recentness of the model. Logically, the model should have many of the same problems of the Loop and Cul-de-Sac model – longer trip lengths than seen in a Grid neighbourhood, increased danger from traffic on higher order roads, and reduced legibility, although likely to a lesser extent then is seen in the Loop and Cul-de-Sac model. One problem that may exist for residents in this model is a perception of the trails as unsafe (especially at night) because of a lack of natural surveillance (something this researcher has noted was a concern of many residents in the Fused Grid neighbourhood in which she previously lived). The earliest version of the Fused Grid model (CMHC, 2000) suggested omitting sidewalks from the residential streets as a cost-saving measure: this would have a negative impact on modal separation, but fortunately this seems to have been dropped in later versions (Grammenos, 2008).

Variations: At the community scale, one proposed version of the Fused Grid goes a step further to incorporate a 350-foot wide mixed use zone bordered by one-way arterial roads to channel intensification and help further facilitate active transportation (Fig. 20, below) (Grammenos, 2008). The CMHC (2000) stated that "bike-ways" could be provided on the residential side of each arterial, but it is not entirely clear if this means multi-used trails or bike lanes. Alleys are also provided for homes facing arterials in some versions of this model.

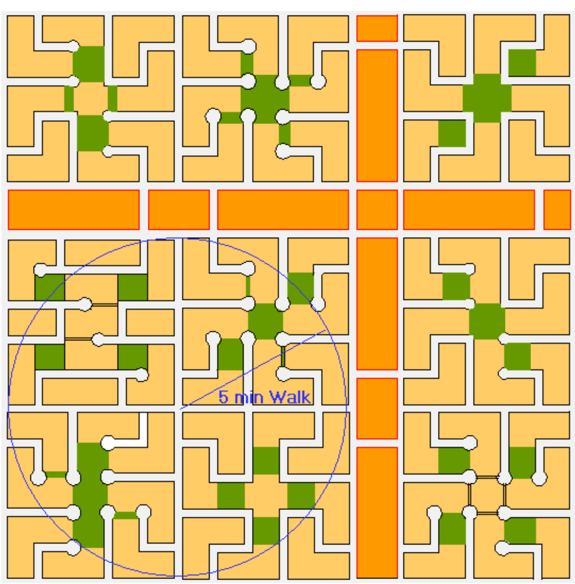


Fig. 20: Mixed use zones incorporated into Fused Grid developments

The dark orange indicates mixed use zone, bordered by one-way arterial roads. Parks and open spaces are shown in green.

(Image source: Grammenos, 2008)

Park

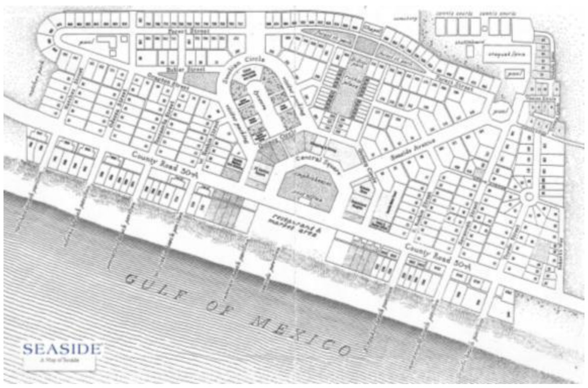
Residential Lands

Mixed Use Zone

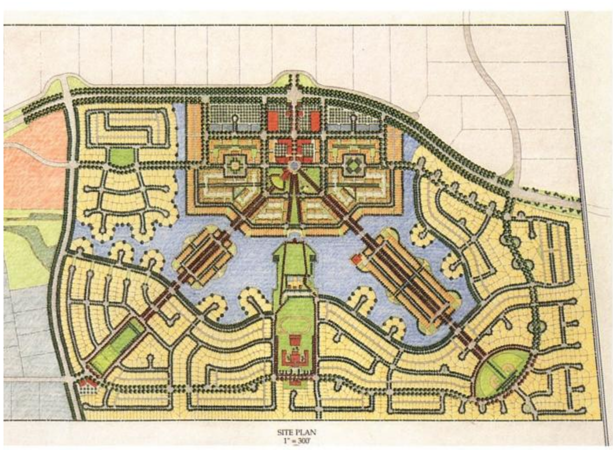
Roads

Model #5: New Urbanist Neighbourhoods

New Urbanism is perhaps more of a mindset than it is a specific model. Nonetheless, a wide range of different designs have come out of the New Urbanist agenda, guided by the design principles set out in the Charter for New Urbanism (Hess, 2008). Fig. 21 below shows three of the most famous New Urbanist communities.



Seaside



Laguna West

Kentlands

Fig. 21: Three examples of New Urbanist design - Seaside, Kentlands, and Laguna West
(Image sources: Duany and Plater-Zyberk, 1982; Calthorpe Associates, 1990; rudi.net, 2012)

Description: New Urbanists seek to create livelier, more walkable communities through the use of grid or modified grid networks coupled with higher density, mixed use development built up along transportation corridors (Duany and Plater-Zyberk, 1991; Calthorpe, 1993; Crane, 1996a, 1996b; Audirac, 1999; CMHC, 2000; Greenwald, 2003; Steuteville, 2004). New Urbanist designs can be grouped into three categories: Transit Oriented Design (TOD), Pedestrian Pockets and Traditional Neighbourhood Design (TND) (Kelbaugh, 1997). The model of greatest interest to transportation planners is TOD (Greenwald, 2003) and will be the focus here, although the physical designs of both the TOD and TND models are similar enough that conclusions about one can likely be applied to the other (Kelbaugh, 1997). The Pedestrian Pocket model has been heavily critiqued for failing to consider the transportation connections needed to the broader region in order to facilitate a reduction in automobile use, and thus will not be considered here (Cevero and Kockelman, 1996; Cevero, 2002; Southworth, 2005).

Streets in New Urbanist developments tend to be narrow (Brown and Cropper, 2001) which helps to slow traffic (Buchanan, 1964; Smith and Appleyard, 1981). Streets are generally fairly long with many intersections and high connectivity (Lee and Ahn, 2003). Other common characteristics include a variety of traffic calming measures, large front porches overlooking the street, reduced setbacks, the use of older architectural styles, and the addition of back alleys (Brown et al., 1998; CMHC, 2000; Krizek, 2003a; Lee and Ahn, 2003; Hess, 2008). Alleys are valued for their ability to remove cars, garbage, driveways and garages from the street in order to make the street more socially active and pedestrian-friendly (Calthorpe, 1993; Langdon, 1994; EDCO, 2003; Hess, 2008). While this improves modal separation by preventing sidewalks (located in the front of homes) from having to cross driveways, it also increases the total land dedicated to roadways in the community (CMHC, 2000). The result is effectively a road on either side of a house, making homes “dual-sided” with public (or semi-public) spaces at the front and back of the house, similar, in a way, to what is seen in Radburn (Lee and Ahn, 2003).

While some New Urbanist developments (such as Kentlands) incorporate substantial trails within parks, they are not always laid out in the same systematic method as seen in Radburn (or, to a lesser extent, as in Fused Grids), creating a “slightly confused pattern” that appears less legible than the road network (Lee and Ahn, 2003, p. 62). New Urbanist developments create distinct neighbourhoods by laying out different sections of the road network in unique patterns (see Fig. 21 for Kentlands, above) (Southworth, 1997). Some developments, such as Seaside and Laguna West, have also made use of long, radial roads and/or greenways to help direct people towards the centre of the development (Southworth, 1997; Lee and Ahn, 2003).

Advantages: The use of a fine-grained grid layout substantially reduces walking and biking distances (CMHC, 2000). Sidewalks (and bike lanes, if present) are not crossed by driveways, which are a point of conflict between pedestrians, cyclists, cars and children at play. Narrow roads and other traffic calming measures help to slow motorized traffic and improve safety. In theory, reductions in street width can reduce construction and maintenance causes, help with efficiency (as roads that bear so little traffic may not need to be as wide as others), and help increase density (Southworth and Ben-Joseph, 2003). However, these benefits may not all be realized where alleys add to the total street length.

The popularity of New Urbanism has led to numerous studies being conducted to assess the effects of this model on travel. Results have been mixed (Hawkins, 2007), but in most cases, residents in such neighbourhoods have been found to walk and bike more for utilitarian purposes (Hess, 2008; CMHC, 2010) but not necessarily recreational ones (Handy, 1996b, 1996c; Shriver, 1997; Lund, 2003).

Disadvantages: New Urbanist designs have been critiqued as being overly concerned with aesthetics and form, being mere imitations of more “genuine” neighbourhoods, and, ironically, for giving over more land to the car despite a walkability agenda (see, for instance, Boarnet and Crane, 2001; Grammenos et al., 2005; Knox, 2005; Marshall, 2005). There is also considerable debate over claims concerning the ability of grid networks to reduce motorized traffic (McNally & Ryan, 1993; Crane, 1996a, 1996b) or maintain vehicular traffic flow at acceptable levels, which, opponents note, was arguably responsible for the shift to hierarchical networks in the first place (CMHC, 2000; Marshall, 2005). The extent of roads in a New Urbanist development actually means that a greater total area is paved and dedicated to the street network (Wells, 1993; IBI, 1995). A study by the CMHC (1996) concluded that, as a result, the infrastructure costs associated with the neotraditional (NTD) approach were about 35% higher than those of a conventional Loop and Cul-de-Sac design. As such, a NTD development must have higher density in order to off-set the increased costs of its dense transportation network.

Variations: Because its guidelines are relatively broad, the New Urbanist model allows a great deal of room for variation. Different elements that may or may not be included in designs include radial roads, large central parks, loops and/or cul-de-sacs integrated into the dominant grid network, etc. (see Southworth, 1997; Lee and Ahn, 2003; CMHC, 2010).

Assessing Models

In order to determine the potential for different models to facilitate active transportation, we must have some means of empirically assessing them. Morphological analysis, which examines the form of the built environment, has been the most common method used in active transportation research to compare the spatial, topological and physical characteristics of different theoretical models and real-world neighbourhoods (see Conzen, 1968; Moudon, 1997; Filion and Hammond, 2003).

There are several different schools of morphological thought and a wide range of techniques used in their analyses, including figure and ground diagrams (Trancik, 1986) space syntax (Hillier and Hanson, 1984; Hillier, 1996; Steadman, 2004), graph theory (Kruger, 1977; Steadman, 1983) and what is sometimes referred to as typo-morphological analysis (Pinho and Oliveira, 2009). One of the most important studies in the North American context is that of Moudon (1992), whose pioneering work provided the basis for a North American typology through her descriptions of common neighbourhood types built between the 1920s and the 1990s in Puget Sound (Moudon, 1992; Lee and Ahn, 2003). Other typologies of urban form have since been developed, but the most commonly used in the North American residential context has been that of Southworth and Owens (1993). Southworth and Owens provided the basis for more extensive typo-morphological studies of neighbourhood form by developing a system to quantify and compare several variables, including street length, number of intersections and neighbourhood access points. In addition to these count data, they provided standard depictions of network layouts to help readers visualize the difference between neighbourhoods (see Fig. 22 below). Their work was also groundbreaking in their conviction that analyses had to be performed at multiple scales – the street and lot, the neighbourhood, and the community.

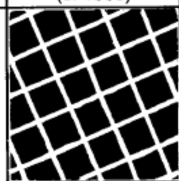
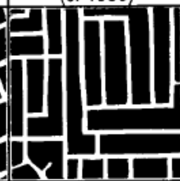
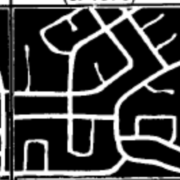
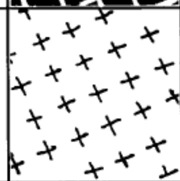
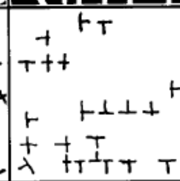
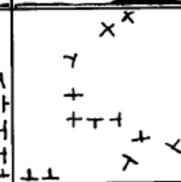
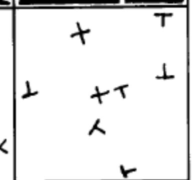
	Gridiron (c. 1900)	Fragmented Parallel (c. 1950)	Warped Parallel (c. 1960)	Loops and Lollipops (c. 1970)	Lollipops on a Stick (c. 1980)
Street Patterns					
Intersections					
Lineal Feet of Streets	20,800	19,000	16,500	15,300	15,600
# of Blocks	28	19	14	12	8
# of Intersections	26	22	14	12	8
# of Access Points	19	10	7	6	4
# of Loops & Cul-de- Sacs	0	1	2	8	24

Fig. 22: Southworth and Owen's (1993) basic framework

(Image source: Southworth and Owen, 1993, p. 280, Fig. 13)

Several studies have since then made use of Southworth and Owens' framework to compare either models or existing neighbourhoods, including Southworth himself in 1997 with a study on the similarities and dissimilarities between New Urbanist developments and traditional developments. The CMHC (2000) used the framework to compare Loop and Cul-de-Sac, New Urbanist and Fused Grid models, but also added X vs. T-intersection counts (as a measure of safety and connectivity) as well as calculations of the percent difference between models for various variables. They also followed Southworth and Owens' recommendation to work at multiple levels, having included a community-level assessment of the effect of changing a sizeable portion of Ottawa over to a Fused Grid. This was the only study that could be found that attempted to work with models at something much larger than the neighbourhood scale, something which is important when attempting to consider potentially longer bicycle trips. In their comparative study of New Urbanist and Greenway neighbourhood developments, Lee and Ahn (2003) expanded on the Southworth and Owens' (1993) methodology by adding explicit connectivity, continuity and active transportation measures.

Not all morphological studies have made use of the Southworth and Owens' framework, even though many of the same variables are often considered. Three studies which developed alternative frameworks include Aultman-Hall et al. (1997), Filion and Hammond (2003) and Peponis et al. (2007). Aultman-Hall et al. (1997) examined a proposed development and an alternate design for the same, using GIS to quantify the effects of design on walkability. Filion and Hammond (2003) also looked at land use (including the amount of land dedicated to various network componnents) and walking distances, as well as intersection types and access points (as used in the Southworth and Owens (1993) methodology), housing mix and infrastructure efficiency in Ontario neighbourhoods. Peponis et al. (2007) also looked at existing neighbourhoods, and have been able to do one of (if not the) most extensive morphological studies in North America to date, largely, it would appear, because of the time-savings that result from using a GIS. In their study, they evaluated 118 urban areas in the United States in terms of their connectivity and legibility, a variable which had yet to be measured in any of the other previous studies reviewed. A more detailed summary of each of these morphological studies can be found in Appendix B.

There is a trend in these studies to move from being purely descriptive (as seen in Southworth and Owens, 1993) to being able to relate urban form to how people travel. For instance, in Lee and Ahn's (2003) study, they go from a simple description of intersection counts and street length to a calculated measure of connectivity (a directness ratio). These functional measures have a clearer relevance to pedestrians, cyclists, planners, and developers, and address the biggest critique of the vast majority of morphological studies – the "so what?" Table 5 below summarizes the list of network-related variables considered in each study.

Table 5: Morphological studies of neighbourhood models – network characteristics assessed

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Sidewalks, trails, or alleys in quantified measures?	Not explicitly assessed [1]	●	●	●	●	●	Not explicitly assessed [1]	●
Connectivity	O[2]	O[2]	●	O[2]	●	●	●	●
Intersections	●	●	Not assessed	●	●	●	●	Not assessed
Access points	●	●	O Described, but not quantified	●	●	●	Not assessed	Not assessed
Bicycle network	Not assessed *	Not assessed*	Not assessed*	Not assessed*	Not assessed	Not assessed	Not assessed	Not assessed
Street network (length or area)	●	●	●	●	●	●	●	O (combined with paths)
Street types	●	●	Not assessed	●	Not assessed	●	Not assessed	Not assessed
Road widths and right of way	●	●	Not assessed	●	O (by total area)	●	Not assessed	O (% roads < 7.6m)
Active transportation network coverage (sidewalks and/or trails)	Not assessed*	Not assessed*	Not assessed	Not assessed*	O (by area instead of length)	●[3] (pedestrian only)	Not assessed	O (combined with roads and alleys)
Continuity: intersection conflicts	Not explicitly assessed[5]	Not explicitly assessed[5]	Not assessed	Not assessed	Not assessed	●	Not assessed	Not assessed
Continuity: driveway conflicts	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Modal separation	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed	Not assessed
Legibility	Not assessed	Not assessed	Not assessed	Not assessed*	Not assessed	Not assessed*	●	Not assessed

●: Assessed O: Partially assessed *: Not assessed, but mentioned briefly.

[1]: *It is possible that these studies may have included alleys in some neighbourhoods, but if so, they were never quantified separately.*

[2]: *Did not discuss connectivity directly, although the quantification of linear streets and blocks over a set area are essentially connectivity measures.*

[3]: *While much of the "pedestrian only" network could be used by cyclists, bike lanes or other types of biking infrastructure were not discussed, nor is it clear whether cycling is permitted on sidewalk portions of the network.*

[4]: *May not be applicable to models, as none of them explicitly omit sidewalks (although this sometimes happens in practice, particularly in Loop and Cul-de-Sac developments)*

[5]: *While these studies provided an intersection density measure, it was never stated that they were being included for the purposes of assessing continuity.*

There are a few problems and limitations common to the majority of these studies. Despite an explicit interest in active transportation, none except Lee and Ahn (2003) provided any assessment or depiction of the active transportation network independent of the road network, and none attempted to systematically address bicycling, modal separation or continuity as it pertains to driveways (an important feature of the New Urbanist and Greenway models). None of these studies included a detailed methodology or protocol for their calculations or development of figures, and as a result there is some variation between them. For example, Southworth and Owens (1993), Southworth (1997) and Peponis et al. (2007), did not count cul-de-sacs as having any intersections (because they do not provide any opportunities for route choice), while in other papers (CMHC, 2000; Lee and Ahn, 2003), they are counted as having one. This affects both intersection counts (and thus, connectivity) as well as the depiction of the intersections (see Fig. 23 below), making it difficult (if not impossible) to compare results between studies. It is also unclear in most studies whether or not alleys are included in road counts.

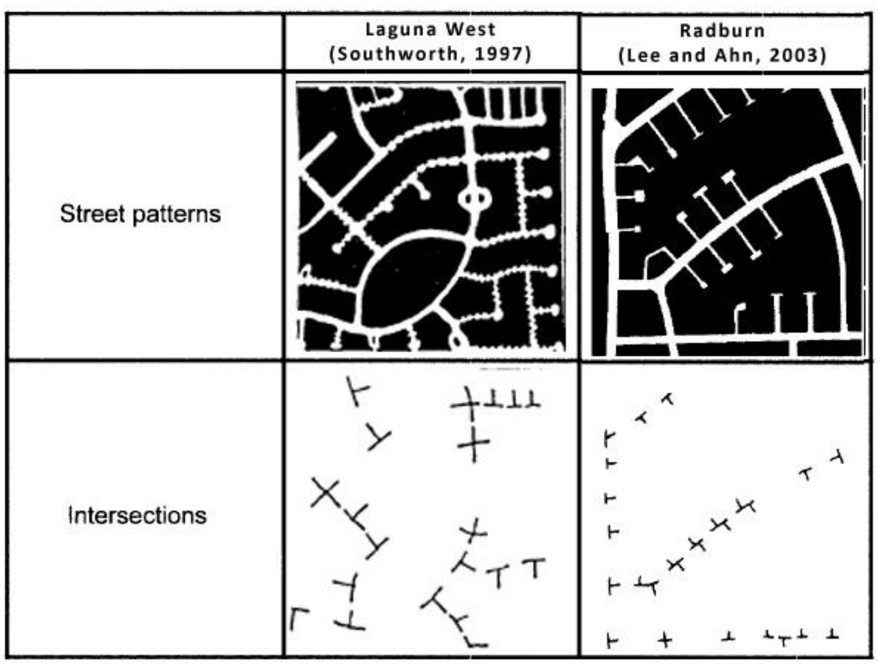


Fig. 23: Differences in methodologies, such as in the treatments of cul-de-sacs (as shown here)
(Image sources: Southworth, 1997, p. 41, Fig. 23; Lee and Ahn, 2003. p. 61, Fig. 6)

Similarly, where models are used, researchers have not always been explicit about the principles used to generate the model. For instance, in the CMHC (2000) study, their New Urbanist model contained no loops or cul-de-sacs, even though this does not reflect the reality of many New Urbanist developments (see, for instance, Southworth, 1997). Thus, methods are needed not only for analysis and results, but also to describe the process of model development, so that other researchers can see how well a model follows (or fails to follow) stated design principles or truly resemble existing developments.

Overall Evaluation of Neighbourhood Walkability & Bikeability

While describing and assessing the characteristics of models through morphological analysis is relatively easy, effectively evaluating neighbourhood models as a whole is challenged by the need to know the importance of any given characteristic to travel behaviour. While it is generally held that the built environment exerts a modest influence on travel behaviour, there is by no means any consensus on the exact importance of any one characteristic and how it should be weighted accordingly in an overall evaluation of a neighbourhood. As noted in Part I of this chapter, several reviews have concluded that various issues, including the number of studies, inconsistencies in data, differences in populations under study and methods of analysis make it difficult to reach definitive conclusions concerning the magnitude of effects (Saelens et al., 2003; Badland and Schofield, 2005; Saelens and Handy, 2008).

Evaluation is made particularly difficult when it comes to assessing neighbourhood models as opposed to case study neighbourhoods. Any known correlation between urban form and travel from previous research must necessarily be the result of studying some population's actual travel behaviours. And depending on the population under study, the strength of a correlation can change (for instance, how experienced cyclists place less value on bike lanes and trails than less experienced ones – see Hunt and Abraham, 2007). Neighbourhood models do not have associated populations, however, nor can planners know for certain who will choose to live in a neighbourhood once it is built. Furthermore, even within a given population, the strength of a correlation often varies by the type of trip: what is particularly valuable for a recreational trip (for example, park space) may be relatively unimportant for an utilitarian one, considerably confounding any attempt to make broad generalizations about a neighbourhood's "walkability" or "bikeability".

Of the eight morphological studies considered, only Filion and Hammond (2003) attempted any sort of systematic evaluation by ranking each neighbourhood considered (1^{st}, 2^{nd}, 3^{rd} or 4^{th}) on each variable. However, they choose not come up with a final score based on those rankings, instead leaving it to the reader to decide what was "best" based on those attributes they considered the most important.

Outside of these morphological studies, travel behaviour researchers, planning practicioners and community organizations often assess neighbourhood walkability and bikeability through indicies. These indices come in two basic types – those that are done on site through subjective or objective audits and those that are done remotely using a GIS (CHP, 2009).

There are considerable limitations with on site audits. They are time-consuming, costly, and require specially trained evaluators (Parks and Schofer, 2006). In some cases, inter-rater reliability has been low, in particular for subjectively measured variables. Many such indices are limited in the total area they can evaluate, and as a consequence, most assess only specifically chosen routes, rather than entire neighbourhoods (see, for instance, SPACES, PIN3 and PEDS indices by Pikora et al., 2002; Evenson et al., 2009 and Clifton et al., 2007 respectively). Finally, many variables used in such indices may be time sensitive (the amount of traffic on the road) or entirely subjective (how safe the road seems).

GIS-based evaluations, on the other hand, offer several advantages over site-audit based indices, enabling researchers and urban planners to quickly and objectively assess entire neighbourhoods, using existing data sets for transportation networks, land use designations, traffic and crime rates, etc. (Göçmen and Ventura, 2010). More importantly, they can assess *proposed* developments as well as existing ones and test the impacts of alternative design and scenarios (Parks and Schofer, 2006). This is a particularly important benefit to municipal planners and developers, because while knowing the active transportation potential of a model is useful for its ability to provide general direction for neighbourhood designs (the main purpose of this study), it is not as useful for evaluating proposed plans, as these often deviate from model specifications, whether as the result of local topography, developer preference, municipal policies or street standards. As such, it is important for planners to be able to evaluate proposed designs against evaluation criteria on a case-by-case basis, but their efforts are stymied by a lack of tools for doing so. GIS-based tools can help meet these needs, but despite these considerable benefits, most indices are still of the site audit variety. In their review of

100 such tools, researchers at the CHP (2009) found only six tools which were exclusively based in GIS. Each of these tools considers only a small subset of the variables potentially measured using a GIS, such as sidewalk coverage, road width, etc. Thus, it is not surprising that researchers have called for research and indices which are more comprehensive in the number of variables they consider (Leslie et al., 2007; Heinen et al., 2010). Variables which are under-addressed or not addressed in these six indices, but which could be considered in a GIS-based index include network continuity, modal separation, legibility and differential connectivity (see 1000 Friends of Oregon, 1993; Replogle, 1995; FHA, 1998a, 1998b; Moudon, 2001; Parks and Schofer, 2006; Leslie et al., 2007). Appendix C provides a comparison of the six GIS-based indices.

Dvelopers of both site-based and GIS-based indices, however, have also struggled with the issue of how to weight specific built environment characteristics. Using connectivity (one of the network design characteristics most commonly included in active transportation research) as an example, different travel behaviour researchers have used the following relative weights in their indices:

Table 6: Weight of connectivity measures in studies making use of walkability indices

Paper	Relative weight of connectivity measures in assessing walkability
Frank et al. (2005)	12.5% (Equally weighted to density; land use mix given a 6x weight)
Frank et al. (2006)	40% (2x weight relative to density; equally weighted to land use mix)
Frank et al. (2009)	25% (one of four Z-scores used to calculate the total)
Sundquist et al. (2011)	42.8% (1.5x weight relative to density and land-use mix)

Note: Although they may have been intended as such, coverage measures ("Are sidewalks or trails present?") were not considered connectivity measures for the purpose of constructing the above table.

It is clear that determining appropriate weights for urban form characteristics is a research topic in-and-of-itself, and indeed, is likely the single greatest challenge facing both researchers and planning practicioners hoping to evaluate neighbourhood designs.

Summary: Active Transportation Networks and Neighbourhood Models

Most active transportation takes place on a set of predefined pathways, here collectively referred to as Active Transportation Networks (ATNs). ATNs can be made up of several different types of pathways, including sidewalks, trails, greenways, bike lanes, bike routes, roads and woonerven. Network components vary in the users they are designed to accommodate, their design speed, coverage, continuity, degree of modal separation and location within a neighbourhood.

Many models have been developed to meet society's changing expectations for "good" neighbourhoods. These include the Grid, Greenway, Loop and Cul-de-Sac, the Fused Grid, and New Urbanist designs. The trend in most conventional (Loop and Cul-de-Sac) developments has been towards increased privacy, quiet, and (arguably) safety through the use of increasingly disconnected and hierarchical road networks designed to keep out through traffic: changes which have been made largely at the expense of pedestrian and cyclists. Several alternative models have sought to instead focus on creating neighbourhoods which are more walkable (and, less explicitly, bikeable). While these models share at least one common goal (walkability), they vary in the ways they seek to achieve it, particularly with regard to the connectivity and modal separation within their transportation networks.

Several papers have sought to assess various subsets of these models using morphological analysis, in many cases building off of Southworth and Owens' (1993) framework. However, none have looked at all of them at once using a clearly articulated and well-defined methodology, making comparison or replication of results between studies difficult. None of the papers reviewed attempted to evaluate bikeability, despite the potential for biking to replace a greater proportion of car trips than walking due to the greater distances that can be covered. Only two of the studies (Filion and Hammond, 2003; Lee and Ahn, 2003) looked at the active transportation network separately from the road network. Modal separation and continuity have barely been addressed, likely due to conceptualization and measurement issues. Similarly, while Peponis et al. (2007; 2008) have made in-roads in developing methods for assessing legibility, no studies could be found which assessed the legibility of neighbourhood models (as opposed to pre-existing developments).

Many of these issues have been noted in the literature. Saelens et al. (2003) have called for further evaluation of the effect of active transportation infrastructure on nonmotorized transportation, as it has been evaluated only infrequently in most research to date, while Kockelman (1997) and Matley et al. (2000) point to the need for more advanced measurements of the built environment and more detailed methodologies so as to improve the comparability between studies of the active transportation potential of different neighbourhoods. Dill (2004) brings attention to the need for research which depicts and considers active transportation networks directly, rather than using the road network as a proxy. This is likely particularly important for models such as the Fused Grid or Greenway in which all or part of the active transportation network may be completely separated from the road. Researchers have also noted the need for studies which are more comprehensive in the number of variables they consider (Heinen et al., 2010) and that help to elucidate the structural relationship between variables (McMillan, 2005), such as that which exists between connectivity and continuity.

Meanwhile, GIS has emerged as a potentially powerful tool in the assessment of models. However, in order for GIS to be useful, clear protocols must be developed. While Forsyth et al. (2007) have created numerous protocols to address most of the variables used in studies of models, there is still a need for more, particularly for such variables as legibility and modal separation, and for a system to relate these measures back to broader morphological frameworks (such as that of Southworth and Owens, 1993). Regardless of the technique used to describe and assess a neighbourhood, however, all researchers remain challenged by the question of how best to weight built environment characteristics when trying to come up with an overall evaluation of that neighbourhood's walk- and bikeability.

CHAPTER 3: METHODOLOGY

The following chapter discusses the general study approach, the modes that were assessed, the version of each model that was studied, the scale of study, how the GIS models were developed, the variables assessed, the tools used, the methods for data analysis and evaluation and finally any assumptions which may have affected the results.

General Approach

Due to methodological differences (both in model development and analysis) in past morphological studies and the fact that no one study has simultaneously considered all five models of interest, it remains unclear how these models compare in terms of their ability to facilitate active transportation. To address this problem, this study provided a morphological assessment of the five models and tested claims made by their proponents concerning their potential for improving walk- and bikeability. It assessed the models through a framework based upon that used by Southworth and Owens' (1993) and subsequent researchers, and aimed to be more comprehensive in the number of variables assessed, particularly with regards to continuity, modal separation and legibility, which are understudied in the literature to date. Density and ratio-based measures were produced in place of count data wherever possible to so as to allow comparison of this study's models with neighbourhoods of other sizes. Most importantly, a detailed, step by step methodology for model building and analysis was created (see Appendix F - H) to allow for replication of these results or for the use of other researchers wishing to apply a similar framework, and to provide a better understanding of how these results were obtained so as to enable comparisons between the findings of this and other studies.

In order to compare and evaluate the neighbourhood models in terms of their ability to support active transportation, GIS- based representations of each (henceforth referred to as "GIS models") were constructed using ArcMap 10.0 and ArcCatalog 10.0 (Build 3200 with Service Pack 3) and subsequently analyzed using basic program tools, the Network Analyst extension, Microsoft Excel 2007, ActivStats (for boxplots) and Data Desk 6.1.

A Geographic Information System (GIS) was chosen as the main tool for this study because of the considerable benefits it offers in terms of speed of analysis, ability to incorporate sophisticated, objective measurements of both spatial and non-spatial data at multiple scales and its ability to easily create and compare alternative designs and scenarios – a tremendous advantage over earlier pen-and-paper techniques (Aultman-Hall et al., 1997; Moudon, 1997, 1998; Pinho and Oliveira, 2009; Sallis, 2009; Göçmen and Ventura, 2010). GIS was also selected because of the potential for the tools developed here (particularly for continuity and modal separation) to be of use to other researchers or planners wishing to assess proposed designs for their active transportation potential, making the value of this work extend beyond just an assessment of these five particular models to having a broader applicability within the real world context.

Finally, the models were evaluated upon how well they address Cervero and Kockelman's (1997) 3Ds of density, diversity (land use mix) and design (here, network design) on an equally-weighted basis to determine their overall active transportation potential.

Modes Assessed

A common problem in active transportation research has been the lumping together of pedestrian and cyclists, even though they may travel across different networks and have different preferences for network variables (Dill, 2004). In this study, unique values were calculated for pedestrians and cyclists by establishing separate networks for each. Furthermore, since some models explicitly emphasize improved connectivity values for pedestrians and cyclists relative to cars, values for the motorized transportation network (MTN) were also calculated so as to allow for the calculation of such differential measures. Depending on the model:

The pedestrian network was made up of

- Sidewalks
- Trails
- Driveways
- Frontdoor connections to sidewalks
- Alleys

The cyclist network was made up of

- Roads (with and without bike lanes)
- Trails
- Driveways
- Frontdoor connections to roads
- Alleys

The motorist network was made up of

- Roads
- Driveways
- Alleys

Models & Model Variations

Table 7 outlines the types of models and which variation of each was considered in this study. Further hybrids and permutations of these models are undoubtedly possible (Marshall, 2005) but were outside the scope of this study and therefore not considered.

Table 7: Variation considered for each model

Model	Variation	As Described By…
Grid	Oblong Grid	Southworth and Owens (1993) CMHC (2000)
Greenway	Greenway Interlaced with Cul-de-Sacs (minus guest parking)	JLAF (2010) (Radburn[1] described by: Stein (1957) Lee and Ahn (2003) Southworth and Ben-Joseph (2003))
Loop and Cul-de-Sac	Loops and Lollipops	Southworth and Owens (1993) CMHC (2000, 2010) Filion and Hammond (2003)
Fused Grid	Quadrant designs 4, 5, 6 and 7 (selected at random), to be combined into one 2 x 2 quadrant grid	CMHC (2000, 2002, 2004, 2008) Grammenos (2008)
New Urbanist	Axial (Seaside/Laguna West) (with some elements drawn from Kentlands)	Southworth (1997) Lee and Ahn (2003) Hess (2008) CMHC (2010)

[1]: While the Greenway model produced for this study more closely resembles the JLAF design than Radburn, some elements of the Radburn design were still drawn upon to develop the final GIS model.

Model Development

GIS models were developed in ArcGIS using the model principles outlined in the sources listed in Table 7 above and from case study data (taken from the literature). In many cases the available literature on the neighbourhood models includes no specifications for some of the more basic network and lot features (such as the width of bike lanes, driveways, etc.). Where a specification could not be found and where there was no reason to believe that the applicable case studies reflect specific model design principles rather than, for instance, local site planning requirements, the following sources were used to develop these features:

Table 8: Sources for general network and lot specifications

Model or Feature	Sources
Roads, alleys and right-of-ways	Kulash (2001) Southworth and Ben-Joseph (2003) Girling and Kellett (2005) Transportation Association of Canada (2007) Hess (2008)
Sidewalks	National Association of Home Builders et al. (2001) Transportation Association of Canada (2007)
Trails	Flink and Searns (1993) Urban Land Institute (2001) Transportation Association of Canada (2007)
Bike lanes	American Association of State Highway and Transportation Officials (1991) Transportation Association of Canada (2007)
Setbacks and space between homes	Moudon (1992) Southworth and Ben-Joseph (2003)
Driveways	Transportation Association of Canada (2007)

The general design principles used to develop the GIS models are summarized in Chapter 4, while more detailed information and the exact specifications used for each GIS model can be found in Appendix E.

Scale of Study

The potential difference in length between what is considered reasonable for walking trips and biking trips (up to 1 km vs. up to 5 km) presents a challenge in assessing neighbourhoods for active transportation (see differences in studies by Untermann, 1984; Hydén et al., 1998; Curran et al., 2006; Grammenos, 2008; Titze et al., 2008). The scale at which most designs are studied, the neighbourhood (2,000 x 2,000 feet or approximately 100 acres, as defined by Southworth and Owens, 1993), is suitable for studying walkability, but arguably too limiting when it comes to bikeability.

The CMHC's 2000 study was the only study identified in which an attempt was made to look at the effect of pursuing a given model (the Fused Grid) at a much larger scale (which then, in theory, would do a better job of assessing bikeability). In order to do so, they applied the Fused Grid to a large section of Nepean, Ontario.

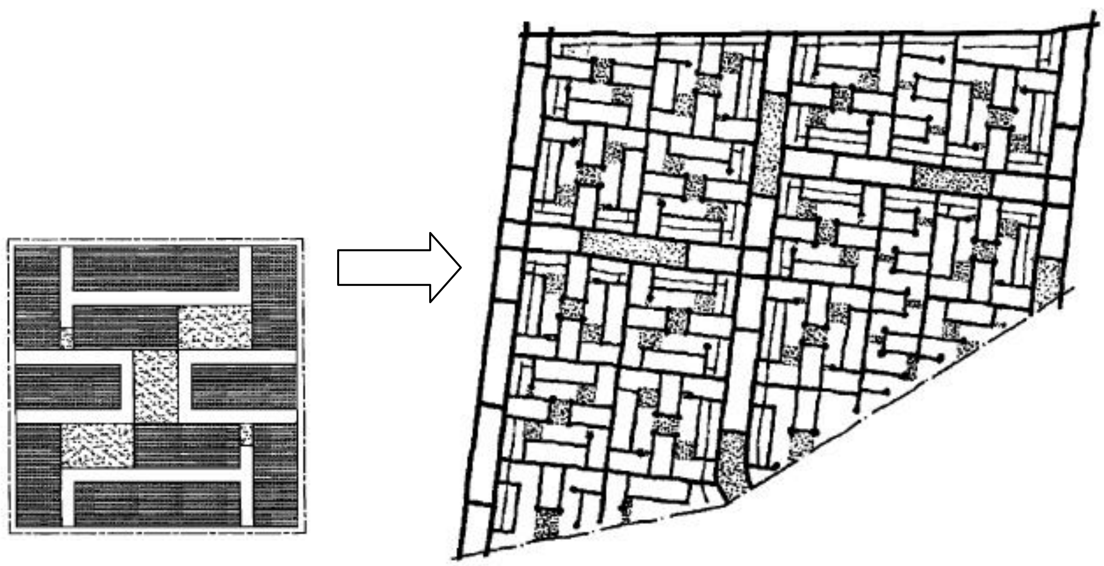


Fig. 24: The application of one Fused Grid quadrant to a much larger area of Nepean

(Image source: CMHC, 2000, p. 57)

However, such "scaling-up" inevitably results in designs that are unlikely to reflect reality, as it is improbable that an area 5 km long or wide would be made up of the same type of neighbourhoods, or even be entirely made up of "neighbourhoods" at all – more likely it would include a mixture of commercial, industrial areas, etc. As well, it could not account for regional network elements such as long-distance greenways, designated bike routes, etc. which are not normally included in neighbourhood models. And as scaled up models of this type do not include these regional-scale variations, any results from such studies will, by in large, be similar (in proportion) to findings at the smaller neighbourhood scale save for, perhaps, the reduction in some edge effects.

As such, for the purpose of this study, a neighbourhood scale was used, with it being recognized that for the purpose of many bike trips, the design presented will only cover a portion of any given trip, but that this portion is also all that a given neighbourhood could realistically be expected to contribute, the rest being largely dependent upon the surrounding local context.

Of the models under study, the Fused Grid is the most prescriptive about its dimensions, wherein each quadrant is approximately 40 acres. Since it is easier to modify the other models to fit the Fused Grid's area than vice versa, the Fused Grid's dimensions were used to establish a standard frame of roads for all five models (see Fig. 25 below). As a 2 x 2 grid of Fused Grid quadrants was used, this gave a final frame size of 160 acres, or 2640' x 2640' (804.7 m X 804.7 m) – slightly larger than the size of neighbourhoods used in the Southworth and Owens (1993) study.

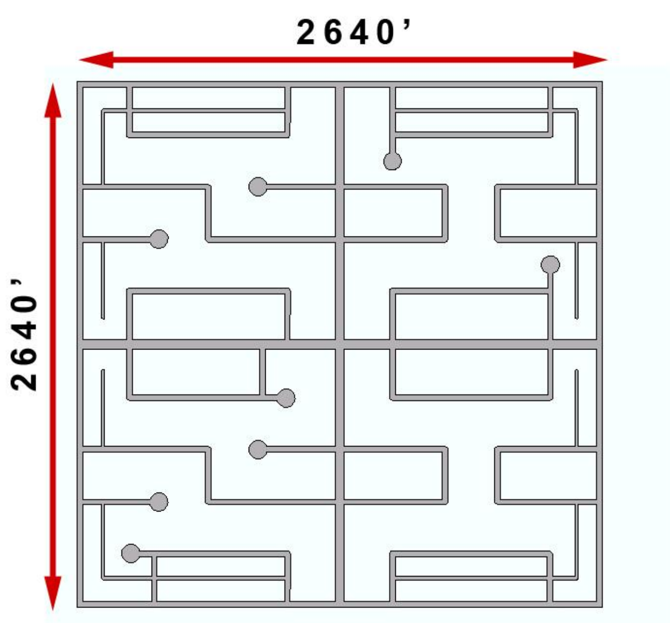


Fig. 25: Model frame

Because most previous studies of neighbourhood models have been done and given dimensions in imperial, the models were built and analyzed in imperial feet.

Variables Assessed

The explanatory variables in this study are the 3Ds of Diversity, Density and Design (as per Cervero and Kockelman, 1997).

"Design" in this study was limited to "Network Design", as past research has shown that the most important design variables (such as trip length, time and safety) are largely or entirely dependent on network design, rather than, for instance, the overall aesthetics of the streetscape. These explanatory variables are the result of the neighbourhood model characteristics, and in turn determine the potential for walkability and bikeability (the active transportation potential) in the models (the response variable) (see Fig. 26, below).

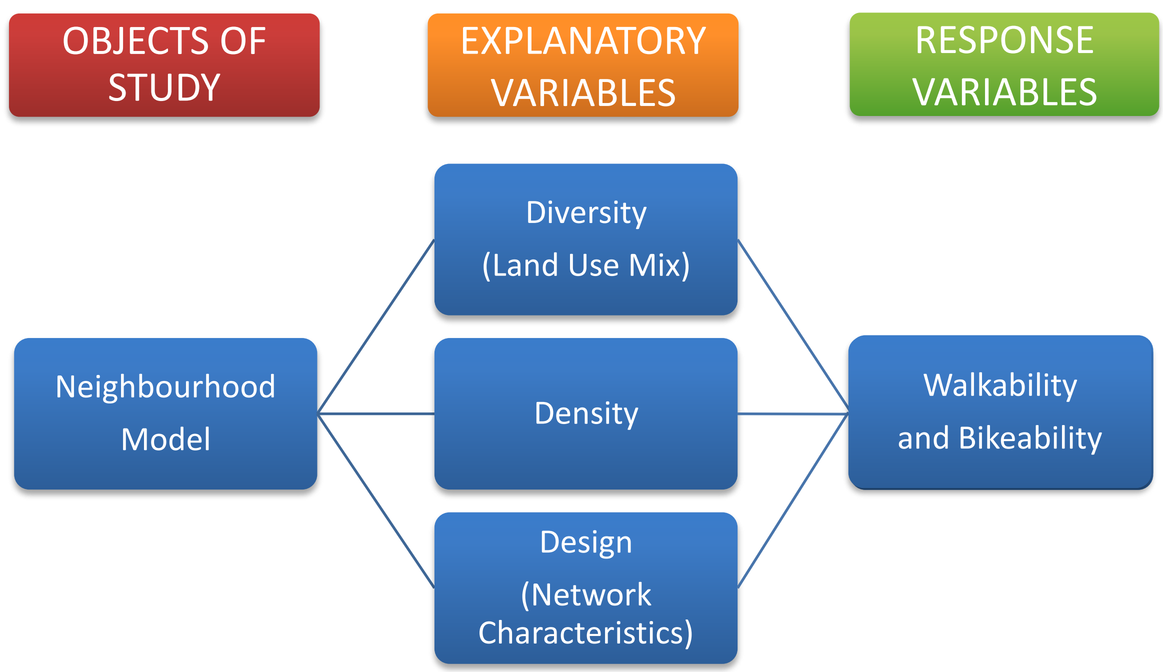


Fig. 26: Explanatory & response variables

Since the publication of Cervero and Kockelman's paper, other researchers have added additional "Ds" to the list, such as "Destination Accessibility" (essentially proximity), "Distance to Transit" and "Demand Management" (see Ewing and Cervero, 2010). For the purposes of this study, only the original 3Ds will be used, as "destination accessibility" is viewed as a product of design (network layout) and diversity (land use mix), and neither distance to transit nor demand management can effectively be considered for a neighbourhood model in isolation of a specific community, population, and transit-context.

Cervero and Kockleman (1997, p. 210) recognized that for the 3Ds, "each dimension can be expressed by different variables, no one of which, alone, fully portrays that dimension, but which together more completely characterize the dimension". As a consequence, they used several measures to assess each dimension, an approach which was emulated in this study. While Diversity (land use mix) and Density are relatively straight-forward concepts which could be measured with only one or two variables, there are several different characteristics that are important to a network, such as connectivity and coverage, each of which required their own measures (see Figure 27 and 30 below).

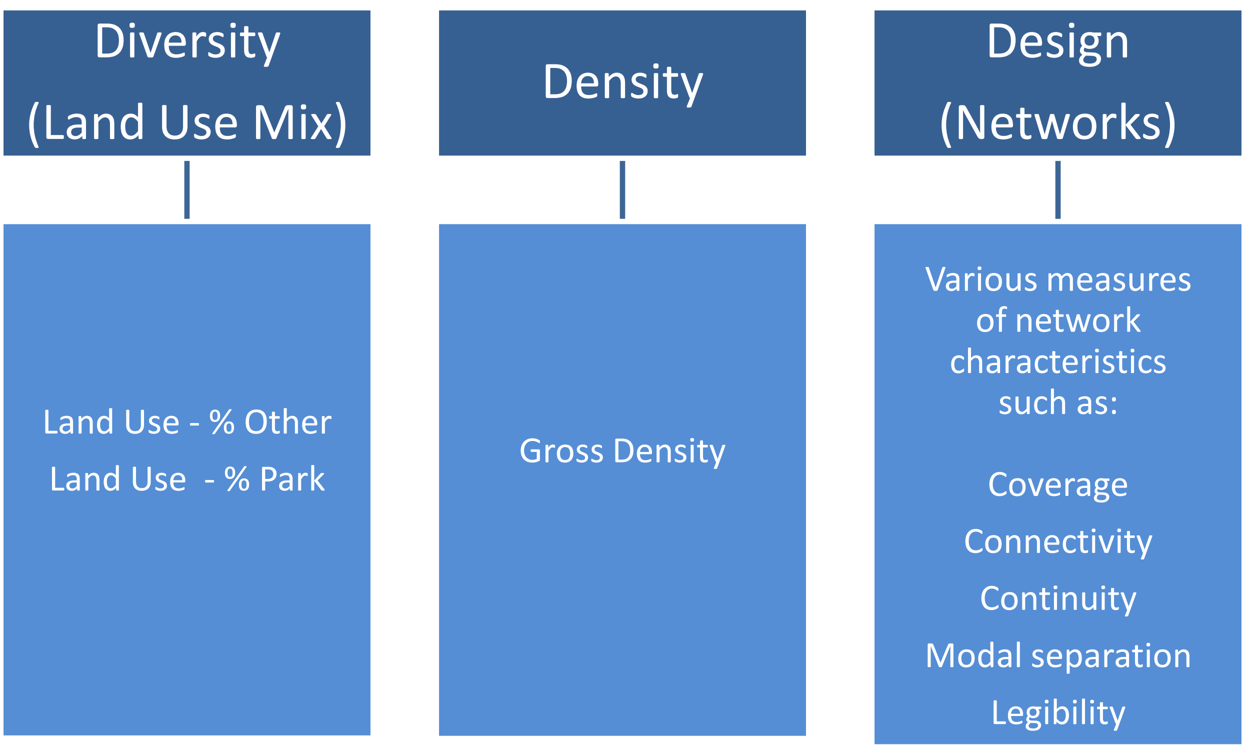


Fig. 27: Types of measures calculated for each of the "3Ds".

Choice of Network Design Characteristics

The network design characteristics which were measured were coverage, connectivity, continuity, modal separation and legibility, as described in Chapter 2. For many of these characteristics, the choice of measures was inspired by, but considerably expanded upon, those used in the Southworth and Owens (1993) framework and subsequent morphological studies. Looking back to Table 5 (p. 67), it can be seen that most of the gaps in previous morphological studies have been in the areas of continuity, modal separation and legibility, so a special effort was made to incorporate or develop measures for them.

Network Design Characteristic Measures: Network-Based vs. Trip-Based Measures

There are two basic ways to measure the network design characteristics that may affect walking and biking. The first is to look directly at the network itself, independent of any homes or destinations on it. Examples of such **"network-based measures"** include measures of network coverage, intersection density and metric reach. Because they are independent of the origins and destinations involved in trip-making, network measures only take into consideration the public portion of networks (i.e., they exclude driveways) (see Fig. 28).

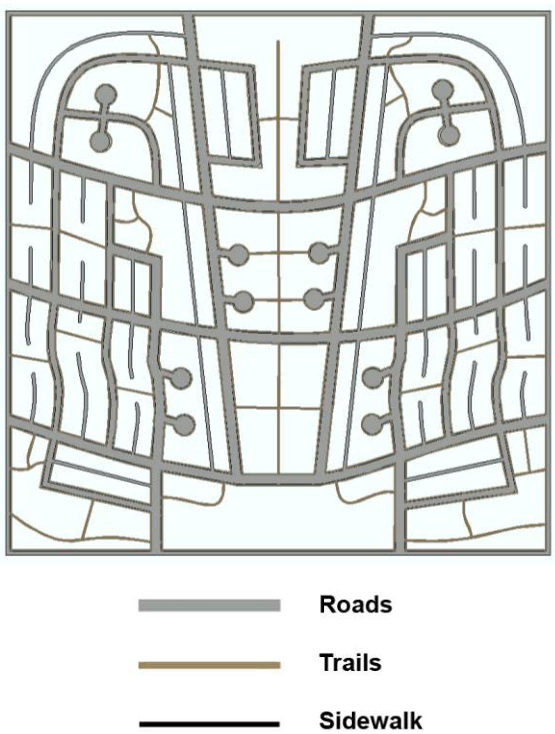
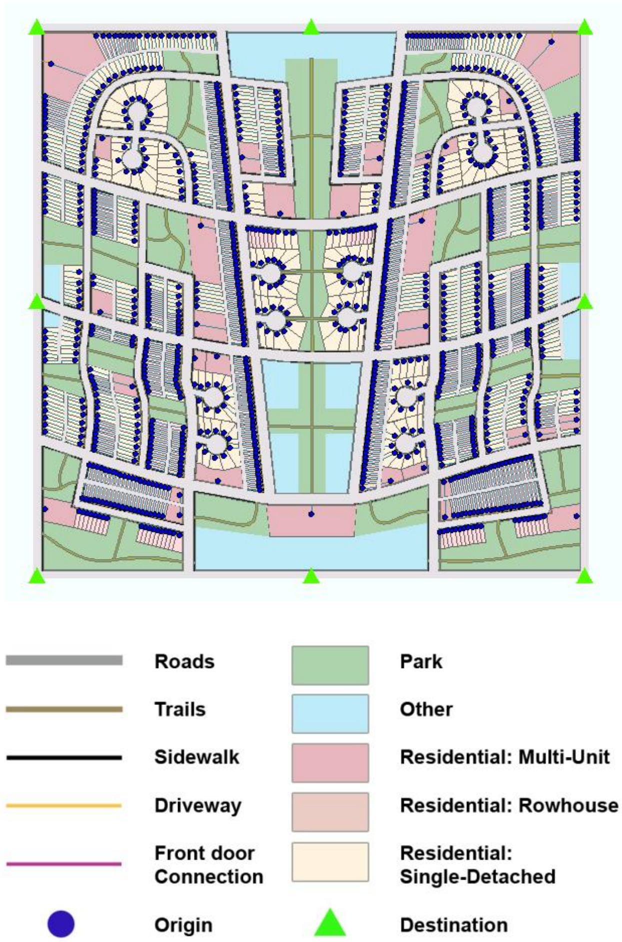


Fig. 28: A neighbourhood as it would be seen from a "network-based" perspective
(showing public network elements only)

Every neighbourhood model advocates for a particular combination of a network layout, density, and land use mix. However, while it is well-established that higher densities and greater land use mix support more walking and biking, it is less clear which basic network layout is *inherently* best, regardless of the final locations and densities of homes and destinations. Network-based measures are best suited to solving this problem, and, in turn, support efforts to synthesize new and improved models which combine optimized network layouts with desirable levels of density and land use mix. Examples of studies making use of network-based measures include Southworth (1997), CMHC (2000) and Peponis et al. (2008).



Zoomed in:

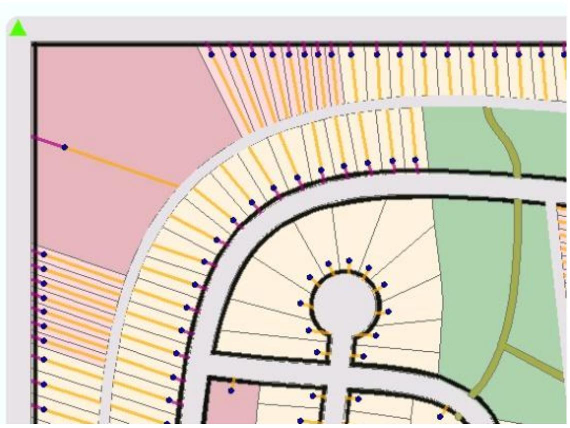


Fig. 29: A neighbourhood as it would be seen from a "trip-based" perspective
(showing the network plus the distribution of origins and destinations, land use, driveway and frontdoor connections)

An alternative to **network-based measures** are **trip-based measures,** which require specific origin and destination points to be loaded onto a network and can therefore be affected by where and how density is distributed across that network (see Fig. 29). For instance, loading most homes onto a highly disconnected portion of the network will produce higher average trip lengths; locating them on well-connected portions of the network will reduce them. Trip-based measures are not affected so much by what the density is so much as how it is distributed through the network. These, then, are essentially synthetic measures, which are driven both by network design and density distribution, and help reveal how choices about density distribution can affect the travel experience through a neighbourhood for its residents, whether in terms of trip length, time, or barriers encountered while trying to get to a specific destination.

Like network-based measures, trip-based measures can be calculated for a variety of network characteristics. For example, whereas intersection density is a network-based measure of connectivity, a measure of trip length looks at how connectivity affects the length of a specific trip. Whereas "point of conflict density" is a network-based measure of continuity, "number of points of conflict encountered during a trip" would be is trip-based equivalent. Examples of studies making use of trip-based measures include Aultman-Hall et al. (1997) and Lee and Ahn (2003).[1]

Since in this study "Density" was captured separately from the network design, it was important for the purposes of the *overall* evaluation of walkability and bikeability in the models that only network-based measures, rather than trip-based measures, be used to assess the "Design" dimension so as to avoid confounding the effects of density and design.

The network characteristics (e.g. connectivity, legibility, etc.) that made up the "network design" variable in this study and the measurements that were used to assess each are outlined in Fig. 30 below. In the case of some of the network characteristics, multiple measures were used to better capture multiple facets of the characteristic at hand where a variety of different measures are used in the literature (for instance, connectivity). In this case, the models were ranked as to how they fared on each, and then the results averaged to give their "average rank" for that particular network characteristic.

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[1] *: Another form of trip-based measure used in research looks at not only the distribution of origins and destinations, but the actual number of trips made to and from each. However, as such research requires real people to generate trip demand, it is not applicable in a study of this nature.*

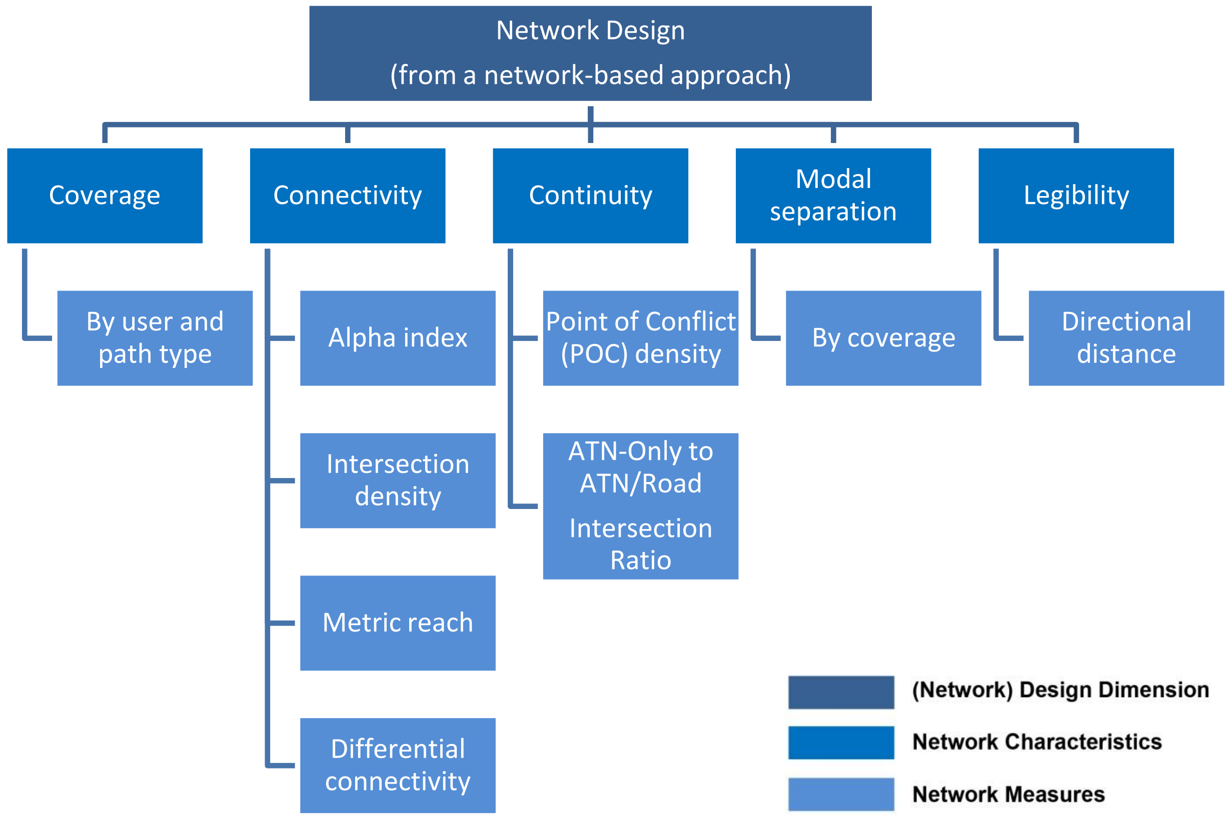


Fig. 30: The "Design" variable, network design characteristics & their measures

Although by necessity network-based measures were used for the evaluation of overall walk- and bikeability, it is nonetheless valuable to be able to compare trip characteristics between the models, especially as network design measures are only relevant insofar as they have an actual impact on the trips being made. Reporting on trip-based measures also allows comparison between the models used here and those used in other studies reporting trip-based results. As such, the following trip-based measures were also calculated (Fig. 31):

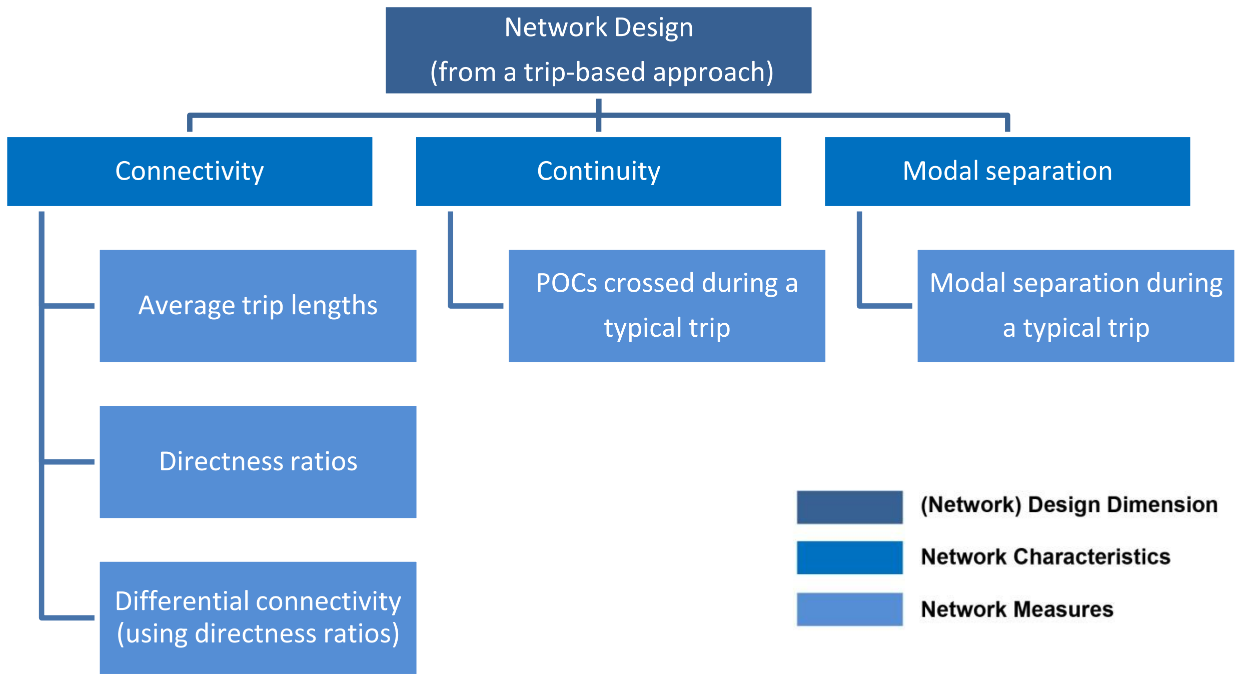


Fig. 31: Trip-based measures

Lot-based vs. Density-based Approaches to Trips

There are two basic approaches that can be used when calculating a trip-based measure such as average trip length between homes and a destination of interest. One is to assume that each lot represents a single origin point (a building) (see, for instance, Lee and Ahn, 2003). In this case, a single-detached house, row house and an apartment building would all end up equally weighted, regardless of the number of units in the apartment building. A second approach is to place a single origin point on each lot, but to weight that point based on the number of dwelling units (or, if known, people) within. This was the approached used by Aultman-Hall et al. (1997), and is reflected in their proposed neighbourhood design shown in Fig. 32 below.

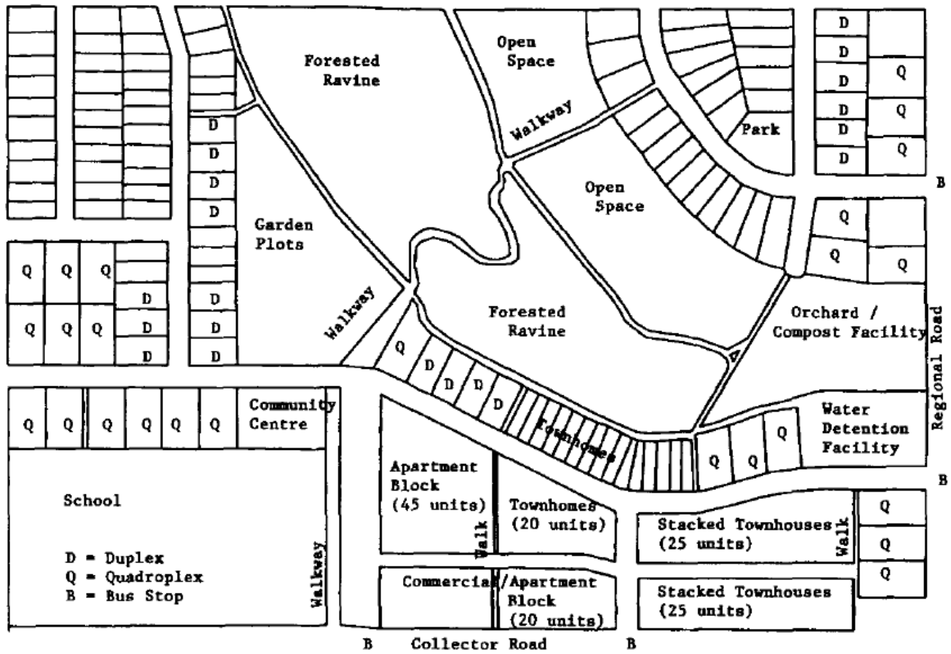


Fig. 32: Aultman-Hall et al.'s 1997 (p. 12, Fig. 1) representation of lots and dwelling units

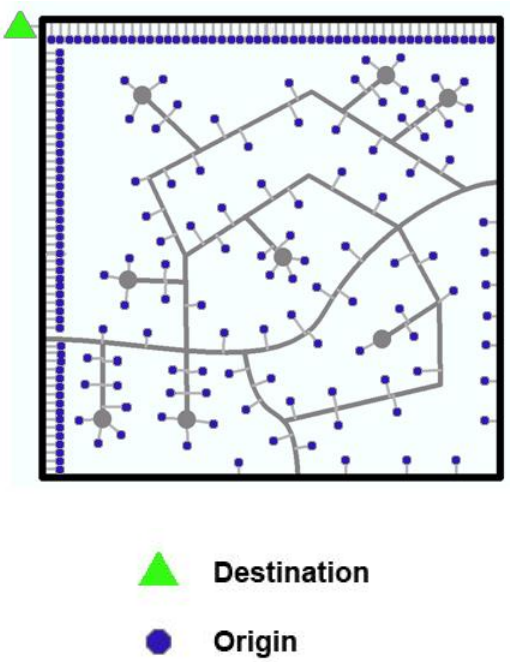
Although none of the studies reviewed explicitly discussed the reason for their choice of approach, it is obvious that differences in approach can have considerable impacts on results. Fig. 33 below illustrates how this approach affects calculated trip lengths in a model for three different scenarios. In each scenario, there are 200 dwelling units distributed across the model space. Consistent with most neighbourhood models, a greater proportion of these units (in this case, 100 units) have been distributed along the better-connected, higher order roads, close to the destination of interest (the green triangle) along the left and top edges of the model frame. The remaining 100 units are scattered through the remaining model space and are all assumed to be single-detached homes.

In the first scenario, these edge units are assumed to be row houses. In this scenario, every home would have a weight of 1 regardless of whether a lot-based or dwelling-unit based approach is used. The average trip length is 2,119', and 100 out of the 200 records in the resulting origin-destination matrix would come from these 100 units.

In the second and third scenarios, these 100 edge units are compressed into two apartment buildings with 50 dwelling units in each. If the same lot-based approach is used as in the first scenario, these 50 dwelling units are compressed into a single lot which has the same weight (1) as any other lot in the model, even if those other lots only contain single-detached homes . In this scenario (scenario 2), the average trip length is increased to 3,016' – a tremendous increase of 44%, *even though the network and basic distribution of homes and destinations have not changed*. The hundred units become only 2 records out of a 102 record origin-destination matrix with the remaining 100 coming from the homes in the centre of the model. If the apartments building are weighted based on dwelling units (scenario 3), however, the average trip length changes by only 4' (2,115') – a mere 0.2% difference. (It is essential to note that while this example uses trip length, any trip characteristic can potentially be affected by the decision to go with a lot-based or density-based approach).

Thus, assuming that all models will try to located higher densities along higher-order roads, assessing trip lengths based on lots systematically skews results in favour of models which use strategically placed **low**-rise buildings (instead of high-rise buildings) to achieve density. Not only that, but when one considers that in many studies differences in connectivity between neighbourhoods is less than 44%, the potential for the effects of housing type to completely overwhelm the *actual* changes in network design in the results are extremely high.

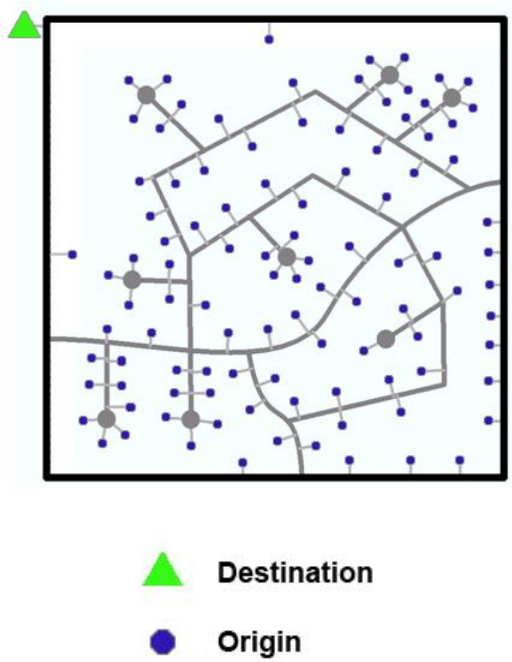
Scenario 1: Row houses on the edge



Average trip length: 2,119’

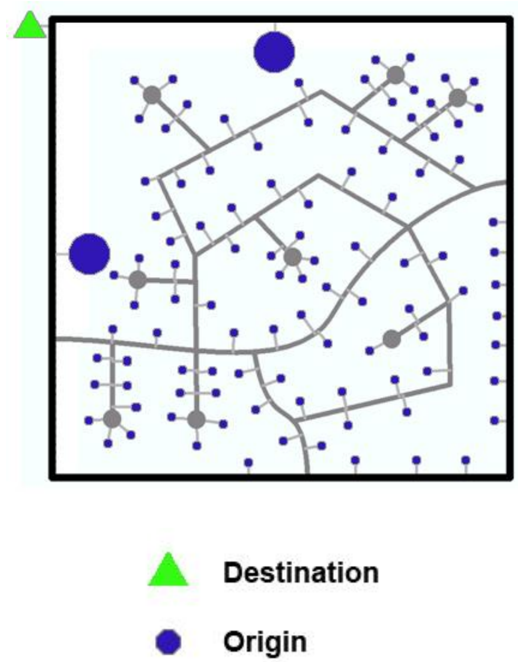
(With row houses, the same trip length results regardless of whether a lot-base or dwelling-unit based approach is used)

Scenario 2: Two apartment buildings on the edges – weighted by lots



Average trip length: 3,016’

Scenario 3: Two apartment buildings on the edges – weighted by dwelling units



Average trip length: 2,115’

Fig. 33: Lot-based vs. dwelling-unit-based approaches to trip measurement

This finding is especially important in a study such as this, where some models tend to load higher density into rowhouses and low-rise buildings (New Urbanist, Fused Grid) while others tend to use high-rise apartments to achieve their desired density (Loop and Cul-de-Sac, Grid, Greenway).

Since it is people, not lots, driveways or buildings which will ultimately make the trips in a neighbourhood, it makes sense to assess neighbourhood models based on where people will be likely to be – that is, based on their homes (dwelling units). It is noted that while dwelling units do not serve as a perfect means of assessing how many people might live in an area (as some units may be home to large families and some tend to be owned by single people), it is nonetheless the best proxy which can be used without having a real neighbourhood (and trip-making population) to assess. Therefore, a dwelling-unit approach was used for all trip-based measures in this study.

Locations of Origin & Destination Points

In order to use trip-based measures, decisions had to be made concerning the location of origin and destination points.

Destination Points

A set of destination points were placed at the exact same coordinates in each model. The destinations were positioned to capture two spatial concepts – travel to the model edge and travel to the model centre (see Fig. 34 below). The centre was easily represented by a single destintion point, but defining “the edge” through destination points was more complicated as there are an infinite number of possible locations along the edge. Using just one point to serve as “the” edge destination may create unintentional skew in the results for average trip distance if, by chance, one model happens to have most of its density located near that point. To help prevent this, eight points were placed around the edge and the results to them averaged to create a value which represents the “typical” trip experience (length, number of intersections crossed, etc.) when trying to get to the edge of the neighbourhood. Each model therefore had a total of nine destination points within it.

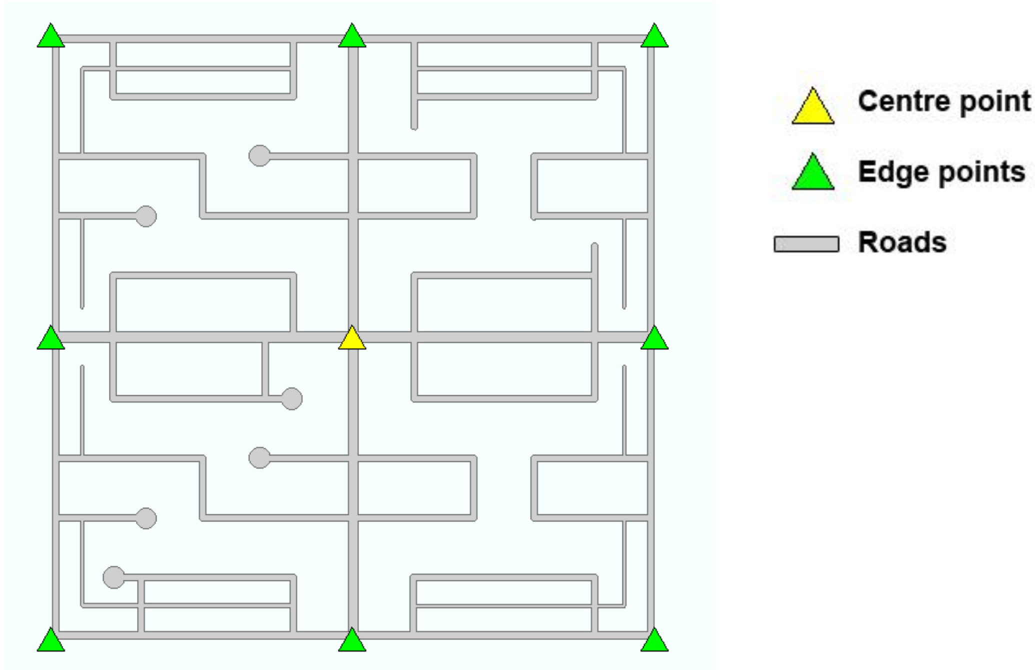


Fig. 34: Destination points for trip-based measures

Thus, results for both trips to the edge and trips to the centre could be generated. However, as comparing models on two such results simultaneously can be challenging (for instance, if one model had a 100’ shorter trip to the centre than another, but a 450’ longer trip to the edge, would it be considered better overall or worse?), the results were averaged to produce results for a single value (called “a typical trip”) that could be compared between the models:

(Trip to Centre + Average Trip to Edge) /2 = “Typical Trip” from a dwelling unit

It is noted that the nine destinations do not represent any specific non-residential land use, as any such designation (for instance, saying one would find a school in a New Urbanist neighbourhood but not in a Fused Grid one) would be largely arbitrary. Thus, results describe moreso the experience moving through the neighbourhood rather than attempts to reach any particular type of location. (This also explains why although origins were weighted by number of dwelling units to reflect a demand for trips based on households, destinations were not assigned any weights because it would be entirely arbitrary to assign demand to them).

Origin Points (Dwelling Units)

Only residential dwelling units will be treated as potential origin points in this study. Origin points will be located in the centre of a lot (width-wise), and set back from the road (depth-wise) in accordance with any given model's design principles, so as to affect travel distances (however minimally).

Residential population density will vary between the models, and will be designed such that the values for the models fall within the range specified by the model's design principles and/or found in applicable case studies (see Chapter 4 and Appendix E for more details). Buildings that support a greater number of dwelling units will be located towards higher-order roads where possible, unless otherwise specified by the design principles of a given model.

Capturing Safety

Safety is the most complex of walking and biking correlates affected by network design, and no one measure can serve as a fair assessment of it. Of the network characteristics considered, continuity and modal separation have the clearest connection to safety. Continuity here measures the number and density of possible points of conflict (e.g., intersections, the most common location of crashes), while modal separation looks at the extent to which different modes are kept in close proximity (which, at the very least, is known to have a strong relationship to the *perception* of risk, regardless of any impacts on actual crash incidence). However, beyond presenting the results of measures of these two characteristics and qualitatively discussing the potential for natural surveillance between the models, no overall assessment of safety was made.

Other Measures of Interest

While the main purpose of this study was to assess the overall potential for active transportation between the five study models, active transportation potential alone is not the only factor considered by municipalities and developers when assessing the viability of a neighbourhood design. Some of these other characteristics of interest are easily calculated through the GIS models, and thus were included here because of their importance to implementation (buildable, network and paved areas; net density), or future attempts at model synthesis (gross unit and density potential). Fig. 35 outlines these additional measures.

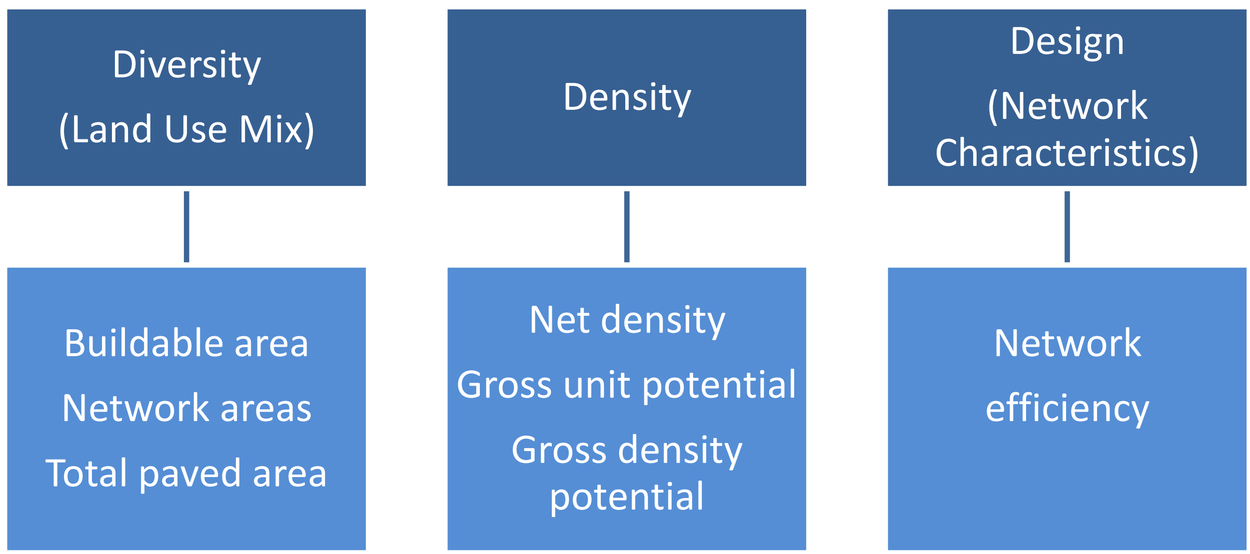


Fig. 35: Additional measures of interest

Assessment of Study Variables

All of the measures listed will be assessed using ArcGIS and Microsoft Excel where applicable. It has been noted that the GIS measures used in past research have rarely been described in enough detail to allow replication (Forsyth et al., 2006; Sallis, 2009). To help address this problem this study will make use of the basic methodology laid out by Forsyth et al. (2006) for the creation of protocols for the assessment walkbility and bikeability-related variables using GIS. This methodology consists of six steps, which are to:

1) Define the basic concept
2) Establish a basic definition, formula or procedure
3) Provide a detailed definition or formula
4) Provide comments and explanations
5) Outline the general GIS approach
6) Detail the exact GIS steps

For each variable and its corresponding measures, Tables 9 - 17 below list the name of its measure(s), their conceptualization, why they were chosen for inclusion in this study, how they were measured (including the basic GIS approach and equations where applicable) and any additional notes. The detailed steps used for both model construction and assessment can be found in Appendices F - H. Separate values were calculated for pedestrians, cyclists and motorists for all measures with the exceptions of network efficiency and differential connectivity (for both network-based and trip-based measures), for which only the pedestrian and cyclist values were calculated.

Table 9: Land use measures

Variable	Conceptualization	Why is it Included?	Measure	Notes
Land use – "other"	The amount of land dedicated to commercial, institutional and industrial uses.	Used with total amount of park space (below) as a proxy for land use mix in the models. (It is noted that land used for non-residential purposes does not always produce a high mix of different types of purposes, but is the best proxy available).	Pre-defined as percent of total model area. Options used: "High" (8%), "Medium" (6%) or "Low" (4%)	Value based on available case-study data and design guidelines in the literature.
Land use – "park"	The amount of land dedicated to parks and open spaces.	A second non-residential land use measure: separated out from "other land use mix" because high values in this category (over 20% of available land in some New Urbanist developments) could easily overwhelm the smaller range of values (4 – 8%) in the "other land use mix" category.	Total area of "park" lots in the GIS models (expressed as both a total area and as a percent of the study area)	Value based on available case-study data and design guidelines in the literature.
Land use – "residential"	The amount of land dedicated to residential use.	Included because of its connection to density and interest to decision makers.	Total area of "residential" lots in the GIS models (expressed as both a total area and as a percent of the study area)	Land leftover after the road network and other and park land use lots were accounted for. Also broken down into sub-types: "multi-unit" "row" and "single-detached"
Buildable area	The amount of land available for any type of development, once road networks are taken into account.	Important for developers when evaluating the viability of a model.	Model area – road network area	Model area: 160 acres Land for sidewalks was not subtracted because they are located within individual lots, while land for trails was not subtracted because they are typically located within parks.
Road network area	The amount of land dedicated to roads.	Important for developers when evaluating the cost of a model's network; important to municipalities in terms of servicing requirements, stormwater management, etc.	Road network area (as measured by ArcMap in the "networklines_buffered" attributes table)	Includes alleys and bike lanes, but not driveways.
Other active transportation network (ATN) area	The amount of land dedicated to trails and sidewalks.	Important for developers when evaluating the cost of a model's network; important to municipalities in terms of servicing requirements, stormwater management, etc.	Sidewalk + trail network areas (as measured by ArcMap in the "networklines_buffered" attributes table)	Bike lanes counted under "road network area", above and not included here.
Total paved area	The total paved area of the publicly accessibly transportation network within a neighbourhood.	Important for environmental reasons (groundwater recharge and stormwater management) and for developers (cost of paving).	Road network area + other ATN area	Does not include driveways.

Table 10: Density measures

Variable	Conceptualization	Why is it Included?	Measure	Notes
Gross density	The average number of dwelling units per unit of model area.	Important for walkability and bikeability in terms of its ability to support transit, higher land use mix, and make driving less appealing (via increased traffic). Important for developers for evaluating return on investment. Important for municipalities for tax base and servicing costs for an area, as well as for determining the viability of public transit.	Total number of dwelling units / model area	Model area: 160 acres Measures of density used in this study only take into consideration the potential for people living in the neighbourhood. It does not consider employment density.
Net density	The average number of dwelling units per unit residential area.	Common variable of interest for all development stakeholders; helps to describe how the gross density is achieved.	Total number of dwelling units / total residential land	Does not consider employment density.
Gross unit potential for single-family homes	The number of single-family homes that could fit into the model's buildable area, using a standard lot size (5750 sq. ft., equivalent to a 50 x 115' lot).	Useful as a standard means of comparison between models (how many homes each model could contain if they all built homes of the same size)	Buildable area / 5,750 sq. ft.	Standard lot area taken from CHBA, 2010.
Gross density potential for single-family homes	The gross density one would achieve if all buildable land in a model was put into single-family homes with a standard lot area (5,750 sq. ft., equivalent to a 50 x 115' lot).	Useful for model synthesis (assessing the potential of a given model for higher densities, regardless of the densities normally associated with it). Unlike gross unit potential, this value is reported on a per acre or per hectare basis, enabling comparison with neighbourhoods of different sizes.	Gross unit potential for single-family homes / model area	Model area: 160 acres

Table 11: Network coverage measures

Variable	Conceptualization	Why is it Included?	Measure	Notes
Coverage by path type	The total length of a given path type in the network.	Defines amount of each type of path available and allows comparison between (for instance) length of roads vs. trails, etc.	Total length of network lines of a given type	Four types of coverages were calculated: 1) Road (all roads including alleys, but not including driveways) 2) Sidewalk 3) Bike Lane (the length of roads with bike lanes) 4) Trail
Density of coverage by path type	The average length of a given path type in an acre.	Density values are more useful than simple measurements because they allow comparison between neighbourhoods of different sizes.	Coverage of path type / model area	Model area: 160 acres
Coverage by mode	The total length of paths available to each mode (driving, walking, biking), together defining the extent of the network available to them.	Defines the length of network available to each type of user.	Total length of lines available for a given user(s)	User group lines included for each mode were: **Car:** All, Bikelane, Mixed **Walking:** All, Ped, PedBk **Biking:** All, Bike, Bikelane, Mixed, PedBK (see Appendix F for more information)
Density of coverage by mode	Average length of paths available to each mode in an acre.	Density values are more useful than simple measurements because they allow comparison between neighbourhoods of different sizes.	Coverage of all paths available for a given mode / model area	Model area: 160 acres

Table 12: Connectivity measures

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Alpha index	Network-based	A topological measure of the number of cycles in a graph relative to the number possible.	Captures route options (Dill, 2004). Valued for measuring connectivity independent of the number of nodes (Rodrigue et al., 2009).	(# of cycles) / [(# of nodes *2) – 5] *Where Number of Cycles = # of Links – # of Nodes + # of Subgraphs*	The alpha index is a topological measure, and so is only concerned about the connections of points to one another, regardless of the actual space between them.
Intersection density	Network-based	Average number of a given type of intersection per acre. (See discussion of intersection types on p. 106 below)	Captures both trip length & route options facets of connectivity; easy to measure.	# of a given intersection type and divide model area	Reported on intersections by type, as well as the total density of intersections available to each mode Possible types of intersections: Regular Road ATN-Only (Trail/Trail, Midblock, Greenway Crossing, Underpass)
Metric reach	Network-based	The average length of pathways that can be reached within a given network travel distance from the midpoint of each road or path segment.	An innovative, relatively new tool for assessing connectivity. Captures both trip length & route options facets of connectivity.	The average length of pathways that can be reached within 0.25 miles of travel from the midpoint of each road or path segment. Calculated using Peponis et al.'s (2008) "Spatialist Lines" software.	While this study used 0.25 miles for the distance threshold, any value could be used.
Average trip length	Trip-based	The average length of a "typical trip" (itself the average of "travel to edge" and "travel to centre") for each dwelling unit in the neighbourhood	Allows a comparison of typical trip lengths between models.	Calculated using an origin/destination matrix (in the Network Analyst extension of ESRI's ArcGIS) For each dwelling unit: Typical trip length = [(Trip length to the centre destination) + (average trip length to the edge destinations)] / 2 Then averaged for all dwelling units in the model	Captures trip length Requires logical Origin-Destination (OD) pairs
Directness ratios	Trip-based	The ratio between average trip distance along the network and the Euclidean (straight-line) distance between two points	Like density measures, directness ratios are useful as a basis of comparison between different studies and neighbourhoods because they are not dependent on the size of the area under study.	For each dwelling unit: [(Trip length to centre/Euclidean distance to centre destination) + (average trip length to edge destinations/average Euclidean distance to edge destinations)] / 2 Then averaged for all dwelling units in the model. Euclidean distances calculated using the Point Distance tool in ArcGIS.	Captures trip length (relative to Euclidean distance)

Table 13: Differential connectivity measures

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Differential connectivity – intersection density	Network- based	The percent difference in intersection density between motorized and active modes	Differential connectivity may be as (or even more) important to active transportation than absolute connectivity (see Hawkins, 2007) and is a fundamental component of some models.	Intersection density (ped or bike) / intersection density (car) * 100%	Intersections between alleys and roads were included in this measure.
Differential connectivity – metric reach	Network- based	The percent difference in metric reach between motorized and active modes	Differential connectivity may be as (or even more) important to active transportation than absolute connectivity (see Hawkins, 2007) and is a fundamental component of some models.	Metric reach (ped or bike) / metric reach (car) * 100%	
Differential connectivity – trip distances	Trip-based	The ratio between trip distance by walking or biking versus by car, to reflect how much better or worse the active transportation networks are relative to their motorized counterparts.	Compares the differences in connectivity between modes, which Hawkins (2007) found to be important in assessing travel behaviours.	(Average trip length by an active mode for dwelling units in the model) / (average trip length by car for dwelling units in the model)	

Table 14: Continuity measures

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Points of Conflict (POC) density	Network-based	The density of possible points of conflict within a given area, to reflect the potential for conflict in the network.	Continuity has rarely been studied in the literature. As a density measure, this measure will be useful for future comparison with this study's results, regardless of the size of other neighbourhoods or models under study.	(Number of points of conflict) / model area	See p. 105 for an explanation of points of conflict. Model area: 160 acres Points of conflict will be grouped into: ATN/ATN POCs (trail/sidewalk, trail/trail, sidewalk/sidewalk, frontdoor/sidewalk, frontdoor/trail) ATN/Driveway POCs (sidewalk/driveway, sidewalk/other driveway, trail/driveway, trail/other driveway) ATN/Road POCs (sidewalk/road, trail/road) Road/Road POCs (road/road, including alley/road)

Table 14: Continuity measures (cont.)

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Ratio of ATN-only intersections to regular road intersections	Network-based	The ratio of ATN-only intersections to road intersections. Where the ratio is higher, there are more opportunities for pedestrians and/or cyclists to change direction without having to worry about cars.	An easily calculated measure to assess the proportion of intersections dedicated exclusively to active modes relative to car-oriented ones in the network.	ATN-only intersections / regular road Intersections	Somewhat similar conceptually to X vs. T intersection ratios used in other studies, but with an explicit active transportation continuity (rather than connectivity) focus. Measure incorporates both ATN/ATN and ATN/Road intersections: it is worth noting that cars would still be present at ATN/Road intersections, although unable to turn in the same way active moves would be. The actual safety of those midblock intersections, however, would be dependent on the sort of signage and intersection features present (not assessed in this study).
Conflict points encountered on a trip	Trip-based	A description of the number of potential points of conflict neighbourhood residents would encounter while making a typical trip.	Describes the number of POCs a person may pass through when attempting to reach neighbourhood destinations (and thus, recognizes that POCs on well-travelled paths have a larger impact than those on poorly travelled ones – something which cannot be captured through its network-based counterpart, POC density).	Counted using accumulation attributes when running an Origin/Destination matrix on the Network Dataset. Results for each home: [(POCs to centre destination) + (average POCs to edge destinations)] / 2 Results will then be averaged for all dwelling units in the model. Reported both as a total (count data) and as a POC count per mile travelled, in order to account for differences in trip lengths between models.	POC points will be grouped into the following categories, depending on mode under study: ATN/ATN (trail/sidewalk, trail/trail, sidewalk/sidewalk, frontdoor/sidewalk, frontdoor/trail) ATN/Driveway (sidewalk/driveway, sidewalk/other driveway, trail/driveway, trail/other driveway) ATN/Road (sidewalk/road, trail/road) Road/Road (road/road, including alley/road)

Table 15: Modal separation measures

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Modal separation by coverage	Network-based	How much modal separation is provided by the different paths that make up the total network (by length)	Modal separation has rarely been studied in the literature, and is known to be important to many pedestrians and cyclists.	(Length of paths with a given level of modal separation) / total coverage * 100%	**Modal separation options for pedestrian paths were:** "Complete separation from cars" "No separation from cars due to parking (alleys and crossing driveways)" "No separation from cars due to road crossings" **For the cyclist network, the options were:** "Complete separation from cars" "Partial separation via bike lanes" "No separation due to on- road mixed traffic conditions" "No separation due to parking (alleys and crossing driveways)" **For the motorized network, the options were:** "Partial separation from cyclists via bike lanes" "No separation from bikes due to on-road mixed traffic conditions" "No separation from cyclists or pedestrians due to alleys"
Modal separation by trip	Trip-based	What proportion of a "typical trip" takes place on paths of different levels of modal separation	Describes the modal separation (by path length) a person would experience when attempting to reach destinations (and thus, recognizes that modal separation on well-travelled paths – e.g., well connected paths – will have a larger impact than those on poorly travelled ones, something not captured by its network based equivalent, modal separation by coverage).	Counted using accumulation attributes when running an Origin/Destination matrix on the Network Dataset. Results for each home: [(Length of paths with a given level of modal separation to centre destination) + (Average length of paths with a given level of modal separation to edge destinations)] / 2 Results will then be averaged for all dwelling units in the model, with the final result for each trip type being divided by the total trip length to express the average proportion of each trip occuring on paths with different levels of separation in each model.	Modal separation levels will be the same as those described in "modal separation by coverage", above.

Table 16: Legibility measures

Variable	Type	Conceptualization	Why is it Included?	Measure	Notes
Directional distance	Network-based	The average length of path that can be travelled without making more than a given number of direction changes from the midpoint of path segment	Legibility is often considered to be an important element of network design. It is believed that easy-to-navigate networks encourage walking and biking and also make travel easier for individuals with cognitive disabilities.	Calculated using Peponis et al.'s (2008) "Spatialist Lines" software Values calculated for 2 direction changes using an angle threshold of 10 degrees and a "very short line segment" of 0.1 miles.	Directional distance was chosen as the measure of legibility because it is intuitively easy to understand and captures not only sharp changes in directions but also those resulting from gradually curving roads, which can be disorienting for travelers.

Table 17: Efficiency measures

Variable	Conceptualization	Why is it Included?	Measure	Notes
Network efficiency	How much more or less land dedicated to transportation network elements is required to improve directness ratios relative to the worst network (% Improvement in directness ratio (over the worst-case network) relative to % change in path area)	A performance based measure which looks at how effectively each model uses the land it dedicates to the active transportation network elements in terms of its impact on trip distances (through directness ratios). This would be valuable for both planners and developers when trying to advocate for the use of any given model.	Each model is compared against the model with the worst average directness ratio for a given mode. Percent improvement in directness ratio calculated as: (Mode's directness ratio for model) / (Mode's directness ratio for worst model) x 100% Percent improvement in path area calculated as: (Mode's network area for model) / (Mode's network area for worst model) x 100%	Measured for pedestrian and cyclist networks only.
Infrastructure efficiency - total	How much land is consumed for roads, sidewalks and parks for each dwelling unit in the model.	Helps to assess the infrastructure costs per dwelling unit, which is important to developers when trying to determine the costs of going with a particular model.	(Total public portion of the network area + total park area) / number of dwelling units in model	Presented by both total model area as well as per dwelling unit. Network area includes alleys but not driveways.
Infrastructure efficiency – by paved area only	How much land is consumed for roads, sidewalks, bike lanes, and trails for each dwelling unit in the model.	Helps to assess the additional infrastructure costs per dwelling unit, which is important to developers when trying to determine the costs of going with a particular model.	Total public portion of the network area / number of dwelling units in model	Presented by both total model area as well as per dwelling unit

About Points of Conflict & Intersections

Points of conflict and intersections were used in this study to help assess continuity and connectivity respectively.

A point of conflict in this study was defined as a point where two paths meet, creating the potential for conflict (and collision) due to crossing or turning traffic flows, whether by the same or a different mode (adapted from TAC, 2007). A point of conflict occurs at every point where two paths meet. As such, multiple points of conflict can be found within a single intersection (see Fig. 36 on p. 107). The type of POC is defined based on the type of pathways which cross. The POC types used in this study were:

Road/Road POC types:

"rd_rd" (for road/road)

ATN/Road POC types:

"sd_rd" (for sidewalk/road)

"sd_dri" (for sidewalk/driveway)

"sd_od" (for sidewalk/other driveway)

"rd_tr" (for road/trail)

"tr_dri" (for trail/driveway)

"tr_od" (for trail/other driveway)

ATN/Driveway POC types:

"sd_dri" (for sidewalk/driveway)

"sd_od" (for sidewalk/other driveway)

"tr_dri" (for trail/driveway)

"tr_od" (for trail/other driveway)

ATN/ATN POC types:

"sd_sd" (for sidewalk/sidewalk)

"sd_tr" (for sidewalk/trail)

"sd_fd" (for sidewalk/front door)

"tr_fd" (for trail/front door)

"tr_tr" (for trail/trail)

An intersection in this study was defined as an area where two or more paths meet or cross at grade, and includes both roadways (if present) and any roadside facilities for active modes (adapted from TAC, 2007). There was only one intersection counted for all the paths that connected in a given area, regardless of the number of segments, path types and potential points of conflict that occur there (see Fig. 36). Path crossings had to be within 50' of one another to be considered part of the same intersection.

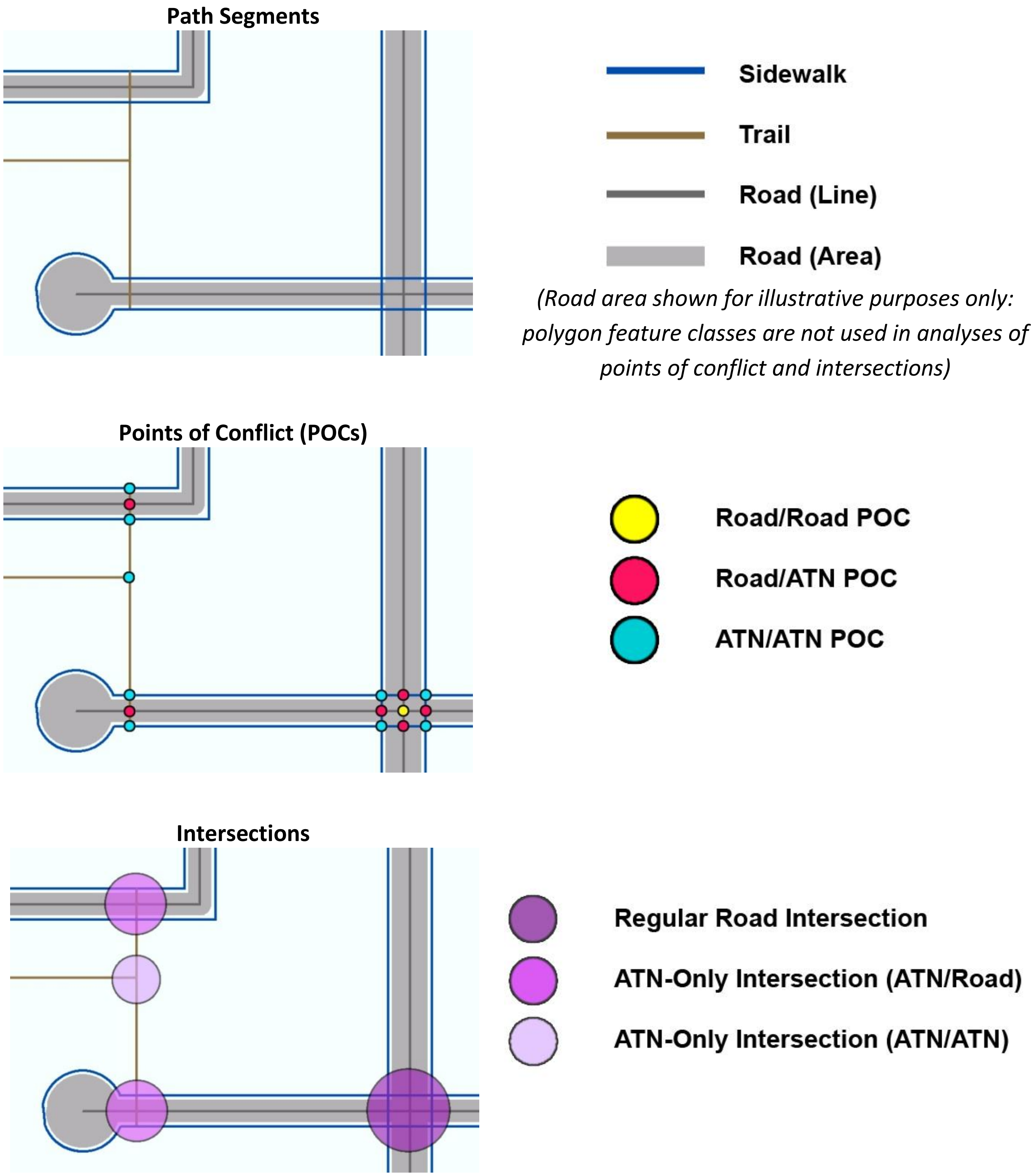


Fig. 36: Paths, points of conflict and intersections

As Fig. 36 shows, there is only one "Road/Road" POC encountered when driving or biking through a road intersection (on the central blue line), as any possible turn movement can occur as one motion. For pedestrians crossing the road from a sidewalk, more than one POC could be crossed depending on the movement (including both a sidewalk/road POC as they cross the road and the sidewalk/sidewalk POCs they would encounter as they cross paths with pedestrians traveling perpendicular to them.

A variety of intersection types were considered in this study. The most common type (and what people typically imagine when an intersection is mentioned) was called a **"Regular Road"** intersection, which was defined as any intersection at which two or more road segments (including cul-de-sacs and alleys) meet. In the case of all models except the Greenway, these intersections will also include sidewalk crossings and possibly trail crossings.

In addition to "Regular Road" intersections, there are **"Active Transportation Network (ATN)-only"** intersections, *where pedestrians and cyclists have the option of changing direction onto a new segment but motorists (if present) do not*. Because most past studies into neighbourhood walk- and bikeability have used roads as proxies for the ATN, the presence or density of ATN-only intersections has rarely been described. There were several possible sub-types of ATN-only intersections used in this study:

- **Trail/Trail:** Where a trail crossed another trail outside of a regular road intersection. (Sidewalk/Sidewalk in not an intersection type because sidewalks crossing sidewalks only occurred within "regular road" intersections).

- **Midblock:** Where trails crossed roads (and usually sidewalks) outside a regular road intersection, providing an opportunity for both pedestrians and cyclists to cross and turn onto the sidewalk (pedestrians) or road (cyclists).

  Note: There was one exception to this, which is where a cyclist traveling on a trail hit an arterial road. For pedestrians, where a trail hits an arterial road it also hits the road's sidewalk, providing them an opportunity to go in two different directions. For cyclists, however, a trail hitting an arterial road is assumed to function as an "on-ramp" where they can only turn right (i.e., the road is assumed to be too busy to allow crossing, and cyclists are assumed not to use the sidewalk). In such cases, the junction acts as a midblock intersection for pedestrians, but is not counted as an intersection for cyclists.

Two types of ATN-only intersections were unique to the Greenway model:

- **Underpass:** These are points where a Greenway trail meets an arterial road but actually would go under it. However, it is assumed cyclists could choose to get onto the road network at these points as well as choose to continue through the underpass. Thus, these points do not count as intersections at all for pedestrians (who have no opportunity to change direction), but for cyclists, who can choose to continue to go straight or turn right at these points (therefore having two turn options available where the trail hits an arterial road, versus only one in other models) these count as a special type of ATN-only intersection.

- **Greenway Crossing:** Because all trail crossings in the Greenway model take place outside of regular road intersections, it has been assumed that these crossings must have stop signs or lights to provide pedestrians and cyclists using the trail a means of crossing the road. (The only exception to this is as underpasses along arterials, which are assumed to be necessary in order to reduce intersection density along these busier roads). Where a trail meets a road at grade in the Greenway model, there is no opportunity for pedestrians to change directions – these are essentially “2-way” intersections similar to a train track crossing at a road for them. However, cyclists can change direction at these intersections by choosing to get onto the road when the motorized traffic stops, making them “4-way” intersections for them. Thus, like the Underpass intersections, these do not count as intersections for pedestrians in the Greenway model (though they do count as points of conflict), but do serve as a type of ATN-only intersections for cyclists. This is the only model to which this scenario applies, as in all other models, where a trail hits a road (except at arterials), both pedestrians and cyclists have a turn option – pedestrians onto the sidewalk and cyclists onto the road.

Model Construction

Representation of Networks

The majority of past neighbourhood morphological studies have used the road network as a proxy for the active transportation network (ATN), even though the two are often not synonymous: for instance, where roads do not have sidewalks, or where trails are present (Dill, 2004). This is essentially the equivalent of trying to draw conclusions about sidewalks by looking at road maps, and since all three alternative models include ATN segments which are separate from the road network, this means that some studies which have attempted to consider their effects on walkability and bikeability undoubtedly contain significant errors. As such, this study sought to improve upon previous active transportation research by aiming to accurately represent the motorized and non-motorized transportation networks in the models. In order to do so, each type of pathway (road, trail, sidewalk) was represented by a unique line segment in the GIS models. Where a complete spatial separation exists (for instance, between sidewalks and roads), the lines were located the appropriate distance apart. This allowed the models to more clearly illustrate the spatial separation between modes (e.g., the difference between a sidewalk right along the edge of the road versus one with a vegetated boulevard) and to show where paths actually cross. (It is noted, however, that bike lanes were treated as a type of lane on a road, and thus were included only as an attribute of the single network centerline used to represent the roadway in the GIS).

GIS Feature Classes and Tools Used

Models were made up of a mix of network lines, polygons (used to represent the frame, buildable area, network area and lots) and points (used to represent origins, destinations, points of conflicts and intersections). A description of each feature class along with a step by step methodology for model development and analysis can be found in Appendices F - H.

Model Validation

Describing the construction of models and the principles used to create them is as important as the final results, but is often a neglected step. While all reasonable effort was made to ensure that the models remained consistent to the specifications set out in Chapter 4 and Appendix E, in some cases it was found that the final model deviated from those specifications in some way. In some case this was just that it was difficult (for example) to maintain an exact 75% / 25% on intersection types over the course of the design, while in others a deviation from the original specifications proved necessary (for example,where there was leftover buildable area after all homes had been accounted for, thus necessitating either an increase in gross density or additional park space in the model).

To ensure that models matched the intended designs as closely as possible, a summary of each model in terms of its land dedicated to parks, "other" and residential uses as well as its density and housing mix were provided and any modifications that had to be made noted (see the second half of Chapter 4: Model Specifications & Validation). This will allow subsequent researchers to judge how well a model follows (or fails to follow) stated design principles and the extent to which they resemble existing developments of a given type.

Evaluation

Evaluating neighbourhoods for walk- and bikeability is always a challenge because what is considered "best" depends on an individual's goals and what trade-offs they are willing to accept to meet them. Similarly, what has the greatest influence on walking or biking may shift with the population using the space or the types of trips (utilitarian vs. recreational) under consideration. Models were therefore ranked from best to worst on each of the study variables, thereby allowing readers to evaluate which model they feel is best, based on their own set of criteria. This approach is consistent with other tools such as the Pedestrian Infrastructure Prioritization Tool (PIP) (see Moudon, 2001) and past work by Filion and Hammond (2003).

For the purposes of an overall evaluation for this study, each model was also ranked on the "3Ds" of Diversity, Density and Design for both the walking and biking modes. These three factors were equally weighted in this study. Although research has shown that all three of these dimensions are important in active transportation, it is noted that the decision to weight them equally is nonetheless still somewhat arbitrary. As research into walkability and bikeability continues, more information will become available to help determine which measures are best and what weights to assign (FHA, 1999), which could then be applied to the results here to come up with a more accurate evaluation as time progresses. In the meantime, however, just as with other walkability indices, having some final score to use to discuss overall potential (however tentatively) was felt to be valuable, and in the absence of a more refined understanding in the literature of the relative value of each of these three known components, an equal weighting has been used.

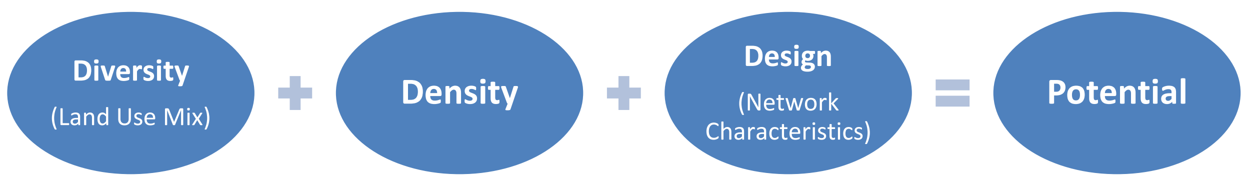


Fig. 37: Evaluation formula

The ranking for each model under each of the "3D" headings was dependent on how it ranked on the various measures that fell under that category. For Density, only a single measure (gross density) was used, as this reflects the total number of dwelling units in the model space and was felt to be a better measure for density as it relates to active transportation than net density. For Diversity, the ranks from two measures (% land in "other" uses and % land in "park" uses) were averaged to produce the final rank. Coming up with an overall rank for "Network Design" was more complicated: in this case, an overall rank for each of the five network characteristics (coverage, connectivity, continuity, modal separation and legibility) were first calculated by averaging the ranks for each of the measures used to assess the variable, and then the ranks for each characteristic averaged to produce the final rank.

Fig. 38 below illustrates how the specific measures, network variables and 3Ds will contribute to each model's final score. A rank of "5" is considered high and a rank of "1" considered low. The maximum final possible score is 15 (derived from a maximum possible rank of 5 for each of the 3Ds).

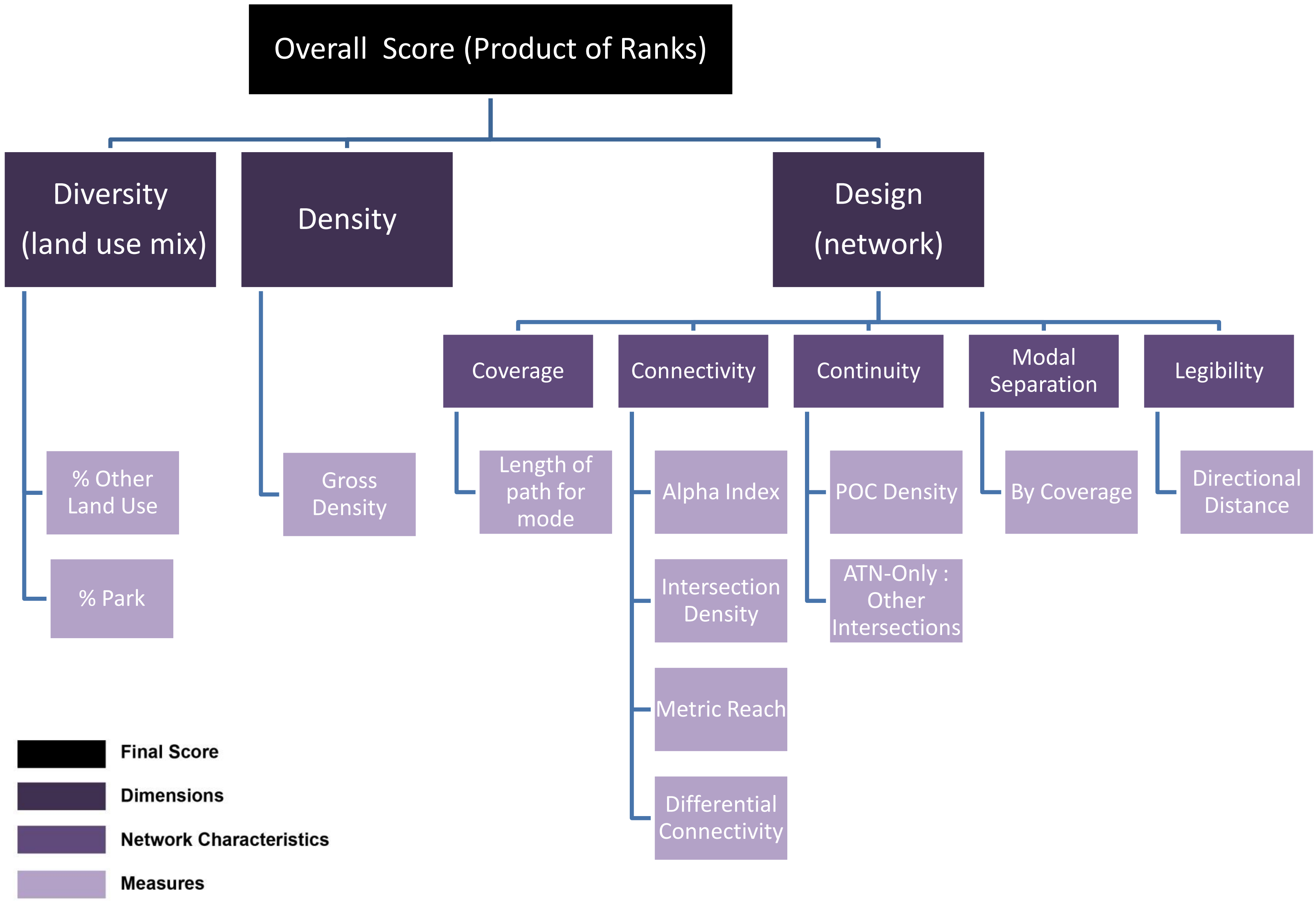


Fig. 38: Ranking system

Since density and network design are both assessed separately in the above evaluation scheme, no trip-based measures were included in the evaluation of walkability and bikeability, although their results are discussed in the second part of Chapter 5: Results (see p. 189). Similarly, the variables assessed for their importance to the development community, although important for decision making, are also presented separately (see p. 215) and were not included in the evaluation of overall potential.

Model Assumptions

It has been assumed that:

1) The backyard of every home is fenced off, and is therefore not accessible to travelers.
2) Cyclists will bike on roads even if they lack the appropriate active transportation infrastructure (i.e. bike lanes).
3) Motorists, pedestrians and cyclists are able and willing to travel down alleys.
4) Pedestrians and cyclists emerging from a trail at a road will be able to cross the road at that point (i.e. make a midblock crossing) except on arterials where traffic is assumed to be too high to permit it.
5) Land is flat and there are no water bodies (or similarly constraining landscape features) present.

CHAPTER 4: MODEL SPECIFICATIONS & VALIDATION

This chapter outlines the basic specifications that were used in developing each GIS model. The inclusion of model specifications was considered important in order to assure the reader that the designs do fairly represent the models they are based upon, particularly as they relate to the 3Ds of Density, Diversity and (network) Design. A more detailed explanation and justification of each along with additional specifications used in the study are provided in Appendix E. Due to time limitations, not all elements that may go into the design of a neighbourhood could be considered. As such, this study focused primarily on the basic network elements that would affect active transportation as well as those necessary to provide data on paved and buildable areas for each of the models.

Models considered:

- **Density**
  - Number of dwelling units
  - Housing type (single-detached, row, multi-family)
  - Lot dimensions
- **Diversity**
  - Land use as assigned to individual lots (residential, park/open space, and an "other" category for any other possible uses such as institutional or commercial)
- **Network Design**
  - Road type
  - Road width
  - Intersection spacing and the angles at which path segments meet
  - Active transportation network pathways (sidewalks, bike lanes, trails, mixed traffic lanes on roads)
  - Parking (on road lanes and driveways)
  - Curbs and gutters (as a common component of "paved area")
  - Boulevards (to determine location of sidewalks relative to roads)
  - Setbacks

Models did not consider:

- Building footprints
- Other types of roads (freeways, divided roads, frontage or service roads, bridges)
- Other types of intersections (such as roundabouts) or intersection features (curb cuts, curb/turn radii, divisional islands, channelization)
- Special types of lanes (right turn, left turn, acceleration, deceleration, weaving or transit)
- Other types of parking (off-peak only parking lanes, woonerven)
- Road speeds
- Guidelines for horizontal curves (tight curves will be avoided in all models)
- Clear throat length, curb radii or flares for driveways
- Necessary corner clearances for driveways near intersections
- Shoulders (roads assumed to be curb only)
- Raised medians
- Grade, slope and drainage
- Clear zones
- Space requirements for road widening
- Utility placement
- Space for snow-piling, snow drifting
- Traffic volumes and composition (see “assumptions” on p. 117)
- Traffic barriers
- Stopping sight distances (from road, sidewalks, bike lanes, trails and driveways)
- Bus pullouts
- Driveway corner clearances

Assumptions:

1) While traffic volumes were not explicitly included in this study, an assumption concerning volumes was necessary in order to come up with appropriate road lane widths where bikes may be present. Therefore, for arterial roads, an Average Annual Daily Traffic (AADT) in the outer lane was assumed to be 3,000 – 4,000 vehicles per day, while for collectors, it was assumed to be 0 – 1,000 vehicles per day.

2) A four lane arterial width was assumed to be necessary for any model where the road network is largely disconnected (Loop and Cul-de-Sac, Fused Grid and Greenway models). A two lane arterial was used for the New Urbanist model, and no arterials were included in the Grid model (as all roads were assumed to be local roads).

3) Right-of-ways were assumed to be included in lot depth dimensions.

Conversions: All conversions between metric and imperial were done to one decimal place. While the use of rounding occassionally caused some change to calculated values when switching between measurement systems, the differences were so small as to be insignificant. All conversions were made using onlineconversion.com.

Notes:

1) Intersection density numbers from Southworth and Owens (1993) and Southworth (1997) were not used to develop specifications because they did not include cul-de-sac intersections in their counts, making them inconsistent with later studies.

2) Where a range of possible values was found in the design manuals and/or case studies for any given characteristic, intermediate values were chosen, provided these fell within the TAC (2007) guidelines considered acceptable for Canada.

3) Minimum intersection spacing was tested by measuring the distance between road centerlines, rather than the edge of the roadways.

Specifications: All Models

Model size: Each model was constructed to be 2,640 x 2,640 feet, the equivalent of 4 quadrants in the Fused Grid model (the most standardized of the models under study) and a size similar to that used in studies following Southworth and Owen's 1993 framework (2,000 x 2,000 feet). Some Loop and Cul-de-Sac neighbourhoods have also been found to occur in frames of this size as a result of their agricultural origins (see Moudon, 1992).

Model frame: Each model was framed by four straight roads, which were arterial roads in all models which use a hierarchical road network (e.g., all models but the Grid). The frame is defined by the road centrelines, and as a consequence, only half the outermost roads (by width) were included in the model space, in keeping with previous work on the Fused Grid model (CMHC, 2000, 2002).

Road network specifications: The basic road network specifications were based on design guidelines from TAC (2007) and the NAHB et al. (2001) (see Appendix E for details), and were used for all models save where a model explicitly used another value. These specifications only applied where a given element was actually present in a model (for example, not all models have cul-de-sacs). How successful the final GIS models ultimately were in conforming to these design specifications is outlined in in the second part of this chapter.

General Specifications

General specifications were established for the following model elements:

Land Use, Density & Housing Mix

- **Land use mix:** Three land use types were included in the study – "Residential", "Park", and "Other" (which would include commercial, institutional and industrial uses). Each model had a minimum of 5% of the model space set aside for parks and open space. For "Other" land uses, each model was assigned a "low" (4%), "medium" (6%) or "high" (8%) value based on the extent to which the model's design guidelines and case studies appear to incorporate land use mix. While land use mix is often assessed through an index of the variety of uses in an area (see, for instance, Kockelman, 1996; Acharya and Bennett, 2001), it was felt this would be too arbitrary for a model-based scenario. All remaining land that was not used by the road network was made residential, which was further broken-down into three sub-types ("multi-unit", "row" and "single-detached").

- **Density & housing mix:** Although governments sometimes produce recommendations for density and/or housing mix for specific areas targeted for growth, there are no universal base standards for housing mix and density and so these values were model specific in each case.

- **Building setbacks:** The minimum setback for all models in this study was 3.3' (1.0 m). Setbacks have been allowed to vary because previous studies have found building setbacks to be useful predictors of walkability and pedestrian-oriented design (Cervero and Kockelman, 1997; Vuchic, 1999; Frank et al., 2009; Sallis et al., 2009).

- **Target lot size for single-detached homes:** 50' x 115' in all models except New Urbanist (which explicitly makes use of narrower lots), based on the average lot size in Canada in 2009/2010 (CHBA, 2010). A standard lot size was seen as an important element in the models, as differences in lots sizes in case study neighbourhoods are likely more the result of the era they were built in (e.g., homes and lots were smaller prior to World War II) than a requirement of the model per se. In some cases, the layout of roads did not allow for perfect 50' x 115' lots: in these cases, lot lines were modified, where possible, to have the total lot area be approximately the same regardless of its actual dimensions (i.e. 5,750 sq. ft.)

Roads

- **Road types:** Roads could be arterials, collectors or local roads (made up of three possible subtypes: through roads, loops, and cul-de-sacs).
    - In non-hierarchical models (i.e. the Grid) all roads were local roads.
    - In hierarchical models, arterials were limited to the four bounding roads that made up the model frame.
    - Collectors were any through roads which connected directly to arterials, covered a significant part of the model area and should not constitute "yield flow" conditions for the two lanes of moving traffic (see TAC, 2007)
    - Any road that was not an arterial or a collector was made a local road.

- **Road width:** Determined by road type (arterial, collector or local) and the presence of bike lanes and/or parking lanes. Curbs and gutters were also included in all road (but not alley) widths, as they contribute to the total amount of paved surface resulting from the road network.

- **Traffic flow conditions on local roads:** The traffic flow conditions for which local roads are designed affects their recommended width. In this study, all local roads were assumed to be designed for slow flow or yield flow conditions.

- **Cul-de-sacs:** The turning circle radius was set at 14 m (45.9') with no centre island for all models, while the maximum number of homes on a cul-de-sac was 25.

- **Alley location & width:** Alleys were only included in those models that explicitly use them. They were not included in the Grid model so as to enhance the difference between it and the New Urbanist model. A standard alley width of 15.7' (4.8 m) was used in all applicable models.

- **Intersections:** 2-way (a railroad-style crossing for trails at midblock), 3-way and 4-way intersections were used in the models. All intersections were simple intersections (no flared/auxiliary left or right turn lanes). The range of acceptable angles for network segments approaching intersections was 70 – 110^o. A minimum spacing of 656.2’ (200.0 m) was required between intersections on arterials, 196.7’ (60.0 m) on collectors and 131.2’ (40.0 m) on local roads. As they function somewhat similarly to driveways and can, at most, occur one lot depth away from a regular road intersection, intersections between alleys and other roads were not counted towards minimum spacing requirements.

Active Transportation Network Elements

- **Sidewalks:** Were present on both sides of the road in all models. This essentially presents a “best case scenario” for each model, even though it has been found in other studies (CMHC, 2010) that Loop and Cul-de-Sac developments often do not have a full complement of sidewalks. Sidewalk width can be seen as an indicator of design for “pedestrian capacity” (Cervero and Kockelman, 1997) and so was made to vary between the models, based on their emphasis on walkability. Sidewalks had a width of 5.9’ (1.8 m) for the traditional models and a wider 6.6’ (2.0 m) for the three alternative models which emphasized active transportation. All models had a 5.0’ (1.5 m) boulevard between sidewalks and roads.

6) **Bike lanes:** Bike lanes were assumed to be present on both sides of arterials and collectors in all models except the Greenway, and not present on local roads. All bike lanes will be single lane on either side of the road (where present). Individual bike lanes had a width of 5.2’ (1.6 m) on arterials and 4.9’ (1.5 m) on collectors.

- **Trails:** Trails were located in all park spaces in all models, and had a standard width of 11’ (3.4 m). Trails were designed so that they connected different roads to one another where possible.

Parking

- **On-road parking:** On-road parking lanes were included on both sides of local roads (although no extra width was provided on the turning circle portion of cul-de-sacs) and on one side of collectors. Lanes were 7.9’ (2.4 m) wide on local roads and 9.2’ (2.8 m) on collectors.

- **Residential driveways:** All single-detached and row house residential driveways were made to be a single lane 11.5’ (3.5 m) wide at approximately 90 degrees to the road and spaced a minimum of 3.3’ (1.0 m) apart. There were no shared driveways in this study. For multi-family residences containing 30 or more dwelling units, driveways were double lane, 23.0’ (7.0 m) wide and assumed to access a rear parking lot (i.e. there were fewer driveways than units in such cases).

- **“Other” land use driveways:** Since any division of “other land use” lands into different lot sizes between models would be largely arbitrary, a fixed value of 1 driveway per 98.4’ (30.0 m) road length was in these areas. Each driveway was 23.0 ‘ (7.0 m) wide.

Model-Specific Specifications, Validation & Problems Encountered During Construction

In addition to the general specifications above, many model-specific specifications were used to guide the development of the GIS models. The most important of these (dealing with basic network characteristics, block size, land use, density, and housing mix) are described below. The background case studies and design guidelines that were used as a basis for these specifications, along with additional specifications pertaining to network design, are described in Appendix E.

Over the course of model construction, it became apparent that it would not always be possible to meet the specifications as they were initially set out. As such, the table following each model's overview describe not only what those initial targets were, but whether or not they were met and if not, what modifications had to be made to the original specifications and why. Significant changes from the original specifications are noted in red italics.

The overview of specifications for each model ends with a map depiciting network lines, lots, origins and destinations. For each model, an additional set of maps was also created, showing:

- Active and motorized transportation networks
- Locations of roads by type
- Locations of intersections by type
- Locations of fake line segments

These maps are presented in Appendix I.

GRID MODEL

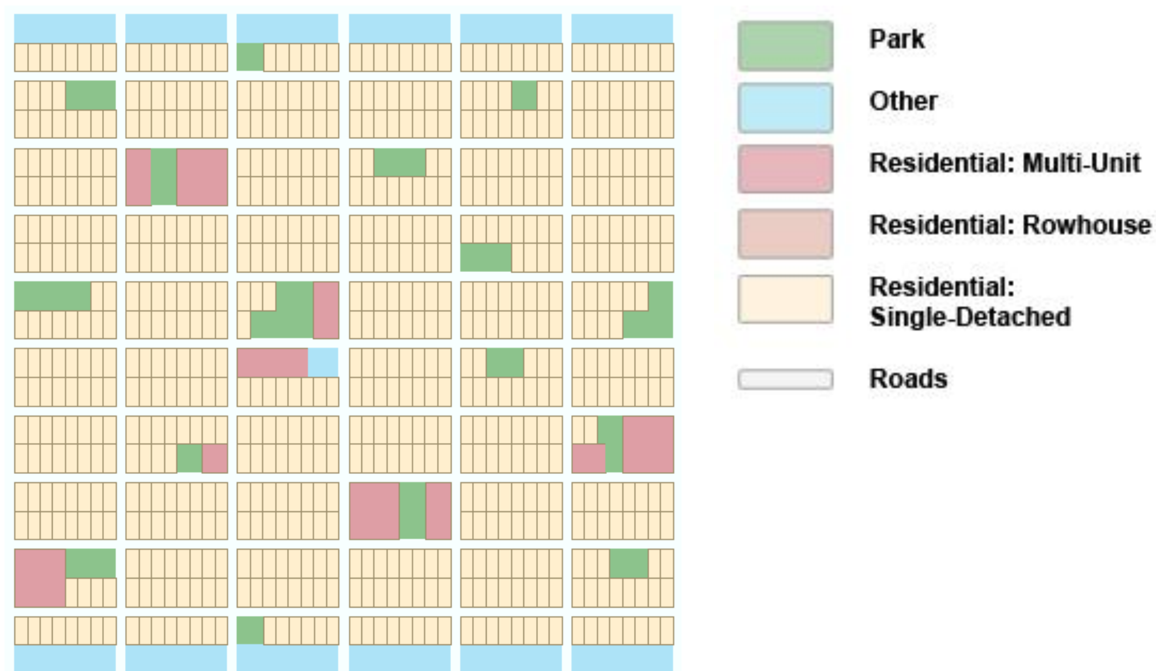


Fig. 39: The study's Grid model

General description: The Grid model for this study is made up of an oblong (rectangular) grid, which the CMHC (2000) notes is the most common type of grid seen in cities. The model's road network is a pure grid of straight, through roads meeting at X-intersections and repeating at regular intervals. The motorized transportation network is non-hierarchical, with all roads being local roads. The land use mix is high (8% of available land), while the proportion of land dedicated to parks is minimal (5%). Sidewalks are ubiquitous, but trails are uncommon and bike lanes are absent. Although alleys are not uncommon in many Grid neighbourhoods, they were not included here so as to allow a more stark comparison between the traditional Grid and New Urbanist designs.

Basic block dimensions: - other studies:

- CMHC (2000): 360' x 200' or 410' x 200'
- Moudon (1992): 460 - 660' x 260' - 360'

Basic block dimensions - this model: 400' x 230'

Location of non-residential land uses: Commercial and institutional uses are located in strips between residential streets (as per Southworth and Owens' 1993"speculative grid" and "interrupted parallel" grid typologies). Parks are small and interspersed throughout the model area.

Table 18: Grid model – specification targets vs. final GIS model

LAND USE			
	% Park	**% Other**	**% Residential**
Target	5% (8.0 acres / 348,480 sq. ft.)	8% (12.8 acres / 557,568 sq. feet)	(No target)
Final	5% (8.0 acres / 348,213.6 sq. ft.)	8% (12.8 acres / 557,570.4 sq. ft.)	65.0% (104.0 acres / 4,530,273.6 sq. ft.)
RESIDENTIAL DENSITY			
Target	Gross density of 10.0 d.u./acre (1,600 dwelling units in the model area)		
Final	*Gross density of 9.3 d.u. / acre* *(1,492 dwelling units)*		
HOUSING UNITS			
	Single	**Row**	**Multi**
Target	50% (800 d.u.)	0	50% (800 d.u.)
Final	50% (746 d.u. of 1,492 d.u.)	0	50% (746 of 1,492 d.u.)

d.u.: dwelling unit

Table 19: Grid model - intersections

Type	Number
Regular Road: Road/Road	77
Regular Road: Road/Alley	0
ATN-Only: Trail/Trail	0
ATN-Only: Midblock (onto a collector or local road)	27
ATN-Only: Midblock (onto an arterial)	0
ATN-Only: Underpass	0
X Intersections [1]	77 of 77
Y Intersections [1]	0 of 77

[1]: X- and Y-intersections only look at road/road intersections and only include road segments in the count so as to be consistent with other studies (thus, although a trail may make a 3-way intersection functionally a 4-way intersection for pedestrians, the intersection would still be counted as a Y-intersection). All intersections falling on the edge of the model frame were assumed to be X-intersections.

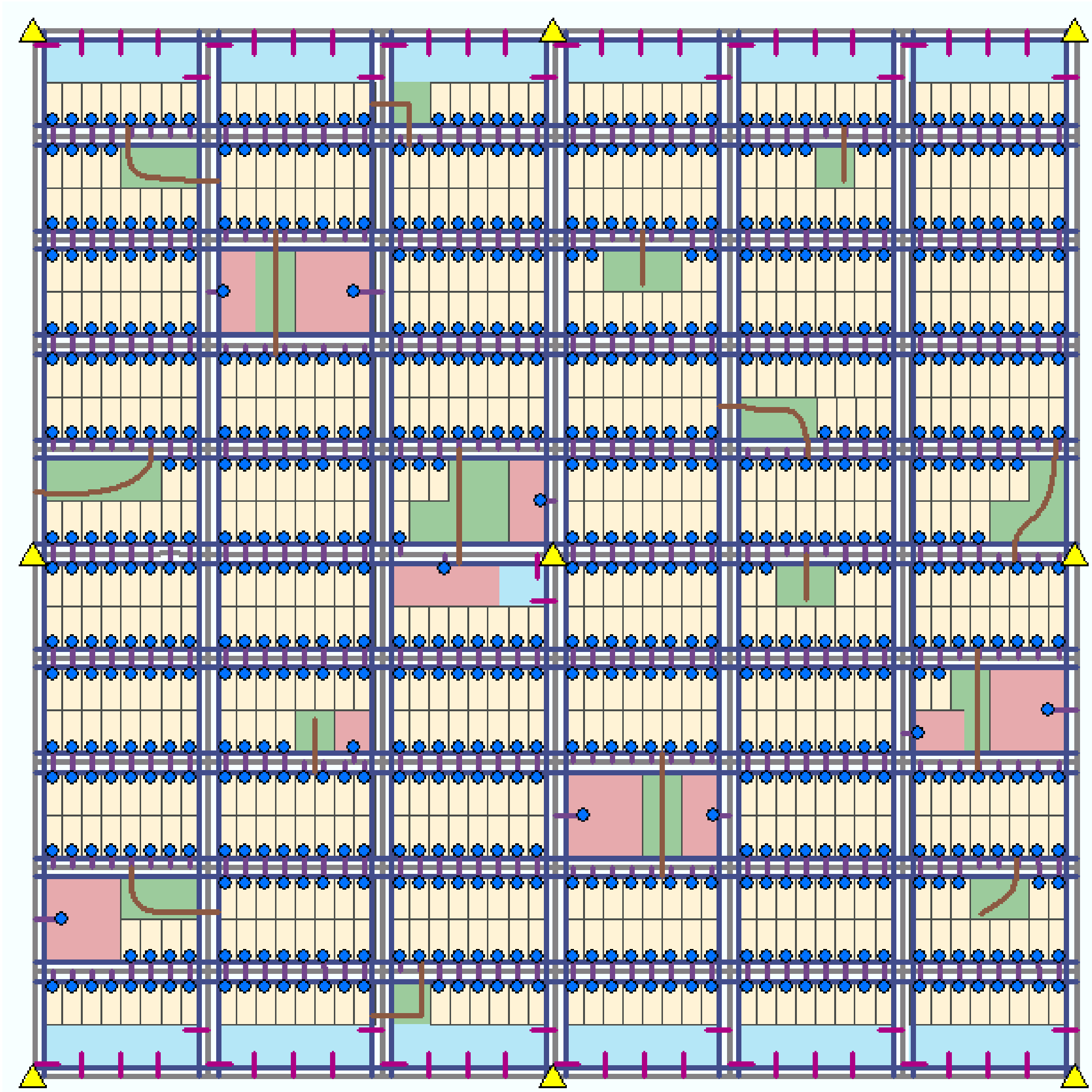
Table 20: Grid model - points of conflict

Type	Number
Road/Road (includes Road/Alley)	77
Road/Sidewalk	272
Road/Trail	27
Sidewalk/Sidewalk	240
Sidewalk/Trail	53
Sidewalk/Driveway	756
Sidewalk/Other driveway	62
Sidewalk/Front door	0
Trail/Trail	0
Trail/Driveway	12
Trail/Front door	0
Underpass	0

Problems encountered with the Grid model:

- ***Density fell below target:*** *It was not possible to fit more single-detached units without reducing lot size of apartments, and even by doing so, the number of units that could be added would have been insufficient to meet original targets. It is believed that this is likely the result of smaller lot sizes in the case study communities the specifications were based on (especially probable given that Grid neighbourhoods were typically built in times when lot sizes were smaller).*

Fig. 40: Grid model - transportation network, lots, origins and destinations



(Network lines symbolized according to path_subtype attribute)

LOOP AND CUL-DE-SAC MODEL

Fig. 41: The study's Loop and Cul-de-Sac model

General description: The Loop and Cul-de-Sac model has a curvilinear, discontinuous street pattern achieved through frequent use of T-intersections, loops and cul-de-sacs of varying configurations and lengths (see CMHC, 2000). The road network is hierarchical. The land use mix is low (4%), while the proportion of land dedicated to parks is relatively high (12%). Sidewalks and trails are fairly ubiquitous, while bike lanes are present on collectors and arterials. No alleys were included in this design.

Basic block dimensions: N/A (extremely variable)

Location of non-residential land uses: Commercial and institutional land uses are located in two major zones, centered around key intersections (see Southworth and Owens, 1993). Parks are few but mostly large, located mainly towards the interior of the neighbourhood.

Table 21: Loop and Cul-de-Sac model - specification targets vs. final GIS model

LAND USE			
	% Park	**% Other**	**% Residential**
Target	12% (19.2 acres / 836,352.0 sq. ft.)	4% (6.4 acres / 278,784.0 sq. ft.)	(No target)
Final	12% (19.2 acres / 836,100.1 sq. ft.)	4% (6.4 acres / 278,197.1 sq. ft)	66% (105.1 acres / 4,576,127.4 sq. ft.)
RESIDENTIAL DENSITY			
Target	Gross density of 6.0 d.u. / acre (960 dwelling units in the model area)		
Final	Gross density of 6.0 d.u. / acre (960 dwelling units)		
HOUSING UNITS			
	Single	**Row**	**Multi**
Target	70% (672 d.u.)	20% (192 d.u.)	10% (96 d.u.)
Final	70% (672 d.u.)	20% (192 d.u.)	10% (96 d.u.)

d.u.: dwelling unit

Table 22: Loop and Cul-de-sac model - intersections

Type	Number
Regular Road: Road/Road	49
Regular Road: Road/Alley	0
ATN-Only: Trail/Trail	5
ATN-Only: Midblock (onto a collector or local road)	8
ATN-Only: Midblock (onto an arterial)	2
ATN-Only: Underpass	0
X Intersections [1]	12 of 49
Y Intersections [1]	37 of 49

[1]: X- and Y-intersections only look at road/road intersections and only include road segments in the count so as to be consistent with other studies (thus, although a trail may make a 3-way intersection functionally a 4-way intersection for pedestrians, the intersection would still be counted as a Y-intersection). All intersections falling on the edge of the model frame were assumed to be X-intersections.

Table 23: Loop and Cul-de-Sac model - points of conflict

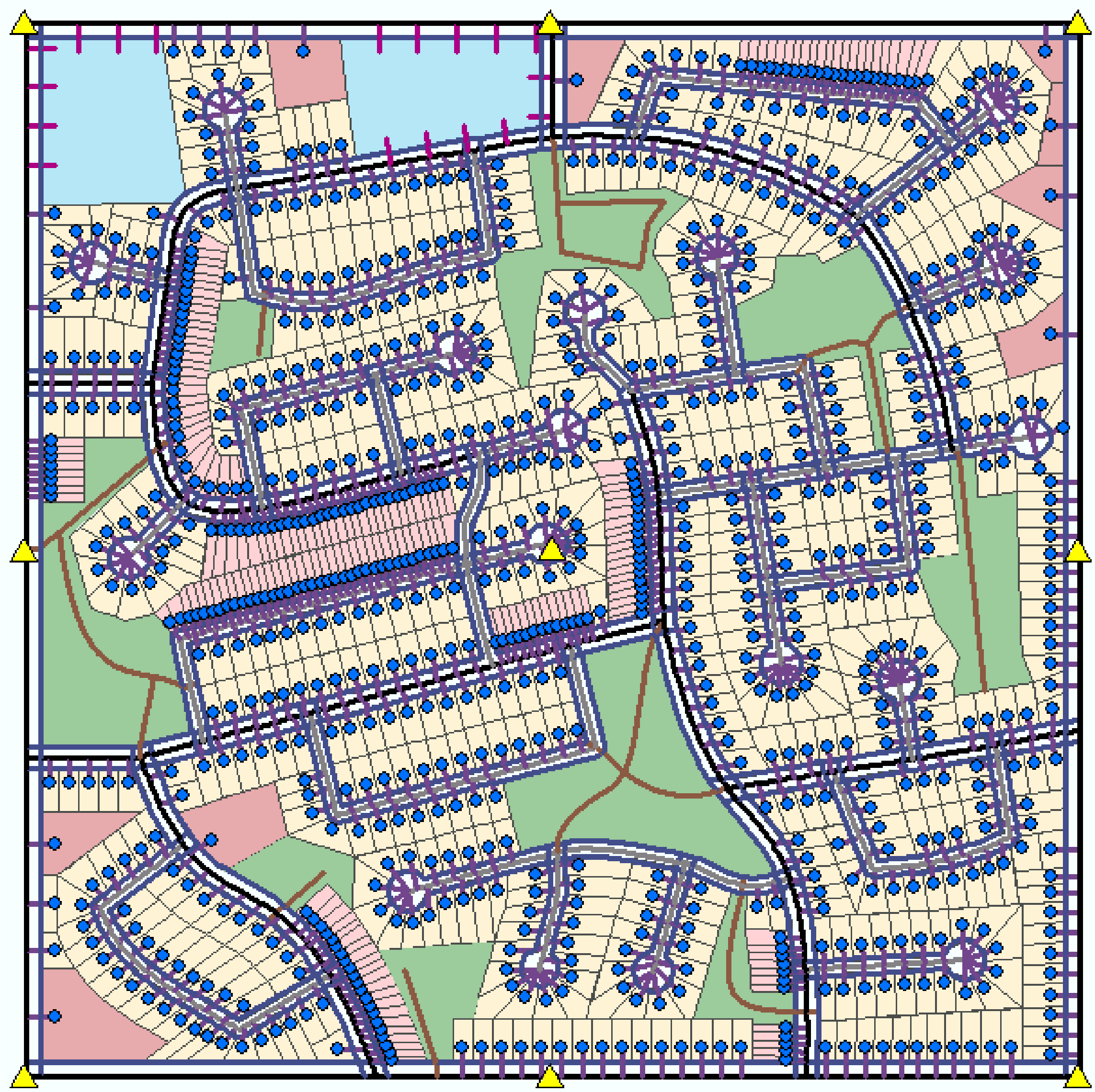
Type	Number
Road/Road (includes Road/Alley)	49
Road/Sidewalk	139
Road/Trail	17
Sidewalk/Sidewalk	168
Sidewalk/Trail	26
Sidewalk/Driveway	880
Sidewalk/Other driveway	18
Sidewalk/Front door	0
Trail/Trail	5
Trail/Driveway	0
Trail/Front door	0
Underpass	0

Problems encountered with the Loop and Cul-de-Sac model:

- ***Odd lot shapes affected setback lines:*** *Because of the curvilinear shapes of the roads and cul-de-sac turning circles, many lots ended up having somewhat unusual shapes which in turn created some difficulty in establishing setback lines. It is not expected that this would have caused any significant impact on the final results.*

- ***Low-rise multi unit buildings:*** *Because of the small number of units to be located in multi-unit buildings, it proved necessary to make the majority of these buildings "low-rise", because to concentrate these into higher rise buildings, a higher overall density or more park space would have been required. It is likely that the proportion of low to high rise apartment buildings in this model is higher than what is seen in many Loop and Cul-de-Sac developments.*

Fig. 42: Loop and Cul-de-Sac model - transportation network, lots, origins and destinations



(Network lines symbolized according to path_subtype attribute)

NEW URBANIST MODEL

Fig. 43: The study's New Urbanist model

General description: This study's New Urbanist model incorporates elements of both the Kentlands and Laguna West case studies, namely, distinct street layouts for each section of the model and a couple of major axial streets. The road network is hierarchical and largely grid-like, but with a more varied grain, more T-intersections and the occasional cul-de-sac (see Calthrope, 1997; Southworth, 1997; Lee and Ahn, 2003). Alleys are common. The land use mix is high (8%), as is the proportion of land dedicated to parks (21%). Sidewalks are present on all roads and bike lanes are present on collectors and arterials. There are many short and a few long trails. Different housing types are often commingled on the same block.

Basic block dimensions: Variable; smaller than seen in the Loop and Cul-de-Sac model.

Location of non-residential land uses: Most commercial and institutional land uses are located at the meeting point of the axial streets, near the edge of the development, as seen in Kentlands (see Lee and

Ahn, 2003). Parks are numerous but most are relatively small and front onto roads so as to improve their accessibility.

Table 24: New Urbanist model - specification targets vs. final GIS model

LAND USE			
	% Park	**% Other**	**% Residential**
Target	17% (27.2 acres / 1,184,832.0 sq. ft)	8% (12.8 acres / 557,568.0 sq. ft)	(No target)
Final	*21%* *(34.2 acres /* *1,488,785.5 sq. ft.)*	8% (12.8 acres / 556,008.2 sq. ft.)	49% (78.1 acres / 3,403,029.9 sq. ft.)
RESIDENTIAL DENSITY			
Target	Gross density of 6.0 d.u./acre (960 d.u. in the model area)		
Final	*Gross density of 8.8 d.u. / acre* *(1,400 dwelling units)*		
HOUSING UNITS			
	Single	**Row**	**Multi**
Target	31% (298 d.u.)	40% (384 d.u.)	29% (278 d.u.)
Final	31% (434 of 1,400 d.u.)	40% (560 of 1,400 d.u.)	29% (406 of 1,400 d.u.)

d.u.: dwelling unit

Table 25: New Urbanist model - intersections

Type	Number
Regular Road: Road/Road	58
Regular Road: [1] Road/Alley	36
ATN-Only: Trail/Trail	12
ATN-Only:[1 2] Midblock (onto collector or local roads)	38
ATN-Only: Midblock (onto an arterial)	9
ATN-Only: Underpass	0
X Intersections [3]	34 of 58
Y Intersections [3]	24 of 58

[1]: Where an alley and trail met each other across opposite sides of the road (such that at the intersection there would be 2 road segments, 1 trail segment, and 1 alley segment), the intersection was classified as road/alley.

[2]: The point at which the trails in the very centre of the model emerged onto the ends of cul-de-sacs were not treated as intersections, but rather as just a change of path type (as the direction of travel remained unchanged).

[3]: X- and Y-intersections only look at road/road (not road/alley) intersections and only include non-alley road segments in the count so as to be consistent with other studies (thus, although a trail may make a 3-way intersection functionally a 4-way intersection for pedestrians, the intersection would still be counted as a Y-intersection). All intersections falling on the edge of the model frame were assumed to be X-intersections.

Table 26: New Urbanist model - points of conflict

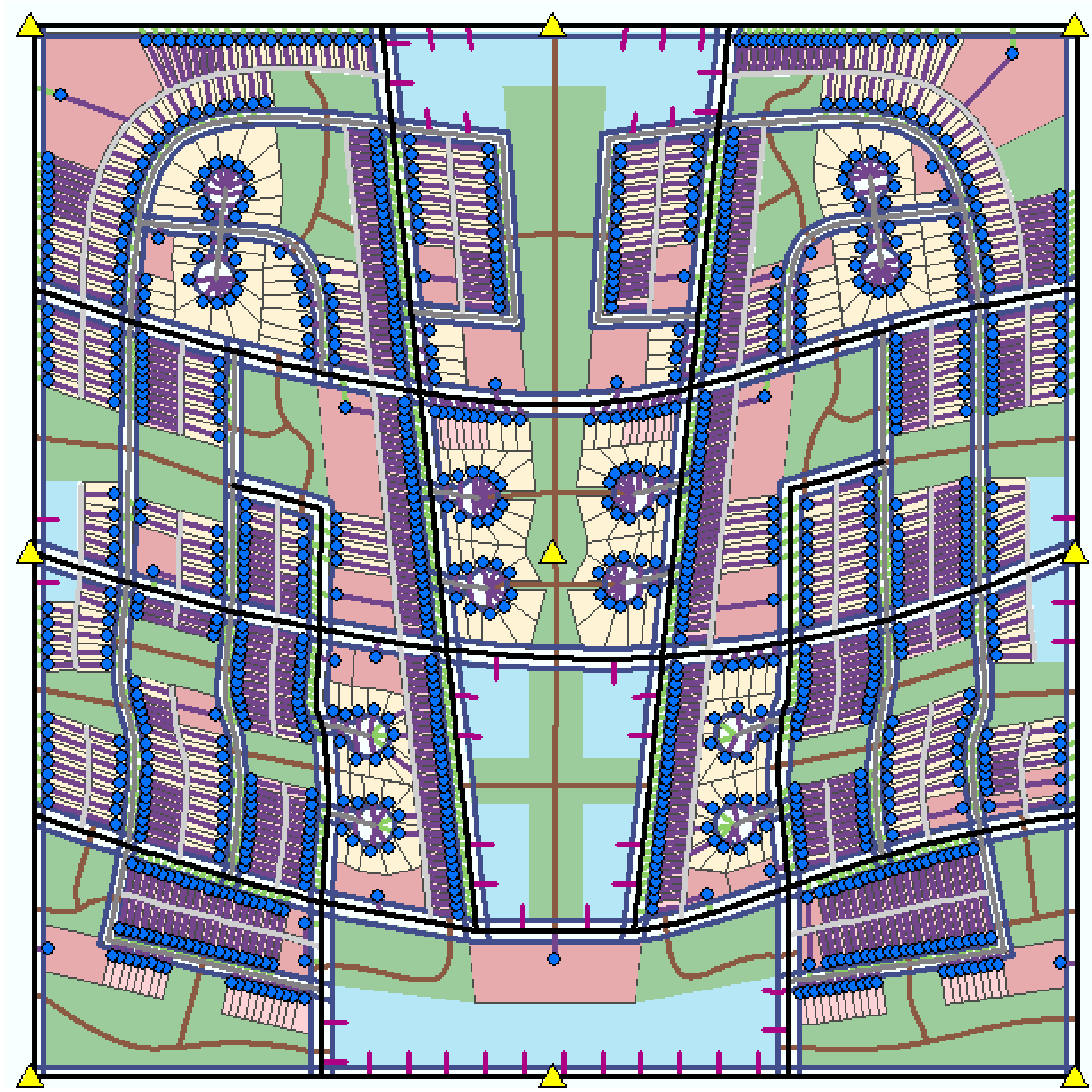
Type	Number
Road/Road (includes Road/Alley)	94
Road/Sidewalk	236
Road/Trail	59
Sidewalk/Sidewalk	200
Sidewalk/Trail	95
Sidewalk/Driveway	218
Sidewalk/Other driveway	45
Sidewalk/Front door	814
Trail/Trail	12
Trail/Driveway	8
Trail/Front door	1
Underpass	0

Problems encountered with the New Urbanist model:

- ***Higher density & more park space than planned:*** *Because of the high proportion of units in row houses and multi-unit buildings, the New Urbanist model had a great deal of leftover space once the target density had been reached. Since the amount of land for "Other Land Use" was fixed between the models (as high, medium or low), the only solution was to increase park space and residential density, while keeping the overall housing mix fixed.*

- ***No alleys on cul-de-sacs:*** *Because of the difficulty of incorporating them into the design, alleys were not provided for homes on cul-de-sacs.*

Fig. 44: New Urbanist model - transportation network, lots, origins and destinations



(Network lines symbolized according to path_subtype attribute)

FUSED GRID MODEL

Fig. 45: The study's Fused Grid model

General description: This model incorporates layouts 4, 5, 6 and 7 of the original seven quadrant configurations proposed by the CMHC (2000). The road network is made up of a grid of collectors and arterials with internally disconnected local roads laid out in quadrants. Sidewalks are present throughout, bike lanes are present on collectors and arterials and trails run through small parks to create a fully-connected active transportation network. Alleys are present only for those homes which face arterial roads (and the homes on the other side which then back onto the alleys). Land use mix is assumed to be medium (6%). Higher density homes are located towards the edge of each quadrant, while lower density housing is located towards their centres. There is medium-density development around some parks.

Basic block dimensions: Quadrants are 1320' x 1320', with loops creating some smaller blocks within (as per CMHC, 2000).

Location of non-residential land uses: In some versions of the Fused Grid a 350' wide arterial by-way is created in which the majority of commercial and institutional land uses are located (see CMHC, 2000). Since such a by-way would extend beyond the perimeter of the study frame, for the purposes of the GIS model those land uses are located instead along the arterials and collectors (otherwise, land use mix would drop to "none"). Similarly,in the "by-way" version of the model, arterials are paired one-way roads which border the by-ways, but for the GIS model the arterials are regular two-way roads located on the edge of the model space. Parks are many but small and used to connect otherwise unconnected roads, and their locations defined by the quadrant layouts presented by the CMHC (2000). The total park area (11%) was determined by model construction, as park areas are shown, but their dimensions not specified, in the original CMHC (2000) document.

(Note: In the fourth quadrant layout, the CMHC (2000) clearly differentiates between a square-ended dead-end road and the cul-de-sacs seen in configurations five and six. As such, these roads in this quadrant of the model were not given cul-de-sac turning circles, although they are still classified as "cul-de-sacs" for the purposes of road type classificastion).

Table 27: Fused Grid model - specification targets vs. final model

LAND USE			
	% Park	**% Other**	**% Residential**
Target	N/A (Defined by prescribed quadrant layout)	6% (9.6 acres / 418,176.0 sq. ft.)	(No target)
Final	11% (17.1 acres / 743,894.1 sq. ft.)	6% (9.6 acres / 418,751.4 sq. ft.)	65% (104.5 acres / 4,552,432.3 sq. ft.)
RESIDENTIAL DENSITY			
Target	Gross density of 10.5 d.u. / acre (1,680 dwelling units in model area)		
Final	*Gross density of 7.3 d.u. / acre (1,172 dwelling units)*		
HOUSING UNITS			
	Single	**Row**	**Multi**
Target	50% (840 d.u.)	50% (840 d.u)	0%
Final	50% (586 d.u.)	50% (586 d.u.)	0%

d.u.: dwelling unit

Table 28: Fused Grid model - intersections

Type	Number
Regular Road: Road/Road	38
Regular Road: Road/Alley	16
ATN-Only: Trail/Trail	1
ATN-Only: Midblock (onto collector or local road)	26
ATN-Only: Midblock (onto an arterial)	0
ATN-Only: Underpass	0
X Intersections [1]	32 of 38
Y Intersections [1]	6 of 38

[1]: X- and Y-intersections only look at road/road (not road/alley) intersections and only include non-alley road segments in the count so as to be consistent with other studies (thus, although a trail may make a 3-way intersection functionally a 4-way intersection for pedestrians, the intersection would still be counted as a Y-intersection). All intersections falling on the edge of the model frame were assumed to be X-intersections.

Table 29: Fused Grid model - points of conflict

Type	Number
Road/Road (includes Road/Alley)	54
Road/Sidewalk	138
Road/Trail	30
Sidewalk/Sidewalk	106
Sidewalk/Trail	58
Sidewalk/Driveway	646
Sidewalk/Other driveway	41
Sidewalk/Front door	487
Trail/Trail	1
Trail/Driveway	14
Trail/Front door	45
Underpass	0

Problems encountered with the Fused Grid model:

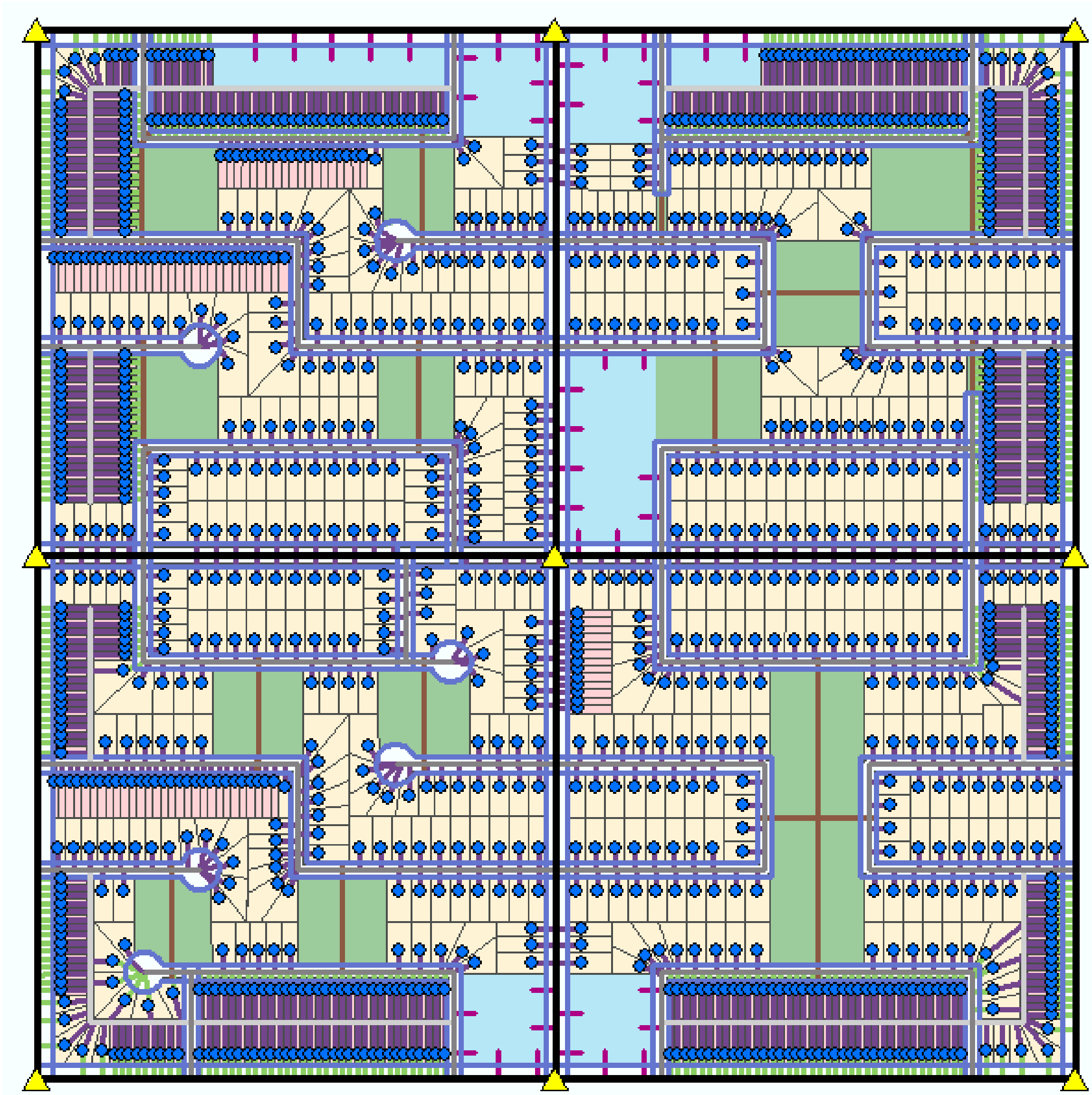
- ***Density under target:*** *Given the fixed lot size and housing mix, it was not possible to fit the target number of dwelling units into this model. Real developments seeking to achieve the prescribed level of density could do so by including multi-unit buildings or using smaller lot sizes.*

- ***Intersection spacing standards not met:*** *This particular combination and arrangement of Fused Grid quadrants does not meet minimum intersection spacing requirements along arterials. Having one-way arterials as in the original model likely compensates for this to some extent (As well, the assumption that all intersections along the arterial would be X intersections seems less plausible for this model than the others because of the unusually high intersection density along the arterials, and as such, the X:Y ratio may be slightly higher than it would be in an actual development). There was also one spot in the model where intersection spacing standards were not met along a collector.*

Other notes:

- ***Alley extensions:*** *Alleys in the Fused Grid's GIS model used in this study do not have extra extensions at arterial-arterial and arterial-collector corners (as seen on pg 52 of the CMHC, 2000 report) as these were deemed unnecessary given the arrangement of lots.*

Fig. 46: Fused Grid model - transportation network, lots, origins and destinations



(Network lines symbolized according to path_subtype attribute)

GREENWAY MODEL

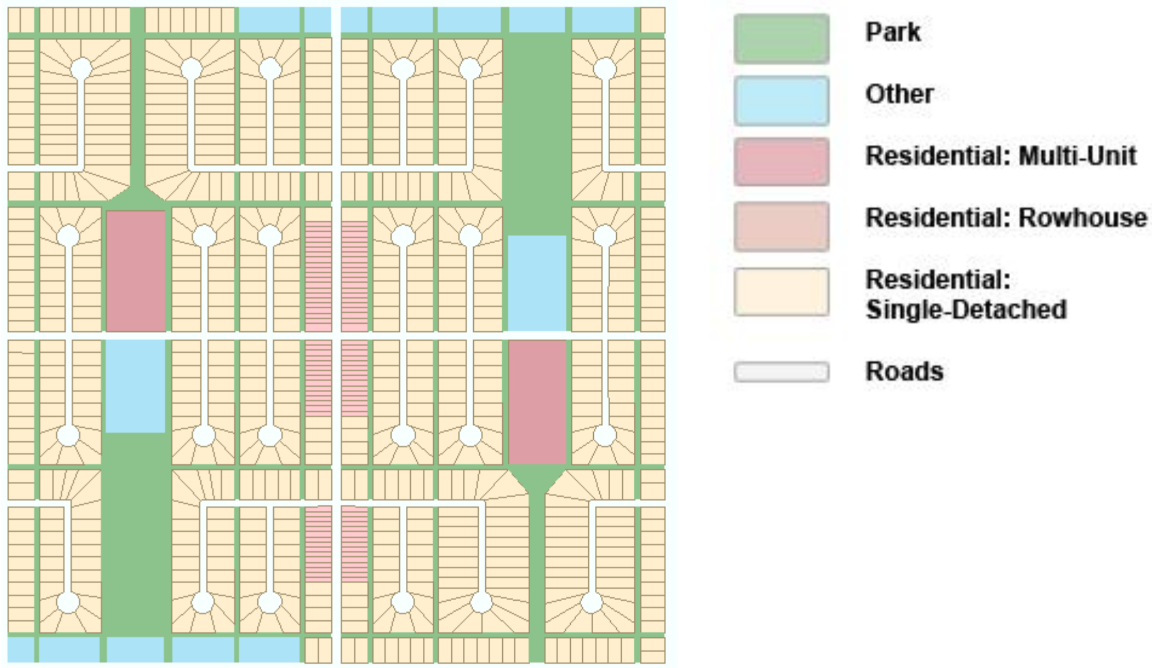


Fig. 47: The study's Greenway model

General description: The Greenway model is similar in many respects to the Fused Grid model. It is made up of regularly repeating cells which form a grid (Nock, 2006), while the internal local roads remain disconnected. The road network is hierarchical and, for the purposes of this study, relatively straight as proposed in the JLAF (2010) model (comparerd to the Radburn case study in which the roads are more curved). Unlike the Fused Grid, all local roads are cul-de-sacs, and the active transportation network forms an almost perfect oblong grid (whereas that of the Fused Grid contains many T-intersections). Sidewalks are completely replaced by trails which run between the fronts of homes while roads are located to the back. Land use mix is assumed to be medium (6%). The area contains a large amount of almost completely uninterrupted greenspace (16% of available land). There are no alleys in this model. Different types of housing are generally located on different blocks, as seen in Radburn (Lee and Ahn, 2003).

Basic block dimensions: 1,740' x 1,740' for the superblock in the greenwayneighborhoods.net model (JLAF, 2010). Given the frame size of 2,640' in this study, this was scaled down somewhat to produce four quadrants the same size as seen in the Fused Grid (1,320' x 1,320').

Location of non-residental land uses: The majority is located along the arterial, as per the JLAF (2010) model. A linear park space exists between every row of houses.

Table 30: Greenway model - specification targets vs. final GIS model

LAND USE			
	% Park	**% Other**	**% Residential**
Target	16% (25.6 acres / 1,115,136.0 sq. ft.)	6% (9.6 acres / 418,176.0 sq. ft.)	(No target)
Final	16% (25.9 acres / 1,130,072.9 sq. ft.)	6% (9.6 acres / 418,386.6 sq. ft.)	65% (103.2 acres / 4,496,879.4 sq. ft.)
	DENSITY		
Target	Gross density of 6.0 d.u./acre (960 d.u. in the model area)		
Final	*Gross density of 6.4 d.u./acre* *(1,020 dwelling units)*		
	HOUSING UNITS		
	Single	**Row**	**Multi**
Target	70% (672 d.u.)	10% (96 d.u.)	20% (192 d.u.)
Final	70% (714 of 1,020 d.u.)	10% (102 of 1,020 d.u.)	20% (204 of 1,020 d.u.)

d.u.: dwelling unit

Table 31: Greenway model - intersections

Type	Number
Regular Road: Road/Road	25
Regular Road: Road/Alley	0
ATN-Only: Trail/Trail	48
ATN-Only: Midblock (onto collector or local road)	0
ATN-Only: Midblock (onto an arterial)	0
ATN-Only: Greenway crossing	40
ATN-Only: Underpass	12
X Intersections [1]	21 of 25
Y Intersections [1]	4 of 25

[1]: X- and Y-intersections only look at road/road intersections and only include road segments in the count so as to be consistent with other studies (thus, although a trail may make a 3-way intersection functionally a 4-way intersection for pedestrians, the intersection would still be counted as a Y-intersection). All intersections falling on the edge of the model frame were assumed to be X-intersections.

Table 32: Greenway model - points of conflict

Type	Number
Road/Road (includes Road/Alley)	25 (0 road/alley)
Road/Sidewalk	0
Road/Trail	42
Sidewalk/Sidewalk	0
Sidewalk/Trail	0
Sidewalk/Driveway	0
Sidewalk/Other driveway	0
Sidewalk/Front door	0
Trail/Trail	52
Trail/Driveway	2
Trail/Front door	756
Underpass	12

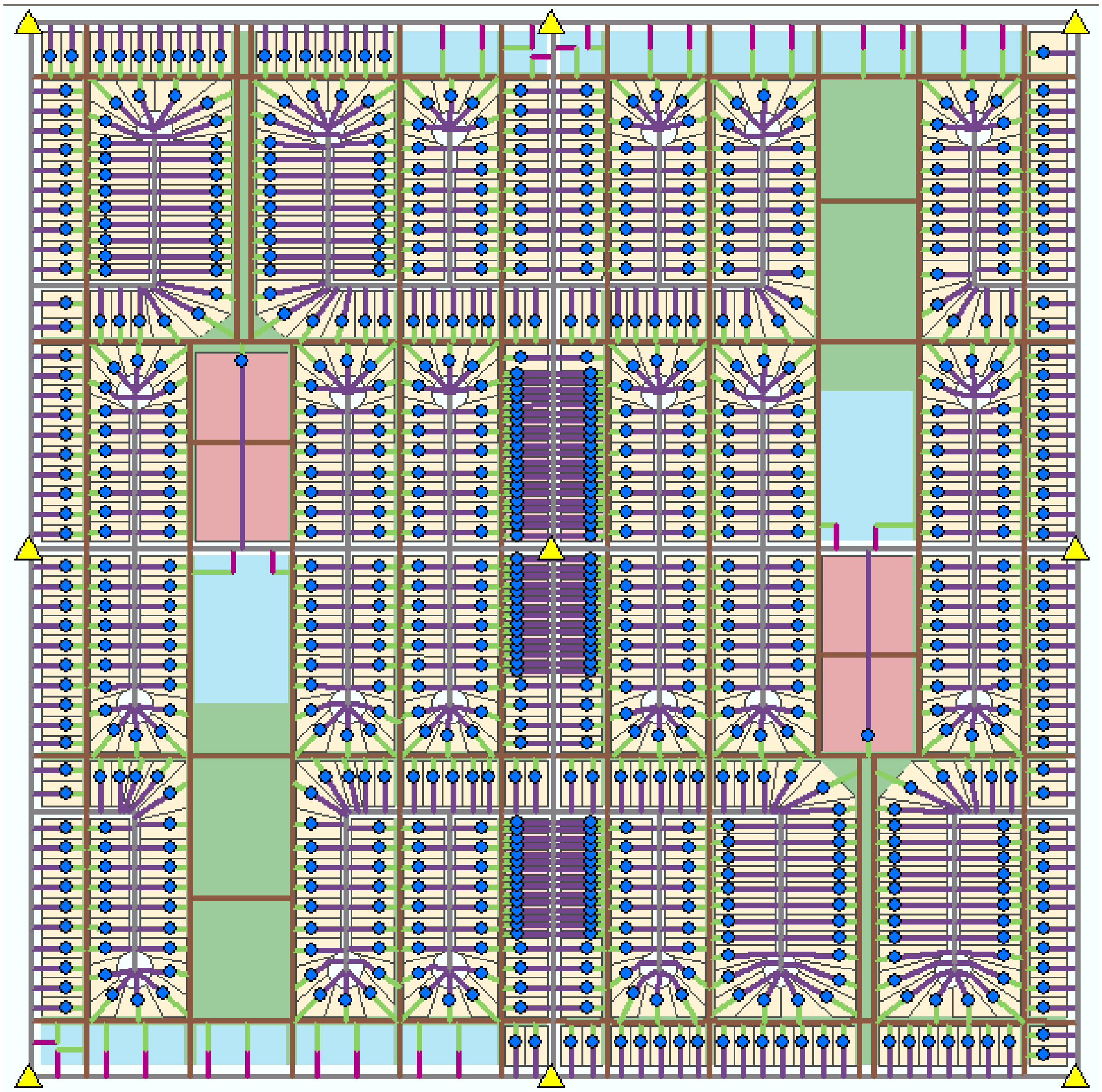
Problems encountered with the Greenway model:

- ***Higher density & more park space than planned:*** *Like the New Urbanist model, the Greenway model ended up having more residential land available than was necessary to meet density targets, and so park space and total number of dwelling units were increased in order to use it up.*

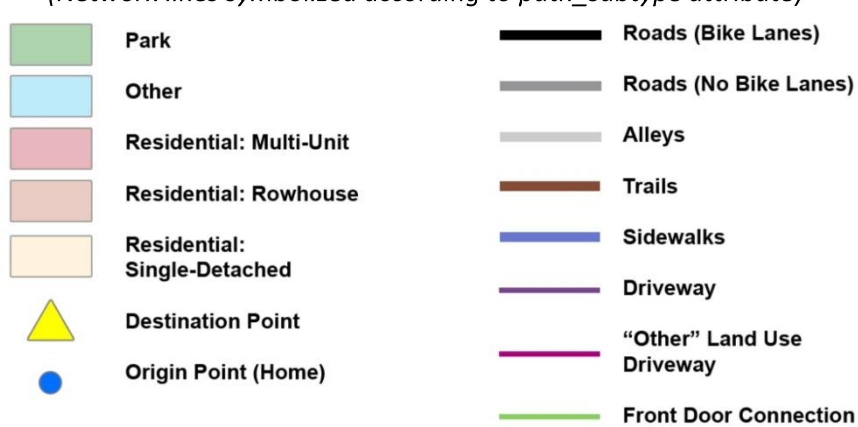
- ***Intersection density along arterials:*** *With both ATN-only intersections (greenway crossings) and regular road/road intersections occurring along arterials, the Greenway model did not meet TAC's (2007) minimum spacing requirements for intersections, as in the Greenway model it is assumed the trail crossings must be signalized to allow pedestrians and cyclists to cross these busy roads wherever underpasses are not present.*

- ***More X-intersections than planned:*** *The model ended up being almost entirely made up of 4-way intersections, because it was found that off-setting the local roads to create T-intersections would have interrupted the active transportation network's grid (see p. 574 in Appendix I for map showing locations of X-intersections). This makes the model more similar to the JLAF (2010) design than the Radburn case study.*

Fig. 48: Greenway model - transportation network, lots, origins and destinations



(Network lines symbolized according to path_subtype attribute)



CHAPTER 5 - RESULTS: OVERVIEW

The results from this study have been divided into four parts:

- **Part I: Evaluation results** (p. 149 - 188) - which reports on the density, diversity and design variables used to evaluate the overall active transportation potential of the five models.

- **Part II: Trip-based measures** (p. 189 - 214) - which describes what trips through the different neighbourhoods would be like in terms of trip lengths, directness ratios, points of conflict encountered and modal separation.

- **Part III: Additional results important to decision makers** (p. 215 - 228) - provides additional results of importance to developers and municipalities when it comes to making decisions regarding the use of models.

- **Part IV: Summary** (p. 229 - 232) - provides a summary of all three sets of results for the models and discusses their implications for planners, municipalities and the development community.

Limitations

Several limitations should be kept in mind when considering these results:

1) Only one GIS model was produced per type of neighbourhood model, which fails to capture much of the possible diversity of designs. (For instance, the CMHC has proposed 7 basic different cell designs for the Fused Grid but this study could only consider 4; other models, such as the Loop and Cul-de-Sac and New Urbanist, could potentially embody an even wider range of variation).

2) The models underestimate total paved area due to lack of turning lanes, curb radii and driveways only going as far as the front door.

3) Because trips were calculated from origin points representing the front door (e.g., based on building setback from the edge of the front of the lot), driveway line segments located to the back of buildings would be longer than those located to the front. This occurred along alleys in the Fused Grid and New Urbanist models, and in all residential lots for the Greenway model. The net effect would be slightly longer trip lengths by car (see Appendix J), and a slightly greater proportion of trips occurring on driveways.

PART I: EVALUATION RESULTS

This part of the results isdivided into three results sections:

- Diversity (Land Use Mix)
- Density
- Design (Network Characteristics)

In each section, models are ranked on each variable of interest, with “5” being the best model and “1” being the worst. Where models tied, the rank has been split between them. Finally, the chapter ends with a section evaluating the active transportation potential of each of the five models using the basic equation outlined in Chapter 3 (p. 112).

Diversity (Land Use Mix)

Land use mix is important to walking and biking because it affects both the proximity of destinations and origins and the number and variety of places to go, which can have positive trip-generating effects (Frank and Pivo, 1994, 1995; Newman and Kenworthy, 1991; Kitamura et al., 1997; Kockelman, 1997; Crane, 1999; Badoe and Miller, 2000; Ewing and Cervero, 2001; Frank and Engelke, 2005). As can be seen in Table 33 below, all three alternative GIS models emphasized land use mix and dedicated anywhere from 11-21% of the available land to park space. Although the Loop and Cul-de-Sac model was the worst for dedicating land to "other" uses, it was slight better than the Fused Grid model in terms of the amount of park space it provided (12% vs. 11% of available land, respectively).

Table 33: Land dedicated to "Other" and "Park" uses in the models

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Land use mix - other	High (8% of total land)	Low (4% of total land)	Medium (6% of total land)	High (8% of total land)	Medium (6% of total land)
Land use mix – park	5% of total land	12% of total land	11% of total land	21% of total land	16% of total land

It is noted that while land use mix was prescribed by the researcher for each neighbourhood model in this study, the same is true in real neighbourhoods, where mix is prescribed by zoning decisions made by local planners and councils. Although this is useful for evaluating models as a whole (where the level prescribed reflects what is typically reported in the literature), it is important to recognize that there is nothing *explicitly* preventing any neighbourhood using a given model's network layout from adopting a different level of land use mix than is the norm for that type. This issue is explored in greater detail in the "Synthesis" section on p. 246.

To produce rankings for land use, each model's rankings on "other" and "park" uses was equally weighted (see Table 34).

Table 34: Rankings for land use mix

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Land use mix – other	4.5	1	2.5	4.5	2.5
Land use mix – park	1	3	2	5	4
Average rank for "Diversity"	**2.75**	**2**	**2.25**	**4.75**	**3.25**

Discussion

Since higher land use mix is consistently correlated with walking and biking, it is easy enough to conclude that those models with a higher mix are better for walking and biking, although this must come with a caveat that the effects of land use mix may be somewhat mitigated if residents consistently choose more distant facilities because of extra amenity they provide (as was found by Handy and Clifton, 2001). When it comes to land use, then, planning for active transportation cannot be completely divorced from issues of economics, the market and consumer preference.

While the impacts of increased land use mix have been fairly widely studied, less has been done into the effects of total amount of open space and its distribution on walking and biking rates. It is known that like streets, parks can act as an important location for walking or biking within a neighbourhood, but the amount of green space often varies with neighbourhood type (IBI, 1995; Southworth, 1997; Lee and Ahn, 2003) and what parks there are are not always evenly distributed (Giles-Corti et al., 2005). Consistent with such past findings, this study found that the models varied in the total amount of open space they provided, their proximity to residences and whether parks and greenways were many, but small; few, but large; or universal but narrow. Since it is known that the presence of green space is correlated with active transportation and physical activity (Sallis et al., 1997; Sallis et al., 1998; Giles-Corti et al., 2005) and can have positive amenity to the travel experience (Giles Corti et al., 2005; Thompson and Aspinall, 2011), it seems likely that these different approaches to parks would have an effect on travel behaviour, but more research would need to be done to determine if that is the case.

Planners need to consider what types, shapes, sizes and distribution of parks will best meet people's needs. Since participation in organized sports is likely to decrease as the population ages, there will be a growing need for communities which support individual forms of recreation, such as walking, through (for example) the inclusion of parks and trails (Foot and Stoffman, 1996). Even now, there is strong evidence that walking and biking are already preferred forms of recreation: for instance, in 1994-1995, it was found that of the 95% of the U.S. population that had engaged in outdoor recreation activities in the past year, 68% had been involved in trail or street activities (such as biking) but only 22% had been involved in individual sports (Cordell et al., 1999). In their 2005 study, Giles-Corti et al. found that only 5% of park users were engaged in organized sports.

While organized sports usually require large parks shaped to maximize area relative to perimeter, walking and biking benefit from having narrow parks with a lower area-to-perimeter ratio. In this regards, the Loop and Cul-de-Sac model, which puts a great deal more emphasis on providing large parks optimized for group sports, may be becoming outdated, while models like the Greenway and, to a lesser extent, the New Urbanist that provide longer trail networks may become more desirable.

Other research provides additional considerations that may have bearing when trying to decide which model provides the best open space network for facilitating active transportation. Scott and Jackson (Scott and Jackson, 1996), upon surveying park non-usersand infrequent-users to learn what would encourage them to use the park more often, found "making parks safer", "building parks closer to home" and "providing more park activities" were common answers – all three of which would have some bearing on the shape, size and distribution of park space in a neighbourhood. The question of "many small parks vs. few large parks" is also relevant: Whyte (1996) estimated that about 80% of all park users will come from within a radius of three blocks and several other studies have also shown that the distance one must travel to a park is likely to be a strong indicator of physical activity in them (Sallis et al., 1997; Wilcox et al., 2000; Troped et al., 2001; Giles-Corti and Donovan, 2002). If one assumes that park use is tied to walking and biking rates within it, then this would seem to favour any of the three alternative models over the traditional ones. Giles-Corti et al. (2005) and Wendel-Vos et al. (2004) however found that quality of park also mattered, and that users gravitated towards parks with a high level of service, in which case, the Loop and Cul-de-Sac model (and possibly some versions of the New Urbanist) would be best. Several authors (Turner, 1995; Houston, 2012) have suggested that linear parks are more supportive of walking and biking, which would favour the Greenway.

It's clear then, from the literature, that given the importance (and likely further ascendance) of walking as the principal form of exercise, that "the connection between transportation planning and recreation and park planning and design must be strengthened" (Godbey et al., 2005, p. 155) and that research should serve to provide more guidance to neighbourhood planners looking to optimize the dedicated open space in their designs.

Density

Table 35 below provides the gross densities values for the models, which ranged from a low of 6.0 dwelling units/acre in the Loop and Cul-de-Sac model to a high of 9.3 dwelling units/acre in the Grid. Additional density measures such as net density may be of greater interest to developers and municipalities, and as such have been provided in Part III of this chapter (p. 219).

Table 35: Gross densities

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Gross density (d.u./gross acre)	9.3	6.0	7.3	8.8	6.4
Rank for "Density"	**5**	**1**	**3**	**4**	**2**

As the results show, the Grid and New Urbanist models had the highest densities, while the Loop and Cul-de-Sac had the lowest. It is interesting that this should be the case despite the fact that grid-based networks typically produce less buildable area to work with, suggesting that as with land use mix, it should be possible to combine the network layouts from the non-grid models and a higher level of density than may be their norm (see also Southworth and Ben-Joseph, 2003).

Design (Network Characteristics)

Design in this study has been limited to network design, which in turn has been seen as consisting of five network characteristics of interest:

- **Coverage**
  - Assessed by: Total length of path by each type and to each mode
  - Evaluated by: Total length of path available to each mode

- **Connectivity**
  - Assessed by: Alpha index, intersection density, metric reach and differential connectivity (of metric reach)
  - Evaluated by: Average rank across all connectivity measures but alpha index

- **Continuity**
  - Assessed by: Point of Conflict (POC) density, ratio of ATN-only to regular road intersections
  - Evaluated by: Average rank across the two continuity measures

- **Modal separation**
  - Assessed by: Separation by network coverage
  - Evaluated by: Separation by network coverage (proportion of network providing complete separation from cars)

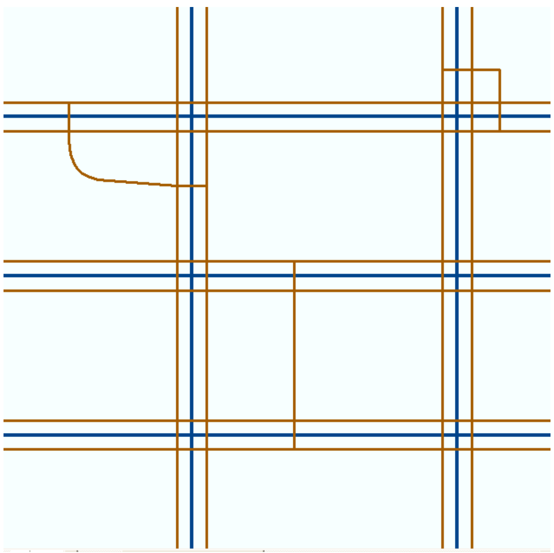
- **Legibility**
  - Assessed and evaluated by: Directional distance

All the measures used in this section with the exception of driveway-based points of conflict are soley network based, e.g., independent of the layout of dwelling units in the model space. However, it was felt that including the density of driveway-based POCs was important, as the elimination of driveway and sidewalk (or trail) conflicts is a key feature of the New Urbanist, Greenway, and to a lesser extent, Fused Grid models.

Network Coverage

Network coverage describes the length of a network path, regardless of the width and area it occupies. Coverage is important because it describes the amount of active transportation infrastructure available to pedestrians and cyclists. Network coverage was assessed using the GIS network lines for all path types (see Fig. 49 below).

Fig. 49: Calculating network coverage



Line network used for calculating coverage (trails and sidewalks, shown in brown, are treated as continuous across roads, shown in blue)

These coverage values slightly exaggerate the length of some types of paths (for instance, sidewalks and trails) which are continuous across roads in the GIS line networks used for analysis, but which in reality would disappear at the road and then begin again on the other side. While it is possible to clip such lines to reflect these disappearing path elements (something which was done for the total paved area calculations – see p. 216), it is expected that most assessments of coverage calculate network length based on map or GIS line features because it is more time-efficient. As such, it was felt that this was the most useful way to present coverage data here. For the development community, however, the preference may be to know the length of sidewalks and trails without counting the section that falls over roads, so as to enable better cost estimates based on path length. To facilitate this type of comparison, these results are provided in Appendix K.

Consistent with the overall approach of this study (trying to represent model elements in real space), roads and trails have been reflected by a single-line network, while sidewalks have been represented by a separate line on either side of the street. As a consequence, in most models the length of sidewalks is approximately double that of roads.

Table 36: Network coverage

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Road network coverage[1] (total feet of path)	47,520.0	35,396.4	43,630.4	55,217.2	28,615.4
Density (per acre, in feet)	*297.0*	*221.2*	*272.7*	*345.1*	*178.8*
Sidewalk coverage (total feet of path)	84,480.0	64,903.7	64,585.5	74,674.8	N/A
Density (per acre, in feet)	*528.0*	*405.6*	*403.7*	*466.7*	*N/A*
Trail coverage (total feet of path)	4,123.4	5,669.8	4,707.9	12,813.6	37,999.0
Density (per acre, in feet)	*25.8*	*35.4*	*29.4*	*80.1*	*237.5*
Bike lane coverage (total feet of path)	N/A	20,440.3	15,840.0	27,341.7	N/A
Density (per acre, in feet)	*N/A*	*127.8*	*99.0*	*170.9*	*N/A*

[1]: Includes alleys but not driveways

Looking at Table 36, it can be seen that counter to what one would expect, it was an alternative model (New Urbanist) that actually provided the greatest *length* of network to cars (and bikes travelling on roadways), even though the Grid model provided the most network area because of its wider roads and finer overall grain (see p. 218). Otherwise, the pattern between models is as would be expected – the Greenway had the least road network coverage and the Fused Grid and Loop and Cul-de-Sac models fall in the middle.

Of the models with sidewalks, the Fused Grid model had the least sidewalk coverage, but this value was very close to that of the Loop and Cul-de-Sac model, which had only 0.5% more sidewalks. The Grid model had the greatest sidewalk coverage (a 30.8% difference between it and the Fused Grid model).

There is a tremendous difference in the length of trails between the models, running from a low of 4,123.4’ in the Grid up to 37,999.0’ in the Greenway (a difference of 921.5%). The high Greenway value was expected (because it uses trails as a substitute for sidewalks), but it is also worth noting that the New Urbanist model (12,813.6') had more than twice the length of trails of the next runner-up (the Loop and Cul-de-Sac mdoel with 5,669.8') and that the Fused Grid model, despite being aimed at pedestrians (and, to a lesser extent, cyclists) had very few trails – only 4,707.9', a value closer to that of the Grid's than anything else.

By comparison, when looking at the range between road lengths, the difference between the model with the longest length of road (New Urbanist) and that with the shortest (Greenway) is only 94%. Thus, comparing between models with a given element, it could be said that the models varied more in their trail coverage than in the coverage of any other path type. The provision of trails is the key difference between models when it comes to the supply of active transportation infrastructure.

Coverages can also be compared by user, rather than just path type, as shown in Table 37:

Table 37: Network coverage by mode

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Dedicated pedestrian path coverage in feet (sidewalk + trail in model area)	88,603.4	70,573.5	69,293.4	87,488.4	37,999.0
Density (feet per acre)	*553.8*	*441.1*	*433.1*	*546.8*	*237.5*
Dedicated cyclist path coverage in feet (bike lane+ trail in model area)	4,123.4	26,110.1	20,547.9	40,155.3	37,999.0
Density (feet per acre)	*25.8*	*163.2*	*128.4*	*251.0*	*237.5*

[1]: Includes alleys but not driveways

Combining the coverage of network elements by mode, one can see that the Grid model provided the most coverage for pedestrians (88,603.4') while the Greenway model provided the least (37,999.0'). For cyclists, the New Urbanist provided the most (40,155.3') and the Grid (4,123.4') provided the least, largely because of its lack of bike lanes in this study. The Greenway is the only model that had comparable coverages (actually identical) for both pedestrians and cyclists. Although it appears for most other models that pedestrians had a greater length of infrastructure coverage than cyclists, this is not entirely accurate as bike lanes were represented by a single line (despite having a separate path on either edge of the central road) and sidewalks were represented by a double line.

While coverage defines the amount of infrastructure available to different users, how it is laid out can have a tremendous impact on trip lengths – see page 235 for more discussion.

Network Connectivity: Intersection Densities

Intersection densities serve to capture both the "route option" and (less directly) "trip length" elements of connectivity. Table 38 below describes the intersection densities for each of the five models (see Appendix L for a more detailed breakdown of these results).

Whether or not alleys should be included in intersection density counts (or in connectivity measures in general) is a matter of debate: consider that, for a grid-based model, adding an alley for every road would double intersection density while having only a very marginal effect on trip lengths. More research is clearly needed into the effects of including alleys on various measures, with the ideal outcome being that the treatment of alleys become standardized.

In the case of this study, the decision to treat alley/road meeting points as intersections or parking (where alleys are essentially treated as communal driveways) had profound implications on the results (as demonstrated in Table 38 below). It also affected model rankings for cyclists, wherein the New Urbanist model had the highest intersection density if alleys were included but the Greenway did if they were not. Since in the latter case, their higher intersection density is also the result of dual-sided lots (cyclists being able to access trails on one side and roads on the other), it seemed fair to include alley/road crossings as a type of intersection in the overall evaluation, and these are the results reported upon in the discussion below.

Table 38: Intersection densities

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Total pedestrian intersection density per acre (including alleys)	0.65	0.40	0.51	0.96	0.30
Total pedestrian intersection density per acre (not including alleys)	0.65	0.40	0.41	0.73	0.30
Total cyclist intersection density per acre (including alleys)	0.65	0.39	0.51	0.90	0.78
Total cyclist intersection density per acre (not including alleys)	0.65	0.39	0.41	0.68	0.78

Pedestrians: The New Urbanist model provided the greatest intersection density (0.96/acre), while the Greenway model, with its relatively coarse-grained grid, provided the worst (0.30/acre).

Cyclists: For cyclists, the New Urbanist model again had the highest density per acre (0.90), while the Loop and Cul-de-Sac model had the worst (0.39). Interestingly, the Greenway model did much better for cyclists (0.78 intersections/acre) than for either cars (0.16) or pedestrians (0.30), because cyclists get access to two separate (off-set) networks in this model and have the opportunity to make direction changes wherever they overlap, unlike the other two modes.

Since intersection density does not penalize a network for having "T" instead of "X" intersections as the alpha index does (see p. 162), it may actually be a better variable for discussing *overall* route choice. On the other hand, it does not discriminate between the two intersections types, and thus is unable to give any less credit for a T-intersection than an X-intersection. It also does not penalize for dead-ends, and thus may have a weaker relationship to trip distances than another connectivity measures such as metric reach and the alpha index.

Network Connectivity: Metric Reach

Metric reach is a parametric value which calculates the total length of pathways that fall within a given travel distance (called the radius, in this case 0.25 miles) from the midpoint of each network segment. A higher metric reach shows that there are more paths accessible from a given point, and thus that it has greater connectivity.

As with the alpha index, a single-line network has been used to represent sidewalks, and a set of fake lines added to the edge of the Greenway pedestrian network to reflect the fact that the trails are not dead-ends. This approach is somewhat consistent with the work done by in Peponis et al. (2007), where they extended the study frame as necessary to ensure complete blocks were used in the coverage, save that, in this case, the additional lines were kept within the study frame. As a consequence, the network lines in the Greenway model are slightly denser than they would otherwise be, which would result in a slight increase in the model's metric reach. Table 39 provides the average metric reach and the standard deviation for network segments in each model. Standard deviation results have been included to show how much variability there was about the mean between the models; the lower the standard deviation, the more spread out the various metric reach values of the road midpoints were from the mean.

Table 39: Average metric reach results

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrian (average, in miles)	3.02 (st. dev: 0.73)	1.72 (st. dev: 0.50)	2.01 (st. dev: 0.42)	3.67 (st. dev: 0.83)	2.42 (st. dev. 0.49) (or 2.13 with a st. dev. of 0.49 without added frame)
Bicyclist (average, in miles)	3.02 (st. dev: 0.73)	1.72 (st. dev: 0.50)	2.01 (st. dev: 0.42)	3.67 (st. dev: 0.83)	3.53 (st. dev: 1.09)

Note: Values calculated using a distance threshold of 0.25 miles (1320')

The results showed that the New Urbanist model had the greatest metric reach for both modes, while the Loop and Cul-de-Sac model was the worst for cyclists and pedestrians. This is slightly different from the results for intersection density, where the Greenway was the worst for pedestrians. The difference is likely caused by the fact that many of the crossing points for the pedestrian network along the arterial are not intersections (they are underpasses), but when using a closed frame to look at metric reach the edge can contribute to the metric reach values. (And, with a relatively small block size along the top and bottom edges when using the closed frame, likely relatively high values – otherwise, the pedestrian block sizes in the Greenway model are fairly large). The Loop and Cul-de-Sac Model and the Fused Grid model had relatively low standard deviations, indicating that there is a wide range of metric reaches occurring depending on which segment's midpoint one starts from, while the Grid, New Urbanist and Greenway (cyclist only) models had high standard deviations, suggesting a more tightly packed distribution of possible metric reaches around the mean (e.g. a more regular network with less variation overall). Metric reach was unique among the three connectivity measures considered for its ability to report a standard deviation, and thus to provide some description of the regularity of the network.

Network Connectivity: The Alpha Index (Route Options)

The alpha index was used to assess route options between models. A higher index means that the nodes (intersections) are better connected and more route options are available to network users (Dill, 2004; Tresidder, 2005).

For the "Cyclist Network" alpha index, "nodes" were assumed to include all regular road and all types of ATN-only intersections as well as CDS heads and dead-ends (including those found in alleys). Roads were considered to be bikeable regardless of whether or not they had bike lanes. "Links" were assumed to include all trail and road segments, including alleys.

For the "Pedestrian Network" alpha index for all models but the Greenway, "nodes" were assumed to include all regular road and ATN-only intersections as well as CDS heads and dead-ends (including those found in alleys). For the Greenway network, only trail/trail intersections were included for nodes. "Links" were assumed to include all sidewalk, trail and alley segments. Because graphs represent topological, rather than spatial, relationships, sidewalk segments were represented here by a single rather than a double line).

For additional notes on graph construction and analysis, please see Appendix M.

Table 40: Alpha index by mode

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Road network[1]	0.40	0.13	0.24	0.19	0.04
Pedestrian network	0.37	0.13	0.20	0.20	With closed frame: 0.36[2] (Without: 0.20)
Cyclist network	0.37	0.13	0.20	0.20	0.29

[1]: Road network results included here to highlight some of the problems encountered when switching between the results for motorized vs. active modes.

[2]: Problems encountered with the Greenway model's pedestrian network required the creation of a set of links to act as a "closed frame" around the edge of the model – see p. 164 below for more details.

Although the alpha index was relatively easily calculated, the results in Table 40 above revealed three (rather substantial) problems with this measure:

1) Despite having demonstratably better connectivity (i.e., having shortcuts not available to motorists), the alpha indices for walking and biking were worse than those for driving for both the Grid and the Fused Grid model.

2) The use of roads for the model frame created an artifically high number of dangle nodes for the Greenway's pedestrian network, resulting in a much lower alpha index than for the Grid – even though their networks were practically the same.

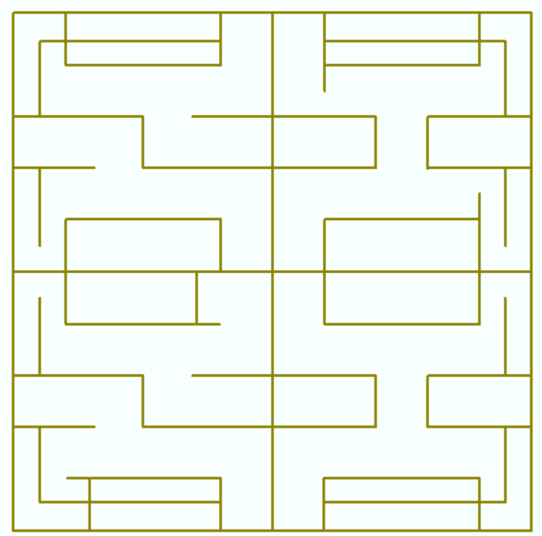
3) Despite obviously having more route choice, the alpha index for cyclists was worse than that for pedestrians in the Greenway model.

These problems are elaborated upon below.

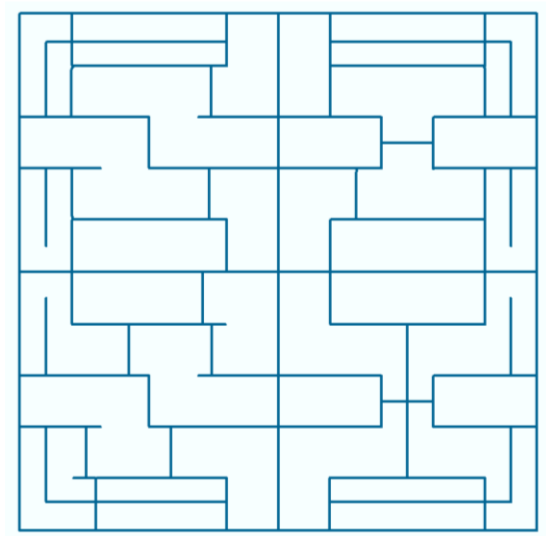
Decreased alpha index for active modes: Counter to expectations, the index decreased for both the Grid and Fused Grid models when moving from their road network graphs to their pedestrian and cyclist network graphs. Since road network lines were identical for both motorists and cyclists, and used as a proxy for sidewalks for the pedestrian graphs, the only difference between these graphs was the *addition* of trail shortcuts. Conceptually, the addition of a shortcut should increase connectivity and route options, and any measure of connectivity should effectively capture this. However, in practice, if a trail shortcut creates T- rather than X- intersections, it actually reduces the alpha index (see Appendix M for more details).

By testing a few different scenarios, it was found that the more T-intersection type trail shortcuts that are added, the worse the alpha index becomes, <u>even though connectivity and route options are clearly increasing.</u> The source of the problem is that for every one T-intersection type trail link made, two new nodes are created. Since in a graph these nodes are essentially treated like destinations, the addition of the shortcut *adds* two poorly connected "destinations" and reduces the index accordingly, even though, from a built environment perspective, these nodes do not actually add any new places to go. This is clearly seen in the Fused Grid model, where the majority of trail shortcuts create T- rather than X-intersections (Fig. 50 below).

Fig. 50: Alpha index links for motorized vs. active modes in the Fused Grid model



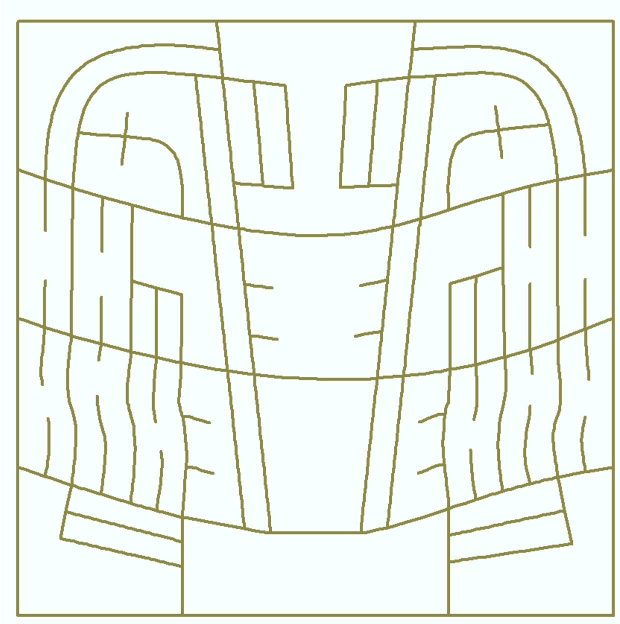
Links in the Fused Grid road network (alpha index of 0.24)

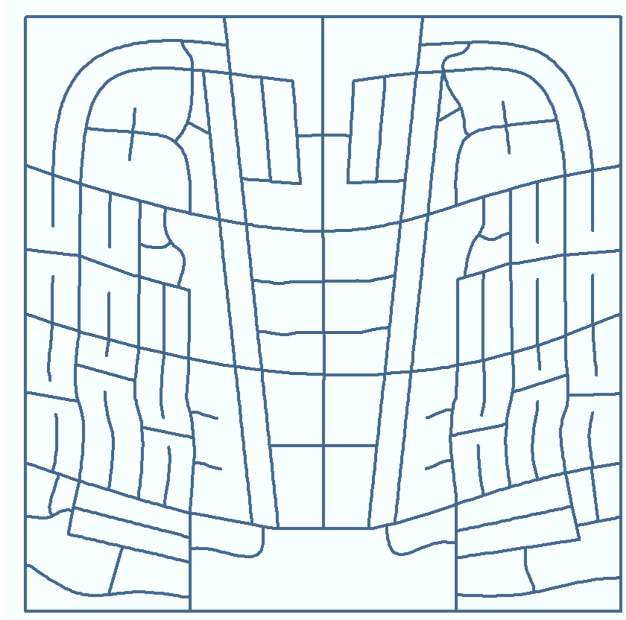


Links in the Fused Grid pedestrian and cyclist networks (alpha index of 0.20)

By comparison, if trail shortcuts serve to produce more X-intersections and connect otherwise unconnected nodes, the alpha index can be improved, as was the case in the New Urbanist model:

Fig. 51: Alpha index links for motorized vs. active modes in the New Urbanist model





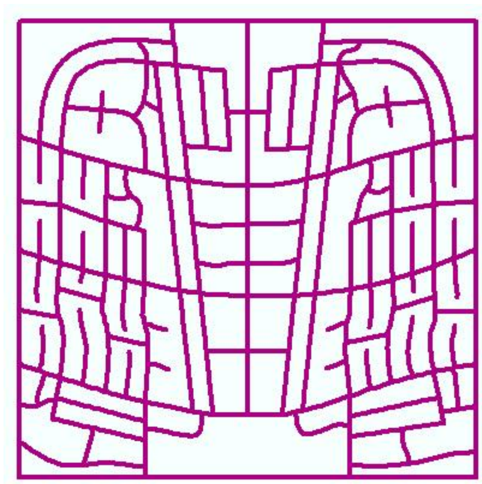
Links in the New Urbanist road network (alpha index of 0.19)

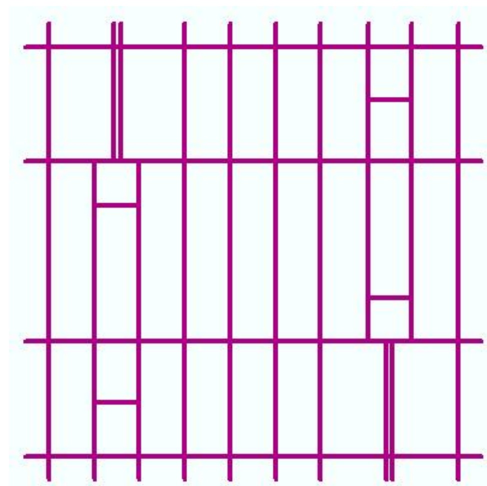
Links in the New Urbanist pedestrian and cyclist network (alpha index of 0.20)

The alpha index is most often used in transportation research for assessing non-road networks – for instance, railway networks and air service. In these cases, nodes are "true" destinations (e.g., train stations and airports), where it makes sense to assess how well connected each node is, and where no single link would ever exist *only* to act as a shortcut. The alpha index likely works well in this regard, but it appears to have some major shortcomings when it comes to acting as a measure of the connectivity of active transportation networks (especially when used to compare active transportation networks to their motorized counterparts), producing results which are counter-intuitive and even misleading.

Excess dangle nodes as a result of frame choice in the Greenway model: In the initial calculations for the pedestrian graphs, there was a wide range in alpha indexes across the models, running from a low of 0.02 in the Greenway up to 0.37 in the Grid. This result was counter-intuitive, however, as the Greenway's pedestrian network *is* itself a grid, and although it may be a coarser grid, the alpha index is relatively insensitive to grain (see Appendix M for an example).

Further analysis revealed that the discrepancy was due to the fact that for models with sidewalks, the four roads located around the edge of the models created a completely "closed frame" without dangle nodes for those networks. For the Greenway model where the pedestrian network is a completely offset grid of trails, however, the use of the arterial roads as frames meant that all trails ended with disconnected links (see Fig.53 below).





New Urbanist **Greenway**

(Network segments accessible to pedestrians shown in magenta)

Fig. 53: The effect of using roads for the model frame

While in most models (such as the New Urbanist, pictured on the left) the sidewalks along the roads at the edge of the models created a completely "closed" set of links for the segments there, the Greenway model (pictured on the right), with its off-set system of trails, was left with a very high proportion of dangle nodes in its pedestrian network, despite sharing the same common frame of roads with the other models.

This is an important finding, because it shows that frame choice can not only impact results due to edge effects (something regularly observed in other studies – see Tresidder, 2005; Peponis et al., 2008), but that *it can systematically underestimate values for one mode relative to another where off-set networks exist*. Since it is common in transportation research to frame a study area based on its roads (particularly because these often serve as the boundaries for census areas or TAZs), this could have serious implications on past (and future) research into Greenway neighbourhoods or other models that use off-set networks.

Ideally to compensate for this, a different frame placement would have been used when initially creating the Greenway model, such that it would penalize the road and active transportation networks equally. As this was not possible due to time constraints, a series of extra links were added to the graph to reflect the fact that none of these dangling segments ended in true dead ends; all would connect to perpendicular trail segments on the far side of the arterial road (see Fig. 54 below).

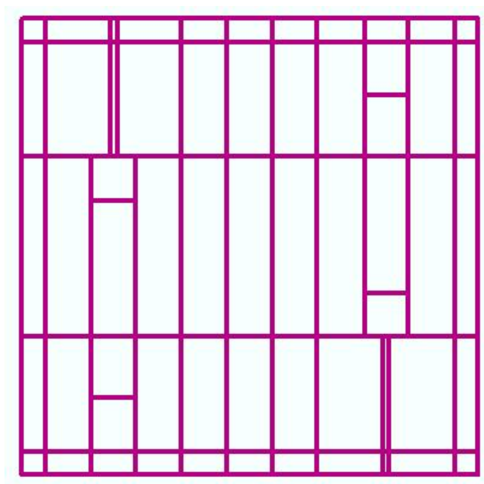
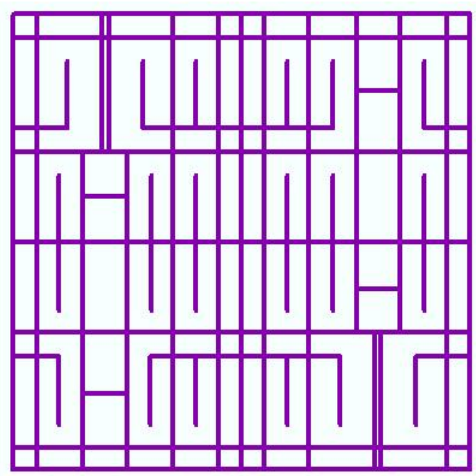


Fig. 54: Modified Greenway pedestrian network graph

Using the modified model for the Greenway's pedestrian paths, a revised pedestrian network alpha index was calculated called "alpha index with closed frame" (see Table 40 above).

Reduced alpha index for cyclists relative to pedestrians in the Greenway model: For the Greenway model, the ability to travel on roads (and the correspondingly higher path densities) caused a *reduction* in alpha index for cyclists relative to pedestrians, due to the inclusion of the dead-end cul-de-sacs (see Fig. 52 below). This was another counter-intuitive result, since the inclusion of more links undoubtedly provides cyclists with *more* route choice relative to both pedestrians and cars. This problem is essentially the result of a having parallel pathways on both sides of a lot (here, a trail in front and a road in the back), and could be encountered in any model that has such a network, regardless of whether it is an active mode that can use both pathways (as is the case for cyclists in the Greenway) or a motorized mode (as is the case for cars in the Fused Grid and New Urbanist models where alleys are present). This requires that caution be used when using graph-based approaches to studying models with dual-sided homes/networks.



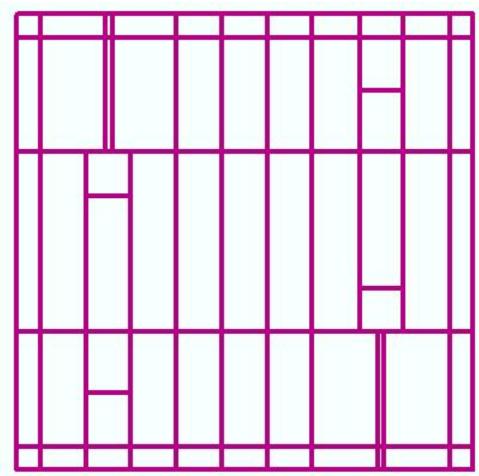


Fig. 52: Comparing the alpha index links in the Greenway cyclist and pedestrian networks

Links in the Greenway cyclist network (alpha index of 0.29)

Links in the Greenway pedestrian network (alpha index of 0.36)

More research into the implications of these findings is needed. It may be that a revised index could be developed where shortcut trails add links but not nodes, or one where only the "best" set of lines servicing an area are included, although that may be complicated if it is not immediately clear which set of paths provides the most connected network. (For instance, it is easy to say in this study's New Urbanist model that dropping alleys in favour of only considering roads would make sense, but if there were some connected alleys serving some disconnected roads, a decision concerning which link was best would have to be decided on a case-by-case basis).

Rather than describing the alpha index as "a tool to assess route options", it may be more accurate to describe it as a tool to assess the configuration of a network, given a set of links. In this case, the alpha index would evaluate a network on how well it lays out a given set of links to promote connectivity (for which it makes sense to have the index go down if a trail shortcut is not placed in the "optimal" position), rather than being seen as a measure of the *total* route options or connectivity.

Discussion of results: Looking back at the results for pedestrians and cyclists, all models but the Greenway model had identical pedestrian and cyclist values, showing that, as expected, there was no real difference in terms of route choice between these modes. Looking at the revised numbers (using the closed frame for the Greenway model), the Grid remained the best model for route choice (alpha index of 0.37), the Greenway became second best (instead of being the worst) with a value of 0.36 for pedestrians and 0.29 for cyclists, the Fused Grid and New Urbanist model tied for third with an alpha index of 0.20, and the Loop and Cul-de-Sac model became the worst with an index of only 0.13. Of these results, the tie between the Fused Grid and the New Urbanist models is perhaps the most interesting. The Fused Grid model's guidelines makes explicit reference to having a disconnected network inside each quadrant. By comparison, New Urbanist guidelines explicitly call for connected road networks (see CNU, 2001; Hess, 2008), but in practice tend to incorporate cul-de-sacs and, in the case of this particular model, had several alleys which ended in parks (i.e. dead ends). As a result they ended up with similar values – even though their stated design principles differ.

Network Differential Connectivity

Differential connectivity compares connectivity between modes to determine how easy travel is likely to be by one mode relative to another – in this case, by an active mode compared to driving. Differential connectivity can be assessed for any connectivity measure: Tables 41 and 42 below provide the differential connectivity results for intersection density and metric reach for this study. (Differential connectivity has not been calculated for the alpha index because of the methodological problems encountered using that measure). A higher ratio here favours the active mode over the motorized one (for instance, a ratio of 1.5 on "intersection density" would mean that there are 1.5 intersections available to a cyclist or pedestrian for every one available to a motorist). The motorist intersection density and metric reach values used to produce these values can be found in Appendix J.

Table 41: Differential connectivity by intersection density

	Grid	Loop and Cul-de-Sac	Fused Grid[1]	New Urbanist[1]	Greenway
Ratio of pedestrian intersection density to motorist intersection density	1.35	1.29	1.53	1.69	2.19
Ratio of cyclist intersection density to motorist intersection density	1.35	1.29	1.53	1.69	5.13

[1]: Including alley/road intersections as a type of road intersection

Table 42: Differential connectivity by metric reach

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Ratio of pedestrian metric reach to motorist metric reach	1.09	1.32	1.40	1.25	2.03
Ratio of cyclist metric reach to motorist metric reach	1.09	1.32	1.40	1.25	2.97

The most important observation to be made from the results is that for both measures, *all models favour active modes over motorized ones, making differential connectivity a de facto part of every model*. In both cases, the Greenway model offered the highest level of differential connectivity for both modes. However, there are some differences in terms of how the other models ranked between the two different measures. For instance, when using intersection density, the New Urbanist model had the second highest level of differential connectivity; when using metric reach, the Fused Grid did. Similarly, while the Grid had the lowest differential connectivity by metric reach, the Loop and Cul-de-Sac model was the worst by intersection density. This highlights a reoccurring problem when studying connectivity – even though many different measures exist, they do not often produce the same rankings when comparing neighbourhoods. This suggests that there is a need for better measures which more directly capture the variables of interest (route options and trip lengths) so as to prevent the variation in rankings that is often seen when using proxy measures (such as intersection density or metric reach).

Comparing these two measures, metric reach is likely a better measure of connectivity than intersection density because it is sensitive to both the length of pathway available (coverage) as well as how well connected it is, whereas intersection density weighs intersections equally regardless of how well connected they are. As such, metric will be the measure used for rankings of differential connectivity and the calculation of active transportation potential in this study.

Network Continuity: Point of Conflict Density

Continuity in this study is conceptualized as the potential for conflict from intersecting lines of traffic flow in a network, measured by the number and type of potential points of conflict (POCs) that exist within the model space. It is seen as being important because of the effects it may have on safety (both real and perceived) as well as trip times (as different types of conflict points may require a user to slow or stop completely in order to make sure the way is clear). Tables 43 and 44 below detail the POC density in each of the models.

For pedestrians, POCs have been grouped into two different types – "ATN/Road", where sidewalks or trails crossed roads, and "ATN/Driveway" where sidewalks crossed driveways. It was necessary to keep the two types separate because of how they act differently on pedestrians and also because otherwise changes in the number of sidewalk/driveway POCs (of which there were often many) would quickly overwhelm and hide changes in the number of sidewalk/road POCs (of which there were few). The final score for the POC density measures is the average rank of the "ATN/Road" and "ATN/Driveway" categories (see Table 43 below).

Table 43: Pedestrian network: Pedestrian/Car POC density

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
ATN/Road POC density per acre (all sidewalk/road and trail/road crossings)	1.9	1.0	1.1	1.8	0.3
ATN/Driveway POC density per acre (all sidewalk/driveway crossings)	5.2	5.6	4.4	1.7	0.0
Averaged rank (1-5) (equal weight to ATN/driveway and ATN/road)	**1.5**	**2.5**	**3**	**3**	**5**

Note: ATN/ATN points of conflict (such as trail/sidewalk intersections) were not included here because only conflicts with cars are assumed to be important, but can be found on p. 126 - 144.

For pedestrians, the Greenway model did the best at reducing both categories of POCs (and completely eliminated all POCs in the case of the ATN/Driveway category). The Grid and New Urbanist were the two worst models when it came to ATN/Road intersections (with very close results of 1.9 and 1.8 POCs per acre respectively), while for ATN/Driveway POCs the worst model was the Loop and Cul-de-Sac. This result was unexpected, as the Loop and Cul-de-Sac model is often associated with lower densities overall and higher densities being put into large multi-unit buildings. Looking more closely at the model's specifications (see Chapter 4) the Loop and Cul-de-Sac model had 192 row houses, much more than the Grid (0), although much less than the Fused Grid (586) and the New Urbanist (560). In the cases of the two latter models, however, most row houses were located on roads with alleys and thus would not be contributing to the POC density count, even while having a larger number of units overall. This suggests that the alternative models are largely successful in their attempts to reduce ATN/Driveway conflicts, such that they are able to produce fewer such conflicts than even a low-density model like the Loop and Cul-de-Sac.

Looking at the results for the pedestrian network, it is clear that *continuity exhibited a wider range of variation between the models than connectivity*: for instance, there was a 633% difference in the ATN/Road POC density per acre between the best and worst models (the Greenway and Grid respectively), but for metric reach there was only a 213% difference (between the New Urbanist and Loop and Cul-de-Sac models). It may be that smaller changes in connectivity are still more important in determining travel behaviour, however, this is not known for certain because continuity has rarely been taken into consideration in past research. It is hoped that by developing tools to assess continuity, this study will contribute to future attempts to quantify how changes in continuity affect travel.

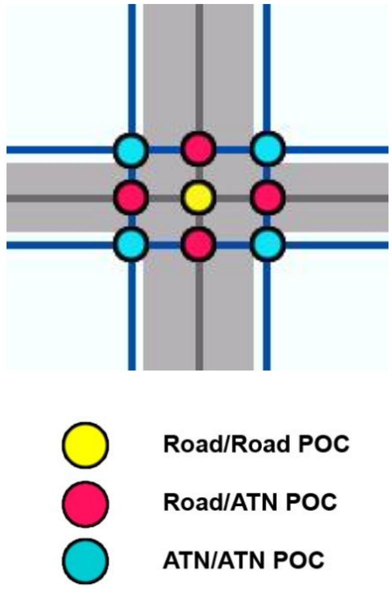
For cyclists, all POCs in which a cyclist might encounter a car on a road were grouped together to calculate the results (see Table 44 below). Originally it was hoped that an additional category to represent the points at which driveways met roads and/or bike lanes would also be included, but challenges resulting from overlapping POC points from driveways on either side of the road in the GIS made the quality of these results uncertain, and as such, the category was eliminated.

For cyclists, the Loop and Cul-de-Sac model provided the best continuity, while the New Urbanist was the worst, putting cyclists in conflict with cars more than twice as frequently as in the Loop and Cul-de-Sac model.

Table 44: Cyclist network: Cyclist/Car POC density

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Car/Cyclist POC density per acre (Road/road and road/trail)	0.7	0.4	0.5	1.0	0.5

Fig. 55: Road/Road vs. Sidewalk/Road POCs



Since there are 3 sidewalk/road (ATN/Road) POCs for pedestrians at a T-intersection and 4 sidewalk/road POCs at an X-intersection but only 1 "road/road" POC at a road intersection (the only one a cyclist would pass through – see Fig. 55), POC density for cyclists was consistently lower than for pedestrians, with the exception of the Greenway model for which it was higher. This is because in the Greenway model, cyclists have POCs at road/road intersections where pedestrians have none (due to the off-set network of trails).

Network Continuity: Ratio of ATN-Only Intersections to Regular Road Intersections

Both ATN-only and regular road intersections can contribute to connectivity for pedestrians and cyclists, but by providing more ATN-only intersections, a model can allow cyclists and pedestrians more opportunities to make the same sort of direction changes made at regular road intersections without the same level of potential for conflict with cars, enhancing overall continuity. Two different variations of this ratio could be created: one which includes only trail/trail intersections in the "ATN-only" category (i.e., where trails cross trails and travelers are completely free of risk from motorized vehicles) and one that includes any ATN-only intersection (i.e., where trails cross trails and trail or sidewalk midblock crossings, where travelers are free of risk from turning vehicles but may encounter them as through traffic along an otherwise uninterrupted stretch of road where there may or may not be signs or crosswalks to have the vehicles slow or stop). The latter has been used here.

From Table 45 below, it can be seen that only the Greenway model offered a greater proportion of ATN-only intersections than regular road intersections, while the Loop and Cul-de-Sac had the lowest ratio of only 0.31 ATN-only intersections for every one regular road intersection. The New Urbanist model offered twice the number of ATN-only intersections for every road intersection relative to the Grid, undoubtedly as a result of its greater number of parks and trails. Finally, as was the case for many of the network design variables, the Fused Grid fell in the middle, with a ratio of 0.54.

Table 45: Ratio of ATN-only intersections to regular road intersections

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Ratio for pedestrians	0.35	0.31	0.54	0.70	2.08 (or “perfect”)
Ratio for cyclists	0.35	0.27	0.54	0.62	3.76 (or “perfect”)

The Greenway model again presented some difficulties in interpretation. The purpose of this ratio is to assess the proportion of turns that could be made away from a regular road intersection. Unlike in the other models, pedestrians do not have the option to make a turn at regular road intersections; for all intents and purposes, these intersections do not exist for them. Since it is not possible to divide by zero, this complicates the right side portion (“regular road intersections”) of the ratio equation. As such, a ratio was produced that compared the ATN-only intersections to regular road intersections for pedestrians (2.08:1), but it may be more accurate to describe the ratio as “perfect” – all intersections for pedestrians in the Greenway model are ATN-only intersections.

The situation for cyclists in the Greenway model was further complicated by the fact that although cyclists are physically able to get on roads they are not obligated to do so: because of the dual-sided natural of lots in the model, a cyclist wishing to travel only by trail could do so and have a similarly “perfect” set of turn options. Regardless of which interpretation is used, however, the Greenway model remains by far the best model when it comes to ATN-only versus regular road intersections.

Network Modal Separation: Using Network Coverage

Modal separation has rarely (if ever) been quantified in neighbourhood studies, likely because of the difficulty in determining how it best should be measured. This study does so by assessing the different levels of modal separation that are provided to active modes relative to the length of network coverage available to them. Only paths which are public were included in the assessment (i.e. travel up or down driveways was excluded, but where sidewalks or trails were crossed by driveways, a reduced level of modal separation was assumed for those sections because of the increased potential for encountering a car exiting a driveway). Loss of modal separation from parking vehicles was treated as distinct from that of vehicles traveling on regular roads, as the latter would like be, in most cases, perceived as a greater threat by pedestrians and cyclists. Cars travelling down alleys were assumed infrequent and to be "in the process of parking", and so travel by pedestrians and cyclists through alleys is assumed to be affected by "parking vehicles" rather than "regular road traffic".

Table 46: Network modal separation between pedestrians and motorists

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Total network coverage[1] (in feet)	88,360.6	70,532.8	69,068.8	86,384.9	37,991.6
Complete separation from cars (in feet) (sections of sidewalks and trails outside of intersections and not interrupted by driveways or alleys; also includes underpasses)	67,895.8 (76.8%)	53,781.6 (76.3%)	55,448.2 (80.3%)	72,872.8 (84.4%)	36,691.7 (96.6%)
No separation from cars - due to road crossings (in feet) (sections of sidewalks or trails crossing any type of road except alleys, and not including underpasses)	10,168.8 (11.5%)	5,888.4 (8.3%)	4,711.4 (6.8%)	8,698.0 (10.1%)	1,253.8 (3.3%)
No separation from cars – due to parking (in feet) (walking in alleys, down driveways or along sidewalk sections that cross driveways or alleys)	10,296.0 (11.7%)	10,862.8 (15.4%)	8,909.3 (12.9%)	4,814.1 (5.6%)	46.0 (0.1%)

[1]: Coverages in this section were created following topological validation in the GIS, which shifted roads very slightly, resulting in slightly different total coverage than described in Tables 36 and 37.

For pedestrians, the New Urbanist model provided the greatest absolute length of path in which they were separated from cars, while the Greenway model offered proportionately the most. Interestingly, the Grid and Loop and Cul-de-Sac models were very similar in the proportion of their paths that were completely modally separated (76.8% and 76.3% respectively), although the Grid offered substantially more of this path type. Looking more closely at the numbers, it can be seen that this is because the Grid has proportionately less of its network affected by driveways compared to the Loop and Cul-de-Sac model (which included more row houses), which compensated for its higher proportion of network spent in road crossings. The Grid had proportionately more of its pedestrian network crossing over roads than the other models (11.5%), while the Greenway had the least (3.3%). The Loop and Cul-de-Sac had proportionately the most (15.4%) in conflict with cars trying to park (where driveways crossed sidewalks), while the Greenway model again had the least (0.1%). These results show that for pedestrians, the Greenway model's network layout is by far the most modally separated of those in this study.

One element this measure of modal separation fails to effectively capture is the benefit of introducing alleys to reduce conflict on sidewalks, because it combines the length of paths from alleys and the sections of sidewalk affected by driveways. In a Loop and Cul-de-Sac neighbourhood, a sidewalk is made up of alternating lengths of "completely modally separated sidewalk" and sidewalk which crossed over driveways. In a New Urbanist neighbourhood, this instead becomes a totally separate alley and a continuous sidewalk. Even if the proportion of each type of network stays constant (for example, if 50% of a sidewalk was in driveways and 50% of a sidewalk being driveway-free in a Loop and Cul-de-Sac model vs. 100% of an alley in "parking" and 100% of a sidewalk being driveway-free in the New Urbanist), the experience of modal separation (and the modal separation options available) are obviously very different. In the Loop and Cul-de-Sac example, there is only one route choice, which has moderate modal separation; in a New Urbanist neighbourhood, a pedestrian has a choice between the two ends of the spectrum – a completely modally separated pathway (the sidewalk) or a completely unseparated path (the alley). This can be captured through an assessment of ATN/Driveway POC density (a continuity measure), which counts *instances* where modal separation is lost, but it would be desirable to have a corresponding coverage-based modal separation measure. Although not done due to time constraints, one possibility would be to evaluate entire lengths of sidewalks as "complete" or "interrupted" and using those as two separate modal separation categories.

Unlike pedestrians for whom the modal separation choices were complete separation or no separation, cyclists had an additional “partial separation” possibility as a result of bike lanes (see Table 47 below). Since bike lanes often represent a larger portion of the network than the totally separated trails, a “sum of complete or partial separation” value calculated to reflect how well models fared on these two types of path together, which would collectively reflect efforts made to provide modal separation to cyclists via active transportation infrastructure.

For the Greenway model, a second scenario in which cyclists were assumed not to use roads (as a universal trail network is present and roads have no bike lanes) was also assessed. If cyclists only use the trail network, then the percent of network which has complete separation jumps to 96.7% and the proportion in which they must travel through car traffic drops to 3.2% (where trails cross roads). For the purposes of overall evaluation, however, the first scenario (in which bikes are assumed to still be able to use roads) will be used. The Greenway is the only model for which producing a second scenario void of roads is possible: in all other models, eliminating the roads from the network would render the majority of destinations inaccessible by bike.

Table 47: Network modal separation between cyclists and motorists

	Grid	Loop and Cul-de-Sac	Fused Grid – cyclists using alleys and roads	New Urbanist – cyclists using alleys and roads	Greenway – cyclists using roads and trails	Greenway – cyclists on trails only
Total network coverage (in feet)	51,347.7	40,916.9	48,058.1	67,581.7	66,607.0	39,554.3
Complete separation from cars (in feet) (trails outside of road intersection crossings, alleys, or parking)	2,866.9 (5.6%)	4,983.1 (12.2%)	3,587.7 (7.5%)	10,629.3 (15.7%)	36,384.8 (54.6%)	38253.0 (96.7%)
Partial separation from cars (in feet) (bike lanes)	0.0 (0.0%)	20,440.3 (50.0%)	15,840 (33.0%)	27,341.7 (40.5%)	0.0 (0.0%)	0.0 (0.0%)
Sum – complete or partial separation from cars *(in feet)*	*2,866.9 (5.6%)*	*25,423.4 (62.1%)*	*19,427.7 (40.4%)*	*37,971.0 (56.2%)*	*36,384.8 (54.6%)*	*38,253.0 (96.7%)*
No separation from cars on roads (in feet) (mixed traffic on roads not including alleys, trail crossings over road)	48,460.8 (94.4%)	15,493.5 (37.9%)	21,784.0 (45.3%)	15,533.6 (23.0%)	30,176.1 (45.3%)	1,255.3 (3.2%)
No separation in parking areas (in feet) (alleys, trail driveway crossings)	20.0 (0.0%)	0.0 (0.0%)	6,846.4 (14.2%)	14,077.1 (20.8%)	46.0 (0.1%)	46.0 (0.1%)

For cyclists, the Greenway network once again provided both the greatest proportion of completely modally separated paths by far (54.6% vs. 15.7% in the next best model, the New Urbanist). It's interesting that even though the New Urbanist model does not emphasis modal separation for cyclists it still managed to do better in the "complete separation" category than all the other models except the Greenway. This is because of the higher proportion of park space and its corresponding length of trails, showing that higher densities can actually support modal separation if designed correctly, by allowing developers to allocate more land to parks while achieving the same number of sellable units. Looking at the other models, the Loop and Cul-de-Sac model offered proportionately more bike lanes than the others (50.0%), but not as much actual length (20,440.3') as the New Urbanist model which had the most (27,341.7'). The Grid model provided the least separation from cars (both in terms of on-road travel in mixed traffic, and in parking areas), almost entirely because of the lack of bike lanes in the model.

Of all the variables considered in this study, modal separation has been the least assessed in previous research and so warrants some additional discussion here. Modal separation in the models took two basic forms: the first, providing separation through parallel pathways (for instance, sidewalks, bike lanes or trails along a road) and the second by providing separation within intersections (only applicable in this study to the Greenway model, where underpasses were used). That modal separation at intersections was so uncommon even though a large proportion of accidents take place at intersections (Transport Canada, 2004; Loukaitou-Sideris et al., 2007) likely the reflects the cost of providing this type of modal separation, as well as potential aesthetic concerns tied to underpasses and overpasses. While there is as of yet no widely accepted means of providing modal separation in *space* at intersections, "scramble intersections" (alternately known as "X crossings" or "a Barnes Dance") provide an alternative means of providing greater separation in *time*. As such, it may be more useful in the context of intersections to develop modal separation measures that can look at separation from both these dimensions.

When looking at separation from parallel lines of traffic rather than intersections, there were only three types of paths aimed at providing modal separation for active modes in the models: **sidewalks** (both interrupted and uninterrupted), **trails** and **bike lanes**. Research to date suggests that sidewalks are sufficient for providing adequate modal separation for pedestrians and changes in this path type may have a moderate, weak or even no impact on walking behavior depending on the study (Ewing and Cevero, 2010).

Although sidewalks may provide sufficient modal separation for pedestrians walking, the cyclist network is another story. For cyclists, Hunt and Abraham (2007) found that for those uncomfortable or inexperienced with biking, time spent on trails was the less onerous than biking in bike lanes or in mixed traffic. Despite this, all models but the Greenway addressed cyclist needs primarily through the incorporation of bike lanes rather than trails (see Table 47 above). These are, however, perhaps the most inequitable of the active transportation pathways regularly provided in urban areas, and very much favour those who are comfortable travelling in and near traffic over those who are not, such as (for example) seniors, those with disabilities, less experienced cyclists, women and children.

Network Legibility: Directional Distance

Legibility in this study was assessed using Peponis et al.'s (2008) "Directional Distance" tool. Like metric reach, directional distance is calculated for the midpoint of each path segment in a network, making these results independent of origin and destination points as well as variations in density between the models. For this study, the total length of path that could be travelled without making more than 2 direction changes was calculated. Because of problems arising from its offset grid, the Greenway model was given the same "extra frame" treatment as it was given for the alpha index (see p. 164). A single line network was used for sidewalks to ensure that they had the same weighting as an equal length of trail in the final assessment.

Table 48: Directional distance – average length of pathways within two direction changes

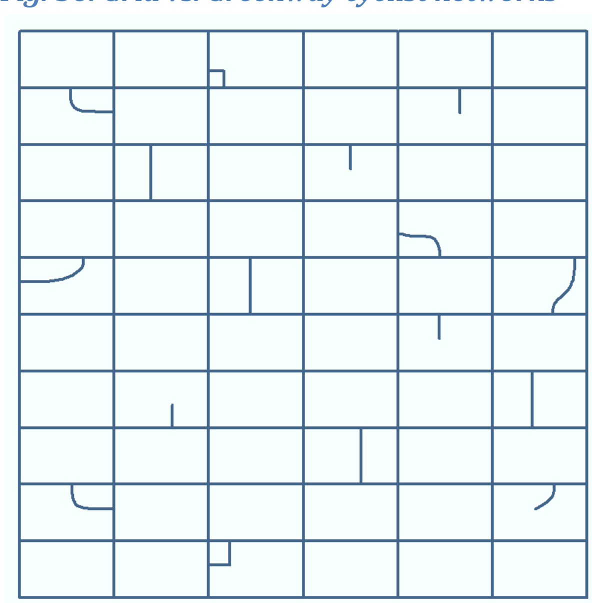
	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrians (in miles)	6.4 (st. dev. 2.0)	0.7 (st. dev. 0.6)	2.0 (st. dev. 1.6)	3.1 (st. dev. 2.3)	7.8 (st. dev. 1.2) (or without frame, 5.6 with a st. dev of 1.3)
Bicyclists (in miles)	6.4 (st. dev: 2.0)	0.7 (st. dev: 0.6)	2.0 (st. dev: 1.6)	3.1 (st. dev: 2.3)	9.1 (st. dev: 2.7)

Values calculated using an angle threshold of 10 degrees and a "very short line segment" of 0.1 miles.

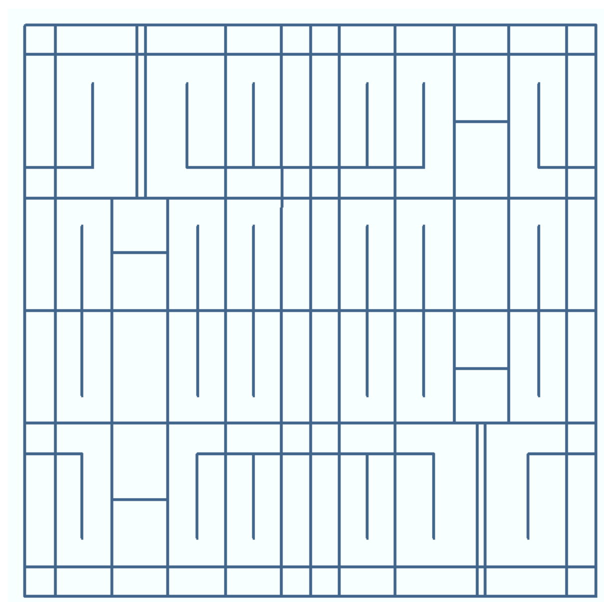
For both modes, the Greenway model had the most legible network (greatest directional distance) and the Loop and Cul-de-Sac the least. While it has been argued that curvilinear roads used in the Loop and Cul-de-Sac model are attractive to homeowners, it seems unlikely that irregular road layouts would be a selling feature for any resident. If curving roads are needed, they could be made to curve in a regular pattern back and forth, maintaining their overall trajectory.

That the Greenway cyclist network had a higher directional distance (9.1 miles) than the Grid (6.4 miles) was unexpected, as it includes disconnected cul-de-sacs not seen in the Grid cyclist network that should have the effect of lowering legibility: comparing the two models, it would appear that this is likely the result of numerous small trail segments requiring a turn before much distance could be traveled in the Grid model and the higher density of cyclist pathways in the Greenway – the total size of the network available to cyclists in the Grid is 51,643.4' but in the Greenway is 66,614.4' (see Fig. 56 below).

Fig. 56: Grid vs. Greenway cyclist networks



Grid Cyclist Network



Greenway Cyclist Network

One weakness of this tool that was found is that while it is effective at assessing changes in direction, it fails to capture the "predictability" element of network legibility. This is particularly evident with regards to the Fused Grid model, whose regular approach to active transportation segments is very predictable (there are always paths through the centre of a quadrant connecting the otherwise disconnected roads), but which still produces a relatively low directional distance. Another weakness is its sensitivity to grain (as seen in the case of cyclist networks in the Greenway vs. Grid models, above): a perfect grid with a fine grain will produce a higher legibility than a grid with a coarse grain, even though one could argue they have the same legibility – they are both exactly as easy to navigate. (And in fact, as the above case shows, an arguably less legible network with a higher path density can still come out as being more legible than a grid network as a result!) In this regard, the directional distance tool basically captures path density (a connectivity measure) as well as direction changes (a legibility measure). One way to compensate for this in future research would be to weigh the results against the total network length, so that the measure looks at the *proportion* of the network accessible within two direction changes, rather than its total length.

Calculation of Network Design Ranks

An overall rank for the "network design" variable was calculated for each of transportation mode, using the ranking results from the five network characteristics (coverage, connectivity, continuity, modal separation and legibility) (see Tables 49 and 50 below). For connectivity and continuity, an average rank was produced based on the multiple measures used to assess these two characteristics, with the exception of the alpha index for connectivity which was dropped because of the problems found to arise from its use.

The basic "overall rank" for the network design dimension assumes that coverage, connectivity, continuity, modal separation and legibility should be equally rated. How different elements of network design should be weighted continues to be a source of uncertainty for all researchers in the active transportation field, and in particular for those trying to develop walkability or bikeability indices.

For pedestrians, it is clear that connectivity is a very important design element, but it is difficult to say how important other measures (particularly continuity, modal separation and legibility) are when they have barely been studied to date. As such, in addition the basic "overall rank" produced using equal weighting of the five network characteristics, a second scenarios has been provided in which it is assumed that connectivity contributes half of the overall value (the other half coming from the remaining four variables, equally weighted). Since the connection between connectivity and walking has been so strongly established and tends to be the strongest correlate of walking among built environment variables, it is this second weighted scenario, where connectivity has half the weight of the "network design" equation, that was used in the final assessment of active transportation potential (see p. 186). However, it is noted that as the body of research into walkability and bikeability grows, it may become apparent that a different set of weights would be more appropriate, and as such, this evaluation (and that made for cyclists) should be viewed as tentative at best.

For cyclists, results with regards to the relative value of connectivity and other network measures remains largely ambiguous: what data there is suggests that connectivity is likely less important to cyclists than pedestrians. While the literature to date seems to suggest that continuity, modal separation and network coverage may actually be more important than connectivity to cyclists, it is not felt that there is as of yet a sufficient weight of evidence to warrant developing a second scenario as was done for pedestrians. As such, the only scenario is for the "overall rank" in which each of the five variables is equally weighted, and will be used in the final assessment (p. 186). (It may be that what is needed for cyclists is a measure that looks at the time (rather than distance) it takes to travel through the neighbourhood, which would act as the intersection of connectivity and continuity and perhaps provide a means for explaining the ambiguous results between them, however, that is beyond the scope of this study).

Table 49: Network design ranks for pedestrians

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Coverage - by mode	**5**	**3**	**2**	**4**	**1**
Connectivity – intersection density (available to pedestrians)	*4*	*2*	*3*	*5*	*1*
Connectivity – metric reach	*4*	*1*	*2*	*5*	*3*
Connectivity – differential connectivity by metric reach	*1*	*3*	*4*	*2*	*5*
Connectivity – averaged	**3**	**2**	**3**	**4**	**3**
Continuity – POC density (equally weighting ranks for ATN/Road and ATN/Driveway)	*1.5*	*2.5*	*3*	*3*	*5*
Continuity – ratio of ATN-only intersections to regular road intersections	*2*	*1*	*3*	*4*	*5*
Continuity – averaged	**1.75**	**1.75**	**3**	**3.5**	**5**
Modal separation – by coverage (proportion of network providing complete separation from cars)	**2**	**1**	**3**	**4**	**5**
Legibility – by directional distance	**4**	**2**	**3**	**3**	**5**
NETWORK DESIGN: SCENARIO 1 (average rank for the five network characteristics above)	**3.15**	**1.95**	**2.80**	**3.70**	**3.80**
NETWORK DESIGN: SCENARIO 2 (rank for the five network characteristics above if connectivity was assigned a value equalling half the total weight, and the remaining four the other half)	**3.09**	**1.97**	**2.88**	**3.81**	**3.50**

Depending on the weighting used, the model with the best network for walking was either the Greenway (if all five variables are equally weighted) or the New Urbanist (if connectivity is weighted as being worth half the total "network design" value). The worst network for walking regardless of weighting was the Loop and Cul-de-Sac.

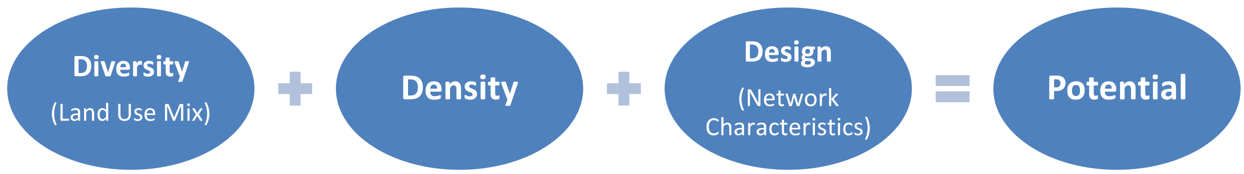
Table 50: Network design ranks for cyclists

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Coverage – by mode	**1**	**3**	**2**	**5**	**4**
Connectivity – intersection density	*3*	*1*	*2*	*5*	*4*
Connectivity – metric reach	*3*	*1*	*2*	*5*	*4*
Connectivity – differential connectivity by metric reach	*1*	*3*	*4*	*2*	*5*
Connectivity – averaged	**2.33**	**1.67**	**2.67**	**4.00**	**4.33**
Continuity – POC density (all car/cyclist POCs)	*2*	*5*	*3.5*	*1*	*3.5*
Continuity – ratio of ATN-only intersections to regular road intersections	*2*	*1*	*3*	*4*	*5*
Continuity – averaged	**2**	**3**	**3.25**	**2.5**	**4.25**
Modal separation – by coverage (proportion of network providing complete separation from motorists)	**1**	**3**	**2**	**4**	**5**
Legibility – by directional distance	**4**	**1**	**2**	**3**	**5**
NETWORK DESIGN (average rank for the five network characteristics above)	**2.07**	**2.33**	**2.38**	**3.70**	**4.52**

As can be seen in Table 50 above, the model with the best network for biking was the Greenway, and the worst network the Loop and Cul-de-Sac.

Evaluation of Active Transportation Potential

The evaluation of active transportation potential in this study uses the following formula, based on the "3Ds" of diversity, density and design identified by Cevero and Kockelman (1997):



Like any index, how well it relates to what it seeks to assess depends on the variables chosen and how correctly they have been weighted. In this case, the three dimensions have been equally weighted (as all have been weakly to moderately tied to travel behaviour in the literature), but as active transportation research continues to expand, it is hoped that further refinements to weightings might be made. In the meantime, users of these results can also choose to ignore this weighting scheme and use the original results for each variable to produce their own assessment.

Tables 51 and 52 below provide the final evaluation of active transportation for the models. The final ranking of models proved to be the same for both walking and biking modes. The best model overall for both walking and biking was the New Urbanist, while the worst was the Loop and Cul-de-Sac. Although a traditional model (the Grid) turned out to be second best for both walking and biking overall, this is largely due to its high density, while the Fused Grid model came in second last, largely, it seems, as a result of not being especially strong in any of the categories (although still being an improvement over the Loop and Cul-de-Sac).

Table 51: Evaluation of active transportation potential for pedestrians

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Diversity (land use mix) (Average rank of "Other" and "Park")	2.75	2	2.25	4.75	3.25
Density (Rank of gross density)	5	1	3	4	2
Network design (Connectivity worth half; all other measures worth half)	3.09	1.97	2.88	3.81	3.50
Total (out of 15)	10.84	4.97	8.13	12.56	8.75
Final rank	**4**	**1**	**2**	**5**	**3**

Table 52: Evaluation of active transportation potential for cyclists

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Diversity (land use mix) (average rank of "Other" and "Park")	2.75	2	2.25	4.75	3.25
Density (rank of gross density)	5	1	3	4	2
Network design (all measures weighted equally)	2.07	2.33	2.38	3.7	4.52
Total (out of 15)	9.82	5.33	7.63	12.45	9.77
Final rank	**4**	**1**	**2**	**5**	**3**

As Table 53 below shows, though, there were important differences in ranks between "overall potential" and "network design" , which points to opportunities for better synthesis between models (see p. 246).

Table 53: Best model for each mode under different weighting scenarios

	Best Model	Best Network – Equal Weights	Best Network – Alternate Weights
Walking	New Urbanist	Greenway	New Urbanist
Biking	New Urbanist	Greenway	N/A (No alternate weighting system considered for cyclists)

Table 53 is dominated exclusively by the New Urbanist and Greenway models. That it is two alternative models that performed best in both categories (for all modes) indicates that these alternative models have been successful in improving over traditional Grid and Loop and Cul-de-Sac designs (at least in all the ways considered here), and warrant serious consideration when new neighbourhoods are being planned.

PART II: TRIP-BASED MEASURES

Trip based measures are valuable for describing what a specific or “typical” trip through a neighbourhood might be like, whether in terms of trip lengths, directness ratios or number of points of conflict one must pass through to reach destinations. They also reflect the relative importance of well-connected (and thus well-used) portions of the network, whereas in network-based measures (see Part I of this chapter), all network elements are considered equal. For instance, even if a network has a considerable length of trail (as measured by network coverage), its benefits (both in terms of trip distance and increased modal separation) may be negligible if it is located in poorly used or poorly connected parts of the neighbourhood. Thus, a good design is one that locates network elements so that they offer the greatest benefit to the greatest number of users, for instance, by offering bike lanes on the busiest roads as opposed to the quietest ones.

For this study, five types of trip-based measures were calculated:

- Average trip lengths
- Trip-based connectivity using directness ratios
- Trip-based differential connectivity using trip distances
- Trip-based continuity using potential points of conflict on trips
- Trip-based modal separation using separation of path types on trips

For some measures, edge, centre and “combined” (equally weighted) results are presented separately; in others, only the “combined” results have been reported for the sake of time. Results for driving trips have been included in Appendix J.

Data was assessed for normalcy using the descriptive statistics tool provided in Microsoft Excel 2007, which included measures of centre, standard deviation and skewness. In general, combined values to the edge were more normal than values to the centre, and models which had a more regular distribution of dwelling units between buildings (whether that meant being entirely single-detached or having many multi-unit buildings with small numbers of dwelling units in each) had more normal results than those that had many single-detached buildings and then a large number of dwelling units concentrated in a few apartment buildings (which tended to create peaks in the histograms).

Trip-Based Connectivity: Average Trip Lengths

Trip lengths are the best proxy variable available for assessing trip times, a key determinant of travel behaviour (Agrawal et al., 2008; McDonald, 2008). The average trip distances varied for each of the five models and each of the study modes (see Table 54 below). Trips to the centre were consistently shorter than trips to the edge, as the farthest an origin point could be from the centre point was only half the length of the model's frame. Average trip lengths to the edge ranged from a low of 2,296.9' for cyclists in the Greenway model to a high of 2,761.3' for cyclists in the Loop and Cul-de-Sac model, while average trip lengths to the centre ranged from a low of 1,226.3' for cyclists in the Greenway model to a high of 2,004.3' in the Loop and Cul-de-Sac model. The difference in trip lengths between pedestrians and cyclists was rarely more than 50' or so, with the exception of the Greenway model for which greater differences (around 100') were obtained. A comparison of the trip results for motorists (Appendix J) showed that motorists regularly had the furthest to travel and pedestrians the least, again demonstrating that differential connectivity is a de facto component of all five models.

Table 54: Average trip lengths

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Walking trip to edge (in feet)	2,325.1	2,708.4	2,393.2	2,317.0	2,384.0
Walking trip to centre (in feet)	1,361.3	1,901.4	1,513.0	1,359.7	1,396.7
Edge & centre equally weighted walking trip length (in feet)	**1,843.2**	**2,304.9**	**1,953.1**	**1,838.4**	**1,890.4**
Bike trip to edge (in feet)	2,349.2	2,761.3	2,410.2	2,342.7	2,296.9
Bike trip to centre (in feet)	1,384.8	1,945.0	1,534.9	1,371.7	1,226.3
Edge & centre equally weighted bike trip length (in feet)	**1,867.0**	**2,353.2**	**1,972.6**	**1,857.2**	**1,761.6**

When equally weighting trips to the edge and trips to the centre to give a standard means of comparison between the models, the Loop and Cul-de-Sac model had the longest trip lengths and Fused Grid the second longest trip lengths for both modes. The New Urbanist neighbourhood was the best for walking (although there was less than a 5' difference between it and the Grid, making them essentially tied), while the Greenway neighbourhood was the best for biking (with a 95.6' difference between it and the runner up, the New Urbanist).

Table 55 below describes the differences in trip distance between the best and worst model for each mode/destination type combination. Differences in trip distances ranged from a low of 16.9% for pedestrians walking to edge destinations up to a high of 58.6% for bike trips to the centre destination point. The differences in trip distances to the edge were likely smaller than those to the centre because the greater number of points along the edge means that even if an origin is poorly located with regards to one destination, it will be well located with regards to another, creating less variation between models. When measuring trip distance to a single centre point, on the other hand, a model which happened to have high density located around that point could produce substantially shorter trip distances over another model which did not focus development in this way, resulting in a larger variation between models. Regardless, a key conclusion that can be drawn from these results is that *model choice can have a large impact on trip distances – almost a 60% difference in some cases.*

Table 55: Differences in trip lengths between best and worst models

	Best Case	**Worst Case**	**Difference in trip length between worst and best model (in feet)**	**Difference in trip length compared to best case as a percent**
Walking trip to edge	New Urbanist	Loop and Cul-de-Sac	391.4	16.9%
Walking trip to centre	New Urbanist	Loop and Cul-de-Sac	541.7	39.8%
Equally weighted walking trip	New Urbanist	Loop and Cul-de-Sac	466.50	25.4%
Bike trip to edge	Greenway	Loop and Cul-de-Sac	464.4	20.2%
Bike trip to centre	Greenway	Loop and Cul-de-Sac	718.7	58.6%
Equally weighted bike trip	Greenway	Loop and Cul-de-Sac	591.6	33.6%

Determining the Causes of Differences in Trip Distances

In this study, trip distances were furthered analyzed using box plots in order to demonstrate their use in assessing the distribution of trip lengths to a given destination and to better understand how the differences in average trip distances between the models came about. Appendix N contains two examples of such analysis, using box plots to compare the two models with the greatest difference in trip lengths for a given mode (the Greenway and Loop and Cul-de-Sac models for cycling trips to the centre destination point), and the two models with the least difference in trip lengths for a given mode (the New Urbanist and Loop and Cul-de-Sac model for walking trips to edge destinations).

The box plots revealed a clear pattern wherein trips to centre were shorter than trips to the edge, and that among the eight edge points, those located in the corners consistently had longer trip lengths than those located at the centre of the four bounding roads. The use of boxplots also helped to identify origins which had outlier trip lengths, thereby identifying particularly poorly connected sections of the network. This same technique could therefore be used to determine where adding extra pathways would offer the most benefit to a proposed design.

Lastly, box plot and descriptive statistics results were combined with a measure of proximity to determine if reductions in trip length to destination points might be the result of more dwelling units being located in closer proximity to a given point. If a destination point had lower overall proximity than another but still produced shorter trip lengths, this was a good indication that the change in trip length was the result of better network connectivity between origins and that point.

Comparing Dwelling-unit and Lot-based Approaches to Measuring Trip Lengths

As discussed in the methodology section on p. 88, there are a few different ways trip lengths can be measured in a neighbourhood. One way is to assume that each lot has a single origin point (a spatial or lot-based approach), while another is to place a number of origin points equal to the number of dwelling units or people that live or work on that lot (a density or dwelling-unit based approach).

In this study, a density-based approach was used. To determine the extent of effect this choice of approach had on the trip results, a comparison was made of the resulting percent differences in trip lengths depending on which approach was used (see Table 56 below). Negative values indicate not only that a change to a density-based approach produced shorter trip lengths, but more precisely, *that the distribution of dwelling units in the model was able to reduce trip lengths.* Positive values, on the other hand, indicate that the dwelling units were poorly distributed (relative to the destination points) and that switching to a dwelling-unit based approach actually increased trip lengths.

Considering dwelling units had the effect of decreasing trip lengths by a maximum of 1.7% (for the Greenway model's car trips to centre) and increasing them by a maximum of 6.5% (trips to centre by all modes for the Grid model). Differences were greater in trips to the centre rather than trips to the edge for all modes: this is likely again due to the fact that the distribution of multiple points around the edge of the models had the effect of moderating results.

Surprisingly, only the Greenway and Loop and Cul-de-Sac models had densities distributed in such a way as to reduce walking and biking trip lengths to edge and/or centre. However, it seems likely that in practice, even where a model that emphasizes the distribution of density across an entire neighbourhood (such as the New Urbanist) is used, planners and developers would still choose to increase the density around key destinations once these are known (something which was not done in this study, instead using more general guidelines to distribute units in the model space).

Whether or not this is sufficient of an effect to warrant the additional calculation a density-based approach entails in future research is debatable, however, it is likely that some designs will be more affected by the choice of method than others (for example, the hypothetical scenario described on p. 91 saw a much larger impact than was found in the study models). Unfortuntely there is not as of yet a quick method to determine when the extra work to go from a lot-based to dwelling-unit based approach is needed. However, what can be concluded from these results is *that the strategic location of dwelling units can have a positive effect on trip lengths for users*, and that this can be effectively assessed through a GIS.

Table 56: Differences in model trip lengths as a result of lot vs. dwelling unit based approach

	Percent Difference for Model				
Trip Type	**Grid**	**Loop and Cul-de-Sac**	**Fused Grid[1]**	**New Urbanist**	**Greenway**
Walking trip to edge	1.4%	-0.5%	0.0%	0.4%	-0.3%
Walking trip to centre	6.5%	4.4%	0.0%	1.4%	-0.6%
Equally weighted walking trip	3.3%	1.5%	0.0%	0.8%	-0.4%
Bike trip to edge	1.4%	-0.6%	0.0%	0.4%	0.0%
Bike trip to centre	6.5%	4.4%	0.0%	0.9%	0.7%
Equally weighted bike trip	3.3%	1.5%	0.0%	0.5%	0.2%
Car trip to edge	1.4%	-0.7%	0.0%	0.0%	0.3%
Car trip to centre	6.5%	4.1%	0.0%	-0.6%	-1.7%
Equally weighted car trip	3.3%	1.3%	0.0%	-0.2%	-0.3%

Negative values indicate a reduction in trip distance when using a dwelling-unit approach; positive values indicate an increase in trip distance.

[1]: As the Fused Grid no units in multi-unit buildings, there is no difference in trip lengths regardless of whether a lot-based or dwelling-unit based approach is used.

Trip-Based Connectivity: Directness Ratios

Ratios of route directness compare the trip length along the network between an origin and destination point to the "as the crow flies" Euclidean distance between the same two points. The value reflects how much farther a person needs to travel along a network compared to the Euclidean distance – for instance, a directness ratio of 1.33 means that the trip is 33% longer than it would be if it could be flown. A low directness ratio indicates that the network provides a relatively direct connection between two points.

Assessing connectivity using ratios of route directness helps to control for differences in sizes between communities as well as differences in the distance (proximity) between origin/destination pairs. While not necessary for this study where the model size is constant and trip lengths are a desired variable to show how changes in design (both in terms of network and the distribution of dwelling units) can affect trip distances, directness ratios are still useful for their ability to allow comparison to other communities of different sizes in other research. Directness ratios do have a weakness, however, in that they do not describe the actual distance between destinations in a given neighbourhood – having a good directness ratio may be moot if a trip is simply too long to make on foot.

Table 57: Directness ratios

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrian directness ratio to centre	1.32	2.03	1.36	1.41	1.57
Pedestrian directness ratio to edge	1.29	1.52	1.31	1.30	1.35
Equally weighted pedestrian directness ratio (average of edge and centre results)	**1.31**	**1.78**	**1.34**	**1.36**	**1.46**
Cyclist directness ratio to centre	1.34	2.08	1.38	1.43	1.31
Cyclist directness ratio to edge	1.31	1.55	1.32	1.32	1.30
Equally weighted cyclist directness ratio (average of edge and centre results)	**1.33**	**1.82**	**1.35**	**1.38**	**1.31**

Note: Results are derived from trips calculated on per-dwelling unit basis.

The Loop and Cul-de-Sac model was again the worst for both modes and all destination types. The Grid was the best overall for walking when looking at the equally weighted values (directness ratio of 1.31), while the Greenway was the best overall for cyclists (directness ratio of 1.31). No model had a directness ratio of less than 1.29, although many neared this point, suggesting that it may be difficult to do much better than this in a planar transportation network with (at most) four-way intersections.

The Fused Grid model had better directness ratios than the New Urbanist model for all trips to centre (regardless of mode). This means that even when units were located further away from the centre point, they typically still had more direct pathways available to take them there. This is likely the result of the curved "east-west" roads in the New Urbanist model and the units located on dead-end cul-de-sacs (which lacked the trails present in the Fused Grid model to connect them).

Trip-Based Differential Connectivity: Trip Length Ratios Between Modes

Trip-based differential connectivity was assessed using the equally weighted trip distances calculated on p. 190. Results are provided in Table 58 below.

Table 58: Differential connectivity values based on trip distances

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Pedestrian:Motorist *(from average of edge & centre trip distances)*	0.98	0.95	0.89	0.92	0.95
Cyclist:Motorist *(from average of edge & centre trip distances)*	1.00	0.97	0.90	0.93	0.89

Note: A lower differential connectivity value favours the active mode.

Both the traditional models (Grid and Loop and Cul-de-Sac) offered very little by way of differential connectivity. The models with the greatest connectivity differentials were the Greenway model for cyclists versus motorists and the Fused Grid for pedestrians versus motorists, both with a value of 0.89, or an average 11% reduction in active travel distances relative to driving distances. The Greenway model was tied for the second worst value for pedestrians vs. cars; however, this is again likely partly the result of frame choice, which put all destination points in line with road network elements (producing shorter trips for cars) and consequently, as a result of its off-set grid, out of line with the pedestrian network (producing longer trips for pedestrians) (see Fig. 57 below).

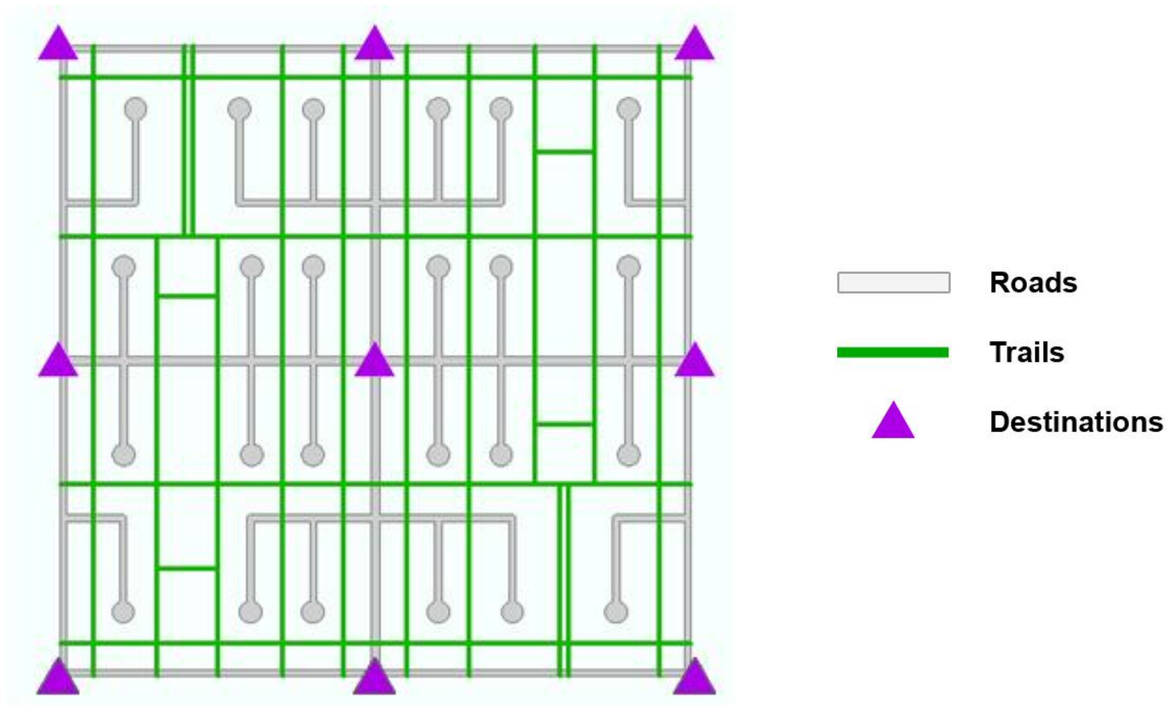


Fig. 57: Destination points relative to road and trail networks in the Greenway model

This again demonstrates the problem noted previous in Part I of this chapter: that the choice of frame and destination points within a model can *systematically skew results in favour of one mode over another* when spatially separate network elements are present.

Trip-Based Continuity: Using Conflict Points

In Part I of this chapter, continuity was assessed on a network basis by looking at point of conflict (POC) density. Here, continuity is measured on a trip basis, in which the number of POCs a pedestrian, cyclist or motorist must pass through in order to make the shortest possible trip to a destination is counted.

In order to make it easier to compare between models, all results reported here weigh equally trips to the centre and the edge to produce a single value upon which to compare (separate results for trips to edge and centre are reported in Appendix P). The average number of POCs encountered on the trips is provided for each model and mode combination, but because trip length varied between models, the average POCs per mile travelled were also calculated in order to make it possible to compare continuity independent of trip length. Depending on the mode, the following groups of POCs were assessed:

- ATN/ATN (where a sidewalk, trail and/or front door connection crossed, plus underpasses for pedestrians in the Greenway model)
- ATN/Road (where a sidewalk or trail crossed a road or alley, plus the bike ramps onto roads at underpasses for cyclists in the Greenway model)
- ATN/Driveway (where a trail or sidewalk crossed any type of driveway)
- Road/Road (where travel occurred through the middle of an intersection where road segments met, rather than along its edge – i.e., for cars and bikes travelling along the road centerlines in the GIS, but not pedestrians travelling along the sidewalk lines – see Fig. 55 on p. 172)

It should be noted that any POCs that fell along a fake line that had to be travelled to reach a destination are included in the counts in Tables 59 and 60 below. These results may therefore slightly overestimate the number of POCs encountered compared to what one would see if destinations fell directly along the network in question, rather than requiring these additional links to be added in order to connect the two. However, as the "fake" links were kept as short as possible (and were at most only ever the length to connect a destination point to the next closest intersection belonging to the unconnected network), the effects would be extremely minimal (see Appendix I for maps location of the fake line segments and maps of the distribution of the POCs for each of the models). The only exception to this was for “Road/Road” POCs encountered by pedestrians, which *all* would have been the result of the central destination point being located in the middle of an intersection and the fake lines that that required (since otherwise, pedestrian travel paths never took them through the centre of a regular road intersection – see Fig. 55 on p. 172 for an example), and as such, could be eliminated completely from Table 59 below.

Table 59: Average number of conflict points encountered by pedestrians making trips

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway	
	Avg. count	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**
ATN/Driveway[1]	14.5	41.5	28.9	66.3	17.2	46.4	4.9	14.0	0.0	0.0
ATN/ATN	11.5	32.9	11.6	26.6	21.9	59.2	20.3	58.2	43.7	122.1
ATN/Road	5.5	15.7	3.4	7.7	4.3	11.6	5.0	14.4	1.4	4.0

[1]: For pedestrians, ATN/Driveway POCs are considered on a per mile basis, because in this case, the main source of conflict is from crossing driveways while walking, rather than traveling along them as cars do to park. As such, the number of these POCs encountered increases the further one walks.

Even though the inclusion of alleys or the use of an offset network has little impact on the number of ATN/Driveway POCs encountered by drivers, they have a substantial affect on pedestrians, as shown in Table 59 above. Pedestrians travelling in the Loop and Cul-de-Sac neighbourhood had to constantly cross driveways (and potentially parking cars) - an average of 66.3 times per mile walked. On the other hand, this type of conflict was completely eliminated in Greenway neighbourhoods. The New Urbanist model also did a good job of reducing this type of conflict (down to an average of only 14.0 POCs per mile walked), while the Grid and Fused Grid models fell somewhat in between (41.5 and 46.4 respectively). The higher number of POCs in the Fused Grid model versus the Grid model, despite its moderate use of alleys, is likely due to the higher proportion of rowhouses and consequently smaller lots and more driveways. Thus, density and housing mix can have an impact on driveway-based continuity.

The most important type of POC for a pedestrian is undoubtedly the ATN/Road type, where there is the greatest potential for their path to be crossed by a car (since driveways are used infrequently compared to roads). The Greenway model had the fewest of these POCs per mile walked (an average of 4.0), while the Grid had the most (15.7). This is likely the result of the Greenway's coarse-grained, disconnected road network which provided the opportunity for a more continuous trail network between cul-de-sacs. The Grid, on the other hand, was relatively fine-grained and required pedestrians to cross roads on a regular basis. Not surprisingly, the Loop and Cul-de-Sac model with its similarly (if less regularly laid out) disconnected road network was next best after the Greenway (with an average of 7.7 POCs per mile walked). For pedestrians, the Loop and Cul-de-Sac model does a better job of reducing potential conflict (in terms of frequency) between them and on-road traffic than either of the Fused Grid or New Urbanist models. This is one of the few categories in which the Loop and Cul-de-Sac model did better than some of the alternative models. Comparing these results to those for the ATN/Driveway category, <u>it appears that where the Fused Grid and New Urbanist models have sought to improve on the continuity of the Loop and Cul-de-Sac model, it has been by eliminating driveway crossings rather than road crossings</u>.

While ATN/ATN crossings can act as potential points of conflict, their impact on walking is likely minimal. The Loop and Cul-de-Sac model had the fewest ATN/ATN points of conflict (26.6 per mile), while the Greenway had the most (122.1 per mile), reflecting the different uses of trail networks within them; in the Loop and Cul-de-Sac model, trails only play a minor connective function and thus have few

ATN/ATN crossings, whereas in the Greenway model, trail/trail intersections are extremely common and inevitably occur along pedestrian travel paths. It is important to note, however, that the majority of POCs in this category in the Greenway model would be front door/trail POCs (an average of 38.6 of the 43.7 ATN/ATN POCs typically encountered on a trip).

Table 60: Average number of conflict points encountered by cyclists making trips

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway	
	Avg. count	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**
Road/Road	5.3	15.1	4.8	10.9	3.9	10.3	5.3	15.1	2.0	6.1
ATN/Driveway[1]	1.0	N/A	1.0	N/A	0.6	N/A	0.3	N/A	0.2	N/A
ATN/ATN	0.4	1.2	1.4	3.0	2.5	6.6	2.8	7.9	20.5	61.4
ATN/Road	11.6	32.8	10.5	23.5	8.4	22.5	9.5	26.9	3.0	9.1

[1] *Because in these scenarios cyclists only travel down driveways at the start of their trips (and driveways do not cross bike lanes or roads in the same way that they cross sidewalks in the GIS models), the maximum value per trip in these models is 1, and a per mile value not applicable. A value of less than 1 indicates that some cyclists were able to leave their origin points without crossing a sidewalk or trail; e.g., through a back alley.*

For cyclists, Road/Road POCs (where they must travel through an intersection with car traffic) are likely of the greatest concern. The New Urbanist and Grid models were tied for worst for potential Road/Road conflicts on a per-mile basis (15.1/mile). These results show that both the New Urbanist and Grid models make cyclists pass through a high number of road intersections during their trips. The Greenway model had the fewest Road/Road conflicts, meaning that it did the best in keeping cyclists out of potential conflict with motorists.

Consistent with the results for pedestrians, for the ATN/Driveway category, the New Urbanist model was the best and the Loop and Cul-de-Sac and Grid models were tied for worst.

For ATN/ATN POCs for cyclists, the Grid was the best model (whereas for pedestrians, it was the Loop and Cul-de-Sac model). This would be due to cyclists not encountering sidewalk/sidewalk POCs at the corners of road intersections (like pedestrians do), coupled with a lack of trail/trail crossings in the model. The Greenway model was again the worst by far, with 61.4 such points of potential conflict per mile versus only 7.9 in the next runner up (the New Urbanist model). This means that the Greenway model has the greatest potential for putting pedestrians and cyclists in conflict in off-road locations. However, it’s worth noting that again in the Greenway’s case, the majority of the ATN/ATN POCs are of the ATN/front door type (18.2 of the 20.5 ATN/ATN POCs typically encountered), which would likely have far less potential for conflict (i.e., traffic coming from a perpendicular direction) than the trail/trail or sidewalk/sidewalk POC types included in this category.

Cyclists would typically encounter ATN/Road POCs either where they get onto a road from a mid-block trail crossing or where they potentially cross travel paths with pedestrians crossing the road at an intersection. These conflicts were most common in the New Urbanist neighbourhood (26.9/mile), while the Greenway model was again the best (9.1/mile), as a result of its off-set grid. This means that the New Urbanist model has the greatest potential for putting pedestrians and cyclists in conflict in on-road locations.

Comparing the Variation in Trip Continuity and Connectivity Between Models

Models vary in both their connectivity and continuity characteristics, however, it was not known how much models varied in terms of one relative to the other. To assess this, a comparison was made between the amount of variation in directness ratios (a connectivity measure) and ATN/Road POCs per mile (a continuity measure) for both walking and biking (see Tables 61 and 62 below).

Table 61: Differences in connectivity and continuity for walking trips

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Connectivity Measures					
Walking trip directness ratios (equally weighted trips to edge and centre)	1.31	1.78	1.34	1.36	1.46
Percent increase (compared to best case)	*0.0% (Best case)*	*35.9%*	*2.3%*	*3.8%*	*11.5%*
Continuity Measures					
ATN/Road POCs per mile on a "typical" trip	15.7	7.7	11.6	14.4	5.1
Percent increase (compared to best case)	*207.8%*	*51.0%*	*127.5%*	*182.4%*	*0.0% (Best case)*

Note: Values reflect percent increase over best case.

For pedestrians, there was at most a 35.9% difference in directness ratios between the models, while for the three alternative models, there was only a 9.0% (1.46/1.36) difference between the best model (Fused Grid) and the worst model (Greenway). On the other hand, when looking at POC conflicts with cars, the five models differed by up to 10.6 ATN/Road POCs per mile – a difference of 207.8% (or 182.4% when considering only the three alternative models). Cyclists experienced a similar pattern between differences in connectivity and continuity (see Table 62, below).

Table 62: Differences in connectivity and continuity for cycling trips

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Connectivity Measures					
Equally weighted bike trip directness ratios to edge and centre	1.33	1.82	1.35	1.38	1.31
Percent increase (compared to best case)	*1.5%*	*38.9%*	*3.1%*	*5.3%*	*0.0% (best case)*
Continuity Measures					
Road/Road POCs per mile	15.1	10.9	10.3	15.1	6.1
Percent increase (compared to best case)	*147.5%*	*78.7%*	*68.9%*	*147.5%*	*0.0% (best case)*
ATN/Road POCs per mile	32.8	23.5	22.5	26.9	9.1
Percent increase (compared to best case)	*260.4%*	*158.2%*	*147.3%*	*195.6%*	*0.0% (best case)*

Note: Values reflect percent increase over best case.

From this, it can be concluded that *models varied much more in their continuity than their connectivity* – even though connectivity is typically at the centre of design debates. If the purpose of focusing on *connectivity* is because of its relationship to trip *times* (rather than just length), then it would appear that continuity may have a more important role to play than has traditionally been considered. Given the substantial differences in continuity noted here and those in trail coverage noted on p. 156, it is clear that there is a need to expand the discussion around neighbourhood design, which so often focuses almost exclusively on connectivity, and reframe it in terms of what different networks can achieve: they vary by much more than connectivity alone!

Trip-Based Modal Separation: Using Path Type

A major drawback to assessing modal separation through the coverage of each path type is that a modally separated path may not actually be used if it is poorly connected to the network, regardless of how much of the total coverage it may represent – for instance, a large recreational loop trail that does not connect to any destination may represent a significant portion of the total network length, but be rarely used for utilitarian trip making. The ability to assess modal separation on a trip-making basis can therefore also help planners determine how best to lay out new pathways within a community when opportunities arise.

In this study, trip-based modal separation was assessed by calculating how much of the shortest possible trips to edge and centre destination points occurred on paths with different levels of modal separation. A network is considered to have better modal separation if less of a trip need to take place on pathways with multiple users (cars, cyclists and/or pedestrians). “Fake” segments were included, and assumed to be the type of pathway that would be used to reach a given destination point if it fell directly on the mode’s network (i.e., the fake segments were treated as through roads for motorists in the New Urbanist model, trails for pedestrians in the Greenway model, and sidewalks for pedestrians in all other models). Since fake segments were assigned a single path type attribute for their entire length, these results slightly underestimate the total amount of travel which would occur on interruptions to such segments (such as driveways), but this was seen as being preferable to having to reduce effective trip length and potentially cause a greater distortion in the relative proportion of different path types travelled along during a trip. Results are presented in Tables 63 and 64 below; a “N/A” indicates a path type not present in the given model.

Whether or not cyclists are assumed to use roads in the Greenway model, or pedestrians and cyclists alleys in the Fused Grid or New Urbanist models can have a substantial effect on trip-based measures of modal separation.

As noted in the network-based modal separation section (p. 174), the Greenway model is the only model for which completely restricting bike travel to trails is a possibility, by virtue of its dual-sided lots: in all other models, travel by road is necessary in order for cyclists to leave their starting lots and to make their way through the neighbourhoods (their trail networks being discontinuous). That said, producing this “best case” scenario for modal separation for the Greenway is somewhat unfair to the other models, which typically have some trails which correspond more or less directly to roads and which “cyclists” (i.e., the computer software) could, with more work, be forced to use in their place.

For the Fused Grid and New Urbanist models, alleys (which offer no modal separation) could be dropped from the network to produce a “travel on sidewalks and trails” only scenario for pedestrians without impacting the ability of travelers to reach destinations. In fact, since alleys are continuous but driveways (when at located the front of homes) are spaced out along a sidewalk, a pedestrian walking down an alley would actually spend *more* of their trip “no separation” conditions than a pedestrian walking down a similar length of driveway-interrupted sidewalk. However, while it was easy to calculate a “trail only” scenario for cyclists in the Greenway (being equivalent to the results for pedestrians in that model), calculating a second set of results in which pedestrians opt not to travel through alleys requires the creation of new network datasets, or the assignation of substantial weights to those path types to prevent their use. This was not done in the interests of time, but may be worth exploring in a future study. In the case of cyclists, travelling through an alley offers better modal separation than travelling on some types of roads (i.e. those without bike lanes), and so it makes sense to include alleys for that mode. (A more complicated network analysis could also allow travel through alleys as an alternative to roads without bike lanes, but prevent such travel where bike lanes are present).

Pedestrians

Table 63 below summarizes the modal separation experienced by pedestrians making equally weighted trips to the edge and centre in the models (separate values to edge and centre are provided in Appendix Q). For pedestrians, the proportion of a trip spent crossing roads is likely their greatest concern. The Grid was the worst in this regard, with pedestrians spending 10.4% of their trips (by distance) crossing roads, followed by the New Urbanist model at 8.1%. This reflects both the high number of road intersections in these models and the need for pedestrians to actually travel through them when trying to walk the shortest possible distance to a given destination. The results for Fused Grid and Loop and Cul-de-Sac were quite close and significantly better (6.0% and 5.5% respectively) while the Greenway model was the best with only 2.0% of a trip (by distance) occuring in road crossings.

Table 63: Average percent of shortest path trips along each path type – pedestrian

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Complete separation (sidewalks, trails, frontdoor connections and walking through underpasses)	78.4	77.1	79.6	81.7	98.0
No separation – higher order roads (crossing arterials or collectors)	N/A	3.1	2.2	6.1	1.3
No separation – local roads (crossing local roads)	10.4	2.4	3.8	2.0	0.7
No separation – parking (driveways and alleys)	11.2	17.5	14.3	10.2	0.0
Sum – crossing roads	10.4	5.5	6.0	8.1	2.0
Sum – no separation	21.6	23.0	20.3	18.3	2.0

Note: As a result of rounding, the sum of modal separation percentages did not always add up to exactly 100.0%

Building on this idea, crossing arterials and collectors would be more stressful than crossing local roads. The New Urbanist model had pedestrians spending the greatest proportion of their trips on these higher-order roads (6.1% versus only 3.1% in the next closest model, the Loop and Cul-de-Sac). Since every model with arterials had the same length of arterial roads, this would likely be due to the much longer network of collector roads in the New Urbanist model (19,166.5' or 34.7% of its roads, versus 10,078.9' or 28.5% of its total road length in the Loop and Cul-de-Sac model). Whether or not New Urbanist designs would consistently have a greater proportion of collector roads in real developments is unknown, as is whether or not people would choose to walk along them if only slightly longer trips on local roads were possible. (One advantage the New Urbanist model does have is that travel on local roads is likely possible for a greater proportion of most trips because of its highly connected road network, compared to a disconnected road network such as that of the Loop and Cul-de-Sac model which limits the route choices available for getting to any one destination). This finding also points to a possible important difference between the Grid and New Urbanist models: although the Grid has a higher percent of trips spent in crossing, those crossings are made entirely on local roads, whereas the hierarchical New Urbanist model has a substantial portion of trips being spent crossing higher-order roads. The Greenway model had pedestrians spending the lowest proportion of their trips crossing higher-order roads (2.0%).

The category with the *greatest* range in the results was for the proportion of trip spent on completely separated paths (sidewalks, trails and frontdoor connections), ranging from a low of 77.1% of a trip in the Loop and Cul-de-Sac neighbourhood to a high of 98.0% in the Greenway – a difference of 20.9%. This shows again that the provision of modally separated paths (and in particular trails, as shown in the network coverage section on p. 155), is not only a defining feature of the models, but has substantial impacts on the actual travel experience through a neighbourhood.

The models also varied in how of a trip was spent walking on or by driveways and alleys. The Loop and Cul-de-Sac model had the greatest amount of walking past or along driveways and alleys (17.5%), and the Greenway the least (0%). This finding is important because it shows that *walking past or along driveways and alleys can represent a significant proportion of walking trips.* In fact, walking past or along parking areas represented a greater proportion of trips than walking across roads in every model save for the Greenway where such crossings were eliminated completely from the pedestrian network.

Cyclists

For cyclists, the greatest difference between the five models was in the amount of a trip spent on network segments offering a high level of modal separation, which, in the case of cyclists in this study, only included trails (including those in underpasses) and front door connections (see Table 64 below). Here, the Greenway had 48.8% of the length of bike trips taking place on these segments (or 98.0%, if bikes are assumed to not to use roads), compared to only 16.9% in the next runner-up (the New Urbanist). The worst model (the Grid) had only 2.9% of trip lengths occurring on these paths.

Table 64: Average percent of shortest path trip along each path type – cyclist

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway – Cyclists allowed on roads	Greenway – Cyclists on trails only
Low separation - Parking (biking in mixed traffic with cars and pedestrians) (i.e., driveways and alleys)	1.8	1.6	4.5	8.2	5.6	0.0
Medium separation (biking in bike lanes)	N/A	64.9	52.6	64.9	N/A	N/A
Low separation - Roads (biking in mixed traffic with cars)	95.3	26.5	33.9	10.0	45.5	2.0
High separation (biking with pedestrians only) (i.e. trails, sidewalks, front door connections and through underpasses)	2.9	6.9	9.0	16.9	48.8	98.0

Another substantial difference was in the proportion of trips spent in mixed traffic. This ranged from a high of 95.3% of trip lengths in the Grid model to a low of only 10.0% in the New Urbanist model (likely due, at least in part, to its high proportion of collectors with bike lanes relative to local roads) or only 2.0% in the Greenway model (if cyclists are assumed not to travel on roads, in which case, all of this 2.0% reflects road crossings).

There is less of a difference between the three models with bike lanes in terms of the proportion of trip spent on them, ranging from 51.8% in the Fused Grid to 62.1% in the Loop and Cul-de-Sac model. The proportion of trips spent on bike lanes was consistently higher than the proportion these paths made up of the total network, reflecting the relative importance of these pathways when trying to make the shortest possible trips to the study destinations (i.e they are more heavily used because of their high connectivity and location relative to destinations).

Cyclists spent far less time traveling through "parking areas" (driveways and alleys) than pedestrians, which is to be expected, given that their paths were not treated as being crossed by driveways, while sidewalks were (see Appendix F). Consequently, driveways were only encountered at the start of the trip where cyclists had to use driveways to get onto the road network. Although for pedestrians the Loop and Cul-de-Sac model was the worst in this regard, for cyclists, it was the New Urbanist model that had the greatest proportion (8.2%) of a trip occurring in parking areas, undoubtedly because of its large number of alleys.

Comparing Trip-Based vs. Network-Based Ranks for Network Design Variables

Appendix O contains several tables comparing the ranks for trip-based vs. network-based measures of the network design variables (connectivity, continuity and modal separation). While a more extensive discussion of those results has been confined to the appendix, what becomes immediately evident from those tables is that while in some cases a model/mode combination might have the same ranking for all types of trip-based and network-based measures used to assess a given variable (e.g. connectivity), this was the exception rather than the norm. While in most cases the ranks for the different measures hovered within one or two ranks of one another for the variable in question, in others, the difference was greater – a notable example of which was for connectivity cyclists in the New Urbanist model, for which the two network based measures (intersection density and metric reach) produced a rank of 5 but for which the trip-based directness ratio ranked only 2. Thus, not only do models vary in how they rank *between* variables, the measure used can affect how they rank *within* variables.

This finding raises questions about how well any of these measures does at capturing what is intended, and which approach is most appropriate when designing or making decisions about a development. If "trip length" is the built environment-dependent characteristic designs hope to modify, then it would seem to make sense that decisions should be based on actual trip lengths between origins and destinations, rather than on network-based measures which are only expected to produce shorter trips. On the other hand, since developments change over time, it may make more sense to develop the network with intrinsically the best ability to support shorter trip lengths, regardless of where and how origins and destinations will be initially distributed at build.

Another highlighted by these results is that ranking itself is a very coarse means of comparison which is insensitive to the degree of difference between models. As a consequence, very slight changes in design can change the rankings between models that have, for all practical purposes, more or less the exact same characteristics (e.g., there may only be a 10' difference in trip lengths between the model ranked 4th and 5th, a ranking which could be reversed with the curving of an otherwise straight road in the better model). Where there are sharp differences in a given characteristic between models, this becomes less of a problem, which likely explains why the rankings for the Loop and Cul-de-Sac model (which was often "the worst by far") were fairly consistent compared to those of the other four (see Appendix O).

In light of these problems, a more refined scoring system (rather than a ranking system) may be preferable for comparing between models, but such attempt would be challenged by the need to create appropriate sizes of classes upon which to assign scores. If assessing a large number of developments, one alternative would be to use Z-scores to evaluate neighbourhoods based on how they fair on different measures relative to the others under study (regardless of what the total range of a given variable may be). This was the approach used by Frank et al. (2009). While it solves the problem of having to create appropriate class sizes for scoring, it is limited by a need for multiple neighbourhoods to be included in the assessment (so to have enough other neighbourhoods to create a mean to meaningfully compare Z-scores against) and by its inability to compare results with neighbourhoods not included in the initial study (because had the other neighbourhoods been included, they may have affected the Z-scores of that initial set).

PART III: ADDITIONAL RESULTS IMPORTANT TO DECISION MAKERS

Simply knowing which model best supports active transportation is, in many cases, inadequate to see those models translated into real-world neighbourhoods, where developers must balance municipal mandate against market demands and the need for profits. At the same time, municipalities also find themselves weighing active transportation goals against other environmental concerns (e.g. stormwater management), restricted budgets, and a need to maintain a certain level of service for motorized transport users.

The following section provides the results for land use, density and network efficiency measures that were calculated for the GIS models in order to support municipal planners, councilors and developers in their decision making. With the results of the previous two parts of this chapter, these results help to address the fifth objective of this study, which was "to make recommendations regarding the use of these models in planning new neighbourhoods which are informed by the results concerning their active transportation potential and a comparison of additional built environment characteristics known to be of importance to the development community".

Land Use

Beyond the amount of land used for parks, residential and "other" uses (see p. 150 in Part I of this chapter), the amount of land used for the transportation network and the amount of land remaining for building are of importance to developers and municipalities because they can determine the costs and opportunities associated with different models of neighbourhood design. Four additional land use variables are therefore include here:

1) Buildable area, which determines the amount of land available for residential or other non-network uses (and thus, by extension, potential density, given a preferred housing type and lot size)

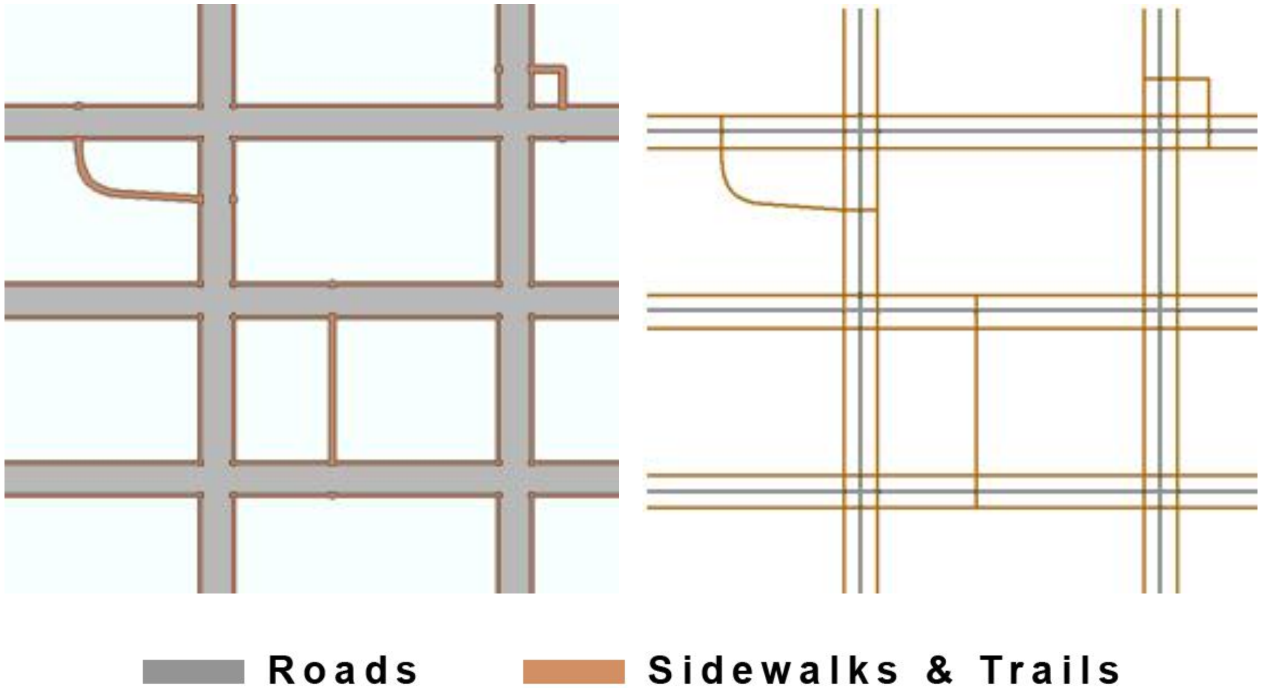
2) Road network area, which determines the amount of land which must be turned into road (and maintained and serviced accordingly)

3) Other active transportation network area (made up of sidewalks and trails), which, like road network area, represents an additional construction, maintenance and servicing cost for developers and municipalities

4) Total paved network area, which is important to municipalities for stormwater management and groundwater recharge

Unlike the earlier coverage measurements which were based on the length of network lines, network area calculations assumed that only one type of path type can exist in a given space, and as such, trails and sidewalks areas were treated as discontinuous at roads (see Fig. 58 below for a comparison). A hierarchy was used to determine which path was continuous where overlapping occurred (see p. 468 of Appendix F for more details).

Fig. 58: Network area vs. coverage



Buffered network polygons used for calculating network area (trails and sidewalks disappear at roads)

Line network used for calculating coverage (trails and sidewalks, shown in brown, treated as continuous across roads, shown in blue)

The results for these four additional "land use" measures are presented in Table 65 below. There were some important differences between the models. When it came to the results for buildable area, it became apparent that the models could be split into three groups by network type – "Grid-based" (Grid and New Urbanist), with buildable areas around 78%, "Partially Disconnected" (Loop and Cul-de-Sac and the Fused Grid), with buildable areas around 82%, and "Disconnected" (Greenway) with a buildable area of almost 87%. These differences in buildable area were the result of differences in land dedicated to road networks in the models (which varied by up to 8.7%). Thus, it can be seen that the less connected the road network, the greater the land available for building.

That said, the results show less of a difference between some models than has been found by other researchers. For instance, IBI (1995) found that in some cases Grid networks could have up to 40%

more land dedicated to roads than a Loop and Cul-de-Sac neighbourhood. Here, the difference was only an additional 4.6% over the amount of land used in the Grid.

Similarly, the results show less of the total land area going towards roads than has been found or suggested by other researchers. For instance, Southworth and Ben-Joseph (2003, p. 6) have suggested that streets can make up to 30% the total land in a neighbourhood, while IBI (1995) looking at Greater Toroto Areas found a maximum of 34.9%. Here, the maximum was only 22.0%.

Table 65: Other land use results

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Buildable area as a percent of model area *(model area – road network area)*	78.0%	81.6%	81.9%	78.1%	86.7%
Road network area[1]	22.0%	18.4%	18.1%	21.9%	13.3%
Other active transportation network area[2] (sidewalk + trails)	6.7%	5.8%	6.2%	7.8%	5.7%
Total paved network area[3] (road network area + other active transportation network area)	28.7%	24.2%	24.3%	29.7%	19.0%

[1]: All roads including alleyways and bike lanes, but not driveways. Results somewhat underestimate total road network area in a typical neighbourhood, as turn lanes were not included in the designs.

[2]: Does not include alleyways, driveways, "front door" connections or bike lanes.

[3]: Includes roads, alleyways, trails and sidewalks, but does not take into account buildings or driveways.

There was less of a range in how much land was dedicated to sidewalks and trails ("Other Active Transportation Network Area") between the models, with the Greenway having the least (5.7%) and New Urbanist the most (7.8%). It's interesting to note that even though the Greenway and Loop and Cul-de-Sac models have very similar amounts of land dedicated to sidewalks and trails (5.7% and 5.8% respectively – a difference of only 0.1%), they differed quite substantially when it came to trip lengths and directness ratios (see Part II of this chapter). This suggests a difference in the efficiency of their networks, an idea which is explored in more detail on p. 225.

Looking at total paved network area, there was a 10.7% difference between the model with the least (Greenway at 19.0%) and the model with the most (New Urbanist with 29.7%). Models with less paved areas are desirable from a stormwater management perspective, because they reduce (potentially polluted) stormwater runoff and increase groundwater recharge (Brabec et al., 2002; Gaffield et al., 2003).

Overall, it can be seen that the Greenway model required the least amount of land for transportation networks by far. However, it is important to recognize that even though a model may offer significant benefits in buildable area and reduced transportation infrastructure, this is moot if the network cannot support its motorized traffic. Other authors (see especially Crane, 1996b and 2000) have also noted this problem. While such an assessment is beyond the scope of this study, it would be extremely valuable to know how each of the models fares in terms of its ability to address the need for motorized traffic, and what density each could theoretically support as a result.

Density

When it comes to density, for developers, being able to sell more units at less cost (e.g., on less land) increases the potential for profit (CMHC, 2011). It is surprising, then, that even with so fewer units than the other four models (see Table 66 below), the Loop and Cul-de-Sac model has been so successful. This likely points to market forces, wherein people frequently demand larger lots, particularly where land is cheap (Myers and Gearin, 2001; Glaeser and Kahn, 2003). For municipalities, density is an important determinant of the viability of public transit as well as the cost to service each unit (see section on infrastructure efficiency on p. 223).

While gross density was used for the evaluation of overall active transportation potential, net density is another important variable that decision makers consider, and better reflects how densely packed homes actually are within residential areas (something which cannot be determined by gross density only). While higher net densities typically lead to reduced lot sizes and/or more multi-unit buildings, they also make the dedication of more land to parks and other uses more economically viable for a developer, who can then make the profit they need from a greater number of housing units on less land (Moore, 2010). This held true in this study, where even though the Grid had the highest gross density, the New Urbanist model had the highest net density, showing that although it had fewer units overall, it was able to fit them into a smaller amount of space and thus freed up more land for parks and other uses (see Table 66 below and Chapter 4 for differences in park space between the models). (The economic viability of these GIS model is a question for another study, but certainly there has been enough success in selling New Urbanist developments today to indicate the feasibility of the model in general).

Table 66: Gross vs. net densities between models

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Gross density (d.u./gross acre)	9.3	6.0	7.3	8.8	6.4
Net density (d.u./net residential acre)	14.3	9.1	11.2	17.9	9.9

It is well established that people walk and bike less once they own a car (Kitamura et al. 1997; Crane and Crepeau, 1998; O'Regan and Quigley, 1998; Hawkins, 2007). If this is the case, then any attempt to increase walking and biking must ensure that car ownership is not necessary, which, in a country like Canada with early winter sunsets (leaving pedestrians and cyclists in the dark), colder weather and potentially dangerous path conditions means having access to public transit in winter is a must – making density essential for any attempts to increase walking and biking rates. Consistent with this, Wynne (1992) found that people are more likely to use active modes if public transportation is available (Wynne, 1992), so the question for municipalities, then, is "how much density is necessary to support a successful public transit system?"

Newman and Kenworthy (2006) have suggested that "long-term data from cities around the world appear to show that there is a fundamental threshold of urban intensity (residents and jobs) of around 35 per hectare where automobile dependence is significantly reduced." This translates to a density of 14.2 people and jobs per acre. Similarly, Pickrell (1999) found that density under 20 people per hectare (8.1 per acre) tended to have only extremely small effects on travel behavior, while densities at or above 40 people per hectare (16.2 per acre) were need to cause signficiant increases in transit use.

In 2006, the average household size in Canada was 2.5 people per household (Statistics Canada, 2010b). Using this number, an approximate residential population density can be generated for each of the five models. These estimates are provided in Table 67 below, although it is noted that higher density models would, in actuality, likely average slightly below the 2.5 people per household, since people in higher density areas tend to have smaller households (Dunphy and Fisher, 1996; Sun et al., 1998).

Table 67: Theoretical residential population densities

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Gross residential population density per acre (estimate)	23.3	15.0	18.3	22.0	16.0

(Based on an average 2.5 persons per household, as per the 2006 Canadian Census)

Surprisingly, it appears that all five models would produce more than the minimum density (14.2 people and jobs/acre) that Newman and Kenworthy suggest is needed to reduce car use (although the Loop and Cul-de-Sac just barely meets their proposed minimum). When one considers that these are residential population densities only and do not include additional employment densities on top of them (which would count towards the target), all five models should more than comfortably fall into this range. However, given that consensus from most quarters is that there is still too much dependence on automobiles in cities, it seems more likely that either Newman and Kenworthy's proposed 35 people and jobs / hectare is too low, or that the case study densities the Loop and Cul-de-Sac model was based on may be misrepresentative of the majority of neighbourhoods built in this style. More research would be needed to determine which is the case. Looking at Pickrell's proposal that density needs to be at or above 16.2 / acre to cause a significant shift towards sustainable transportation (transit), it can be seen that both the Loop and Cul-de-Sac and Greenway models would be insufficient, while the Grid, Fused Grid, and New Urbanist models should be able to generate a modal shift.

In addition to asking "how much density is enough?", we can also ask "how much density is possible?" In this study, gross and net densities were prescribed for each model, based on existing case studies and design guidelines. Although we are used to seeing high density development in Grids and low density development in Loop and Cul-de-Sac neighbourhoods, density does not necessarily have to be tied to network layout (Southworth and Ben-Joseph, 2003) or be constrained by precedent or design guidelines. For example, although the Fused Grid model used in this study contained no multi-unit residential buildings (as per CMHC, 2000), it is easy to envision a neighbourhood where these would be found, perhaps near the meetings of collectors and collectors or collectors and arterials, as is seen in many Loop and Cul-de-Sac neighbourhoods today.

Consequently, a useful value to know would be one which reflects the *potential* for density resulting from network layout (and its resulting buildable area) alone rather than the type of model or what is already seen in case study neighbourhoods.

To do so, a "Gross Unit Potential for Single-Detached Homes" was calculated by taking the total buildable area for each model and dividing it by a standard single-detached home lot size (50' x 115'). This gives the number of homes each model could support if they all adopted the same net residential density (i.e., lot size per unit) and used all buildable land for single-family homes . This was then converted into a gross density measure to give the gross density that would be achieved if all buildable land was put into single-detached homes of a standard size (see Table 68 below).

Table 68: Gross unit & gross density potential for single-detached homes

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Gross unit potential for single-detached homes[1] (number of single-detached units in model possible when using a standard lot size)	945.5	989.2	993.3	946.5	1,050.9
Gross density potential for single-detached homes [2] (average number of single-detached units per acre possible when using a standard lot size)	5.9	6.2	6.2	5.9	6.6

Although the true gross density varied by 3.3 d.u./acre between the models (see Table 66 on p. 220), the gross density potential between them only varied by 0.7 d.u./acre. This shows that while density is, in part, dependent on network layout, *the greatest differences in density are actually the result of the design philosophies driving the models* (for instance, in the Loop and Cul-de-Sac model, the preference for expansive "quasi-rural" living or the more compact urban feel of New Urbanist neighbourhoods). This finding supports Southworth and Ben-Joseph's (2003) argument that densities do not necessarily need to be tied to a given network layout, and points to an opportunity for greater synthesis between models (matching good layouts with higher densities and land use mix), something which will be explored in greater detail in the "Synthesis" section on p. 246.

Infrastructure Efficiency

Infrastructure efficiency is important to both developers and municipalities. Here, it is conceived of as the total amount of land dedicated to roads, sidewalks and parks required per residential unit, consistent with the work of Filion and Hammond (2003). Trails have not been included because they only occurred in park space in the models and thus would result in double-counting of park land. For municipalities, less land per unit is likely always preferable, but developers must weigh increased land requirements against the potential for increased profits that may go with them (i.e. less efficient, low density models may still be easier to sell and more profitable on the whole).

Looking at the results in Table 69 below, it can be seen that the Grid was the most efficient model in terms of the amount of infrastructure land required per residential unit (1,553.2 sq. ft. per dwelling unit) while the Loop and Cul-de-Sac was the worst (2,567.8 sq. ft. / dwelling unit).

Table 69: Infrastructure efficiency

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Roads (sq. ft.) (including alleys and bike lanes, but not including driveways)	1,533,239.7	1,281,901.8	1,258,411.7	1,526,983.5	926,931.7
Sidewalks (sq. ft.)	435,886.3	347,073.5	393,899.9	428,119.9	0.0
Parks (sq. ft.)	348,213.6	836,100.1	743,894.1	1,488,785.5	1,130,072.9
Total (sq. ft.)	2,317,339.6	2,465,075.4	2,396,205.7	3,443,888.9	2,057,004.6
Per dwelling unit (sq. ft.)	1,553.2	2,567.8	2,044.5	2,459.9	2,016.7

Looking more closely at Table 69, it appears that most of the efficiency of the Grid model stems from its small total area dedicated to parks, less than a quarter of what is available in the model with the most (the New Urbanist). If park space was not seen as being a major cost to a developer or municipality (for instance, if the open space land was undevelopable to begin with), or if the loss of park space was not seen as a desirable way to improve efficiency, it may make more sense to look at infrastructure efficiency solely in terms of the amount of land dedicated to all elements of the transportation network which would require paving and maintenance (Table 70 below). This perspective is also more useful for assessing efficiency with regards to stormwater management, as parks in that case become a net benefit rather than a cost (although a measure specifically targeted towards stormwater management would ideally also include driveways and building footprints). From this perspective, the Greenway model was the most efficient (1,296.4 sq. ft. of paved network area per unit), while the Loop and Cul-de-Sac model remained the worst (1,753.6 sq. ft.).

Table 70: Infrastructure efficiency by paved area only

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Total paved network area[1] (sq. ft.)	2,001,372.7	1,683,438.1	1,691,979.6	2,070,119.1	1,322,347.0
Per dwelling unit (sq. ft.)	1,341.4	1,753.6	1,443.7	1,478.7	1,296.4

[1]: Includes roads, alleys, bike lanes, sidewalks and trails but not driveways

Note that the results in Tables 69 and 70 above do not take into account the differences in the amount of land dedicated to "other" land uses between models, which would affect the total number of dwelling units present. While this approach is consistent with that of other researchers (CMHC, 2000; Filion and Hammond, 2003), some models may end up having higher per dwelling unit infrastructure requirements just because they contain more "other" land use land, which would still be serviced but which would be rolled into the infrastructure requirements per dwelling unit using the above measures. An alternate way to calculate efficiency that addresses both these problems be to look at infrastructure requirements relative to total development land available: Table 71 provides results from this perspective.

Table 71: Infrastructure efficiency by model area

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Infrastructure area per acre of model space (sq. ft./acre)	14,483.4	15,406.7	14,976.3	21,524.3	12,856.3
Paved network area per acre of model space (sq. ft./acre)	12,508.6	10,521.5	10,574.9	12,938.2	8,264.7

These results show that on a per acre basis the New Urbanist model required both the most infrastructure and total paved area, and the Greenway the least.

Network Efficiency

One goal of network design is to achieve the best possible travel patterns for the lowest cost, which, for a developer, depends on the amount of land dedicated to that network. As such, it is useful to have a measure of the efficiency of a network – that is, what the value of a travel variable (such as trip distance) is relative to the amount of land required to achieve it.

In this study, "network efficiency" is conceived as a measure of how efficient the models were at producing shorter trip lengths relative to the amount of land they required in order to do so. For instance, it is easy to imagine that adding more trails to a Loop and Cul-de-Sac neighbourhood could do little to improve trip lengths if sidewalks those trails tended to be loop trails which failed to connect roads together. Such network elements would still cost the same amount for a developer to put in, but the neighbourhood receives less value for them (at least insofar as they relate to trip lengths).

Tables 73 and 73 below describe the network efficiency of the models for pedestrians and cyclists in terms oftheir relative directness ratios and corresponding changes in network areas, as compared to the model with the worst directness ratios (the Loop and Cul-de-Sac model).

Table 72: Pedestrian network efficiency

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrian directness ratio (PDR)[1]	1.30	1.79	1.34	1.36	1.48
Area of sidewalks + trails (in sq. ft)[2]	468,133.0	401,536.3	433,567.9	543,135.5	395,415.3
% Improvement in PDR compared to model with worst PDR (Loop and Cul-de-Sac)	37.7%	0.0%	33.6%	31.6%	20.9%
% Change in path area	16.6%	0.0%	8.0%	35.3%	-1.5%

[1]: Directness ratios calculated using the Euclidean and "typical trip" (equally weighted trips to edge and centre) shortest path distance for all dwelling units in each model
[2]: Sidewalks and trails treated as discontinuous at roads

Several key observations can be made from the above table. Although there are three models that have relatively similar PDRs (Grid, Fused Grid, and New Urbanist), they varied greatly in terms of how much pedestrian network area they require to achieve them. For instance, the New Urbanist model required a 35.3% increase in network area to go from the Loop and Cul-de-Sac's PDR of 1.79 down to its

PDR of 1.36, but the Fused Grid required only a 8.0% increase in network to achieve an even better PDR of 1.34, meaning that is provides the more efficient network. The Grid model, with the best PDR of all (1.30) required a 16.6% increase in network area over the Loop and Cul-de-Sac. The Greenway model, despite having only a moderately improved PDR over the Loop and Cul-de-Sac model (going from 1.79 down to 1.48), managed to do so while actually reducing both total path length and the amount of land dedicated to the network. This result demonstrates that good network layout can enhance active transportation potential while still reducing the total amount of land dedicated to transportation infrastructure.

While it was possible to calculate cyclist network efficiency, two caveats are needed. First, because cyclists could use roads in all models, it was possible to have a very small amount of land dedicated to bike lanes or trails and still have an excellent directness ratio because of the land dedicated to roads. (Thus, the results would seem to suggest that the best way to improve the cost effectiveness of neighbourhoods would be to eliminate bike lanes, but this would obviously not be an acceptable solution because of its impact on trip quality). To partially address this problem, a second set of results (the bottom half of Table 73 below) was included to count land used by cyclists traveling in mixed traffic conditions as well, in which case, all the road area (rather than just the portion dedicated to bike lanes) is considered. However, since roads may be wider in some models to accommodate greater car use (rather than bicycle use), increases in path area here may not actually be aimed at serving "cyclist network efficiency" per se, making these results equally troublesome.

A second problem with the basic cyclist network efficiency measure (from a development perspective) is that when network area is calculated as "area of bike lane + area of trail", it fails to take into account the potential for eliminating the need for sidewalks. This is the case in the Greenway model, which comes out requiring much more land for trails but which receives no credit for reducing the amount of land needed for sidewalks (the comparison of total land required for the active transportation networks in the models given on p. 218 does a better job of reflecting this aspect of the models). Although the relative costs and benefit of putting land into bike lanes, sidewalks or trails could not be assessed in this study, future research to quantify these costs and benefits may be helpful to decision makers in choosing one model over another.

Thus, while these results are provided as an initial foray into the concept of cyclist network efficiency, more work must be done to develop a more defensible measure to be used in decision making processes.

Table 73: Cyclist network efficiency

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Cyclist directness ratio (CDR)[1]	1.33	1.83	1.35	1.38	1.30
Considering Bike Lanes and Trails Only					
Area of bike lanes + trails (in sq. ft.)	30,308.2	271,533.4	197,295.4	372,100.1	393,126.0
% Improvement in CDR compared to worst model (Loop and Cul-de-Sac)	27.3%	0.0%	26.2%	24.6%	29.0%
% Change in path area	-88.8%	0.0%	-27.3%	37.0%	44.8%
Considering All Roads and Trails					
Area of all roads + trails (in sq. ft.)	1,563,547.9	1,553,435.2	1,455,707.1	1,899,083.6	1,320,057.7
% Improvement in CDR compared to worst model (Loop and Cul-de-Sac)	27.3%	0.0%	26.2%	24.6%	29.0%
% Change in path area	0.7%	0.0%	-6.3%	22.3%	-15.0%

[1]: Calculated using equally weighted trips to edge and centre for all dwelling units in the model

While all the models provided a complete set of infrastructure for pedestrians, there was much more variability in how much was developed for cyclists. As such, there was a much wider range in the efficiency results for this mode when considering only bike lanes and trails.

Looking at the results, the Grid model was able to dramatically improve the Cyclist Directness Ratio (from 1.83 down to 1.33, the second best of the five models), while dropping the amount of land dedicated to bikes by 88.8%. However, this is largely due to the lack of cyclist infrastructure (no bike lanes) while enabling bikes to travel on a highly connected mixed-traffic road network. Similar to the findings for the pedestrian network efficiency, the Fused Grid was able to again provide substantial improvements on the CDR (by 26.2%) while reducing the amount of land required to obtain these values (by 27.3%). The New Urbanist model offered slightly less gains on the CDR (down by 24.6%), but required a 37.0% increase in infrastructure area to do so. Because of the differences in infrastructure provided, these results should only be considered in conjunction with the coverage and modal separation results in Part I of this chapter which provide a network-based assessment of the coverage of each type of pathway available.

As previously discussed, the results for Greenway are a bit more difficult to interpret here, as the values do not reflect the land saved in replacing sidewalks with trails when looking at bike network elements alone. As such, even though the Greenway model dedicates the least total amount of land to ATN infrastructure (see p. 218), to achieve a 29.0% gain in directness ratios for cyclists, it required an additional 44.8% of land for trails over the Loop and Cul-de-Sac model.

If all land dedicated to roads is considered instead of just that which is dedicated to bike lanes, then the Grid requires almost exactly the same amount of land as used in the Loop and Cul-de-Sac model, instead of the 88.8% less that results if only bike lanes and trails are considered. With roads in the picture, the Greenway now offers the best improvements on CDR (a 29.0% improvement over the Loop and Cul-de-Sac model) with the least amount of land (15.0% less than the Loop and Cul-de-Sac). In this scenario, the Fused Grid was also able to provide an improvement on the CDR (26.2%) with less land (-6.3%) – the only instance a model other than the Greenway was able to do so.

PART IV: SUMMARY OF RESULTS

Most past research into neighbourhood models has focused on either several variables for a few models and/or case studies (see, for instance, Southworth and Owens, 1993; Southworth, 1997; Filion and Hammond, 2003; Lee and Ahn, 2003) or a small number of variables for a large number of case studies (Peponis et al., 2007). As a result, there has been a lack of research that provides a comprehensive comparison of the available models and how they relate to specific correlates. This study has addressed this problem by better illustrating how five of the most important neighbourhood models differ on a number of key characteristics, particularly with regards to the approach they take to enhancing walk- and/or bikeability. These findings are summarized in Table 74 below, which builds upon the initial summary created for the literature review (found in Appendix D). Where a model had only a moderate value for a given characteristic (e.g., medium levels of land use mix in the Fused Grid and Greenway neighbourhoods), it was listed as neither a strength nor a drawback. Characteristics which are known to be true for the model based on the literature review, but which were not explicitly assessed in this study, have been marked in italics.

Table 74: Summary of model strengths and drawbacks for active modes

	Strengths	**Drawbacks**
Grid	High land use mix High density High legibility High connectivity High infrastructure efficiency	Low amount of park space Low continuity (road & driveways) High amount of paved area
Loop & Cul-de-Sac	High amount of park space High continuity (Road/Road, ATN/Road) *(Reduction of traffic on local roads)*	Low land use mix Low density Low legibility Low connectivity Low continuity (ATN/Driveway) Low infrastructure efficiency *(Increased traffic on higher-order roads)*
Fused Grid	High differential connectivity High network efficiency *(Reduction of traffic on local roads)*	Low legibility[1] *(Increased traffic on higher-order roads)*
New Urbanist	High land use mix High amount of park space High density High connectivity High continuity (from driveways) High legibility	Low amount of buildable area High amount of paved area Low continuity (ATN/road, road/road) Low infrastructure efficiency Low network efficiency
Greenway	High amount of buildable area High amount of park space Low amount of paved area High differential connectivity High continuity (all types) Complete modal separation High legibility (walking/biking) High network efficiency *(Reduction of traffic on local roads)*	Low density Low network coverage Low connectivity (intersection density) Loss of roads as spacers between building fronts *(Increased traffic on higher-order roads)* *(Fewer "eyes on the street")*

[1] *In terms of the number of direction changes, rather than predictability*

The findings strongly echo those of Filion and Hammond (2003), who in their study of two Grid and two Loop and Cul-de-Sac neighbourhoods concluded that each model tries to achieve the goal of increased active transportation in its own way, and that each contains its own shortcomings. A model strong in one area is often weak in another. Here, it was found that in some cases this was because of a structural relationship between two variables (such as connectivity and continuity) wherein an increase in one usually resulted in a decrease in the other, and in others because the network characteristic in question was simply not a focus of the model (such as legibility in the Loop and Cul-de-Sac model).

What constitutes the "best" model depends on the goals to be achieved. However, the extent to which any given factor supports walking and biking varies with the population in question – for instance, in neighbourhoods with a high number of children, improvements in continuity and safety may create the greatest increase in walking, while in a community predominantly made up of young professionals shorter trip distances may offer the best gains. This, then, is a problem for planners, who can plan neighbourhoods but not the people who live in them. What makes the best model also depends on which mode (walking or biking) is being designed for – as shown in the results, some networks were better for biking, while others are better for walking (see p. 241 for more discussion on design for walking vs. biking).

However, it is clear that each of the three alternative models (New Urbanist, Fused Grid and Greenway) make considerable improvements over the Loop and Cul-de-Sac model and, to a lesser extent, the Grid on almost all fronts. This means that planners should, by the use of these alternative models, be able to increase walking and biking in residential neighbourhoods. The question really, then, is which model to select in any given scenario. Models could be selected based on those characteristics that are known to be most strongly correlated with travel in broad studies of the population (e.g., trip length), or they could be tailored to specific groups that may have preferences (even strong preferences) different from "the average" (for instance, the higher value placed on modal separation by/for children).

It is undoubtedly easier to increase walking and biking by meeting existing latent demand for more walkable and bikeable neighbourhoods than it is to try and create new demand. If planners are to determine which types of neighbourhoods are needed for their area, then the question must become what latent demand already exists (would people bike more if they felt safer, or if trips were shorter?) and what types of neighbourhoods need to be built in order to meet it. Neighbourhoods that do not serve to address existing latent demand should not be built. Similarly, it would make sense to design neighbourhoods to support as many potential users as possible, rather than incorporating elements (such as bike lanes) which can only be comfortably used by a narrow segment of the population, an idea effectively embodied in the concept of universal design (Center for Universal Design, 1997).

Ultimately, it may be that there is no universal “best” model, but it is clear that better designs are possible on any given front. Lessons from existing models can provide insights into how best to go about designing new models, and important opportunities for synthesis may exist.

CHAPTER 6: RESEARCH CONCLUSIONS

This study was successful in fulfilling the five research objectives, which were to:

1. Identify the characteristics known to be correlated with active transportation use

2. Identify and describe neighbourhood models aimed at facilitating active transportation and create a GIS-based model neighbourhood of each

3. Quantitatively and qualitatively assess the extent to which the built environment characteristics known to be correlated with active transportation use are incorporated (or not incorporated) into the models under consideration

4. Compare these models in terms of their potential to facilitate active transportation and identify the model most likely to be successful in this regard

5. Make recommendations regarding the use of these models in planning new neighbourhoods which are informed by the results concerning their active transportation potential and a comparison of additional built environment characteristics known to be of importance to the development community

This research has helped to comprehensively describe neighbourhood models and network layouts which may not have been adequately considered to date. In addition to substantive findings with regards to the ability of the models to support walking and biking, this study also developed new means of measuring understudied concepts such as continuity and modal separation and developed a GIS-based methodology which can be used in future studies. It has given a compelling demonstration of the power of neighbourhood models in general and the use of GIS-based models in particular to design more walkable and bikeable neighbourhoods.

Key Findings – Neighbourhood Models

In response to the research question "How do neighbourhood models compare in terms of the characteristics known to affect active transportation rates, and which model is most likely to be able to facilitate active transportation as a result?" the findings of this study with regards to five the models were largely consistent with those of Filion and Hammond (2003), who noted in their study of Grid and Loop and Cul-de-Sac neighbourhoods that designs varied in the approach they used to try achieve greater walkability. Some models provided high connectivity, while others provided high continuity, modal separation, legibility, density, etc. What the "best" model is depends on the mode and user being designed for. What is important, however, is that alternative models consistently outperformed the traditional Grid and Loop and Cul-de-Sac models in terms of their walk- and bikeability.

For dedicated network ***coverage***, the best model for pedestrians was the Grid and the best model for cyclists was the Greenway.

For network-based ***connectivity***, the best model for pedestrians was the New Urbanist and for cyclists, the Greenway (as measured by the average ranks for intersection density, metric reach and differential connectivity). For trip-based connectivity, the best model for pedestrians was the Grid and the best model for cyclists was the Greenway (measured using directness ratios). High connectivity models would likely do the best job at increasing walking and biking for those to whom distance is the most important concern when selecting a travel mode.

For network-based ***continuity***, the best model was the Greenway for both pedestrians and cyclists (as measured by the average ranks for POC density and ATN-only:regular road intersection ratio). For trip-based continuity, the best model was also the Greenway for both active modes (measured using average of ATN/Driveway and ATN/Road POCs encountered ranks for pedestrians and average of Road/Road and ATN/Road ranks for cyclists). High continuity (along with modal separation) would likely be one of the most important of these built environment measures for those to whom perceived safety is the most important factor – e.g., children, parents with children, and the elderly.

For network-based and trip-based ***modal separation*** (in terms of the proportion of network offering complete separation from cars) for pedestrians as well as cyclists the best model was the

Greenway. Like continuity, modal separation is likely of high importance to those for whom travel safety is a primary concern.

For ***legibility***, the best model for both pedestrians and cyclists was the Greenway (as measured by metric reach). While the impacts of legibility on walking and biking are less clear than those of continuity and connectivity, high legibility would likely be of greatest benefit to travelers who are trying to navigate a neighbourhood for the first time or to those with cognitive disabilities which may make navigation more difficult.

From a development standpoint, the best model for ***buildable area*** (high) and ***road network area*** (low) was the Greenway model. The best model for ***gross density*** was the Grid, but the best for ***gross density potential*** was the Greenway. The best models for ***land use mix*** were the Grid and the New Urbanist.

Looking at the above results, it is clear that the Greenway's network outperformed the other four model in almost all cases, with the exception of connectivity. Given the dominance of connectivity as the main variable of interest in most studies (often to the exclusion of others) and the much greater level of research dedicated to walking over biking, it is not surprising that the New Urbanist model (with its grid-based road network) has managed to become so popular. However, it's clear that the Greenway model merits more serious consideration, especially where a better biking environment is a main goal or where continuity and modal separation are likely to be as great a concern as trip distances to area residents.

The results also conclusively show that the Loop and Cul-de-Sac model, which consistently placed last among the models, has no place in new developments that aim to be walkable or bikeable, and it should be replaced in all such situations by a better model. Of the models considered here, the New Urbanist and Greenway models offered the greatest improvements in terms of walkability and bikeability, but if these are seen as too dramatically different from more conventional neighbourhoods, the Fused Grid model bears much similarity to the Loop and Cul-de-Sac while improving considerably upon its design.

Some results were unexpected. Although connectivity and trip lengths dominate much of the debate on design for active modes, the greatest differences between the models were actually in other attributes such as continuity, modal separation and the total coverage of trails. Differential connectivity was found to be a de facto part of all models even where not a part of the explicit design philosophy, and in fact, it was so common for there to be differences in network variables between modes within a given model that it may be appropriate to refer more broadly to the idea of “differential design” when describing and analyzing various neighbourhood designs.

The results showed that both the transportation network and the decisions made about how many homes and destinations are placed on it and how they are distributed across it have an impact on trip lengths and other characteristics. They also showed-that the density of dwelling units in a neighbourhood was more dependent on the overall philosophy of the model than the amount of buildable area left after the road network was constructed, which points to an opportunity for greater synthesis *between* models, in which any given network layout could theoretically be used in conjunction with higher, strategically located densities and land use mix. This, then, makes the choice of network layout the most fundamental aspect of neighbourhood design.

Key Findings – Methods

The development and analysis of the GIS-based models provided an opportunity to explore some of the challenges that arise from different types of model features (such as off-set networks and alleys) and trying to accurately represent active transportation networks in space. In particular, the following findings may have important bearings on future research:

1) Rankings varied between models depending on what measure was used for any given network characteristic, indicating that how models compare within a study is strongly dependent on the measures chosen.

2) Frame choice can not only affect results, but can systematically skew results in favour of one mode over another .

3) Assuming higher residential densities are purposely located near destinations, using lot-based rather than dwelling-unit trip-based measures can skew trip length results in favour of models which use low-rise buildings (such as triplex, duplex and row houses) rather than high-rise buildings to achieve higher densities.

4) The network characteristics of active transportation networks and motorized transportation networks can be extremely different, and the use of roads as proxies for sidewalks and trails can mask many of the benefits alternative models have to offer.

Important Limitations

Conclusions about the superiority of a model for any given characteristic or for its active transportation potential as a whole were based off rank data. While rank data is useful for stating whether one thing is better or worse than another, it does not quantify the extent of differences between values, which may be inconsistent between the different items ranked, and also between different measures of the same network characteristic (see p. 212). Furthermore, the weightings used to assess overall active transportation potential, while driven by the idea of the “3Ds” known to support active transportation, are still largely arbitrary. It is hoped that as research into walking and biking continues, a greater understanding of the relative importance of each of these three variables will be achieved, but in the absence of such data, it is up to individual researchers to use the weightings that seem the most appropriate. The inclusion of pre-weighted data and ranks in this study will allow other researchers or planning practitioners to apply the weights they feel are most appropriate, should they differ from those used in this study.

Contribution to the Literature

The study has contributed to the literature by:

- Assessing the five study models for their ability to support active transportation using a consistent and relatively comprehensive methodology.

- Providing additional reflection on the different models based on the literature review, model-building experience and subsequent analysis which may assist in further refinement of these designs in support of walking and biking.

- Proving that the differences in densities (and thus potential for land use mix) between the models are more the result of a model's philosophy concerning them than a necessity driven by choice of road network and the buildable area it leaves, thus opening the door for greater synthesis between designs.

- Providing a clearer conceptualization of several network-related variables which are often used interchangeably in the literature: coverage, completeness, continuity, and modal separation.

- Developing new GIS-based methods to assess continuity (points of conflict) and modal separation within neighbourhoods which, despite being the central to two of the models (the New Urbanist and Greenway) and being extremely important to many users (particularly the young, women and elderly) are almost never measured.

- Demonstrating that it is not only possible to assess the active transportation network as separate from road network, but that significant differences can exist in their network characteristics, and that the use of motorized (i.e. road) transportation networks as proxies for active transportation networks can obscure the benefits created through the use of alternative models, an effect that is particularly pronounced where ATNs and MTNs are not coincident (as in the Greenway Model).

- Revealing the implications of using double-line vs. single line feature classes to represent network pathways on different network measures, as well as some of the potential effects of incorporating driveways into GIS models.

- Identifying potential weaknesses in morphological analysis methodologies related to the alpha index, intersection density, choice of model frame, the location of origin or destination points, and whether trips are assessed using lot-based or dwelling-unit based approaches.

Contribution to Practice

The results of this study contribute to professional planning practice by:

1) Providing planners and developers grounds on which to justify the use of alternative neighbourhood models.

2) Substantiating the importance of recording and mapping active transportation networks as distinct from their motorized counterparts.

3) Demonstrating the use of GIS-based assessments of neighbourhood designs, which can allow planners to quickly and cost-effectively assess any design's inherent walk- and bikeability *prior* to plan approval, unlike many walkability and bikeability indices which depend on subjective field measures that can only be taken after a neighbourhood is already developed (see Parks and Schofer, 2006). Being able to assess plans prior to approval means that walk- and bikeability can be improved before construction takes place, saving municipalities from the need for costly retrofits later on.

4) Providing planners and municipalities a better sense of what is possible within neighbourhood designs, which could be used to inform the development of design standards (such as connectivity standards) for active transportation networks.

CHAPTER 7: ADDITIONAL OBSERVATIONS & AREAS FOR FUTURE RESEARCH

The following chapter is broken into 4 parts:

- **Part I: Neighbourhood Design** (p. 241 - 250) – This section provides some additional observation and discussion around the overall topic of neighbourhood design, including the extent to which the study models focused on walking vs. biking and how new designs could be created through synthesis, differential design, and/or by drawing from other models around the world.

- **Part II: Methodology** (p. 251 - 258) **–** This section discusses some of the more important methodological challenges encountered over the course this study and how the methodology might be improved upon in future research related to neighbourhood design.

- **Part III: The Alternative Models –Discussion & Opportunities for Improvement** (p. 259 - 277) **-** The results of this study have clearly shown that the three alternative models offer considerable advantages over more traditional models in terms of their potential walk- and bikeability. This section summarizes the findings for these models, discusses some of their more notable strengths and weaknesses, and offers suggestions on how these designs could be improved in the future.

- **Part IV: Other Areas for Future Research** (p. 278 - 279)

PART I: NEIGHBOURHOOD DESIGN

Neighbourhood Design for Cycling vs. Walking

While walking is a more universal form of transportation than biking, biking has more potential to reduce air pollution and carbon emissions because it can act as a substitute mode for a greater proportion of car trips (based on maximum possible trip distance). Since exercise is known to have a dose-benefit relationship with health (Pate et al., 1995; U.S. Department of Health and Human Services, 1996) and biking usually burns more calories than walking (ACE, 2012), these longer trips will also have a greater health benefit. Furthermore, because road networks must be designed to handle peak hour traffic (i.e., rush hour) (CMHC, 2000), the ability of bikes to handle *commuting* trips means that the load on the road network could be lightened, and thus reduce the costs of added road widening, maintenance, etc. Other economic factors are a consideration as well: while it is known that having a high level of land use mix facilitates active transportation, not every neighbourhood can host every type of service, because some businesses must serve a wider area in order to generate the demand they require to be profitable (for instance, most “big box” stores). It is easier to plan for (and to get businesses to buy into) a certain mix of land uses within a typical biking distance than it is to fit all the desired services within an acceptable walking distance. Cycling is also much faster than walking, and in some high-traffic areas can even prove to be faster than motorized modes (Olde Kalter, 2007). Thus, it is clear that biking offers some very substantial benefits over walking as a sustainable transportation mode.

Despite this, the failure to purposefully plan for bicyclists was undoubtedly a shortcoming in all these models. While elements such as land use mix, density, lot setbacks, uninterrupted sidewalks and trails are often discussed in the literature as key features for walking and/or connectivity, little or nothing is said about the design of any of the models in terms of their ability support biking, save for perhaps the occasional mention of a bike lane or “bike way” (see, for instance, CMHC, 2000 p. 47). The common assumption seems to be that if a model is good for walking, it will be good for biking as well, even though the two depend on different network elements (i.e., bike lanes vs. sidewalks) in most models. Krizek and Roland (2005) found that bike planning tends to be ad hoc and case specific: it may be that this is in part because neighbourhood models have provided so little guidance in this regard! It is vitally important, then, that models begin to incorporate planning explicitly for cyclists, who often have different and unique concerns from pedestrians; for instance, effects from on-street parking, bike lane discontinuities, stronger safety fears due to proximity with traffic, etc. (Krizek and Roland, 2005; Southworth, 2005; Heinen et al., 2010).

There are several possible explanations for the lack of planning for cyclists in neighbourhood models, including the fact that bicycling is even less studied than walking as a mode of transportation (Heinen et al., 2010) and that the scale of neighbourhoods may seem too small in light of possible trip distances by bike to be designed to effectively support that mode. For instance, Moudon (1991) noted that urban design theory suggests design is most relevant for “nonmotorized travel” and at small spatial scales, at least relative to the scales at which land use mix and density are typically conceived and measured. Biking, however occurs at what can be described as an intermediate scale, with trips farther than what is commonly walked being possible, and with cars in turn being capable of making much farther trips than are commonly biked. Since biking can provide a good alternative to driving across good portions of most mid-sized cities, larger-scale planning for cyclists is needed (see Ewing and Cervero, 2001 for further discussion on planning at the regional scale). However, the need for larger-scale planning for cyclists does not eliminate the need for planning at smaller scales – if the infrastructure is missing from the doorstep, it may not matter if a larger system is in place. Thus, municipalities must find ways to persuade developers of neighbourhoods to come up with designs which will put in place the pieces of a larger, regional system at the time of development – even if the rest of that system has yet to be built.

Studies that aim to consider both walking and biking are also challenged by these differences in average trip lengths. For instance, in their research into connectivity, both Dill (2004) and Tresidder (2005) chose to use the census tract because it “resembles the probable walking and cycling area for an individual” with a median size of 1.16 sq. miles (3.00 sq. km, or 1.73 x 1.73 km) for the area under study (Dill, 2004). While this may be an appropriate scale for walking, it is far smaller than an area which may be considered bikeable (see discussion on p. 25). Southworth and Owens (1993) recognized the effects of different scales on active transportation behaviours, and recommended that planners and urban designers work at three scales: 1) the street, house and lot, 2) the neighbourhood, and 3) the community. Doing so would more effectively allow researchers to assess walkable and bikeable distances simultaneously (wherein the neighbourhood scale could be used for shorter trips and the community scale for longer ones), and is thus recommended for planners hoping to encourage travel by both these modes.

Part of the problem for both planning researchers and practitioners may be that paying attention to the interests of cyclists can complicate things considerably: when planning for pedestrians, connectivity has become an almost “holy grail” of design, but for cyclists, added intersections can be seen as increasing travel times and the physical effort required to reach a destination (Fajans and Curry, 2001). Similarly, while modal separation for pedestrians is easily achieved within the confines of commonly accepted designs (i.e. sidewalks), providing that same level of separation for cyclists requires a more dramatic rethinking of urban form.

Another possible explanation for this lack of planning for cyclists in neighbourhood models is that it may stem from recommendations such as US Federal Highway Administration’s (1999) that biking facilities such as bike lanes be implemented where the majority of cyclists are “group B” cyclists, which are defined as “casual or new adult and teenage riders who are less able to operate in traffic without provisions for bicycles” (Minnesota Department of Transportation, 1996, p.1(2)). Since models are typically developed without regard to the specific populations that may live in the resultant neighbourhoods, proponents may opt to eliminate any design elements for cyclists, leaving it to those working to develop a new neighbourhood to incorporate on a context specific basis. This problem is seen in recommendations for trails as well. For instance, (Flink et al., 2001, p. 34) recommended that “Trails should be located along corridors that assume maximum use by the *intended user groups*” (emphasis added). However, such an approach, when implemented across a larger urban area, can create several problems:

1) The design is irregular and unpredictable, with the distribution of different cyclists groups in the population leading to a checkerboard of infrastructure types (or lack thereof) across a city’s landscape.

2) The design may end up catering to more experienced cyclists at the cost of those less comfortable with riding in traffic, which may prevent those who do not yet bike from ever becoming regular cyclists in the first place.

3) The design may cater to a current population, but be ill-matched to the people that move into the neighbourhood in ten or twenty years' time.

4) Municipalities may have to do extra work to determine what group of cyclists they "should" be planning for on a development-by-development basis, or risk lacking the necessary background information to even try to implement these sorts of recommendations.

As such, it would make sense for neighbourhood models to be as explicit about how their design aims to support cycling, recognizing that even if one model ultimately proves to be better for biking than another, there are always opportunities for synthesis between them.

To be fair to planners and policy makers, the cycling movement itself has suffered from a divided voice which makes planning for them difficult. On the one hand, there are the vehicular cyclists who want bicycles to be treated as vehicles and allowed to travel with cars on roads, and on the other, the non-vehicular cyclists who require a higher level of modal separation in order to feel comfortable and safe (Pucher et al., 1999; Pucher, 2001). The latter group suffers what could be described as "a silent majority": while walking is a part of every trip (State of Vermont Agency of Transportation, 2002) and a fairly common travel mode in its own right in Canada, biking is optional and the reality is many people never bike, and generally do not become politically active in advocating for more bikeable neighbourhoods. Those who do bike the most (typically vehicular cyclists whom the transportation network can more-or-less already accomodate) end up doing most of the advocating (even though their concerns differ markedly from the other group), presumably because biking is already such an important part of their travel experience (Pucher et al., 1999). However, given that only 1.3% of Canadians bike to work (Statistics Canada, 2008a), it could be argued that it should be the concerns of the other 98.7% that should be paramount when trying to create a modal shift.

The fact that cycling rates are so low is surprising when one considers that the mode is quick, inexpensive, and capable of making relatively long trips. Time and cost are widely held to be the two most important factors in travel decisions. It stands to reason, then, that if people are choosing to walk over bike, that these factors are being superseded by something else. Of those variables known to be associated with walking and biking (see Chapter 2), safety immediately stands out as the most likely variable one could reasonably expect to be considered more important than time and cost when it comes to choosing a travel mode.

If safety is a key factor, then one would expect that populations that are more concerned with safety, such as women, would be less likely to bike (see Abdalla et al., 1997; Byrnes et al., 1999; Corless and Ohland, 1999; Surface Transportation Policy Project, 2002; Campos-Outcalt et al., 2003; Loukaitou-Sieris et al., 2007). Consistent with this hypothesis, we see that biking is more gendered than walking – while approximately equal numbers of men and women walk to work (Statistics Canada, 2008b) many studies have shown that in North America, a far greater number of men bike than women (USDT, 1997; Pucher et al., 1999; Emond et al., 2009). The 2006 Canadian census showed only a 28.3% difference in walking rates between women and men (with 7.7% of women walking and 6.0% of men), while there was a 150% difference in biking rates (with only 0.8% of women biking and 2.0% of men) (Statistics Canada, 2008b). In Europe, on the other hand, approximately an equal proportion of women and men bike, and many researchers attribute this to higher levels of modal separation and a more extensive bicycle infrastructure in those countries (see Tolley, 1997; German Federal Ministry of Transport, 2002; Pucher and Buehler, 2008a, 2008b). This argument is consistent with other research, which has shown that almost all cyclists appreciate dedicated bicycle infrastructure for its ability to create a sense of safety (Antonakos, 1994; Heinen et al., 2010), but that women, younger cyclists and inexperienced cyclists tend to value them more highly (Stinson and Bhat, 2003; Krizek et al., 2004; Stinson and Bhat, 2005; Garrard et al., 2008). Similarly, Dill and Voros (2007) found when surveying random adults in Portland that people often said they would cycle more if more bike paths were available, and if those paths were well connected to useful destinations and easy to reach (see also Dickinson et al.'s 2003 study of British employees for similar results). If safety concerns are what is driving the low cycling rates in Canada, then a renewed focus on modal separation and continuity is warranted in research and municipalities should begin favouring neighbourhood models that offer these in their networks.

In addition to personal safety concerns, convenience and the childcare responsibilities are often cited as reasons to choose not to bike for women (Dickinson et al., 2003; Emond et al., 2009). If women's childcare responsibilities are a deciding factor (i.e., if she needs to take her children with her when she travels), then it is not only how safe a network feels for the woman that matters, but how safe she feels it is for her children. In these cases, the design for the adult is only sufficient if it is also sufficient for children. Since it is clear that most parents would not feel comfortable having young children biking on busier roads with them to reach destinations (even where bike lanes are present), then it stands to reason that once again having more extensive off-road facilities that offer better modal separation (as seen in Europe) may be the key to designing neighbourhoods which are more supportive of biking.

Design Synthesis

All neighbourhood designs exist along a morphological continuum (Hanson, 1989), and in practice designs can easily blend into one another as different elements are combined to different degrees. In some cases, designs are purposely synthetic, looking to blend the best features from a set of other models. The Fused Grid model is a prime example of a synthetic design (merging the Loop and Cul-de-Sac model with the traditional Grid), but more permutations are undoubtedly possible. Several authors (Lee and Ahn, 2003; Southworth and Ben-Joseph, 2003) have called for new designs which will synthesize elements of existing neighbourhood models to create better ones.

Southworth and Ben-Joseph (2003) found that we often become complacent in accepting "the whole package" of a model without recognizing that just because two elements (such as high density and grid networks) tend to go in hand, this does not always need to be the case. When we consider that it appears that both density and land use can be prescribed to any network layout regardless of what a model normally calls for (or what is normally found in case study neighbourhoods), then it becomes clear that it is the layout of transportation networks that is the most prescriptive and fundamental aspect of any neighbourhood model. This is reflected in the fact that models are typically named after the layout of their networks ("Grid" "Greenway" "Loop and Cul-de-Sac" "Fused Grid" all being excellent examples), regardless of the density or land use mix they advocate for.

As transportation patterns shift and new types of network components are introduced, designs will continue to evolve. Synthesizing new models is made considerably easier by the availability of GIS, which allows researchers to easily isolate and manipulate a variable of interest and to produce and analyze a wide range of possible designs and variations. Furthermore, models with block schemes (including all three of the alternative models in this study) are inherently compatible, which should further support design synthesis and the integration of individual elements (Lee and Ahn, 2003).

The question, then, becomes one of seeking out which combinations of patterns may best integrate the strengths of one or more models while compensating for their weaknesses. That models will need to incorporate higher densities and land use mix is fairly well-established, although if the "ideal" level of land use mix cannot be provided in every neighbourhood, then this again points to the need for good quality transit and better design for biking, which can allow people to make inter-neighbourhood trips within a comfortable period of time. Thus, future designs will likely seek to merge superior network layouts with higher density and land use mix, and do so in conjunction with better regional designs to address travel between neighbourhoods. The choice of neighbourhood network should depend largely on what characteristic is believed to be most important in facilitating walking in a new development (connectivity, continuity, legibility, modal separation, etc.), preferably based on existing latent demand.

Attempts at synthesis can be guided by the results of this study, which have highlighted the means by which each model strives to facilitate active transportation and their relative ability to affect various built environment measures. Here, the overall potential was assumed to be the product of diversity, density and design (as per Cervero and Kockelman, 1997) (see Fig. 59 below).

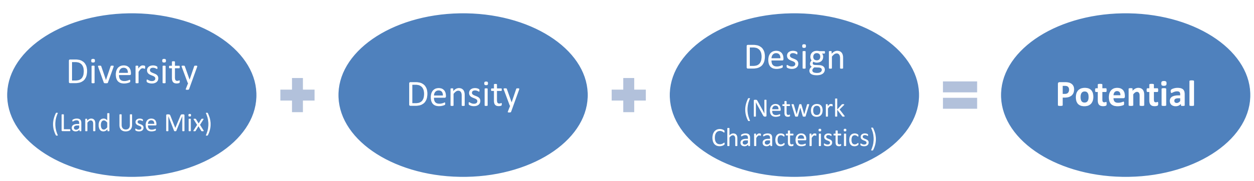


Fig. 59: Active transportation potential

The main weakness of this study, however, is that gross density and land use targets (two-thirds of the "active transportation potential" equation) had to be defined in advance of the development of the GIS models by the researcher, based on available case study data and design guidelines, rather than being "results" in and of themselves (i.e., a direct product of the design). This is arguably not dissimilar from practice, however, where both density and land use mix are prescribed through local zoning. In reality, though, while land use mix can be zoned, whether or not the desired mix is actually achieved is ultimately dependent on density, as it is the number of people in an area who may use a service which determines its financial viability. There are certainly many places in North America where the reality for an area has yet to align with its planning vision, undoubtedly to the frustration of area planners. Density, in turn, is itself also the product of zoning (and market forces), but, assuming there are limits to how high a building people are willing to see go up, how much density can actually be put into an area depends on the amount of land actually available (buildable area). Finally, we see that buildable area is a product as well – the product of network design (Fig. 60).

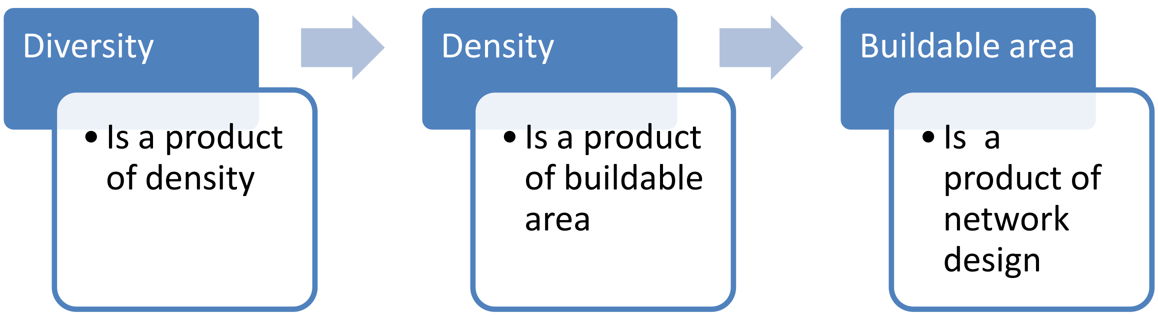


Fig. 60: Deriving elements of the "Active Transportation Potential" equation

Thus, recognizing that, given a policy environment that is seeking to encourage land use diversity and density, and economic and market conditions capable of supporting them, the *potential* for these two variables is actually the product of buildable area, the original equation can be simplified:

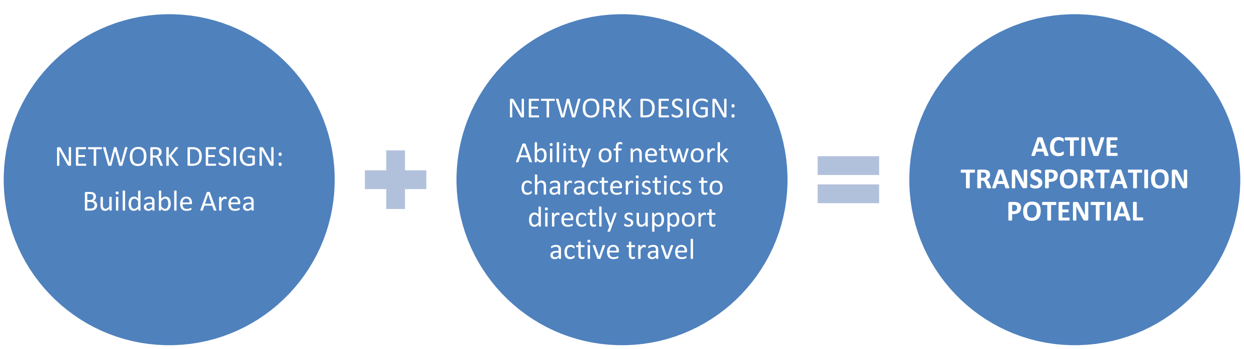


Fig. 61: Refined active transportation potential formula

As Fig. 61 shows, given the conditions noted above, the *inherent active transportation potential of a neighbourhood is entirely the product of network design.*

It may be possible to simplify the formula proposed in Fig. 61 even further. One thing the "density potential" calculations in Part III of the results (p. 222) conclusively demonstrated was that the differences in density between the models were primarily the result of decisions about what density to pursue, much more so than they were the product of buildable area. Looking at past case studies, it can be seen that the areas that typically have the highest densities and land use mix are often Grid neighbourhoods, even though the grid network produces the *least* amount of buildable area (p. 218). As this is the case, it stands to reason that either the level of density planners typically strive to can easily be accommodated in *any* of the models in this study. If both density and the subsequent potential for land use mix are largely the result of planning philosophies and *not* buildable area, then the raw (pre-zoning) potential for a neighbourhood design to support walking and biking becomes *entirely* dependent on network layout and design (insofar as the variables included in this study are concerned). Therefore, it stands to reason that any future attempts at model synthesis should focus on the design of the transportation networks.

Beyond Differential Connectivity: Differential Design

Two of the alternative models, the Fused Grid and Greenway, make an explicit use of "differential connectivity" to improve walkability and bikeability. Looking at the results for other characteristics such as legibility and continuity, this concept could justifiably be expanded to what could be termed "*differential design*" – the idea that any built environment variable could be purposely made to be better for one mode relative to another. For example, the Greenway model exhibits differential legibility between its road and pedestrian networks in addition to its differential connectivity. Recognizing the potential for differential design opens up new possibilities when it comes to model synthesis or coming up with completely new ways of approaching neighbourhood design.

Drawing From Other Models and Neighbourhoods Around the World

Other models which could be more fully explored in future research or use as a basis for the synthesis of new designs include Le Corbusier's Ville Radieuse and Ville Contemporaine designs (LeCorbusier, 1922, 1935 – see Fondation Le Corbusier, 2012), designs which would result from recommendations made by Christopher Alexander (1977), Hardewick's Velo-City model which includes suspended bike tunnels for commuting (see velo-city.ca, 2012), hexagonal cell-based designs (see Buchanan, 1964) or Savannah-style grids (see CMHC, 2000). Specific neighbourhood elements not included in any of this study's models but used elsewhere include woonerven, pedestrian or cyclist overpasses, pedestrian only roads, roundabouts, 5+ way intersections, Barnes Dances ("pedestrian scrambles") and other types of signalization at intersections, etc., any of which could potentially contribute to the walkability or bikeability of future designs.

PART II: METHODOLOGY

Morphological Analysis Methodologies - General

Differences in morphological analysis methodologies between studies (such as in the treatment of cul-de-sac intersections noted on p. 68), difficulties caused by the presence of off-set networks and the problems identified in this study that can arise from frame and destination choices make clear the need for researchers to be more explicit about their methodologies. Based on findings from the literature review and lessons learned over the course of the GIS-model building experience, the researcher would note that areas which especially require elaboration include:

- What constitutes a node or intersection (which could further be classified by the modes that can use them and what types of turn actions are available)

- What constitutes a point of conflict (which could further be classified by the type of conflict and the level of risk, either real or perceived, that it represents)

- The treatment of parallel networks (e.g. alleys and their corresponding uninterrupted sidewalks in the Fused Grid and New Urbanist models; trails and roads for cyclists in the Greenway model)

- What types of paths were included and which were omitted, and if any path was used as a proxy for another (for example, if roads were used as a proxy for sidewalks)

- How the study frame was chosen and any modifications that had to be made to the network to address problems created as a result (e.g., if cutting off roads at the frame boundaries produced artificial "dangle nodes"), and if the choice of frame would have favoured some designs or modes over others

- How origin/destination points were established (if applicable), how their locations relate to the different types of network pathways present, and any modifications that needed to be made in order to enable different modes to reach those points (as, for instance, in this study where a fake link had to be created in order to allow motorists in the New Urbanist neighbourhood to reach the central destination point which ended up being located in a park)

- Whether a lot-based or network-based approach was used to calculating trip lengths or other trip characteristics

Ultimately, it would be beneficial if morphological analysis could follow the same sort of standardized methodology being developed for GIS-based analysis by the Design for Health research group (see their *Neighbourhood Environment for Active Transport – GIS Protocols Manual*) (DFH, 2012). The research community would also benefit from studies that, like this one, aim to assess a greater number of possible neighbourhood types at once, so as to reduce the need to look at results between several different studies with differing methodologies in order to compare a set of models of interest.

Choice of Variables

Despite finding their basis in the most basic of planning ideas (the separation of non-compatible uses and activities) and here being proven to be fundamental components of several of the study models, continuity and modal separation have been poorly conceptualized, measured and consequently studied in the literature. It appears that the emphasis on network connectivity in research and recent developments may be leading to a focus on this factor at the expense of all others. This may, in part, be due to the fact that there are many easy ways to assess connectivity (although different measures often produce different results – see Appendix O) , while tools to assess other network characteristics (such as modal separation, continuity, and also legibility) have only recently been developed for GIS. Now that there are tools to calculate such measures, future active transportation research should make a concerted effort to incorporate these network design characteristics, so as to better describe the neighbourhoods at hand and to enable a better assessment of the effects of these different variables on travel behavior.

Representation of Active Transportation Networks

Many, if not most, studies of neighbourhood active transportation networks to date have failed to fully depict the active transportation network and have relied on roads to serve as proxies instead. This study has shown that it is possible to represent the active transportation network as distinct and separate from the motorized transportation network, and that doing so can considerably change the resulting measurements for built environment variables (see results in main body of this paper for cyclings and pedestrians versus those found for motorists (i.e. roads) in Appendix J). This becomes even more important in many alternative models where the urban form characteristics vary markedly between modes: for some models (namely the Fused Grid and the Greenway), this is in fact a key element of its design and completely lost if neighbourhoods are assessed using roads alone. As such, it is imperative that any studies attempting to compare designs for their ability to support walking and biking include all public network segments available to those modes: a failure to do so could produce extremely misleading results.

In Tresidder's 2005 study of connectivity measures and how the inclusion of trails could affect those measures, he found that adding trails in a neighbourhood with a sizeable park space affected the results within a census tract by up to 14%. Tresidder argued that such changes in connectivity are too small to warrant the extra work required to include the ATN in connectivity measures; however Hawkins (2007) found that changes in differential connectivity as low as 10% for pedestrians vs. motorists were associated with a 23% decrease in local vehicle miles travelled, while a 10% improvement on directness ratios was associated with a 25.9% increase in the odds of walking at least 30 minutes per day. Tresidder's findings also showed that including trails can have larger effects on connectivity at smaller scales (e.g. in the immediate area), which would be more important for short trips and individual developments within a larger area.

In this study, differences in connectivity measures ranged by as much as 800% for active transportation networks compared to motorized transportation networks (see Table 75 below). The effects are greatest where the active transportation network is purposely designed to be different than the road network, as is often the case for the alternative models. These differences are obviously of a magnitude sufficient to warrant any extra time required to assess the two types of networks separately. It should be noted that although Table 75 below only outlines the effects of including trails on connectivity measures, it is important to note that other network characteristics assessed in Chapter 5 (such as continuity) would be affected as well.

Table 75: Changes in connectivity measures when including trails

Connectivity Measure	Tresidder – Effect on Whole Census Tract	Tresidder – Effect on ½ mile area around taxlot by park	Fused Grid	Greenway
Intersection density	14%	21%	53% *(for pedestrians vs. cars)*	362% *(for cyclists vs. cars)*
Alpha index	0%	-4%	-16.7% *(for pedestrians and cyclists vs. cars)*	800% *(for pedestrians with a closed frame vs. cars)*

*Note: Percent change measured as [(higher value/lower value) – 1] * 100%*

This point applies to more than just academic research: *municipalities cannot effectively evaluate neighbourhoods (existing or proposed) without including all components of the active transportation network in their assessments*. While using road networks offers the benefit of being able to depend on easily accessible extant datasets (Tresidder, 2005), using roads as proxies of active transportation network elements is a poor practice that renders invisible the benefits that may come from the most promising alternative designs and should be eliminated in any municipality seriously committed to improving walking and biking conditions.

Single-Line vs. Double-Line Representation of Network Paths

Facilitating active transportation is a relatively new priority in planning, and our systems of analysis and data collection are still struggling to catch up. While much research has used single-line road networks as a proxy for the active transportation network, this study sought to more accurately depict active transportation network elements by locating them within metric space, with the result being that sidewalks were depicted as double-line networks (one line on either side of a road) while trails and roads were depicted using single-line networks. All lines were assigned a path_width attribute, and this could be used at any time to generate a set of polygons to reflect how the pathways would actually appear in space and to reveal relationships obscured when all possible lines of travel are combined into the single road line (for instance, to see where sidewalks cross roads).

It was found that double-line representation is essential to continuity measures, which require the lines to be spatially separated in order to record where they cross. Consequently, it was observed that *single-line representation of network elements (and more specifically sidewalks) effectively favours analysis of connectivity at the cost of continuity*. This may provide a partial explanation for the observed tendency in past research to measure connectivity but not continuity, which would have be hindered by the lack of necessary datasets. Depending on how it is assessed (whether as an attribute of a path, e.g. "partially separated from cars" or as a measure, e.g. "5' separation from cars"), modal separation may be affected as well: while attributes can be added to a path regardless of whether combined or spatially separated lines are used, actual measurements of the level of separation achieved in space would obviously require a spatially accurate representation of the path network. However, using a double-line network can create its own problems: for instance, it was found that the use of a double-line network gave pedestrian networks disproportionately high network coverage values relative to cyclist or road networks, which made comparison between the two difficult.

As such, double-line networks should be used whenever an assessment of continuity and/or certain measures of modal separation is required, while single-line representations of active transportation networks should be used for measures of connectivity, legibility, and, depending on its purpose (i.e., calculating length of path for pedestrians vs. amount of sidewalk that will have to be paved for developers), coverage. Having double-line representations of sidewalks on hand may also provide municipalities benefits in terms of being able to better visualize where current infrastructure exists along a stretch of road and where it is still needed.

Modeling Trip Lengths vs. Travel Times

Handy (2005, p. 11) stated that "the choice to walk may be best conceptualized as a choice as to how to allocate one's time". Many morphological studies (including this one) have used trip distance as a proxy for trip time (Aultman-Hall et al., 1997; Lee and Ahn, 2003; see also Crane, 1996b and Crane and Crepeau, 1998 for further discussion), which is likely the single most important variable when selecting a travel mode. There is no guarantee, however, that improved trip distances (i.e. connectivity) will result in reduced trip times, especially if that connectivity is achieved through high intersection density. In fact, looking at the behaviour of motorists, one often sees that drivers will go out of their way to get onto routes with low connectivity and high continuity (e.g. arterials and highways) so that they will have to stop less often. Even though this results in longer travel distances, there is obviously no question in the minds of most drivers that doing so saves time. But because studies typically focus on trip distance, little is known about the relationship between neighbourhood design and trip times. The possible "points of conflict" (i.e., breaks in continuity) identified in each model through the methodology outlined in Appendix F in this study could be used to more accurately model trip times in a GIS (by being able to add in pauses at path intersections). Since people often assess their trips in terms of "how long will it take to get there?" rather than "how many miles is it?", this could be key to more accurately assessing how changes in the built environment may induce changes in travel behaviour.

Modeling Points of Conflict (Continuity)

All three alternative models emphasized the elimination of driveway and active transportation pathway crossings as a means of improving continuity. While modeling road-based points of conflict was relatively easy, effectively assessing changes to driveway-based continuity required the inclusion of line features to represent driveways, a time-consuming task which may explain the failure to do so in past studies. Doing so in the future would allow researchers to better assess if people choose routes because it minimizes their exposure to cars in driveways and how much of an effect providing this sort of improved continuity may have, but it would be desirable to develop a faster means of modeling and assessing this facet network design. Other possible options for measuring continuity would be to use a simpler measure that defines paths as "interrupted" or "uninterrupted" at the street segment scale (thus eliminating the need to include individual driveways to assess the loss of continuity along sidewalks); a measure which would assess the frequency of interruption without having to model each individual driveway (for instance, "driveway every 40'); or a more complex one for both driveway and intersection-based continuity which weights interruptions (for instance, based on traffic or intersection characteristics).

Trip-Based Modal Separation Measures

While the use of accumulation attributes proved to be fairly successful for an initial foray into the measurement of neighbourhood modal separation in a GIS (see p. 207), it is clear from some of the problems encountered that there is still much room for improvement when it comes to measuring trip-based modal separation. It is hoped that the shortcomings of this study may serve as a starting point for other researchers seeking to find a way to better incorporate an analysis of modal separation into studies of network design.

Based on the experiences of this researcher, the following recommendations are made for others considering work in this area:

1) The GIS should be able to differentiate between changes in modal separation along the length of a line segment (what types of users may be travelling in the same path) and the loss of continuity resulting from intersections (where other traffic may cross the line segment).

2) When looking at specific trips, origins and destinations should be located (whenever possible) so as to have pre-existing connections to the transportation network, eliminating the need for additional “fake” path segments which make the comparison of proportions of trips occurring on different types of paths difficult. In some cases, this may most easily be achieved by just extending the area under consideration: in this study, fake segments could have been eliminated by including the sidewalk and/or trail segments immediately on the “far” side of the road (beyond the frame’s boundary).

3) Researchers should be explicit about whether or not cyclists or pedestrians will be assumed to travel on “less desirable” pathways (roads or alleys) where other parallel but spatially separated facilities are present (such as trails or uninterrupted sidewalks).

4) Any tool to assess modal separation should have a means to give credit to a design for incorporating off-road elements (in most cases, trails) – both those that clearly correspond to adjacent roads and those that diverge from them.

5) Researchers should consider the development of more refined measures of modal separation which go beyond assessing just what users may be travelling along a given path to assessing their characteristics in terms of traffic volume, speed, and vehicle mix, as well as the distance between modally separated pathways (for instance, the difference between a sidewalk that runs right alongside a road and one that has a vegetated boulevard acting as a buffer between the two).

Finally, more research is needed to determine if it is better to assess (and possibly create standards for) neighbourhoods in terms of the proportion of their networks that offer high modal separation or by the total amount of modally separated network coverage available.

GIS Methodologies

While the methods used in this study were satisfactory for its purposes, two changes would be recommended for future researchers looking to perform similar analyses:

1) Although U-turns at dead-ends were allowed in the network analyses performed in this study (a setting found under the Network Analyst Window's "Layer Properties"), it is recommended that future researchers do not allow U-turns at all if including private driveways in the network, as the result is that the GIS may have the calculated route include entering a private driveway in order to turn around, even if it is on an arterial road, something unlikely to happen in real-world scenarios.

2) The development of setback lines was too time-consuming relative to the benefit it offered, and their impact on trip length could have been more easily assessed by simply adding setback distance to final trip lengths. The Densify tool to inserts vertices along line or polygon features could be used to produce origin points along sidewalks, trails or the edges of lots instead.

PART III: THE ALTERNATIVE MODELS – DISCUSSION & OPPORTUNITIES FOR IMPROVEMENT

As the results in Chapter 5 show, the three alternative models offered considerable improvement over the more traditional Grid and Loop and Cul-de-Sac models for almost all the urban form characteristics under consideration. In order to provide a stronger basis for decisions made concerning the use of these models, the following section summarizes the findings for each of the three alternative models, discusses their implications for walking and biking in new developments, and offers suggestions for ways in which they could potentially be improved. Tables of the results and rankings for each of these three models has been provided in Appendix R to allow for an "at a glance" summary of the findings for each.

Fused Grid Neighbourhoods

The Fused Grid was successful in its attempt to limit the land required for roads in order to leave more space for parks and housing (see CMHC, 2000), providing more buildable area than all models save the Greenway. In terms of its walkability and bikeability characteristics, it ended up ranked in the middle (2^{nd}, 3^{rd} or 4^{th}) for every value except one: pedestrian differential connectivity (based on trip measures), which is the primary means through which this model aims to support active transportation (see Tables R.1 – R.4 in Appendix R). It is also the most important way in which it deviates from the Loop and Cul-de-Sac model, which it otherwise bears great similarity to.

One surprising finding was that despite a large scale grid network for its roads, the Fused Grid's active transportation network does not form a regular grid in the sense of having long, straight pathways which pass through several X-intersections before terminating. Instead, it is more of an irregular grid, where trail segments end at the first road they hit, creating a high number of "T" intersections.

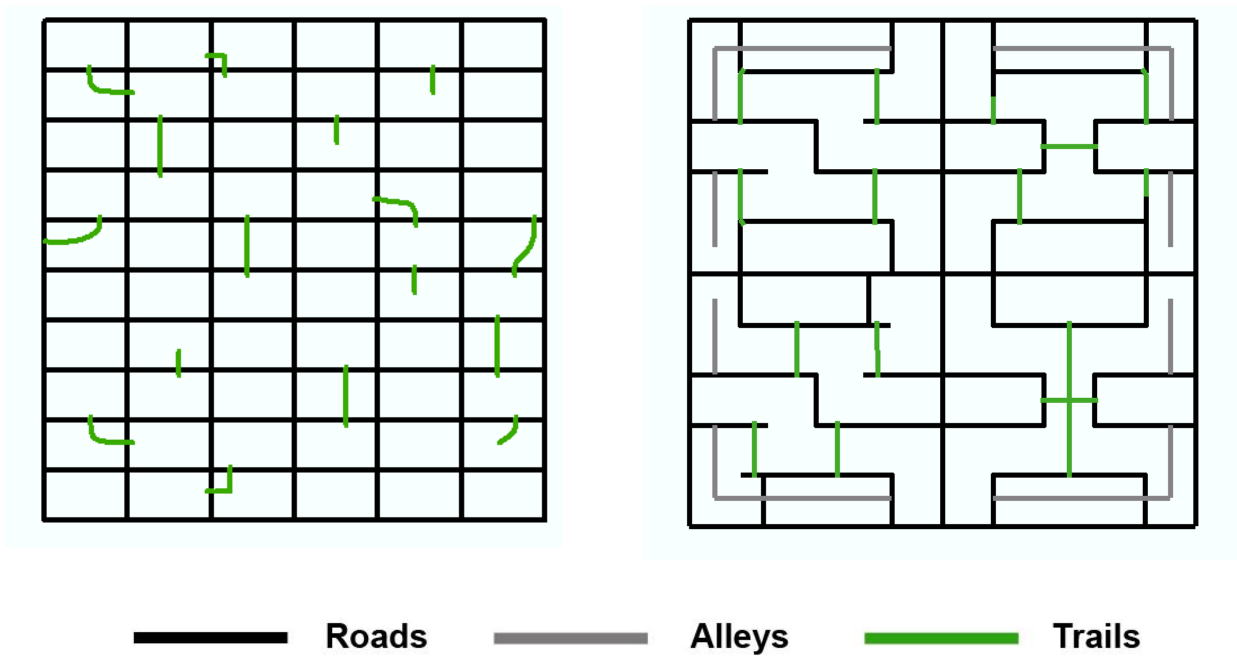


Fig. 62: Comparison of Grid and Fused Grid models
Comparing a regular grid network (left) to the irregular grid network used in the Fused Grid (right).

This has the effect of reducing network legibility within cells – the Fused Grid model, as presented by the CMHC (2000) lacks the predictability of a more regular Grid or Greenway model (which is built around many similar principles). This is further confounded by the number of cell layouts available and the suggestion that they can be mixed together in any combination (see CMHC, 2000, p. 71). While true (four different cells were easily fit together for this study), this would further reduce the predictability of the active transportation network. This problem could easily be solved, though, by opting to replicate just one or two cells, and by modifying the designs so as to provide more “through” trail connections.

Mixing the different cell arrangements together also occasionally resulted in road intersections too close to one another to meet TAC (2007) spacing guidelines. Although the Fused Grid is still one of the easiest models to lay out and understand, it is important to realize it cannot be used in a straight “cookie cutter” approach. Designs must be responsive to the environment in which they are used, and may need to be modified in order to accommodate variations in topography or to better align with surrounding developments and pre-existing infrastructure elements (such as trails).

The quadrants used in this model would likely improve the viability of public transit, since every local road connects directly to a higher-order through road (collectors and arterials) where buses are likely to travel, unlike in a Loop and Cul-de-Sac neighbourhood where one can live several roads away from the nearest bus stop. This conclusion is supported by findings regarding trip distances in these two models. Like the New Urbanist model, the Fused Grid actively aims to incorporate higher densities, which would further help to support a public transit system.

Although the Fused Grid makes differential connectivity the focus of its design, both the Greenway and New Urbanist model scored higher in some measures of this variable (i.e. network-based measures using metric reach and intersection density, as well as trip-based measures looking at trip lengths for cyclists), indicating that there may be ways to further strengthen this aspect of the design.

The Fused Grid layout resulted in an absence of park spaces towards the edge of cells (i.e. along higher order roads). This meant that trails were provided in the quietest (and arguably safest) parts of the neighbourhood, but pedestrians had to walk on sidewalks and cyclists go on roads in what would be the busiest ones. It is possible that the biway corridors included in some papers on Fused Grid design (e.g. CMHC, 2002) would effectively address this, but more research would be needed in this area. The use of alleys along arterials would also present an opportunity for uninterrupted bike lanes, trails and/or sidewalks along the edge of these roads.

The lack of visibility from surrounding buildings may reduce the use of the Fused Grid’s trails somewhat (something that the author has regularly found to be a problem growing up in a Fused Grid neighbourhood, where residents often perceive the parks and trails as unsafe at night). McMillan (2007) found that the number of windows facing “the street” had a positive correlation with walking and biking to school among children: whether or not the benefits that a trail offers from a traffic safety standpoint would more than compensate for the loss of visibility (relevant from a crime safety standpoint) warrants further investigation.

Possible modifications

The only categories in which the Fused Grid fared worse than the Loop and Cul-de-Sac model were in the size of its parks, the total coverage (length) of its active transportation pathways (bike lanes, trails and sidewalks), and the subsequent level of modal separation its network can provide. These are all areas, however, on which the Fused Grid design could be modified to improve: quadrant designs that make use of larger and longer linear parks with through trails may provide the greatest opportunity in this regard.

Summary

In many ways, the Fused Grid is like a systematic and well-thought out redesign of the popular Loop and Cul-de-Sac model. Developing a neighbourhood according to the Fused Grid model requires very little change from traditional Loop and Cul-de-Sac designs, and there appears to be no reason that it should not completely replace the Loop and Cul-de-Sac as the principal "single-sided lots on disconnected roads" model for new developments, particularly if a few small improvements to park space and trail layout could be made.

Ironically, although the Fused Grid rarely did better than the other models on its network and trip characteristics and came in second last in terms of its overall active transportation potential, it is its similarity to the Loop and Cul-de-Sac model that is perhaps its greatest strength. If market preference is for single-sided homes on disconnected lots, then the Fused Grid may offer the best chance for municipalities to see improvement in neighbourhood design for active transportation without encountering too much resistance from developers concerned that other designs may prove either too unfamiliar to potential purchasers (as is a challenge for the Greenway model) or too expensive to implement (as can be the case for the New Urbanist). And not only is the Fused Grid better than the Loop and Cul-de-Sac for walking and biking, but it also maintains similar or even slightly better conditions for motorized vehicles than most Loop and Cul-de-Sac neighbourhoods (at least for those variables under study here), making it more palatable to traffic engineers (see Appendix J). In fact, in some existing Grid neighbourhoods, residents have pushed for the installation of Berkeley barriers (making roads through roads for pedestrians and cyclists but dead-end streets to motorists), functionally changing their neighbourhoods into Fused Grids of their own accord (see CMHC, 2000).

In short, the Fused Grid is an easy substitute for more traditional models, combining, as its creators intended, many of the benefits of the Grid for pedestrians and cyclists with those of the Loop and Cul-de-Sac for residents.

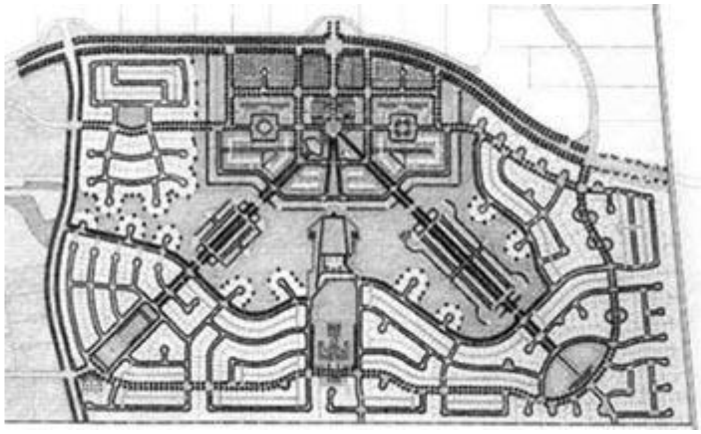
New Urbanist Neighbourhoods

The New Urbanist was the best model for land use mix, the provision of park space and density (see Tables R.5 and R.6 in Appendix R). Looking at its design characteristics, it had the best network connectivity for both pedestrians and cyclists and the best trip-based connectivity (trip length) for pedestrians, as well as some of the best results for coverage and modal separation for both pedestrians and cyclists (Tables R.7 and R.8 in Appendix R). However, it also had some of the worst results for continuity in terms of Road/Road and ATN/Road continuity, the most paved area and the second worst infrastructure efficiency.

The biggest differences between the New Urbanist model and the model it was derived from – the Grid – were the amount of land dedicated to parks and the total coverage of trails. In this regard, this "neotraditional" model proves to be just that – derived from a traditional model, but making some clear improvements on it which are obviously aimed at quality of life and increased walking and biking. Where the Grid had only 5% of its land dedicated to parks, the New Urbanist had an extraordinary 21% (being able to incorporate even more than had originally been intended – see Chapter 4 for more details), and when it came to trails, the 12,813.6' in the New Urbanist model far exceed the mere 4,123.4' feet in the Grid.

The model produced only moderate results with regards to network legibility. This is likely due to the more American-style New Urbanist design, which incorporates some cul-de-sacs, loops, and many parks), compared to Canadian designs which tend to use more regular grid patterns (see Fig. 63 below). Whether this apparent difference is the result of geography or time (many of the Canadian New Urbanist developments are more recent than the famous U.S. examples of Kentlands and Laguna West) is unknown. The dead-end alleys found in the design used in this study would also have had a detrimental effect on legibility scores, something which could be easily improved on in other plans.

Fig. 63: American/older vs. Canadian/newer New Urbanist designs



An example of an American New Urbanist neighbourhood (Laguna West)

(Image Source: Calthorpe Associates, 1990)

An example of a Canadian New Urbanist neighbourhood (Cornell in Markham, Ontario)

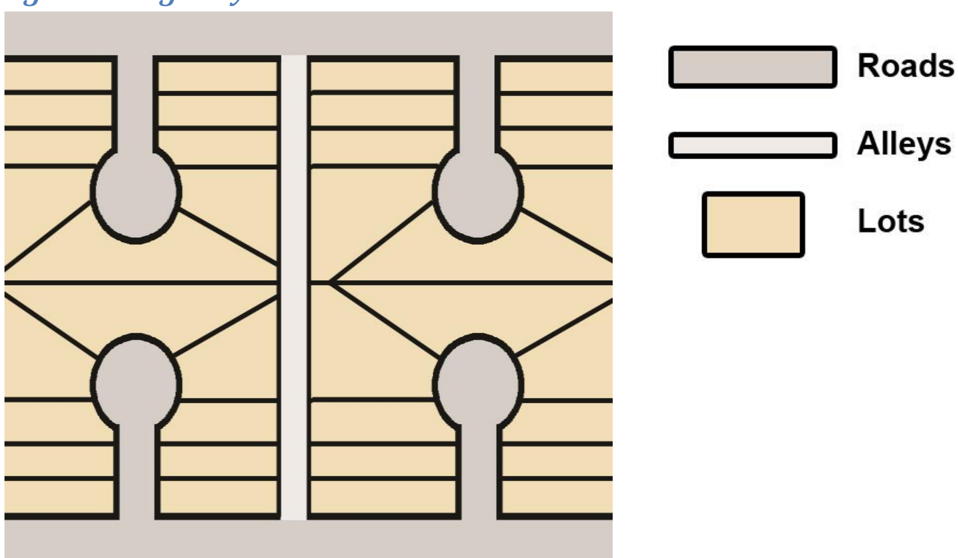
(Image Source: Cnes/Spot Image et al., 2012)

The New Urbanist model had the highest proportion of roads with alleys among the study's GIS models. In practice, alleys are not so much a strategy to deal with traffic as it is to relocate parking and unsightly features such as garbage pick-up, garages and driveways (see Hess, 2008). The main benefit of this for active transportation is to pedestrians, who no longer have to worry about crossing driveways when walking on sidewalks. Cyclists in bike lanes may also benefit somewhat in that there would be fewer driveways connecting with the road along the fronts of homes, but may benefit even more if the continuous fronts were seen as an opportunity to create a biking trail beyond the boulevard in place of a bike lane. This would differ substantially from the "traditional" neighbourhoods these neotraditional neighbourhoods are based on, but would significantly improve modal separation for cyclists.

It was found, however, that even though the alleys improved ATN/Driveway continuity, they substantially reduced ATN/Road continuity by as much as doubling the number of intersections along some stretches of road (assuming alleys are seen as a type of road rather than a driveway). Whether it is preferable to have uninterrupted sidewalks but double the number of intersections along the roadway, or to have fewer intersections but sidewalks interrupted by driveways is unfortunately unknown.

Although the alleys do provide some gains in connectivity, these gains would be minimal where they serve pairs of through roads as seen in grid networks (since they only provide additional through pathways where there are already two through streets in close proximity). This connectivity benefit could be increased if they were modified to serve “back to back” disconnected roads (e.g. cul-de-sacs) while acting themselves as through roads (see Fig. 64 below). However, this may cause challenges for transportation planners if the alleys became over-used by drivers wishing to take shortcuts through a neighbourhood.

Fig. 64: Using alleys to connect otherwise disconnected roads



It was also found that if alleys are seen as roads instead of multi-unit driveways, they can create problems for intersection spacing in this model. Since TAC (2007) calls for a minimum of 131.2’ (40 m) between intersections on local roads and the average lot depth of a home in Canada in 2010 was only 115’, having a road, a single lot, and then an alley provides inadequate spacing between the road and alley. If this is a concern, then the suitable design solution would be to increase lot depth, although in many cases, developers would likely be hard-pressed to further reduce the already very narrow lot widths in this model to compensate for this change.

Because of the high road and alley density, findings with regards to ATN/Road and Road/Road continuity in the New Urbanist model were consistent with those of Lee and Ahn (2003, p. 67), who concluded that “New Urbanist street systems are based on an interconnected grid that allows through traffic, and so one cannot argue that they are more desirable than Radburn's cul-de-sacs for families with young children". However, the New Urbanist model may provide an important advantage over the Greenway (the other model assessed by Lee and Ahn, 2003) in terms of keeping "eyes on the street" (see Jacobs, 1961), provided that pedestrian and car traffic does not become split between roads/sidewalks and alleys. This splitting of traffic is a problem potentially common to both the New Urbanist and Greenway models, and more research should be done to determine its extent and its effect (if any) on the perception of safety.

Another key feature that differentiates the New Urbanist model from the others in this study is its use of narrower roads as a means of controlling traffic. (This also has the benefit of somewhat compensating for the greater length of road found in the model). Since in the U.S. local residential streets constitute 80% of the total national miles of roads but support only 15% of total vehicle miles travelled (FHA, 1991), narrowing roads makes a lot of sense from an efficiency standpoint. However, adding a parallel alley for each road has a negative impact on the *total* land actually dedicated to roads. For instance, local roads in this study were 30.2' wide in the Loop and Cul de Sac model. New Urbanist local roads were only 28.6' wide, but once a 15.7' alley is added, the result is a greater total combined road width on local roads than in any other model (44.3'). Additionally, the land for these alleys often comes out of yard space, leading to some residents complaining about backyards too small for children to play in (Hess, 2008). However, given Canada's aging population and history of building new developments for families with children, building some new developments that are not necessarily aimed at young families may not really be a problem.

Even if the New Urbanist model fails to reduce the total paved area of roadways, its narrower roads are still likely to make travel safer, as wider roads have been positively associated with pedestrian crashes. Cyclists also prefer roads and intersections with fewer lanes (Krizek and Roland, 2005; Petritsch et al., 2006; Shankwiler, 2006), something which a model with high road density and a grid-like network can relatively easily provide.

One of the most unexpected findings for the New Urbanist model was that despite consistent claims to the contrary and its use of narrower roads, it did not do especially well in terms of either overall infrastructure or paved network area efficiency, finishing second-worst in both these categories. The high density found in these neighbourhoods was not enough to compensate for the additional roads, sidewalks, bike lanes and trails this type of neighbourhood requires. To be fair, this study did not include the provision of other municipal services in its measures (e.g., sewer and water lines, garbage pickup, etc.) which would also benefit from having denser housing, and may outweigh the added costs resulting from the increased network and park infrastructure requirements of the design.

It's worth noting that it is not just concerns about the walkability or bikeability that must factor into municipal decisions about neighbourhood design: neighbourhoods must also still provide a reasonable level of service to motorists. While outside the scope of this study, this seems likely to be a particular problem for the New Urbanist model. Proponents of New Urbanist neighbourhoods often argue that grid networks can provide the same (or even better) level of service to motorized traffic as a more hierarchical and disconnected network (e.g., the Loop and Cul-de-Sac model) because they more evenly disperse flow and reduce trip lengths (see Kulash et al., 1990; Stone et al., 1992; Crane, 1996b). Advocates for hierarchical networks, on the other hand, point to problems of grid lock as evidence that such networks handle cars very poorly, which may make New Urbanist designs less attractive to both transportation planners and potential residents.

If drivers *do* dislike neighbourhoods with high intersection density because of all the stops-and-starts required (and the necessary deceleration and acceleration that goes with it), it is possible cyclists may as well – and maybe even more so, since stop-and-starts for them require an extra physical effort not experienced by drivers (Fajans and Curry, 2001). Consistent with this theory, it has been found that people are less likely to cycle in cities which have a large number of stops (Rietveld and Daniel, 2004). Similarly, it has been found that even though intersection density is typically one of the most important factors for walking trips, there is no significant evidence yet that road density or block size (connectivity) have an impact on cycling (Moudon et al., 2005; Zacharias, 2005; Heinen et al., 2010). It may be that intersections are a more significant confounding factor for cyclists than pedestrians, as their effect on continuity and travel speed is felt much more acutely (because cyclists, unlike pedestrians, must slow considerably coming up to a stop) and which may be felt to cancel out the connectivity (trip distance) benefits they offer. If this is the case, then it may be that the model would do less to support cycling than one might otherwise expect.

Possible modifications

Results for ratios of route directness suggests that the distribution of dwelling units in the New Urbanist model (scattered throughout the network and mixed within the same block) may be inefficient with regards to trip lengths, particularly when compared to other models which put more of an explicit emphasis on density loading onto higher order roads. Unless it can be shown that the social benefits New Urbanists often argue come from this scattered approach to density outweigh the health and environmental benefits offered by shorter trip lengths, it should be replaced with a more systematic approach. The model would also benefit from strategies to improve sense of safety at intersections, as it suffered from the second worst ATN/Road continuity of the models.

Summary

The New Urbanist model proved to be the best model overall for walking and biking in the study, mainly as a result of its high land use, density, and connectivity. It was also the most explicit of the five models when it came to providing guidance on the land use and density fronts, making it arguably the most comprehensively designed of the five. The model's greatest weakness appears to be its continuity, which presents a design challenge for any model emphasizing connectivity as the New Urbanist does, but which, if successfully overcome, would make this a difficult model to beat for walk- and bikeability.

Greenway Neighbourhoods

This study found that the Greenway model was the best model in terms of buildable area and the best at providing a high level of modal separation and continuity throughout its active transportation network, both in terms of road intersections and driveway crossings (see Tables R.11 and R.12 in Appendix R). It is the only model of the five studied that gives pedestrians and cyclists their own unique corridor for any substantial part of the network, rather than having them traveling alongside the road network. The model also had the highest levels of differential connectivity (as measured by metric reach), the most legible active transportation network, and the best trip lengths and directness ratios for cyclists. Its network produced pedestrian directness ratios 17.3% better than the Loop and Cul-de-Sac model with 14.5% less land, which it did by merging several parallel pathways (bike lanes and sidewalks on either side of the street) into one, making it an extremely efficient model in terms of the connectivity it achieved relative to the total area of ATN required.

Where the model fared the worst was in its coverage and intersection density for pedestrians. It also contained a low gross density, which would have repercussions both for the level of land use mix it can normally support and the viability of public transit in a Greenway neighbourhood. In fact, looking at the evaluation of overall active transportation potential on p. 186, it can be seen that it was its low density and medium level land use mix that pulled down this model's final score, finishing 3rd overall for both walking and biking despite having the best network for cycling and the second best for walking (when assuming that connectivity should be half the network design weight; otherwise, it would come in first for pedestrians as well). However, as it also had the highest density *potential* (see p. 222), it would appear that the model is well-poised to accommodate a greater number of housing units (and, by extension, land use mix) – if it turned out that the road network could support the increased car traffic likely to result.

Perhaps the most surprising finding with regards to the Greenway model, though, was how much it favoured cyclists (ranking a four or five in almost all network and trip-based measures for biking), even though it was not explicitly designed to do so. If cycling is to be treated as being as important a mode as walking, then this alone makes the model warrant further consideration.

Of the alternative models, the Greenway requires, by far, the greatest changes to neighbourhood design as most people know it. Even though this study has helped to illuminate some of the ways this model supports walking and biking, it is clear that there are still many things that would need to be better understood before it is likely to be adopted. These include:

- Whether or not a Greenway model must double intersections (due to the presence of a trail/road intersection between every road/road intersection), or if through superblocking and changes to park and lot sizes it can ultimately end up with an intersection density along roads comparable to a regular Grid or even one of the other models.

- The extent to which the design affects sense of safety from traffic (e.g., from less exposure to cars), and what impacts this may have on travel behavior.

- Ways to improve the sense of defensibility along paths and safety from crime, which proved to be the nail in the proverbial coffin of a Radburn-style public housing development in New South Wales (see Woodward, 1997 and Lee and Ahn, 2003). This is likely one of the two greatest potential drawbacks to the Greenway model (the other being the loss of a "curbside view" when selling), but it may be that higher residential densities could be a simple cure and well in-line with the push for higher density development currently occurring in many (if not most) North American cities.

- Whether there would need to be new conventions for the naming of trails for wayfinding (since road signs would no longer be visible from the active transportation network).

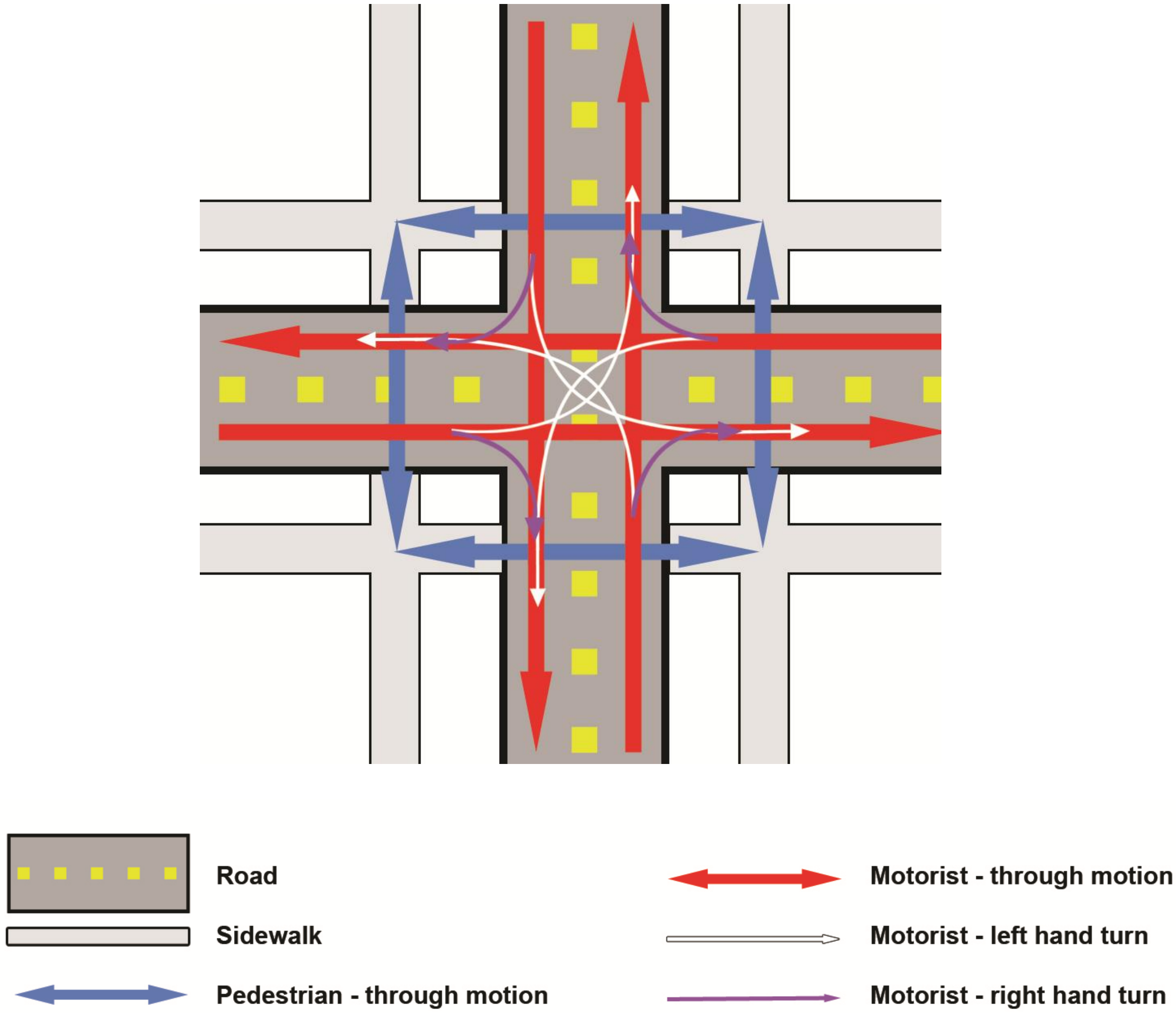
- How other design and architectural elements must change to best accommodate the Greenway's network layout, such as spacing between the front of homes (as there is no road to act as a spacer), the orientation of store fronts, how best to handle creating front door connections, etc.

- The effects of splitting bicycle traffic between parallel pathways: Since all roads in this model have matching parallel pathways (trails), the Greenway offers more potential for "traffic splitting" for cyclists than any other model in this study. This splitting of traffic between roads and trails may reduce the total number of cyclists using the roads, which would likely worsen on-road conditions for vehicular cyclists (who prefer biking on roads) by worsening motorist behaviour, who, through reduced exposure, may become less practiced in sharing the road with cyclists. (A similar effect may be seen for pedestrian traffic in models with alleys, but since sidewalks are normally kept apart from vehicular traffic anyways, the most significant impact in those cases would likely be in terms of visibility/”eyes on the street” rather than in changes in motorist behaviour).

This model may offer many other unique benefits worth researching, too, which were not identified in the initial literature review:

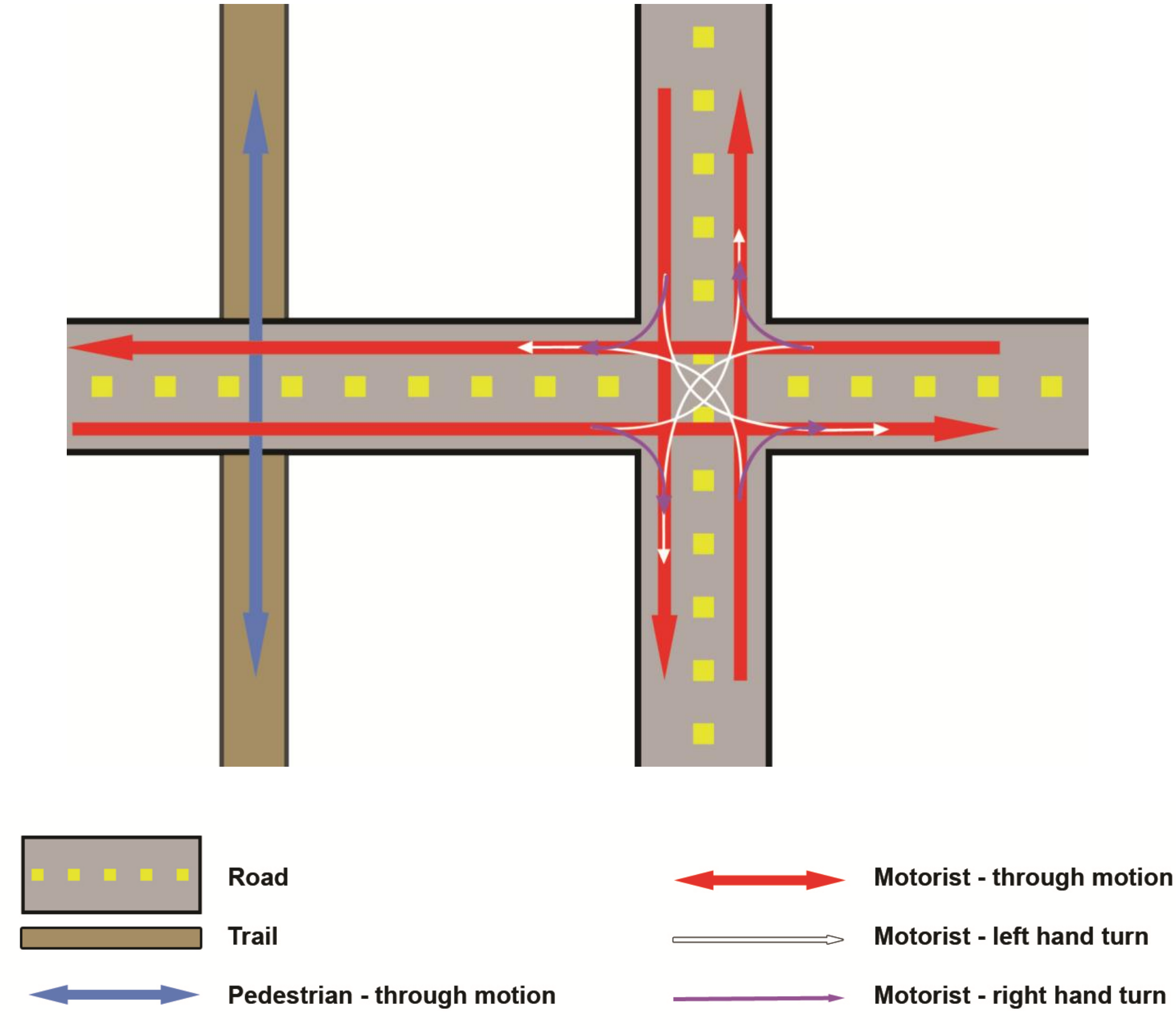
- **Elimination of turn conflicts:** The Greenway model emphasizes safety primarily through improved path continuity. However, one way it may improve safety is, as far as this author knows, so far unstudied – the way it eliminates turn actions where pedestrians and cars cross paths (see Fig. 65 below), making these intersections more like railroad crossings than the regular road intersections where turns typically take place in all of the other models.

Fig. 65a: Elimination of turn conflicts in the Greenway model – regular road intersections



In a neighbourhood model with sidewalks at intersections, pedestrians crossing roads may encounter cars driving straight through or turning left or right into the lane they are walking across.

Fig. 65b: Elimination of turn conflicts in the Greenway model – Greenway intersections



In a Greenway neighbourhood, pedestrians cross roads along a trail network located away from road intersections, eliminating the need for either motorists or pedestrians and cyclists to cross paths where turns take place.

Since between 1992 and 2001 about 25% of pedestrian injuries and 7% of pedestrian fatalities in Canada occur when a car is making a turn (Transport Canada, 2004), and an estimated 40% of pedestrian/motorist collisions occur at intersections (Lord et al., 1998) this benefit may be very significant indeed.

- **Perception of the network:** The location of a trail at the front of homes, in place of a road, may affect people's perception of the active transportation network, and people may see trails in a way they do not really see (or notice) sidewalks. Similarly, relegating roads to backyards behind fences may have an "out of sight, out of mind" effect when it comes to driving, helping to normalize walking and biking as ways to get about.

- **Smoother travel surfaces:** The relative smoothness of an asphalt trail relative to concrete sidewalks would likely offer a benefit to seniors, who are at greater risk from trip hazards, (WHO, 2008) and likely also to those cyclists who would normally choose to bike on less-even sidewalks over roads they perceive as dangerous in other types of neighbourhoods (see Aultman-Hall and Adams, 1998).

- **Reduced pollution exposure:** The increased distance between the trails and the road network compared to that between sidewalks, bike lanes and roads in other models would serve to reduce air pollution exposure for trail users (see Colvile et al., 2004; Zhao et al., 2004; Kaur et al., 2005), which may make walking and biking more pleasant in Greenway neighbourhoods – particularly when it comes to needing to follow along high-traffic arterial roads.

- **Systematic use of park space:** Like the Fused Grid model, the Greenway model provides municipalities a systematic way to use park conveyances to support active transportation (which serves as both exercise and transportation), rather than just using that space for soccer fields and baseball diamonds (which provide exercise only). Given an aging society (Statistics Canada, 2010a) and trend towards less exercise coming from group sports and more coming from independent activities like walking and biking (CFLRI, 1998; Eyler et al., 2003), this may not only serve to better meet a city's environmental goals but possibly its health ones as well, if the types of facilities seen in this model (long, linear parks) better align with people's preferred forms of physical activity.

It is possible that the combination of some of these factors may help improve the positive utility of travel by creating a more enjoyable walking or biking experience. Since the ability to prevent the "drawbacks" to walking and biking are limited (e.g. exposure to weather, slower speeds, etc.) the ability of a model to create *positive* utility may be quite important (Handy, 2005).

Another surprising finding for this model was that despite an unconnected road network, it did very well in terms of motorized trip length to both edge and centre, as well as in its network continuity for cars (see Appendix J). This suggests that if most trips are assumed to take place between homes on local (disconnected) roads and destinations on main (well connected) roads, rather than locations on local roads and local roads, then having a disconnected road network may not be so much of a disadvantage after all - at least where the size of the super-block is kept relatively small.

Possible modifications

Even though they use similar cellular designs, the Greenway model does not have as many different proposed design templates as the Fused Grid model. It may be that Greenway advocates would benefit from using the CMHC's (2000) approach of proposing multiple layouts in order to improve the (perceived) flexibility of the model.

While the Greenway model is effective at reducing the number and types of potential conflicts between pedestrians and cars, it does increase the potential for conflict between pedestrians and cyclists. How much of an impact this would have on biking and walking rates and crash incidence and severity is unknown, but the use of divided or marked trails (as seen in Vancouver – see Fig. 66 below) may be a relatively simply solution to such problems.

Fig. 66: Divided and marked trails help to keep pedestrian and cyclist traffic separate

(Image source: http://www.pedbikeimages.org / Sundstrom, 2008)

For network continuity, the GIS model used in this study would have benefited from the relatively long cul-de-sacs used (up to 24 houses on a road), which is more in keeping with the "greenwayneighborhood.net" (JLAF, 2010) proposed design than the original Radburn case study in which the cul-de-sacs were quite short. (By way of comparison, some recently constructed Loop and Cul-de-Sac and New Urbanist neighbourhoods studied by the CMHC in 2010 had only 5 and 10 single-detached homes on a cul-de-sac respectively). Long cul-de-sacs allow for a lower road/trail intersection density, which in turn reduces the need for frequent stops and starts for trail users. However, the design could be modified to use shorter cul-de-sacs, or possibly even make use of different types of roads, such as a Greenway neighbourhood built around loops, which may help address some of the servicing concerns neighbourhoods with cul-de-sacs can create.

Summary

Despite its benefits for active transportation, the Greenway model has been largely ignored since the 1930s. Much of this is likely due to the car culture that sprang up almost immediately thereafter, the uniqueness of its design and, perhaps in more recent years, an emphasis on connectivity over continuity and modal separation in active transportation research. That said, the model proves that it is possible to have both a high-continuity and high-connectivity active transportation network. Its ability to demonstrate this, however, is entirely dependent upon an assessment of active transportation networks that is separate from that of motorized networks, something which is often missing in morphological research. It also requires that more care be taken in frame choice, which can skew the results in favour of one mode over another as a result of its offset networks for some measures (see p. 165).

From a development perspective, the model offers a great deal of potential in terms of buildable area and network efficiency, but the question of whether or not people are willing to have roads located behind homes rather than in front of them remains key. Having shown the potential of this model, then, market research may be every bit as important as research into the health and environmental benefits of the model if it is to ever be seen as a viable option for developers and municipalities.

Consistent with the findings of Lee and Ahn (2003), the results of this study have shown that the Greenway model manages to achieve, without any especial recommendations regarding architecture, density or land use mix, a more walkable and bikeable environment through a more carefully thought out network layout alone.

PART IV: OTHER AREAS FOR FUTURE RESEARCH

1) **Model variations:** This study assessed only one possible example of each of the models under consideration. Designs exist along a continuum (Hanson, 1989), and so studies which elucidate (at least some of) the possible range of variation within a given model would be helpful. Similarly, variations in which a single variable is manipulated would help to determine the impact of specific types of changes (see Southworth, 2005).

2) **Traffic studies for different models:** As noted in the "Synthesis" portion of this chapter (p. 246), much of the ability for a model to support active transportation can be condensed down into its choice of network (which drives buildable area and in turn the capacity for density and land use mix). However, a model must also be able to support the level of motorized traffic one would anticipate with any given density prescribed for it. Traffic studies may go a long way to making it easier for planners to recommend alternative models, if they can demonstrate that those models do not unduly hinder motorized traffic and emergency service provision.

3) **Sensitivity and accuracy of network measures:** As this study has shown, sometimes network measures are not effective in capturing (or equitably capturing changes in) the concept they are expected to. Two examples are measuring connectivity the alpha index, which was found to sometimes worsen with the addition of trail shortcuts (see p. 162), and intersection density, whose value increased dramatically with the inclusion of alley intersections (see p. 158) even though these did little to improve trip distances. Similarly, a comparison of neighbourhood ranks between network-based and trip-based measures revealed considerable discrepancies in rankings depending on the measure used, suggesting that some measures must be more valid than others (see p. 212). It would be helpful for there to be more research into which measures are the most robust and accurate when it comes to assessing active transportation networks, and for the situations in which it is appropriate to use a certain measure (such as the alpha index) to be more clearly defined. Ideally, a measure would increase in regular increments relative to the benefits granted.

Related Areas of Research

In addition to the above areas for future study which are specific to morphological analyses of neighbourhoods for their active transportation potential, there are related questions that must be answered before we will be able to fully understand the implications of changes in neighbourhood design on travel behaviour. These include:

- Travel and exercise budgets
- Residential self-selection & latent demand
- Possible design thresholds that must be passed before behaviour change can be observed
- Effect of active transportation network proximity on its use, perception and travel behaviour
- The relationship between safety and design (and in particular, the impact of intersections and modal separation)
- The amount of positive utility derived from different types of designs

For local governments it is also important for there to be more research into the impact of design on the provision of city services, while for developers more work needs to be done to determine the business case (or lack thereof) for each of the different models.

CHAPTER 8: RECOMMENDATIONS

Based on the study results, subsequent observations and review of the literature, the following actions are recommended:

For Practitioners

1) **Alternative models should be adopted in all new residential developments, with specific model choice being dependent on the priorities for the development and community.**

   The “Loop and Cul-de-Sac” model should be eliminated, as it offers no significant advantages over the other models and mostly seems to be designed to confuse travelers. Of the three alternative models under study, the Fused Grid model was most similar structurally to the Loop and Cul-de-Sac model, and may be the easiest for developers more familiar with the Loop and Cul-de-Sac model to adopt. However, the New Urbanist and Greenway models seem to offer the best overall potential for facilitating walking and biking, depending on the objectives to be met (wherein New Urbanist designs are best for connectivity and Greenway designs best for continuity and modal separation).

2) **Active transportation networks be treated as distinct from motorized transportation networks, and should be mapped and measured accordingly.**

3) **Cyclists need to be treated as distinct from pedestrians, and neighbourhood models should seek to explicitly address their needs within proposed designs.**

4) **A greater range of network characteristics should be assessed when evaluating new developments for their ability to support walking and biking.**

   More specifically, connectivity, coverage, continuity, modal separation and legibility should all be assessed, as they are important to various network users, and, as this study has shown, can easily be assessed using GIS prior to the actual construction of new developments. Including a greater range of such walkability and bikeability measures will improve the ability of theoretical models to replicate travel patterns and behaviours (Replogle, 1997; see also Saelens et al., 2003).

5) **Networks need to connect origins to destinations, not just destinations to other destinations.**

Because active transportation networks were until recently a low priority in many municipalities, the emphasis, when connections were made, was often on connecting destinations to other destinations (as for instance in Boston's "Emerald Necklace"). Since a review of the literature has shown that people will only regularly use networks that are easy (i.e. quick) for them to get onto, it is important that these networks be close to home. Designing networks in this way also makes sense in light of the fact that most trips either start or end at home. The use of alternative models that provide better connections between homes and the active transportation network can help planners to do this.

6) **Trails should always be designed to serve a connective function.**

All models included trails, and it was found that the total coverage of trails was one of the most substantial ways in which the study models differed. Since trails typically offer the highest levels of modal separation and continuity in a network, they should be designed so as to connect different roads, origins and/or destinations wherever they are built, regardless of how they may have been used in the past within a model.

For Researchers

1) **Active transportation networks be treated as distinct from motorized transportation networks, and should be studied accordingly.**

2) **Assumptions and methodologies used in morphological analyses should always be explicitly stated.**

3) **Decisions concerning frame choice and establishment of origin and destination points should be made in such a way as to be equitable to the different transportation modes available.**

4) **Incorporate more useful measures:** More work needs to be done to ensure that morphological description and analysis ties back into walkability/bikeability – we need to move from simply describing different neighbourhoods to explaining the "so what?"A good example of this is the shift from the "lineal feet of streets" in a set area used by Southworth in 1997 to the ratios of route directness used by Lee and Ahn, 2003, which allow readers to see what impact the networks actually have on trip distances.

5) **Ensure comparability of results:** In order for morphological research to be more easily applied to scenarios of potentially different sizes, research should shift from using count data (such as the number of intersections in a case study neighbourhood) to providing ratio and area metrics (such as the intersection density per hectare for that neighbourhood).

CLOSING REMARKS

With a long love affair with the car now coming to an end, planners around the world are seeking to determine how best to design neighbourhoods to support the more healthy and sustainable modes of walking and biking.

Since concern over conflicts between active and motorized modes began, many models have been advocated for based on their ability to keep people safe and to facilitate walking and/or biking. Models are powerful tools for visually communicating any given planner or designer's vision for better communities (Marshall, 2005). They can change the shape of our cities, guide us on the path to making vibrant walkable and bikeable neighbourhoods or car-dependent bedroom communities on the far edges of suburbia. They challenge our conventions and stimulate debate (Lane, 1993; Southworth, 1997).

With the advent of GIS, models can do more than ever before to demonstrate what is possible at the neighbourhood level. By examining the density, land use and network design characteristics of five popular models, this study has shown that neighbourhoods *can* be designed to be more supportive of walking and biking, and do so in ways that maintain the same (or even greater) buildable area that developers have come to expect from their investments.

It's clear, though, that there is still more work to be done. More attention needs to be paid in proposed models to the needs of cyclists, particularly because of the potential for biking to replace a greater proportion of car trips than walking. There is a need for research which incorporates a wider variety of active transportation correlates (such as modal separation and continuity) and which moves beyond the almost single-minded focus that has been paid to connectivity in recent years. At the implementation level, more needs to be done on how to incorporate smaller scale neighbourhood designs with larger-scale active transportation planning initiatives. Rather than treating the design of neighbourhoods as a pendulum which swings according to the dominant philosophy of the day (Filion and Hammond, 2003), we should be seeking to synthesize and improve upon designs.

Researchers have concluded that the current available evidence “is sufficient as a basis for advocating for changes in planning policies” (Saelens and Handy, 2008, p. S564), and the push now for researchers, planners and municipalities must be to determine how best to take what is known about design for walking and biking and turn it into reality. As the results of this study into neighbourhood models have shown, it is already within our power to create more walkable and bikeable neighbourhoods: all that is left is to build them.

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APPENDIX A: COMPONENTS OF ACTIVE TRANSPORTATION NETWORKS & NEIGHBOURHOOD MODELS

Components of Active Transportation Networks (ATNs)

Active transportation networks are places where active modes have priority over other modes. Infrastructure components of these networks may include sidewalks, trails, greenways, bike lanes, bike routes, "pedestrian only roads" and woonerven or "unified street systems" (Southworth and Ben-Joseph, 2003). Research has shown that the type of infrastructure matters to pedestrians and cyclists (Heinen et al., 2010). The extent of infrastructure also matters, and it has been shown that countries with greater levels of cycling infrastructure have greater levels of cycling (Pucher, 2001; Pucher and Buehler, 2006).

Active transportation networks have been evaluated infrequently in relation to transportation behaviour (Saelens et al., 2003) and neighbourhood models. In order for these networks to be addressed more effectively, an understanding is needed of what the potential types of infrastructure are and what research has learned about their relationship with travel behaviour to date.

Sidewalks

Sidewalks are the oldest type of network component used to separate pedestrians from larger and faster transportation modes (Southworth and Ben-Joseph, 2003). What most sets sidewalks apart, however, is their ubiquity – in most cities, sidewalks are the only type of active transportation network that even come close to matching roads in terms of the area and number of buildings served. Many studies have shown that the presence of sidewalks is crucial for facilitating walking (see, for instance Corti et al., 1996; Moudon et al., 1997; Kitamura et al., 1997; Hess et al., 1999; Giles-Corti and Donovan, 2003; Ewing et al., 2004; Rodriguez and Joo, 2004).

Location: Where present, sidewalks almost invariably run alongside roads, and are interrupted by the road network where they cross at driveways and intersections. For any given road, there may be two sidewalks (one on either side), one sidewalk (on one side, commonly seen on residential streets) or no sidewalk at all. Not all communities require new developments to include sidewalks, at least on lower-order roads (Southworth and Ben-Joseph, 2003). They are important not only for transportation, but also contribute to for street life, natural surveillance, and sense of community (Jacobs, 1961; Newman, 1972; Mehta, 2007).

Users: In most communities, cycling on sidewalks is discouraged or prohibited by law, and so sidewalks are typically used only by pedestrians (and in some cases, children on bikes).

Trails & Greenways

A trail is any rarely interrupted pathway (often paved with asphalt), in which (in most cases) multiple forms of non-motorized transport may potentially occur. Greenways, for the purposes of this paper, are trails located through a linear corridor of open green space.[2] Traditionally, greenways were built to meet conservation and/or recreational goals, but are increasingly being used as a key element in active transportation networks as well (Little, 1990; Flink and Searns, 1993; Flink et al., 2001; Hellmund and Smith, 2006). These non-motorized "green freeways" have recently experienced a surge in construction and popularity, both nationally and internationally, spurred by the health, ecological, cultural and educational functions they support (Fabos and Ahern, 1995; Coutts, 2008).

Location: While they occasionally run alongside roads, it is more common for trails or greenways to be more spatially separated from car traffic than sidewalks, often running behind buildings or homes, or through open spaces such as parks. Despite being spatially offset from them, they still tend to run parallel to road networks (as their arrangement is usually constrained by that of surrounding buildings, which are in turn constrained by the layout of roads). Greenways frequently run parallel to waterways or other linear features in a landscape, such as railways or escarpments (Little, 1990; Flink and Searns, 1993).

Users: Potentially any kind of non-motorized transportation may occur in trails and greenways, including walking, biking, inline skating, skateboarding, cross-country skiing and even horseback riding (Flink and Searns, 1993). Trails are usually more popular for biking than sidewalks: this is undoubtedly due, at least in part, to their relative smoothness (important for bikes moving at high speeds) and continuity relative

[2]*: There are many other, broader definitions for greenways, most of which emphasize conservation or recreation goals. Not all greenways include trails (Little, 1990), and not all trails are considered greenways.*

to sidewalks. Bicyclists are much less likely to fall or be in a collision on a trail than on a sidewalk (Aultman-Hall and Adams, 1998).

It is interesting to note that despite the similarity of these two types of facilities, there seems to be an acceptance of mixed traffic (cyclist and pedestrian) on trails, despite laws to prevent this on sidewalks.

Bike Lanes

A bike lane is a section of road dedicated to cyclists, and provides cyclists a degree of separation from cars. Bike lanes help cyclists to feel safer (Lott et al., 1978; Antonakos, 1994; Harkey and Stewart, 1997; Moritz, 1997), though it is worth noting that as there is not a change in grade between most bike lanes and the road, they likely offer cyclists less protection than a sidewalk does a pedestrian. Some bike lanes do attempt to provide extra protection for cyclists through the use of bollards, raised lanes, or colour markings along the road to help drivers recognize the space (Cranstone, 2010). “Road diets” are scaled-up versions of bike lanes, in which an entire lane a road is converted for use by cyclists, creating much larger lanes than would otherwise be available (see Burden and Lagerwey, 1999).

Bike lanes may not be sufficient for all users, some of whom may require off-street bicycle trails (Krizek et al., 2009). It is generally believed that the broad order of preference among most cyclists for bicycle facilities is for bike paths (trails) first, bike lanes second, and riding in mixed traffic as a final option (Heinen et al., 2010). Some studies have shown that having more bike lanes and trails is positively correlated with a higher modal share for cycling (Barnes and Thompson, 2006; Pucher and Buehler, 2006), although Moudon (2005) concluded that they have no significant effect. People, however, will typically say that they would bike more if more bike lanes were available (Dill and Voros, 2007), and perceiving bike lanes to be present is positively associated with biking locally (Hoehner et al., 2005).

Location: Outside edge of the road, but before any on-street parking. This location presents a challenge for cyclists making left-hand turns, who must enter into motorized vehicle lanes in order to do so. On-street parking also creates a safety risk from cars pulling in to park or which suddenly open their doors and may thus hit an oncoming cyclist (Krizek and Roland, 2005; Cranstone, 2010). Bike lanes are more common on higher-order roads (and in particular, arterials or collectors), and are rarely seen on residential streets. Bike lanes may be unidirectional and on both sides of a road, or, less commonly, bi-directional on one side.

Users: Cyclists only.

Bike Routes & Roads

Where no active transportation network is present, pedestrians and cyclists must share the road with cars. Sometimes this is intentional (as in woonerven), but in most cases, it is the result of a lack of adequate planning for pedestrians and cyclists. In some such instances, a road will have a "bike route" designation added to it. These are roads which municipalities have decided to try and funnel bike traffic onto (even though they have no special structural feature for cyclists), in most cases because those particular roads are felt to be safer for some reason (e.g., less traffic) (see Cranstone, 2010; Draper City et al., n.d.). Bike routes are marked by signage, and help raise awareness among drivers that they may be sharing the road with cyclists. These are likely the most useful where limited space or funds prevent the installation of designated bike lanes.

In their study of 1128 cyclists in Edmonton, Hunt and Abraham (2007) found that time spent biking in mixed traffic was significantly more onerous that time spent on bike trails or bike lanes (see also Antonakos, 1994; Aultman-Hall, 1996; Copley and Pelz, 1995; Guttenplan and Patten, 1995; Goldsmith, 1996).

Location: On regular roads (and in the case of bike routes, as designated by a municipality)

Users: Motorized vehicles, cyclists and (less commonly) pedestrians

Woonerven or "Unified Street Systems"

Woonerven are pedestrian-priority spaces used frequently in Europe (and increasingly in Asia) in place of traditional residential roads (Southworth and Ben-Joseph, 2003). Whereas most types of active transportation infrastructure seek to separate modes, woonerven are the epitome of modal integration. Unlike roads or other active transportation network components, woonerven are as much for use as an outdoor living space (e.g., for play, gardening, socializing, etc.) as they are for transportation and parking. In some countries, it is illegal for a motorized vehicle traveling through a woonerf to travel faster than walking speed. Traffic may be slowed by the presence of people and design features such as changes in pavement, the placement of planters, trees, etc. (Southworth and Ben-Joseph, 2003).

Location: Woonerven are typically located between the fronts of homes in residential areas, though they may also be found in commercial areas.

Users: Pedestrians, cyclists, people socializing, children at play and motorists.

Other Model Components

In addition to the features that make up the road and active transportation networks, there are several other design elements that are of importance to developers, utility providers and municipalities, including:

Block Size: A function of street length, block size is important for its potential to affect travel distances. Longer blocks reduce route choice, which in turn often lengthen trips, while shorter blocks shorten them.

Buildable Area: The buildable area is the area leftover in a development once roads and right-of-ways have been accounted for. Buildable area is important to developers as it affects how many buildings can be fit onto a piece of land (which in turn affects profit).

Intersections: Road crossings can be at-grade (signalized or unsignalized) or grade-separated (overpass or underpass) (Flink and Searns, 1993). Intersections may be X-intersections or T-intersections, depending on the arrangement of the road network.

Rights-of-Way and Streets: A right-of-way (ROW) is land devoted to or acquired for transportation purposes, and which permits the legal passage over another's land (TRT, 2012). The more land that is dedicated to ROWs, the less is available for lots (and consequently buildings) (Southworth and Ben-Joseph, 2003). Right-of-ways also limit how close a building's setback can be relative to the property line. Streets are the paved portions of ROWs. Streets and ROWs affect land use efficiency by their width and their frequency of occurrence (CMHC, 2000).

APPENDIX B: SUMMARY COMPARISON OF PREVIOUS MORPHOLOGICAL STUDIES OF NEIGHBOURHOODS

Table B.1: Morphological studies of neighbourhood models – overview

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Model or case study?	Case studies (8)	Case studies (3)	Case study (with and without walkways) and corresponding "sustainable" model	Case study (1) and two corresponding models (New Urbanist and Fused Grid)	Case studies (4)	Case studies (2)	Case studies (118)	Case studies (8)
Type of neighbourhoods	Gridiron Fragmented Parallel Warped Parallel Loops and Lollipops Lollipop on a Stick	New Urbanist (Kentlands & Laguna West) Streetcar Suburb (Elmwood) (modified rectilinear grid)	Late 1990s (a visual assessment of the study suggests the neighbourhood is an example of "loops and lollipops") Sustainable model more of a warped grid with added trails to create network with differential connectivity	Loops and Lollipops Fused Grid New Urbanist	"early 1900s - 1920s"(Grid) "1950s" (Elongated grid) "1960s and early 1970s" (roughly Loops and Lollipops) "mid-1980s – early 1990s" (roughly Lollipops on a Stick)	Greenway (Radburn) New Urbanist (Kentlands)	118 urban areas from the 12 metropolitan regions in the U.S.A. (of which, 16 were pre-1920s Grid, 3 Olmsted-style suburbs, 4 Garden City influenced neighbourhoods, 2 Levittowns and 10 Edge Cities)	New Urbanist (4) Loop and Cul-de-sac (4)
Size of study areas	Three scales: community, neighbourhood and street Community: ~6,000 acres or 9 square miles Neighbourhood: 100 acres or 10 minute walk (2,000 feet) across Street and housing lots: simple cross-sections, street-scale analysis	Neighbourhood: ~100 acres (2,000 x 2,000 feet) Kentlands: 356 acres (at buildout) Laguna West: 1018 acres (at buildout) Elmwood: ~ 225 acres	23.3 ha (complete) (= 57.6 acres)	337.7 ha (= 834.5 acres)	1 km^2 (constrained) (= 247.1 acres) (modified slightly to follow property lines and road patterns) (see p. 275 of their work)	356 acres (Kentlands) 149 acres (Radburn)	(2x2 miles) + any additional area needed to fully capture any blocks intersected by the frame (and any smaller blocks contained within those blocks) (Final range: 9.1 sq. km to 38.6 sq. km, or 2248.7 to 9538.3 acres)	Ranged from 0.75 km^2 to 4.2 km^2 (= 185.3 to 1037.8 acres)

Table B.1: Morphological studies of neighbourhood models – overview (cont.)

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Borders defined	By the frame (how frame was centred was not discussed)	By the frame (same as Southworth and Owens, 1993) Plans for Kentlands and Laguna West Elmwood likely delineated by geo-political boundaries (identified as "the Elmwood district")	Development boundaries	By major roads (possibly original development boundaries, but not stated)	Locating frame in "centre" of neighbourhood, using arterials where possible	Development boundaries (Kentlands) Homeowners' association (Radburn)	All blocks that intersect with 2x2 mile frame plus any blocks contained within those blocks	Development boundaries
Acceptable walking distance	None (Mentions 10 minute walking distance for "neighbourhood scale", but does not actually say that this is seen as a reasonable trip length or anything like that)	400' to ¼ mile (122 m to 400 m) (but used absolute radius, rather than network distance)	400 m (0.25 miles)	400 m (0.25 miles)	500 m (0.31 miles)	0.25 miles (402 m) (0.33 miles or 531 m was the goal for original Radburn plan) (0.25 miles was the goal for New Urbanist plans)	1 mile (1609 m)	Not specified
Acceptable biking distance	Not discussed	Not discussed	Not discussed	Not discussed	Not discussed	Not discussed	Not discussed	Not discussed
Primary methods of analysis	Morphological analysis of neighbourhood characteristics within study frame; visual analysis of neighbourhood character	Morphological analysis of neighbourhood characteristics within study frame; visual analysis of neighbourhood character	Measurement of neighbourhood characteristics and GIS-based analysis of case study and proposed alternative model	Measurement of neighbourhood and network characteristics between case study and alternate models	Field surveys to identify lots with different land uses; measurement of neighbourhood and network characteristics from orthographs	Expanded version of Southworth's (1997) system for morphological analysis and measurement of some trip characteristics	"Spatialist_lines" software to measure characteristics of existing GIS-based representations of street networks	Surveys of residents, followed by morphological and statistical analysis
Overall evaluation technique	General discussion by topic No overall score	General discussion by topic No overall score	General discussion by topic No overall score	General discussion by topic No overall score	Rank (1st, 2nd, 3rd or 4th) for each neighbourhood by each topic No overall score	General discussion by topic No overall score	No evaluation of communities (study mostly tested techniques and described trends)	General discussion by topic Modal share No overall score

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Table B.2: Morphological studies of neighbourhood models – network characteristics assessed

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Inclusion of sidewalks, trails, or alleys in quantified measures?	None (Pedestrian and bike pathways mentioned) (not clear if alleys in road counts or not – they do not appear to be on the thumbnails)	Alleys (pedestrian and bicyclist paths mentioned briefly)	Walkways	Alleys	Sidewalks (as a land use) Allowed sidewalks and pathways to be used in shortest path calculations	"pedestrian only" networks assessed separately	Not explicitly included, although alleys may be captured if included in a city's street network feature class in the GIS	Alleys, sidewalks and trails (termed "paths")
Connectivity measures[1]	Road coverage, number of blocks and number of intersections within a given area (which could be converted into densities)	Road coverage, number of blocks and number of intersections within a given area (which could be converted into densities)	Proportion of residences outside 400 m (via the network) of three types of destinations (schools, open spaces, transit stops) Average and maximum walking distance to three types of destinations (schools, open spaces, transit stops) Linear feet of roads	None	Proportion of residences within 500 m (via the network) of three types of destinations (schools, supermarkets, convenience stores)	Ratios of travel distances (essentially measures of differential connectivity) for all trips to certain destinations (school, shopping, and park) Air:Drive Air:Walk Drive:Walk	Assessed using metric reach	Ratio of travel distances (as the crow flies vs. ped network) between homes Street/path/lane density
Intersection measures	Visual depiction of all intersections (X and T) Total intersection count (CDS intersections not counted)	Visual depiction of all intersections (X and T) Total intersection count (CDS intersections not counted)	Not assessed	X vs. T- counts Total number of intersections Considered *percent change* in T- and X-intersections between models (CDS intersections counted - see pg. 61)	X- vs T- counts	Visual depiction of all intersections (X and T) Total intersection count	# of choice intersections # of choice intersections/sq. kilometer (CDS intersections not counted – see pg. 887)	None (Network density could act as a proxy, though)
Neighbourhood accessibility	Count, but "access points" not defined (presumed to mean points connecting to arterials, but may include collectors)	Count, but "access points" not defined (presumed to mean points connecting to arterials, but may include collectors)	Mentioned that values increased between models, but did not quantify (p 16)	Count of entry points	Entrance/exit point counts to arterial network	Count of "access points"	(None)	None

[1]: In some studies, the coverage of the road network is used as a proxy for connectivity (under the assumption that more roads will typically provide more connections), and so has been included here.

Table B.2: Morphological studies of neighbourhood models – network characteristics assessed (cont.)

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Bicycle network	Mentioned very briefly, but not assessed	Mentioned, but not assessed or depicted	Not assessed (bicycling mentioned very briefly)	Mentioned, but not assessed or depicted	Not explicitly assessed (Unclear whether "sidewalk" counts include pathways or not, which authors did suggest they wished to consider and use for shortest path calcs - see 276)	Not discussed	(None)	Not discussed beyond question regarding perceived safety of combined walking and biking
Street network (described in…)	Linear feet	Linear feet	Linear meters	By area and as percent of land use	By area	Linear feet	Length in kilometers Length in km / sq. km	Density (combined with lanes, paths) % streets <7.6 m wide
Street types	Count of loops and cul-de-sacs (as one category)	Count of loops and cul-de-sacs (as one category)	Not assessed	Count of loops Count of cul-de-sacs Considered *percent change* in loops and CDS between models (Amber notes: dwelling units located on loops or CDS would be better measure, since lengths of loops and CDS can vary considerably between models)	Not assessed	Count of loops and cul-de-sacs (as one category)	(None)	Not assessed
Road widths and Right-of-Ways (ROWs)	Trends/range provided	Range (and in some case, specifications) provided	Not assessed	For Fused Grid only: Area and % breakdown for local roads, rear lanes, and ½ of perimeter roads	Not assessed (Although land dedicated to roads was)	Ranges (and in some cases, specifications) provided	(None)	Road widths assessed % <7.6m wide given ROWs not discussed
Active transportation network coverage (sidewalks and trails)	Not assessed	Not assessed	Not assessed (surprising, given that focus was on adding pathways)	Not assessed	Not assessed (area of network, but not length)	Lineal feet of "pedestrian only"	(None)	Combined street/lane/path density % of roads with sidewalks on both sides % of roads without sidewalks

Table B.2: Morphological studies of neighbourhood models – network characteristics assessed (cont.)

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Continuity: intersection conflict points	Not assessed (Intersection density)	Not assessed (Intersection density)	Not assessed	Not assessed	Not assessed	Mean number of street crossings during trips	Not assessed	Not assessed
Continuity: driveway conflict points	Not assessed	Not assessed	Not assessed	Not assessed	Indirectly (area dedicated to driveways and parking lots)	Not assessed	Not assessed	Not assessed (though discussed availability of parking spaces)
Modal separation	Not assessed	Briefly mentioned	Not assessed	Not assessed	Not assessed	Discussed	Not assessed	Assessed by analysis of proportion of streets with sidewalks on both sides and path density (unfortunately not presented separate from road and sidewalk density)
Legibility	(None – mentions non-directional nature of later curvy roads on pg. 275)	Not assessed	Not assessed	Not assessed (though mentioned as a goal)	Not assessed	Mentioned, but not assessed	Assessed using directional distance	Not assessed

Table B.3: Morphological studies of neighbourhood models – density, land use and other characteristics assessed

	Southworth and Owens (1993)	Southworth (1997)	Aultman-Hall et al. (1997)	CMHC (2000)	Filion and Hammond (2003)	Lee and Ahn (2003)	Peponis et al. (2007)	CMHC (2010)
Housing	Discussed, but not assessed	Visual depiction of mix; % mix not given	Total number of units % mix by type	For Fused Grid only: Total and % mix by housing type	Total and % mix by housing type	Total and % mix by housing type	Not assessed	% single-detached houses
Land use measures	No quantification: discussion of trends, maps	Open space (total area and by percent; also general description of number vs. size)	Developed area Community or open space Serviced road length Commercial floor space	Total area and % for: Residential Commercial & institutional Recreation & open space *(broken down into community centre, public parkland, buffer)* Transportation *(broken down into public streets, private streets and lanes/alleys)* Vacant land	Total area and % for: Building footprint Road surfaces Driveways, parking Sidewalks Undeveloped lots Patios, pools, decks Green space Residential portion Also provided a separate breakdown using the same categories but just looking within the land dedicated to residential	Total are and % for: Open space	Not assessed	Counted non-residential land uses within 1 km % open space
Infrastructure assessment	Mentioned very briefly	Not assessed	Mentioned very briefly, not assessed	None	Residential area infrastructure load per housing unit (m^2) (included roads, sidewalks, open space)	Not assessed in terms of efficiency (open space values provided)	Not assessed	Not assessed in terms of efficiency (open space values provided)
Density	No assessment – some general discussion	Dwelling units per net acre by housing type; also by total average Dwelling units per gross acre (total average)	Units/ha	For Fused Grid model only: Number of dwelling units Gross residential density % units on perimeter vs. % units on loops or cul-de-sacs	Residential units per km^2	Gross density (dwelling units/acre as well as persons/acre) Net density for single detached homes (also total number of dwelling units in each)	Not assessed	Gross density (units per hectare)
Blocks	Count	Count	Not assessed	None	Not assessed	Count (Considers both those formed by streets and the smaller ones created by the ATN)	Count #blocks / sq. km	Not assessed
Lot sizes	Range provided Graphic example provided	Range provided	Not assessed (though affected results)	Not assessed	Not assessed	Described (building footprints too)	Not assessed	Not assessed
Building setbacks	Mentioned briefly	Not assessed	Included in the distance measurements but actually just nodes located in the centre of lots (so used lot size as a proxy for setbacks)	Not assessed	Not assessed	Mentioned briefly	Not assessed	Assessed (Correlation only)

APPENDIX C: MEASURES USED IN GIS-BASED WALKABILITY AND BIKEABILITY INDICES

Table C.1 below summarizes the types of measures considered in the six GIS-based walkability and bikeability indices identified by the Centre on Health Promotion Research for Persons with Disabilities in 2009.

Table C.1: Measures used in GIS-based walkability and bikeability indices

	Walkability/Bikeability Measures									
Index/Tool	**Land Use**	**Density**	**Connectivity**	**Sidewalk Coverage**	**Bicycle Infrastructure**	**Building Setbacks**	**Transit Stop Conditions**	**Topography**	**Intersections**	**Vehicle Parking**
PLIT1 (Moudon, 2001)	**No**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
PLIT 2 (Moudon, 2001)	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**No**	**No**
PEF (1000 Friends of Oregon, 1993)	**No**	**No**	**Yes**	**Yes (listed as continuity, but really a measure of coverage)**	**No**	**No**	**No**	**Yes**	**Yes**	**No**
Montgomery County Example of a PBEF (Replogle, 1995)	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Objective Built Environment Indices (Parks and Schofer, 2006)	**No**	**No**	**Yes**	**Yes**	**No**	**Yes**	**No**	**No**	**Yes**	**Yes**
GIS Walkability Index (Leslie et al., 2007)	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**	**No**

APPENDIX D: SUMMARY COMPARISON OF BASIC MODEL ELEMENTS & DESIGN PRINCIPLES IN THE LITERATURE & CASE STUDIES

The following four tables summarize the basic elements and design principles that make up each of the five study models. For the most part, these have been informed by the literature, but in some cases a visual assessment of case study neighbourhoods was performed in order to complete the tables. These are meant to provide a general description only; see Appendix E for more detailed measurements from a variety of case studies and design guidelines, as well as the specifications used to construct the GIS-based models used in this study.

Table D.1: Comparison of basic neighbourhood characteristics of different models

	Grid	**Loops & Cul-de-Sacs**	**Fused Grid**	**New Urbanist**	**Greenway**
Net density	Not prescribed (often high)	Low	Low-medium	Medium-High	Low
Land use[1]	Not prescribed (usually mixed)	Single-use (residential)	Mixed	Mixed	Mixed
Through traffic (motorized)	Common	Significantly reduced	Significantly reduced	Common	Significantly reduced
Block size	Small	Large	Medium	Small	Medium
Open space	Optional, small	Optional, usually medium-large	Required (many small); optional larger parks within the mixed-use bi-way in some versions	Optional, usually several small and possibly a few large	Required (greenways created by front yards) Optional larger parks as well

[1]: Land use – any model listed as "mixed" regularly includesand advocates for retail and institutional land uses as part of their plans, though mixed uses may not be present on every street.

Table D.2: Comparison of road network characteristics of different models

	Grid	**Loops & Cul-de-Sacs**	**Fused Grid**	**New Urbanist**	**Greenway**
Road network layout	Grid	Loops and cul-de-sacs	Loops and cul-de-sacs	Grid or modified grid	Loops and cul-de-sacs
Network hierarchy	Non-hierarchical	Hierarchical	Hierarchical	Hierarchical (theoretically could be non-hierarchical, but unlikely in practice)	Hierarchical
Road location	Front of homes (occasionally dual-sided due to alleys)	Front of homes	Front of homes (dual-sided due to alleys for homes on arterials)	Dual-sided due to alleys	Back of homes
Alleys	Occasionally	No	Rarely (for homes located on arterials in some models)	Often	No
Driveway location	Front (no alleys) or back (with alleys)	Front	Front (back for homes on arterials with alleys)	Back (when alleys present)	Back
Connectivity type[1]	Uniform	Uniform	Differential	Uniform	Differential
Connectivity and route choice for cars	High	Low	Medium or low (depending on superblock size)	High	Medium or low (depending on superblock size)

[1]: Differential here refers to an intentional and systematic effort to increase pedestrian and/or cyclist network connectivity over that of motorists'; uniform means that they are roughly the same

Table D.3: Comparison of active transportation network characteristics of different models

	Grid	Loops & Cul-de-Sacs	Fused Grid	New Urbanist	Greenway
Pedestrian network layout	Same as road network (Grid)	Same as road network (Loops and Cul-de-sacs)	Fused Grid	Same as road network (Grid or Modified Grid)	Off-set grid
Network Components					
Sidewalks	Yes	Optional	Yes[1]	Yes	No
Trails	Optional	Optional (but common)	Yes (connecting disconnected roads)	Optional (but common)	Yes (replace sidewalks)
Greenways	Optional	Optional	Optional	Optional	Yes
Bike lanes or routes	Not explicitly	Not explicitly (but increasingly common on higher order roads)	Along arterials in some versions	Not explicitly (but likely common on higher order roads)	Unlikely (cyclists expected to travel on trails)
Woonerven (North American examples only)	No	No	No	No	No

[1]: Sidewalks were suggested as being optional on local roads in the CMHC (2000) report "Learning from Suburbia: Residential Street Pattern Design", but have not been listed as such since.

Table D.4: Anticipated Active Transportation Network Characteristics[1]

	Grid	Loops & Cul-de-Sacs	Fused Grid	New Urbanist	Greenway
Connectivity and route choice for pedestrians and cyclists	High	Low	Medium-High	High	Medium-High
Continuity – as a result of intersection conflicts	Low (frequent intersections)	High (rare intersections)	High (rare intersections)	Low (frequent intersections)	High (rare intersections)
Continuity – as a result of driveway conflicts	Low (frequent driveways)	Low (frequent driveways)	Low (frequent driveways)	High (no driveways crossing sidewalks)	High (no driveways crossing trails)
Modal separation	Low	Low-Medium (trails, bike lanes present)	Medium (some sidewalks free of driveways; trails, bike lanes present)	Medium (most sidewalks free of driveways; trails, bike lanes present)	High (near-complete separation through trail network)
Natural surveillance	High (roads, sidewalks)	Medium (roads, sidewalks)	Medium [2] (sidewalks) Low (trails)	High (roads, sidewalks)	Medium (trails) Low (roads)

[1]: These are based on the literature review, and are presented separately from the actual results of this study found in Chapter 5.

[2]: Only medium because of low-mid densities; in a high-density neighbourhood, natural surveillance on these path types would be high.

Table D.5: Comparison of lot characteristics of different models

	Grid	Loops & Cul-de-Sacs	Fused Grid	New Urbanist	Greenway
Privacy	Low	High	Medium-High	Low	Medium
Housing faces…	Road	Road	Road	Road	Greenway
Back yards	Small	Large	Large	Small	Large
Front yards	Small or non-existant	Medium	Medium	Small or non-existant	Dependent on width of greenway[1]
Right-of-ways	Single	Single	Single (possibly double where alleys present)	Single (possibly double where alleys present)	Double (public access required for road and trails)

[1]: If the greenway is narrow, a deeper front yard will be required to create extra space between homes in the absence of a road.

APPENDIX E: ADDITIONAL GUIDELINES & SPECIFICATIONS

The following tables outline the specifications that were used in GIS model development. The first set of tables lists the specifications for various characteristics that provided the starting point for model construction, except in instances where specific guidelines or case studies exist that suggest that the neighbourhood model should deviate from them. Such model-specific information is provided in the remaining five sections, which outline design guidelines and case study data for each of the neighbourhood models under consideration, and the design targets that were used during the construction of each of the five GIS models.

Table E.1: Road network elements

Options Available	Arterial, collector, local (includes cul-de-sac, loop, and through roads) and alleys (laneways)	
Notes:	**Lane widths:** Can range from 3.0 m per lane (TAC (2007)'s minimum for local roads) to 4.5 m (TAC's maximum for lanes that allow biking in mixed traffic and an Average Annual Daily Traffic (AADT) in the shared lane of 3,000 – 6,000). Individual roads will be a constant number of lanes throughout the model space. (The exact number of lanes used for roads in each model is specified in the model specific tables, starting on p. 363) **Traffic flow conditions on local roads:** Slow flow or yield flow	
	Design Guidelines	**This Study's Models**
Specifications	**Arterial width:** TAC (2007) recommends 3.5-3.7 m (11.5 – 12.1') per through lane for a 60 km speed along "minor arterials". If bike lanes are not provided, the lane width on arterials needs to be increased to accommodate bike traffic. Assuming an AADT of 3,000 – 4,000 vehicles, the recommended lane width is 4.0 m – 4.5 m (13.1' – 14.8'). In some cases it may be possible to narrow the other lanes to compensate for this (TAC, 2007). **Collector width:** TAC (2007) recommends 3.5 – 3.7 m (11.5 – 12.1') per through lane in residential areas while NAHB et al. (2001) recommends a paved area of 32-36' (9.8 m – 11.0 m) for two lanes and two parking lanes. As with arterials, if bike lanes are not provided, the lane width on collectors needs to be increased to accommodate bike traffic (TAC, 2007). Assuming an AADT of 0 – 1,000 vehicles, the recommended land width is a standard width (3.5 – 3.7 m) up to 4.0 m (13.1'). In some cases it may be possible to narrow the other lanes to compensate for this.	**Arterials:** • 3.7 m (12.1') per through lane on roads with bike lanes, 4.2 m (13.8') for the outside lane on roads without. **Collectors:** • 3.5 m (11.5') per through lane on roads with bike lanes, 4.0 m (13.1') for the outside lane on roads without. Note: In "no bike lane" scenarios on roads with more than one lane going in either direction, it will be assumed that the inside lanes cannot be narrowed further even when the outside lane is expanded to allow for safer mixed traffic.

Table E.1: Road network elements (cont.)

	Design Guidelines	This Study's Models
Specifications	**Local width:** TAC (2007) recommends 3.0 m (9.8') – 3.7 m (12.1') per through lane in residential areas while NAHB et al. (2001) suggests a minimum 18' (5.5 m) with no parking, 22 to 24' (6.7 – 7.3 m) for low volume streets with limited parking, or 24 to 26' (7.3 – 7.9 m) for two parking lanes with a yield-flow traffic lane, or one parking lane with two moving lanes (slow flow operation). In some high density areas, two moving lanes (free flow operation) may be required (NAHB et al., 2001). **Cul-de-sac turning circles:** TAC (2007) recommends a minimum 14 m (45.9') radius without centre island for cul-de-sacs, while NAHB et al. (2001) notes that 30' (9.1 m) is usually sufficient, or 42' (12.8 m) where the road is frequently used by larger vehicles such as school buses and garbage trucks. **Cul-de-sacs – length:** NAHB et al. (2001) recommends that a cul-de-sac be able to accommodate a maximum of 20 to 25 houses, while Southworth and Ben-Joseph (2003) found that cul-de-sacs usually serve up to 20 homes. **Alley locations:** Alleys should be considered where lot widths are less than 50' (15.2 m) (NAHB et al., 2001). **Alley widths:** TAC (2007) recommends alleys be a minimum 4.8 m (15.7') wide, while NAHB et al. (2001) recommends a 12 foot (3.7 m) pavement width. **Curbs and gutters:** Gutters range in width from 0.25 m – 0.50 m (0.8 – 1.6'), with higher order roads having gutters at the upper end of this range (TAC, 2007). It is assumed that the width of the curb must be in addition to this. TAC does not specify a width for curbs, but a visual analysis of the manual's diagrams suggests a width of around 0.15 m (0.5').	**Local width:** Varies by model (allowable range of 3.0 m to 3.7 m per through lane) (9.8 – 12.1'). **Alley locations:** Alleys will only be included in models that explicitly include them. **Alley width:** Alleys in all models will have a 4.8 m (15.7') wide paved surface **Cul-de-sac turning circles:** While other types of turning areas are possible (for instance, T- or Y-shaped turnarounds for very short streets) (NAHB et al., 2001) all dead-end streets in this study will be treated as ending in a traditional cul-de-sac with a 14 m (45.9') radius and no centre island. (Note: this is with the exception of one dead-end road purposely shown not to end in a cul-de-sac in the CMHC's (2000) representation of one configuration of the Fused Grid model) **Cul-de-sacs – length:** Cul-de-sacs will be designed to support a maximum of 25 dwelling units. **Curbs and gutters:** Assumed to be present on all roads but not alleys. Curbs are assumed to be the standard 0.15 m (0.5') high, which is low enough to not count as lateral obstructions and thus eliminates the need for a 0.6 m (2.0') horizontal clearance zone between the bike lane and edge of road, as per TAC (2007). *Width on local roads and collectors:* • A combined width of 45 cm (30 cm gutter + 15 cm curb) (1.5') *Width on arterials:* • 55 cm (40 cm gutter + 15 cm curb) (1.8')

Table E.2: Intersections

Options available	2-way, 3-way (T), 4-way (X)	
Notes:	**Two-way intersections:** Are intersections where no turning options are available, such as when a railway or multi-use trail crosses a road mid-block and continues on the other side. **Intersections:** All intersections will be simple intersections (no flared/auxiliary left or right turn lanes). Models will assume every intersection requires a full stop.	
	Design Manuals	**This Study's Models**
Specifications (for those characteristics which will be common to all models)	**Minimum spacing of intersections along roads:** TAC (2007) recommends a minimum spacing of 200 m (656.2') between signalized intersections on arterials. Desirable spacing is based on cycle length: assuming an 80 second cycle length and a 60 km/hr running speed, there is a desired spacing of 665 m (2181.8') between signalized intersections for arterials. For a 50 km/hr running speed, the desired spacing would be 555 m (1820.9'), or for 40 km/hr, 445 m (1460.0'). TAC recommends a minimum spacing of 60 m (196.9') between intersections along collectors, while NAHB et al. (2001) recommends a minimum of 250' (76.2 m). For local streets, NAHB et al. (2001) recommends 125' (38.1 m) between intersections., while TAC recommends a minimum of 60 m (196.9') for X intersections, 40 m (131.2') for T intersections. **Range of Acceptable Angles for Network Segments Approaching Intersections:** 70 – 110°, with 90° preferred (TAC, 2007)	**Spacing along arterials:** Will vary by model, but minimum spacing will be 200 m (656.2'). **Spacing along collectors:** Minimum spacing of 60 m (196.9') for any type of intersection **Spacing along local roads:** Minimum 40 m (131.2') between any type of intersection. **Range of Acceptable Angles for Network Segments Approaching Intersections:** 70 – 110°.

Table E.3: Active transportation network elements

<table>
<tr><td>Options available</td><td colspan="2">Sidewalks, bike lanes, multi-use trails</td></tr>
<tr><td>Notes:</td><td colspan="2">Bike lanes: All bike lanes assumed to be one-way exclusively used by cyclists.

Biking in mixed traffic: Extra wide through lanes for biking in mixed traffic addressed in Table E.1, above.

Trails: All trails are assumed to be two-way and multi-use (shared by pedestrians and cyclists)</td></tr>
<tr><td></td><td>Design Manuals</td><td>This Study’s Models</td></tr>
<tr><td>Specifications (for those characteristics which will be common to all models)</td><td>Sidewalks location: Desirable on both sides of the street and generally placed on at least one, with the exception of short P-loops and cul-de-sacs less than 150 m (TAC, 2007).

Sidewalk width: Minimum 1.5 m (4.9’), 1.8 m (5.9’) (desirable/standard), 2.0 m (6.6’) (to accommodate an individuals in a wheelchair) and up to 2.4 m (7.9’) (in higher traffic areas such as in commercial areas) (TAC, 2007). 2.4 m is also required for people with strollers, wheelchairs, or groceries to be able to pass one another.

Minimum 4‘ (1.2 m) and often 5‘ (1.5 m) (NAHB et al., 2001).

Bike lane location: Where on-street parking is allowed, bike lanes fall between the motorized traffic lanes and the parking lanes (TAC, 2007). Otherwise they are located along the outer edge of a road.

Bike lane width:
TAC recommends 1.5 – 2.0 m (4.9 – 6.6’) for one-way exclusive bike lanes while AASHTO (1991) recommends a minimum of 5’ (1.5 m) for one-way exclusive bike lanes.</td><td>Sidewalk locations: On both sides of the road in all models in order to reflect a “best case” scenario.

Sidewalk widths:
• Standard width: 1.8 m (5.9’)
• Wider width: 2.0 m (6.6’) (for those models that emphasize active transportation)

Bike Lanes:
• 1.6 m (5.2’) on arterials in all models with bike lanes (Loop and Cul-de-Sac, Fused Grid and New Urbanist)
• 1.5 m (4.9’) on collectors in all models with bike lanes
• No bike lanes on local roads

Front Door Connections:
• Models with alleys will require an additional line segment to connect the front door to sidewalk or trail (in absence of a driveway). These connections will have a width of 3’ in all models.</td></tr>
</table>

Table E.3: Active transportation network elements (cont.)

	Design Manuals	This Study's Models
Specifications (for those characteristics which will be common to all models)	**Landscaped boulevards:** 2.0 – 3.0 m (6.6 – 9.8') recommended by TAC (2007), 3 - 5' (0.9 – 1.5 m) recommended by NAHB et al. (2001). **Trail location:** Trails are generally kept parallel to the road network or other corridors and should be designed to keep the number of road crossings to a minimum (TAC, 2007). It is recommended that they not be located in the boulevard. **Trail width:** Recommended widths for two-way shared multi-use trails: • 3.0 – 4.0 m (9.8 – 13.1'), noting that the minimum values are only suitable where bike and pedestrian traffic is low (TAC, 2007) • 8' to 10' (2.4 – 3.0 m) wide for shared trails (NAHB et al., 2001) • 12' (3.7 m) (suburbs) and 14' (4.3 m) (urban) (Flink and Searns, 1993)	**Landscaped buffers (boulevards):** All models will have a 1.5 m (5') boulevard, which is seen as being a compromise between NAHB et al. and TAC recommendations and between those models that often have larger boulevards (loop and cul-de-sac) and those which typically have narrower ones (grid, New Urbanist). **Trail location:** Model-dependent, but always designed to connect roads where possible. (In some cases parks may only face one road, in whch case, the trail may result in a dead-end or terminal loop). **Trail width:** 11' (3.4 m)

Table E.4: Parking elements

Options available	On-road parking, driveways	
Notes	**On-road parking:** The width of these lanes will be included in the overall roadway width and not created as separate lines. **Parking lots:** are assumed to be part of the larger land dedicated to "% Other" land use type and will not be depicted in the models.	
	Design Manuals	**This Study's Models**
Parking specifications (common to all models)	**On-road parking location:** Can have on-street parking on both sides of local streets, but should not have any on-street parking on collectors (NAHB et al., 2001). Despite this recommendation, however, the NAHB et al. manual still gives road widths for collectors with parking lanes. TAC (2007) also suggests that on-road parking is possible for non-local streets, as it provides a lane width for non-local road scenarios. **On-road parking lane width:** 2.4 m (7.9') wide parking lanes for local streets, 2.8 m (9.2') for all other types of streets (TAC, 2007). **Residential driveways:** TAC recommends that single-lane residential driveways be 3.0 – 7.3 m (9.8 – 24.0') wide, spaced a minimum of 6.0 m (19.7') apart where on-street parallel parking is present (otherwise, the minimum spacing is 1.0 m (3.3') apart).	**On-road parking location:** • None on arterials • One side of collectors • Both sides of local roads (but no extra width provided on the turning circle portion of cul-de-sacs) **On-road parking lane width:** • 2.4 m (7.9') wide parking lanes for local streets • 2.8 m (9.2') for collectors **Residential driveways:** • All single-detached residential driveways are assumed to be a single lane 3.5 m (11.5') wide at 90 degrees to the road and spaced a minimum of 1.0 m (3.3') apart on streets without parallel parking and a min. 6.0 m (19.7') apart otherwise. • There will be no shared driveways used for neighbouring detached houses in this model. • Multi-unit buildings with more than 30 dwelling units were treated as having double lane driveways, 7.0 m (23.0') wide and assumed to access a rear parking lot (e.g., there will be fewer driveways than units in these cases).

Table E.4: Parking elements (cont.)

	Design Manuals	This Study's Models
Parking specifications (common to all models)	**Driveway widths – all other land uses:** For other land uses, two to five- lane driveways are common (TAC, 2007). TAC recommends a total width of 7.0 – 12.0 m (23.0 – 39.4') for two-way driveways in commercial areas, or up to a maximum of 17.0 m (55.8') where a five-lane driveway occurs. **Number of driveways for non-residential land uses:** TAC (2007) recommends 1 driveway for a land use with a 15 m (49.2') frontage, up to 2 for a 16-50 m (52.5 – 164.0') frontage, up to 3 for a 51-150 m (167.3 – 492.1') frontage and 4 or more for properties with 150+ m (492.1'+) frontage.	**Driveway widths – all other land uses:** • All "other land use" driveways will be assumed to have a double lane width (7.0 m / 23' wide) **Number of driveways – all other land uses:** Since any division of "other land use" properties into different lot sizes between models would be largely arbitrary, a fixed value of 1 driveway per 30 m (98.4') of lot fronting the road will be used for these lots.

Table E.5: Land use types

Options available	Residential Parks/Open Space "Other" (includes commercial, institutional, industrial, etc.)	
Notes	(None)	
	Design Guidelines	**This Study's Models**
Specifications (common to all models)	**Residential area:** No specific guidelines available (tends to vary by model) **Park area:** While none of the manuals consulted deal with land use allocations, the Ontario Planning Act (1990) section 42(1) enables municipalities to require up to a 5% parkland dedication as a condition of residential development. **"Other" land uses:** Since specifications concerning land use is typically a component of neighbourhood models, no general design guideline information was collected on this variable.	**Residential area:** Varies by model **Park area:** A minimum 5% of each model will be set aside for parks and open space. **Other land uses:** Will vary by model, using the following arbitrary values based on qualitative descriptions of the models in the literature as having "low" "medium" or "high" land use mix. • Low land use mix: 4% (based off the known value for the Loop and Cul-de-Sac neighbourhoood of Barhaven in Ottawa) (CMHC, 2000) • Medium land use mix: 6% • High land use mix: 8% (based off the known value for Savannah in CMHC, 2000)

Table E.6: Housing types and lot characteristics

Options available	Single-detached (1 dwelling unit per building) Rowhouses (minimum 4 dwelling units in a row) Multi-unit (includes apartments, condos, duplexes and triplexes) (2+ dwelling units per building)	
Notes	The distance of the origin points from the road in each model will be based off the building setbacks for each (as this would reflect the proximity of a front door to a given pathway). (One exception for this is the Greenway model, in which the origin points will be set back from the trail at the front of the homes instead). Front doors for all properties will be located (width-wise) at the centre of each lot.	
	Design Guidelines	**This Study's Models**
Specifications (common to all models)	**Building setbacks:** TAC (2007) requires a minimum 0.3 – 1.0 m (1.0 – 3.3') buffer (border) between sidewalks and buildings on local and collector roads, and notes that a wider border may be needed on arterials and freeways. They similarly note that having a building right beside a sidewalk or other pathway reduces its usable width by 0.6 to 0.9 m (2.0 – 3.0'). **Lot size for single-detached homes:** Average lot size in Jan. 2010 was 50' x 115' (15.2 – 35.1 m) (CHBA, 2010)	**Building setbacks:** the minimum setback for all models in this study will be 1.0 m (3.3'). **Target lot size for single-detached homes:** 50' x 115' (15.2 – 35.1 m) in all models except the New Urbanist (which explicitly makes use of narrower lots). *(Lot size for row houses was typically less than 50' wide but still 115' deep; lot size for multi-unit buildings depended on the number of dwelling units it contained and the style of housing common to the model – i.e. low rise or high rise).*

MODEL #1: GRID MODEL

Table E.7: Grid model specifications – network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road spacing and/or block dimensions	**Elmwood:** 0.25 blocks / acre (Southworth, 1997) **Gridiron:** 0.31 blocks/acre (Southworth and Owens, 1993)	(Based on block length for this model, set at 400' x 230', or 121.9 m x 70.1 m)
Road widths	**Elmwood:** Streets are 30 – 34' (9.1 – 10.4 m) wide (Southworth, 1997) **Wallingford:** 53', 60' or 66' (16.2 m, 18.3 m or 20.1 m) (Moudon, 1992). (Note: Not clear if this is ROW or paved area, but likely the ROW).	**Local roads:** 11.7 m (38.4') (Two 3.0 m through lanes + two 2.4 m parking lanes on either side of street + 0.45 m of curb and gutter for each side of the road) *(Note: In other models, local roads had one through lane under "yield" conditions and two parking lanes, but as it is hard to imagine an entire grid network where roads only had one through lane, two were used here instead).* **Collectors and Arterials:** N/A – all roads in the Grid model will be local roads
Road pattern (proportions of different road or intersection types)	<u>**Proportion of Intersection Types:**</u> **Rosemount** T/X/5-way: 42.86%, 54.76%, 2.38% (Filion and Hammond, 2003) **Kingsdale** T/X/5-way: 59.52%, 40.48%, 0% (Filion and Hammond, 2003) **Gridiron:** 0 loops and/or cul-de-sacs per acre (Southworth and Owens, 1993)	**Intersection types (target):** 100% X (4-way) intersections **Number of loops and cul-de-sacs:** No loops or cul-de-sacs

Table E.8: Grid model specifications –active transportation network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Alleys	**Wallingford:** Alleys not mentioned (Moudon, 1992) **Elmwood:** Alleys not mentioned (and likely not present in this case, as they are explicitly mentioned for the other communities in Southworth's study) (Southworth, 1997) **Livermore:** Alleys not mentioned (Southworth and Owens, 1993) **Other studies:** Hess (2008) notes that alleys were a common part of many 19th and early 20th century developments.	No alleys in this model in order to further differentiate the "Grid" model from the "New Urbanist" model.
Sidewalks - location	**Elmwood:** Sidewalks on both sides of the streets (Southworth, 1997)	
Sidewalks – width	Not available	Standard (1.8 m / 5.9')
Bike lanes	Not available, though from reference to there being no exclusive cyclist routes in Elmwood, one may infer there are no bike lanes (see Southworth, 1997).	Bike lanes present on both sides of collectors and arterials.
Trails	**Elmwood:** Has no trails (Southworth, 1997)	Trails in parks in this model, but no major trails present.

Table E.9: Grid model specifications – land use, density, building and lot characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
% Residential	**Savannah:** 43% (CMHC, 2000)	Whatever remains once transportation networks, open space and other land uses are accounted for.
% Open space	**Savannah:** 7.0% (CMHC, 2000) **Beach, Cedarvale and Leaside Communities (Toronto):** 2.1 – 5.6% in older Toronto communities which range from true grids to fragmented parallel hybrids (IBI, 1995) **Elmwood:** "Virtually none" (Southworth, 1997)	Minimal (5%) (= 8 acres in model space)
% Other	**Savannah:** 8.0% (CMHC, 2000)	High (8%) (= 12.8 acres in model space)

Table E.10: Grid model specifications – density characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
Density	<u>**Gross densities:**</u> **Elmwood:** 10.2 d.u. / acre (Southworth, 1997) <u>**Net residential densities:**</u> **Elmwood:** Average of 8 d.u. / net acre for single-family residential areas (Southworth, 1997)[1] **Rosemont:** 8.8 d.u./net acre (Filion and Hammond, 2003) **Kingsdale:** 8.7 du/net acre (Filion and Hammond, 2003)	Gross density of 10 d.u./acre (= 1600 d.u. in the model space)

[1]: It is assumed that the lower net residential density than gross density for Elmwood is because of the exclusion of multi-family homes/lots/areas from the net residential density calculation. (As otherwise, net density should always be higher than gross).

Table E.11: Grid model specifications – building and lot characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
% Single detached	**Kingsdale – single-detached and semis:** 43.4% (Filion and Hammond, 2003) **Rosemount – single-detached and semis:** 58.6% (Filion and Hammond, 2003)	50% of dwelling units
% Rowhouse	**Kingsdale:** 0% **Rosemount:** 0.4% (Filion and Hammond, 2003)	0% of dwelling units
% Multi-unit (triplexes or larger)	**Kingsdale:** 56.6% **Rosemount:** 41.0% (Filion and Hammond, 2003)	50% of dwelling units (mostly in high rises)
Lot dimensions for single detached homes	**Elmwood:** Average lot size of 30 - 40' (9.1 – 12.2 m) wide by 120 - 135' (36.6 – 41.1 m) deep (presumably for single-detached homes) (Southworth, 1997) **Wallingford:** 40' x 120' (9.1 m x 36.6 m) (Moudon, 1992) **Other studies:** Often narrow-and-deep, 40' or 50' by 100'+ (12.2 m or 15.2 m x 30.5+ m) (Moudon, 1992)	Standard (50 x 115') (15.2 – 35.1 m)
Setbacks	No data available, but the author has observed that in many grid neighbourhoods the homes are built relatively close to the road.	Shallow Single-detached: 20' (6.1 m) Row: 20' (6.1 m) Multi-unit: 50' (15.2 m)

LOOP AND CUL-DE-SAC MODEL

Table E.12: Loop and Cul-de-Sac model specifications – network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road spacing and/or block dimensions	**Road Spacing:** **Barhaven:** Minor collectors approximately every 650' (198.1 m) and major collectors approximately every 1300' (396.2 m) (CMHC, 2000). **Block Density:** **Loops and Lollipops:** 12 blocks per 2000 x 2000' area (= 0.13 blocks per acre) (Southworth and Owens, 1993) **Lollipops on a Stick:** 8 blocks per 2000 x 2000' area (= 0.09 blocks per acre) (Southworth and Owens, 1993) **Block Dimensions:** **CMHC (2010) Analysis:** • 470' - 740' (143.3 – 225.6 m) for loops • 530' (161.5 m) for cul-de-sacs • 200' (61.0 m) block depth for all their models save for square grid **CMHC (2004) Stratford model:** Block depth of 220' – 270' (67.1 – 82.3 m)	Target of 0.11 blocks per acre or roughly 18 blocks for total model space (160 acres). Typical block depth of 230' (70.1 m) (based on 2010 survey showing average lot dimensions of 50' x 115' for a single-detached house). **Target loop length:** 470' - 740' (143.3 – 225.6 m). **Target cul-de-sac length:** 200' – 600' (61.0 – 182. 9 m) (Allows approx. 10 – 25 houses on any given cul-de-sac, based on a recommended maximum of 25 houses (NAHB et al., 2001). Slightly shorter-than-normal cul-de-sacs allowed in light of what appears to be an increasing societal preference for them).
Road widths	**Upland Green (Washington):** 24' or 28' (7.3 to 8.5 m) paved area (Moudon, 1992) **CMHC (2010) Case Studies (4 Neighbourhoods):** % Streets <7.6 m (24.9') wide: 3.9%	**Local roads:** 9.2 m (30.2') (One through lane at 3.5 m per through lane + 2.4 m parking lanes on both sides of the road + 0.45 m curb and gutter on both sides of road) **Collectors:** 13.9 m (45.6') (Two through lanes at 3.6 m per through lane + one 2.8 m lane of on street parking + two 1.5 m bike lanes + 0.45 m curb and gutter on both sides of road) **Arterials:** 19.1 m (62.7') (Four through lanes at 3.7 m per through lane + no on street parking + two 1.6 m bike lanes + 0.55 m curb and gutter on both sides of road)

Table E.12: Loop and Cul-de-Sac model specifications – network characteristics (cont.)

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road pattern (proportions of different road or intersection types)	**<u>Proportion of Intersection Types:</u>** **Barhaven:** T/X: 94.9%, 5.1% (CMHC, 2000) **CMHC's Stratford Model:** T/X: 92%, 8% (CMHC, 2004) **Forest Hill** (~Loops and Lollipops): T/X: 84.1%, 15.9% **Lakeshore North** (~Lollipops on a Stick) T/X: 98.0%, 2.0% **<u>Number of Loops and Cul-de-Sacs:</u>** **Barhaven:** 46 loops and cul-de-sacs in 834.5 acre area (= 0.06 per acre) (CMHC, 2000) **Loops and Lollipops:** 8 loops and CDS per 2,000 x 2,000 area (=0.09 per acre) (Southworth and Owens, 1993) **Lollipops on a Stick:** 24 loops and CDS per 2,000 x 2,000 area (=0.26 per acre) (Southworth and Owens, 1993)	**Intersection types (targets):** 90% T-intersections 10% X-intersections **Number of loops and cul-de-sacs:** Range of 0.1 – 0.2 per acre considered acceptable *(Works out to a target of 16 to 32 loops and cul-de-sacs for the model).*
Alleys	Never mentioned as an element of the Loop and Cul-de-sac case studies reviewed (Moudon, 1992; Southworth and Owens, 1993; CMHC, 2000)	No alleys in this model

Table E.13: Loop and Cul-de-Sac Model specifications –active transportation network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Sidewalks - location	**Upland Green (Washington):** Only two streets have a sidewalks on one side; all other pedestrian ways are trails separated from the road network (Moudon, 1992) **CMHC (2010):** Average 28.5% of road length with sidewalks on both sides	
Sidewalks – width	No data available	1.8 m (5.9') (standard width in Canada)
Bike lanes	No data available	Bike lanes present on both sides of collectors and arterials.
Trails	(No data available, but the author has observed that trails are a common feature in parks in many loop and cul-de-sac neighbourhoods in Ontario)	Included in parks; length will be variable.

Table E.14: Loop and Cul-de-Sac model specifications – land use, density, building and lot characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
% Residential	**Barhaven:** 54.5% (plus 2.7% vacant land) (CMHC, 2000) **Forest Hill:** 83.2% (includes streets and sidewalks) (plus 0.3% vacant land) (Filion and Hammond, 2003) **Lakeshore:** 79.0% (includes streets and sidewalks) (plus 3.3% vacant land) (Filion and Hammond, 2003)	Whatever remains once transportation networks, open space and other land uses are accounted for.
% Open space	**Toronto Suburbs:** 1.6 – 16.7% (CMHC, 2000) **Post WWII Communities:** 10.7 – 16.5% (IBI Group, 1995) **Barhaven:** 7.3% (CMHC, 2000) **CMHC (2010) Case Studies:** Average: 14.4% (made up of 8%, 10%, 10% and 19%) **CMHC (2008) Calgary Case Studies:** Walden: 12.3% Mahogany: 9.4%	12%
% Other	**Barhaven:** 3.8% (CMHC, 2000)	Low (4%)

Table E.15: Loop and Cul-de-Sac model specifications –density and building characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
Density	<u>**Gross Densities:**</u> **Clarence Perry's Neighbourhood Unit:** 5 d.u./acre (CMHC, 2000) **CMHC (2010) Case Studies:** Average: 4.6 d.u. /acre, with a range of 4.2 – 6.5 d.u./acre **CMHC (2008) Calgary Case Studies:** Walden: 8.6 – 9.4 d.u./acre Mahogany: 10.1 – 11.1 d.u./acre <u>**Net Residential Densities:**</u> **Filion and Hammond (2003) Case Studies:** Forest Hill: 7.2 d.u./acre Lakeshore North: 5.7 d.u./acre	Gross density of 6 d.u. / acre (= 960 dwelling units in the model)
% Single detached	**CMHC (2010) Case Studies:** Average: 70% **Filion and Hammond (2003) Case Studies - single family and semi-detached:** Forest Hill: 50.9% Lakeshore North: 77.3%	70% of dwelling units
% Rowhouse	**CMHC (2010) Case Studies:** Woodbine North: 15% Nouveau Saint-Laurent: 24% **Filion and Hammond (2003) Case Studies:** Forest Hill: 22.7% Lakeshore North: 12.6%	20% of dwelling units
% Multi-unit (triplexes or larger)	**Filion and Hammond (2003) Case Studies - Apartments:** Forest Hill: 26.4% Lakeshore North: 10.1 % **Filion and Hammond (2003) Case Studies - Duplex/Triplex:** Forest Hill: 0% Lakeshore North: 0% **CMHC (2010) Case Studies:** Nouveau Saint-Laurent (multi-unit, not including townhouses or semis): 20%	10% of dwelling units, mostly in high-rises

Table E.16: Loop and Cul-de-Sac model specifications –lot characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
Lot dimensions for single detached homes	**Moudon (1992) Case Studies** Firlock (Washington): 50’ to 80’ by 100’ deep (15.2 m to 24.4 m by 30.5 m deep) Moudon also noted that lot types in these types of neighbourhoods vary, but often include wide-and-shallow (for single-detached), zero-lot –line (for semi-detached homes) and garden apartment lots. The wide-and-shallow lots are often 60’ x 100’+ (18.3 m x 24.4 m).	Standard (50 x 115’ for single-detached homes) (15.2 x 35.1 m)
Setbacks	**CMHC (2010) Case Studies:** Average % of homes with setbacks > 5.5m (18.0’): 83.7%	Standard Single-detached: 40’ (12.2 m) Row: 30’ (9.1 m) Multi-unit: 50’ (15.2 m)

NEW URBANIST MODEL

Table E.17: New Urbanist model specifications – network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road spacing and/or block dimensions	<u>**Block Density**</u> **Kentlands:** 0.15 blocks per acre, not including alleys (Southworth, 1997) **Laguna West:** 0.17 blocks per acre (no alleys) (Southworth, 1997) <u>**Block Dimensions**</u> **Hess (2008) Case Studies - Mean block size:** Cornell: 4.0 acres (= 0.25 blocks /acre) Oak Park: 3.0 acres (= 0.33 blocks/acre) Woodbine: 8.4 acres (=0.12 blocks/acre) (Note: Hess does not explicitly state whether alleys are considered to divide blocks or not, but a visual inspection suggests he did not). **Kentlands :** Approx. 220‘ (67.1 m) width, but length varies (Lee and Ahn, 2003)	Target of 0.17 blocks per acre (Approx. 27 blocks in the model space)
Road widths	**Kentlands:** 36’ (11.0 m) wide (which includes two 8’ on-street parking lanes and two 10’ driving lanes) (Southworth, 1997) **Laguna West:** Local streets narrower than the other streets. Local streets are 30’ (9.1 m) (paved) (Southworth, 1997). **Hess (2008) Case Studies:** Cornell: 8 m (26.2’) Oak Park: 8.5 m (27.9’) Woodbine: 7.5 m (24.6’) **CMHC 2010 Case Studies:** Average % of streets <7.6 m (24.9’) wide: 11.5%	**Local streets:** 8.7 m (28.6’) (One 3.0 m through lane + two 2.4 m parking lanes on either side of street + 0.45 m curb and gutter on each side) **Collectors:** 13.7 m (44.9’) (Two 3.5 m through lanes + one 2.8 m on-street parking lane + two 1.5 m bike lanes + two 0.45 m curbs and gutters) **Arterials:** 11.3 m (37.1’) (Two 3.5 m through lanes + no parking lanes + two 1.6 m bike lane + 0.55 m curb and gutter on each side)

Table E.17: New Urbanist model specifications – network characteristics (cont.)

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road pattern (proportions of different road or intersection types)	<u>**Proportion of Intersection Types**</u> No case study data found on proportion of X vs.T intersections. The CMHC (2000) developed a New Urbanist model in which 31.5% of intersections were X-intersections and 68.5% were T-intersections. <u>**Loops and Cul-de-Sacs**</u> **Kentlands:** 0.12 loops and cul-de-sacs per acre (Lee and Ahn, 2003) *(Note: Southworth, 1997 found 10 loops and CDS in 2,000 x 2,000 area, but this may be due to differences in the frame's centre or subsequent development in Kentlands).* **Laguna West:** 0.16 loops and cul-de-sacs per acre (Southworth, 1997) **CMHC (2000) New Urbanist model:** 0 loops and CDS In 337.7 ha area, however, this model poorly reflects the fact that loops and cul-de-sacs are often included in New Urbanist developments. Hess (2008) gave no loop and cul-de-sac counts for his Canadian neighbourhoods under study, however a visual inspection shows that there are very few of either in any of the three study neighbourhoods.	**Intersection types (target):** X: 75% T: 25% **Number of loops and cul-de-sacs:** Target of 0.10 loops and cul-de-sacs per acre (= 16 loops and cul-de-sacs in the model)
Alleys	**Kentlands:** Alleys have 12' (3.7 m) paved lane and 7' (2.1 m) grass strips on each side (Southworth, 1997) **Hess (2008) Toronto Case Studies:** Cornell: 5m (16.4') paved Oak Park: "slightly narrower" than 5 m (16.4')	**Alley width:** 4.8 m (15.7') (the minimum recommended by TAC)

Table E.18: New Urbanist model specifications – active transportation network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Sidewalks – location	**CMHC (2010) Case Studies:** Average % of road length with sidewalks on both sides: 77.4%	
Sidewalks – width	No data available	Wider (2.0 m / 6.6')
Bike lanes	No data available	Bike lanes present on both sides of collectors and arterials.
Trails	**Kentlands:** Around lakes, through greenspaces and in some cases behind homes **Laguna West:** Very few trails. The only major trails are a pair of pathways that serve as the third radial line through the parks at the centre of the development	Trails irregularly interspersed throughout the model, primarily to link parks.

Table E.19: New Urbanist Model Specifications – land use characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
% Residential	**CMHC (2010) New Urbanist Model:** 46.8% (could add 2.7% of vacant land)	Whatever remains once transportation networks, open space and other land uses are accounted for.
% Open space	**Kentlands:** 28% (Southworth, 1997) **Laguna West:** 20% (Southworth, 1997) **CMHC 2010 Case Studies:** Average % open space: 13.8%	17%
% Other	No data found, but New Urbanist designs are typically associated with a higher level of land use mix than conventional loop and cul-de-sac designs (Song and Knaap, n.d.; VPTI, 2012)	High (8%)

Table E.20: New Urbanist model specifications – density, building and lot characteristics

	Additional Information – Case Studies & Design Guidelines	This Model
Density	<u>**Gross Densities:**</u> **Kentlands:** 4.5 d.u./acre (Lee and Ahn, 2003) **Laguna West:** 3.2 d.u./acre (Southworth, 1997) **CMHC (2010) Case Studies:** Average gross density: 8.1 d.u./acre **Hess (2008) Toronto Case Studies:** Cornell: 8.8 du/acre Oak Park: 10.8 du/acre Woodbine: 12.0 du/acre *(Note: Hess' high values explained by the placing of his study frame to not include many parks and other non-residential land uses).* <u>**Net Residential Densities:**</u> **Kentlands:** Single family homes: 7.4 d.u./net acre (Lee and Ahn, 2003) Row houses: 17.0 d.u./net acre (Southworth, 1997) **Laguna West:** Single family homes: 1.3 - 6.5 d.u./net acre Multi-unit: 17.0 – 25.0 d.u./net acre (Southworth, 1997)	Gross density of 6 d.u./acre (= 960 d.u. in the model space)
% Single detached	**Kentlands:** 31% (Lee and Ahn, 2003) (Note: Many homes in Kentlands contain granny flats and are functionally duplexes but included here. See Southworth, 1997). **CMHC (2010) Case Studies:** Average % of units in single family homes: 31%	31% of dwelling units
% Rowhouse	**Kentlands:** 34% (Lee and Ahn, 2003) **Laguna West:** 0% (Southworth, 1997) **CMHC (2010) Case Studies:** Garrison Woods: 20% Cornell: 46% Bois-Franc: 43%	40% of dwelling units

Table E.20: New Urbanist model specifications – density, building and lot characteristics (cont.)

	Additional Information – Case Studies & Design Guidelines	This Model
% Multi-unit (triplexes or larger)	**Kentlands:** 35.3% (Lee and Ahn, 2003) **CMHC (2010) Case Studies:** Cornell: 1% apartments Garrison Woods: 15% duplexes Bois-Franc: 50% multi-unit	29% of dwelling units (mostly in low-rises)
Lot dimensions for single detached homes	**Kentlands:** Small single detached: 44' x 100' (13.4 x 30.5 m) (Lee and Ahn, 2003) Large single detached homes have 66' – 88' (20.1 x 26.8 m) wide lots (Southworth, 1997) Rowhouses: 22' x 100' (6.7 x 30.5 m) lots (Soutworth, 1997; Lee and Ahn, 2003) **Laguna West:** 35'(10.7 m), 45' (13.7 m) and 60' (18.3 m) lot widths for detached homes. (No row houses) **Hess (2008) Toronto Case Studies – Typical Lot Dimensions:** Cornell: 8 x 33m (26.2' x 108.3') Oak Park: 7m x 28m (23.0' x 91.1') Woodbine: 7m x 35m (23.0' x 114.8') (Note: study does not specify if these are row houses or single-detached homes, nor how the "typical" lot was identified) **OMN (1995) Study:** Used frontage values of 15 m (49.2') for regular lots, 9 m (29.5') for compact lots and 6 m (19.7') for row houses.	**Single-detached:** 35' X 100' (10.7 x 30.5 m) **Row-houses:** 20' x 100' (6.1 x 30.5 m)
Setbacks	**Hess (2008) Toronto Case Studies:** Cornell: 2.5 m (8.2') Oak Park: 3.0 m (9.8') Woodbine: 7.0 m (23.0') **CMHC 2010 Case Studies:** Avg. % with setbacks > 5.5m (18.0'): 43.1% **New Urbanist Designs (General):** "Shallow" setbacks (Lee and Ahn, 2003)	Shallow Single-detached: 20' (6.1 m) Row: 20' (6.1 m) Multi-unit: 50' (15.2 m)

FUSED GRID MODEL

Table E.21: Fused Grid model specifications – network characteristics

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road spacing and/or block size or density	Road spacing: Arterials: Every half mile Collectors: Every quarter mile Local roads: No data, although can be measured from diagrams. (CMHC, 2000) Block dimensions: Block sizes: vary from 340 – 720’ (103.6 – 219.5 m) (CMHC, 2000) Block depth: 200’ (61.0 m) used for the proposed design for Stratford (CMHC, 2004) Cul-de-sac length: The CMHC (2000) states that cul-de-sacs in Fused Grid neighbourhoods are designed to support approximately 30 homes (and thus are typically about 60 m (196.9’) in length).	Block dimensions and road length measured from the seven quadrant configurations provided on page 73 and 74 of the CMHC (2000) report “Learning from Suburbia: Residential Street Pattern Design”

Table E.21: Fused Grid Model specifications – network characteristics (cont.)

Characteristic	Additional Information – Case Studies & Design Guidelines	This Model
Road widths	Local streets: 8 m (26.2') recommended for local streets, although the CMHC (2000) also noted that 5.5 to 7 m (18.0 – 23.0') ranges are also possible. Collectors and arterials: No data found	**Local streets:** 8.7 m (28.6') total (based on TAC, 207 guidelines rather than CMHC, 2000, and so as to be consistent with the width used in the New Urbanist model in this study) (One 3.0 m through lane + two 2.4 m parking lanes on either side of street + two 0.45 m curbs and gutters) (Same as the New Urbanist model) **Collectors:** 13.7 m (44.9') (Two 3.5 m through lanes + one 2.8 m on-street parking lane + two 1.5 m bike lanes + two 0.45 m curbs and gutters) (Same as the New Urbanist model) **Arterials:** 18.7 m (61.4') (Four through lanes at 3.6 m per through lane + no on street parking + two 1.6 m bike lanes + two (0.55 m) curb and gutter = 18.7 m (Part-way between New Urbanist and Loop and Cul-de-Sac in terms of width as it falls between the two in terms of its grain)
Road pattern (proportions of different road or intersection types)	**CMHC (2000) Seven Proposed Configurations:** • 2 or 4 loops in each quadrant • 0 to 4 cul-de-sacs **CMHC (2000) Study Example:** X: 10.1% T: 89.8% **CMHC (2004) Stratford Model:** X: 16.0% T: 84.0%	**Intersection types (X vs. T) and target number of loops and cul-de-sacs:** Model will replicate those found in the selected configurations (#s 4, 5, 6 and 7 in CMHC, 2000)
Alleys	Present for homes along arterial roads (CMHC, 2000)	Present along (behind) arterial roads

Table E.22: Fused Grid model specifications – active transportation network characteristics

Characteristic	Additional Information - Case Studies	This Model
Sidewalks - location	In the earliest CMHC document dealing explicitly with the Fused Grid model (CMHC, 2000), the CMHC suggested that sidewalks could be omitted on local streets to save on development costs. However, this concept is not mentioned in later proposals (CMHC, 2004; 2008)	Sidewalks on both sides of all roads in all models with sidewalks in this study ("best case scenario")
Sidewalks – width	No data available	Wider (2.0 m) (Better than standard and the same as the value used for the similarly pedestrian-oriented New Urbanist model)
Bike lanes	Not explicitly mentioned in the original CMHC report (2000).	Present on both sides of arterials and collectors.
Trails	Present in parks to act as connecting links between other network segments. However, their exact location in parks is not shown on the CMHC (2000) diagrams, even though they are a key element of the active transportation network in this model.	Trails will be designed so they run north-south or east-west when connecting roads (no trails laid out in an angle to create an "X" through a park). There will be one trail per pair of roads connected via parks.

Table E.23: Fused Grid Model specifications – land use characteristics

	Additional Information - Case Studies	This Model
% Residential	**CMHC (2000) Study:** Example quadrant: 64.5% of quadrant land Overall model applied to Barhaven: 52.2% (could add 2.7% of vacant land)	Whatever remains once transportation networks, open space and other land uses are accounted for.
% Open space	**CMHC (2000) Study:** Varies from 8 to 12 percent of total area depending on quadrant configuration. (Maximum of 4.8 acres). Example quadrant: 9.3% of quadrant (1.5 ha) Overall model applied to Barhaven: 9.9% (presumably higher due to extra space being allocated in the arterial by-way)	As determined by the CMHC model quadrants (will be between 8 and 12%)
% Other	**CMHC (2000) Study:** Barhaven Fused Grid example: 6.6% Note: this value likely includes lands in the arterial by-way which is not being included in this paper's model.	Medium (6%)

Table E.24: Fused Grid model specifications – density, building and lot characteristics

	Additional Information - Case Studies	This Model
Density	<u>Gross Densities</u> **CMHC (2000) Study:** Example quadrant: 9.7 d.u./acre 5.4 – 10.7+ d.u./acre seen as desirable. **CMHC (2008) Calgary Case Study:** 10.5 – 12.1 d.u. per acre	Gross residential density of 10.5 d.u. / acre (= 1680 units in model area)
% Single detached	**CMHC (2000) – Example for One Quadrant:** Detached units: 21.7% Semidetached units: 25.7%	50% of dwelling units
% Rowhouse	**CMHC (2000) – Example for One Quadrant:** Rowhouse units: 52.6%	50% of dwelling units
% Multi-unit (triplexes or larger)	**CMHC (2000) – Example for One Quadrant:** Multi-family units: 0 (0%)	0% of dwelling units
Lot dimensions for single detached homes	CMHC (2000) does not provide any exact values, although they state that "variety is encouraged".	Will use standard dimensions for single-detached homes (50' x 115' or 15.2 x 35.1 m)
Setbacks	No data available.	Standard (Single-detached: 40' Row: 30' Multi-unit: 50')

GREENWAY MODEL

Table E.25: Greenway Neighbourhood model specifications – network characteristics

Characteristic	Additional Information - Case Studies	This Model
Road spacing and/or block size or density	Block Density **Radburn:** 0.11 per acre, as defined by pedestrian pathways (Lee and Ahn, 2003) **Block Dimensions – Radburn:** Superblock: approx. 30 acres (an area approx. equal to 1150' x 1150' or 350 x 350 m) Pedestrian-pathway defined blocks: 220' x 400' (67.1 x 121.9 m) (Lee and Ahn, 2003) **Block Dimensions - JLAF Model:** **Superblock size:** up to 70 acres (an area approx. equal to 1740' x 1740' or 530 x 530 m) (JLAF, 2010) **JLAF example model:** 1,000' x 1,000' (305 x 305 m, or approx. 23.0 acres) 1,500 x 1,500' also suggested (457 x 457 m, or approx. 51.7 acres) Length of Cul-de-Sacs: **JLAF Model:** Cul-de-sacs are designed to support 10 to 12 houses on each side of the street (20 – 24 homes total) **Measurements from Radburn:** Cul-de-sac lengths range from approximately 200' to 375' (61.0 to 114.3 m).	**Superblocks:** 1320' x 1320' (402.3 x 402.3 m) (same as Fused Grid), four in the model. **Number of regular blocks:** For regular blocks (defined in the case of Greenways by their pedestrian pathways), at 0.11 per acre, there should be approx. 17 blocks in the study space. **Length of cul-de-sacs (target):** 250' – 600'

Table E.25: Greenway Neighbourhood model specifications – network characteristics (cont.)

Characteristic	Additional Information - Case Studies	This Model
Road widths	**JLAF model:** Suggested both collector and arterials would have only two lanes (greenwayneighborhoods.net blog, 2009) **Village Homes:** Collector: 2 lane Arterial: 4 lane (greenwayneighborhoods.net blog, 2009) **Radburn** **Collectors:** 60' - 70' (18.3 – 21.3 m)wide, but Lee and Ahn (2003) were not explicit in whether this was the paved area or simply the ROW. Measurements from satellite imagery suggest a paved width of 40' (12.2 m) for Fair Lawn Ave., the closest collector. **Local roads (Cul-de-sacs):** 30' (9.1 m) wide with an 18' (5.5 m) paved area (Lee and Ahn, 2003) **JLAF model:** Local roads: preferably 22' (6.7 m) wide, but wider widths possible (up to 32' / 9.8 m)	**Local streets:** 8.7 m (28.6') (One 3.0 m through lane + two 2.4 m parking lanes on either side of street + two 0.45 m curbs and gutters) (Same as Fused Grid & New Urbanist) **Collectors:** 10.7 m (35.1') (Two 3.5 m through lanes + one 2.8 m on-street parking lane + no bike lanes + two 0.45 m curbs and gutters) **Arterials:** 15.5 m (50.9') (Four through lanes at 3.6 m per through lane + no on street parking + no bike lanes + two (0.55 m) curb and gutter) (Collector and arterials the same width as in Fused Grid, minus bike lanes)
Road pattern (proportions of different road or intersection types)	<u>Proportion of Intersection Types</u> No data found, but a visual inspection suggests that the vast number of intersections (and all of those involving local roads) in Radburn are T intersections. <u>Number of Loops and Cul-de-Sacs</u> **Radburn:** 19 loops and CDSs in 2,000 x 2,000' area (=0.21 per acre)	**Intersection types (target):** Target of 100% T-intersections **Number of loops and cul-de-sacs:** Target of 34 cul-de-sacs in the model (at 0.21 / acre); no loops.
Alleys	**Radburn:** No alleys, although roads are located where alleys would go in other models. **JLAF model:** No alleys.	No alleys.

Table E.26: Greenway Neighbourhood model specifications – active transportation network characteristics

Characteristic	Additional Information - Case Studies	This Model
Sidewalks – location & width	**Radburn & JLAF models:** N/A	N/A (No sidewalks in the Greenway model)
Bike lanes	No data available, but unlikely to be included in any of these models given the presence of central multi-use trails.	No bike lanes
Trails - location	**Radburn and JLAF Models:** Trails run between the centre of homes and through parks (Lee and Ahn, 2003; JLAF, 2010)	Homes will face trails which will form a grid between roads. The greenway will be considered part of the overall park space for the model.

Table E.27: Greenway Neighbourhood model specifications – land use characteristics

	Additional Information - Case Studies	This Model
% Residential	No data available.	Whatever remains once transportation networks, open space and other land uses are accounted for.
% Open space	**Radburn:** 16% (Lee and Ahn, 2003) **Pineridge:** 22% (JLAF, 2012) **Equipoise:** 65% (JLAF, 2012)	16% (25.6 acres)
% Other	**JLAF (2010) Model:** Proposes a strip of development along arterials, but no % land use given.	Medium (6%) (9.6 acres)

Table E.28: Greenway Neighbourhood model specifications – density, building and lot characteristics

	Additional Information - Case Studies	This Model
Density	Gross Densities **Radburn:** 4.5 d.u./acre (Lee and Ahn, 2003) **JLAF Model:** 7 – 12 d.u./acre (implied) (JLAF, 2010) **Equipoise:** 1.9 d.u./acre (Living Architecture, n.d.) (Note: Equipoise is a rural development and thus its gross density is low due to the inclusion of lands for agriculture). Net Residential Density **Radburn – single family homes:** 7.9 du/net acre (Lee and Ahn, 2003)	Gross density of 6 d.u./acre (= 960 d.u. in the model)
% Single detached	**Radburn:** 70% single family homes (Lee and Ahn, 2003) **Equipoise:** 43.7% (Living Architecture, n.d.)	70% of dwelling units
% Rowhouse	**Radburn:** *7%* (Lee and Ahn, 2003) **Equipoise:** 36.4% (Living Architecture, n.d.)	10% of dwelling units
% Multi-unit (triplexes or larger)	**Radburn:** 13.8% apartments 4.7% in duplexes or semis (Lee and Ahn, 2003) **Equipoise:** 19.9% (Living Architecture, n.d.)	20% of dwelling units (mostly in high-rises)
Lot dimensions for single detached homes	**Radburn:** 45’ x 100’ (13.7 x 30.5 m) (Lee and Ahn, 2003)	Standard (50’ x 115’ (15.2 x 35.1 m) for single-detached)
Setbacks	No data available	Extended (Single-detached: 50’ Row: 40’ Multi-unit: 50’)

APPENDIX F: GIS MODEL CONSTRUCTION STEPS

The following section outlines the steps that were followed in order to build the GIS models used in this study. The specific measurements and dimensions used are outlined in Chapter 4 and Appendix E, while the overall pattern and form of each model's network is described in Chapter 2.

APPENDIX F – CONTENTS

Notes:

1) **File names:** because the exact file name of a feature class varied depending on which of the five GIS models was under construction, the following conventions should be used when interpreting the model construction steps:

    - Any portion of a filename listed as "modelname" should be replaced with the appropriate model name (one of: Grid, GW, FG, Loops, NU).

    - Any portion of a filename listed as "user" should be replaced with the appropriate "user group" names (one of: All, Bike, Bikelane, Mixed, Ped, PedBike – see p. 392).

    - Any portion of a filename listed as "path" should be replaced with the appropriate path name (one of: Alley, Arterial, CDS, Collector, Driveway, Loop, Otherdriveway, Sidewalk, Trail, Through).

For instance, a file named: "modelname_user_path" in this methodology may be named "FG_pedbike_sidewalk" in the actual feature class.

2) **Field calculator:** An error was encountered while using Remote Desktop which prevented the use of Field Calculator for mathematical equations (i.e. "divide by two"), and thus, such calculations were done manually and then the final value entered into Field Calculator for use in populating a given field.

3) **Unit conversions:** All conversions between imperial and metric made using: http://onlineconversion.com/ "Feet" was the unit used in the GIS for the purposes of model construction.

4) **Fused Grid dimensions:** The relative dimensions of roads in Fused Grid cells (CMHC, 2000) were measured by assessing pixel count of each cell in Adobe Photoshop CS2.

Feature Classes, Attributes & Uses

The GIS models included the following features, layers and attributes (Tables F.1 and F.2, below). All layers were be made up of vector objects. Table F.1 below describes those features created "from scratch" in the GIS. The second table (F.2.) lists features produced by ArcGIS by applying one of its tools to one or more of the features listed in Table F.1.

In the following tables, "Attached Attributes" does not include those attributes automatically generated by Arc, such as SHAPE_LENGTH and SHAPE_AREA. Special feature classes not used in the models themselves but for validation (i.e. topologies) and analysis (i.e. the network datasets) are not listed in these tables, but described later on in this appendix.

Table F.1: Manually created feature classes used in the GIS models

General Information	Attached Attributes	Used For
Feature: Network (travel) paths **Feature Class Name:** modelname_networklines **Feature Class Type:** Line	**Path_Type:** (Attribute type: text) "Arterial", "Collector", "Local" or "Alley" for roads; "ATN" for sidewalks, trails or front door connections[1] "Driveway" for driveways **Path_Subtype:** (Attribute type: text) Arterial: "Arterial" Collector: "Connector" Local: "Through", "Loop" or "CDS" Alley: "Alley" ATN: "Sidewalk", "Trail" or "Frontdoor" Driveway: "Driveway" for residential driveways, "Otherdriveway" for driveways for other land use lots **User:** (Attribute type: text) "All" (for pedestrians, cyclists and cars) "Bike" (for bikes only) "Bikelane" (for cyclists and cars sharing roads with bike lanes) "Fake" (for travel over fake segments by any user) "Mixed" (for cyclists and cars sharing road lanes) "Ped" (for pedestrians only) "PedBK" (for pedestrians and cyclists together) **Path_Width:** (of the type: Double) Contains the full width of any given pathway, in feet **Path_Half_Width:** (of the type: Double) Contains the full width of any given pathway, in feet	Measuring coverage Creating user/pathtype lines for network dataset Creating "points of conflict" Creating intersection points Creating buffered path network (used to determine road, ATN land use and to create buildable area feature class)

[1]: FrontDoor attribute will signify a dummy link to represent the ability of residents in Greenway Neighbourhoods to reach the trail in front of their homes. It will not be included in the transportation network length measurements.

Table F.1: Manually created feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Used For
Feature: Destinations (destination points) **Feature Class Name:** modelname_dest **Feature Class Type:** Point	**Dest_Type:** (Attribute type: text) "Centre" or "Edge"	Used as the destination points when running the Origin-Destination Matrix in Network Analyst
Feature: Frame **Feature Class Name:** modelname_frame **Feature Class Type:** Polygon	None	Used as the basis for clipping other feature classes to the model area's boundaries
Feature: Intersections **Feature Class Name:** modelname_intersections **Feature Class Type:** Point	**Type:** (Attribute type: text) "ATN Only" (Trail/Trail, Midblock, Underpass or Greenway Crossing), or "Regular Road" (see p. 108 for definitions)	Used to calculate intersection density
Feature: Lot template **Feature Class Name:** modelname_lot_template **Feature Class Type:** Polygon	None	Used to quickly cut the "lots" feature into multiple polygons
Feature: Setback lines **Feature Class Name:** modelname_setbacks (and subsequent modelname_setbacks_cleaned) **Feature Class Type:** Line	**Setback_Type:** (Attribute type: text) "Single", "Row" or "Multi"	Used to define lines on which the origin points (homes) would be placed.
Feature: Turns **Feature Class Name:** modelname_ND_turns **Feature Class Type:** Turns	(None)	Used to define prohibited turns within the network dataset

Table F.2: Output features classes used in the GIS models

General Information	Attached Attributes	Produced By	Used For
Feature: Grid network ("fishnet") **Feature Class Name:** grid_fishnet **Feature Class Type:** Line	None	"Create Fishnet" tool (no other feature classes required)	Road lines for the Grid model only (copied back into the modelname_networklines feature class)
Feature: Cul-de-sac head points **Feature Class Name:** modelname_CDS_heads **Feature Class Type:** Point	None	"Feature Vertices to Point" tool on the modelname_networklines feature class	To provide a point from which to later create buffered polygons for the heads of the cul-de-sacs
Feature: Cul-de-sac heads **Feature Class Name:** modelname_CDS_heads_buffered **Feature Class Type:** Polygon	None	"Buffer" tool on the modelname_CDS_heads feature class	Merging with the modelname_networklines_roads_buffered feature class to create an accurate representation of the land dedicated to roads.
Feature: Cul-de-sac heads – perimetre line **Feature Class Name:** modelname_CDS_heads_line **Feature Class Type:** Polygon	None	"Feature to Lines" tool on the modelname_CDS_heads_buffered feature class	Used with the "copy parallel" tool to create setback lines

Table F.2: Output feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Produced By	Used For
Feature: Buffered roads **Feature Class Name:** modelname_networklines_roads_buffered and modelname_networklines_roads_buffered_clipped **Feature Class Type:** Polygon	Same as "networklines"	"Buffer" tool on the modelname_networklines feature class Clipped version created by using the "Clip" tool on modelname_networklines_roads_buffered	Serves as an accurate representation of the land dedicated to roads (once the CDS_heads_buffered feature class is copied in and merged) Used to create modelname_buildable_area feature class
Feature: Buffered paths (all types) **Feature Class Name:** modelname_networklines_buffer_all **Feature Class Type:** Polygon	Same as "networklines"	"Buffer" tool on the modelname_networklines feature class, after the "networklines" feature class is complete (includes all network lines, rather than just the roads)	Used to create modelname_networklines_buffer_all_cleaned
Feature: Buffered paths **Feature Class Name:** networklines_buffer_all_cleaned And networklines_buffer_all_cleaned_dissolved **Feature Class Type:** Polygon	Same as "networklines" Added "buff_subtype" to the "networklines_buffer_all_cleaned_disolved" feature class (attribute type: text) Available values the same as the ones in path_subtype.	Used the "Multipart to Singlepart" tool on the modelnam_networklines_buffer_all feature class Used the "Dissolve" tool to merge the polygons based on path subtype and create modelname_networklines_buffer_all_cleaned_dissolved.	Used to assign identity to network lines

Table F.2: Output feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Produced By	Used For
Feature: Network lines identified by buff_subtype **Feature Class Name:** networklines_identity **Feature Class Type:** Line	Same as modelname_networklines, plus the buff_subtype attribute from the modelname_buffer_all_cleaned_dissolved feature class	Used the "Identity" tool on the networklines feature class, using the modelname_networklines_buffer_all_cleaned_dissolve as the bassis of the identity.	Breaking into feature classes by user and path type for the network dataset
Feature: Travel paths by user & buff_subtype **Feature Class Name:** modelname_user_buff_type (e.g. FG_ped_sidewalk) **Feature Class Type:** Line	Same as "modelname_networklines_identity"	Used the "Split Layers by Attributes" tool to split the modelname_networklines_identity feature class on the basis of its users and buff_subtype attributes	Used to create network dataset (which in turn was used to calculate trip lengths and how much of a trip was made on each path type)

Table F.2: Output feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Produced By	Used For
Feature: Buildable area **Feature Class Name:** modelname_buildable_area **Feature Class Type:** Polygon	None	"Erase" tool used on the frame feature class, with the "networklines_buffered" feature class used to define the area to be erase.	Calculating buildable area (the SHAPE_AREA attribute) Creating the "lots" feature class
Feature: Lots **Feature Class Name:** modelname_lots **Feature Class Type:** Polygon	**Landuse:** (Attribute type: text) ("Residential", "Park" or "Other") **Landuse_subtype:** (Attribute type: text) Residential: "SingleD", "Row" or "Multi" Park: "Park" Park: "Other" (see p. 119) **Dwelling_Units:** (Attribute type: integer) ("0" for parks and other; 1 or more for all residential lots) **LotNumber:** (Attribute type: integer) A copy of the "ObjectID" field	Using the "Feature to Polygon" tool on the modelname_buildable_area feature class.	Used to divide up the buildable area into lots, and subsequently assess the amount of land dedicated to each land use; also to establish lots for each origin point (home) to go on. Used to calculate density.
Feature: Lot lines **Feature Class Name:** modelname_lotlines **Feature Class Type:** Line	(None)	"Feature to Line" tool on the modelname_lots feature class	Used for splitting setback lines at the edge of the lot.

Table F.2: Output feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Produced By	Used For
Feature: Setback lines with “identity” **Feature Class Name:** modelname_setbacks_lot_identity (and modelname_setbacks_dissolved) **Feature Class Type:** Line	**LotNumber:** (Attribute type: integer)	Ran the “Identity” tool on “modelname_setbacks_cleaned” to assign lot numbers to the setback lines (so all setback lines could then be dissolved based on the lots they shared, to produce “modelname_setbacks_dissolved”)	Used to create an origin point at the middle of each setback line.
Feature: Homes (origin points) **Feature Class Name:** modelname_homes **Feature Class Type:** Point	**Dwelling_Units:** (Attribute type: text) (# of dwelling units on each lot)	Used the “Feature to Point” tool on modelname_setbacks_dissolved	Used as the origin points when running the Origin-Destination Matrix in Network Analyst; also used as a point barrier in some models to prevent short-cutting through yards

Table F.2: Output feature classes used in the GIS models (cont.)

General Information	Attached Attributes	Produced By	Used For
Feature: Possible points of conflict **Feature Class Name:** Modelname_POCs **Feature Class Type:** Point	**POC_Type:** (Attribute type: text) "sd_dri" (for sidewalk/driveway) "sd_sd" (for sidewalk/sidewalk) "sd_tr" (for sidewalk/trail) "sd_rd" (for sidewalk/road) "sd_od" (for sidewalk/other driveway) "sd_fd" (for sidewalk/front door) "tr_dri" (for trail/driveway) "tr_od" (for trail/other driveway) "tr_fd" (for trail/front door) "tr_tr" (for trail/trail) "rd_rd" (for road/road) "rd_tr" (for road/trail) "rd_up" (for road/underpass)	Using the "Intersect" tool on the modelname_networklines layer	Used as an accumulation attribute in the Network Dataset to count the number of POCs a person must travel through when travelling from an origin to a destination.
Feature: Possible points of conflict **Feature Class Name:** Modelname_POCpts_M2S **Feature Class Type:** Point	(Same as for modelname_POCpts above)	Used the "Multipart to Singlepart" tool on the original modelname_POCpts feature class to allow it to be used with a topology.	Used as an accumulation attribute in the Network Dataset to count the number of POCs a person must travel through when travelling from an origin to a destination.
Feature: POC points by type **Feature Class Name:** modelname_POC_POCtype (e.g. FG_POC_sidewalk_trail) **Feature Class Type:** Point	Same as the modelname_networklines_identity feature class	Used the "Split Layers by Attributes" tool to split the modelname_POCs feature class on the basis of its POC_type attribute field	Used as an accumulation attribute in the network dataset to count number of POCs encountered when making trips.

STEP 1: CREATED FILE STRUCTURE

1) Opened ArcCatalog

2) Created a new File Geodatabase named "Models" by right-clicking in the contents panel

3) Entered the File Geodatabase, right clicked to create new feature datasets, one for each model, named:

- Grid
- GW
- FG
- Loops
- NU

4) Each Feature Dataset was given the following properties:

    Coordinate System: Unknown

    XY tolerance: 0.001 units

    Z tolerance: 0.001 units

    M tolerance: 0.001 units

    Accepted default resolution and domain extent

5) Created three new feature classes (one for the networklines, one for the destinations, and one for the model frame) in each of the feature datasets by entering the model's feature dataset and right clicking in the contents panel:

    - **Network Lines:** called modelname_networklines
        - Alias: (None)
        - Type: Line
        - M-Values: Off
        - Z-Values: Off
        - Accept Default Resolution & Extent

    - Additional Attribute Fields:
        - “Path_Type” (of the type: Text)
        - “Path_Subtype” (of the type: Text)
        - “Users” (of the type: Text)
        - “PathWidth” (of the type: Double)
        - “PathHalfWidth” (of the type: Double)
    - Configuration keyword on default

- **Destinations:** called modelname_dest
    - Alias: (None)
    - Type: Point
    - M-Values: Off
    - Z-Values: Off
    - Accept Default Resolution & Extent
    - Additional Attribute Fields:
        - “DestType”: (of the type: Text)
    - Configuration keyword on default

- **Frame:** called modelname_frame
    - Alias: (None)
    - Type: Polygon
    - M-Values: Off
    - Z-Values: Off
    - Accept Default Resolution & Extent
    - Additional Attribute Fields:
        - (None)
    - Configuration keyword on default

STEP 2: CREATED MODEL FRAME AND INITIAL MAP

1) Opened ArcMap

2) Added all the feature classes in a given dataset (i.e., one of the five models) by clicking the "Add Data" button

3) Changed the default settings in ArcMap to ensure good function during the rest of the model development and analysis processes:
   - Layer Properties: Set Display, Map Units to Feet
   - Turned on Snapping Toolbar (snapping options varied throughout model development)
   - Turned on Topology Toolbar
   - Turned on Editing Toolbar
   - Set Sticky Tolerance to 20 (under Editor Options: Editing -> Options -> General)

4) Started editing

5) Selected the "modelname_frame" template from the "Creature Features" window, and then the "Polygon" tool from the "Construction Tools" window.

6) Used the polygon tool to create a 2,640' x 2,640' square by right clicking in the main window and selecting "Absolute X,Y" to create to create the four corner points at coordinates 0,0 ; 0, 2640; 2640, 2640; and 2640, 0. Right clicked and selected "Finish Sketch".

7) Saved edits.

8) Saved the map as "modelname_construction".

STEP 3: CREATED ROAD NETWORK

1) For all models but the Grid, the road network was manually drawn (see p. 404 below for the construction of the Grid road network). The networklines template was selected from the "Create Feature" window and the "line" tool from the "Construction Tools" window below. Then, using the line tool, lines were drawn in the model space and snapped to the model frame as necessary.

Notes on road network creation:

- All models but the Grid started with the construction of the four arterial roads that follow the edge of the frame and defined the model boundaries, followed by the collectors and final the local roads.

- "Absolute X,Y" and "Delta X,Y" were used extensively to ensure roads were the correct length and "CTRL-E" and "CTRL-P" to ensure lines ran perfectly parallel or perpendicular to other road segments as needed.

- "Sketch Properties" and the Measuring Tool were used to ensure that the distance between specific points were within acceptable parameters, including the distance between intersections.

- In order to ensure that the angle where line segments met at an intersection fell within the required range, a temporary new line was drawn over the first segment and the angle (described as "Direction", visible in the bottom left corner of the screen in ArcMap) was recorded. That line was then deleted (by hitting "ESC") and then the process was repeated for the second segment at the intersection. The first value was then subtracted from the second to determine the angle at which they met. Any roads that met at too large or too small an angle were adjusted as needed to meet model specifications.

- The "Split Line" tool from the Editor toolbar was used as needed.

- Used “Change Segment” (by double clicking and then right clicking while using the Edit tool) to set line segments to “Bezier” in order to curve them where needed. Road shape was further adjusted by the insertion of vertices, using the “Add Vertex” tool from the “Edit Vertices” toolbar.

- Where there were repeating elements in the road network (particularly for the Fused Grid model), the feature of interest was copied into the modelname_networklines feature class, and then the Rotate Tool (found in the Editor Toolbar) used to rotate the copy, then “Move Delta X,Y” was used to set it in its new position (accessed by double clicking on the object and then right clicking to bring up a list of options).

- The Scale tool was used in some instances where it was realized the initial dimensions of a feature were off.

- The Editor -> Merge command was used to ensure that loops were a single line segment and not three (as the points in the road represent gradual turns, as opposed to true intersections).

Grid Model Variation – “Create Fishnet” Tool

As a time-saving measure, the “Create Fishnet” tool (found in the Data Management Tools -> Feature Class toolbox) was used to generate the Grid model’s roads, rather than manually drawing them using the networklines template and line tool. (The Grid model had the only network pattern for which this tool could be used). The following tool settings were used:

- Output: grid_fishnet
- Template Extent: (left blank)
- X-axis coordinate: 0,0
- Y-axis coordinate: 0, 2640

- Cell size width: 440
- Cell size height: 264
- Number of rows: 10
- Number of columns: 6
- Opposite corner of fishnet: 2640 x 2640
- Unchecked “create label points”
- Geometry Type: polyline

These lines were then copied back into the networklines feature class.

2) Once all networklines were drawn, attribute information was added by selecting roads of a given type, opening the attribute table and then using the “Field Calculator” in the attribute table to set path_type, path_subtype, path_width (based on the values in Appendix E), path_half_width and users.

3) When all road networkline edits were complete, they were saved, editing stopped, and the map saved again.

STEP 4: VALIDATED & CORRECTED ROAD NETWORK LINES

A topology was created in order to ensure network line connectivity.

1) Opened ArcCatalog and entered the model's Feature Dataset.

2) Right clicked in the Feature Dataset and selected "New Topology". The new topology was given the following properties:

   - Name: modelname_networklines_topo1
   - Cluster tolerance: 0.001
   - Participating layers: modelname_networklines
   - Rank for modelname_networklines: 1
   - Add rules:
     - Must not have dangles (line)
     - Must not overlap (line)
   - Finish

3) Right clicked on the topology and selected "Validate".

4) Opened Arc Map and added the Topology to the "modelname_construction" map (using the "Add Data" button) to see where errors were occuring.

5) Started an edit session.

6) Opened Error Inspector from the Topology toolbar.

7) Marked exceptions as needed (for instance, dangles were allowed where the represented a CDS head).

8) Manually corrected errors by adjusting vertices, deleting a line and starting afresh, or using the "trim" or "extend" tools in the Error Inspector window, depending on the instance.

9) Saved.

STEP 5: CREATED CUL-DE-SAC NODES

1) In the modelname_networklines feature class, double clicked on cul-de-sac network lines and checked to make sure that the "end" of the line segment (marked by a red as opposed to green vertex) was the dangling one (if not, right clicked and hit "flip" to switch them).

2) Used a definition query (Layer Properties -> Definition Query -> Query Builder, set to "path_subtype" = 'CDS') to make it that only the cul-de-sacs were visible in the networklines layer.

3) Used the "Feature Vertices to Point" tool (ArcToolbox -> Data Management -> Features -> Feature Vertices to Points) to create a new point feature class containing a point object at the centre of each CDS head (the terminal/dangling end of the CDS line segment).

   Input Features: modelname_networklines
   Output Feature Class: modelname_CDS_heads
   Point Type: End

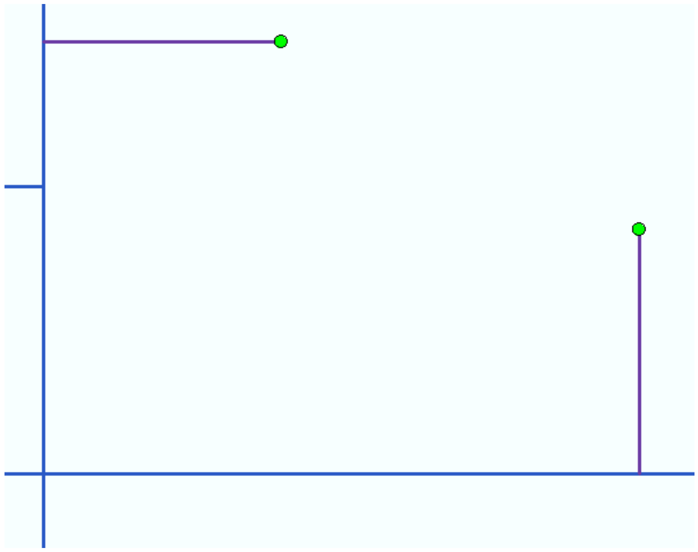


Fig. F.1: Cul-de-sac nodes (point features) at the end of the cul-de-sac network lines

4) Saved edits and stopped editing.

STEP 6: CREATED ROADWAY POLYGONS BY BUFFERING ROAD NETWORK LINES

1) Deleted the definition query on the networklines layer.

2) Checked to ensure that sure all line segments had a complete set of attributes (path_type, path_subtype, users, path_width, path_half_width) in the attributes table.

3) Used the Buffer tool to buffer road lines (Analysis Toolbox -> Proximity -> Buffer)
   - Input Features: modelname_networklines
   - Output Feature Class: modelname_networklines_roads_buffered
   - Distance: (Blank)
   - Field: half_road_width
   - Side type: full
   - End type: round

- Dissolve: List -> path_subtype

4) Used the buffer tool again to buffer the nodes at the ends of the cul-de-sacs (Analysis toolbox -> Proximity -> Buffer)
   - Input Features: modelname_CDS_heads
   - Output Feature Class: modelname_CDS_heads_buffered
   - Distance: 45.9’
   - Field: (Left blank)
   - Side type: (No options when buffering points)
   - End type: (No options when buffering points)
   - Dissolve: None

STEP 7: CLEANED BUFFERED ROADS

1) Turned on the two buffered layers (modelname_networklines_roads_buffered and modelname_CDS_heads_buffered) and turned off all other layers.

2) Used the Cut Polygons tool on the editor toolbar to cut off and then delete any portions of road polygons generated by the use of buffer that extended past the logical edge of the road (see Fig. F.2 below) .

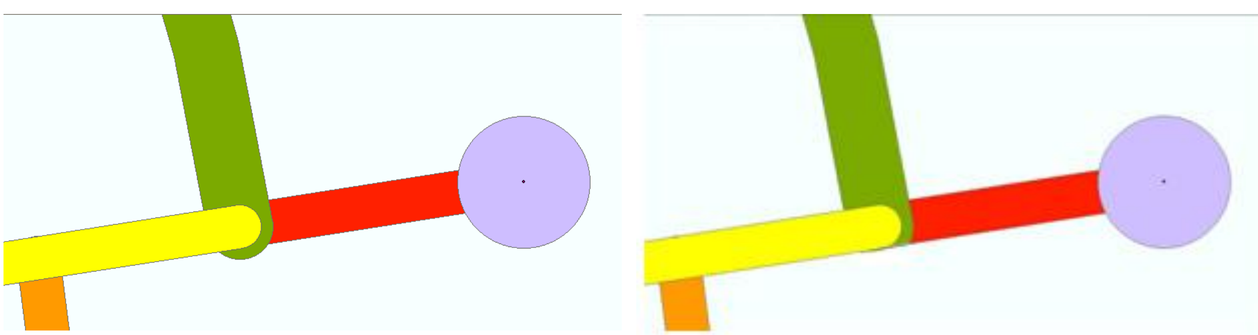


Fig. F.2: Trimming buffered roads

In this example, the greater road width of the collector (represented in green) caused this polygon to extend past the logical road edge for the local roads (left) and had to be trimmed (right)

In some cases, where roads of different widths met, it was necessary to split and trim the polygons so that they gradually merged. In Fig. F.3 below, the green collector polygon was trimmed so as to have the same width as the narrower red cul-de-sac where they met.

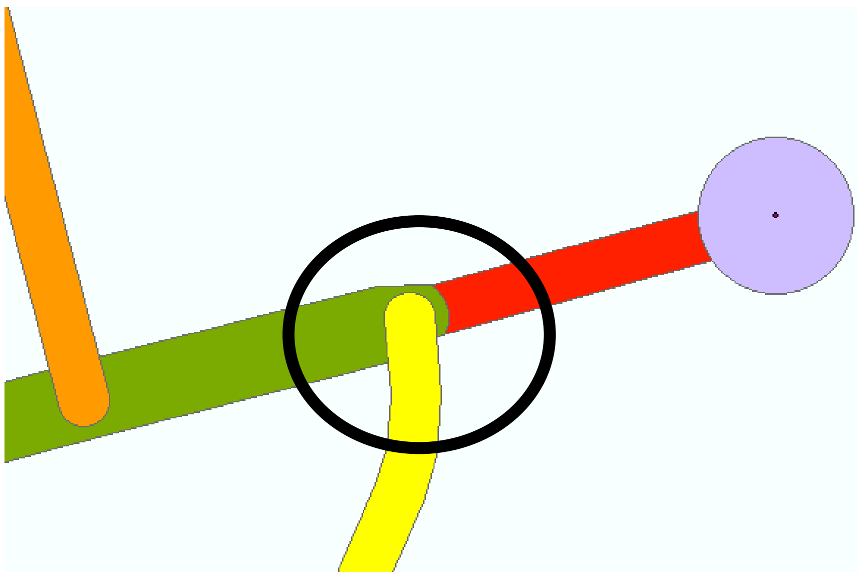


Fig. F.3: Gradually narrowing a wider road to prevent sudden changes in width

3) Saved edits.

STEP 8: CREATED A “BUILDABLE AREA” FEATURE CLASS

1) Turned on the Frame layer in addition to the two buffered layers already on, and ensured all other layers were turned off.

2) Selected the buffered CDS node polygons in the modelname_CDS_heads_buffered feature class, hit “copy”, and then pasted them into the networklines_roads_buffered feature class.

3) Selected the straight CDS road segments along with the CDS heads in the networklines_buffered feature class and hit “Merge” on the Editor toolbar.

4) Saved edits.

4) Used the Clip tool (Analysis -> Extract -> Clip) to delete those portions of roads which extended beyond the model frame (i.e. half the width of the four bounding roads).

   Input Features: modelname_networklines_roads_buffered
   Clip Features: modelname_frame
   Output Feature Class: modelname_networklines_roads_buffered_clipped
   XY Tolerance: (left blank)

5) Used the Erase tool on the modelname_frame feature class to create a new “buildable area” feature class, made up of all the model space falling outside the road network area (Analysis toolbox -> Overlay -> Erase)
   - Input Feature: modelname_frame
   - Erase Features: modelname_networklines_roads_buffered_clipped
   - Output Feature Class: modelname_buildable_area
   - XY Tolerance: (left blank)

STEP 9: CREATED A "LOTS" FEATURE CLASS

1) Used the "Feature to Polygon" tool (Data Management toolbox-> Features -> Feature to Polygon) to create a copy of "modelname_buildable_area" for editing, called "modelname_lots"
    - Input features: modelname_buildable_area
    - Output feature class: modelname_lots
    - XY tolerance: left blank
    - Preserve attributes: checked
    - Label features: left blank

    (Feature to Polygon was used instead of Copy Features because it makes each polygon its own discrete object).

2) Saved edits and stopped editing.

3) Opened the modelname_lots feature class' attribute table and added three attribute fields:
    - "LandUse" (type: text) to store possible land use values (Park, Other, Residential)
    - "LandUse_Subtype" (type: text) to store more detailed land use values (Park, Other, Multi, Row, Single)
    - "Dwelling_Units" (type: text) to store the number of dwelling units at each lot

STEP 10: SPLIT POLYGONS TO MAKE INDIVIDUAL LOTS

1) Turned all layers except the modelname_lots layer off.

2) Started an editing session.

3) Selected a lot polygon and used the “Cut Polygons Tool” on the Editor toolbar to cut the polygon into lots, using a right click and selecting “length” to set the length of each edge to be cut. Repeated this step until all polygons were cut into lots.

4) In some cases, it was faster to create a “lot template” and use that to split larger lot polygons into smaller ones (for instance, in the Grid model, where there were many blocks of the same size that could be designed to contain the same number of lots). To do so, a new polygon feature class called “modelname_lot_template” was created (Data Management toolbox -> Feature Class -> Create Feature Class).

   Feature Class Name: modelname_lot_template
   Geometry Type: Polygon
   Template Feature Class: (Left blank)
   Has M: Disabled
   Has Z: Disabled
   Coordinate System: (Left blank)

5) Created a polygon within the “lot_template” feature class that contained many lots of the desired size

6) Set the transparency of the “modelname_lot_template” feature class to 40% to be able to see how it lines up with the lot polygons underneath it (Layer Properties -> Display).

7) Selected the lot template polygon(s) and dragged it so it was directly above the polygon in the modelname_lots feature class that was to be split (see Fig. F.4, below).

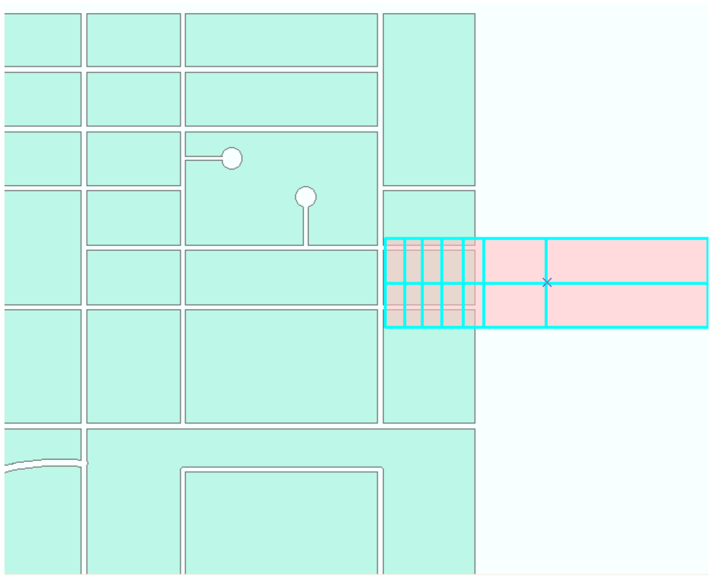


Fig. F.4: A lot template (in pink) placed to split the lot polygon (in blue) below

8) Hit “split polygons” button in the Topology toolbar. Set the target layer to the “modelname_lots” layer and left cluster tolerance at the default 0.001 units.

9) Once all lots were constructed, the attribute table was checked for any very small slivers of lots created as a part of the polygon splitting process. This was done by sorting the “Shape_Area” field to see what the smallest lot was. If a sliver, a neighbouring full-sized lot was selected and the polygon sliver merged with it.

10) Each lot was assigned a “land use type” (‘park’, ‘other’ or ‘residential’) and “land use subtype” (‘park’, ‘other’, ‘single-detached’, ‘row’ or ‘multi’) in the attributes table, either by using Field Calculator on multiple lots at once or by entering them one at a time in the attributes window.

11) Residential lots were given an integer value for their “dwelling_units” attribute (1 for single detached and row houses, and a value 3 or greater for multi-unit buildings).

12) The number of lots for each housing type as well as the total amount of land for each land use was checked to ensure model conformity with specifications (see Chapter 4).

13) Once all lot polygons were of an appropriate size, the edits were saved.

STEP 11: SIDEWALK & TRAIL DEVELOPMENT

1) Turned on the modelname_networklines layer

2) Selected all roads of a similar subtype by going to Selection -> Select By Attributes
Layer: modelname_networklines
Method: create a new selection
Query: (example) "path_subtype" = 'Collector'

3) For all sections of roads *except* cul-de-sac heads, the Copy Parallel tool (found in the editor toolbar dropdown menu) was used to create offset lines for sidewalks, using the following options:

Template: Networklines
Distance: (equal to half road width + boulevard width + half sidewalk width)[1]
Side: Both
Corners: Mitered[2]
Treat Selection as Single Line: Checked
    Create a New Feature for Each Selected Line: Unchecked
Remove Self Intersecting Loops: Unchecked

[1]: In this study, half road width + boulevard width was used, but this has the effect of placing the sidewalk network lines on the inside (road-side) edge of what was meant to be the sidewalk area, rather than the centre. The above equation is recommended for future users of this methodology because it corrects for this problem

[2] *: Although mitered corners were used in this study, rounded corners would be recommended for others hoping to build similar models, as it produces curved lines which better match the shape of sidewalks around bends.*

4) This was repeated for all other subtypes of roads (including the linear portion of each CDS, but not the heads, which are dealt with in the next step)

5) For CDS heads:
   - Used the "Feature to Lines" tool on the buffered modelname_CDS_heads_buffered feature class to create a line representing the edge of the road in the CDS head (Data Management -> Features -> Feature to Lines)

     Input Features: modelname_CDS_heads_buffered
     Output Feature Class: modelname_CDS_heads_line
     XY Tolerance: Left blank
     Preserve attributes: checked

   - Selected all the CDS head lines produced by the "Feature to Lines" tool, then went to the modelname_networklines layer and hit Editor -> Copy Parallel on the Editor toolbar and used the following settings:

     - Template: modelname_networklines
     - Distance: (equal to boulevard width + half sidewalk width)
     - Side: Left
     - Corners: Rounded
     - Treat Selection as Single Line: Unchecked
       - Create a New Feature for Each Selected Line: Unchecked
     - Remove Self Intersecting Loops: Unchecked

Note: In some cases, a cul-de-sac head would end up having segments that went in different directions (i.e., the terminal end of one segment might connect to the terminal end of another, such that both vertices are red, rather than green connecting to red all around the circle). In such a case, it was necessary to select "both" for side when using the "Copy Parallel" tool above, then go back and delete the circles inside the edge of the cul-de-sac head once this step was complete.

6) Since lines created using "copy parallel" are automatically given the attributes of the lines they were copied from (e.g., sidewalk lines could be labeled "collectors"), it was necessary after the "copy parallel" step was complete to go back and reassign attributes to the new sidewalk lines. To do so, all sidewalks were first selected by going to Select -> Select by Location:

    - Selection method: select features from
    - Target layer(s): modelname_networklines
    - Source layer: modelname_lots
    - Spatial selection method: Target layer(s) features intersect source layer features

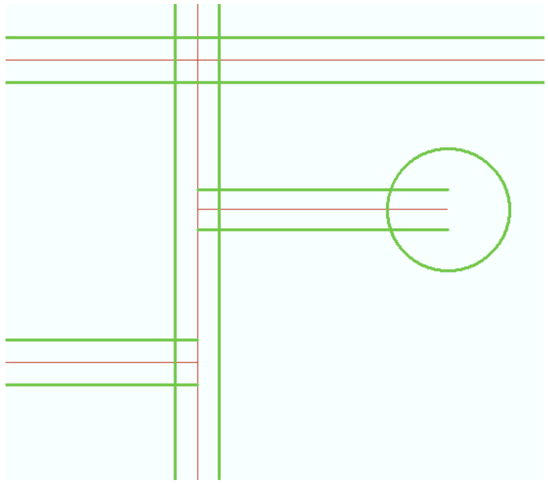
7) Opened the attribute table and used the field calculator to set attributes for sidewalk lines to Path_Type: ATN, Path_Subtype: Sidewalk, Path_Width to the sidewalk width and Path_Half_Width to half the sidewalk width (as per Appendix E).

Cleaning the sidewalk lines

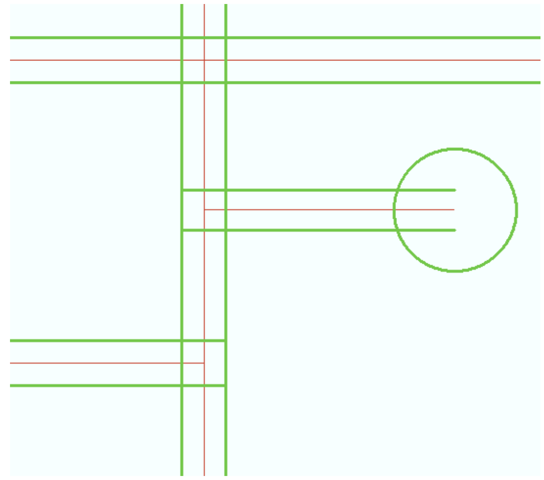
1) Deleted the sidewalks on the outside of the four bordering roads (arterials in all models but the Grid) so that these roads would only have a sidewalk on the interior edge (i.e., so all sidewalks fall within the model space).

2) Turned on edge and end point snapping (if not on already) and added extra segments across roads at all locations where a pedestrian should be able to cross a road (see example in Fig. F.5 below). *Note: this step is key to providing network connectivity during the later network analysis phase.*

Fig. F.5: Adding extra sidewalk segments to allow pedestrians to cross roads



Sidewalks (in green) before crossing segments over roads (in red) were added



Sidewalks (in green) after crossing segments over roads (in red) were added

3) In some cases it was necessary to split a sidewalk line that had fallen short of the intersection's central road line at the edge of the nearest lot in order to extend the connecting sidewalk segment from that point without affecting the location (alignment) of the sidewalk that fell on the lots (as opposed to the road) (see figures F.6, F.7 and F.8 below).

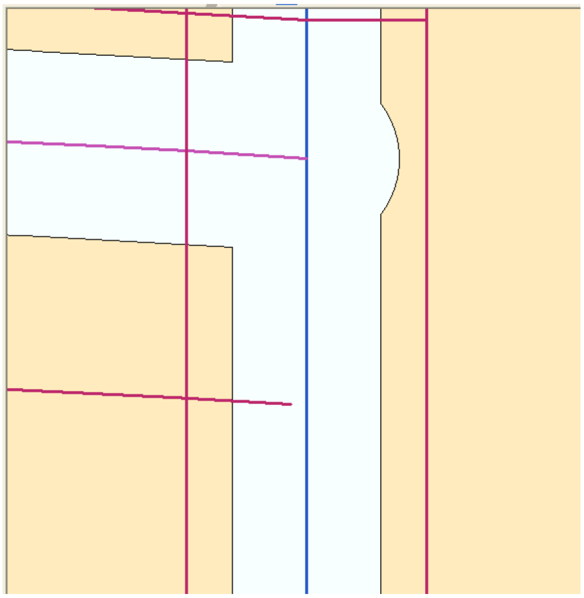


Fig. F.6: Extending sidewalk segments to cross roads

In this example, the sidewalk line (red) at the bottom of this intersection has not extended far enough to cross the road (white, with a blue centre line)

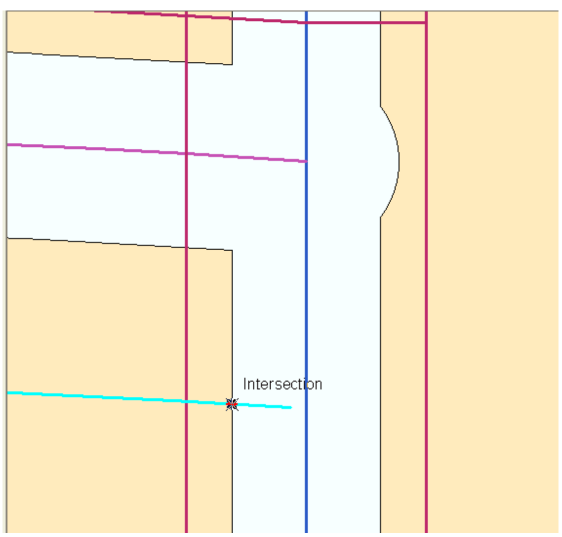


Fig. F.7: Splitting a sidewalk line at the edge of lot

In the above figure, the sidewalk line is being split at the edge of the lot so that any changes to the connecting line across the intersection will not affect the position of the "real" sidewalk running along the edge of the lots, but just the portion that will cross the road.

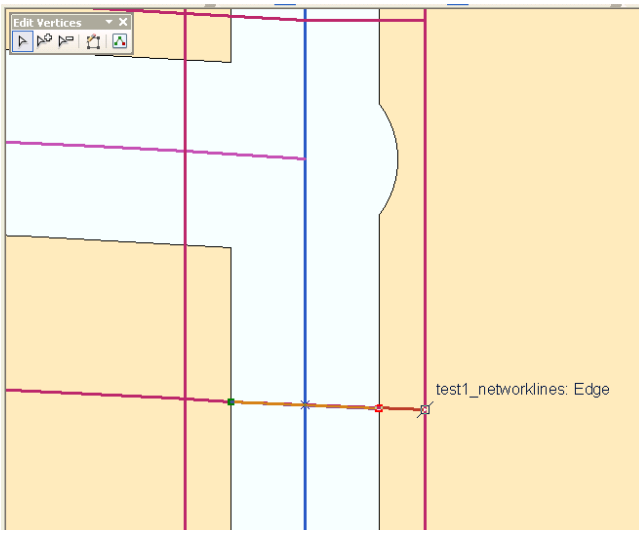


Fig. F.8: Extending the segment to meet up with the sidewalk on the other side

4) Similarly, small overshoots of the centre road line at an intersection had to be split and then the portion of the line extending past the center road line deleted (Fig. F.9 below).

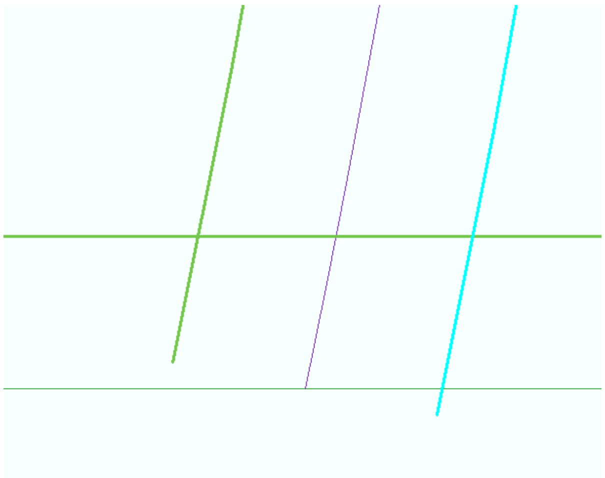


Fig. F.9: Selecting a sidewalk line (green) which was extending past the arterial (horizontal line) at the intersection

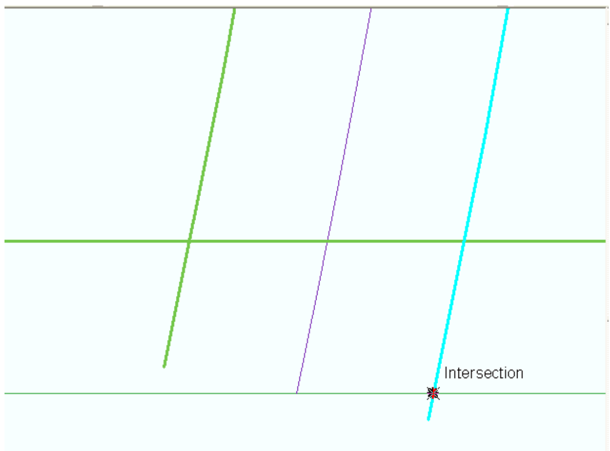


Fig. F.10: Splitting the sidewalk line where it crosses the arterial

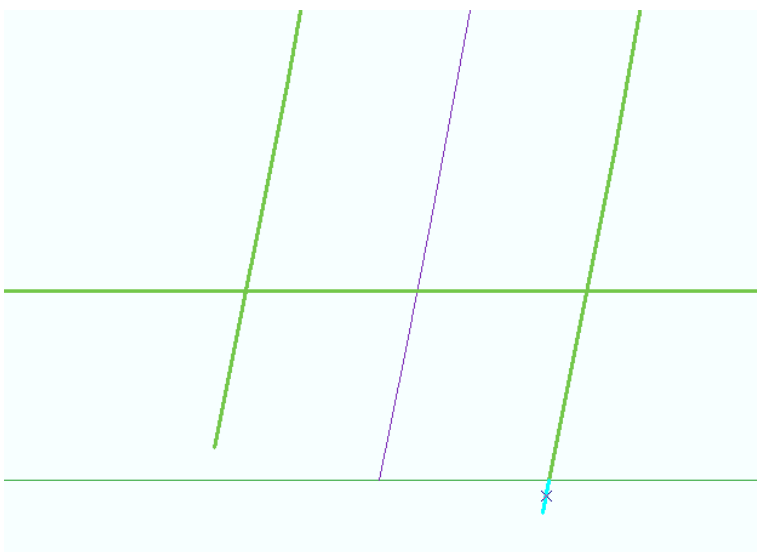


Fig. F.11: Selecting the extra segment in order to delete it

For CDS heads:

1) Turned on intersection snapping and turned off edge snapping
2) Selected the sidewalk lines around the cul-de-sac heads and split at spots where they met the sidewalks for the straight portion of the road using the split line tool. Deleted extra pieces as necessary.

3) Merged the cul-de-sac head's sidewalk with the regular sidewalk sections already created using the "Merge" tool from the drop-down menu on the editor toolbar (see Fig. 12 below).

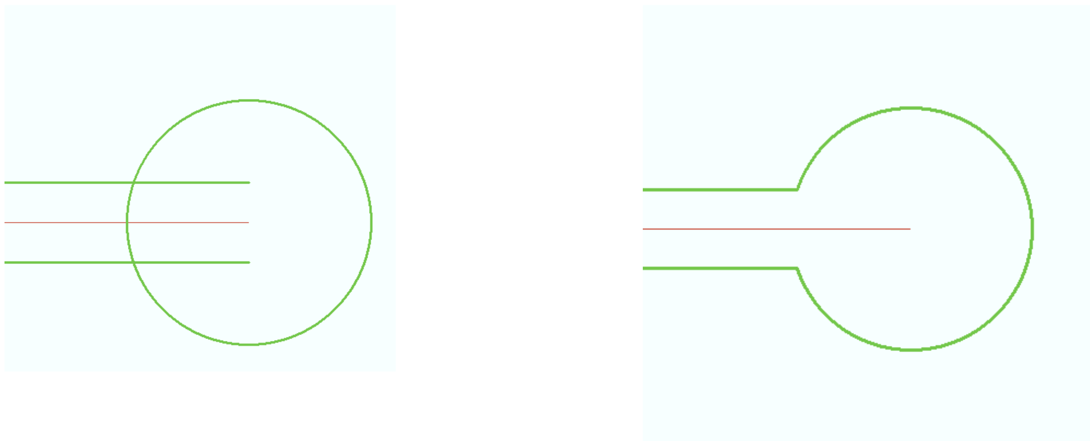


Fig. F.12: CDS heads before (left) and after cleaning (right)

To create trails

1) A new template was created for trails (Create Features Window -> Organize Templates Button -> New Template) which contained the appropriate values for Path_type (ATN), Path_Subtype (Trail), Path_Width and Path_Half_Width (see Appendix E for specifications).

2) Trails were drawn through each park space in every model.

Where trails came out outside of road intersections, they were drawn such that they crossed the road and connected to the sidewalk or trail on the opposite side. This was done with the assumption that pedestrians and cyclists would cross roads in order to access trails, even if this required a mid-block crossing (see Fig. F.13, below).

The exception to this was for where trails met arterials, in which case, it was assumed that pedestrians would not jaywalk to reach a sidewalk or trail on the other side. However, it was still assumed that bikes would have an opportunity to turn right (merging onto a bikelane), although not turn left at these points. Turn classes to prevent left turns for cyclists at this point were created later in step 27 (page 480). In order to accommodate these right turns by cyclists onto arterials, trails at arterials were drawn such that they connected to the arterial road centreline.

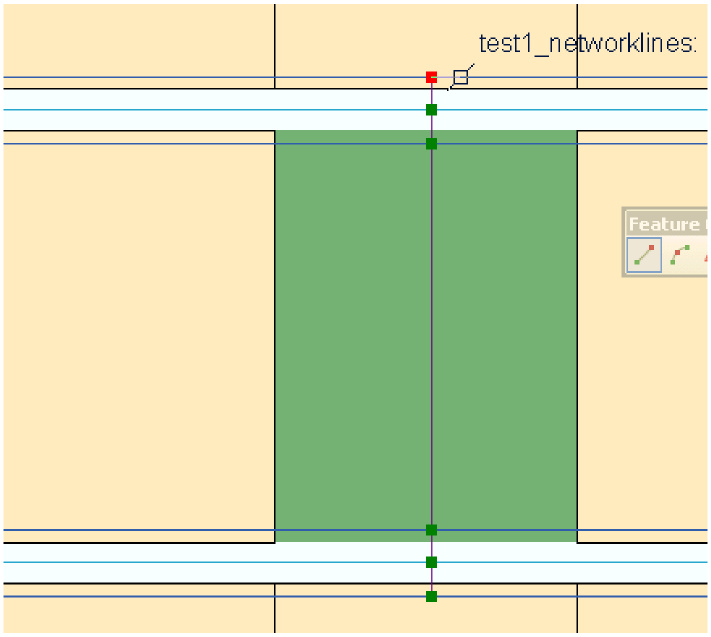


Fig. F.13: A trail extending across the road to connect with the closest ATN segment on the other side (here, a sidewalk)

3) Where trails came out at a road intersection, the trail was just run to the centre of the intersection, rather than across to the other side, to represent the fact that upon arriving at such an intersection, pedestrians from the trail would cross along the sidewalk lines, while cyclists would presumably enter the road network.

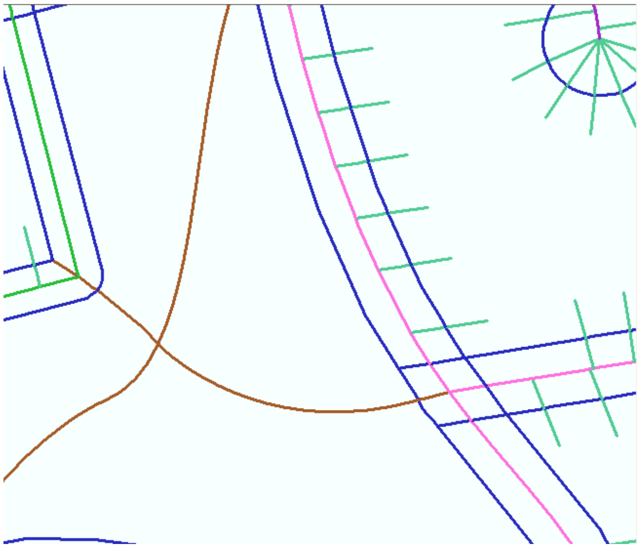


Fig. F.14: A trail connecting to the centre of a road intersection

Greenway Variation

It was concluded that the grain of the Greenway's active transportation network was coarser than desired as a result of the long cul-de-sacs; in order to correct this, some extra trail shortcuts were placed through parks and the large multi-unit residential lots (Fig. F.15 below).

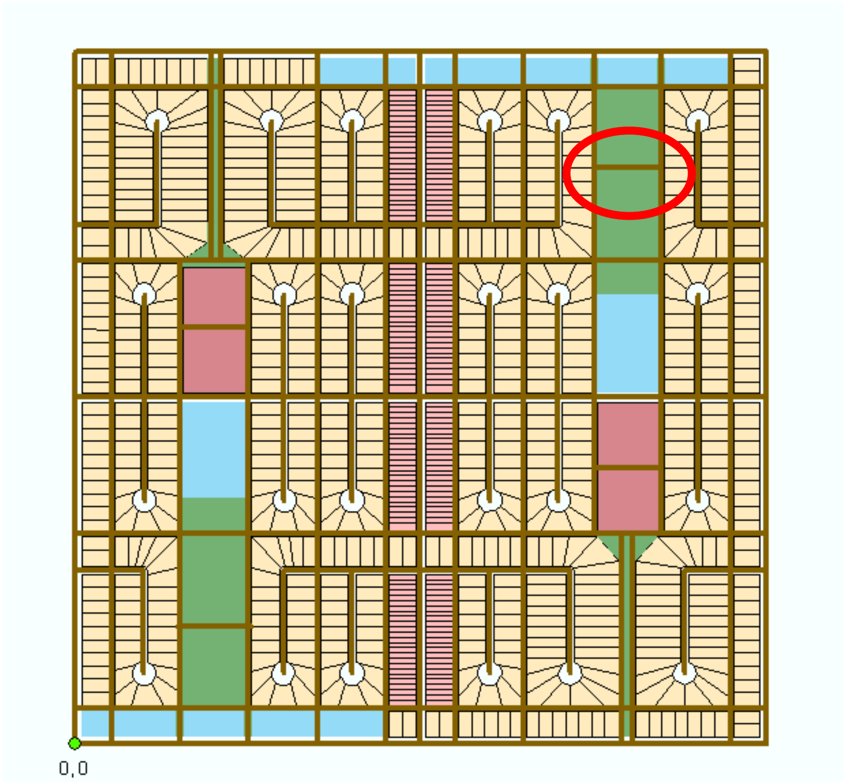


Fig. F.15: Greenway model showing extra east-west trail shortcuts (brown) through parks (green) and the multi-unit residential lots (dark pink)

STEP 12: TESTING TRAIL AND SIDEWALK CONNECTIVITY

1) Once all ATN lines were drawn, the modelname_networklines feature class was checked for dangles and overlapping lines by re-validating the modelname_networklines_topo1 topology.

STEP 13: CREATED SETBACKS

Setback lines were created in order to be able to later locate homes in the centre of lots (width-wise) but set back a certain distance from the road (or in the case of the Greenway model, the trail). To do so:

1) Used the Create Feature Class tool (Data Management -> Feature Class -> Create Feature Class) to create a new feature class for the setback lines:

   Feature Class Name: modelname_setbacks

   Alias: None

   Type: Polyline

   No M, no Z

   Configuration Keyword: Default

2) Added the new setback feature class to map using "Add Data" button

3) Opened the modelname_setbacks attribute table and added an attribute field called "setback_type" of the "Text" data type. (Possible values for this field were: 'Single', 'Row' or 'Multi').

4) Created a new template for modelname_setbacks in the Create Features Window

5) Did a definition query on networklines layer so only sidewalks were showing ("path_subtype" = 'Sidewalk' in the query builder in the layer properties dialog box

6) Selected all sidewalks and then hit "Copy Parallel" in the Editor dropdown menu, using the following options:

   (template: modelname_setbacks)

   Distance: (The value for either single, row or multi-unit setbacks for the model; see Table F.3 below)

Side: Both

Corners: Mitered

Treat selection as new line: Unchecked

Create a new feature for each selected line: Unchecked

Remove self-intersecting loops: Unchecked

Table F.3: Setback lengths for different types of residential lots

Single Detached (in feet)	**Row (in feet)**	**Multi-Unit[1] (in feet)**
SHALLOW SETBACK MODELS (Grid & New Urbanist)		
20	20	50
20	20	50
STANDARD SETBACK MODELS (Loops and Cul-de-Sacs, Fused Grid)		
40	30	50
40	30	50
EXTENDED SETBACK MODELS[2] (Greenway)		
50	40	50

[1]: Used only for those buildings with 30+ dwelling units within; below this number of units, it was assumed single-detached lot setbacks would be acceptable. (It is noted that this value is, however, a bit arbitrary, as many downtown apartment buildings often have little or no setback relative to the street, while those in suburban areas are often surrounded by large, park-like spaces).

[2]: Extended setbacks had to be created for the Greenway model in order to compensate for reducing spacing between home (as there is no road to serve as a "spacer"). Setbacks in the Greenway model were measured from the trail rather than the edge of the lot in order to maintain a consistent distance between the front of the home and the trail (similar to a sidewalk), regardless of the location of the trail in the park (see p. 435).

7) Opened the modelname_setbacks attribute table, selected all data with a null setback type, and changed the setback type to the appropriate value ("Single" or "Row" or "Multi") using the Field Calculator.

8) Repeated steps 5 through 7 for the other type of setback.

9) Symbolized the modelname_setback layer to reflect the two different setback types.

Deleting extra setback lines

At this point, the networklines with the setback lines looked like Fig. F.16, below:

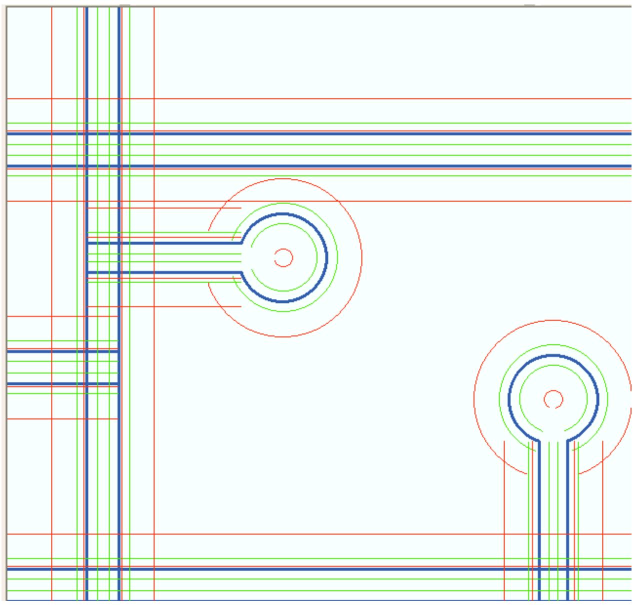


Fig. F.16: Uncleaned setback lines (green and red) created using a "copy parallel" off the sidewalk lines (blue)

Because ArcMap put setbacks on both sides of the sidewalk lines, there was an unnecessary (and incorrect) setback line for every correct one created (located in the road space or on the opposite side of the road, depending on the length of setback). The following steps were used to eliminate these extra lines:

1) Used the Copy Features tool (Data Management -> Features -> Copy Features) on modelname_setbacks to produce a new featureclass called "modelname_setback_cleaned"

2) Turned on modelname_networklines_roads_buffered_clipped layer

3) Used Selection -> Select by Location to select all setback lines which fell in the road space

   Selection Method: Select features from

   Target layers: modelname_setbacks_cleaned

   Source layer: modelname_networklines_roads_buffered_clipped

Spatial selection method: Target layer(s) features are within the source layer feature

4) Deleted all selected lines, leaving a partially-cleaned set of setback lines (see Fig. F.17 below)

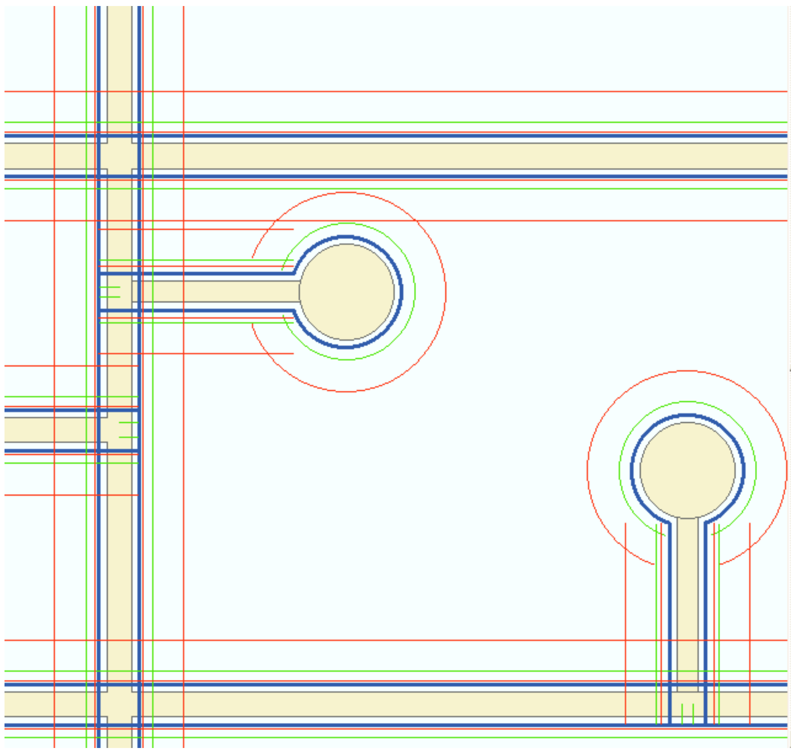


Fig. F.17: Setback lines (green and red) following deletion of all extra lines falling within the road space

1) Next, it was necessary to clean the extra setback lines that fell in the buildable area. In order to do so, a definition query was used so that only one type of setback line is visible (e.g. "Setback_Type" = 'Multi' in query builder).

2) Since all correct multi setbacks should have been (for instance) 50' from the edge of the road, any that were closer than that would have to be the extra lines resulting from the copy parallel off the sidewalk on the other side of the road. To select these lines, a "Select by Location" was used (Selection -> Select by Location).

Selection Method: Select features from

Target layers: modelname_setbacks_cleaned

Source layer: modelname_networklines_roads_buffered_clipped

Spatial selection method: Target layer(s) features are within the source layer feature

Search Distance: (Setback minus 5')

3) Deleted all selected lines.

4) Repeated steps 1 to 3 for single and row setbacks.

Cleaning Setbacks

At this point, it was necessary to further refine the setback lines.

1) A line feature class containing a line for every edge of the model lots was created using the Feature to Line tool (Data Management -> Features -> Feature to Line)

   Input Layer: modelname_lots

   Output Feature Class: modelname_lotlines

   XY Tolerance: (Left blank)

   Preserve Attributes: Checked

2) These lot lines were then selected, copied and pasted into the modelname_setbacks_cleaned feature class.

3) Selected all lines now in the modelname_setbacks_cleaned feature class.

4) Hit the "Planarize Lines" button in the Topology toolbar to split the setback lines at edge of each lot. The cluster tolerance was left on the default 0.001 unknown units.

5) Once the setback lines were planarized, it was necessary to delete the lotlines that had just been added to the modelname_setbacks_cleaned feature class. This was done by opening its

attribute table, sorting by setback_type, and then deleting all records that contained a null value.

6) Next, all setback line segments that were located on the wrong type of lot were deleted. To do so a Definition Query was done on the modelname_lots layer so only lots for single detached houses were showing ("landuse_subtype" = 'Single')

   Then, a Definition Query was done on the setbacks_cleaned feature class so only multi and row setbacks are showing ("setback_type" = 'Multi' OR “setback_type” = ‘Row’)

   A “Select by Location” was then used to select all setback_cleaned lines (now only showing “Multi(-unit)” and “Row” lines) which fell on “Single (detached)” lots:

   Selection Method: Select Features From

   Target Layer(s): modelname_setbacks_cleaned

   Source Layer: modelname_lots

   Spatial Selection Method: Target Layer Feature(s) are within the source layer feature

   Apply Search Distance: (Unchecked)

7) Deleted the selected lines.

8) Reversed the process and repeated steps 6 and 7 to delete all single or row setbacks on multi-unit lots, and all single or multi setbacks on row lots.

9) Turned off the definition queries in both the modelname_lots and modelname_setback_cleaned layers

10) Deleted any setback lines falling in parks or “other” land use lots.

11) Saved edits.

Fixing Corner Lots:

1) Corner lots had a setback line for each edge facing a road (see Fig. F.18 below), and so setback lines were deleted manually to ensure that there was only one setback line per lot, typically chosen such that homes would face the quieter of the two roads (i.e., the road that was lower in the hierarchy defined on p. 468).

Before cleaning *After cleaning*

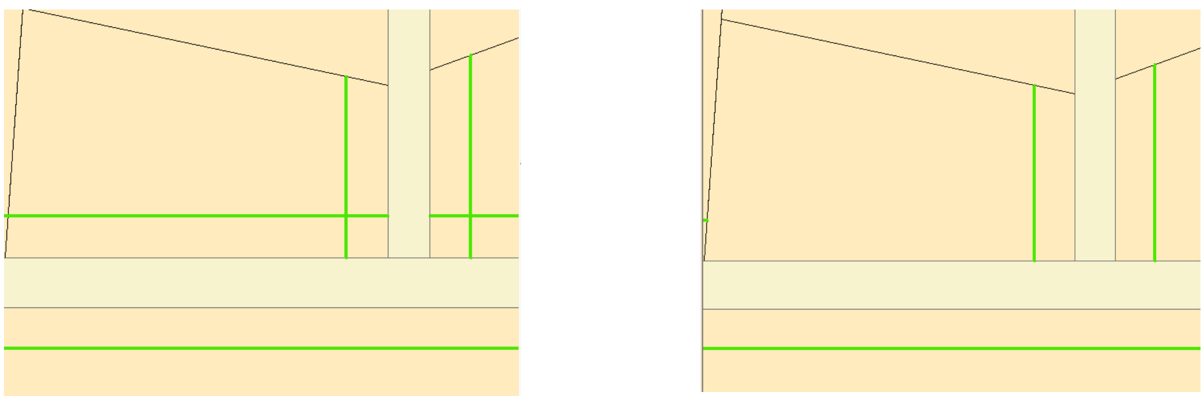


Fig. F.18: Multiple setback lines (green) occurred at corner lots; before cleaning (left) and after cleaning (right)

Straightening Setbacks

1) Setbacks which curved around bends in the road were straighted in order to ensure they would only produce one origin point once "Feature to Point" tool was used. This was done by deleting any internal vertices and changing the segment type to "Straight" if necessary (Fig. F.19).

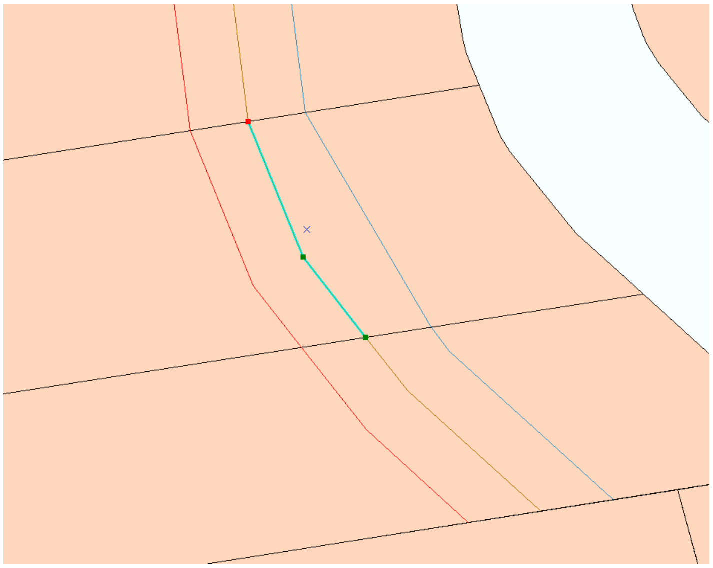
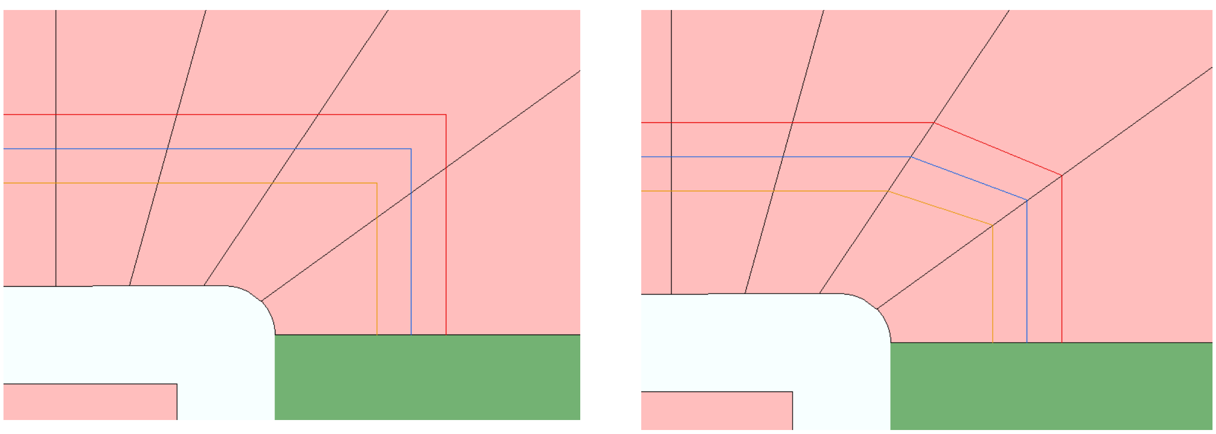


Fig. F.19: A curved setback in which the centre vertex would be deleted

2) Lots which had a "V" setback (see Fig. F.20) were given a similar treatment, wherein the central vertex was deleted to produce a straight setback line.



"V" setback before straightening *After straightening*

Fig. F.20: Correcting "V" setbacks

Extra Setback Lines on Cul-de-Sac Lots

The shape of the cul-de-sac heads resulted in extra setback lines on many of the CDS lots where the setback lines from the rounded end of the cul-de-sac met those from the straight portion of the road.

1) If it was clear that one setback line fit the lot much better than the other, the other was deleted (for instance, in figures F.21 and F.22 below).

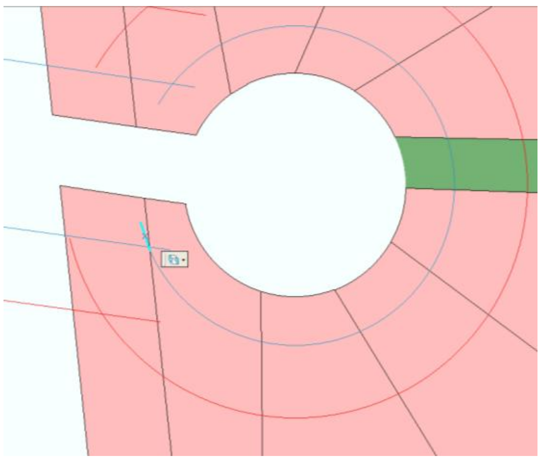


Fig. F.21: Deleting a small setback line segment in favour of preserving the other setback line on the lot

Fig. F.22: Deleting a curved setback line in favour of preserving the straight one on a lot with a straight frontage

2) If the two setback lines met towards the middle of the lot, a new straight setback line was created between the spots where they crossed the lot lines on either side, and the original two setback lines deleted.

3) For some lots, the shape was such that the setback lines fell towards the back of the lots, but in these cases, it was simply assumed that the house has a side yard rather than a front yard (Fig. F.23, below):

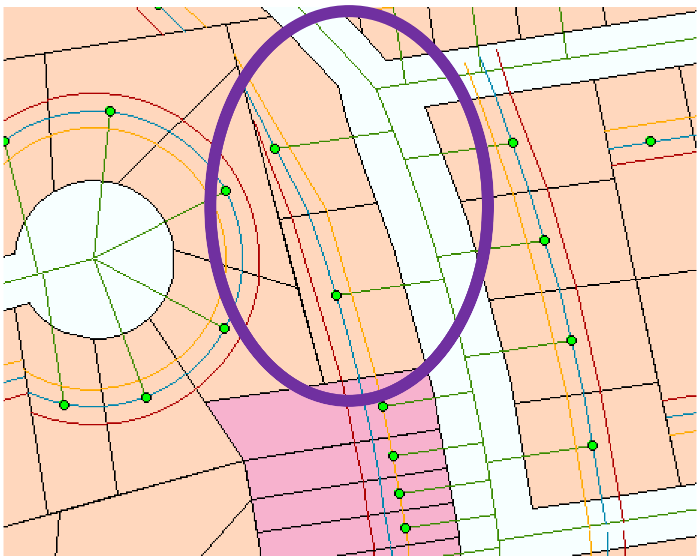
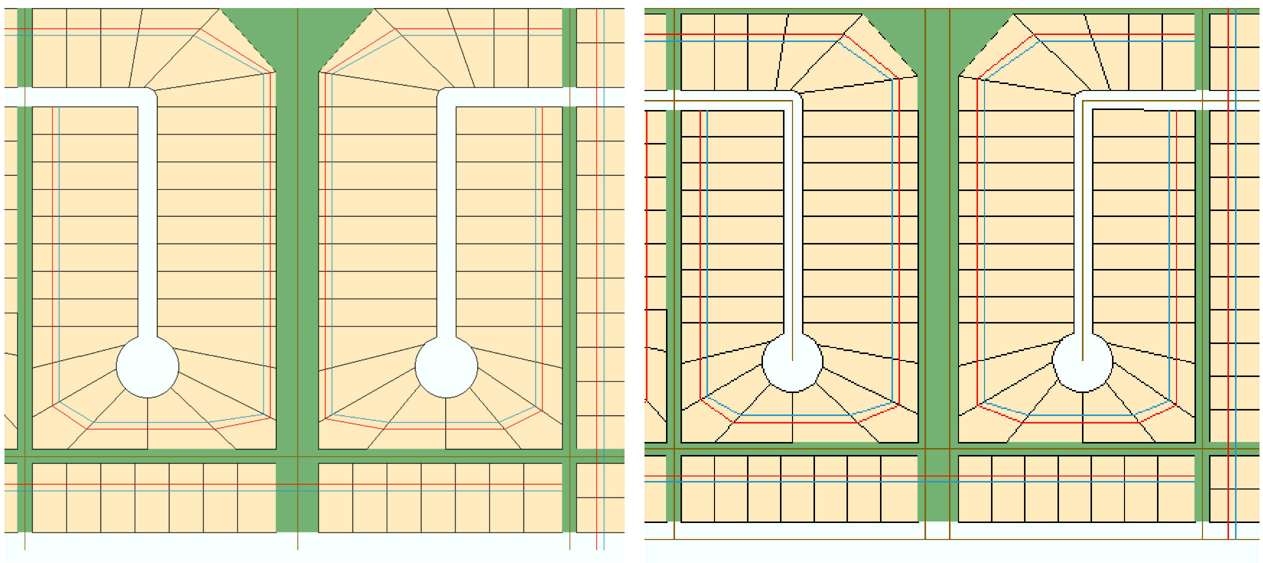


Fig. F.23: Two lots assumed to have side rather than front yards

Greenway Model Variation:

In the Greenway model, trails were used in lieu of sidewalks when using the “copy parallel” tool to create setbacks. Because in some cases there was a large section of park between the start of the lot and trail, some parkland would fall within the setback, with the result being that the “true” setback from the lotline (rather than the trails) varied in different portions of the model. However, doing a copy parallel off trails (rather than lot lines) was still preferred, because this allowed for a constant distance between the front of homes and the parkland trails (making it more comparable to the experience of pedestrians to sidewalks in the other models), even if it meant that some homes effectively had smaller front yards. It was felt that this was acceptable for this particular model, as even with small front yards, homeowners would still have the park space in front of their homes, creating the illusion of a much larger yard than lotlines alone would dictate.

In some cases, however, the setback lines were felt to fall too close to the front of the lots, particularly where there was just one trail through themiddle of a park (Fig. F.24, below). To fix this, the design was modified so that the central trail was replaced by a trail on either edge of the park space and the copy parallel tool then run off those.



Overly shallow setbacks created by having one trail in the centre of the park

Improved setbacks resulting from two-trail design

Fig. F.24: Effect of trail location on Greenway setback location

STEP 13: CREATED ORIGIN POINTS

In order to use the “Feature to Point” tool to create a single point (the home) at the centre of each setback line on a lot, it was necessary that the setback lines themselves be merged within the lot space (as many would have been split into multiple segment as a result of the earlier planarization). To do so:

1) Added an attribute field to modelname_lots called “LotNumber” and used Field Calculator to populate the field with its ObjectID values (LotNumber = [OBJECTID])

2) Ran the Identity tool (Analysis -> Overlay -> Identity) on the modelname_setbacks_cleaned layer, such that it added the lot attributes (including “LotNumber”) to each setback line (in order to be able to tell which lot each line went with).

   Input Features: modelname_setbacks_cleaned

   Identity Features: modelname_lots

   Output Feature Class: modelname_setbacks_lot_identity

   Join Attributes: All

   XY Tolerance: (leave blank)

   Keep Relationships: (unchecked)

3) Used the “Dissolve” tool to merge all setback line segments in the same lot into one line (Data Management -> Generalization -> Dissolve).

   Input Features: modelname_setbacks_lot_identity

   Output Feature Class: modelname_setbacks_dissolved

   Dissolve Field(s): LotNumber

   Statistics Field(s): (Left blank)

   Create Multipart Features: Unchecked

   Unsplit Lines: Unchecked

4) Used the “Feature to Point” tool to create a point at the centre of each setback line (Data Management -> Features -> Feature to Point) (see Fig. F.25 below).

Input Features: modelname_setbacks_dissolved

Output Feature Class: modelname_homes

Inside: Checked (to ensure that the points fell directly on the setback lines)

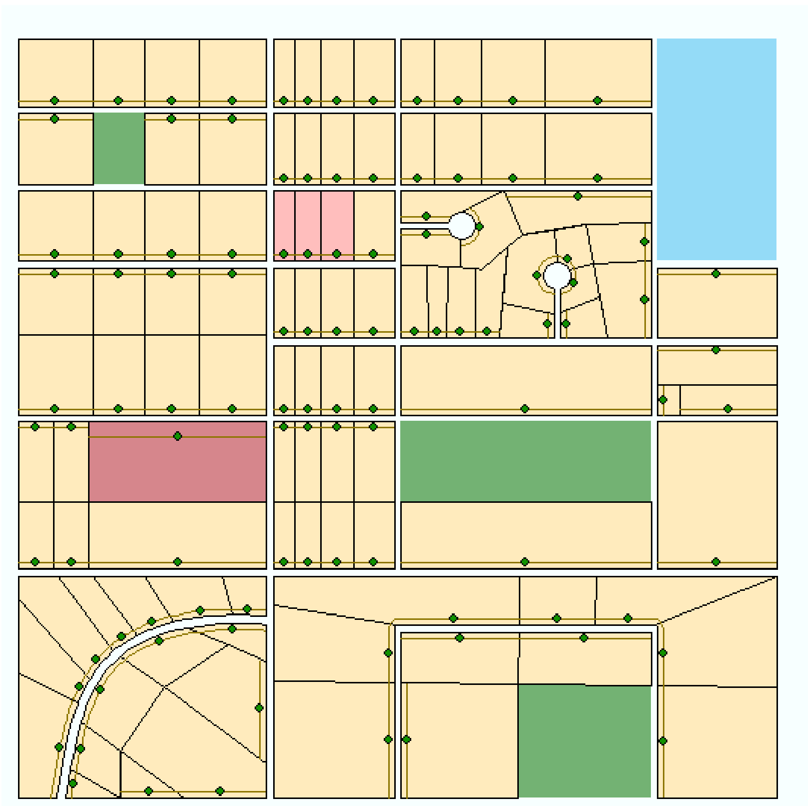


Fig. F.25: An example model showing an origin point (home) created on the setback line for each lot

STEP 14: CREATED DESTINATION POINTS

1) Started an editing session

2) Turned on the modelname_dest layer

3) Selected the modelname_dest template in the Create Features Window and selected “Point” under “Construction Tools” window

4) Right clicked and placed dots at “Absolute X, Absolute Y” for the following coordinates (Table F.4 below), such that, for the points around the edge of the model, they fell 1’ off the frame (thus ensuring that when trying to get to a destination, the route would appear to cross the road):

Table F.4: Destination point coordinates

Destination Point	Coordinates
Point 1 (Edge)	-1 , -1
Point 2 (Edge)	-1 , 1320
Point 3 (Edge)	-1 , 2641
Point 4 (Edge)	1320, 2641
Point 5 (Edge)	2641, 2641
Point 6 (Edge)	2641, 1320
Point 7 (Edge)	2641, -1
Point 8 (Edge)	1320, -1
Point 9 (Centre)	1320, 1320

5) Populated each record’s “DestType” attribute field with either “Edge” or “Centre”

6) Saved edits

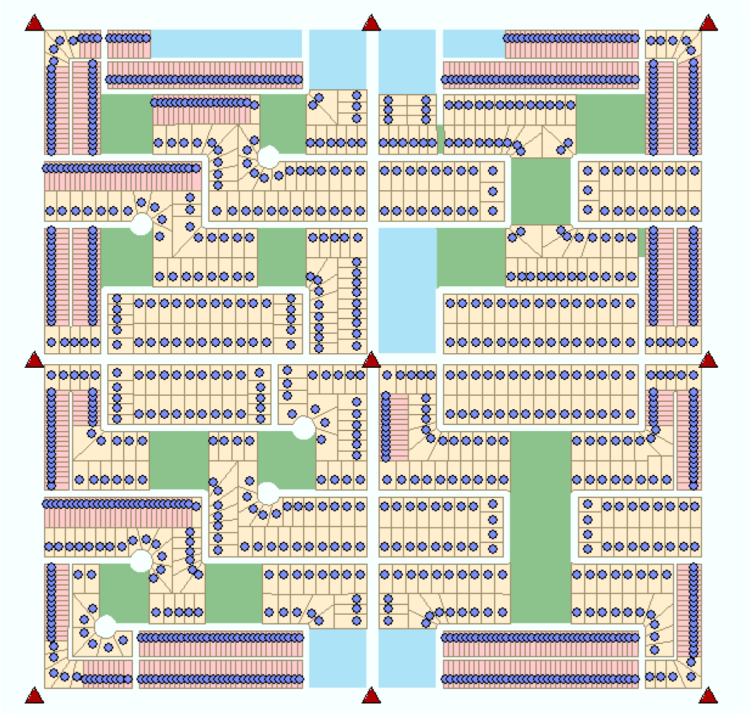


Fig. F.26: The Fused Grid model, showing destinations (red triangles) and origins/homes (blue dots)

STEP 15: CREATED DRIVEWAYS AND FRONTDOOR CONNECTIONS

Creating Residential Driveways

1) Started editing in the modelname_networklines layer

2) Created a new template for "ResDriveway" with path_type = 'Driveway', path_subtype='Driveway' and Users = 'All' (Create Features window -> Organize Templates -> New Template)

   Note: In the Greenway model, the "Users" field for driveways was "Mixed" instead of "All", as pedestrians are assumed to not walk on driveways as they provided no access to the active transportation network.

3) Turned on vertex and edge snapping, and manually added a line running from each origin point (home) to the road or alley, depending on the lot.

4) The number of driveway lines was compared to the number of residential lots in the modelname_lots layer (by comparing the number of records in their respective attribute tables) to ensure that the correct number of lines had been drawn.

5) A “Select by Location” was used to find homes that did not yet have driveways:

- Selection method: Select features from
- Target layer(s): modelname_homes
- Source layers: modelname_networklines
- Target layer(s) features intersect source layer feature(s)

Then opened attribute table and hit “switch selection” button to see which origin points did not yet have driveways running to them, and created driveways for them.

Creating Front Door Connections

1) For all homes in the Greenway model or for any residential lots that connected to an alley in the other models, a second line was run from the home/origin point (assumed to represent the front door) to the road and called “path_type: ATN”, “path_subtype: frontdoor” and “users: PedBike”, to represent the ability of pedestrians to get to the sidewalk and cyclists to the road this way.

Notes on Residential Driveway & Front Door Connection Construction:

- Lines were run such that they were either parallel to the sides of the lotlines (where the lot was relatively rectangular), or so that it fell on an angle roughly halfway between the two sides (where the lot was pie-shaped or some other shape).

- For Cul-de-Sac heads, driveway lines were run such that they connected directly to the end of the CDS road line, until it was possible to run a line that would be relatively perpendicular to the road up to the origin point (home) (see Fig. F.27, below).

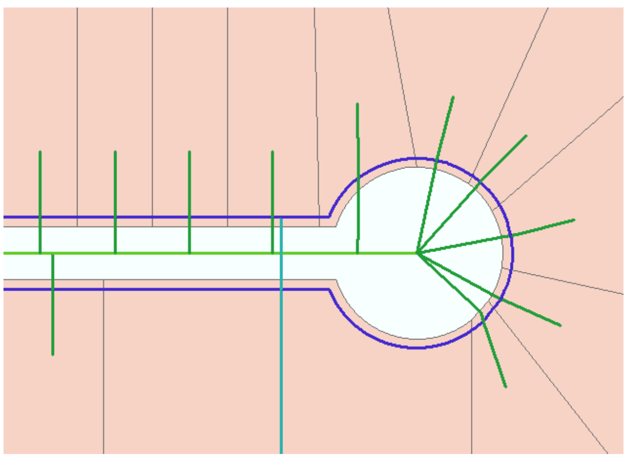


Fig. F.27: Layout of driveways in Cul-de-Sac heads

Creating "Other" Driveways

A driveway was created every 30 m (98.4') along the edge of the "other" land use lots (i.e., those lots which were not residential and not park). Each lot was treated individually for the purposes of calculating the number of driveways that should be located on it. Each lot had to have at least one driveway. In order to create these driveways:

1) In the modelname_lotlines feature class, split the lines of the "other" polygon lot in question at each of its corners (see Fig. F.28 below)

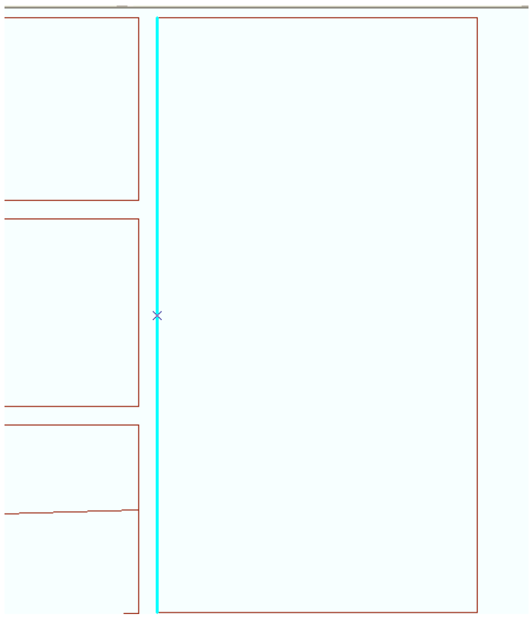


Fig. F.28: An “Other” land use lot showing that its sides have been split

2) Selected the modelname_lotlines template from the Create Features Window.

3) Selected the polygon’s lot lines (only those which faced a road) and used the copy parallel tool to create a 40’ temporary “driveway setback” from each side (Editor -> Copy Parallel) (see Fig. F.29, below)

Distance: 40’

Side: (Whichever side would create a line on the inside of the polygon)

Corners: Mitered

Treat Selection as Single Line: Checked

Create a new feature for each selected line: Unchecked

Remove self-intersecting loops: Unchecked

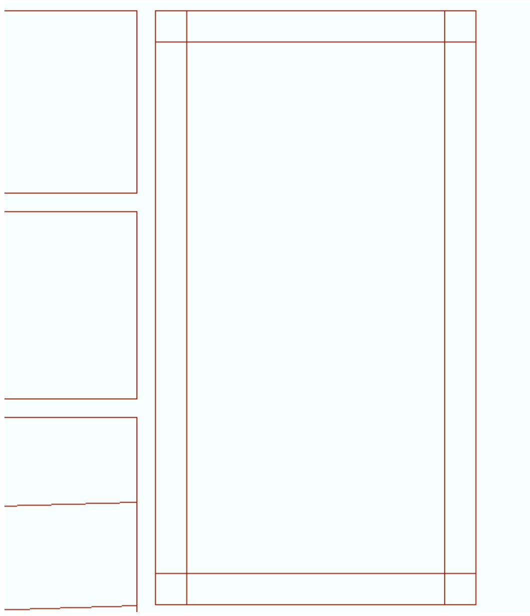


Fig. F.29: An "Other" land use lot showing temporary "driveway setback" lines to assist with driveway construction

4) Selected one of the new lines.

5) Turned on a points layer (such as modelines_dest) and selected its template from the Create Features window.

6) Used Editor -> Construct Points to create a series of temporary points along the line for use in snapping

Template: modelname_dest

Number of points: (blank)

Distance: 98.4' (the distance between each "other" driveway, as per p. 360)

Create additional points at start and at end: unchecked

Orientation: (from start of the line)

7) Repeated steps 4 to 6 for each of the "other" lot driveway setback lines in the model.

8) Created a new modelname_networklines template with path_type = 'driveway', path_subtype = 'otherdriveway' and users = 'all' (except for Greenway, in which the users were "mixed") (Create Features window -> Organize Templates -> New Template).

9) Drew an "otherdriveway" line from each of the temporary points along the driveway setback lines to the road.

10) Once all "otherdriveways" were drawn, the temporary points in the chosen points layer were deleted, as were the temporary setback lines that had been drawn into the modelname_lotlines layer.

Notes on "Other Driveway" Construction

- A problem was encountered when trying to use "Create Points" on some line segments of 107' in the Fused Grid Model, wherein Arc would not add a point at the 98.4' mark but instead would put one at each end. Where this ended up happening, one of the extra points was deleted.

New Urbanist Variation

- Where a driveway would run parallel to alley, it was assumed that the alley would be used for parking and there was no need for an "otherdriveway" along the perpendicular edge (see Fig. F.30, below).

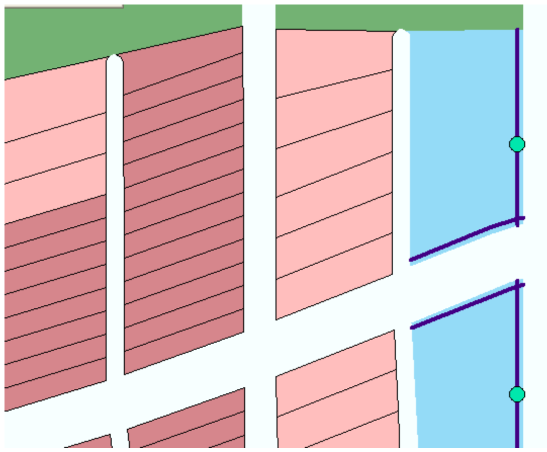


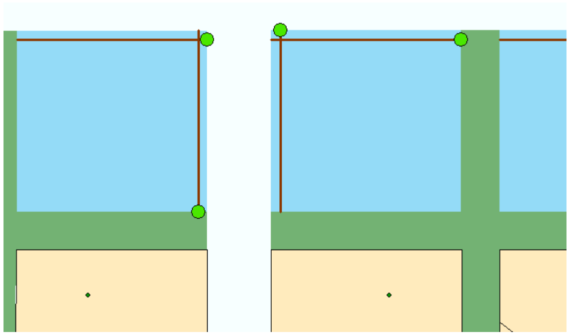
Fig. F.30: "Other" driveway points and alleys

In the example show in this figure, no "otherdriveway" setback points were placed on the temporary setback lines (dark blue) running roughly east/west, because any driveway run from the road to such a point would run parallel to the alleys (located immediately to the left of the blue "other" land use lots in this example)

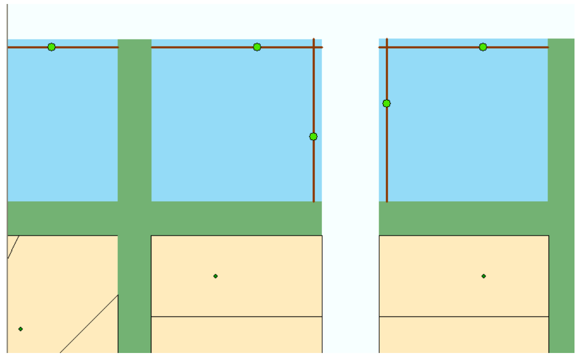
Greenway Variations

- In the case of the Greenway model, a corresponding "frontdoor" line had to also be created to "other" land use lots in order to provide connections for pedestrians coming from the trail network (the only case in which a temporary setback line had to be drawn on a side of a lot not facing a road).

- With Greenway model, the Construct Points tool often dropped the temporary driveway points right at the very end of the line where it would not make sense to have a driveway (being too close to the edge of the road), so these points were manually shifted 40' away from the edge of the road (see Fig. F.31 below).



Points located at the very end of the “driveway setback” lines

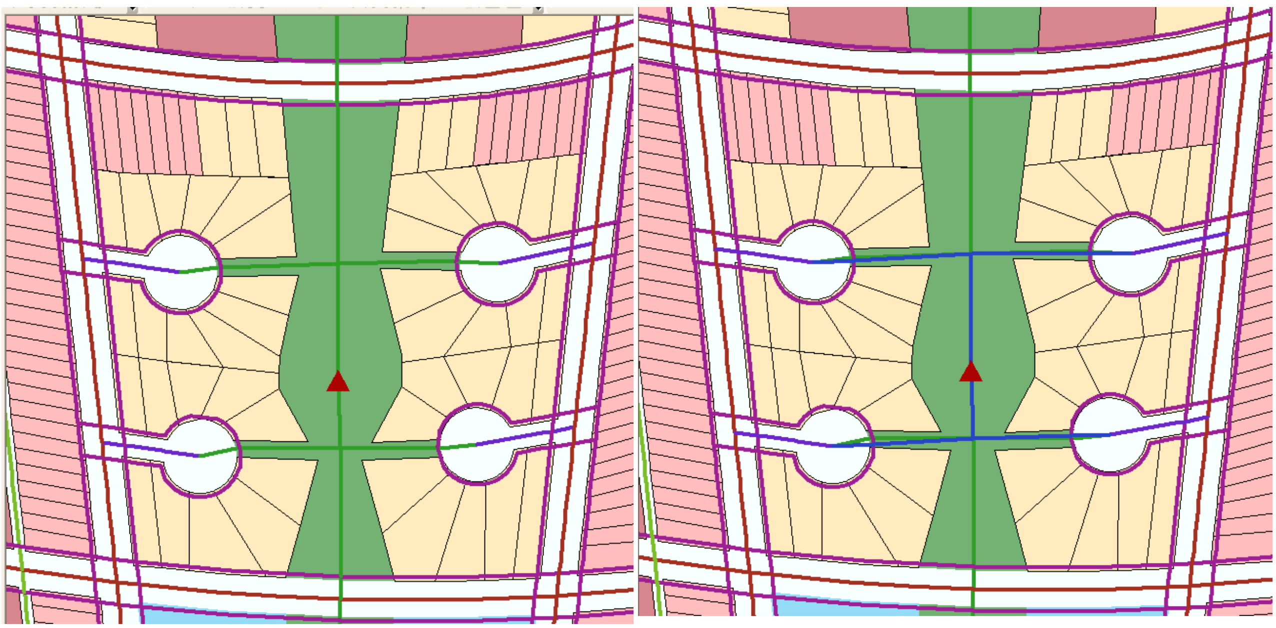


Points shifted to be 40’ from edge of road

Fig. F.31: Shifting temporary driveway points in the Greenway model

STEP 16: CREATED "FAKE" CONNECTIONS

It was not always possible for all modes to reach all destination points using the network lines as they were laid out. An example of this was for the central destination point in the New Urbanist model, which ended up falling along a trail in the middle of a park. While pedestrians and cyclists could reach the destination by using the trail, cars could not (see Fig. 32, below).



While pedestrians and cyclists could access the destination point (red triangle) using trails (green), the point was inaccessible by car.

"Fake" lines (blue) were added to allow cars to reach the destination point.

Fig. F.32: Creating "fake" connections to allow all modes to reach all destination points

In order to address this problem, special line segments (called "fake" segments) were created to connect modes to destinations they would otherwise be unable to reach. This was done in order to ensure that modes which could not reach a destination would not have artificially low trip lengths to it as a result of having the trip end when they had gotten as close as they could get to the destination on their regular network. To do so:

1) Created a new modelname_networklines template called "Fake" with road type = fake and road subtype = fake. (Create Features window -> Organize Templates -> New Template)

2) Drew a segment to represent where the missing pathway would occur in a manner consistent with the mode's overall network pattern. This segment started at the closest intersection with a path accessible to the user in question and ended at the destination point (see Appendix I for maps showing the location of all "fake" connections used in the models).

3) Populated the "Users" attribute field in the modelname_networklines feature class with whatever user group would need to use the fake segment to reach the destination in question.

STEP 17: CREATED "POINT OF CONFLICT" POINTS

A "Points of Conflict" (POC) feature class was needed in order to allow ArcMap to count the number and types of possible points of conflict a traveler would pass through when trying to reach a given destination. The different types of POCs included in this study were:

- "sd_dri" (for sidewalk/driveway)
- "sd_sd" (for sidewalk/sidewalk)
- "sd_tr" (for sidewalk/trail)
- "sd_rd" (for sidewalk/road)
- "sd_od" (for sidewalk/other driveway)
- "sd_fd" (for sidewalk/front door)
- "tr_dri" (for trail/driveway)
- "tr_od" (for trail/other driveway, although it is noted it turned out there were ultimately no instances of this in the model, despite being anticipated)
- "tr_fd" (for trail/front door)
- "tr_tr" (for trail/trail)
- "rd_rd" (for road/road)

- "rd_tr" (for road/trail)
- "rd_up" (for road/underpass)

To create this feature class:

1) Used the Intersect Tool to create a point at each networkline intersection (Analysis -> Overlay -> Intersect)

   Input Features: modelname_networklines

   Output Feature Class: modelname_POCpts

   Join Attributes: All

   XY Tolerance: (left blank)

   Output Type: Point

   This step produced a series of points throughout the path network (Fig. F.33).

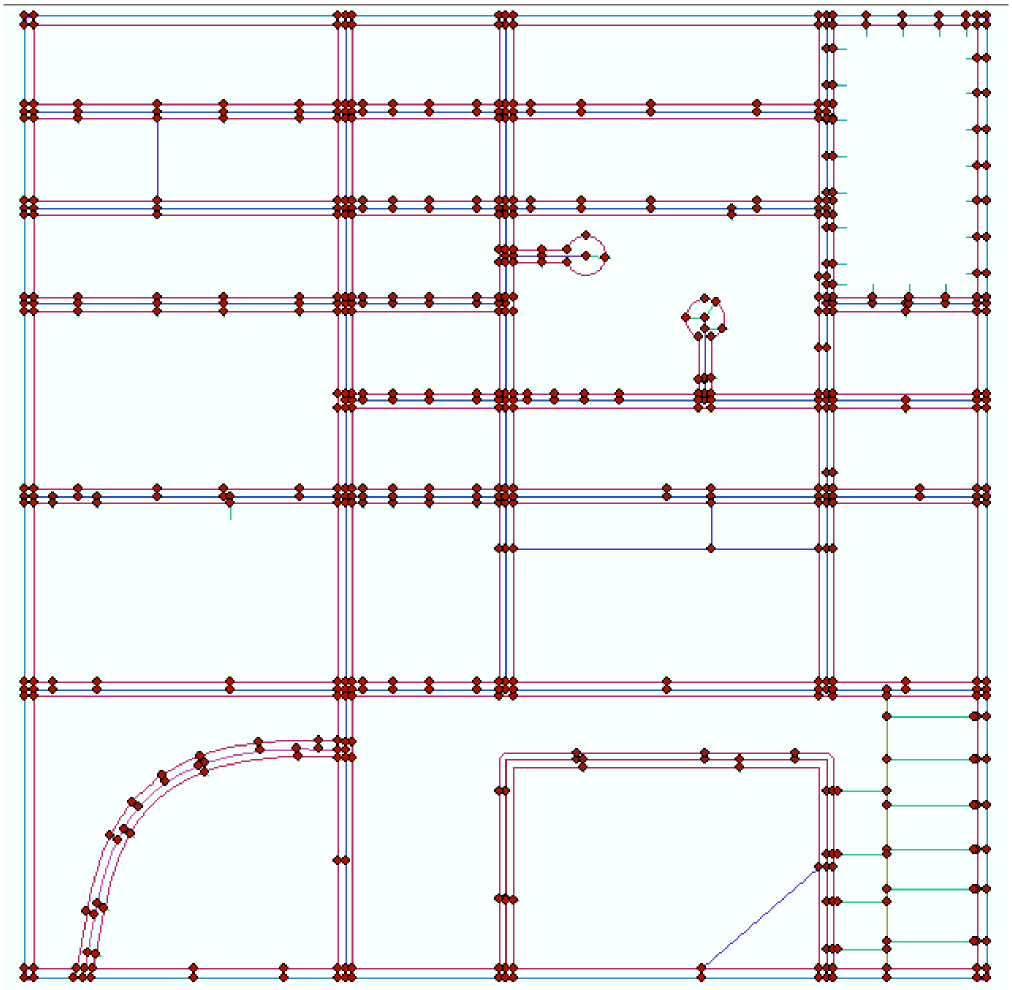


Fig. F.33: An example of what a network might look like with the possible POC points added

2) Opened the modelname_POCpts attribute table and added an attribute field called "POC_type" (data type: text).

3) Created a copy of the modelname_networklines layer called "modelname_networklines_copy" to help in assigning POC types (Data Management -> Features -> Copy Features).

4) Put a definition query on the original networklines layer and the copied layer, such that each had a different type of path represented (for instance, one would be set to show only roads and one set to show only sidewalks, such that any POC point falling on both would have to be a "road/sidewalk" POC).

5) Did the first of two Select by Locations (Selection -> Select by Location):

Selection Method: Select Features from

Feature Class(s): modelname_POCpts

Source Layer: modelname_networklines

Spatial Selection Method: Target layer(s) feature intersects the source layer feature

Apply a search distance: 1’

(In the above example, this would select all the POCs falling on roads)

6) Do a second Select by Location:

Selection Method: Select from the currently selected features in

Feature Class(s): modelname_POCpts

Source Layer: modelname_networklines_copied

Spatial Selection Method: Target layer(s) feature intersects the source layer feature

Apply a search distance: 1’

(In the above example, this would then select all the POCs from the first selection that also fell on sidewalks).

Note: The search distance was necessary because in some cases the POC points did not line up perfectly with the intersection of the lines (see Fig. F.34 below). This seemed to be a problem primarily on curved roads.

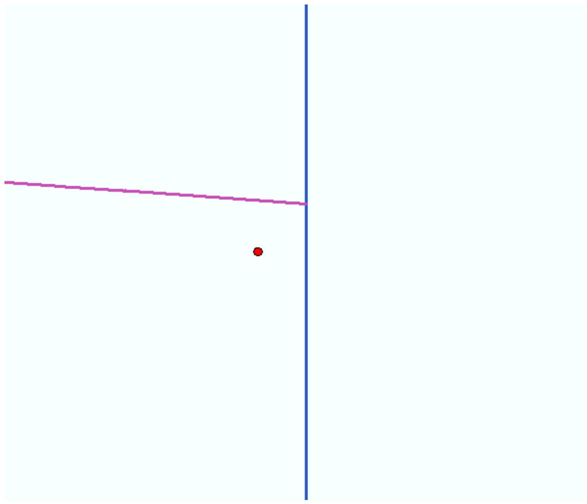


Fig. F.34: A POC point (red) which did not coincide exactly with the intersection of the network lines (scale: 1:0.01)

7) Opened the attribute table, selected the POC_type field, right clicked and used the Field Calculator to name all the selected points based on the POC type they represented .

8) Once all the "two-type" POCs (e.g. road/sidewalk, sidewalk/trail, etc.) had been labeled using the steps above, the "one-type" POCs (i.e., sidewalk/sidewalk and trail/trail) could be easily identified as being the only ones on a given path that did not yet have a "POC_type" attribute assigned to them. To do so:

   Used a "Select by Location" to select all POCs falling on one of the sets of networklines

      Selection Method: Select Features from

      Feature Class(s): modelname_POCpts

      Source Layer: modelname_networklines

      Spatial Selection Method: Target layer(s) feature intersects the source layer feature

      Apply a search distance: 1'

   Then went into the attribute table for the modelname_POCpts feature class and highlighted those selected values that had POC_type = <Null>. Hit the "Reselect Highlighted" button to limit the selection to only those records and then right clicked on the “POC_Type” field heading to use the field calculator to assign them a POC type.

9) In the Greenway model, “road/underpass” POCs had to be classified separately after all other POCs had been assigned a POC type, as these would otherwise come up as “road/trail” POCs when following the steps above.

10) Turned on the modelname_homes layer

11) Used a “Select by Location” to select all POC points that coincided with the homes (created only in instances where a frontdoor connection met a driveway)

    Selection Method: Select Features from
    Feature Class(s): modelname_POCpts
    Source Layer: modelname_homes
    Spatial Selection Method: Target layer(s) feature intersects the source layer feature
    Apply a search distance: unchecked

12) Deleted all selected points.

Cleaning the POC points

During POC creation, the Intersect tool often produced overlapping POC points of the same type at intersections, all but one of which would need to be deleted. To do so:

1) Added XY Coordinates to the modelname_POCpts feature class (Data Management -> Features -> Add XY Coordinates)

2) Used the “Delete Identical” tool to delete the extra points (Data Management -> General -> Delete Identical)

Input Features: modelname_POCpts

Fields:

POC_Type

POINT_X

POINT_Y

XY Tolerance: 1'

3) Once the "Delete Identical" was complete, selected some POCs at random just to ensure there was only one object being selected (i.e., that there weren't still multiple POCs stacked in the same spot).

4) Symbolized the POCs by "POC_type" and turned on the symbolized model_networklines layer, and checked to make sure that the POCs had been assigned the correct type and that no POCs were missing.

5) Deleted any POCs that did not belong (for instance, often ended up with extra sidewalk/sidewalk points in a CDS head because of the way the bulb joined the straight sidewalk segments).

Notes about POC construction:

- Cul-de-sacs and other roads or alleys with dead ends were not given a POC at the dead end (unless there were driveways connecting at that point, in which case, it would be assigned a road/driveway POC point).

- No POCs were added where through roads bent and turned into Cul-de-Sacs in the Greenway model (Fig. F.35 below), just as no POCs were put on the bends of a loop.

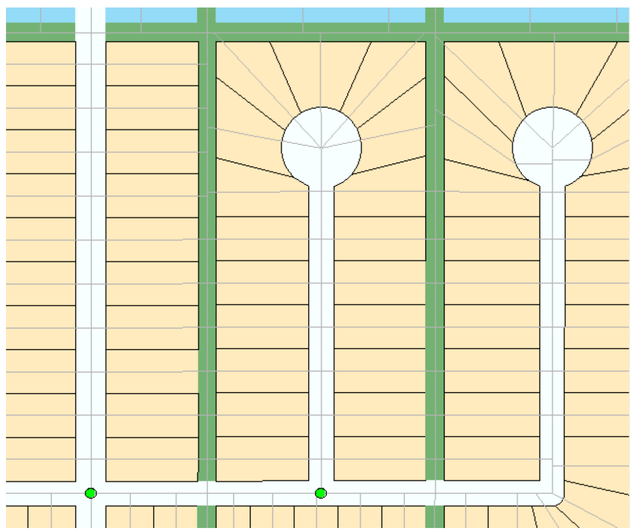


Fig. F.35: No road/road intersections were places where a road became a cul-de-sac

STEP 18: CHECKED THAT THERE WAS NO OVERLAP AMONG POC POINTS

1) Created a single part copy of the multipart modelname_POCpts layer in order to be able to run a topology on it (Data Management -> Features -> Multipart to Singlepart)

   Input Features: modelname_POCpts

   Output Feature Class: modelname_POCpts_M2S

2) Saved the map and exited ArcMap.

3) Opened ArcCatalog and created a topology for the model being worked on to make sure no POC pts overlapped each other by right clicking in the model's feature dataset, selecting "new topology" and using the following options:

   Name: modelname_POCpts_topology

   Cluster Tolerance: 0.001

   Participating Feature Classes:

   modelname_POCpts _M2S

   Ranks:

   - modelname_POCpts_M2S: 1

   Rule:

   "modelname_POCpts_M2S" must be disjoint

4) Validated the topology and then checked the Error tab of the topology for any errors. Corrected errors as necessary in ArcMap.

STEP 19: CREATED AN INTERSECTIONS FEATURE CLASS

1) Used the "Create Feature Class" tool (Data Management -> Feature Class -> Create Feature Class) with the following settings:

   Feature Class Location: (the model's feature dataset)
   Feature Class Name: modelname_intersections
   Geometry Type: Point
   Template Feature Class: (left blank)
   Has M: Disabled
   Has Z: Disabled
   Coordinate System: (left blank)
   Configuration Keywork: (left blank)
   Output Spatial Grids (1 through 3): (left blank)

2) Opened the attribute table for the modelname_intersections feature class and added a new field called "IntersectionType" of the "text" data type.

3) Right clicked on the modelname_POCpts feature class and selected "properties".

4) Went to the definition query tab and applied a definition query so that only the "main" POC per intersection would be showing:

   "POC_type" = 'road_road' OR "POC_type" = 'trail_trail' OR "POC_type" = 'road_trail'

   In most cases, this left one POC at most intersections.

5) Started an editting session.

6) Copied the select ed POCs into the modelname_intersections feature class.

7) The modelname_intersections feature class was cleaned by deleting any extra points (for instance, if there was a trail/road and road/road POC in the same intersection) and adding intersection points if any were still missing.

8) Used the “Add XY Coordinates” tool (Data Management -> Features -> Add XY Coordinates) to assign coordinates to each of the intersection points so as to be able to use the “Delete Identical” tool on them after.

9) Used the “Delete Identical” tool (Data Management -> General -> Delete Identical) to ensure there was only a single point in each intersection spot.

   Input Features: modelname_intersections

   Fields:

      POC_Type

      POINT_X

      POINT_Y

   XY Tolerance: 2’

10) Assigned “intersection types” (as per the definitions on p. 108) to each of the remaining points in the “IntersectionType” field of the modelname_intersections attribute table.

STEP 20: CREATED A HIERARCHICALLY BUFFERED NETWORK

1) Turned on the modelname_networklines layer and opened its attribute table.

2) Made sure that all entries had path_width and path_half_width values. Fake paths were allowed to have null values in these fields, while "frontdoor" connections were given a total width of 3'.

3) Buffered the complete set of networklines using the Buffer tool (Analysis -> Proximity -> Buffer)

   Input Features: modelname_networklines
   Output Feature Class: modelname_networklines_buffer_all
   Distance – Linear Unit: (left blank)
   Distance – Field: Road_half_width
   Side Type: Full
   End Type: Round
   Dissolve: List -> path_subtype

4) Selected, copied and pasted the CDS heads from the modelname_CDS_heads_buffered layer into the modelname_networklines_buffer_all feature class.

5) Selected and merged the CDS heads with the CDS straight road segments (using the "Merge" drop down menu tool on the Editor toolbar).

   At this point, the feature class would look something like Fig. F.36 below:

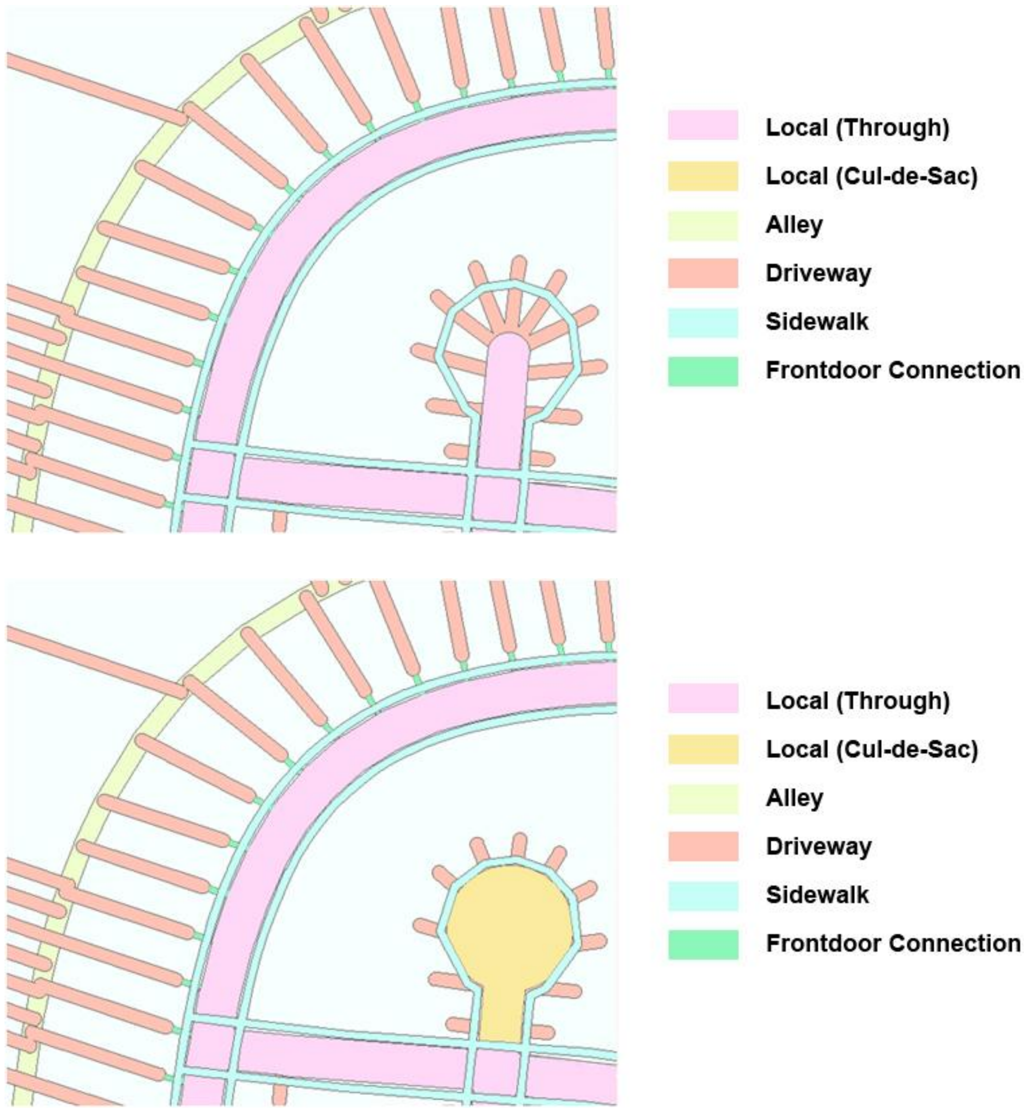


Fig. F.36: Buffered networklines before (above) and after (below) adding the heads of the cul-de-sacs

Note that polygons at this point are stacked, with a great deal of overlap occuring across the model space (demonstrated in Fig. 37 below).

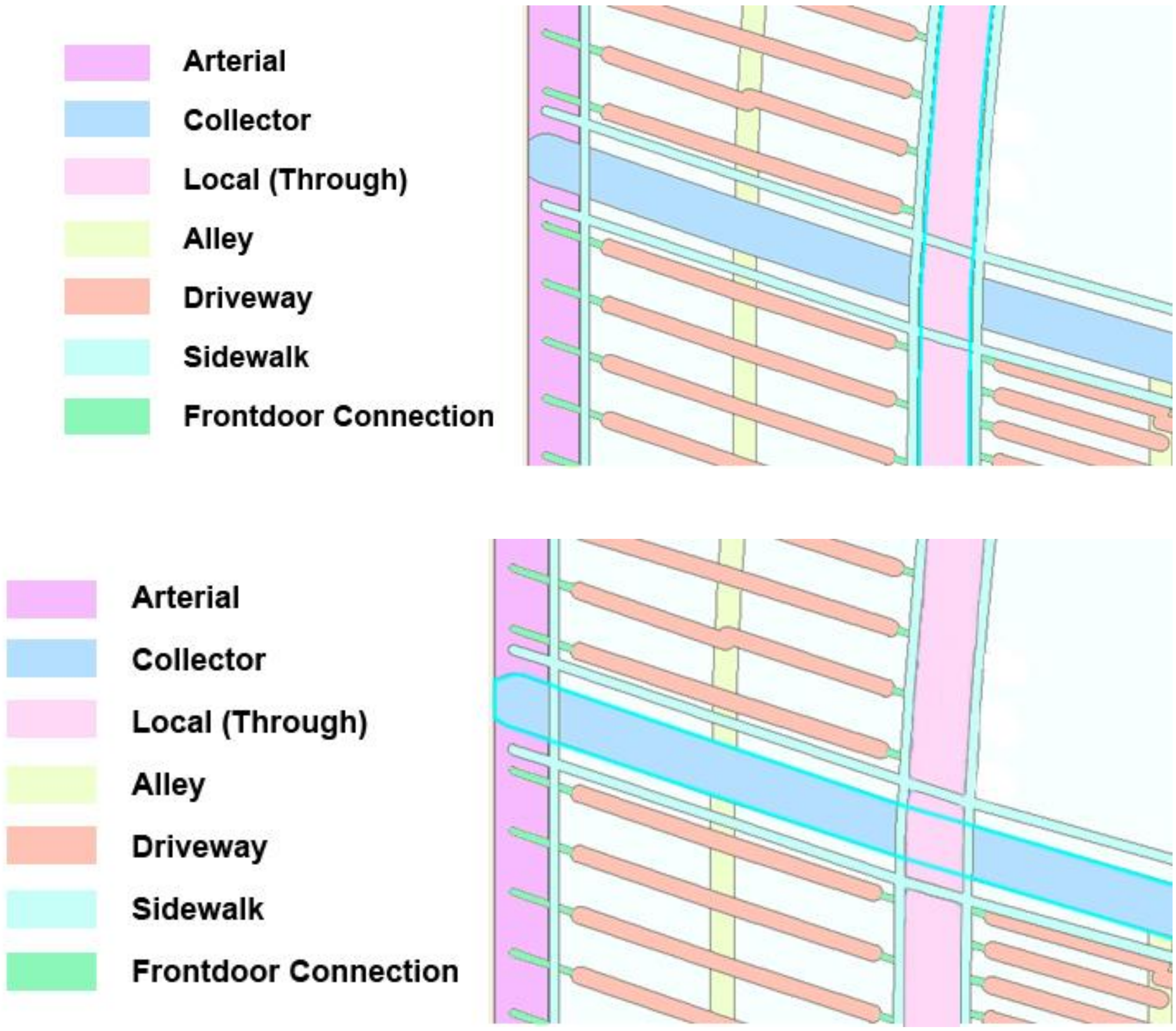


Fig. F.37: Stacked polygons following the buffer step

Changes in selection (blue highlight) reflect the presence of multiple polygons in the same space

6) Used the multipart to single part tool to create a copy of the modelname_networklines_buffer_all feature class in which each polygon would be treated as a separate object, rather than as a single object as the result of the earlier "dissolve" (Data Management -> Features -> Multipart to Single Part)

   Input Features: modelname_networklines_buffer_all

   Output Feature Class: modelname_networklines_buffer_all_cleaned

7) Set the modelname_networklines_buffer_all_cleaned layer to have 50% transparency (on the "Display" tab of "Layer Properties") so as to be able to observe the effects of polygon splitting to take place in later steps.

8) Used a definition query on **modelname_networklines_buffer_all** so that it only showed the "highest order" path type which had yet to be cleaned (in most models, this would be arterials in the first run through this step – see hierarchy on p. 468).

9) Did a definition query on **modelname_networklines_buffer_all_cleaned** so that it did *not* show the path type being displayed in modelname_networklines_buffer_all *or any higher order path types already cleaned on subsequent iterations of this step.*

10) Selected the visible polygons (e.g. arterial roads on the first run through) in modelname_networklines_buffer_all

11) Went to the modelname_networklines_buffer_all_cleaned layer and hit "Split Polygons" button in the Topology toolbar, in order to split all the polygons of other path types that fall within the path area (e.g. arterial road) where they crossed the path, using the following settings:

    Target: test1_networklines_buffer_all_cleaned
    Cluster tolerance: 0.001

    Hit OK.

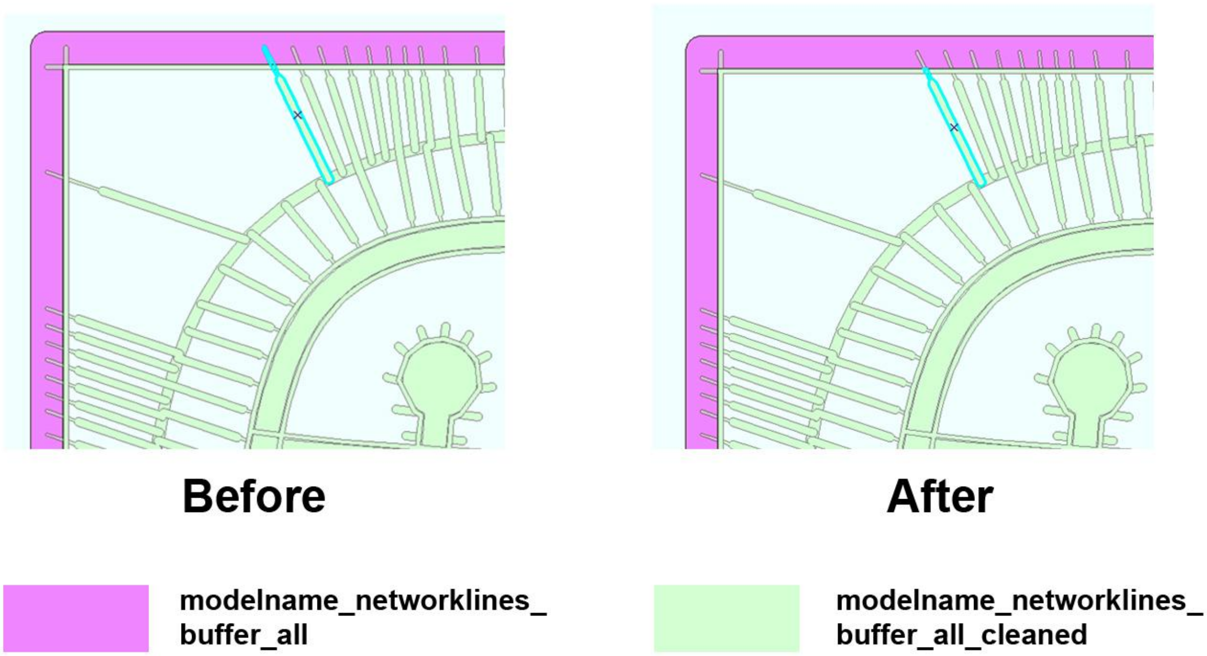


Fig. F.38: Using "Split Polygons" on modelname_networklines_buffer_all_cleaned (before & after)

12) Cleared the selection.

13) Used a Select by Location (Selection -> Select by Location) to select all the newly split polygons in the modelname_networklines_buffer_all_cleaned layer that fell within the polygon area showing in modelname_networklines_buffered_all (in this case, the arterial roads).

    Selection Method: Select Features From

    Target Layer(s): test1_networklines_buffer_all_cleaned

    Source Layer: test1_networklines_buffer_all

    Spatial Selection Method: Target layer(s) features are within the source layer feature

    Apply a Search Distance: Unchecked

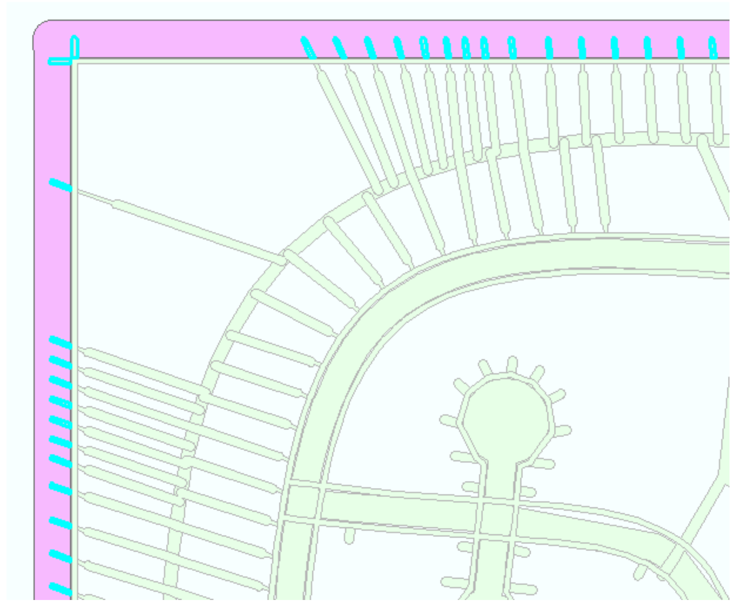


Fig. F.39: Selecting the polygons in the modelname_networklines_buffer_all_cleaned layer that fell within the modelname_networklines_buffer_all layer

14) Deleted all the selected polygons.

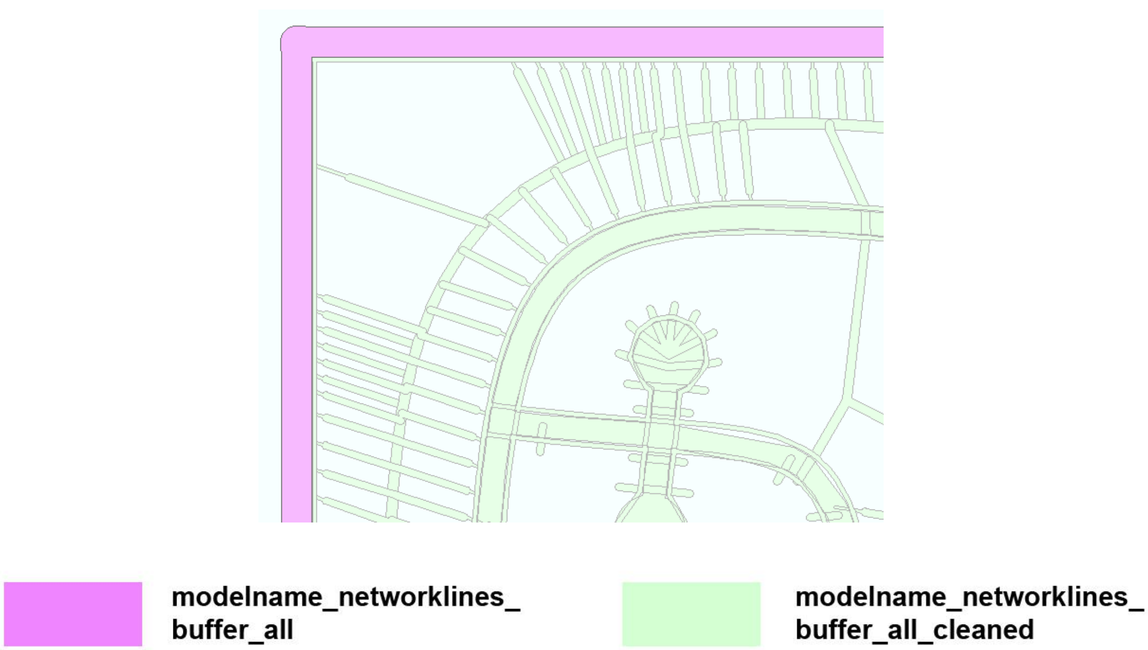


Fig. F.40: After deleting all the polygons in the modelname_networklines_buffer_all_cleaned layer that fell within the modelname_networklines_buffer_all layer

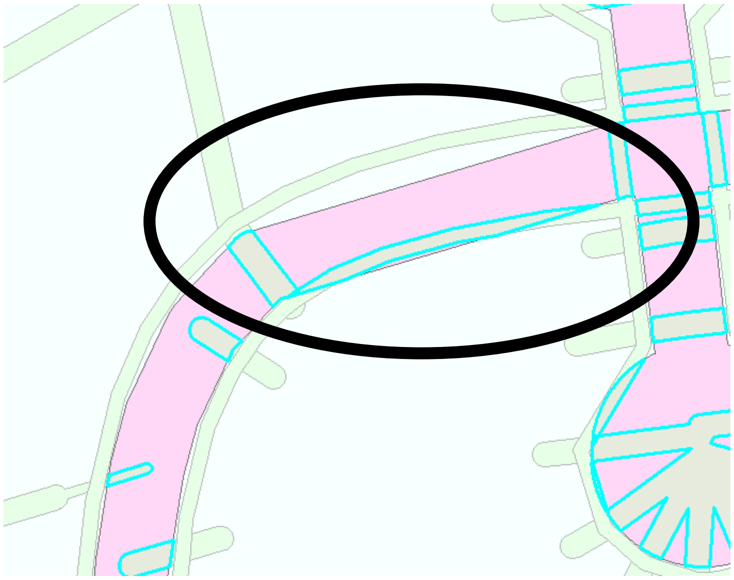


Fig. F.41: Example of an overlap error

(In such rare instances, had to manually deselect polygons where buff_subtype should not be - for instance, sidewalk over road. These errors could be easily recognized by changes in pattern during full extent view)

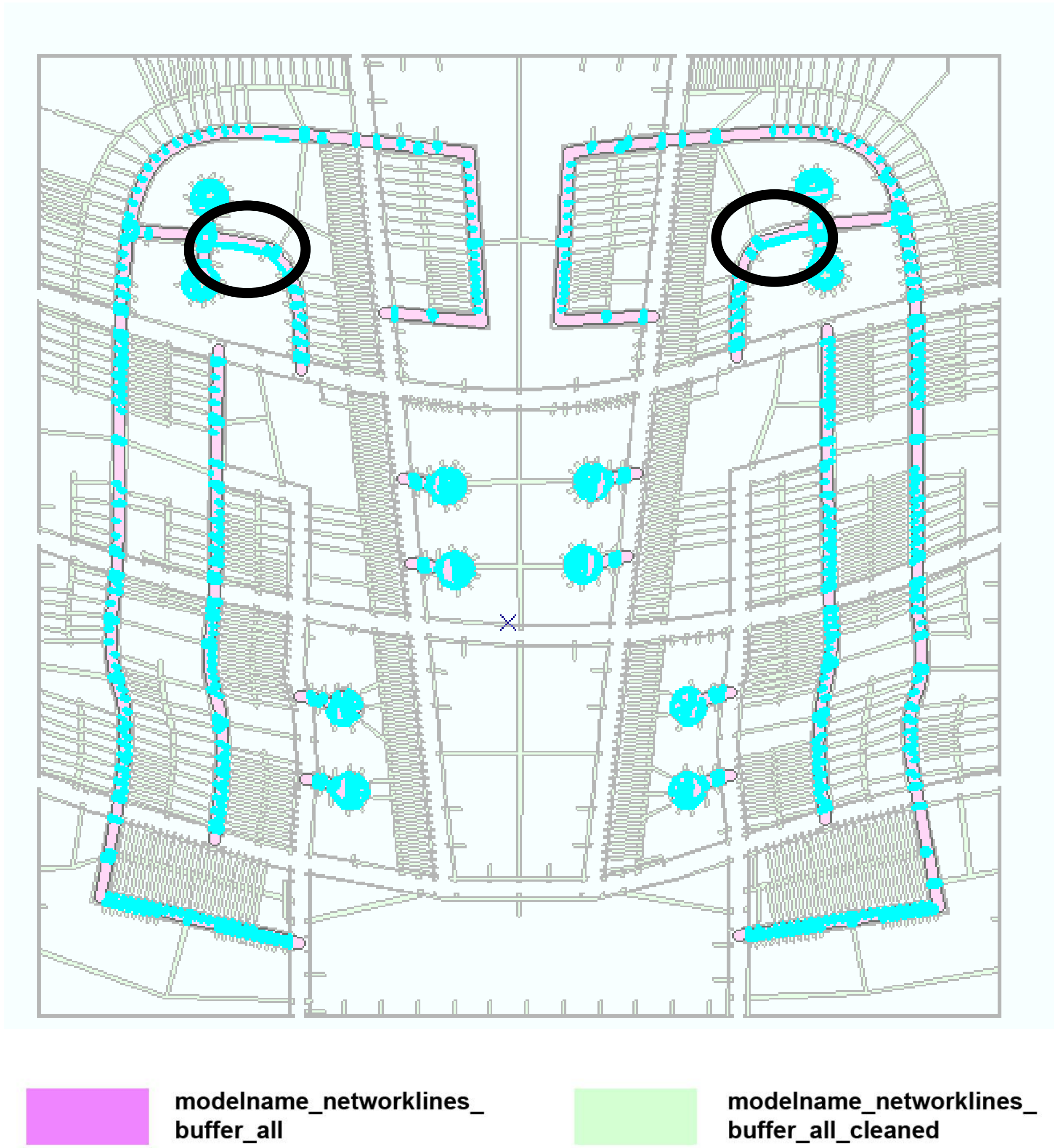


Fig. F.42: Viewing the model at full extent helped to identify possible overlap errors

(Overlap errors tended to occur at bends in the round and around the curved heads of the cul-de-sacs)

15) Repeated steps 8 through 14 for other path types, descending down the hierarchy in terms of path type. When complete, the modelname_networklines_buffer_all_cleaned feature class should contain no overlapping polygons.

    Note: In repetitions of step 8, the definition query on test1_networklines_buffer_all_cleaned only covered one type of path at a time (e.g. "path_subtype" = 'Collector'), while for the definition query on the "test1_networklines_buffer_all_cleaned" layer (step 9), it continued to grow as more path types that had already been dealt with were added to the query (e.g., going from "path_subtype" <> 'Arterial' to "path_subtype" <> 'Arterial' AND "path_subtype" <> 'Collector' on the second run through the steps).

The hierarchy for the path types was defined as follows (listed in descending order):

- Road (Arterial, Collector, Through, Loop, CDS, Alley, in that order)
    - Driveways (Other driveway and residential driveways; can be done at once since they never overlap)
        - Sidewalk
            - Trail
                - Frontdoor
                    - (Fake lines addressed separately – see below)

As such, where a sidewalk crossed a driveway, that section of path would be considered "walking along a driveway" rather than "walking along a sidewalk" (by virtue of having the attribute buff_subtype = 'driveway', even though its path_subtype attribute would remain 'sidewalk' – see assigning buff_subtype step on p. 470). This was necessary in order to provide a different treatment to, for instance, a New Urbanist sidewalk, which is uninterrupted by driveways, and one in a Loop and Cul-de-Sac neighbourhood which is.

Greenway Variation

In the Greenway model, the portions of trail that passed beneath the arterial roads had to be classified separately after all other segments had been assigned their buff_subtype attributes, as these would otherwise come up as path_subtype = 'Trail' and buff_subtype = 'arterial' when following the steps above. (The attributes of these sections of trail should be path_subtype = 'Trail' and buff_subtype = 'Underpass')

Checking for Overlaps

A topology was used in order to ensure that no overlapping polygons remained.

1) Created a new topology named "modelname_ networklines_buffered_all_cleaned_topology" by right clicking in the model's feature dataset and selecting "New Topology", using the following options:

    Cluster Tolerance: 0.001

    Participating Feature Classes:

    modelname_ networklines_buffered_all_cleaned

    Ranks:

    modelname_ networklines_buffered_all_cleaned: 1

    Rule:

    "modelname_networklines_buffered_all_clean" must not overlap

2) Validated the topology

3) Checked the error tab of the topology for errors

STEP 21: SPLIT ROAD SEGMENTS & ASSIGNED BUFF_SUBTYPE ATTRIBUTE

While the initial network lines reflected possible travel routes for different users, they did not always accurately reflect the type of path actually being travelled over. For instance, while it is necessary for a sidewalk line to be continuous over a road in order for a pedestrian to continue travelling in that line when using Network Analyst, these initial lines would not differentiate between when a pedestrian is walking on sidewalk vs. crossing a road.

To address this short-coming, roads were planarized based on the edge of paved pathways (the polygons) so that a new "buff_subtype" attribute could be created to note the type of pavement the line was crossing over (sidewalk, road, trail, etc.), while still maintaining its original "path_subtype" attribute (Fig. F.43, below). Thus, a line segment could have path_subtype = 'sidewalk' for the whole of its length, but have its buff_subtype attribute change from 'sidewalk' to 'collector' as it crossed a road.

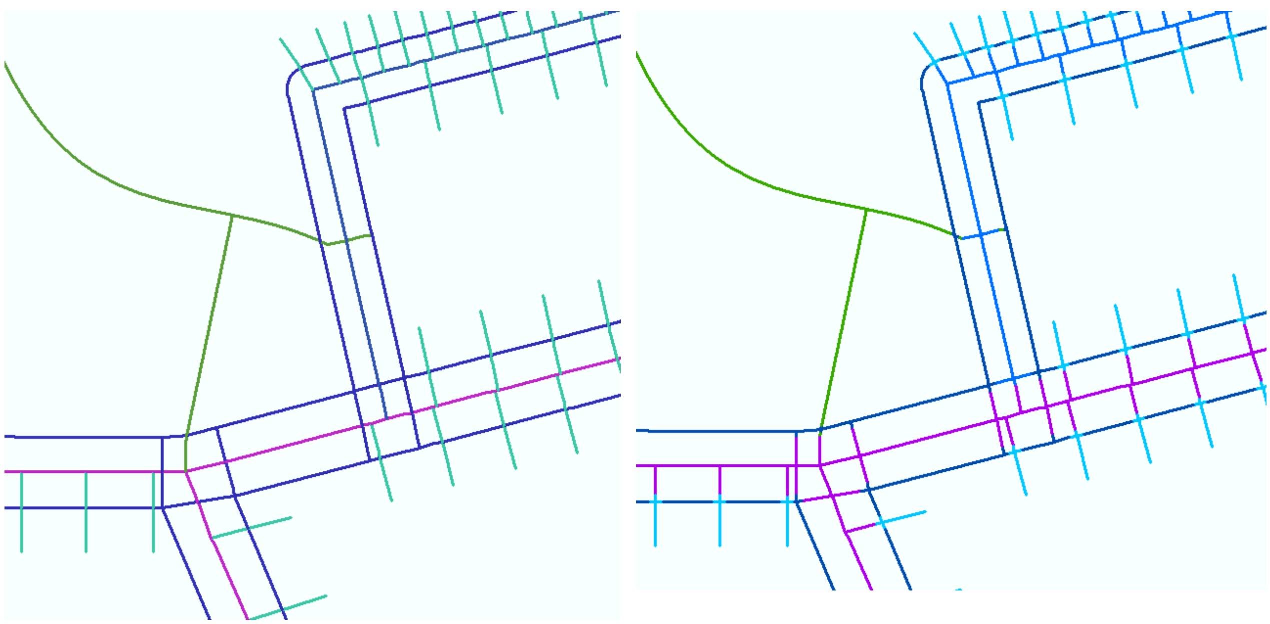


Fig. F.43: Network lines symbolized by path_type (left) and buff_subtype (right)

To do so:

1) Used the Dissolve tool on the “modelname_networklines_buffered_all_cleaned” feature class (Data Management -> Generalization -> Dissolve) to merge path polygons on the basis of their path subtype attribute (see Fig. 44, below)

   Input Feature: test1_networklines_buffer_all_cleaned

   Output Feature Class: test1_networklines_buffer_all_cleaned_dissolve

   Dissolve Fields: Path_Subtype

   Statistics Fields: Left blank

   Create Multipart: Unchecked

   Unsplit Lines: Unchecked

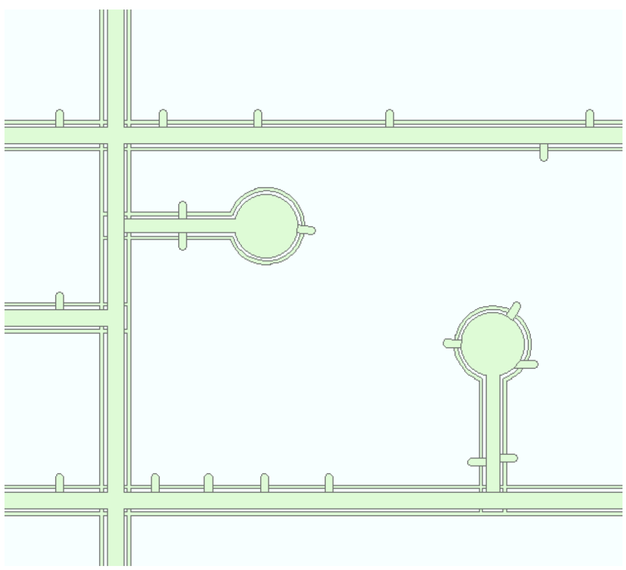


Fig. F.44: A buffered path network following a dissolve

2) Opened the attribute table for the modelname_networklines_buffer_all_cleaned_dissolve polygon feature class.

3) Created a new field called “buff_subtype” (data type: text) and used Field Calculator to populate it with the values from “path_subtype” in the same table.

4) Used the Identity tool on modelname_networklines_buffer_all_cleaned_dissolve and modelname_networklines in order to split the networklines along the edges of the different buffered paths and to give them a corresponding “Buff_Subtype” value to reflect the type of network area the line segment falls in.

   Input Features: modelname_networklines
   Identity Features: modelname_networklines_buffer_all_cleaned_dissolve
   Output Feature Class: modelname_networklines_identity
   Join Attributes: All
   XY Tolerance: (left blank)
   Keep Relationships: Unchecked

5) Opened the modelname_networklines_identity attribute table and deleted the modelname_networklines_buffer_all_cleaned_dissolve “path_subtype” field which had been copied over as a part of the “Identity” process, so that the feature class only contained one such field.

6) Symbolized the modelname_networklines_identity layer using the buff_subtype field in order to make sure the lines had been correctly assigned (producing something akin to Fig. F.45, below).

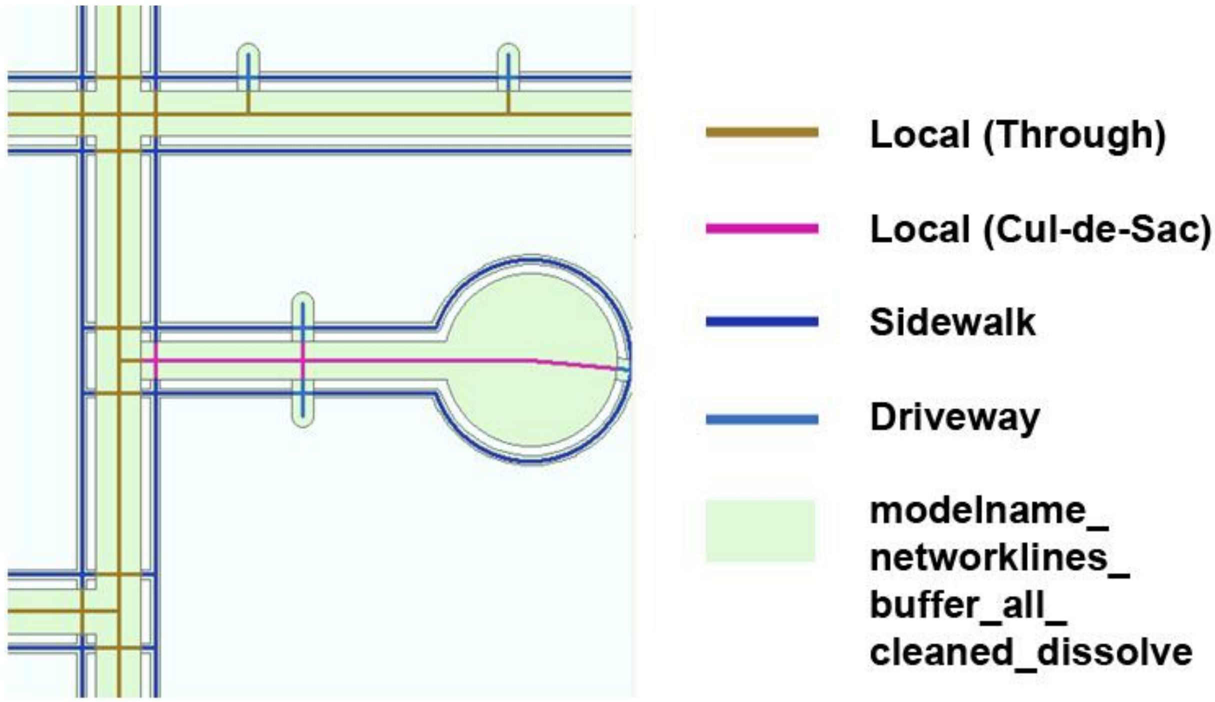


Fig. F.45: Networklines symbolized using "Buff_Subtype" field

In Fig. F.45, it can be seen that while sidewalk lines still cross roads, their buff_subtype field is the same as the road where they cross. (I.e., a sidewalk going over a lot would have path_subtype = 'Sidewalk' and buff_subtype = 'sidewalk', but when crossing over a through road it would have path_subtype = 'sidewalk" and buff_subtype = 'Through').

7) Checked to ensure that all lines had a complete set of attribute values (including "Users"); added any data still missing.

8) Selected all the lines in the modelname_networklines_identity feature class and hit the "planarize lines" button in the topology toolbar to ensure that the lines were split at all the necessary points.

Assigning a buff_subtype to “Fake” lines

1) Fake line segments were manually assigned an appropriate buff_subtype to reflect the type of path that would be normal for a given user to travel along if the network pattern extended to the area requiring this additional network connection. (So, for pedestrians, this would usually be a sidewalk; for a motorist, whatever kind of road would be appropriate to that section of the model).

STEP 22: FINAL NETWORK CHECK

A topology was run to ensure a smooth build of the final set of network lines, checking to ensure homes lined up with the end of driveways, that there were no overlapping segments in the networklines feature class (a common problem, the reasons for which are unknown) and that there were no extra dangles in the networklines.

1) Opened ArcCatalog

2) Created a new topology called “modelname_networklines_identity_topology” by right clicking in the model’s feature dataset and selecting “new topology”, and applied the following settings:

    Cluster tolerance: 0.001 (default)
    Participating layers:
        modelname_networklines_identity
        modelname_homes

    Ranks:

        modelname_networklines_identity: 1
        modelname_homes: 50

Added rules:

"modelname_networklines_identity" must not have dangles

"modelname_networklines_identity" must not overlap

"modelname_homes" must be covered by endpoint of "modelname_networklines_identity"

3) Validated the topology
4) Checked for errors; made corrections as necessary. In the case of overlapping path segments, the "Delete Identical" tool (Data Management -> General -> Delete Identical) was used with the following settings:

Input Dataset: modelname_networklines_identity
Fields: Shape and Buff_Subtype
XY Tolerance: 0.1

After completing the "Delete Identical" step, the topology was re-run. Any remaining errors were correct manually.

Notes:

While the network should have no overlapping segments and all homes should coincide with the start of a driveway, some dangles were allowed. Permissible dangle nodes included:

- The start of driveways (where homes would go)
- End of "Other Land Use" driveways (Path_Subtype = "Otherdriveway")
- End of cul de sacs or dead-end roads

- End of trails not meant to be connected to other portions of the network
- Dead ends (Fused Grid model only)

STEP 23: CREATED A SET OF NETWORK LINES FOR EACH USER & BUFFERED PATH TYPE FOR USE IN THE NETWORK DATASET

1) Created a new folder called "Userlines" on C:\

2) Added the "Split Layers by Attributes" tool created by Dan Patterson (2010, Dec. 29 build) to ArcMap by right clicking the top "ArcToolbox" line in the "ArcToolbox" window, selecting "Add Toolbox" and browing to the file location.

3) Used the "Split Layers by Attributes" tool on the modelname_networklines_identity feature with the following settings in order to create shape files for all the line segments in the feature class with a given "Users" field attribute value (e.g. Ped, PedBike, Mixed, etc.).

   Feature Layer: modelname_networklines_identity
   Field to Query: Users
   Output Filename: (left blank)
   Output Folder: "Userlines"

4) Created a new folder called "Buff_subtype_lines" to store shape files for the user+buff_type shape files created in the next step.

5) Renamed (e.g. shortened) the modelname_networklines_identity feature class "modelname_netl_ID" so that the file names produced by the "Split Layers by Attributes" tool in the next step would not all be the same

6) Used the “Split Layers by Attributes” tool on each of the “user” shapefiles now in the “userlines” folder to further split them based on their buff_subtypes, using the following settings:

Feature Layer: modelname_netl_ID_username
(e.g. fg_netl_ID_PedBK)
Field to Query: Buff_Subtype
Output Filename: (left blank – the tool automatically appends the existing filename with the attribute field values)
Output Folder: “Buff_subtype_lines”

7) Shortened the new “user_buff_subtype” file names to 28 or fewer characters (in order for the custom-built “Shape to Feature Class” tool to be able to handle them).

8) Changed “modelname_netl_ID”’s name back to “modelname_networklines_identity”

9) Used the “Shape to Feature Class” tool (see Appendix G for its construction) to convert them into feature classes in the appropriate Feature Dataset, using the following settings:

Feature Dataset: modelname

Workspace or Feature Dataset: “Buff_subtype_lines” folder

STEP 24: CREATED THE NETWORK DATASET

1) Turned on the network analyst extension (Customize -> Extensions in ArcCatalog)

2) Right clicked in one of the model's Feature Dataset and selected "New -> Network Dataset", and used the following settings:

Name: modelname_ND

Participating Feature Classes:

- All the model's user_buffsubtype lines
- The model's POCpts_M2S feature class

Settings:

- Model Global Turns (Yes)
- Connectivity: All feature classes in a single connectivity group
    - Put "Connectivity Policy" for lines to "Any Vertex" and to "Honor" for points
- Elevation: No
- Network Attributes: Add
    - Name: Trip_Length
    - Type: Cost
    - Units: Feet
    - Data Type: Double
    - Use by Default: Yes
    - Evaluators: Applied to all the line features (POC features left blank)
        - Attribute Values:
            - Type: Field
            - Value: Shape Length
- Driving Directions: No

3) Built the network by selecting “Yes” when asked by Arc.

Note: At this point, the POCs are all in a single feature class (modelname_POCpts_M2S) because it proved to be more efficient to create and test the network (and specifically that the POCs lined up with the network) this way, so that any necessary corrections to the POC feature class could be made through edits to that class alone (rather than multiple POC feature classes split on the basis of POC type, as was used in the final network dataset – see p. 481).

Correcting Build Errors – Standalone Junctions

In some instances, building the network produced “standalone junction errors”, where the POC points did not coincide exactly with the junctions as defined by Arc.

In order to correct this error:

1) Removed the POC points feature class (modelname_POCpts_M2S) from the network dataset and rebuilt the network dataset.

2) Used the Copy Features tool (Data Management -> Features -> Copy Features) to make a copy of the automatically generated ND_junctions feature class, using the following settings:

   Input Features: ND_junctions
   Output Feature Class: ND_junctions_copied
   Configuration Keyword: (left blank)
   Output Spatial Grids (1 through 3): (left blank)

3) Created a new topology by right clicking in the model’s feature dataset in Arc Catalog, selecting “New Toplogy” and using the following settings:

      Name: modelname_junction_topology
      Cluster Tolerance: 0.25
      Participating Feature Classes:

- ND_junctions_copied (rank: 1)
- modelname_POCpts (rank: 50)

Added rule:

"modelname_POCpts" must coincide with "ND_junctions_copied"

4) Validated the topology.

5) Checked for any remaining errors and corrected them manually in ArcMap.

Correcting Build Errors – Edge Feature Too Small

- In some cases following the build an "The edge feature is too small to participate in snapping and may not be connected to other features" error was returned.

- To fix this error, the line segment with the ObjectID in question was located and merged with one of the adjoining line segments.

STEP 25: SPLIT POCs INTO INDIVIDUAL FEATURE CLASSES AND ADD TO NETWORK DATASET

In order to use POCs as accumulation attributes, it was necessary to split the modelname_POCpts_M2S feature class into multiple feature classes based on the values in the "POC_type" attribute field, similar to what was done with modelname_networklines_identity on p. 476. To do so:

1) Opened ArcCatalog

2) Created a new folder called "POCpts"

3) Renamed (e.g. shortened) the modelname_POCpts_M2S feature class "modelname_POCM2S" so that the file names produced by the "Split Layers by Attributes" tool in the next step would not all be the same.

4) Opened Split Layer by Attributes tool, and used the following settings:

   Feature Layer: modelname_POCpts_M2S
   Field to Query: POC_type
   Output Filename: (left blank)
   Output Folder: POCpts

5) The split layer by attribute tool creates shape files (one for each possible value in the "POC_type" field). To convert these back into feature classes, the "Shape to Feature Class" tool created for this study was used with the following settings:

   Workspace or Feature Dataset: Split POCs

   Feature Dataset: modelname

6) The “Shape to Feature Class” tool cuts short filenames, so they had to be renamed after being created to include the full name of the POC types represented.

7) Changed “modelname_POCM2S”’s name back to “modelname_POCpts_M2S”

8) Opened the modelname_ND network dataset.

9) Removed the original combined modelname_POCpts feature class .

10) Added all the new POCpts features.

11) Rebuilt the network dataset.

STEP 26: ADDED OTHER NETWORK ATTRIBUTES

1) Opened the Network Dataset (modelname_ND).

2) Added a set of attributes under the “Attributes” tab to calculate the length of each path type traversed, one per combination of user and buffered path subtype:

    Name: PathL_(users)_buff_(path_subtype)
    (E.g., PathL_Mixed_buff_CDS)
    Usage: Cost
    Units: Feet
    Data Type: Double
    Use by default: Unchecked

Evaluators: Applied to line features only (see Fig. F.46 below)

- "Type: Field" and "Value: Shape_Length" for the line feature class with the same name (in this example, modelname_mixed_buff_CDS)

- "Type: Constant" and "Value: 0" for all other lines; POC points left blank

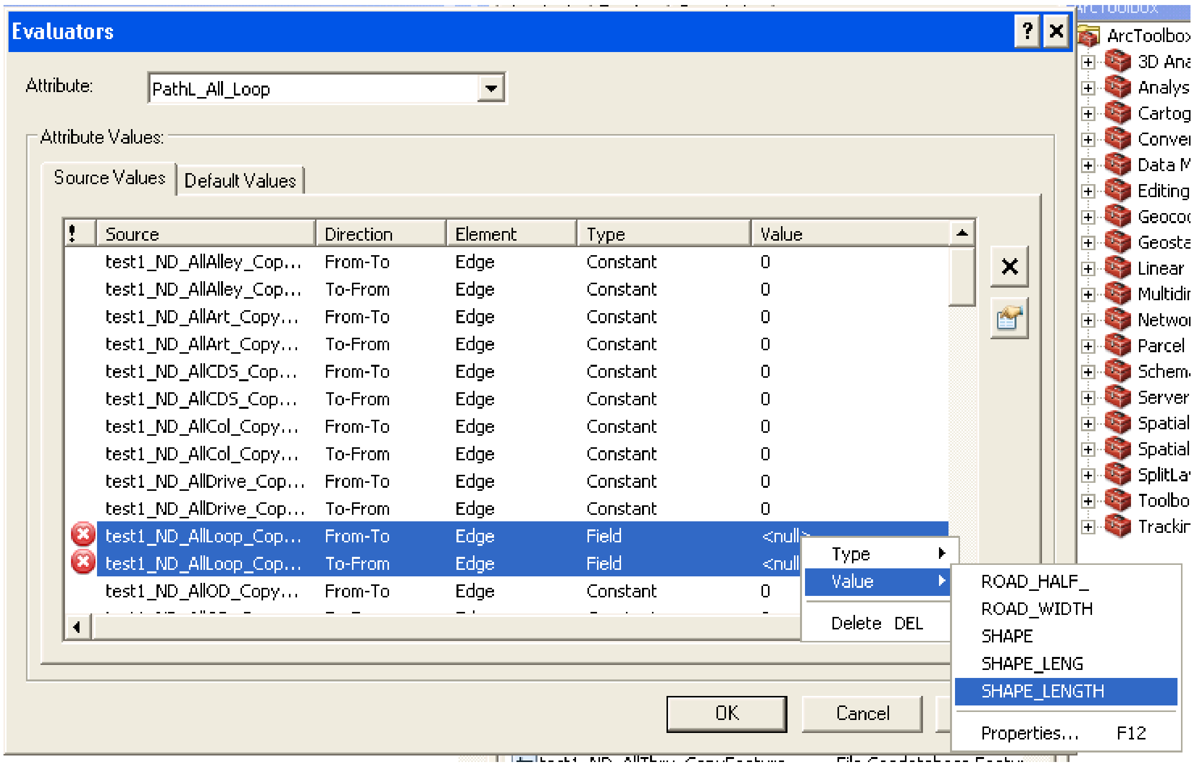


Fig. F.46: Setting up the evaluators for users: all and buffered path type: loop

3) Added a set of attributes to count the number of each type of POC points the travel path crosses through:

Name: POC_(POCType)

(e.g. POC_sidewalk_driveway)

Usage Type: Cost

Units: Unknown

Data Type: Integer

Use by Default: Unchecked

Evaluators (see Fig. F.47 below):

- "Type: Constant" and "Value : 1" for the POCpts feature class with the same name
- "Type: Constant" and "Value: 0" for all user network lines and the ND_junctions feature class

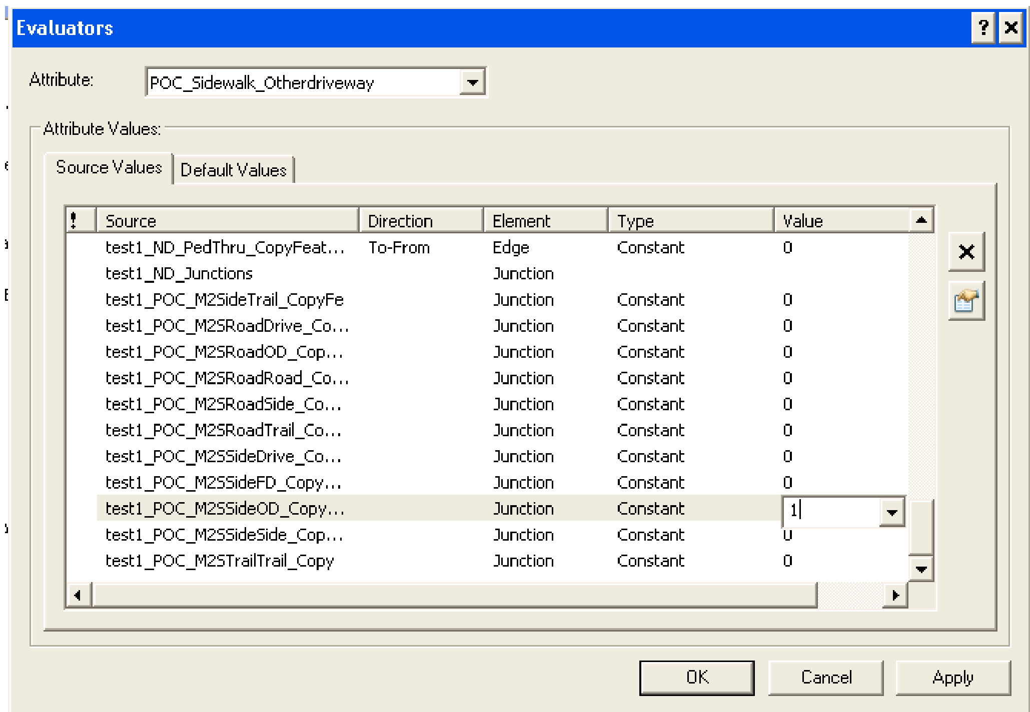


Fig. F.47: Creating POC point evaluators

4) Once all the attributes had been created, hit OK and rebuilt the network dataset.

Note: In the Network Dataset, the userlines define what paths are available when making a trip, while the buff_type serves to record the type of pathway the trip occurs over.

STEP 27: CREATED TURN FEATURES

The only turn restrictions in the models were for where a cyclist was prevented from turning left onto an arterial where a trail met it mid-block, as occurred in the Loop, New Urbanist and Greenway models. In the case of the Greenway model, turn restrictions were only needed where the main trail was assumed to go into an underpass; otherwise, arterial-trail intersections were assumed to be "2-way crossings" where cars would have to stop to let pedestrians and cyclists across the road. These 2-way crossings on arterials are necessary in this model, because there are no opportunities for pedestrians and cyclists to cross at "regular" road interesctions due to its off-set transportation networks.

To create these turn restrictions:

1) Created a new turn feature class in ArcCatalog (Network Analyst -> Turn Feature Class -> Create Turn Feature Class)

    Output Turn Feature Class Name: modelname_ND_turns

    Output Location: (the model's feature dataset)

    Maximum edges: 5

    Input Network Dataset: modelname_ND

    Template Feature Class: (left blank)

    Spatial reference: (left blank)

    Has Z: (left unchecked)

    Geodatabase settings: (left unset)

2) Opened ArcMap and created a blank map.

3) Added the Network Dataset to the map, and selected “yes” when it asked to add all participating feature classes to the map as well.

4) Saved the map as modelname_networkanalysis_test.

5) Started an editing session.

6) Selected the Turns template in the “Create Features” window (making a new template for it if necessary by going to Organize Feature Template -> New Template)

7) Turned on Edge and Intersection snapping.

8) Drew the turn motion that was to be restricted, keeping in mind that order is important. (In the example in Fig. F.48 below, the line would have started on the far right, then a vertex would be placed at the intersection, and then the left turn line added. Had the line been drawn in the reverse order, it would have served to restrict right hand turns coming off the arterial). The turn lines had to lie on top of only two line segments (i.e., be kept short so as not to extend into other segments); if more, an error was generated.

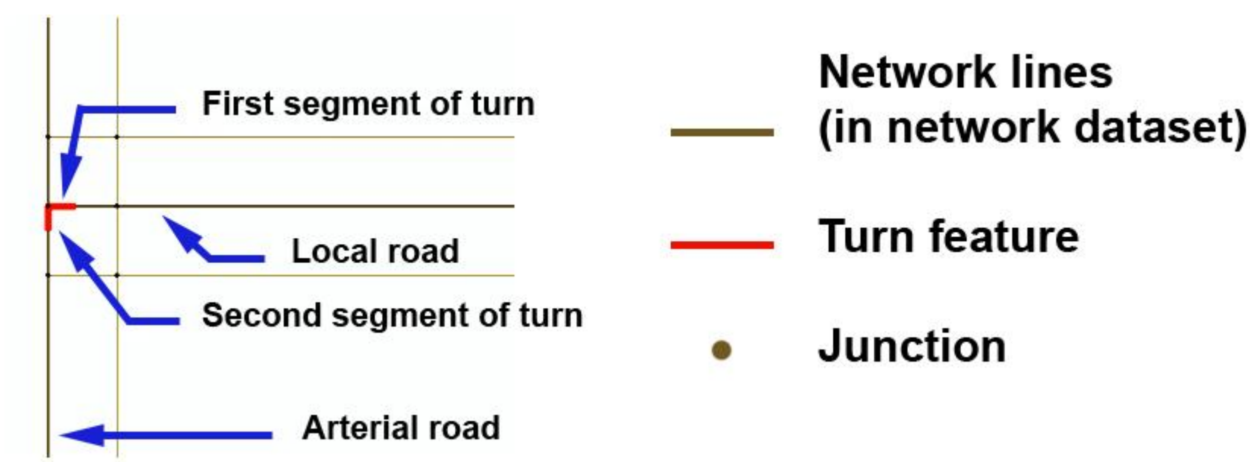


Fig. F.48: A left turn restriction

(Had the two turn segments been drawn in reverse order, the turn restriction would be for right turns off the arterial onto the local road)

9) Saved edits.

10) Stopped editing.

Once the turn features were created, they needed to be listed as possible type of restriction in the network dataset. To do so:

1) Closed ArcMap and opened ArcCatalog.

2) Opened the modelname_ND Network Dataset Properties box.

3) Under the Attributes tab, added a new attribute:

   Name: BikeTurnR

   Usage Type: Restriction

   Use by Default: Unchecked

   Evaluators:

   - Set modelname_ND_biketurns' type to "Constant" and its value to "Restricted"
   - Left all other feature classes ("sources") blank (see Fig. F.49 below)

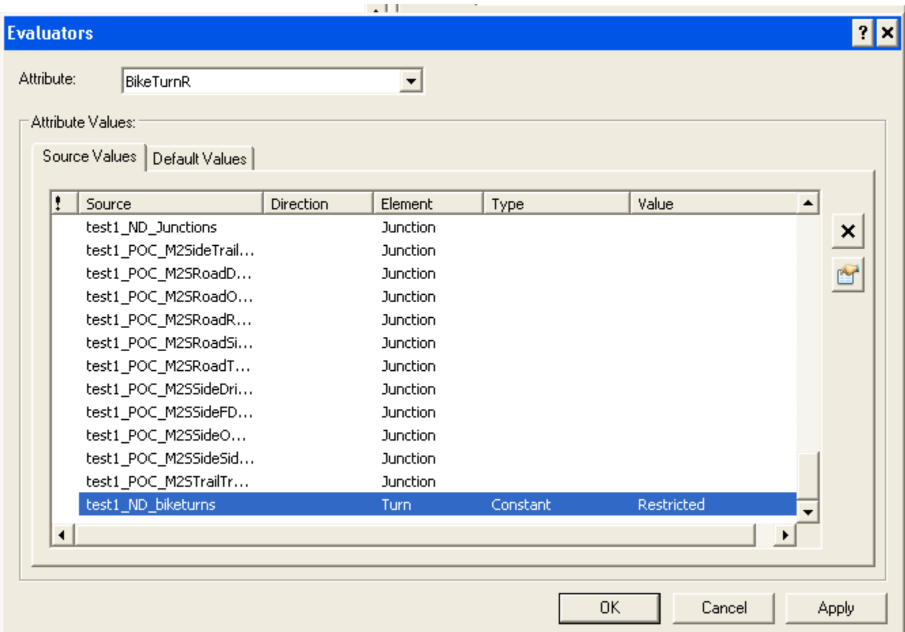


Fig. F.49: Making the turn feature class a restriction attribute

4) Rebuilt the Network Dataset.

5) Closed ArcCatalog.

STEP 28: TESTEDTHE NETWORK DATASET'S CONNECTIVITY AND TURN RESTRICTIONS

1) Opened ArcMap and the modelname_networkanalysis_test map that contains the Network Dataset and all participating layers.

2) Opened the Network Analyst Window.

3) Selected "New Route" from the Network Analyst dropdown menu.

4) Hit the "Route Properties" button in the Network Analyst window. Under the "Analysis Settings" tab, applied the following settings:

   Impedence: Trip_Length (Feet)
   Use Start Time: Unchecked
   Use Time Windows: Unchecked
   Reorder Stops to Find Optimal Route: Unchecked
   U-Turns at Junctions: "Only at Dead Ends".
   Ignore invalid locations: Unchecked
   Restrictions: Checked the BikeTurnR restriction.
   Directions: (left blank)

5) Used this route to test that the turn restrictions are working by adding a stop before and after the turn. If the turn was working, the program would choose to take the long way around (see example in Fig. 50, below)

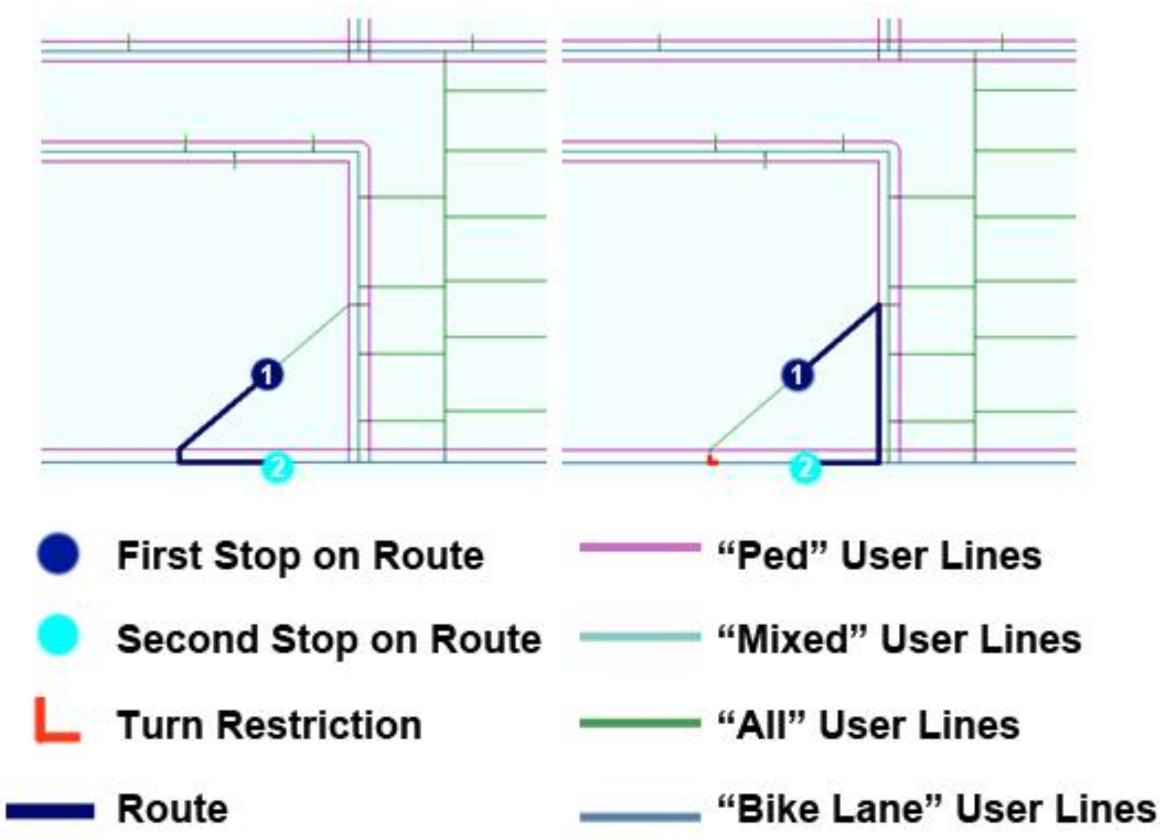


Fig. F.50: Testing turn restrictions - before applying turn restriction (left) and after applying turn restriction (right)

Next, the network was tested to ensure that all origins and destinations had been successfully connected:

1) Opened the modelname_homes and modelname_dest attribute tables and checked to make sure that the individual objects were sequentially numbered (e.g, ObjectIDs of 1, 2, 3, 4… instead of 9, 32, 45, 46…), starting with an ObjectID of 1 for the first object.

2) If not, used the Copy Features tool to create copy of the appropriate feature class which would automatically contain the correct numbering (Data Management -> Features -> Copy Features).

Input Features: (modelname_homes or modelname_dest, as necessary)

Output Feature Class: (modelname_homes2 or modelname_dest2, as appropriate)

Configuration Keyword: (left blank)

Output Spatial Grids (1 through 3): (left blank)

3) Created a new Origin-Destination (OD) Cost Matrix by selecting it from the “Network Analyst” toolbar’s dropdown menu.

4) In the Network Analyst window, made sure the “OD Cost Matrix” was the analysis layer being viewed.

6) Right clicked on Origins and selected “Load Locations”:

Load From: modelname_homes (or modelname_homes2 if a copy had to be made)

Sort Field: ObjectID

Location Analysis Properties: (Left unchanged)

Location Position: Checked “Use geometry” and left search tolerance on the default 5000 meters.

7) Once the origins had been loaded, scanned down their list in the Network Analyst window to make sure all had been successfully placed on the network (based on symbol colour).

8) Hit the Network Analyst Window’s “Layer Properties” button and applied the following settings:

Analysis Settings Tab

Impedance: Trip_Length (feet)

Default Cutoff Value: (None)

Destinations to Find: (All)

U-Turns at Junctions: Allowed Only at Dead Ends

Output Shape Type: Straight Line

Ignore Invalid Locations: Unchecked

Restrictions: BikeTurnR (checked)

9) Hit the “Solve” button on the Network Analyst toolbar.

10) In the Table of Contents window, switched view to “List by Source”.

11) On the “OD Matrix” container icon, right clicked and selected “Add Table ->OD Lines” and hit add to add a table showing the matrix of routes.

12) Opened the OD Lines attribute table by right clicking on the “OD Lines” icon in the Table of Contents window (still in “List by Source” view).

13) Checked to make sure that the number of rows = #homes x #destinations . If so, Arc successfully ran a route between every origin and destination combination.

14) Saved then closed ArcMap.

STEP 29: SETTINGS FOR EACH MODEL/MODE NETWORK DATASET COMBINATION

A different network dataset had to be created and run for each possible model/mode combination. The following set of steps describes the setting for each:

1) Opened ArcCatalog

2) Opened modelname_ND

3) Added a second connectivity group and made it so that all the lines associated with "users" for the mode of interest (see Table F.5 below) were in connectivity group 1 and all others are in connectivity group 2 (see Fig. F.51 below for an example). The POC points were always all included in connectivity group 1.

Table F.5: Modes and applicable user groups

	Mode		
	Walking	**Biking**	**Driving**
Users	All (Fake) PedBike Ped	All Bike Bikelane (Fake) Mixed PedBike	All Bikelane (Fake) Mixed

Note: The "fake" feature classes were only included for a given mode if the specific model necessitated them.

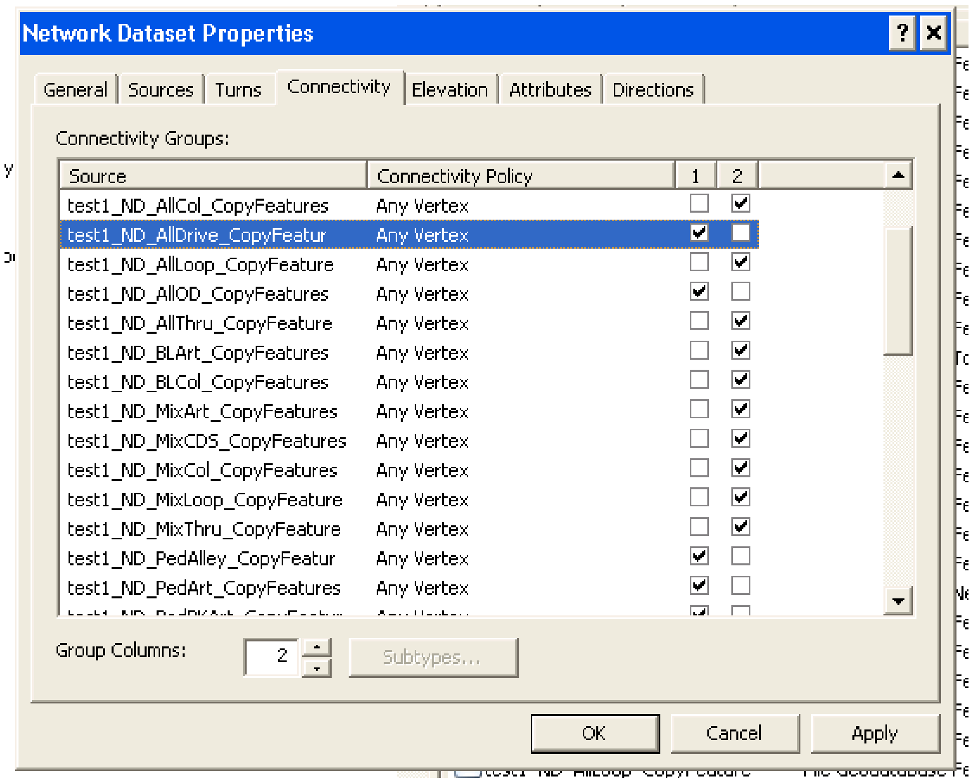


Fig. F.51: Example of connectivity groups set up for pedestrians

Note: To prevent pedestrians from crossing roads by using "User: All" driveways which could potentially meet and act as bridge at the road centre line (see Fig. F.52 below), no "All – (road)" type segments were included, with the exception of All – Alley (where the expectation is that pedestrians will walk along the alley itself). "All – (driveway)" type segments were included in the pedestrian connectivity group in order to allow them to walk down driveways to access the sidewalk.

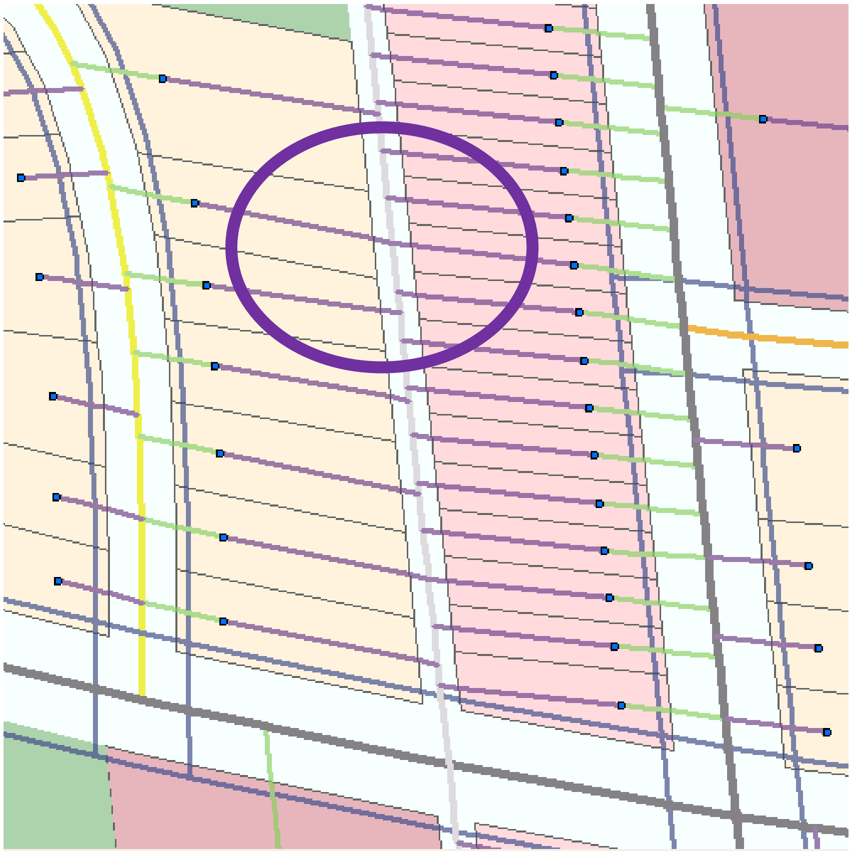


Fig. F.52: Driveways could potentially act as a bridging connection for pedestrians to cross roads

4) Rebuilt the network dataset.

5) Closed ArcCatalog.

6) Opened ArcMap with a blank map

7) Added the model's network data and all participating feature classes set to the map (using the "Add Data" button)

8) Saved the map as modelname_network_analysis

9) On the Network Analyst toolbar, selected “New Route” from the drop down menu in order to create a new route to test that the network dataset was performing properly.

10) Opened the “Layer Properties” in the Network Analyst Window and applied the following settings:

General Tab:

Named the new route “modelname_mode_testroute”

Analysis Settings Tab:

Impedance: Trip_Length (feet)

Reorder Stops to Find Optimal Route: Unchecked

U-Turns at Junctions: Allowed Only at Dead Ends

Output Shape Type: True Shape with Measures

Ignore Invalid Locations: Unchecked

Restrictions: BikeTurnR checked when running the New Urbanist, Loop and Greenway models (bike mode) only

Accumulation Tab:

All possible accumulation attributes checked except for Trip_Length, which gets counted by default.

Network Locations Tab:

Network Location Field Mapping: All values left on default

Finding Network Locations:

- Search Tolerance: 5000 meters (the default value)
- Snap to: Closest
- Snap to feature classes:
  - All group 1 line features (POCs not checked; ND Junctions not checked)
  - Always selected “Shape” only (never “middle” or “end”)

- Exclude restricted portions of the network: Unchecked

11) Dropped various stops throughout the model and solved the route multiple times until satisfied that the network (specifically, the network's connectivity) was behaving as expected (I.e., travel should only occur over those paths in group 1).

(If the tests of the route showed that there were errors in connectivity, they were fixed manually in the appropriate feature classes, the network dataset rebuilt, and test routes run again until it was clear that the network was working properly).

STEP 30: RAN THE FINAL ORIGIN DESTINATION MATRICES

1) Created a new OD Cost Matrix by selecting it from the "Network Analyst" toolbar's dropdown menu.

2) In the Network Analyst window, made sure the "OD Cost Matrix" was the layer being viewed.

3) Opened the Network Analyst Window's "Layer Properties" and set the following options:

General Tab:
Name the new route "modelname_mode_ODMatrix"

Analysis Settings Tab:
Impedance: Trip_Length (feet)
Default Cutoff Value: (None)
Destinations to Find: (All)
U-Turns at Junctions: Allowed Only at Dead Ends
Output Shape Type: Straight Line
Ignore Invalid Locations: Unchecked

Restrictions: BikeTurnR (checked only for bikes in the New Urbanist, Loop and Greenway models)

Accumulation Tab:

All possible accumulation attributes checked except for Trip_Length, which would get counted anyways.

Network Locations Tab:

Network Location Field Mapping: All values left on default

Finding Network Locations:

- Search Tolerance: 5000 meters (the default value)
- Snap to: Closest
- Snap to feature classes:
    - All group 1 line layers (POCs not checked; ND Junctions not checked)
    - Always selected "Shape" only (never "middle" or "end")
    - Note: It is important that locations snap to Group 1 line layers only, to ensure that anyone leaving from a house starts (and thus continues) on the Group 1 network being tested, instead of the Group 2 lines for other modes.
- Exclude restricted portions of the network: Unchecked

Note: See Table F.6 on p. 502 for a summary of those settings that varied between the different model/mode combinations.

4) Right clicked on Origins in the Network Analysis window and selected "Load Locations", using the following options:

   Load From: modelname_homes

   Sort Field: ObjectID

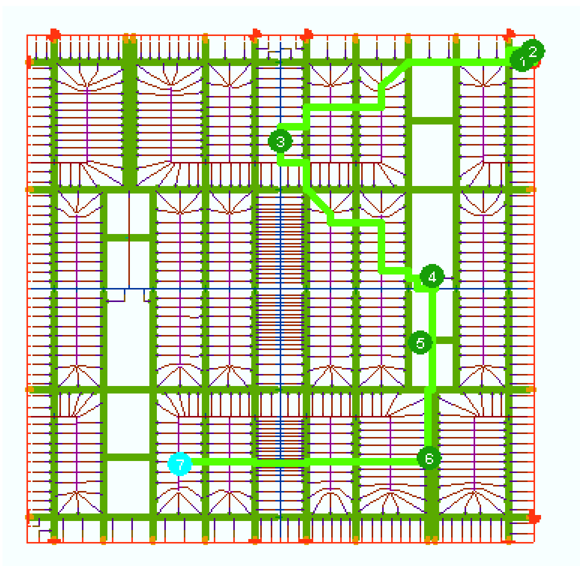
   Location Analysis Properties: (Leave unchanged; Curb approach is by default set to either side of vehicle)

Location Position: Checked “Use geometry” and left search tolerance on the default 5000 meters.

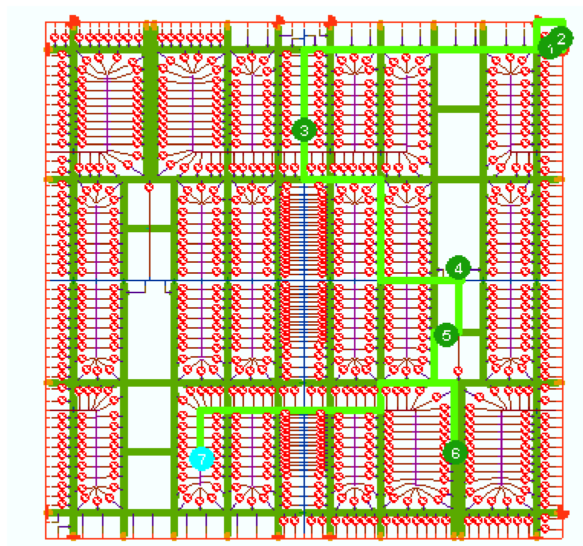
5) Repeated step 16 for Destinations, using the modelname_dest feature class and using the same settings as “origins”.

6) Once the origins and destinations were loaded, scanned down their list in the Network Analyst window to make sure all had been successfully located (based on symbol colour).

7) For some model-mode combinations (where both front door connections and driveways back to an alley met at the origin points/homes) it was necessary to add the homes as “added cost barriers” as well in order to prevent the route from cutting through private yards. (For instance, a pedestrian could walk up to a home other than the one they started from using the “PedBK – Frontdoor” connection, cross onto the “All – Driveway” connection at the back of the house and then use that to exit onto the “All – Alley” path behind) (see Fig. F.53 below).



Route cutting through yards before addition of homes as added cost point barriers



Corrected route resulting from addition of added cost point barriers

Fig. F.53: Yard shortcut error

To add homes as added cost barriers:

- Right clicked on "Point Barriers" in the Network Analyst window and selected "Load Locations" with the following settings:

  Load From: modelname_homes

  Sort Field: ObjectID

  Location Analysis Properties:

    Curb Approach: Either side of vehicle

    Full Edge: False

    Barrier Type: Added Cost

- Entered a value of "1,000,000" in the Attr_Total_Trip_Length row. (This value was chosen because it far exceeds the maximum distance that would be travelled between any two points in the model, making it so any given route passed through one of these points only once on a trip, when it must do so to leave its starting point (a home). The 1,000,000 is then easily subtracted from the final Trip_Length value, which would come out to be something like 1,002,780' and translate to an actual trip distance of 2,780').

This had to be done for the following model/mode combinations:

- New Urbanist: Pedestrians, Cyclists
- Fused Grid: Pedestrians, Cyclists
- Greenway: Cyclists only

8) Hit "Solve" in the Network Analyst toolbar.

9) In the Table of Contents window, switched view to "List by Source".

10) On the “modelname_mode_ODMatrix” container icon, right clicked and selected “Add Table ->OD Lines” and hit add.

11) Opened the new OD Lines table.

12) Checked to make sure that the number of rows equaled the number of homes x number of destinations. If so, the software successfully ran a route between every origin and destination combination.

13) Hit the “Table Options” button and select “Export”. Exported the data as dBASE tables named modelname_mode.dbf.

14) Saved map.

15) Closed ArcMap.

Table F.6: Other characteristics of model/mode combinations used in calculating Origin/Destination matrices

	Walking	**Biking**	**Driving**
Grid	Fake lines: Yes Group 1 line features: All (Driveway, Otherdriveway only), Fake, Ped, PedBike Homes as added cost barriers: No Left turn restrictions: No	Fake lines: No Group 1 line features: All, Mixed, PedBike Homes as added cost barriers: No Left turn restrictions: No	Fake lines: No Group 1 line features: All, Mixed Homes as added cost barriers: No Left turn restrictions: No
Loops and Cul-de-Sacs	Fake lines: Yes Group 1 line features: All (Driveway and Otherdriveway only), Fake, Ped, PedBike Homes as added cost barriers: No Left turn restrictions: No	Fake lines: No Group 1 line features: All, Bike, Bikelane, Mixed, PedBK Homes as added cost barriers: No Left turn restrictions: Yes	Fake lines: No Group 1 line features: All, Bikelane, Mixed Homes as added cost barriers: No Left turn restrictions: No
Fused Grid	Fake lines: Yes Group 1 line features: All (Driveway, otherdriveway, alley only, Fake, Ped, PedBike Homes as added cost barriers: Yes Left turn restrictions: No	Fake lines: No Group 1 line features: All, Bikelane, Mixed, PedBike Homes as added cost barriers: Yes Left turn restrictions: No	Fake lines: No Group 1 line features: All, Bikelane, Mixed Homes as added cost barriers: No Left turn restrictions: No

Table F.6: Other characteristics of model/mode combinations used in calculating Origin/Destination matrices (cont.)

	Walking	Biking	Driving
New Urbanist	Fake lines: Yes (edge only) Group 1 line features: All (but none buffered as roads, except for those buffered as alley), Fake (arterial only), Ped, PedBike Homes as added cost barriers: Yes Left turn restrictions: No	Fake lines: No Group 1 line features: All , Bike, Bikelane, Mixed, PedBike Homes as added cost barriers: Yes Left turn restrictions: Yes	Fake lines: Yes (centre only) Group 1 line features: All, Bikelane Fake (buffered as sidewalk, trail, collector only) Mixed Homes as added cost barriers: No Left turn restrictions: No ***<u>SEE NOTES BELOW</u>***
Greenway	Fake lines: Yes Group 1 line features: Fake, PedBike Homes as added cost barriers: No Left turn restrictions: No (None needed where trails hit arterial because there are no connections for pedestrians on the other side)	Fake lines: No Group 1 line features: Mixed, PedBike Homes as added cost barriers: Yes Left turn restrictions: Yes	Fake lines: No Group 1 line features: Mixed Homes as added cost barriers: No Left turn restrictions: No

Additional notes for the New Urbanist – Driving Origin/Destination Matrix:

- Two OD matrices were created for the New Urbanist/Driving cominbation: one for the trips to the edge destinations and one for trips to the centre destination (the only model for which this was necessary). This was so that in the "Edge" iteration, the fake lines did not need to be included and there was no risk of cars using the fake line segments to cut through the central park space in this model.

- For the OD “driving” matrix to the centre point, the only fake segment origins/destinations were allowed to snap to for the “driving” mode were the “fake_trail” segments, so that only the centre destination point would actually end up locating there.

NOTES ON ERRORS IN MODEL CONSTRUCTION

1) When doing the setbacks for sidewalks, a value of half the road width + boulevard width was used. The correct value would have also included half the sidewalk width, which would have put a line through the middle of the "sidewalk space", rather than on its inside edge. As a result, once buffered, the sidewalk was often a couple of feet closer to the road than had originally been intended.

2) In some cases, Arc had difficulty in applying copy parallel for sidewalks around the edge of CDS heads, and consequently, the distance of the sidewalk from the road at these points was more variable than in the rest of the model. In some cases, an attempt was made to manually correct these lines.

APPENDIX G: THE SHAPE TO FEATURE CLASS TOOL (MODEL)

This simple tool was created for this study in order to convert the shape files produced by Patterson (2010) "Split by Attribute" tool into feature clases for use in the network datasets. Fig. G.1 shows the setup of the tool in Arc's model builder so that it may be reconstructed by other researchers wishing to use it , while Fig. G.2 shows what the tool looks like when being used in ArcMap.

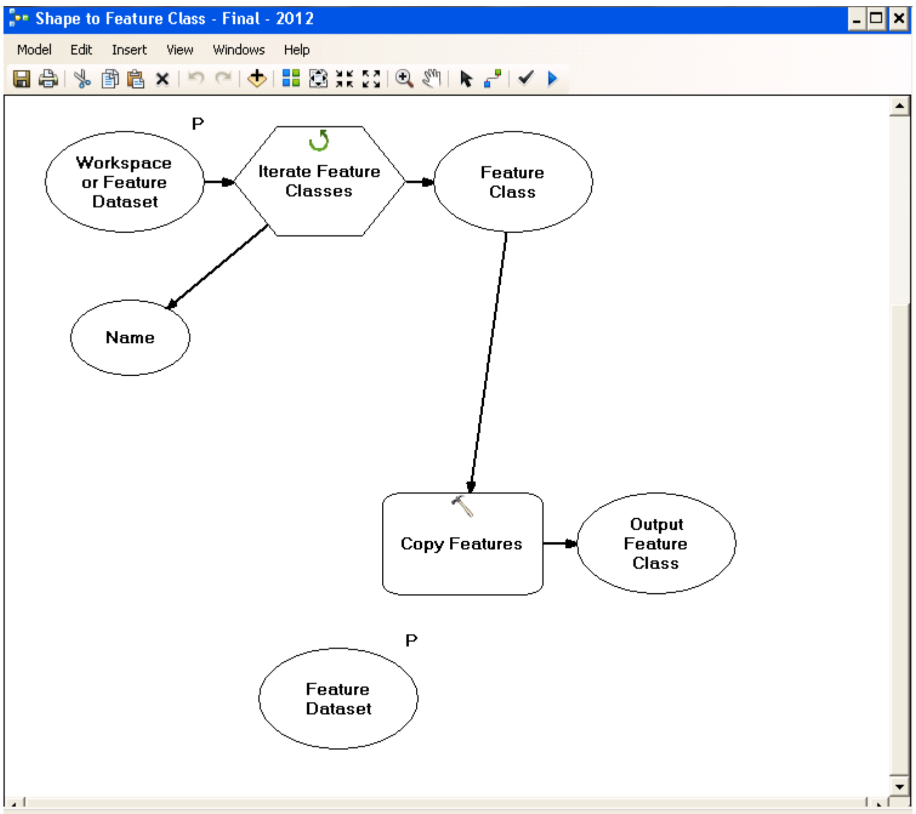


Fig. G.1: Shape to Feature Class tool in the Arc model builder

- In the above figure, the "Workspace or Feature Dataset" is the name of the folder that contains the shape files to be converted.

- The "Feature Dataset" parameter defines the destination feature dataset of the resulting feature classes .

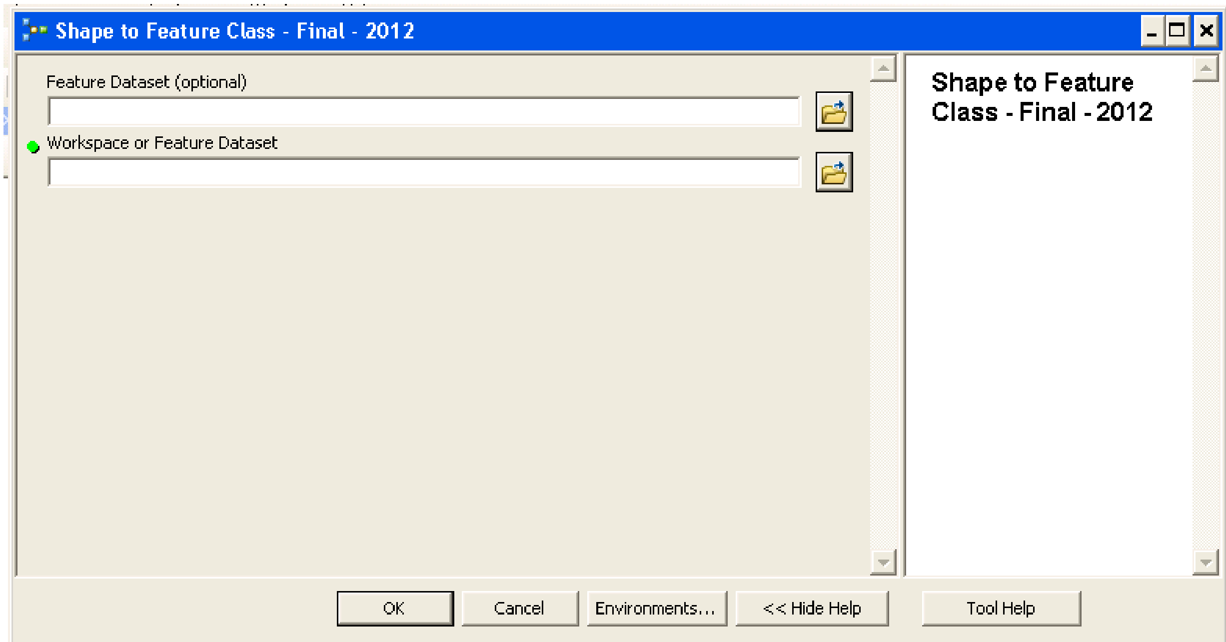


Fig. G.2: The Shape to Feature Class Tool as it appears in ArcMap

(In this tool, "Workspace or Feature Dataset" is where the folder containing the shape files is entered; "Feature Dataset" is the destination for the resulting feature classes).

APPENDIX H: DATA CLEANING AND ANALYSIS

Calculating Model Characteristics

The model characteristics reported in Chapter 4 and used for model validation were calculated directly in ArcMap as follows:

1) Opened the modelname_construction map in ArcMap

To calculate land use, density, and housing characteristics:

1) Opened the attribute table for the “modelname_lots” feature class

- **Land use mix – park:** Selected all records with “landuse = park”, went to “show selected records”, selected “shape_area” column, right clicked, selected “statistics”. Noted the “sum” value. To then convert this into a percent of total area, took the total park area, divided by 6,969,600 sq. ft. (160 acres), then multiplied by 100.

- **Land use mix – other:** Repeated the above for “landuse = other”

- **Land use mix – residential:** Repeated the above for “landuse = residential”

- **Gross density (d.u./gross acre):** Selected all records with “landuse = residential”, went to “show selected records”, selected “dwelling_units” column, right clicked, selected “statistics”. Noted the “sum” value, representing total number of dwelling units in the model area. To then turn this into gross density, divided that total by 160 acres.

- **Residential acreage:** Selected all records with “landuse = residential”, went to “show selected records”, selected “shape_area” column, right clicked, selected “statistics”. Noted the “sum” value.

- **Net density (d.u./residential acre):** Divided the total number of dwelling units by the residential acreage.

- **Housing mix – single detached:** Selected all records with landuse = 'residential' and landuse_subtype = 'single' and noted the total number of records. To get "% single detached homes", took this number and divided it by the total number of dwelling units in the model.

- **Housing mix – row:** Selected all records with "landuse = residential" and "subtype = row" and noted the total number of records. To get "% row houses", took this number and divided it by the total number of dwelling units in the model.

- **Housing mix – multi:** Selected all records with "landuse = residential" and "subtype = multi", went to "show selected records", selected the "dwelling_units" column, right clicked and selected "statistics". Noted the "sum" value. To get "% dwelling units in multi-unit buildings", took this number and divided it by the total number of dwelling units in the model.

To count intersections by type:

1) Opened the attribute table for the "modelname_intersections" Feature Class.

2) Sorted the records by "IntersectionType", noted the total number of records for each type and subtype.

3) Sorted the records by "IntersectionValence", noted the total number of records for each type (X or Y intersections).

To count points of conflict (POC) by type:

1) Opened the attribute table for the "modelname_POCpts_M2S" Feature Class

2) Sorted the records by "POC_type", noted the total number of records for each type and mode.

Calculating Network Coverage

(Both by path type and by user)

To calculate network coverage including areas of line overlap:

1) Used the Dissolve tool (Generalize -> Dissolve) with the following settings to collapse the records into one entry per path subtype (e.g. 'sidewalk', 'loop', etc.):

   Input feature: modelname_networklines

   Output feature: modelname_networklines_coverage

   Dissolve fields: path_subtype

2) Opened the attribute table of the resuling modelname_networklines_coverage feature class and noted the value in the shape_length column for each record.

To calculate network coverage without including areas of line overlap:

1) Used a definition query on modelname_networklines_identity so only segments with path_subtype = 'sidewalk' were showing.
2) Used the Dissolve tool (Generalize -> Dissolve) with the following settings to collapse the records into one entry per path subtype (e.g. 'sidewalk', 'loop', etc.) based on the type of pavement the line segment falls on:

   Input feature: modelname_networklines_identity

   Output feature: modelname_networklines_sidewalk

   Dissolve fields: path_subtype

3) Erased the portions of the sidewalk lines that fell on roads by using the Erase tool (Analysis -> Overlay -> Erase) with the following settings:

   Input features: modelname_networklines_sidewalk

   Erase features: modelname_networklines_roads_buffered_clipped

Output feature class: modelname_networklines_sidewalk_roads_erased

XY Tolerance: (left blank)

4) Opened the attribute table for modelname_networklines_sidewalk and noted the value in the SHAPE_LENGTH field.

5) Repeated process for trails.

Calculating Intersection Density & Differential Connectivity by Intersection Density

To calculate intersection density:

1) Developed an intersection count specific to each of the three study modes by using the totals of each applicable type (previously counted in the step on p. 510).

   Motorists: Count of road intersections only
   (Ran two different scenarios: one where alley/road crossings were counted as intersections and one where they were not)

   Pedestrians: Regular road intersections + ATN-only for pedestrians (trail/trail, trail/road at midblock), except for the Greenway model, where the only intersections available to pedestrians are the ATN-only intersections

   Cyclists: Regular road intersections + ATN-Only for Cyclists (trail/trail, trail/road at midblock except where left turn options are not available and connection serves as an "on-ramp")

2) Converted each of these counts into an intersection density by dividing by 160 acres (to give intersections per acre)

To calculate differential connectivity by intersection density:

1) Took the intersection density available to pedestrians for a given model and divided it by the intersection density available to motorists.

2) Repeated for cyclists vs. motorists.

Calculating Metric Reach & Directional Distance

Peponis et al.'s (2008) "Spatialist Lines Software" tools were used to calculate metric reach and directional distance. The following methodology is adapted from the GIT Morphology Lab (2008). It is recommend that other users of this study's methodology familiarize themselves with Peponis et al. (2008) and the GIT Morphology Lab's (2008) *Spatialist Lines Software Manual* before proceeding, as these documents provide considerably more details about how to obtain metric reach and directional distance than are presented here.

1) Opened a new map in ArcMap

2) Added "modelname_networklines" to map

3) Using definition queries and the Copy Features (Data Management -> Features -> Copy Features) tool, created a feature class of networklines for each model/mode combination, called "modelname_mode_legline" (e.g. "fusedgrid_bike_legline"). Depending on the model, these new feature classes included:
    - Roads and/or trail lines
      (Roads were used as a centerline version of sidewalk lines for the purpose of assessing legibility)

      But not:

    - Frontdoor
    - Driveway
    - Otherdriveway

This was done to ensure that metric reach and directional distance would be measured only for the public portion of the transportation network, not those paths which only served to access individual buildings.

4) Saved these features to a new folder (called "LegLines") in order to make them shape files (as the Shape2Text tool included in the Spatialist Lines software cannot be run on regular feature class files).

5) Cleaned the legline shape files in ArcMap so that there were no unnecessary dangling line segments which had previously been created to allow network users to cross other path types not included in a given set of leglines (hence creating the dangle) (see Fig. H.1 below for an example).

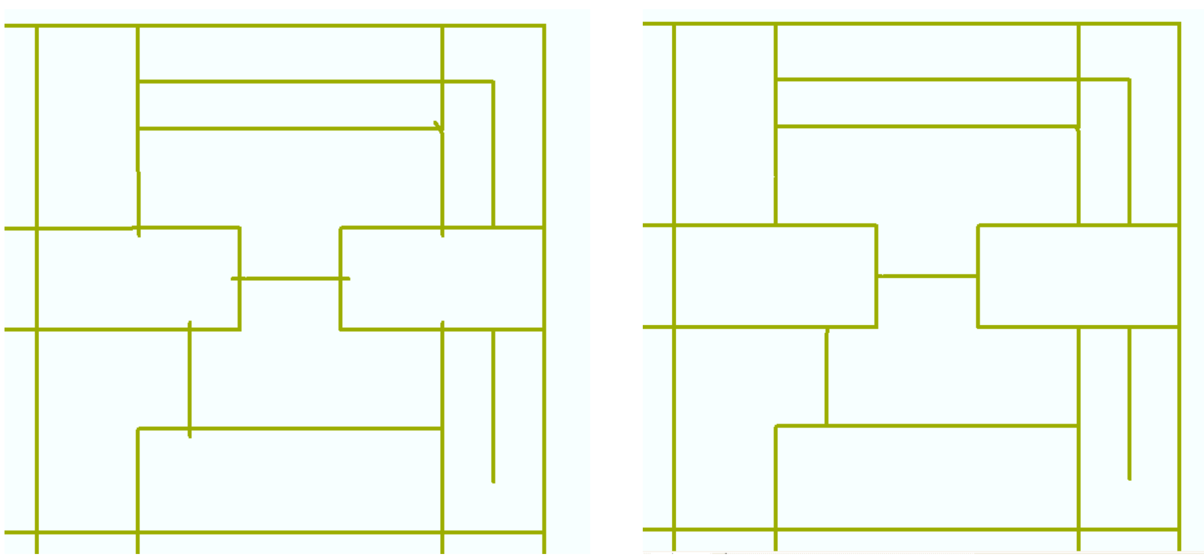


Fig. H.1: "Leglines" before cleaning (left, showing dangles created by crossing extensions) and after cleaning (right)

6) Closed ArcMap

Manipulating the Shape Files in ArcView

1) Opened ArcView

2) Created a project "with a new view"

3) Double clicked on "Views"

4) Hit "Add Theme" button

5) Added a "Legline" shape file for one model/mode combination

6) Turned on View Properties Window

7) In the View Properties window, set map units to feet and distance units to feet

8) Opened the theme table for the shape file

Created a one mile reference line

1) In the View Window, went to "View -> New theme"

2) Selected "Line"

3) Saved the new theme and called it "line1.shp"

4) Clicked on the "Draw Line" button

5) Drew a line one mile (5,280 feet) long

6) Double clicked on line to see values for individual vertices to ensure line was exactly 5,280 feet

Added a sequential numbering sequence for use in joins

1) Copied the Compiled Table Tools file (Compiled_Table_Tools.avx.) from the Spatialist Line software package into the ArcView program's extensions folder.

2) Turned on the "Compiled Table Tools" extension (File -> Extensions)

3) Opened the Theme Table

4) Hit the "Launch Compiled Table Tools" button

5) Hit the "Add Increment Field" button and used the following settings:

    Field name: "LegNum", 6 digits, 0 decimal places
    Field width: 1
    Start counting at: 1

6) Saved

7) Closed ArcView

Converted the shape to a textfile

1) Opened Peponis et al.'s (2008) "Shape2Text" program

    - First line: browsed to the applicable shape file
    - Second line: browsed to the desired destination folder and named the text file the same name as the shape file only with a .txt extension
    - Check fields to export: checked the "LegNumber" field

2) Hit “start”

3) Repeated for all legline shape files as well as the line1.shp. Note that for the tool to work properly, it was necessary to check that the four bounding roads (the arterials for all models but the Grid) were broken into unique segments at each of the frame’s corners.

4) Closed the program

Note: this tool will not work if a feature class contains M-values.

Calculated Metric Reach & Directional Distance

1) Created a folder for each model/mode combination and put their corresponding “leglines” shape file in them

2) Put a copy of Metric.jar and Angle.jar from the Spatialist Lines software package and line1.shp into each folder where the text files were saved

3) In Windows XP, opened the Windows Command Processor (also known as “the command line”) by going to “Start -> Run -> CMD”

4) Navigated to the one of the text file folders by typing
   cd c:\
   and then adding the folder location after the \

5) Entered the following command to calculate metric reach:

   Java -Xmx1024m -classpath metric_alt.jar ReachDD moelname_mode_S2T.txt -f c -d line5.txt -r 0.25 -t 10 -g 0.1 -v

   This command line sets the tool to use a 0.25 mile radius (“r”), a 10 degree angle threshold (“t”) and to treat 0.1 miles as the cutoff for small road segments (“g”).

6) Entered the command to calculate directional distance:

Java -Xmx1024m -classpath angle.jar PolygonReaderWriter modelname_mode_S2T.txt -f c -d line5.txt -x 2 -t 10 -g 0.1 -w 2

This command line sets the tool to use a 2 turn maximum (w), a 10 degree angle threshold ("t") and to count any line segments less than 0.1 miles as a small road segment ("g").

To view the results, it was necessary to join the results to the original leglines shape file. To do so:

1) Opened ArcView

2) Added the new text files (for one model/mode combination, called modelname_mode_S2T.txt) by hitting the "Add" button. (Note: It is necessary that "file type" be listed as "Delimited Text" in order to be able to see these files when looking to find them).

3) Added the "Leglines" shape file for that model/mode combination.

4) Opened the attribute table for one of the results files (either the metric reach or directional distance) and selected its "LegNum" column.

5) Opened the attribute table for the "Leglines" shape file and select its "LegNum" column.

6) Hit the "Join" button.

7) Use "Convert to Shape File" to make the join on the "Leglines" shapefile permanent (Theme -> Convert to Shapefile).

8) Saved.

9) Closed ArcView.

10) Opened ArcMap.

11) Added the new “Leglines” shape file.

12) Opened its attribute table.

13) Exported the data as a .dbf file.

14) Closed ArcMap.

Calculating Average Metric Reach and Directional Distance

1) Opened the .dbf file in Microsoft Excel.

2) Calculated the average of each of the columns of data using the “=average” formula in Excel.

3) Saved as legline_results.xlsx.

4) Closed Excel.

Calculating Differential Connectivity by Metric Reach

To calculate differential connectivity by metric reach:

1) Took the average metric reach for the pedestrian network in a given model and divided it by the average metric reach for the motorist network.

2) Repeated for the cyclist vs. motorist networks.

Calculating Point of Conflict Density

1) Using the point of conflict counts obtained in the “Calculating Model Characteristics“ section on p. 510, combined POCs into the following groups:

   For pedestrians:
   ATN/Road conflicts: (all sidewalk/road and trail/road crossings)
   ATN/Driveway conflicts: (all sidewalk/driveway and trail/driveway crossings, including conflicts from both residential driveways and “other” land use type driveways)

   For cyclists:
   Car/Cyclist conflicts: (all road/road and road/trail crossings)

   (Note: Driveway-based conflicts not included for cyclists because of the problems previously noted with developing this POC type for modes which travel along roadways)

   For motorists:
   Car/Car conflicts: All road/road POCs
   (Note: since cyclists also travel on roads, this first category is functionally Car/Car-and/or-on-road-Cyclist conflicts)
   Car/Active Mode conflicts: All road/sidewalk and road/trail POCs
   (Note: covers potential for conflict with active modes crossing roadways, rather than cyclists travelling along them, which is covered by the “Car/Car” conflicts category instead)

2) Divided the total number of POCs in each group by the total model area (160 acres) to get the POC density per acre.

Calculating Network Continuity – Ratio of ATN-Only Intersections to Regular Road Intersections

1) Took the number of ATN-Only Intersections available to pedestrians (determined on p. 510) and divided by the number of regular road intersections. For the purposes of this calculation, alley/road intersections were considered "regular road intersections".

2) Repeated for cyclists.

Calculating Network Modal Separation Using Network Coverage

1) The total network coverage available to a given mode was noted (calculated in p. 511 above). The network coverage value used included all line segments involved in crossing other types of paths (e.g., sidewalks were treated as continuous over roadways)

2) Opened ArcMap and added the modelname_networklines_identity feature class to a blank map.

3) Used the Dissolve tool (Data Management -> Generalization -> Dissolve) to dissolve the feature class into line segments based on their path_subtype and buff_subtype fields.

   Input Feature: modelname_networklines_identity
   Output Feature Class: modelname_networklines_dissolved
   Dissolve Fields: Path_Subtype, Buff_subtype
   Statistics Fields: Left blank
   Create Multipart: Unchecked
   Unsplit Lines: Unchecked

4) Opened the attribute table of the resuling modelname_networklines_dissolved feature class (where line segments had been merged based on common path_type and buff_subtype attributes) and copied the data into Microsoft Excel.

5) The set of lines available to each mode (based on path_type) was copied and put into a new spreadsheet named either “pedestrian” “cyclists” or “motorist”). (See Table F.6 on p. 502 for a list of the line types available to each mode). Fake lines were not included in the network-based modal separation calculations.

6) The data for each mode was then combined into groups based on the level of modal separation a given line segment would provide (the result of its buff_subtype attribute). The modal separation groupings depended on the mode, and were as follows:

Pedestrians:

- **Complete separation from cars:** Sections of sidewalks and trails outside of intersections and not interrupted by driveways or alleys

- **No separation from cars** - d**ue to road crossings:** Sections of sidewalks or trails crossing any type of road except alleys, and not including underpasses

- **No separation from cars** – d**ue to parking:** Walking in alleys, down driveways or along sidewalk sections that cross driveways or alleys

Cyclists:

- **Complete separation from cars:** Trails outside of road intersection crossings, alleys, or parking

- **Partial separation from cars:** Bike lanes

- **No separation from cars on roads:** Mixed traffic on roads not including alleys, trail crossings over road

- **No separation in parking areas:** Biking down alleys, trail driveway crossings

For cyclists, the total length of network offering “complete” or “partial” separation for cars were also added together to provide a value for what many would consider to be the total length of the cyclist network.

Greenway Variation

For the Greenway model, two different scenarios were run for cyclists – one in which cyclists are assumed to be allowed on the roads (which increases the total length of the network), and one in which they are assumed to be restricted to trails (which decreases total length of network and thus increases the proportion offering complete modal separation).

Cleaning the Excel Worksheets for Trip-Based Measures

1) Opened the modelname_mode.dbf file in Excel

2) Created a new blank row at the top of the table.

3) With ArcGIS open, copied and pasted the correct column names from Arc into the blank row at the top of the table in Excel (the original database file cuts names too short).

4) For all model/mode combinations that had used homes as added cost point barriers, added a new column after “Trip_Length” called “Corrected Trip Length” and subtracted 1,000,000 from the value in the “Trip_Length” column to get the true trip lengths

5) Formatted POC results so they contained integer values (no decimal points), while other results values were displayed as numbers with two decimal points. (Done by selecting the applicable cells, then right clicking and selecting “Format Cells”. Set the “Number” tab’s “Category” to “Number” with the apropriate number of decimal places, then hit “OK”).

6) Sorted data by “DestinationID”

Note that there may be two columns labelled “Destination” – one that coresponds to the actual destination point, and one that ranks the length of trips for the 9 trips to a given origin point. The column that contains the true destination point number will match the one listed in the “Name” column (see Fig. H.2 below)

ObjectID	Name	OriginID	Destination	Destinat_1
1	Location 1 - Location 8	1	8	1
2	Location 1 - Location 1	1	1	2
3	Location 1 - Location 2	1	2	3
4	Location 1 - Location 7	1	7	4
5	Location 1 - Location 6	1	6	5
6	Location 1 - Location 3	1	3	6
7	Location 1 - Location 4	1	4	7
8	Location 1 - Location 5	1	5	8

Fig. H.2: Identifying the true "destination" column

7) Copied trips to destinations 1 through 8 into a new worksheet called "modelname_edge" and copied trips to destination 9 into a new worksheet called "modelname_centre" using the "copy values" option.

Note: For the New Urbanist "Driving" mode, two different databases were created for the trips – one representing trips to the edge and one for trips to the centre (necessary because of the way the fake line segments were set up in that model). As such, this data was already split once the .dbfs were opened in Excel.

8) In the "modelname_edge" worksheet, sorted the data by OriginID so that all eight trips from Origin 1 were listed first. To the right of the existing data (in the same row as the record for Origin1 to Destination1), sum all eight records for each origin point for each column to create a single row's worth of data that reflects all eight trips made to the edge from the origin (see Table H.1 below), using the "=sum" formula in excel (for example, "=sum(A2:A9)").

9) Beneath that row, entered 7 rows of "0" for each variable (trip length, path types travelled on, POCs) (see Table H.1 below).

10) Selected the entire new block of data (i.e. all the new records corresponding to the eight edge trips made from origin 1), clicked the bottom right corner and dragged down to repeat this formula for all remaining origins (see Table H.1 below).

Table H.1: An example of what the newly calculated block of edge destination data looked like

Original Data (Directly from the .dbf file created in ArcMap)							**New Data (created using "=sum" on the original cells to the left)**			
Name	OriginID	Destination ID	Total_Trip_ Length	Total_PathL_ PedBK_buff_ trail	Total_PathL_ PedBK_buff_ through	Total_PathL_ PedBK_buff_ frontdoor	Total_Trip_ Length	Total_PathL_ PedBK_buff_ trail	Total_PathL_ PedBK_buff_ through	Total_PathL_ PedBK_buff_ frontdoor
Location 1 - Location 1	1	1	254.00	0.00	3.30	0.00	20613.01	1312.90	92.40	57.20
Location 1 - Location 2	1	2	1452.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Location 1 - Location 3	1	3	2772.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Location 1 - Location 4	1	4	3706.30	216.70	13.20	28.60	0.00	0.00	0.00	0.00
Location 1 - Location 5	1	5	5025.80	660.70	49.50	28.60	0.00	0.00	0.00	0.00
Location 1 - Location 6	1	6	3706.30	435.50	19.80	0.00	0.00	0.00	0.00	0.00
Location 1 - Location 7	1	7	2508.00	0.00	3.30	0.00	0.00	0.00	0.00	0.00
Location 1 - Location 8	1	8	1187.70	0.00	3.30	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 1	2	1	274.10	0.00	3.30	0.00	20572.81	1306.10	79.20	0.00
Location 2 - Location 2	2	2	1472.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 3	2	3	2792.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 4	2	4	3686.20	213.30	6.60	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 5	2	5	5005.70	657.30	42.90	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 6	2	6	3686.20	435.50	19.80	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 7	2	7	254.00	0.00	3.30	0.00	0.00	0.00	0.00	0.00
Location 2 - Location 8	2	8	1452.30	0.00	3.30	0.00	0.00	0.00	0.00	0.00

(Table does not include full set of trip characteristic columns)

11) Selected the block of data containing the calculated values plus the the name, origin ID and destination ID columns and pasted special -> values into a new spreadsheet, labelled "modelname_edge_merged"

(Deleted any "uncombined" columns of raw results data that were copied over into the new spreadsheet, where applicable)

12) Sorted the new block of data by DestinationID, such that all the rows containing calculated values (rather than 0s) were at the top (i.e., all the cells apparently corresponding to destination 1, but actually reflecting the summed trip values to all eight edge destinations).

13) Calculated the average value for each column containing trip characteristic data in the "modelname_centre" and "modelname_edge_merged" worksheets.

14) Further divided the average values in "modelname_edge_merged" by eight so its values reflect the average value for one trip (instead of to all eight edge destinations).

Note: The "average values" calculated in steps 13 and 14 reflect trip characteristics when measured from a lot-based, rather than density based perspective. The following steps modify the data to reflect the number of dwelling units on each lot.

15) In each of the "modelname_edge_merged" and "modelname_centre" worksheets, created a new column called "Dwelling Unit Multiplier".

16) Opened ArcMap and the attribute table for the modelname_homes feature class.

17) Made sure the data was sorted by ObjectID (the name/number for each origin point), then copied the number of dwelling units at each origin point into the "Dwelling Unit Multiplier" columns in the the "modelname_edge_merged" and "modelname_centre" worksheets, such that they matched up with the origin points listed in the origin point (OriginID) column for the trip characteristic data.

18) At the bottom of the column, used "=sum" on all the preceding cells to calculate the total number of dwelling units in the model.

19) Below the original table in each of the "modelname_centre" and "modelname_edge_merged" worksheets, created a new table of data that contained the original values in each row of trip characteristic results multiplied by the dwelling unit multiplier. Labelled this new table "Results Weighted by Dwelling Units" (see Table H.2 below for example).

Table H.2: Using the dwelling unit multiplier on trip data

Original data and dwelling unit multiplier					
Name	OriginID	Multiplier (MU)	Total_Trip_Length	Total_PathL_PedBK_buff_trail	Total_PathL_PedBK_buff_through
Location 252 - Location 1	252	102	18,861.42106	16,148.71843	85.80034
Location 253 - Location 1	253	1	19,385.2206	16,643.91793	114.4004
Location 254 - Location 1	254	1	19,384.24228	16,613.63913	143.0007
Location 255 - Location 1	255	1	19,701.55517	16,959.55224	114.4004
Data in second table after being subject to dwelling unit multiplier					
Location 252 - Location 1	252	(blank)	1,923,864.948	1,647,169.28	8,751.634
Location 253 - Location 1	253	(blank)	19,385.2206	16,643.91793	114.4004
Location 254 - Location 1	254	(blank)	19,384.24228	16,613.63913	143.0007
Location 255 - Location 1	255	(blank)	19,701.55517	16,959.55224	114.4004

20) Summed the values in each column of the "Results Weighted by Dwelling Units" table and divided by the total number of dwelling units for that model, so that an average is created based on the total number of dwelling units rather than the total number of records (which is what would happen if an "=average" formula was used).

21) Further divided those values in "modelname_edge_merged" by eight so its values reflect the average value for one trip "to the edge" rather than the total values to all eight edge destinations.

Calculating Average Trip Lengths

1) Average trip length values were taken from the average value (for trips to centre) and the aveage value/8 cells at the bottom of the "Trip_Length" columns in the modelname_centre and modelname_edge_combined spreadsheets' "Results Weighted by Dwelling Units" tables.

   (Note: for models which used origin points as additional costs to prevent travel across residential lots, the "Corrected Trip Length" column's results were used instead).

Calculating Average Proximity

In order to calculate the ratios of route directness for a given trip (comparing the network path distance to the “as the crow flies” Euclidean distance), it was necessary to generate a table of Euclidean distances between each origin point (home) and the nine destination points. To do so:

1) In the modelname_network_analysis map in ArcMap, opened the Point Distance tool (Analysis -> Proximity -> Point Distance) and used the following settings:

    - Input Feature: modelname_homes
    - Near Feature: modelname_dest
    - Output Table: modelname_pointdistance
    - No search radius applied

2) Opened the newly created table

3) Exported results as modelname_pointdistance.dbf by selecting “Export” from the Table Options dropdown menu.

4) Opened the new file in Excel.

5) Added a blank row of cells at the top of the block of data.

6) Copied the correct column names from the point distance attribute table in ArcMap and pasted them into the Excel file.

7) Named the worksheet “ProximityCalc”.

To then calculate the average proximity of dwelling units to destination points (see p. 608), the following steps were performed:

1) Sorted the data by the NEARFID column (which corresponded to the 9 destination points, with values 1-8 representing edge points and 9 the centre point)

2) Pasted in the dwelling unit numbers from "modelname_centre" in a new column for each block of data, such that the data aligned with the origin IDs already in the worksheet.

3) In the next empty column, multiplied the point distance values by the corresponding number of dwelling units at that origin point.

4) Inserted two blank rows between the block of data for each origin point (creating 9 blocks of data in total)

5) At the bottom of the column with the point distances for each destination multiplied by the number of dwelling units at each origin, did an "=sum(*first cell in column containing point distance x dwelling unit for origin point:last cell in column containing point distance x dwelling unit for origin point)/(total number of dwelling units*)" to calculate the average Euclidean distance between the origins and the given destination.

Calculating Trip-Based Connectivity: Directness Ratios

Directness ratios were calculated for trips to edge and trips to centre using the following steps:

1) Opened the ProximityCalc worksheet in Excel.

2) Copied the point distances between the origins and destination 9 (before being multiplied by the number of dwelling units at each origin point), into a new column on the modelname_centre worksheet.

3) On the modelname_centre spreadsheet, divided the cell containing original (pre-dwelling unit multiplier) network trip length for a given origin to destination 9 (Trip_Length or Corrected Trip Length, depending on the model) by the Euclidean (point distance) between those two points, to get the directness ratio.

4) In a new column, multiplied the resulting directness ratio value by the number of dwelling units at that origin point.

5) At the bottom of that column, did an “=sum” on the column and then proceeded to divide it by the total number of dwelling units in the model to get the average directness ratio for trips to centre by that mode.

6) Repeated the process for the modelname_edge_combined spreadsheet. In the case of trips to edge, the point distance data had to be sorted by origin, and then added together for all eight trips to edge destinations for that origin point. The combined network trip distance was then valued by the combined point distance to get the average directness ratio from that origin point to the edge. This ratio was then multiplied by the number of dwelling units at the origin point, the directness ratio column then summed and divided by the total number of dwelling units in the model to come up with the average directness ratio for that mode.

Calculating Trip-Based Continuity Using Potential Points of Conflict

1) Opened the “modelname_edge_merged” and “modelname_centre” spreadsheets and copied the averaged trip characteristic data (trip length or corrected trip length and POC results) to edge and centre for all three modes for each model into a new spreadsheet called “modelname _POCs_encountered ”

2) For reporting POC values on p. 126 - 144, the POC point columns were sorted and combined into the following categories, and their values combined in a new column to the right of the existing data(using “=sum” with the applicable cells in Excel):

   - ATN/ATN (sidewalk_frontdoor, sidewalk_sidewalk, sidewalk_trail and trail_trail POCs)
   - ATN/Road (sidewalk_road and road_trail POCs)
   - ATN/Driveway (sidewalk_driveway, sidewalk_otherdriveway, trail_driveway POCs)
     - (Note: there were no trail_otherdriveway POCs in any of the models)
   - Road/Road (road_road POCs)

   (See Table H.3 on the following page for an example of what the spreadsheet would look like)

Table H.3: Example of collected POC summary data in Excel

		Road_ Road	Combined: Road/Road Category	Road_Trail	Sidewalk_ Road	Combined: ATN/Road Category	Sidewalk_Side walk	Sidewalk_Trail	Trail/Trail	Combined: ATN/ATN Category
Bike	Centre	3.54	3.54	1.50	4.60	6.1	0.00	1.52	0.35	1.87
Bike	Edge (/8)	7.11	7.11	2.61	10.20	12.81	0.00	0.97	0.43	1.4
										0
Car	Centre	4.41	4.41	1.62	5.90	7.52	0.00	0.00	0.00	0
Car	Edge (/8)	8.80	8.80	2.28	12.25	14.53	0.00	0.00	0.00	0
										0
Ped	Centre	0.00	0.00	0.65	2.91	3.56	4.55	2.41	0.67	7.63
Ped	Edge (/8)	0.27	0.27	0.60	5.87	6.47	9.60	3.44	0.81	13.85

(Each cell reflects the average values for a given mode to centre or edge. Not all POC types shown).

To go from count data to per mile data:

1) The values for each of the combined POC categories (as per the previous step) for trips to the edge and to the centre were averaged for each category (i.e., edge and centre were weighted equally)

2) The averaged value was divided by the average trip length for the model (which was the average trip distance to edge plus the average trip distance to centre, divided by two) from the modelname_centre and modelname_edge_combined worksheets to give POCs per mile travelled.

Calculating Trip-Based Modal Separation Using Separation of Path Types

1) Using the "modelname_edge_combined" and "modelname_centre" spreadsheets, copied the summary path type data to edge and centre for all three modes for each model into a new spreadsheet called "Path Types" (similar to what was done with POCs previously – see example table for POCs on p. 535, showing the table after "combined" columns for the POC types have been added). In the new "PathTypes" spreadsheet, deleted the columns related to POCs rather than path length travelled..

2) Added a column heading for path type above each column of data to allow a horizontal sort by path type (Fig. H.3 below).

	A	B	C	D	E	F	G	H	I	J
1	RESULTS TO EDGE									
2			Trail	Side	Through	Loop	Front	Drive	CDS	Art
3		Total_TripL	Total_PathL_PedBK_buff_trail	Total_PathL_PedBK_buff_sidewalk	Total_PathL_PedBK_buff_through	Total_PathL_PedBK_buff_loop	Total_PathL_PedBK_buff_frontdoor	Total_PathL_PedBK_buff_driveway	Total_PathL_PedBK_buff_CDS	Total_PathL_PedBK_buff_arterial
4	Edge Combined/8	2588.892	0	0	0	0	0	0	0	0
5										
6	Centre	1781.295	0	0	0	0	0	0	0	0
7										
8										
9										
10										
11										
12										
13										
14										

Fig. H.3: Path type column headings

3) Using an =sum formula, combined the columns for each path type, which had previously been divided into different feature classes by user in order to run the network analysis in ArcGIS. (E.g., the values for Arterial(All), Arterial(Bike), Arterial(BikeLane), Arterial(Mix), Arterial(Ped) and Arterial(PedBK) were added together to reflect *all* portions of a trip made over an arterial within a given set of results from the Network Analysis).

The resulting path types were:

- Alley
- Arterial
- Cul-de-Sac
- Collector
- Driveways (Other & Residential)
- Front Door
- Loop
- Sidewalk
- Through
- Trail

Fake segments were grouped with the appropriate regular path type (i.e., a pedestrian connection along the edge of the model was assumed to be a sidewalk, the fake connection to the central destination point located in a park for drivers in the New Urbanist model was grouped with the “through road” segments, etc.)

4) For reporting the extent of path travelled upon with a given level of modal separation during a trip (see results on p. 207), the distance travelled results for all “path type” columns with a similar modal separation were combined into the following categories, (using “=sum” with the applicable cells in Excel):

For pedestrians

- **Complete separation:** travelling on sidewalks, trails, or frontdoor connections (representing length of travel along lines where buff_subtype = ‘sidewalk’, ‘trail’ or ‘frontdoor’)
- **No separation – higher order roads:** travelling across collectors or arterials (buff_subtype = ‘collector’ or ‘arterial’)
- **No separation – local roads:** travelling across local roads (buff_subtype = ‘through’, ‘loop’ or ‘cul-de-sac’)
- **No separation – parking:** travelling on driveways or alleys (buff_subtype = ‘driveway’, ‘otherdriveway’ or ‘alley’)

For cyclists:

- **High separation:** travelling on sidewalks, trails, or frontdoor connections (along line segments where the “buff_subtype” attribute = ‘sidewalk’, ‘trail’ or ‘frontdoor’)
- **Medium separation:** travelling on roads with bike lanes (buff_subtype = ‘arterial’ or ‘collector’)
- **Low separation:** travelling in mixed traffic (buff_subtype = ‘through’, ‘loop’ or ‘cul-de-sac’)

Greenway variation

As with the calculation of network modal separation, two scenarios were produced for the Greenway model: one in which cyclists were assumed to be allowed to use roads and one in which they were not. In the latter case, cyclist trips were identical to pedestrian ones.

- Once the distances along each modal separation category were calculated, the results were divided by average trip length for the model/mode combination to determine what percent of the trip occurred on paths with a given level of modal separation.

Calculating Differences in Trip Lengths Between Best and Worst Models

1) Differences in trip lengths between the best and worst model for any given mode for trips to the centre, edge and "equally-weighted centre and edge" were calculated by subtracting the trip distance for the worst model (e.g. the longest distance) by that of the best model for that case. Trip distances were taken from the modelname_edge_combined and modelname_centre worksheets.

2) This was then converted into a percent by dividing the difference in trip lengths by the trip length of the best model.

Calculating Trip-Based Differential Connectivity Using Trip Distances

1) For pedestrians vs. motorists: Took the trip distances (to edge, centre, and equally weighted edge-and-centre) for walking and divided it by the trip distances by driving (matching the trip type, i.e., trip distances to edge for pedestrians divided by trip distances to edge for motorists).

2) Repeated for cyclists vs. motorists and cyclists vs. pedestrians.

Calculating Buildable and Network Areas

To calculate road network area:

1) Made a copy of the modelname_networklines_roads_buffered_clipped Feature Class using the "Copy Features" tool (Data Management -> Features -> Copy Features)

    Input Features: modelname_networklines_roads_buffered_clipped
    Output Feature Class: modelname_roads_buffered_merged
    Configuration Keyword: left blank
    Output Spatial Grid (1-3): left blank

2) Started an editing session.

3) Selected all the road polygons in modelname_roads_buffered_merged, then selected "Merge" from the Editing toolbar's dropdown menu.

4) Opened the modelname_roads_buffered_merged feature class' attribute table and recorded the value in the shape_area field.

To calculate buildable area:

1) Opened the modelname_buildable_area Feature Class' Attribute Table and recorded the value in the shape_area field.

To calculate other Active Transportation Network area:

1) Opened the modelname_networklines and applied a definition query (path_type = 'sidewalk' OR path_type = 'trail')

2) Used the Buffer tool (Analysis -> Proximity -> Buffer) with the following settings:

Input Features: modelname_networklines

Output Feature Class: modelname_sidewalk_trail_buffered

Distance:

Selected “field” radio button, and the “path_half_width” field

Side Type: Full

End Type: Round

Dissolve Type: All

Dissolve Fields: (N/A)

When complete, a single polygon reflecting the ATN area should be produced.

3) Took the new layer and subjected it to an erase (Analysis -> Overlay -> Erase) using the feature class showing just the polygons for the road network area (modelname_networklines_roads_buffered_merged)

Input Features: modelname_sidewalk_trail_buffered

Erase Features: modelname_roads_buffered_merged

Output Feature Class: modelname_sidewalk_trail_buffered_no_roads

XY Tolerance: (left blank)

4) Opened the “modelname_sidewalk_trail_buffered_no_roads “ attribute table.

5) Started an editting session.

6) Selected all the trail and sidewalk polygons.

7) Hit “Merge” in the Editting toolbar’s dropdown menu.

8) Recorded the value in the shape_area attribute field.

(Note: the“other active transportation area” measure assumes sidewalks and trails are continuous where intersected by driveways)

To calculate total paved network area:

1) Added the road network area and other active transportation network area together.

(Note: the “total paved network area” does not include driveways)

Calculating Net Density

1) Determined the total amount of land in residential by opening the Attribute Table of the modelname_lots layer, sorting by landuse_type, selecting all records with landuse_type = ‘Residential’, then going to “show selected records”, right clicking on the “shape_area” field and then clicking “Statistics” from the drop down menu. Recorded the “sum” value.

2) Took the number of dwelling units in the model (determined on p. 509 above) and divided them by the number of residential acres to arrive at final value.

Calculating Theoretical Residential Population Densities

1) Took the total number of dwelling units in the model and multiplied by 2.5, the average number of people living in a household in Canada in 2006 (Statistics Canada, 2010b).

Calculating Gross Unit & Gross Density Potential for Single-Detached Homes

To calculate gross unit potential for single-detached homes:

1) Took the total buildable area within a given model (calculated on p. 540 above) and divided by 5,750 sq. ft., the average lot size of a single-detached home in Canada in early 2010 (CHBA, 2010).

To calculate gross density potential for single-detached homes:

1) Took the gross unit potential from the previous step and divided by the total model area (160 acres).

Calculating Infrastructure Efficiency

To produce the infrastructure efficiency results presented on p. 223, the following steps were taken:

1) The total area of roads was pulled from the “total road network area” calculation of p. 540 above, while the total area of parks was pulled from the related step on p. 509 above.

2) The total area of sidewalks was determined by:

   Opening ArcGIS

   Right clicking on the the modelname_networklines feature class to pull up its properties window. Set a definition query of "path_subtype" = 'sidewalk' so that only sidewalks were showing.

   Starting an editting session.

Selecting all the sidewalk lines.

Merging the lines using the tool from the “Editor” menu.

Opening the Buffer toolbox (Analysis -> Proximity -> Buffer) and using the following settings:

Input Features: modelname_networklines
Output Feature Class: modelname_sidewalk_buffered
Distance – Linear Unit: (left blank)
Distance – Field: path_half_width
Side Type: Full
End Type: Round
Dissolve: None

Afterwards, the sections crossing roads had to be removed. To do so, the Erase toolbox was used (Analysis Tools -> Overlay -> Erase) with the following settings:

Input Features: modelname_sidewalk_buffered
Erase Features: modelname_networklines_roads_buffered_clipped
Output Feature Class: modelname_sidewalk_roads_erased
XY Tolerance: (left blank)

Then the attribute of the new “modelname_sidewalk_roads_erased” feature class was opened and the value in its “shape_area” field recorded.

Note: In some instances there were some leftover polygons outside the model space which had to be selected and deleted.

3) The area of roads, parks and sidewalks were then added together and divided by the total number of dwelling units in the model.

To calculate infrastructure efficiency for paved area only:

1) Took the "total paved network area" value calculated on p. 542 and divided by the number of dwelling units

To calculate infrastructure efficiency for model area only:

1) Divided the total infrastructure area by the model space (160 acres) and recorded it.

2) Divided total paved area by model space (160 acres) and recorded it.

Calculating Network Efficiency

1) Identified the model with the worst Pedestrian Directness Ratio (the highest number)

2) Divided the PDR of the other models by the PDR of the worst model, subtracted 1, then multipled by 100 to get the % reduction in PDR.

3) Divided the "area of sidewalks + trails" of the other models by the area for the model with the worst PDR, subtracted 1, then multipled by 100 to get the % reduction in PDR.

4) Repeated for cyclists.

   Note: For cyclists, two different scenarios were run – one in which "the network" was deemed to include all bike lines and trails, and one that included all road space potentially used by cyclists plus trails.

Calculating Descriptive Statistics

1) Opened Excel.

2) Opened the modelname_edge_combined and modelname_centre worksheets.

3) Turned on the "Analysis Toolpack" add-in (Excel Options -> Add Ins -> Manage Add Ins)

4) Copied the trip length data that had already been multipled by the number of dwelling units at each location to create a new worksheet called "modelname_descstats".

5) Switched to the "Data" tab in Excel; hit the "Data Analysis" button in the "Analysis" group. Selected "Descriptive Statistics", hit "OK", then applied the following options:

   Input Range: Selected the data in the trip length (or corrected trip length) column for destination one
   Grouped by: Columns
   Labels in first row: Unchecked
   New worksheet ply: dest1DS
   Summary statistics: checked
   Confidence level for mean: 95% (default)
   Kth Largest: Unchecked
   Kth Smallest: Unchecked

6) Repeated for the trip length data to each of the remaining eight destinations.

7) Repeated for all eight edge destinations to produce the descriptive statistics "to edge". (Trips to centre covered by the initial set of statistics run on destination 9).

8) Used the following equations to calculate the upper and lower quartiles:

=QUARTILE(D3:D962, 1)   FOR LOWER QUARTILE

=QUARTILE(D3:D962, 3) FOR UPPER QUARTILE

9) Saved.

Creating the Box Plots

1) Opened the "ActivStats for Data Desk" software
2) Launched "Data Desk"
3) Opened the relevant set of records in Excel (LIST HERE)
4) In the Trip Length column, added blank rows and made extra copies of trip length records to reflect the number of dwelling units at each origin point (e.g., if there were 5 dwelling units at origin 1, the trip length value for origin 1 – destination 1 would be copied and pasted 4 times beneath the original record). When done, the total number of "trip length" records in the column corresponded to the total number of dwelling units in the model (or 8 times that amount, in the case of trips to the edge).
5) Copied the Trip Length records for the two models being compared and paste them into a new worksheet so the two columns are side by side, with an appropriate heading in each.
6) Selected all the Trip Length records, including the two column headings.
7) Switched to Data Desk.
8) Created a new folder (Data -> New -> Folder) called "Boxplot Data"

9) Pasted the trip length data for the first model in the comparison (Edit -> Paste Variables). Hit "Use these variable names" when the option came up. This produced a "Clipboard" window with an icon for each column's worth of data (Fig. H.4 below)

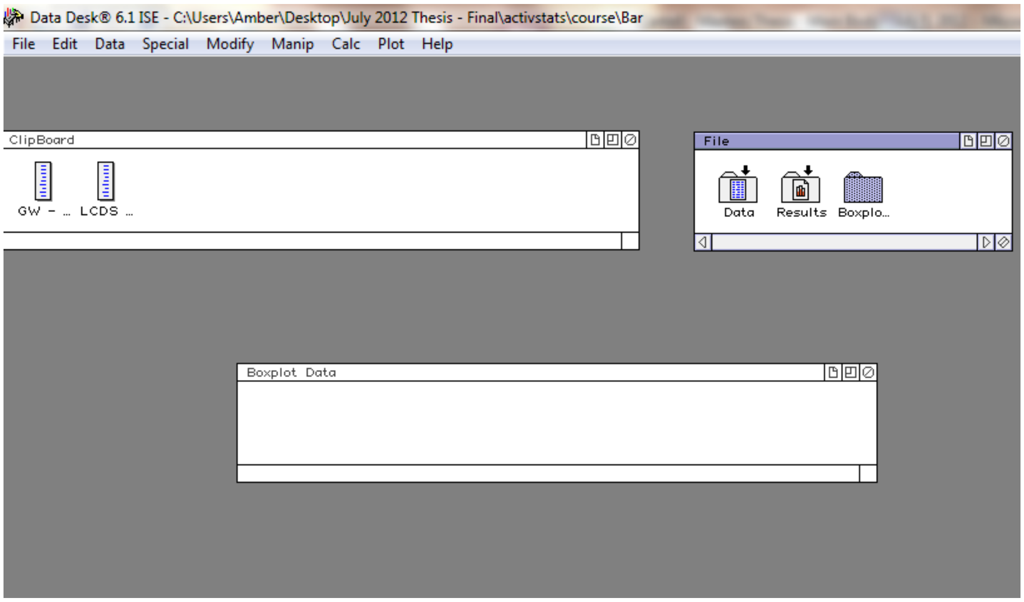


Fig. H.4: The "Clipboard" window in Data Desk

10) The two models each contained a different number of dwelling units and thus a different number of records. As a result, Data Desk copied in "null" records at the bottom of the data for the model with fewer dwelling units. These had to be deleted by double clicking on the appropriate icon (containing the data for the model with fewer units), and then hitting the "backspace" till it reached the bottom of the numerical entries (Fig. H.5)

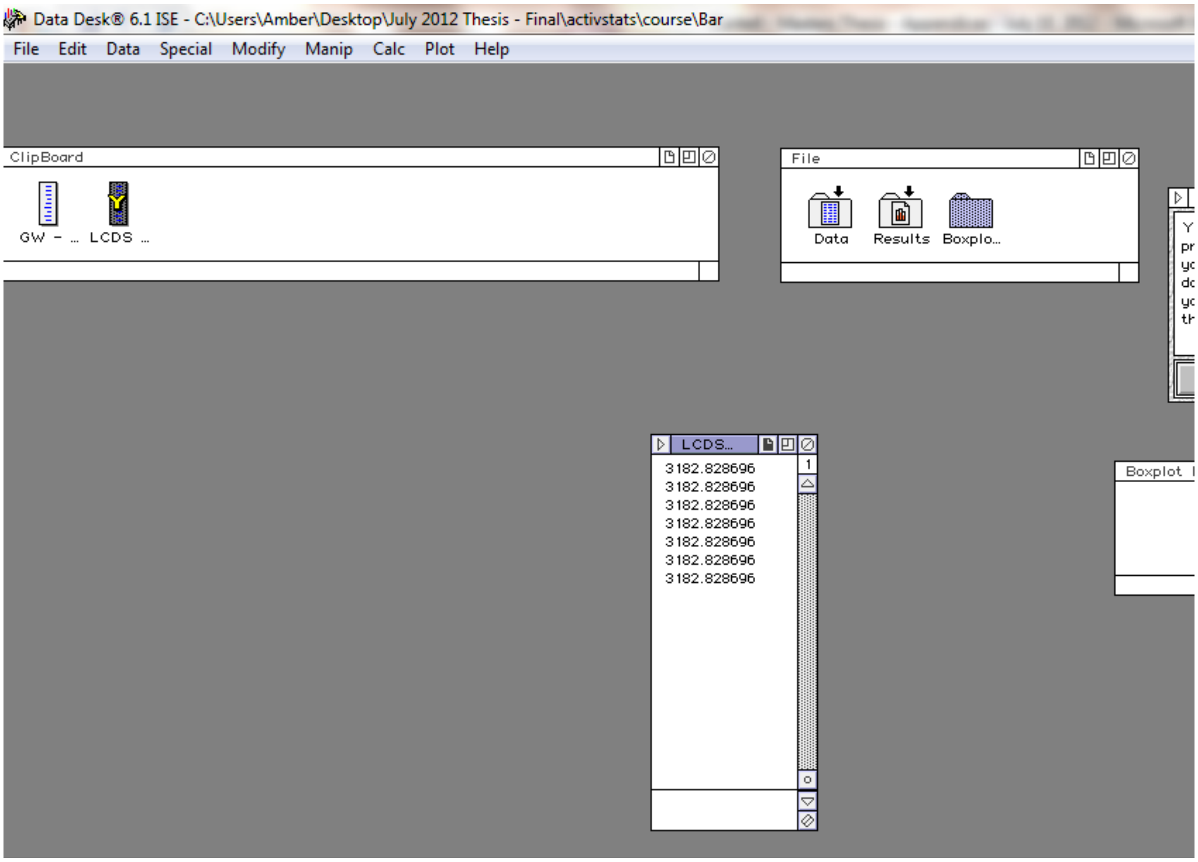


Fig. H.5: The blank space above the black bar in the bottom-middle window represents null records that had to be deleted before the box plot could be created

11) Clicked on the icon in the clipboard window for the first model to give it a yellow "Y", then held CTRL and clicked on the icon for the second model to give it one as well (Fig. H.6)

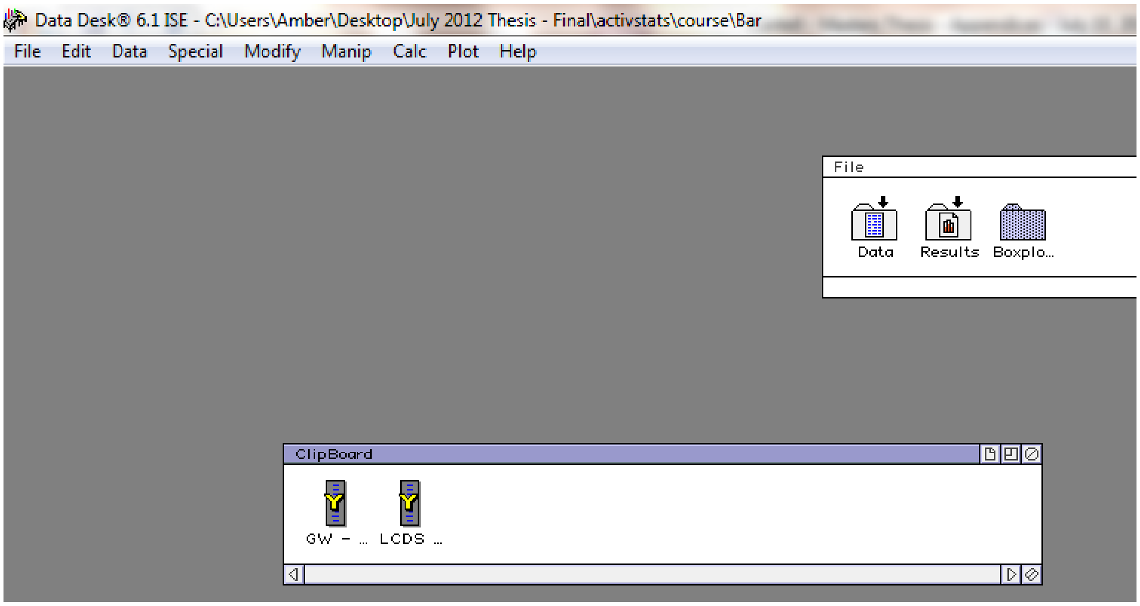


Fig. H.6: Setting both models to "Y"

12) Went to Plot -> Boxplot side by side to produce a box plot similar to the one below (Fig. H.7)

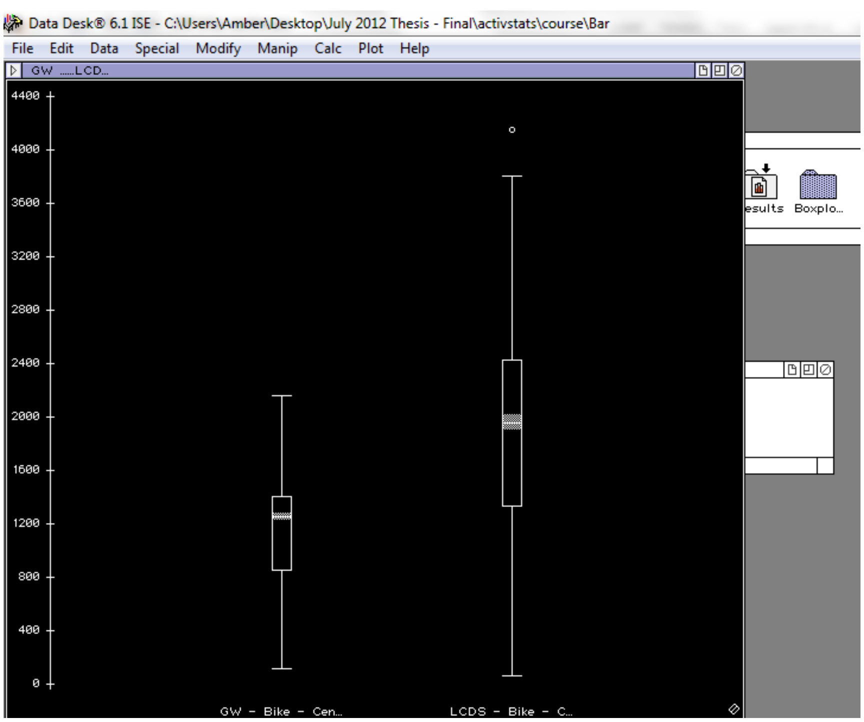


Fig. H.7: An example box plot

13) Went to Modify -> Scale -> Plot Scale to standardize the axes between the different box plots.

14) Went to Plot -> Plot Options -> Show Black on White to switch the colour scheme

15) Saved the file (File -> Save Data Files As)

16) Used "Print Screen" to copy and paste the box plot into Word.

Calculating the Alpha Index

1) Created a new feature class in ArcMap to store the graph using the "Create Feature Class" tool (Data Management -> Feature Class -> Create Feature Class) with the following options:

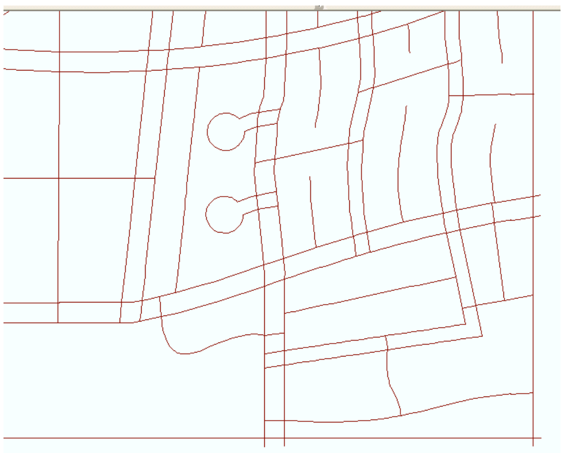
   Feature Class Location: (the location of the model's feature dataset)
   Feature Class Name: modelname_mode_graph
   Geometry Type: Polyline
   Template Feature Class: (left blank)
   Has M: Disabled
   Has Z: Disabled
   Geodatabase Settings: (left blank)

2) Started an editting session.

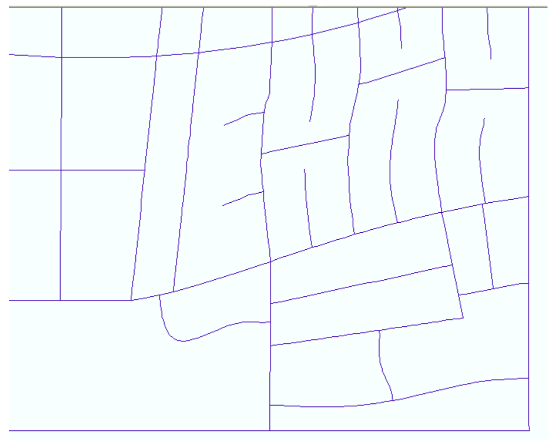
3) Created a graph for the model/mode combination by selecting the appropriate lines from the original modelname_networklines feature class and pasting them into modelname_mode_graph

   Depending on the mode and model, the graphs for calculating the index were made using single-line road, sidewalk and trail segments for links. For the pedestrian indices, the single line road network was used to represent sidewalks instead of the double line sidewalk network which was previously used to calculate coverage. Single-line representation was favoured over double-line representation for calculating the alpha index because it was felt that the thin grids created by sidewalks around roads when represented with a double line would produce an artificially high alpha index without providing any real meaningful increase in route options (see Fig. H.8 below).

Fig. H.8: Comparison of spatially accurate (double-line) vs. single line networks



The spatially accurate double line network reflects spatial separation between sidewalks on either side of road, but creates artificially "gridiness"



Double-line sidewalk lines were replaced with single centrelines for the purposes of calculating the alpha index

Greenway variation:

In the case of the pedestrian Greenway model, an extra frame of line segments had to be added around the periphery of the graph in order to "close" it (this problem explained in more detail on p. 164).

4) To ensure that lines would be broken into segments at intersections and only at intersections, selected all the graph lines and hit "Editor -> Merge". Then selected the lines again and hit "Planarize". Checked to make sure that the lines had been broken as intended.

5) Made a copy of the "modelname_intersections" feature class to serve as a starting point for counting the graph nodes, using the Copy Features tool (Data Management -> Features -> Copy Features) with the following settings:

Input features: modelname_intersections

Output features: modelname_mode_graphnodes

Configuration: (left blank)

Output spatial grid (1, 2 and 3): (all left blank)

6) Used definition queries and added points as needed (notably to the end of cul-de-sacs and dead end roads) until there was a point feature at every node location in the graph (i.e., at all line intersections and at any unconnected ends of the lines).

7) Counted the network nodes and links

For pedestrians:

Nodes: include all sidewalk/sidewalk, trail/trail and trail/sidewalk intersections as well as CDS heads and dead-ends (including those found in alleys).

Links: were assumed to include all sidewalk, trail and alley segments.

For cyclists:

Nodes: all road/road, trail/road and trail/trail intersections as well as CDS heads and dead-ends (including those found in alleys).

Links: were assumed to include all trail and road segments, including alleys.

Roads were considered to be bikeable regardless of whether or not they had bike lanes.

For motorists:

Nodes: were assumed to include all road/road (including alley/road) intersections as well as cul-de-sac (CDS) heads and dead-ends (including those found in alleys).

Links: were assumed to include all road segments, including alleys.

8) Used the following formula to calculate the alpha index:

(# of cycles) / [(# of nodes *2) – 5]

Where Number of Cycles = # of Links – # of Nodes + # of Subgraphs

APPENDIX I: ADDITIONAL MAPS

Four additional maps have been included for each model in this appendix:

- Active and motorized transportation networks
- Locations of roads by type
- Locations of intersections by type
- Locations of fake line segments

Fig. I.1: Grid model - active and motorized transportation networks (public portions only)

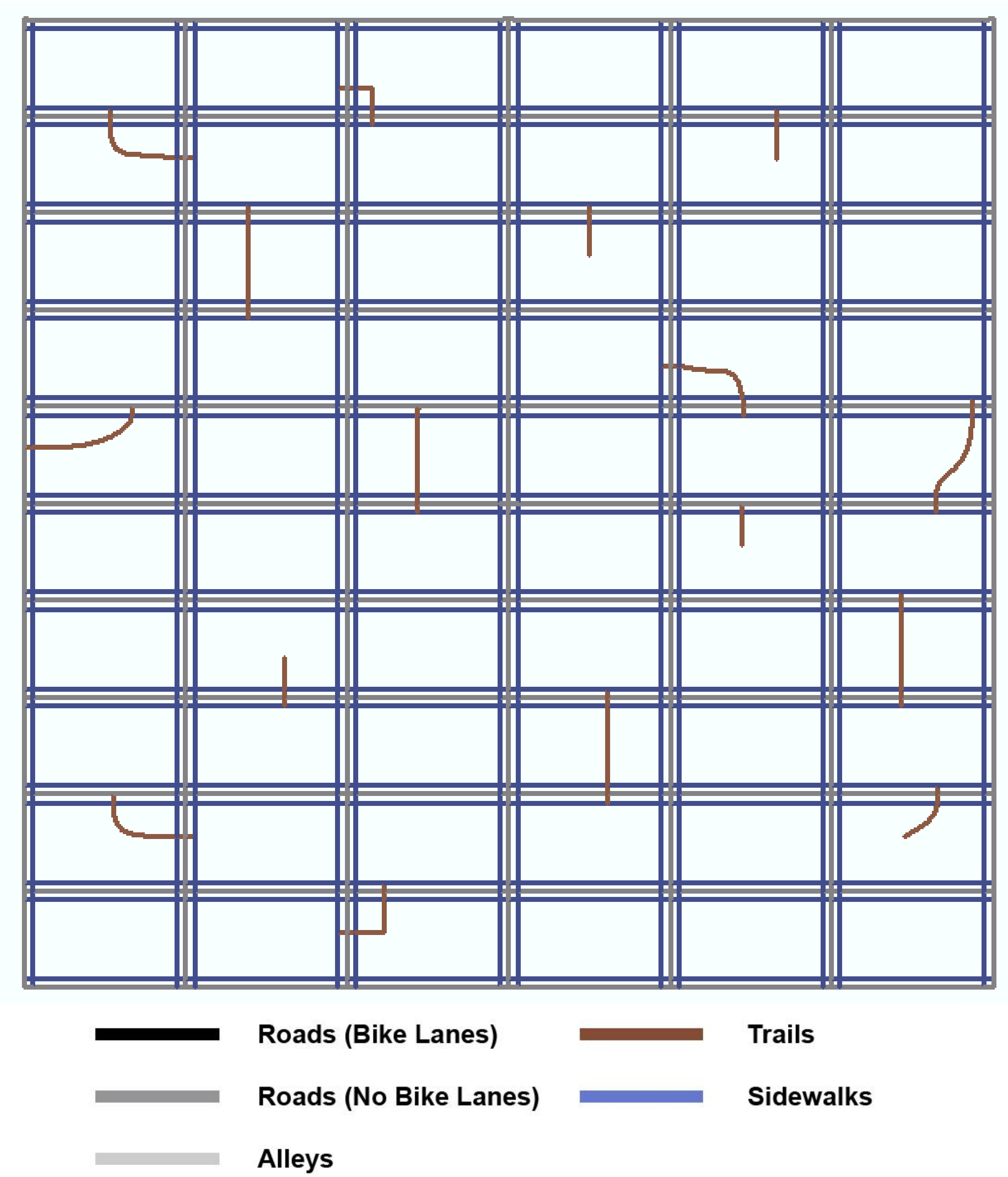


Fig. I.2: Grid model - roads by type

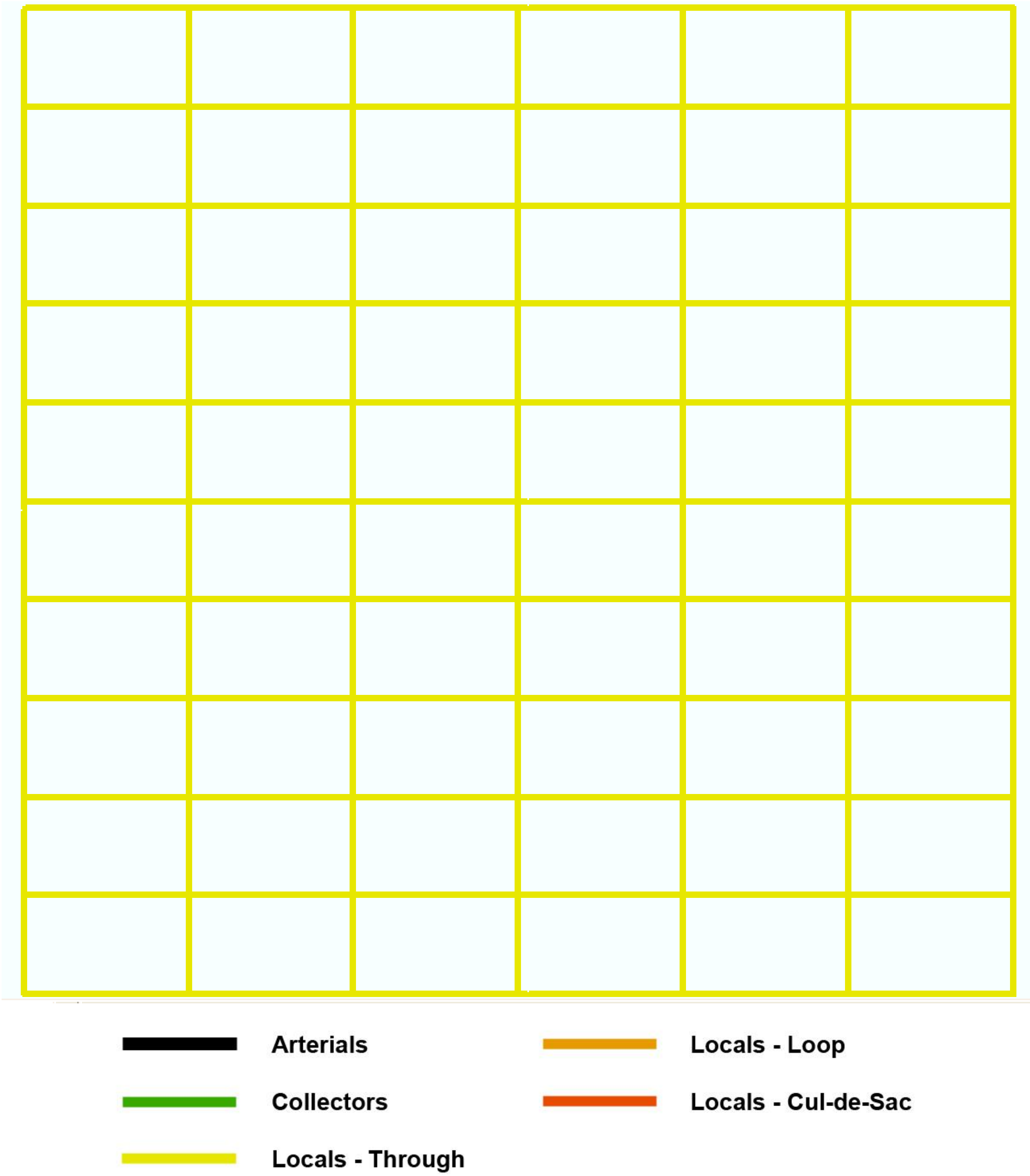


Fig. I.3: Grid model - intersections by type

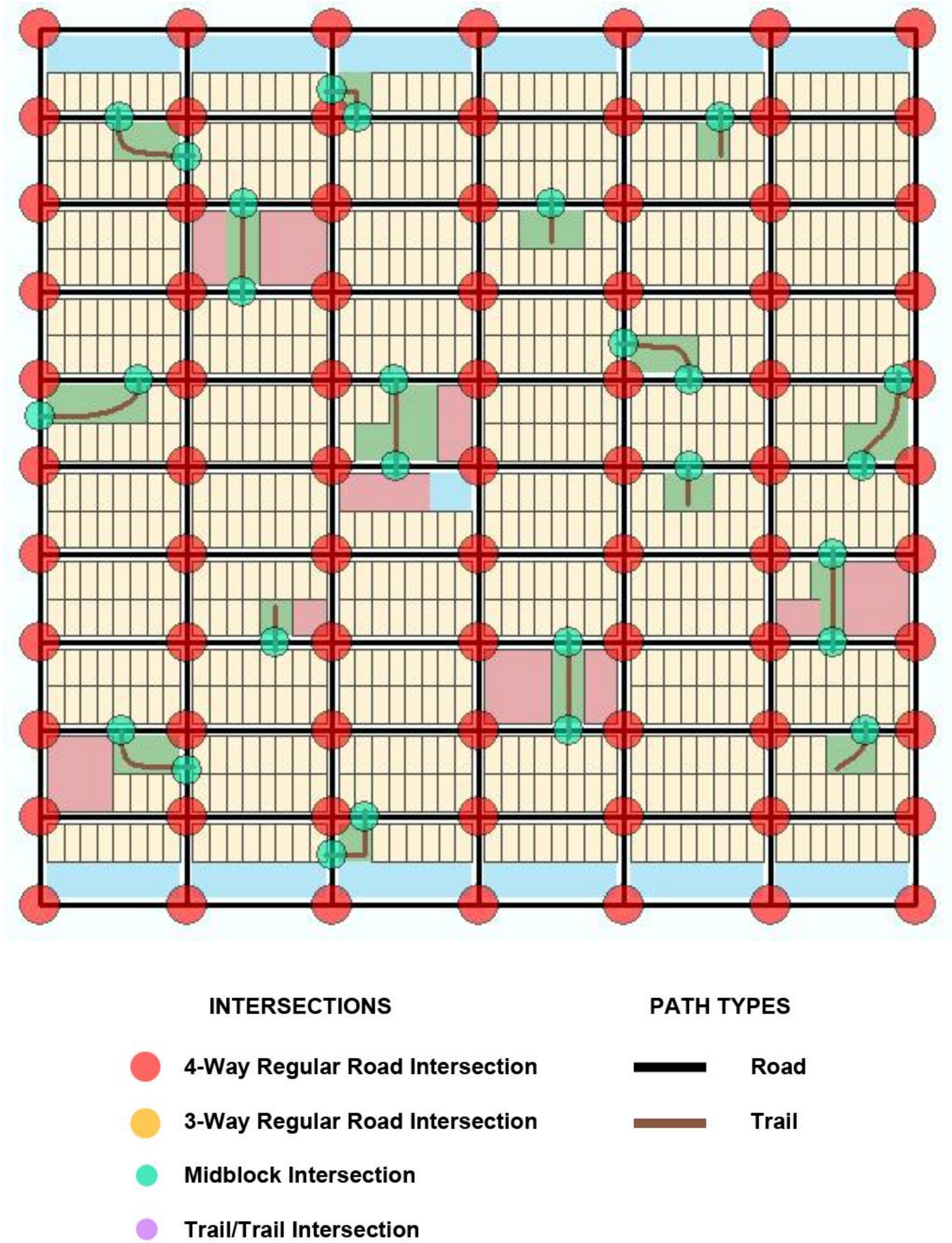
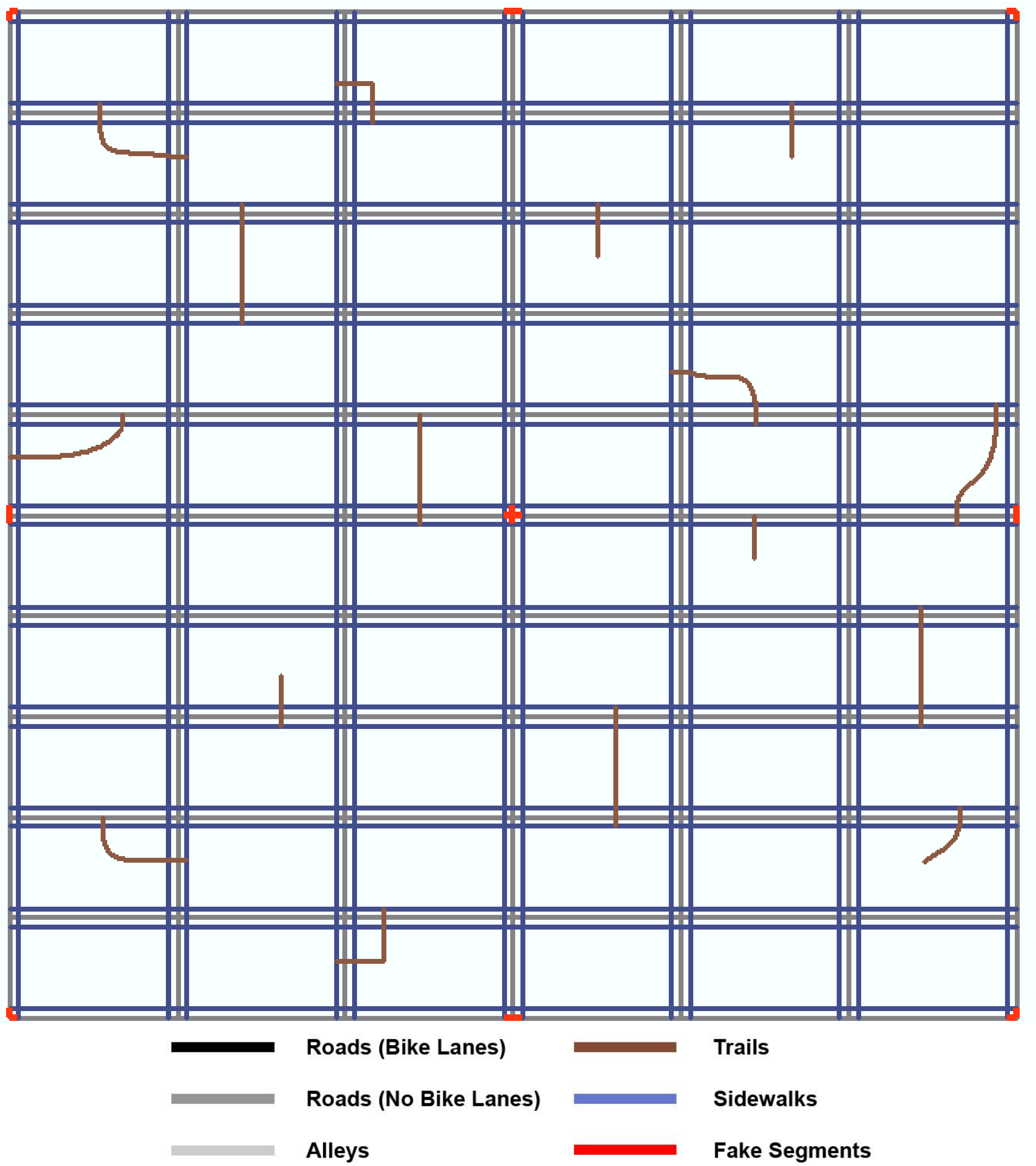


Fig. I.4: Grid model - locations of fake line segments



<u>LENGTH OF FAKE SEGMENTS IN THIS MODEL:</u>

Mode	Type and Length of Fake Segments
Car	N/A
Pedestrian	Sidewalk along local roads: 485.6’
Bike	N/A

Fig. I.5: Loop and Cul-de-Sac model - active and motorized transportation networks (public portions only)

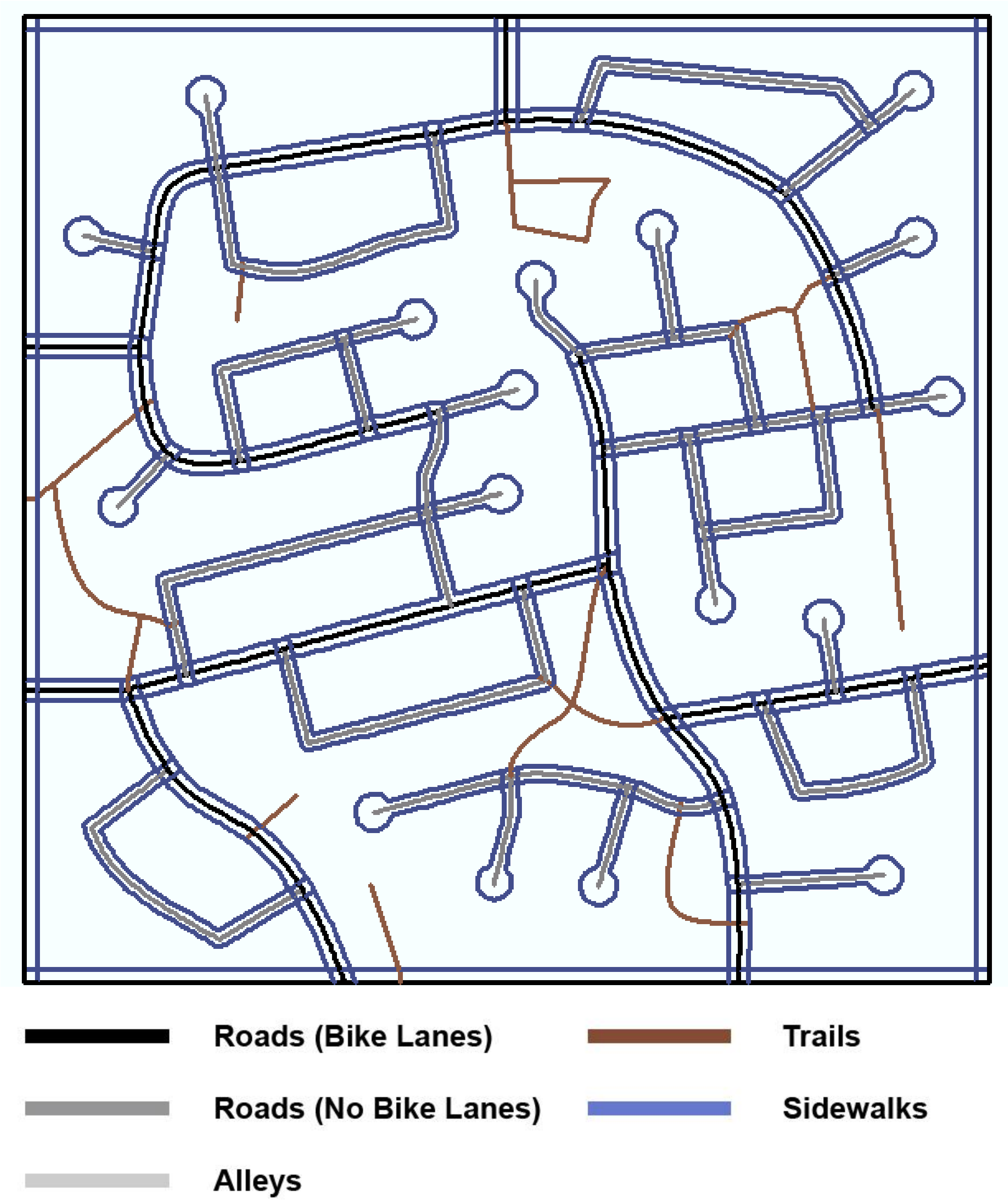


Fig. I.6: Loop and Cul-de-Sac model - roads by type

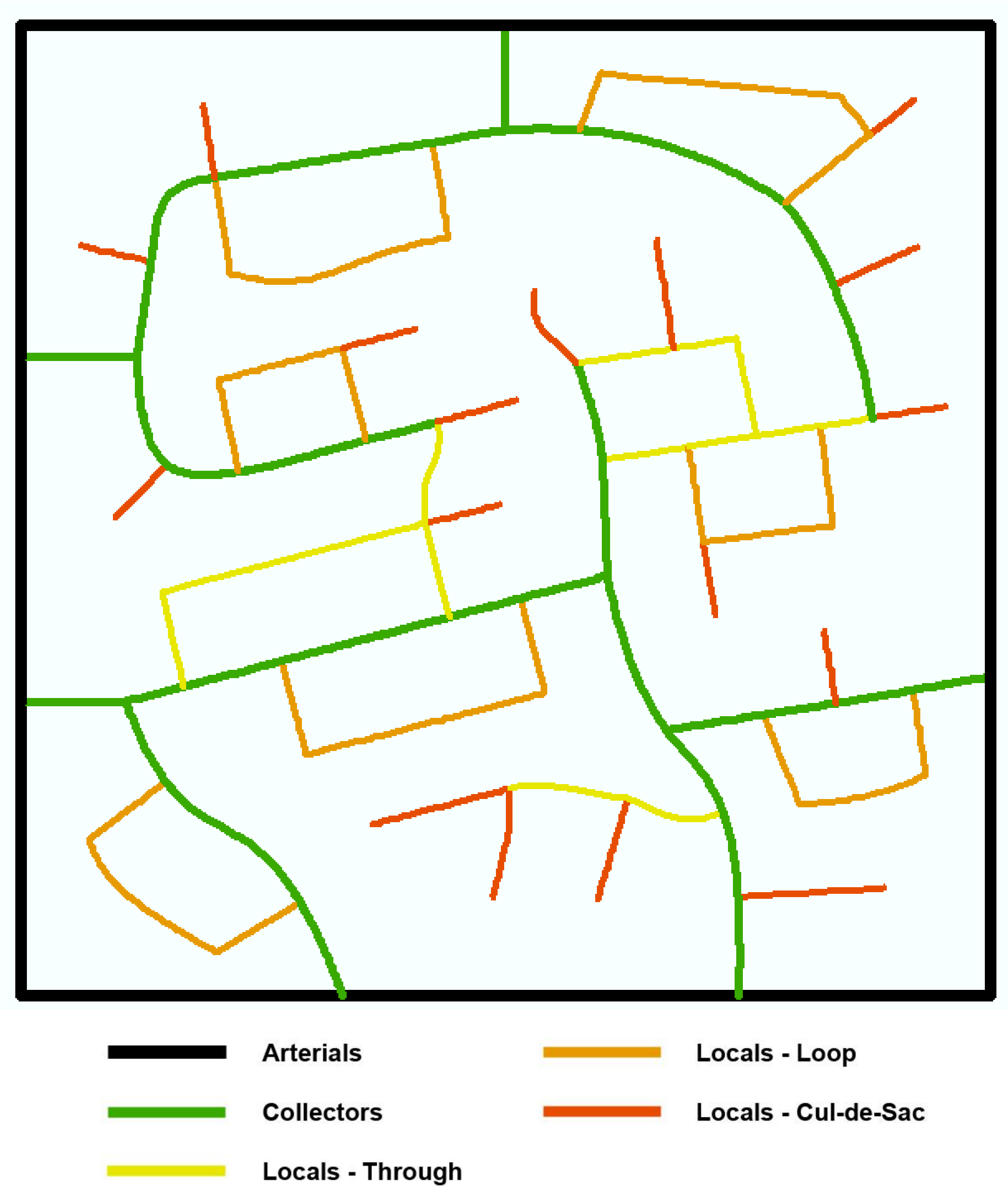


Fig. I.7: Loop and Cul-de-Sac model - intersections by type

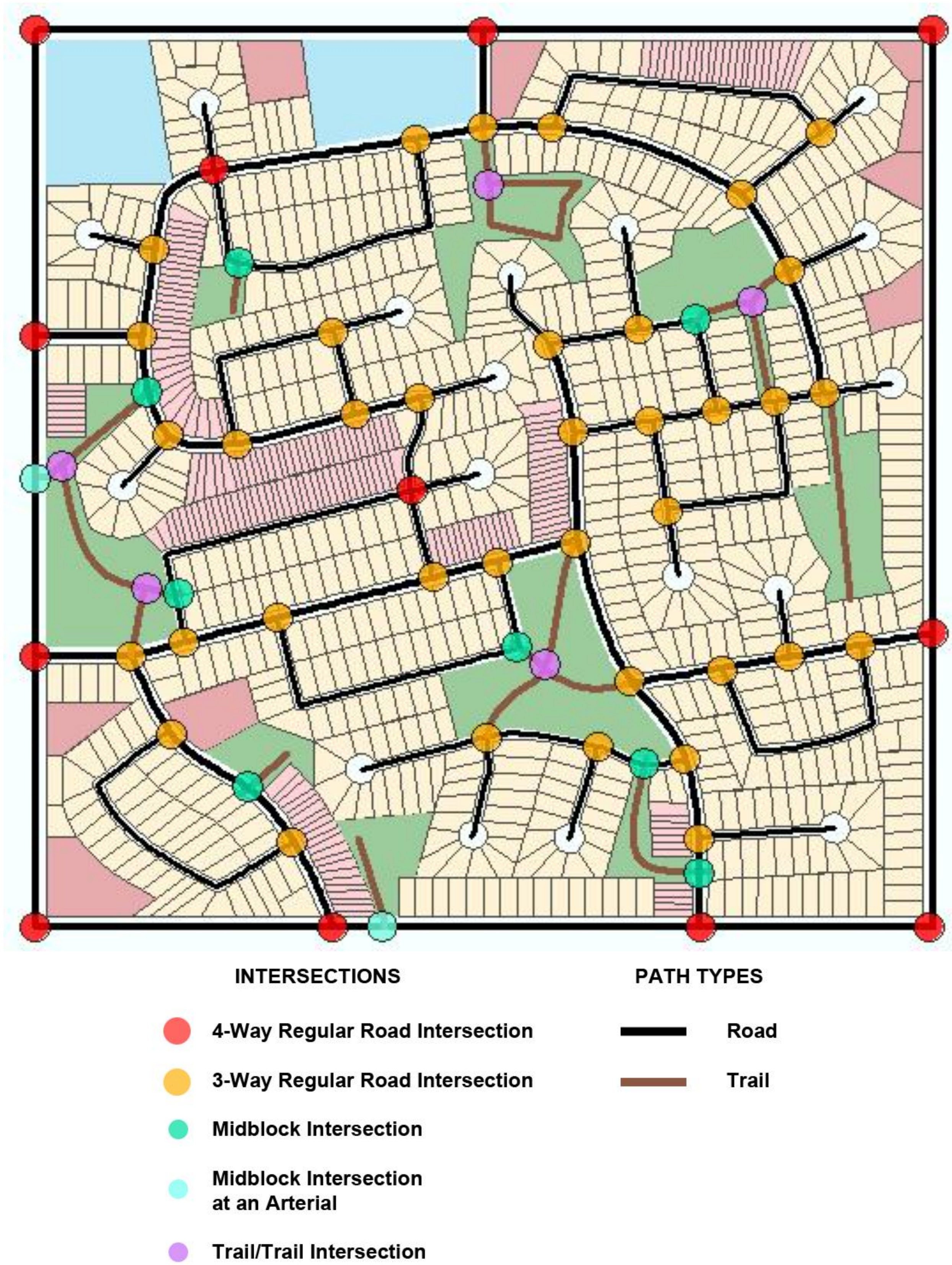
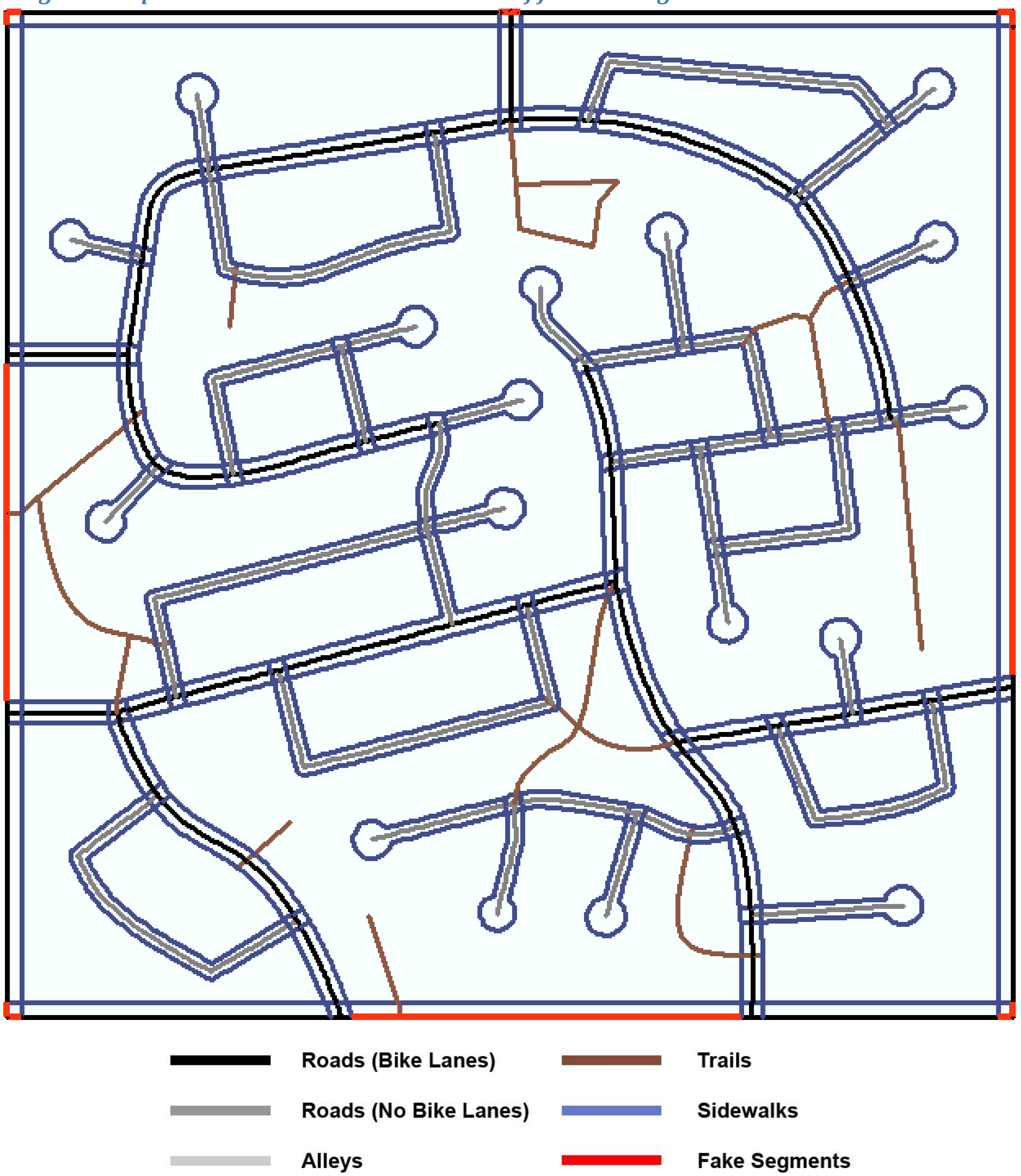


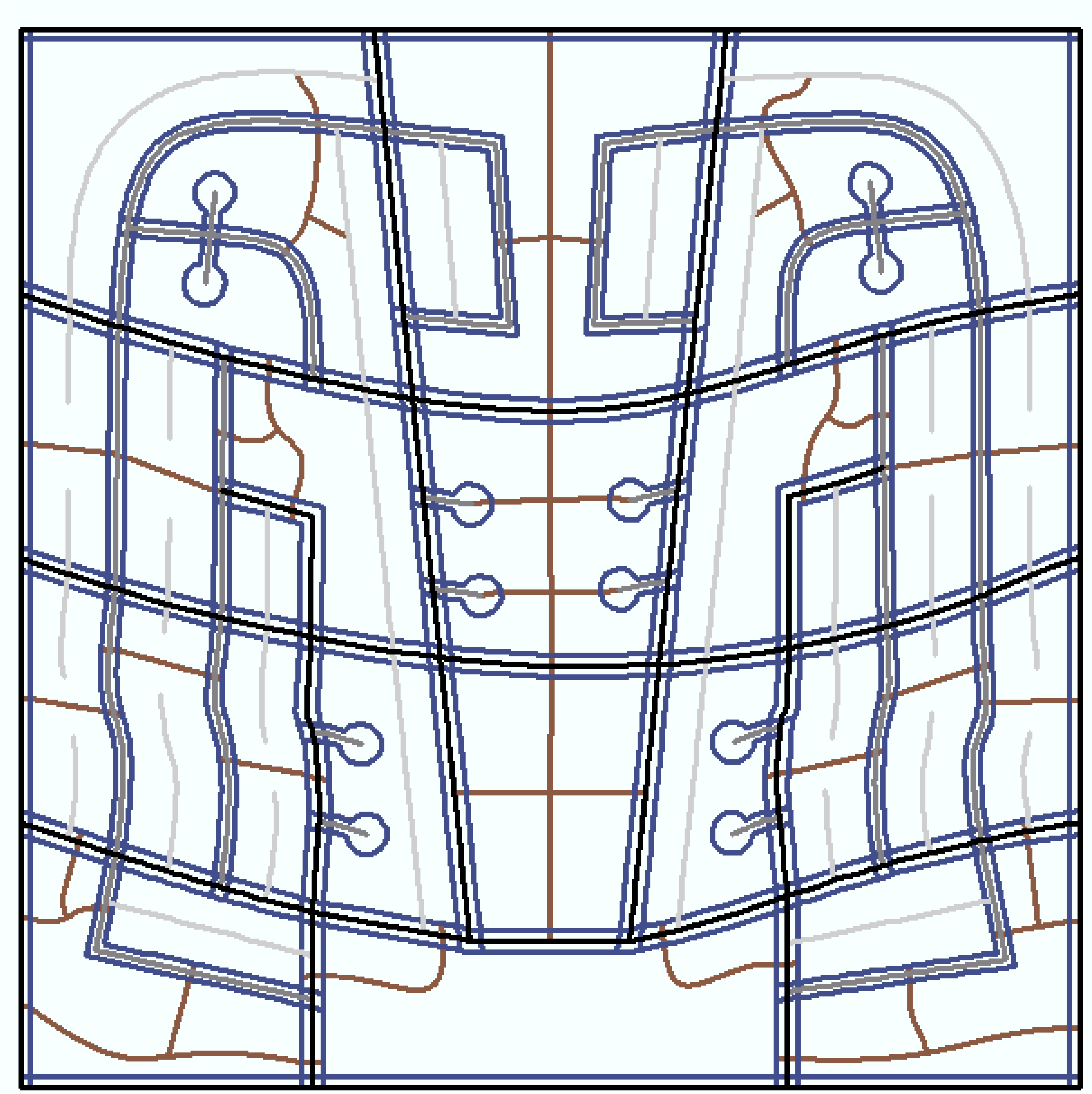
Fig. I.8: Loop and Cul-de-Sac model - locations of fake line segments



LENGTH OF FAKE SEGMENTS IN THIS MODEL:

Mode	Type and Length of Fake Segments
Car	N/A
Pedestrian	Sidewalk along arterial: 3,960.8’
Bike	N/A

Fig. I.9: New Urbanist model - active and motorized transportation networks (public portions only)



Roads (Bike Lanes)

Trails

Roads (No Bike Lanes)

Sidewalks

Alleys

Fig. I.10: New Urbanist model - roads by type

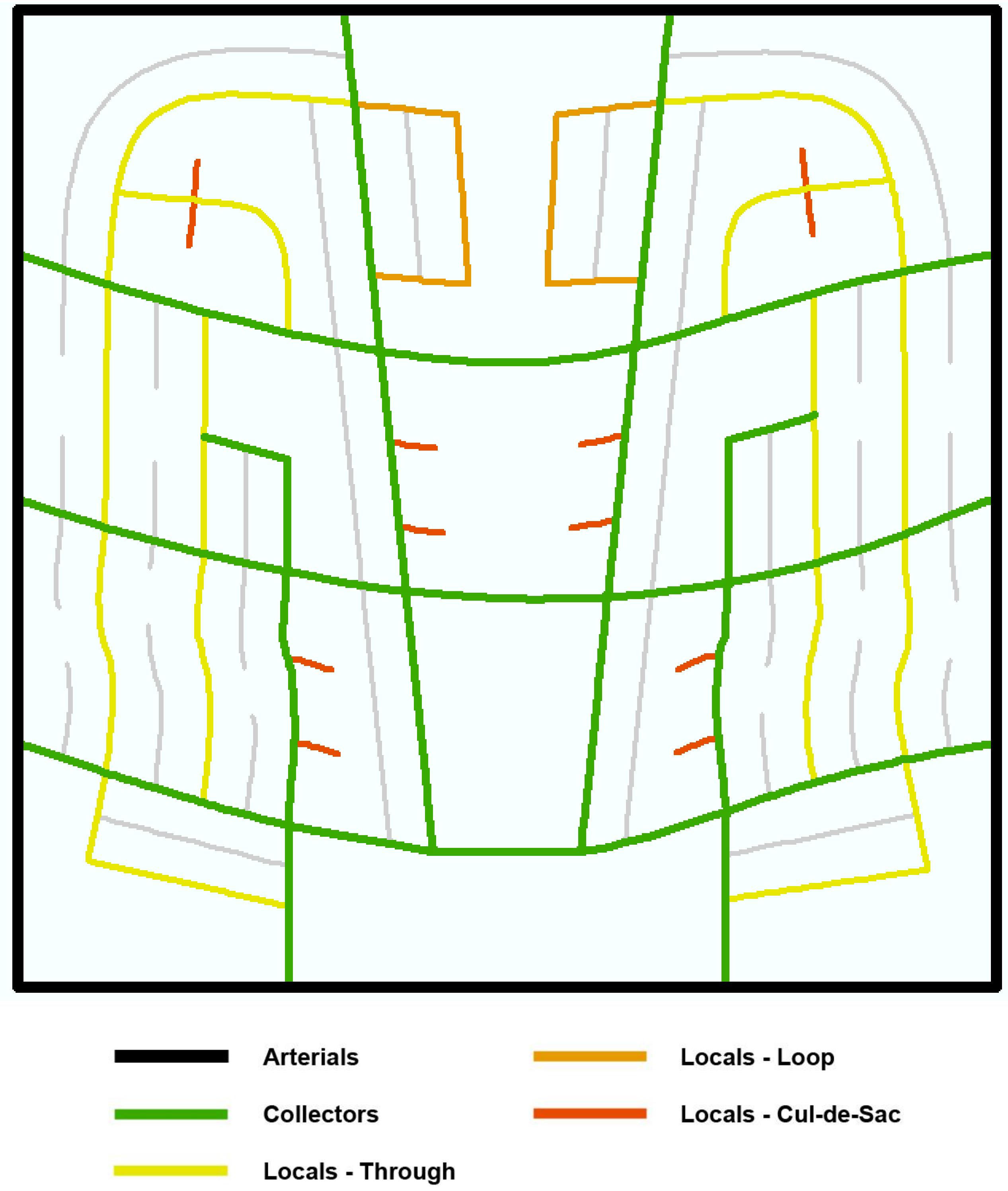


Fig. I.11: New Urbanist model - intersections by type

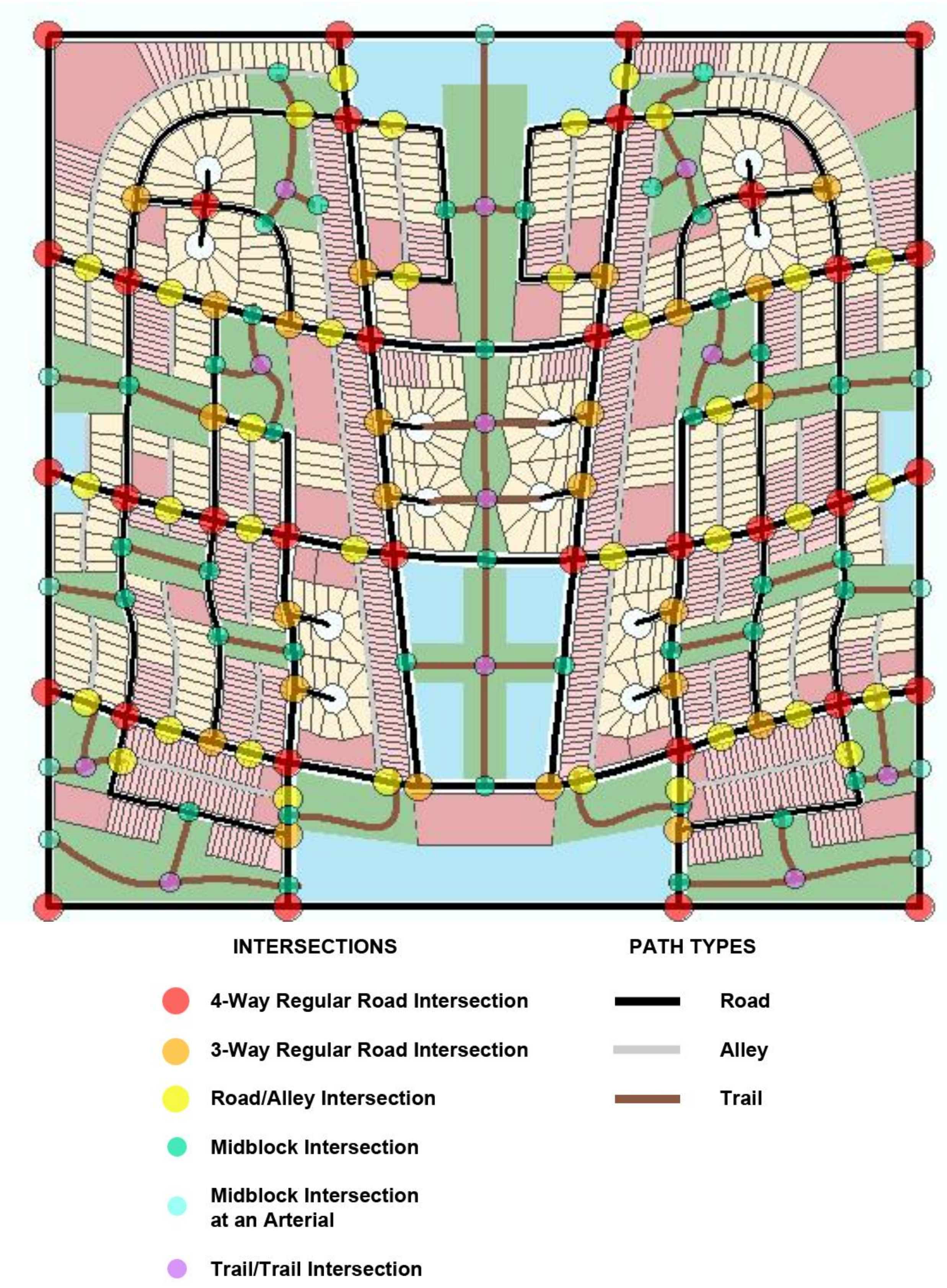
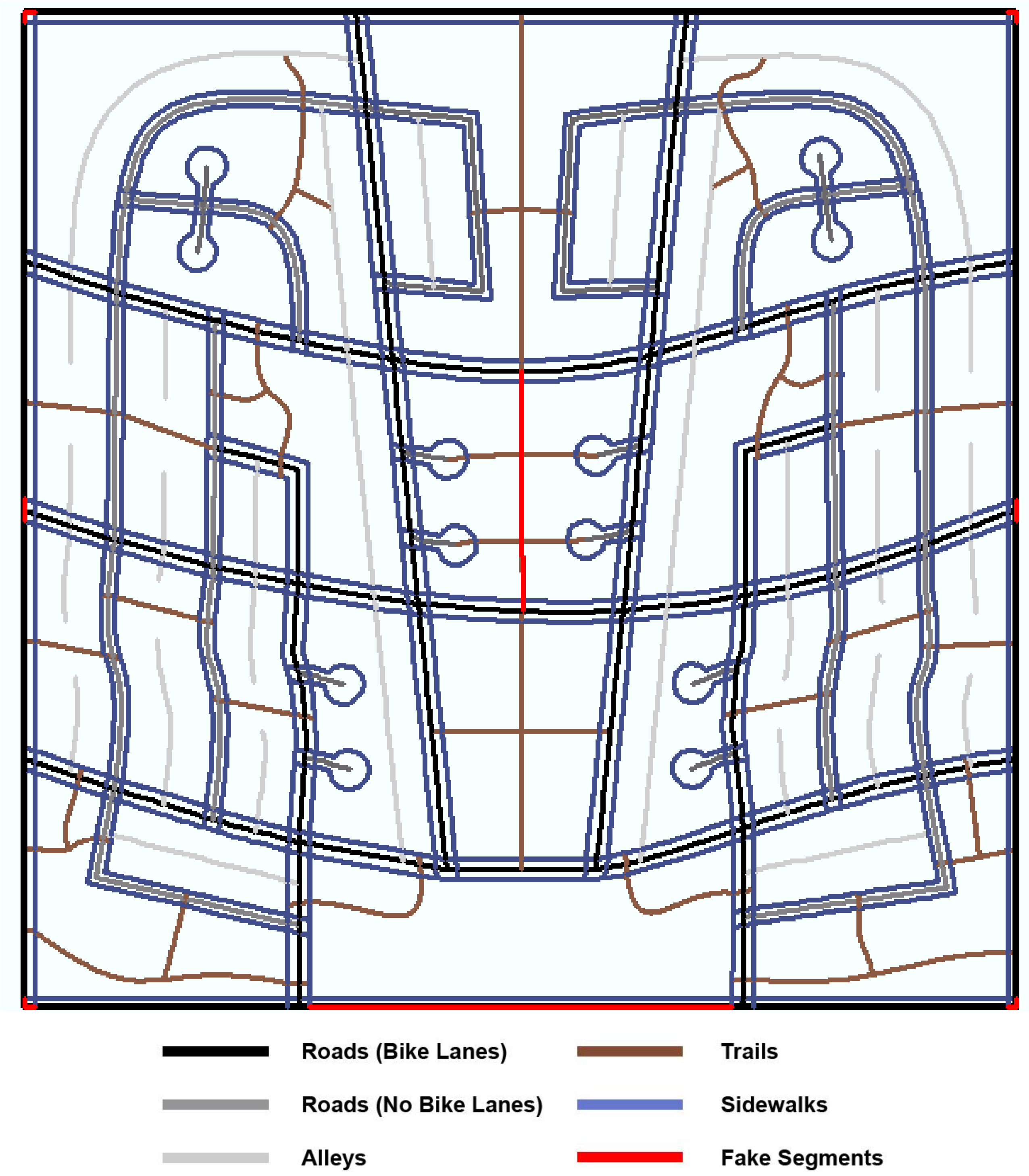


Fig. I.12: New Urbanist model - locations of fake line segments



LENGTH OF FAKE SEGMENTS IN THIS MODEL:

Mode	Type of Fake Segment and Length
Car	Collector: 44.9' ; Through: 592.7'
Pedestrian	Sidewalk along arterial: 1,431.8'
Bike	N/A

Fig. I.13: Fused Grid model - active and motorized transportation networks (public portions only)

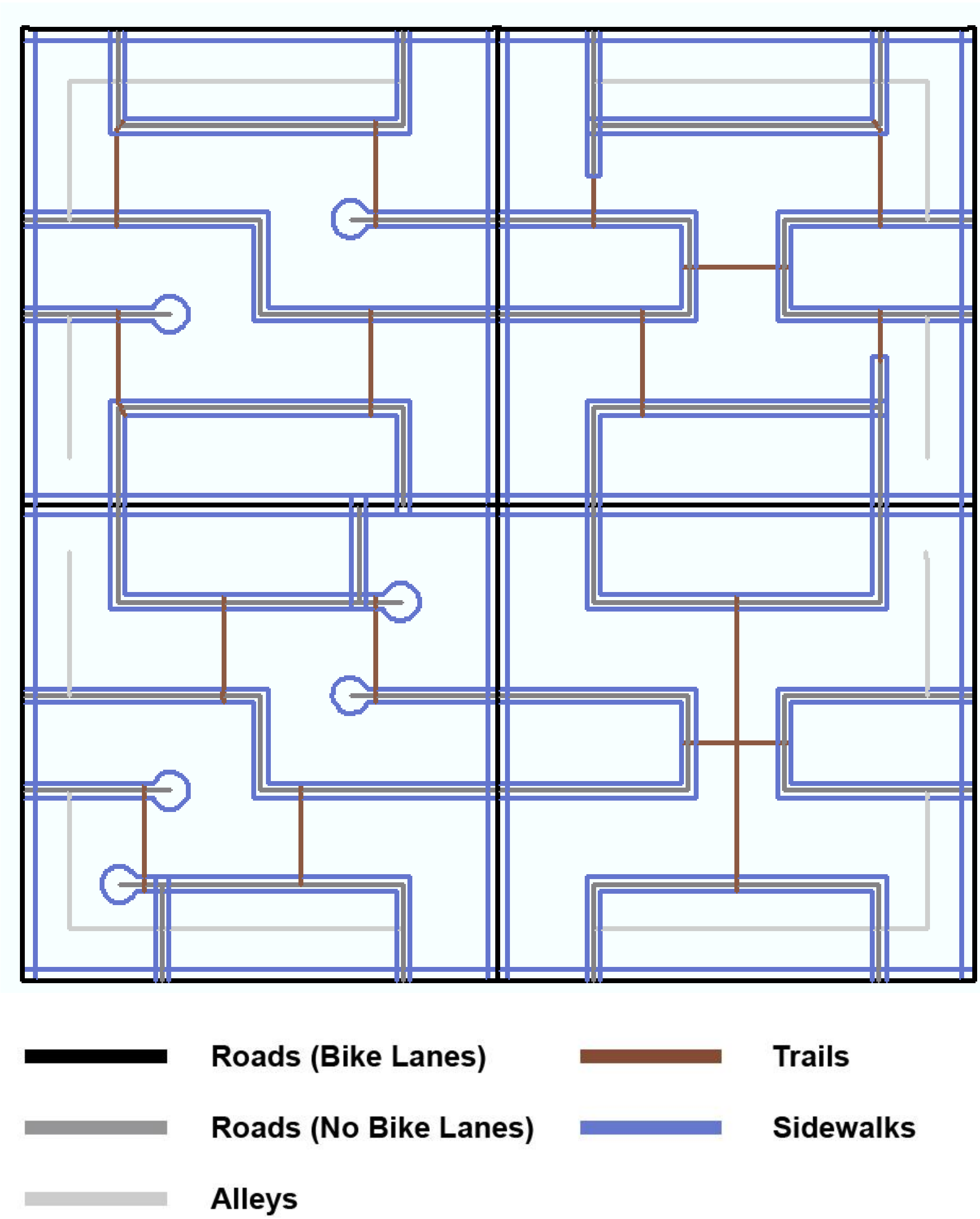


Fig. I.14: Fused Grid model - roads by type

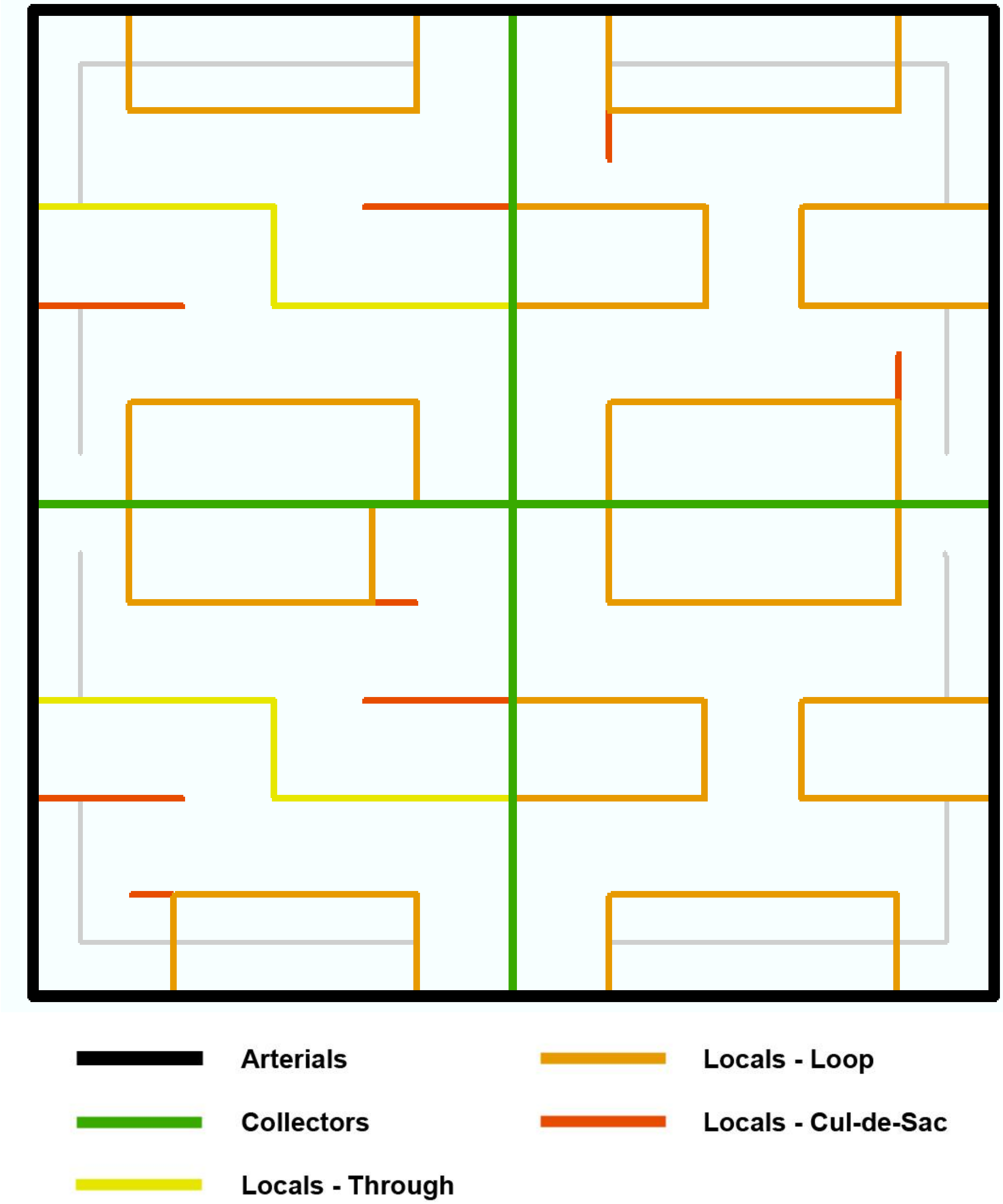


Fig. I.15: Fused Grid model - intersections by type

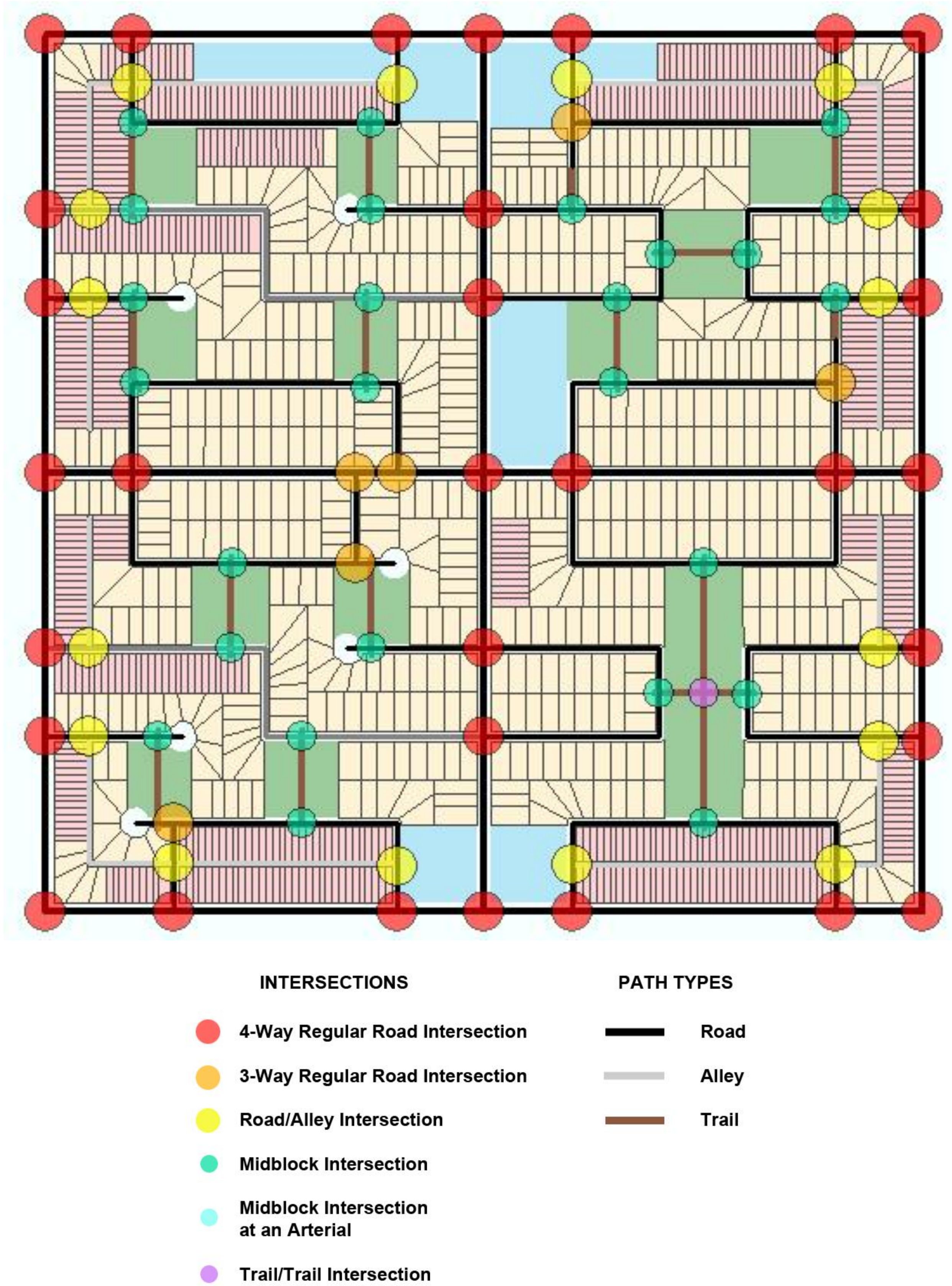
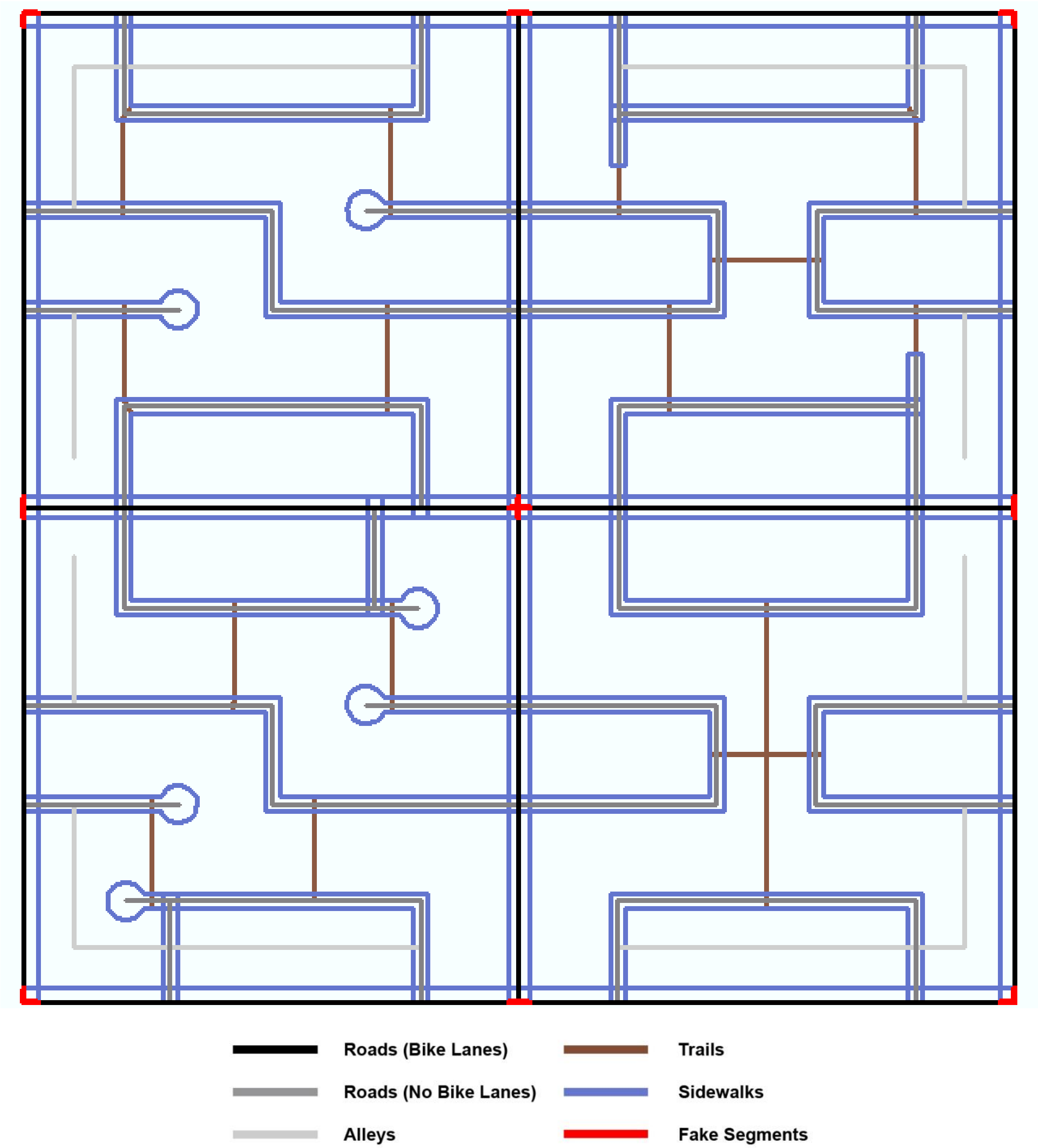


Fig. I.16: Fused Grid model - locations of fake line segments



LENGTH OF FAKE SEGMENTS IN THIS MODEL:

Mode	Type of Fake Segment & Length
Car	N/A
Pedestrian	Sidewalk along arterial: 507.6’ Sidewalk along collector: 109.8’
Bike	N/A

Fig. I.17: Greenway model - active and motorized transportation networks (public portions only)

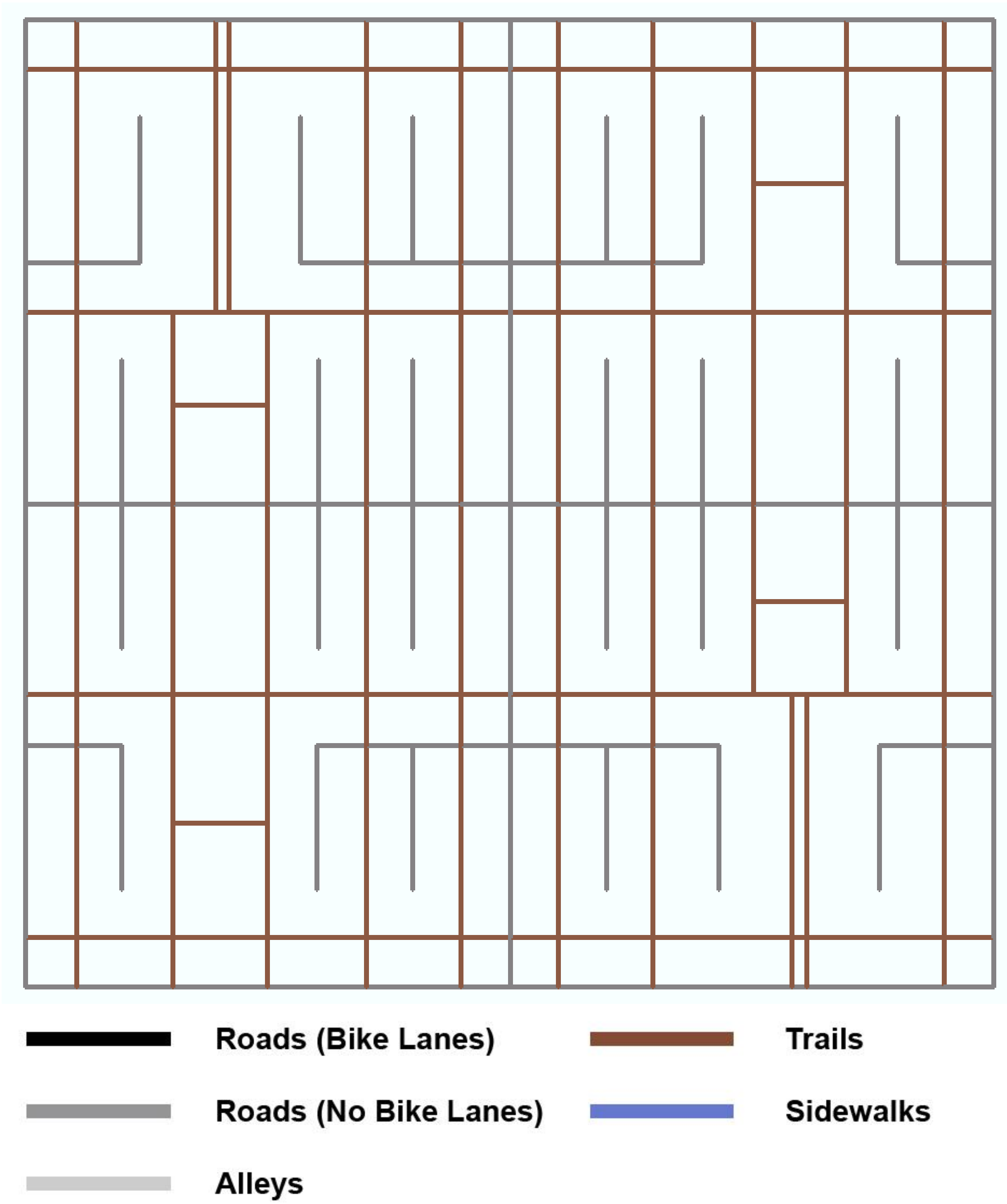


Fig. I.18: Greenway model - roads by type

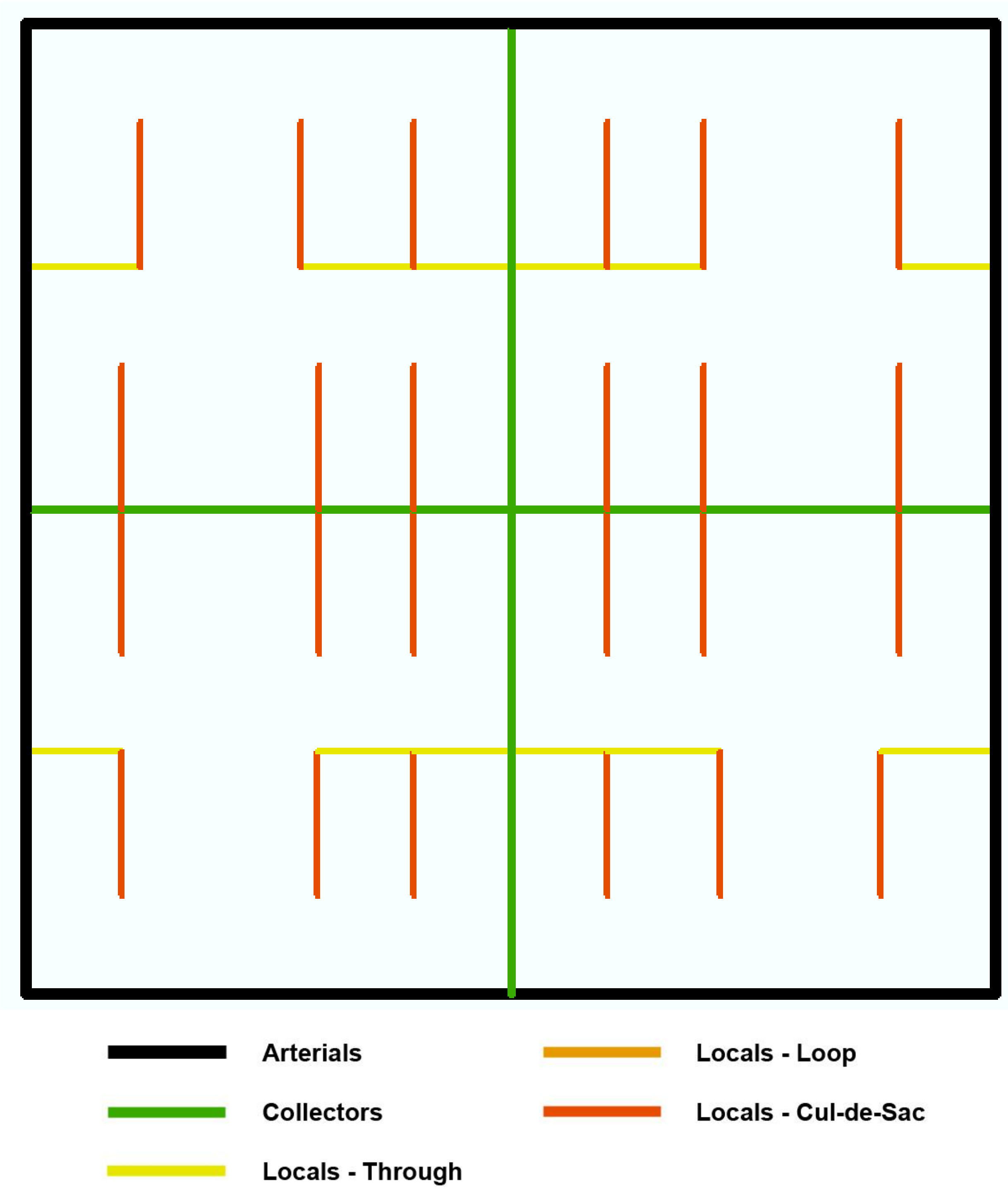


Fig. I.19: Greenway model - intersections by type

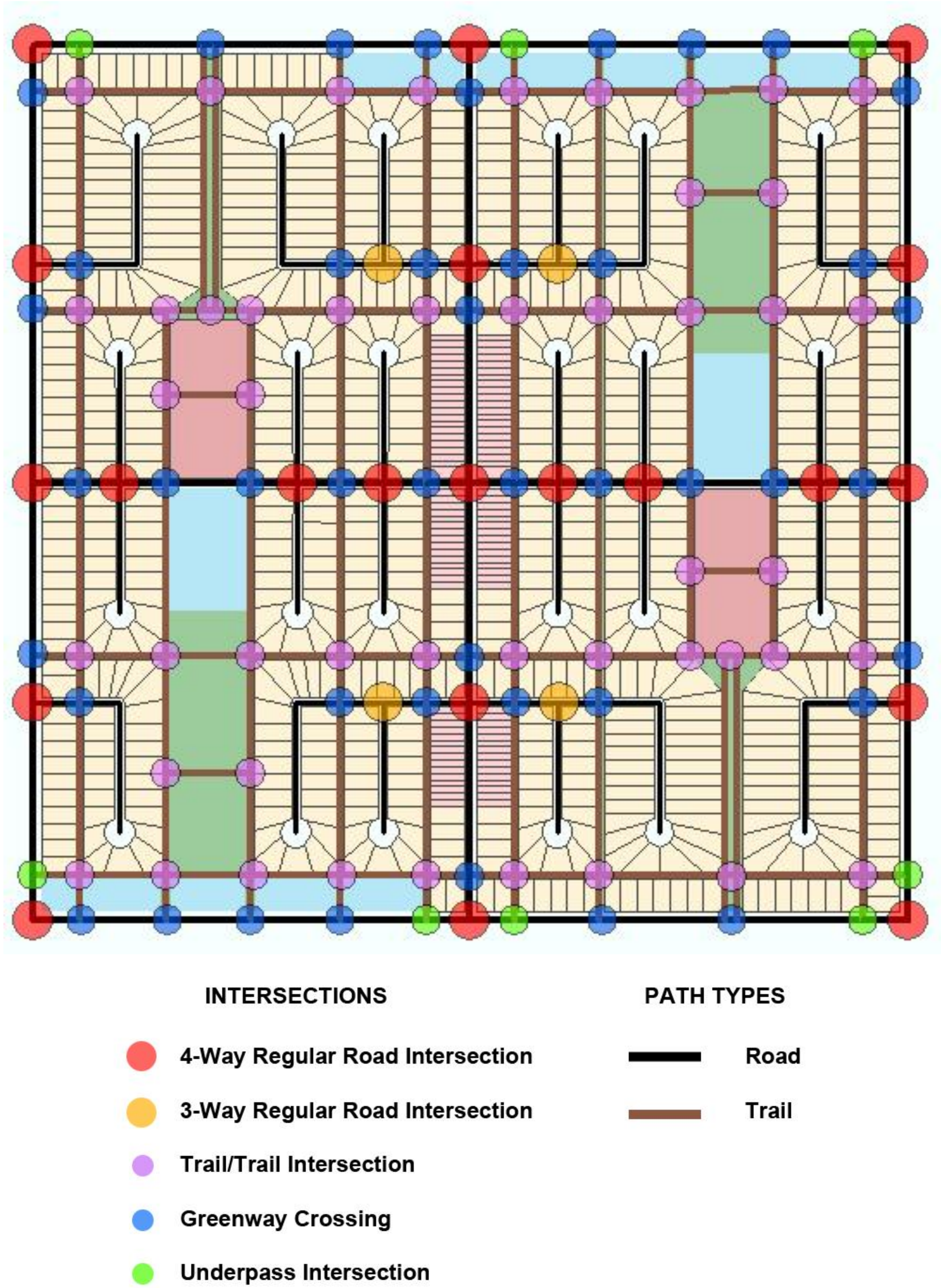
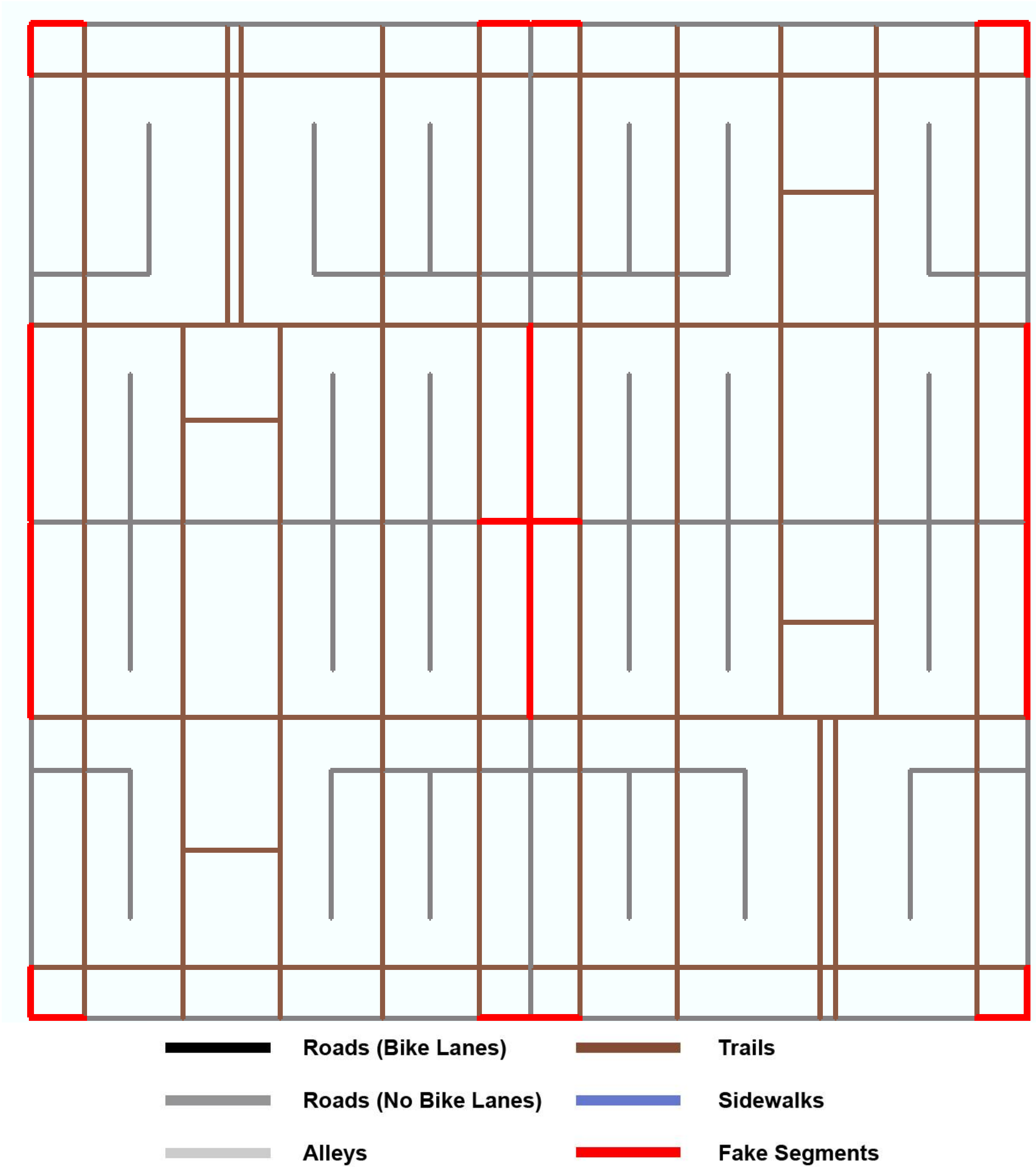


Fig. I.20: Greenway model - locations of fake line segments



LENGTH OF FAKE SEGMENTS IN THIS MODEL:

Mode	Type of Fake Segment and Length
Car	N/A
Pedestrian	Trail along arterial: 3,704.8’ Trail along collector: 1,306.0’
Bike	N/A

APPENDIX J: RESULTS FOR MOTORISTS

Results for the motorized transportation network and driving trips were calculated for almost all variables calculated for the active counterparts in the main body of this document, and are presented below for the purposes of allowing comparison between them. Although one would intuitively expect that what supports walking and biking is likely a deterrant to driving (and vice versa), an overall evaluation of "network potential" for motorists was not made, as more research would be needed to determine if the existing literature would support such a claim before a modified formula built along these lines could be justifiably applied.

Network Coverage

Unlike the active modes, which combined multiple path types (e.g. bike lanes and trails) into their transportation networks, the network for motorists was comprised solely of roads. As Table J.1 below shows, the New Urbanist model provided the greatest network coverage to motorists (16% more than the next closest runner up, the Grid), largely because of the inclusion of alleys in its network. The Greenway model, which provided the least coverage to motorists, had 52% less than the New Urbanist model – quite a substantial difference.

Table J.1: Network coverage by mode

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Dedicated motorist path coverage in feet[1]	47,520.0	35,396.4	43,630.4	55,217.2	28,615.4
Density (feet per acre)	*297.0*	*221.2*	*272.7*	*345.1*	*178.8*

[1]: Includes alleys

Connectivity - Alpha Index

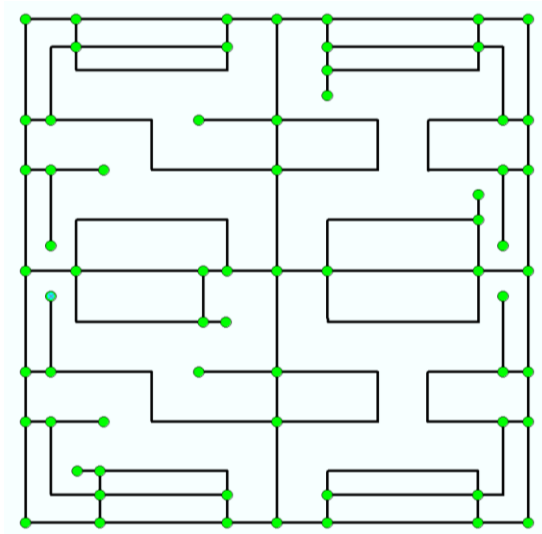
The alpha index values for the road network varied widely between models (Table J.2). The model with the highest value, the Grid, had a value (0.40) ten times that of the Greenway model which had the lowest (0.04). This shows that, for cars, the Grid offers much more route choice in getting between destinations than the systematically disconnected Greenway model.

Table J.2: Alpha index for the motorist network

Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
0.40	0.13	0.24	0.19	0.04

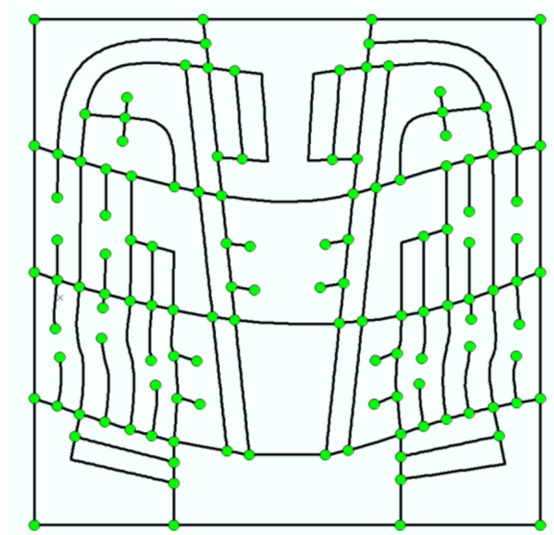
Looking at the other three models, the Fused Grid had the second best alpha index (0.24), followed by the New Urbanist model (0.19) and the Loop and Cul-de-Sac (0.13). That the Fused Grid had a better alpha index than the griddy New Urbanist model was a surprising result. Looking more closely at their graphs (Fig. J.1 below), it can be seen that the Fused Grid would have fared better because of its lack of unconnected nodes, which become weighted heavily in the bottom portion of the alpha index's formula (# of cycles / [(numbers of nodes*2)-5]). Many of the unconnected nodes in this study's New Urbanist model were the result of alleys which ended at parks: it is likely that a different arrangement of parks and alleys could have produced a higher alpha index for the model while still being consistent with New Urbanist design principles.

Fig. J.1: Comparison of the Fused Grid and New Urbanist road network graphs



Fused Grid – Road Network Graph

Links (black): 95
Nodes (green): 66
Cycles: 30
Alpha index: 0.24



New Urbanist – Road Network Graph

Links (black): 173
Nodes (green): 126
Cycles: 48
Alpha index: 0.19

Connectivity – Intersection Density

The only type of intersection that applied to motorists were the “regular road” intersections. Whether or not alley/road intersections were counted as “road” intersections of a modified version of a driveway/road crossing had a large effect on the results, as demonstrated in Table J.3 below.

Table J.3: Intersection densities

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Road intersection count (total intersection density for motorists, including alley-road intersections, but not including cul-de-sac heads)	77	49	54 (38 without alleys)	94 (58 without alleys)	25
Road intersection density per acre (total intersection density for cars)	0.48	0.31	0.34 (0.24 without alleys)	0.59 (0.36 without alleys)	0.16

When including alley/road intersections, the New Urbanist model had the highest road intersection density for motorists (0.59 intersections/acre), despite having fared worse than the Grid model on its alpha index (another connectivity measure). This is due to the large number of alleys in the New Urbanist model, which increased intersection density *without* necessarily adding more cycles (as many ended in dead-ends).

Connectivity – Metric Reach

For motorists, the New Urbanist model provided the greatest metric reach (even higher than the Grid, as a result of its inclusion of alleyways), while the Greenway model was the worst (Table J.4 below). This means that, on average, motorists in the New Urbanist model had a greater length of network segments within a given travel distance (0.25 miles) available to them than the other models, and more than twice that of the Greenway, Loop and Cul-de-Sac and the Fused Grid.

Table J.4: Average metric reach results

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Motorist (average, in miles)	2.78 (st. dev: 0.71)	1.30 (st. dev: 0.39)	1.44 (st. dev: 0.38)	2.93 (st. dev: 0.65)	1.19 (st. dev: 0.49)

Note: Values calculated using a distance threshold of 0.25 miles (1320')

Continuity – Point of Conflict Density

For motorists, POCs were grouped into two relevant categories – Road/Road POCs (for road intersections, where drivers may expect to come into contact with other motorized traffic or cyclists travelling on the road network), and ATN/Road POCs (where roads are crossed by sidewalks or trails, where drivers need to be on the look out from pedestrians and cyclists crossing their path). The Greenway model provided the best continuity for both types (0.2 POCs per acre for Road/Road and 0.3 for ATN/Road), while the New Urbanist was the worst for road/road (0.6 POCs/acre) and the Grid the worst for ATN/Road (1.9 POCs/acre) (Table J.5 below). For drivers, this means that compared to the Greenway model, there are three times as many potential points of conflict with other cars in the New Urbanist model, and six times as many potential points of conflict with active modes in the Grid.

Table J.5: Motorized transportation network: Road/Road and Road/ATN POC density

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Continuity – POC density for Road/Road (created at the centre of regular road intersections[1])	0.5	0.3	0.3	0.6	0.2
Continuity – POC density for ATN/Road (sum of road/sidewalk and road/trail POCs)	1.9	1.0	1.1	1.8	0.3

[1]: Includes POCs created where alleys meet roads.

Network-Based Modal Separation for Motorists

For cars, separation was assessed in terms of separation from cyclists travelling along roadways. (A more complex assessment would also include an assessment of loss of separation from pedestrians where they crossed roads at intersections, but due to time constraints this was not undertaken for this study).

The Greenway model presented a bit of a challenge in this assessment: the model has no bike lanes, however, the trail network could be assumed to be a replacement for bike lanes. (In which case, the model goes from having 100% of roads potentially being shared with cyclists to 0%). On the other hand, since this study assumed that cyclists could still travel on roads if they wished and produced higher values for connectivity and legibility as a result, it seems fair to treat these roads as having bike traffic. However, suggesting that the Greenway model has the same level of modal separation as the Grid is obviously incorrect. The Greenway is the only model to give cyclists a choice between two complete networks: in practice, there would almost certainly be *less* bike traffic on roads where a corresponding trail exists, but that is not something that can be assessed within a hypothetical study of this nature. It is clear from this early attempt at assessing modal separation that more work needs to be done to develop better modal separation measures where dual networks exist. One solution may be to treat Greenway trails as the equivalents of extremely well-separated bike lanes and treat them as part of a road in the same was a bike lane would be. However, this would require decisions concerning which road a greenway trail is assigned to, and also create problems where the road network pattern does not identically match that of the trail network. (For instance, in a Loop and Cul-de-Sac neighbourhood, a sidewalk will always perfectly match the shape of a cul-de-sac, but in a Greenway, where cul-de-sacs are present the central trails extend past them in a grid pattern, while in parks trails can take a variety of forms).

Consequently, depending on one's perspective, the level of modal separation the Greenway model's network offers motorists from cyclists is either 0% (because they can bike on roads) or 100% (because there is never any need for cyclists to bike on roads). If one does not count the Greenway model, the Loop and Cul-de-Sac model had the least amount of its network (including both roads and alleys) requiring driving in mixed traffic with active modes (42.3%, Table J.6 below); this is one of the few variables where the Loop and Cul-de-Sac model fairs better than the alternatives. Ironically, this is at least in part because of the inclusion of alleys in the Fused Grid and New Urbanist models, which increase the proportion of network where traffic is potentially. As expected, the Grid (and arguably Greenway) fared the worst, both with 100% of roads potentially requiring motorists to travel with bicyclists in traffic lanes.

Table J.6: On-road network-based modal separation between cyclists and motorists

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Total road network coverage (in feet) (including roads and alleys but not driveways)	47,520.0	35,396.4	43,630.4	55,217.2	28,615.4
Partial separation from bikes on roads (in feet) (bike lanes)	0.0 (0.0%)	20,440.3 (57.7%)	15,840.0 (36.3%)	27,341.7 (49.5%)	0.0 (0.0%)
No separation from bikes on roads (in feet) (mixed traffic on roads not including alleys, trail crossings over road)	47,520.0 (100%)	14,956.1 (42.3%)	20,984.0 (48.1%)	13,895.2 (25.2%)	28,615.4 (100%) **or** 0.0% if cyclists are assumed to stick to trails
No separation from cyclists or pedestrians in alleys (in feet)	0.0 (0.0%)	0.0 (0.0%)	6806.4 (15.6%)	13,980.3 (25.3%)	0.0 (0.0%)
Total "no separation" (in feet)	*47,520.0 (100.0%)*	*14,956.1 (42.3%)*	*27,790.4 (63.7%)*	*27,875.5 (50.5%)*	*28,615.4 (100%)*

Network Legibility – Directional Distance

The Grid had the most legible network for motorists by far, with an average of 6.68 miles of road (including alleys) reachable without having to make more than two greater-than-10-degree turns from the road midpoints (Table J.7 below). The Loop and Cul-de-Sac was the worst (with less than half the available reach of the next worse model, the Fused Grid), with an average of only 0.71 miles of road within two turns.

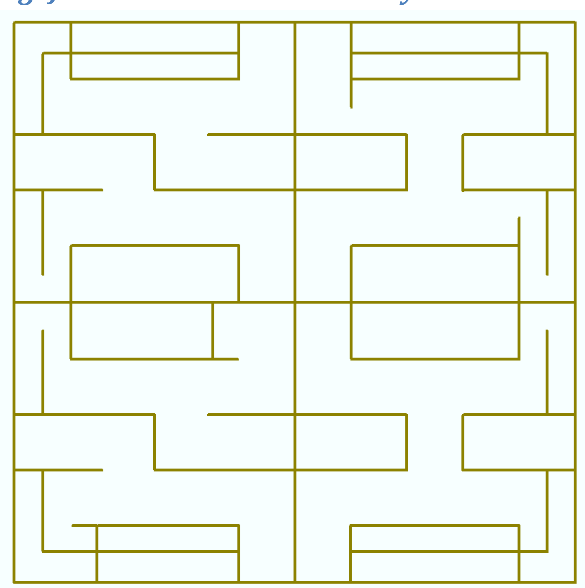
Table J.7: Directional distance for motorists – length of pathways within two direction changes

Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
6.68 (st. dev: 1.22)	0.71 (st. dev: 0.57)	1.88 (st. dev.: 1.46)	2.45 (st. dev: 1.84)	2.24 (st. dev: 1.34)

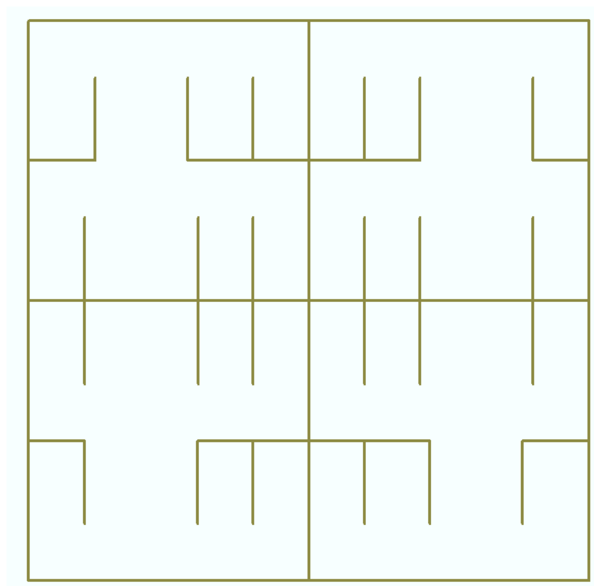
Values calculated using an angle threshold of 10 degrees and a "very short line segment" of 0.1 miles.

That the Greenway model did better than the Fused Grid was a surprising result: looking more closely at their networks, it can be seen that this would likely be the result of the numerous X-intersections created where cul-de-sacs meet towards the centre of the Greenway model, compared to several short segments ending in T-intersections in the Fused Grid model and the additional turns required to navigate its loops (see Fig. J.2 below).

Fig. J.2: Fused Grid vs. Greenway road networks



Fused Grid Road Network



Greenway Road Network

Trip-Based Connectivity for Motorists Using Average Trip Lengths

Average trip lengths (equally weighting trips to the edge and centre) for motorists ranged from a low of 1875.5’ in the Grid to a high of 2,419.1’ in the Loop and Cul-de-Sac, a difference of 29% (Tables J.8 and J.9 below). That the Greenway was second best for car trips was an unexpected finding, given its relatively disconnected network. Logically, this must be the result of another factor such as density distribution, the location of destinations, or the small number of “steps” any local road is from well-connected collectors or arterials, suggesting that, contrary to prevailing wisdom, it may still be possible to get acceptable trip distances even in disconnected networks as long as care is taken in planning these other factors. However, given how at odds this finding is with most theory concerning network layout and trip distances, more research should be done to verify these results and better understand how this was possible in the Greenway’s case before attempting to apply it to other networks.

Looking more closely at that result, it can be seen that there is only 22.1’ difference in the equally weighted trip length between the Greenway and the New Urbanist. Breaking it down into trips to the edge vs. centre, the New Urbanist model was much better in terms of trips to the edge and the Greenway much better in terms of trips to the centre. Since there is a greater potential for destinations to be located on the edge of a neighbourhood than its centre, it may be that the edge should be weighted more heavily than it has been here, but for now that is a question for future research to explore. In this particular case, it may be that relatively high density loading towards the model’s centre contributed to the Greenway’s overall low average trip length there.

Table J.8: Average trip lengths

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Car trip to edge (in feet)	2,365.9	2,833.8	2,588.9	2,488.0	2,613.1
Car trip to centre (in feet)	1,385.0	2,004.3	1,781.3	1,520.7	1,351.4
Equally weighted car trip length to edge and centre (in feet)	1,875.5	2,419.1	2,185.1	2,004.4	1,982.3

Table J.9: Differences in trip lengths between best and worst models

	Best Case	Worst Case	Difference in trip length between worst and best model (in feet)	Difference in trip length compared to best case as a percent
Car trip to edge	Grid	Loop and Cul-de-Sac	467.9	19.8%
Car trip to centre	Greenway	Loop and Cul-de-Sac	652.9	48.3%
Equally weighted car trip to edge and centre	Grid	Loop and Cul-de-Sac	543.60	29.0%

As noted in the main body of this paper (see p. 169), motorists consistently had further to travel than pedestrians and cyclists, again demonstrating that differential connectivity is a de facto component of all five models.

Trip Based Connectivity for Motorists Using Directness Ratios

The model with the best directness ratio for driving trips was the Grid, while the worst was the Loop and Cul-de-Sac, consistent with the findings for trip length. The Fused Grid and New Urbanist reversed their ranks between these two measures, however, with the Fused Grid being second-worst for trip length but the New Urbanist second-worst in terms of directness ratio. This suggests that although the New Urbanist did better than the Fused Grid in terms of trip lengths, this was in part due to how the dwelling units were loaded onto the model, rather than being the result of just the network itself. (The Fused Grid having the inherently more direct network).

Table J.10: Directness ratios

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Motorist directness ratio to centre	1.34	2.14	1.58	1.68	1.44
Motorist directness ratio to edge	1.32	1.59	1.42	1.40	1.48
Equally weighted motorist directness ratio (average of edge and centre results)	1.33	1.87	1.50	1.54	1.46

Trip-Based Continuity for Motorists

As can be seen in Table J.11 below, the Greenway model had the fewest number of points of conflict per mile driven on trips to the destination points for all three types of conflict points.

Table J.11: Number of conflict points encountered by motorists traveling to destinations

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway	
Type of conflict point	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**	**Avg. count**	**Per mile**
ATN/Road	11.8	33.1	11.9	25.9	9.7	23.4	11.0	29.0	4.7	12.6
ATN/Driveway[1]	1.0	N/A	1.00	N/A	0.6	N/A	0.3	N/A	0.2	N/A
Road/Road	5.5	15.5	5.6	12.2	5.2	12.6	6.6	17.4	3.9	10.5

[1]: For cars, the maximum value per trip for this POC type was one (driving down a driveway when they left the origin point, i.e., their home), as there were no driveways included at the end destination points. Where there are no sidewalks or trails crossing driveways (i.e., where alleys are present, or where the ATN is offset from the MTN), this number is, on average, reduced. Consequently, "per mile" values were not calculated for this variable, as it only makes sense on a "count per trip" basis.

ATN/Road and ATN/Driveway POC types reflect the challenges and stress created for drivers where there is an increased possibility of coming into conflict with a pedestrian or a cyclist (outside of regular travel by cyclists along the road with motorists in mixed traffic or in bike lanes). The Grid model was the worst for ATN/Road POCs (where trails and sidewalks hit roads) with 33.1 such POCs per mile travelled. The Grid also tied for worst with the Loop model as for ATN/Driveway POCs (1 per trip), together showing that the Grid model created the greatest potential for conflict between active and motorized modes for motorists on trips. The New Urbanist model was second worst for ATN/Road conflicts (29.0/mile travelled) – not surprising given its grid-based road network - but did much better in the ATN/Driveway category because of its alleys which eliminated driveway/sidewalk conflicts along many of its roads (an average of 0.3/trip). The Fused Grid did second best in both these categories, although it still had drivers encountering almost twice as many ATN/Road POCs than the Greenway model (23.4 vs. 12.6 per mile respectively).

These results show how alleys and offset trail networks offer little benefit to motorists when it comes to reducing ATN/Driveway conflicts (since the most any given driver would encounter in these networks is one at the origin point), making it clear that these design elements primarily exist to serve pedestrians and cyclists.

The Road/Road POCs (i.e., those are the centre of regular road intersections) have a triple impact for drivers, as they provide an increased opportunity for conflict with other cars (and thus collisions), but also have a bearing on travel distances (through their connection to changes in connectivity) as well as travel times (by creating a greater number of possible stops). When measuring connectivity, these intersections are seen as a benefit, but when looking at continuity, they become a drawback.

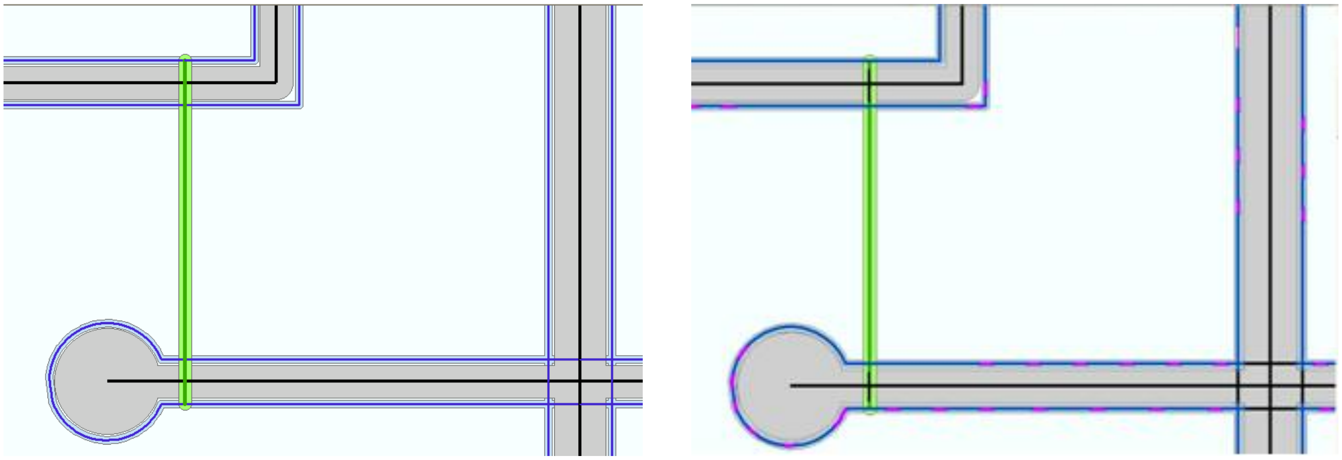
Surprisingly, the New Urbanist model had a greater number of Road/Road POCs than the Grid (likely because of its many alleys), at 17.4/mile travelled vs. 15.5/mile travelled. This shows that the New Urbanist model's network most frequently puts drivers into possible conflict with other drivers. This would undoubtedly have the effect of slowing traffic (due to having less time to get to speed before coming to another intersection). This may also provide a safety benefit to pedestrians and cyclists, if the New Urbanist network forces drivers to be more aware of their surrounding (through a higher number of road intersections and their associated conflict points).

Overall, these results show that for motorists, the Greenway model offers the best continuity when it comes to keeping them out of conflict areas with both active modes and other drivers.

Trip-Based Modal Separation for Motorists

Two problems were encountered when trying to assess trip-based modal separation for motorists. The first was because of the way road crossings were identified in the GIS using a hierarchy of path types (in which roads were treated as being on top and all other types of path disappeared where they crossed them). As a result of this methodology, it was possible to tell where a sidewalk or trail line segment crossed a road (where they went from having, for example, “path_subtype = sidewalk” and “buff_subtype = sidewalk” to “path_subtype = sidewalk” and “buff_subtype = road” during road crossings), but not where a road line segment was crossed by a sidewalk or trail segment (because, at the top of the hierarchy, the “buff_subtype” for roads was always equal to “road”) – see Fig. J.3 below. Appendix F provides a more complete description of the steps used to create the “buff_subtype” attribute.

Fig. J.3: Representing network lines by path_subtype vs. buff_subtype attribute



Network lines symbolized using the "path_subtype" attribute

The same network lines symbolized using the "buff_subtype" attribute

The "path_subtype" attribute reflects the type of path a user would see themselves as "walking/biking/driving along", even where those path types may be discontinuous (e.g. sidewalks at roads).

Network lines in black have "path_subtype=roads", dark green have"path_subtype=trail" and dark blue "path_subtype=sidewalk"

The physical area each path type actually occupies is shown in their corresponding polygons (grey for roads, light blue for sidewalks and light green for trails).

The "buff_subtype" attribute reflects the type of pavement a person would travel over, and changes with discontinuities along a given line. A sidewalk line segment that overlaps a cul-de-sac road would have path_subtype = 'sidewalk' and buff_subtype = 'CDS' for the overlapping portion, and then have path_subtype = 'sidewalk' and buff_subtype = 'sidewalk' once it crossed over to the other side).

Network lines are black where they have buff_subtype = '(a type of road)' and cross over roadways, are dark green where they are on a trail, dark blue where they are actually on a sidewalk, and purple where they are interrupted by driveways.

In this approach, the lines correspond exactly to the edge of the different pavement/path types (the underlying polygons, with precedent being given according to the hierarchy described on p. 468).

A solution to this would be to have a different buff_subtype for “intersection” and to classify the whole area within an intersection as a less modally separated area. Another option would be to go back and assign new “buff_subtype” attributes just to the road lines once all the initial assignments have been done using a modified hierarchy. However, as these could not be done due to time constraints in this study, the below table of results deals only with “in traffic” conditions (e.g., are there other users potentially travelling in the same lane as cars?), rather than “crossing conditions” at intersections (which were possible to assess for the pedestrian and cyclist modes – see p. 207 for results).

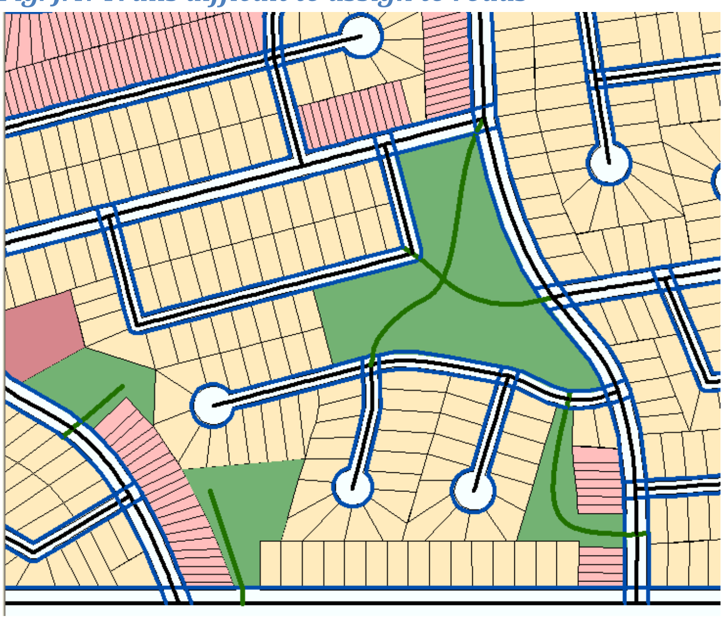
As a result, four categories describing in traffic conditions were considered for trip-based modal separation for motorists:

1) **Complete separation** (no cyclists on roads)
2) **Partial separation** (driving on roads with bikes in bike lanes)
3) **Low separation** (driving on roads in mixed traffic with bikes)
4) **No separation** (cars, cyclists and pedestrians travelling in same space – i.e. alleys and driveways)

The second problem was that even when considering only in-traffic conditions for motorists, it was still extremely difficult to give credit for the presence of nearby parallel trails (as opposed to sidewalks or bike lanes) in the results – essentially the same problem encountered when trying to assess network-based modal separation for motorists (see p. 580). Unlike sidewalks or bike lanes where it can be assumed that all pedestrian or cyclist traffic will remain on those pathways except for short distances on the road with motorists where they must cross intersections or access driveways, where trails are present (and bike lanes absent) there would always have to be some regular on-road bicycle traffic in order to allow cyclists to access buildings and lots (which in most models do not have a direct connection from trails). As a result, the road would be put under the “low separation” category – even though trails may (or may not) be present.

The only model of the five under study here that could pose an exception to this would be the Greenway, where the trail network is complete and buildings designed to connect directly to it, thus eliminating the necessity of at least some on-road (i.e., same-lane mixed traffic) travel for cyclists. While it was simple to create two scenarios for the Greenway (cyclists using both roads and trails and cyclists using just trails) to address this problem for that model, it still seems that there should be a way to give some credit to *any* model when travel by modally separated trails is at least an option for a given length of road (especially where bike lanes are not present). In practice, however, it is not always easy to determine which road a trail should be considered as serving, particularly when there is a substantial space between them or when their layouts do not match – two problems not encountered when considering the modal separation resulting from the inclusion of sidewalks or bike lanes (see Fig. J.4 below). Since the arrangement and extent of trails were one of the main ways the models differed from one another, not being able to include scenarios for the other models in which cyclists would choose to travel on trails wherever possible is a notable shortcoming in these results for trip-based modal separation for motorists.

Fig. J.4: Trails difficult to assign to roads



Black: Roads

Blue: Sidewalks

Dark Green: Trails

As can be seen in this example, many trails present in the models would be difficult to assign as serving specific roads, whereas for sidewalks, it is always clear which road is being served.

In light of these problems, the results for motorists are only included here for demonstration purposes: it is recommended that more work be done to develop better means of assessing modal separation for them. Looking at Table J.12 below, it can be seen that only the Greenway model had the potential to completely eliminate cyclists from roadways (although they would still be present at crossings). Looking at the three models with bike lanes, more than 70% of trips (by length) took place along roads with bike lanes (which were always on collectors and arterials), again showing the relative importance of higher order roads (and placing bike lanes on them!) when assessing trips to the edge and/or centre of these neighbourhoods. The Grid model had the highest proportion of travel occurring on roads with bicyclists travelling in traffic (98.2%) due to the lack of bike lanes and low trail coverage, while depending on the scenario used, the New Urbanist (13.5%) or Greenway (0.0%) had the least. Using the "cyclists traveling on roads" scenario for the Greenway, however, results in an average of 92.5% of a trip taking place in mixed traffic – substantially more than for any other model save the Grid.

Where alleys were present, a substantial portion of trips took place in parking areas (a total of 13.4% in the Fused Grid and 14.4% in the New Urbanist, which includes alleys plus the short section of driveway at the start of each driving trip). While these results reflect what would be true if drivers always chose the shortest possible routes to the study destinations, it is likely in reality that drivers would have some resistance to travelling down alleys, which can be quite narrow. Ideally, it would be possible to incorporate some measure of friction into the network analysis (which could reflect the level of modal separation provided, the narrow road width and/or low traffic speed in alleys), so as to have a greater proportion of trips occurring on the more desirable paths where parallel facilities are present. (Such that, for instance, when modeling drivingtrips the GIS would select routes which would favour roads over the less modally-separated alleyways).

Table J.12: Average percent of shortest path trip along each path type for motorists

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway – Cyclists on Roads	Greenway – Cyclists on Trails Only
Complete separation (no cyclists on roads)	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Partial separation (driving on roads with bikes in bike lanes)	N/A	74.2%	70.5%	72.1%	N/A	N/A
Low separation (driving on roads in mixed traffic with bikes)	98.2%	24.2%	16.1%	13.5%	92.5%	0.0%
No separation (cars, cyclists and pedestrians travelling in same space – i.e. alleys and driveways)	1.8%	1.6%	13.4%	14.4%	7.4%[1]	0.0%

[1]: The Greenway's value was unexpectedly high despite a lack of alleys due to two high density apartment complexes located at the end of unusually long driveways (see Fig. 48 on p. 146). Driveways were also longer in the Greenway and New Urbanist models in general as a result of being drawn from the origin points ("front doors") to the back of lots, rather than from the centre of the lot (which would have created an equidistant front door connection line segment for pedestrians and driveway line into an alley (road, in the case of the Greenway) for motorists).

APPENDIX K: NETWORK COVERAGE BY PAVED ("ACTUAL") PATH LENGTH

The following table provides the coverage (path length) of different types of pathways in the models. Unlike the results presented on p. 155, however, these results reflect not the total length of a line in the GIS, but instead treat the lines as discontinuous where they meet "higher order" lines (for example, a sidewalk is treated as not being present while it crosses a road, even though it appears as continuous in the collection of network lines used by the GIS). As such, the values below better reflect the actual lengths of pavement that would have to be installed when constructing the model neighbourhoods.

Table K.1: Paved path coverage

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway**
Road network coverage[1] (total feet of path)	47,520.0	35,396.4	43630.4	55,217.2	28,615.4
Density (per acre, in feet)	*297.0*	*221.2*	*230.2*	*345.1*	*178.8*
Sidewalk coverage[2] (total feet of path)	75,264.0	59,523.4	60,386.4	66,796.7	N/A
Density (per acre, in feet)	*470.4*	*372.0*	*377.4*	*417.5*	*N/A*
Trail coverage (total feet of path)	3,104.8	5,121.6	3,894.8	10,915.2	36,454.5
Density (Per acre, in feet)	*19.4*	*32.0*	*24.3*	*68.2*	*227.8*
Bike lane coverage (total feet of path)	N/A	20,440.3	15,840	27,341.7	N/A
Density (per acre, in feet)	*N/A*	*127.8*	*99.0*	*170.9*	*N/A*

[1]: Includes alleys but not driveways

[2]: Although when assessing network continuity, "driveway" was considered a higher order path type than "sidewalk", here, sidewalks are presented as being continuous at driveways, to reflect the fact that where they cross, it is the sidewalk's pavement that continues on and the driveway which disapears.

APPENDIX L: INTERSECTIONS USED TO CALCULATE INTERSECTION DENSITIES

Table L.1: Intersections by model

Intersection Type	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Road Intersections					
Regular Road: Road/Road	77	49	38	58	25
Regular Road: Road/Alley	0	0	16	36	0
Total Road (including Road/Alley)	***77***	***49***	***54***	***94***	***25***
ATN-Only Intersections					
ATN-Only: Trail/Trail	0	5	1	12	48
ATN-Only: Midblock (onto a collector or local road)	27	8	26	38	0
ATN-Only: Midblock (onto an arterial)	0	2	0	9	0
ATN-Only: Greenway Crossing	0	0	0	0	40
ATN-Only: Underpass	0	0	0	0	12
Total ATN-Only – Pedestrian	***27***	***15***	***27***	***59***	***48***
Total ATN-Only – Cyclist	***27***	***13***	***27***	***50***	***100***

ATN-Only intersections included in total intersection density for pedestrians include:

All models but Greenway: Trail/Trail, Midblock (onto a collector or local road), Midblock (onto an arterial)

Greenway: Trail/Trail only

ATN-Only intersections included in total intersection density for cyclists include:

All models but Greenway: Trail/Trail, Midblock (onto a collector or local road)

Greenway: Trail/Trail, Greenway Crossing, Underpass

Note: While underpasses served as POCs for both pedestrians and cyclists (there is a potential for conflict for both modes where cyclists potentially come onto the trail from the road), only cyclists have a turn option and thus only they count underpasses as intersections.

Road intersections:

In addition to the their respective ATN-only intersections, regular road intersections were counted for both pedestrians and cyclists for all models, the only exception being the Greenway for which they are not counted for the walking mode. Whether or not alleys were included had a large effect on intersection density results, and so both "with alley" and "without alley" results are presented below.

Table L.2: Pedestrian intersection counts & densities

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrian intersection count (including alleys)	104	64	81	153	48
Pedestrian intersection density (including alleys)	*0.65*	*0.40*	*0.51*	*0.96*	*0.30*
Pedestrian intersection count (not including alleys)	104	64	65	117	48
Pedestrian intersection density (not including alleys)	*0.65*	*0.40*	*0.41*	*0.73*	*0.30*

Table L.3: Cyclist intersection counts & densities

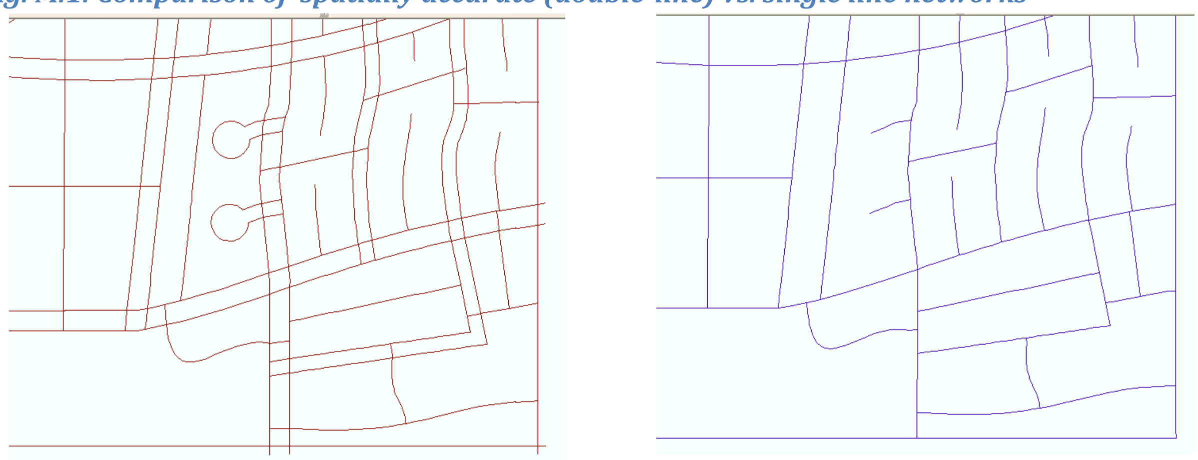
	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Cyclist intersection count (including alleys)	104	62	81	144	125
Cyclist intersection density (including alleys)	*0.65*	*0.39*	*0.51*	*0.90*	*0.78*
Cyclist intersection count (not including alleys)	104	62	65	108	125
Cyclist intersection density (not including alleys)	*0.65*	*0.39*	*0.41*	*0.68*	*0.78*

(Motorist intersections only included "regular road intersections", and are reported in Appendix J on p. 578)

APPENDIX M: ALPHA INDEX GRAPH CONSTRUCTION AND ANALYSIS

Additional notes on graph construction: Depending on the mode and model, the graphs for calculating the index were made using single-line road, sidewalk and trail segments for links. For the pedestrian indices, the single line road network was used to represent sidewalks instead of the double line sidewalk network which was previously used to calculate coverage. Single-line representation was favoured over double-line representation for calculating the alpha index because it was felt that the thin grids created by sidewalks around roads when represented with a double line would produce an artificially high alpha index without providing any real meaningful increase in route options (see Fig. M.1 below).

Fig. M.1: Comparison of spatially accurate (double-line) vs. single line networks

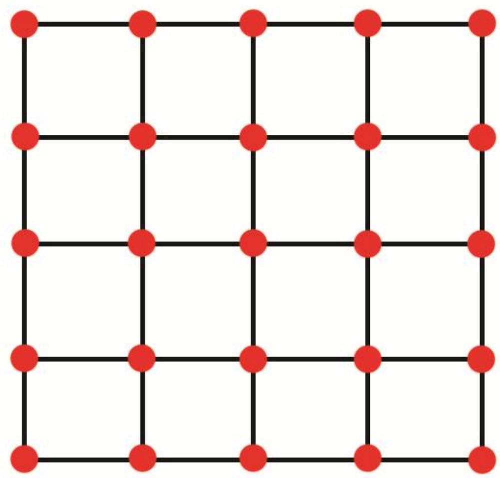


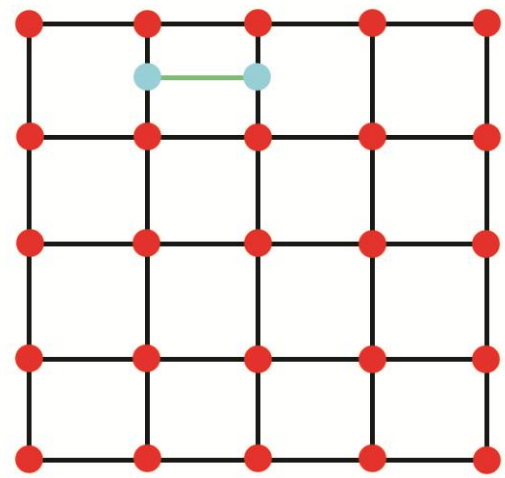
The spatially accurate double line network reflects spatial separation between sidewalks on either side of road, but creates artificially "gridiness"

Double-line sidewalk lines were replaced with single centrelines for the purposes of calculating the alpha index

Analyzing counter-intuitive results: Several counter-intuitive results were encountered for the models' alpha indices, described on p. 162. To determine their cause, some different scenarios were analyzed. The first – the impact of adding a trail shortcut to a network – is shown in Fig. M.2 below, and demonstrates how such an addition can actually worsen the overall index, even while connectivity and route choice are clearly improving.

Fig. M.2: Effect of adding a trail shortcut on the alpha index





Example 1: Roads (5 x 5 grid)
Links (roads in black): 40
Nodes (road/road in red): 25
Cycles: 16
Alpha index:
= (# of cycles) / [(# of nodes *2) – 5]
= 16/45
=0.36

Example 2: Adding one trail shortcut
Links (roads in black, trail in green): 43
Nodes (road/road in red, road/trail in blue): 27
Cycles: 17
Alpha index:
= (# of cycles) / [(# of nodes *2) – 5]
= 17/49
= 0.35

For the Greenway model, another unexpected result was that the initial alpha index for its pedestrian network (0.20) was so much less than that of the Grid (0.39), even though their networks were practically identical. The first possible explanation was considered was that grain size might have an effect – i.e., that a model with a coarse grain would have fewer "edge nodes" (basically T-intersections) compared to "interior nodes" (X-intersections). (Note that, as a topological measure, the alpha index cannot truly be affect by grain size in the sense of block dimensions, but rather, given a confined space – such as a model's frame – it may be affected by the proportion of nodes along the edge relative to the interior – essentially an edge effect resulting from grain). To test this, a graph for two different grids was modelled (Fig. M.3 below):

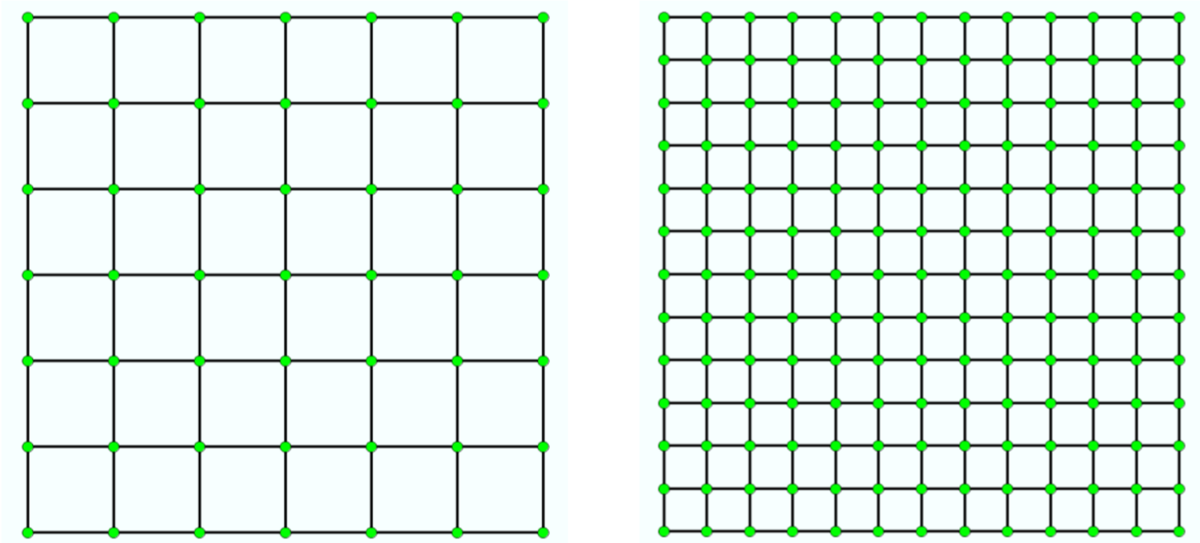


Fig. M.3: Effect of grain on the alpha index within a constrained space

The alpha index is relatively insensitive to grain. Moving from a 7 x 7 grid to a 13 x 13 grid creates only a slight change in alpha index (from 0.39 to 0.43)

Links: 84
Nodes: 49
Cycles: 36
Alpha index: 0.39

Links: 312
Nodes: 169
Cycles: 143
Alpha index: 0.43

As the scenarios presented in Fig. M.3 demonstrate, a difference in grain was obviously not the cause of the problem, which helped the researcher to determine that it was instead dangle notes created by the absent arterial road segments that were the issue. This problem is similar to one encountered by Tresidder (2005), who looked at the impacts of using buffers from a central point vs. census tract borders for eight connectivity measures in a GIS. The use of buffers for assessing connectivity proved challenging because the border would terminate road segments before they reached a node, changing some of the connectivity measures (and in particular intersection density) by as much as 36% (though Tresidder was able to make corrections for most of these problems). In this study's case, the difference in the alpha index was 80% (going from 0.20 to 0.36 with the addition of the frame), suggesting that it may be even more sensitive to such edge effects.

APPENDIX N: LOOKING AT TRIP LENGTHS USING BOX PLOTS

Box plots can be used to look at the distribution of trip lengths within a model/mode combination. In the below figures, the centre line represents the median, and the top and bottom edges of the box the upper and lower quartiles, and the top and bottom of the vertical lines (whiskers) the extent of the main portion of the data (DDI, 1999). Dots beyond the whiskers, if present, represent outliers, while the shaded area around the median represents the 95% confidence interval.

While box plots could be used to study any of the trip length distributions in this study, due to time limitations, only two cases are considered here:

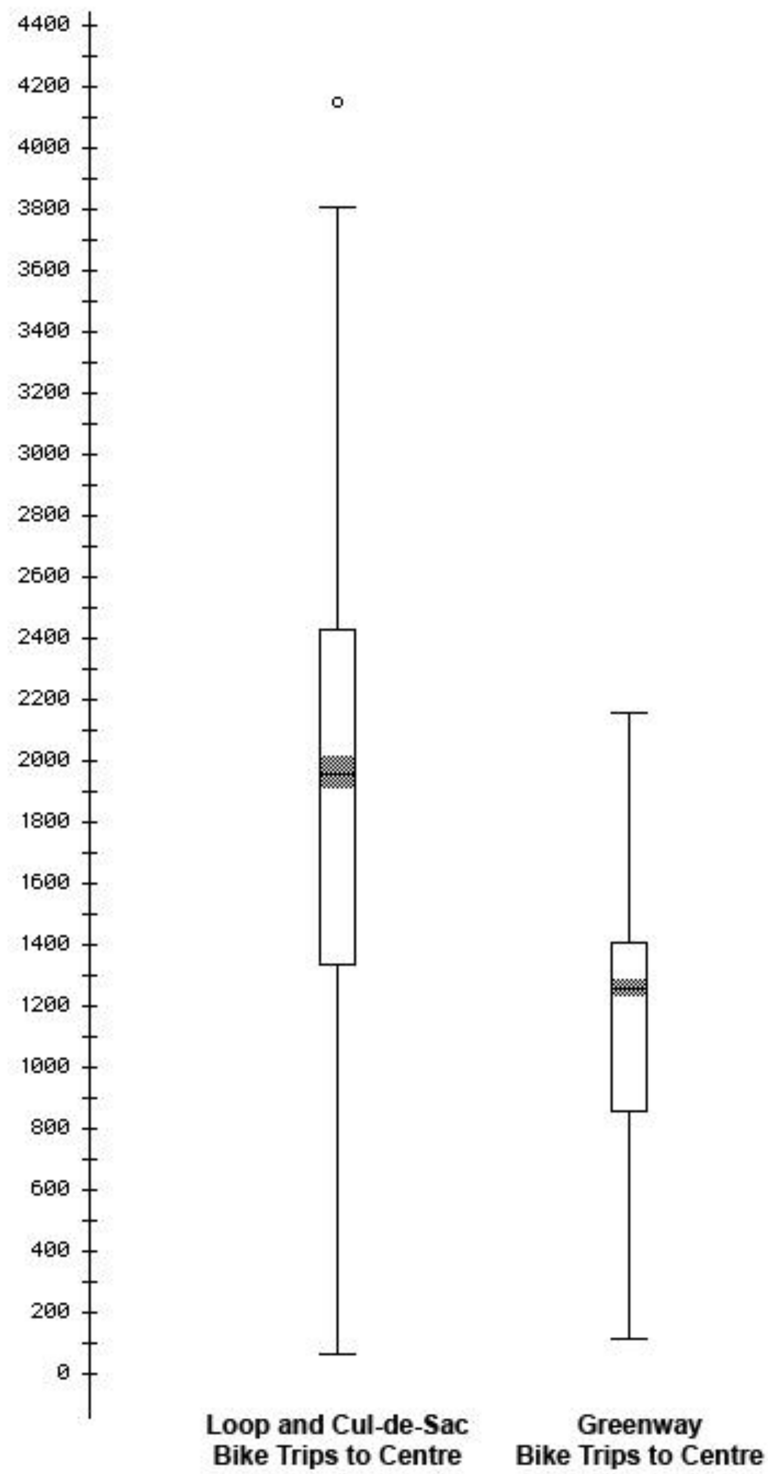
1) **The two models with the greatest difference in trip lengths (to edge or centre) within a given mode,** which was between the Greenway and Loop and Cul-de-Sac models for cycling trips to the centre destination point; and

2) **The two models with the least difference in trip lengths within a given mode**, which was between the New Urbanist and Loop and Cul-de-Sac model for walking trips to edge destinations

Box Plots for the Greatest Difference in Trip Lengths:
Greenway vs. Loop and Cul-de-Sac Bike Trips to the Centre

For bike trips to the centre point, there was a 58.6% difference in average trip length (1226.3' vs. 1945.0') and a 56.0% difference in median trip length (1259.2' vs. 1964.0') between the Greenway and Loop and Cul-de-Sac models. Fig. N.1 below shows the difference in box plots for these two distributions. As can be seen from the figure, the distribution of trip lengths were much more closely centred around the median in the Greenway model than in the Loop and Cul-de-Sac model (having both a smaller box and smaller overall range). Both the range and standard deviation for trip lengths were much smaller in the Greenway model, an indicator of its better connected and more regular network pattern.

Fig. N.1: Box plots for dwelling-unit based bike trips to centre for the Greenway and Loop and Cul-de-Sac models



Greenway Trip Lengths – Descriptive Statistics (in feet)

Mean	1,226.3
Median	1,259.2
Standard deviation	520.6
Min	120.2
Max	2,506.3
Upper quartile	1,522.4
Lower quartile	889.7
Range	2,386.1

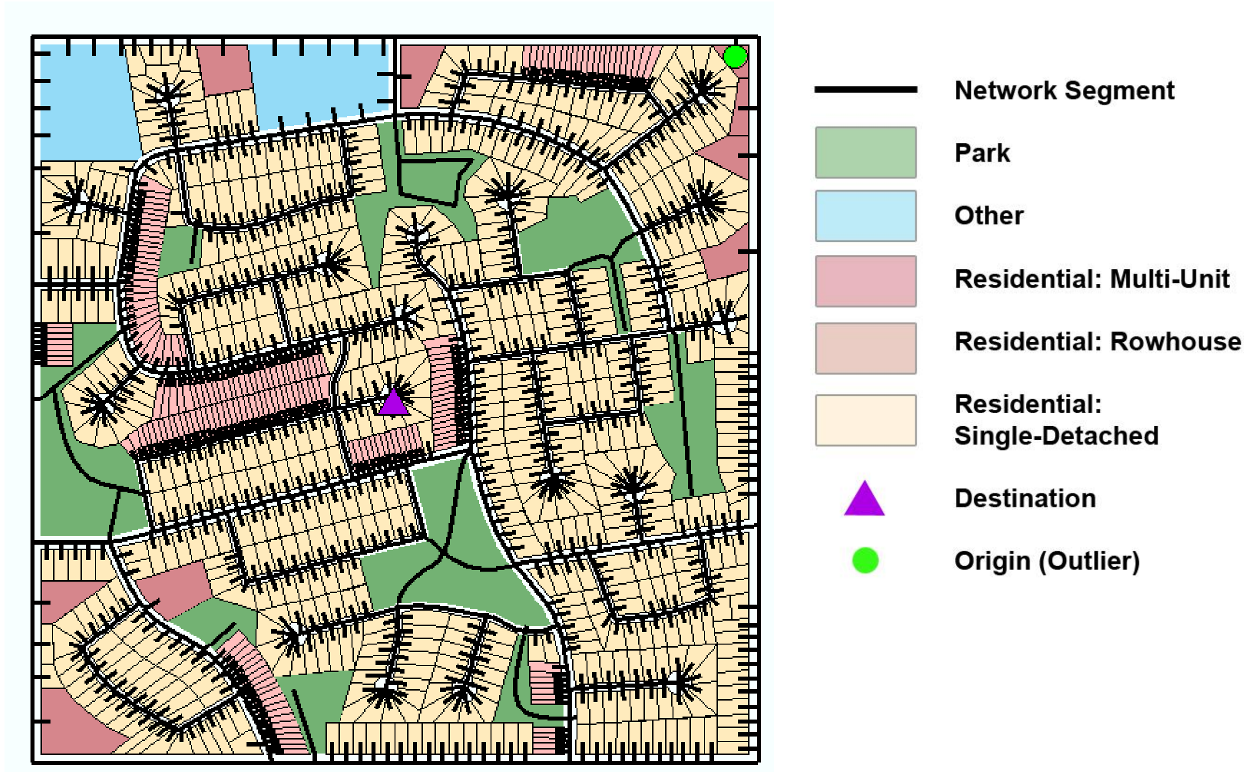
Loop and Cul-de-Sac Trip Lengths – Descriptive Statistics (in feet)

Mean	1,945.0
Median	1,964.0
Standard deviation	816.1
Min	64.9
Max	4,154.7
Upper quartile	2,433.7
Lower quartile	1,340.5
Range	4,089.8

Note: Trip lengths based on one trip per dwelling unit. Boxplots created in ActivStats; descriptive statistics in Excel.

The Loop and Cul-de-Sac model also had a single outlier that produced excessively long trip distances, whose location in the far top right corner of the model, is shown in Fig. N.2 below.

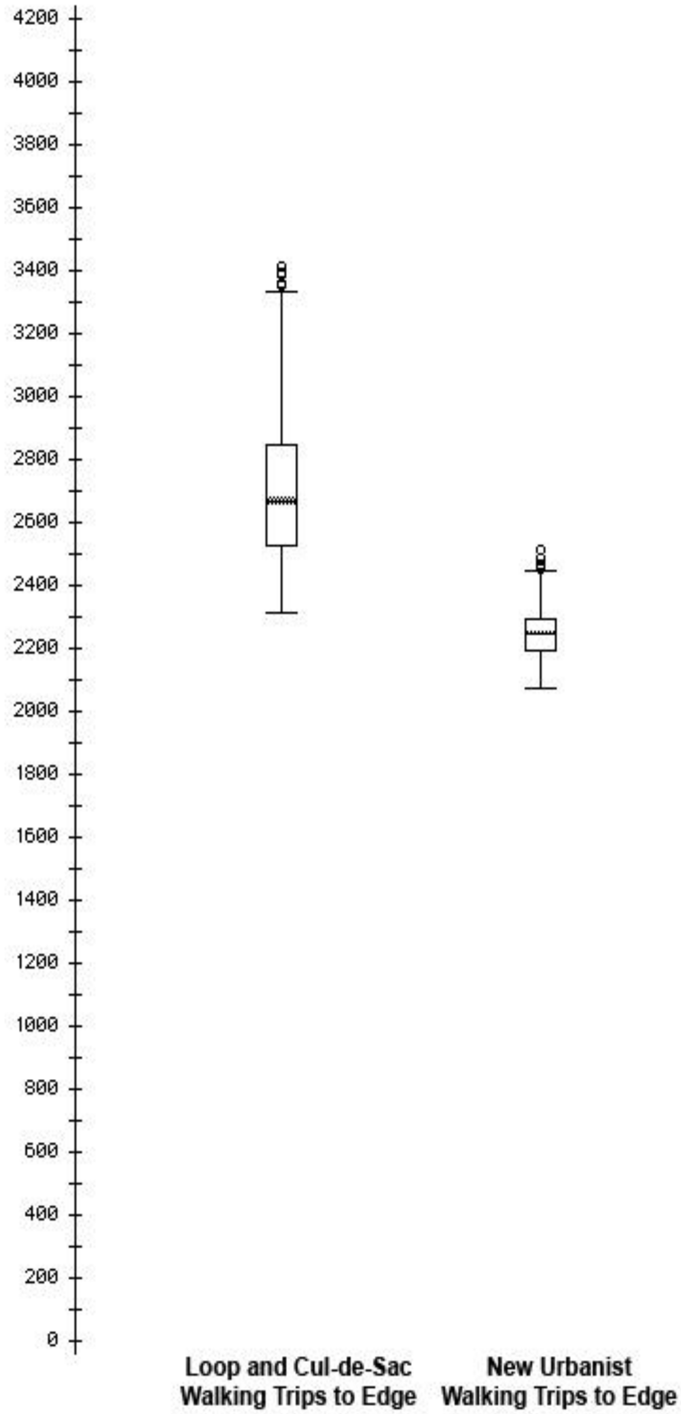
Fig. N.2: Outlier for biking trips to the centre in the Loop and Cul-de-Sac model



Box Plots for the Least Difference in Trip Lengths:
New Urbanist vs. Loop and Cul-de-Sac Walking Trips to the Edge

The least difference in average trip lengths between the best and worst models was for walking trips to the edge between the New Urbanist and Loop and Cul-de-Sac models (16.9%, or 2,317.0' vs. 2,708.4'), which corresponded to a 16.1% difference (2,299.3' vs. 2,670.0') in median trip length. Fig. N.3 below shows the difference in box plots for these two distributions.

Fig. N.3: Box plots for dwelling-unit based walking trips to edge for the New Urbanist and Loop and Cul-de-Sac models



New Urbanist Trip Lengths – Descriptive Statistics (in feet)

Min	2,075.6
Max	2,620.9
Average	2,317.0
Median	2,299.3
Standard deviation	125.6
Upper quartile	2,401.1
Lower quartile	2,226.3
Range	545.3

Loop and Cul-de-Sac Trip Lengths – Descriptive Statistics (in feet)

Min	2,318.8
Max	3,417.6
Average	2,708.4
Median	2,670.0
Standard deviation	221.2
Upper quartile	2,851.3
Lower quartile	2,529.2
Range	1,098.8

Note: Trip lengths based on one trip per dwelling unit. Boxplots created in ActivStats; descriptive statistics in Excel.

The difference in median and total range between the New Urbanist and Loop and Cul-de-Sac models was much smaller than what was seen for the Greenway and Loop and Cul-de-Sac bike trips to centre. In this case, there was only a 370.7' difference in median between the two models vs. a 704.8' difference for the Greenway and Loop and Cul-de-Sac models for bike trips to centre, and only a 553.5' difference in total range vs. a 1,703.7' difference in the previous case. However, even though their trip lengths were more similar overall, the distributions themselves have far less overlap, with the New Urbanist box being quite small relative to the Loop and Cul-de-Sac's and the end of its upper whisker not even reaching the start of the Loop and Cul-de-Sac box. This shows that there is a much greater range of possible trip lengths for walking trips to the edge in the Loop and Cul-de-Sac model than in the New Urbanist one, very similar to what was seen with the Greenway vs. Loop and Cul-de-Sac model in the bicycle trips to centre example. This suggests that the New Urbanist model, like the Greenway, is a more "regular" model wherein one's choice of dwelling unit (from those placed in the model in this study) has less of an effect on trip distances than one's choice in the Loop and Cul-de-Sac model.

Both models again had outliers in the upper end of their distributions. Figures N.4 and N.5 below show the location of these outlier origins relative to the eight edge destination points.

Fig. N.4: Outliers for walking trips to the edge in the New Urbanist model

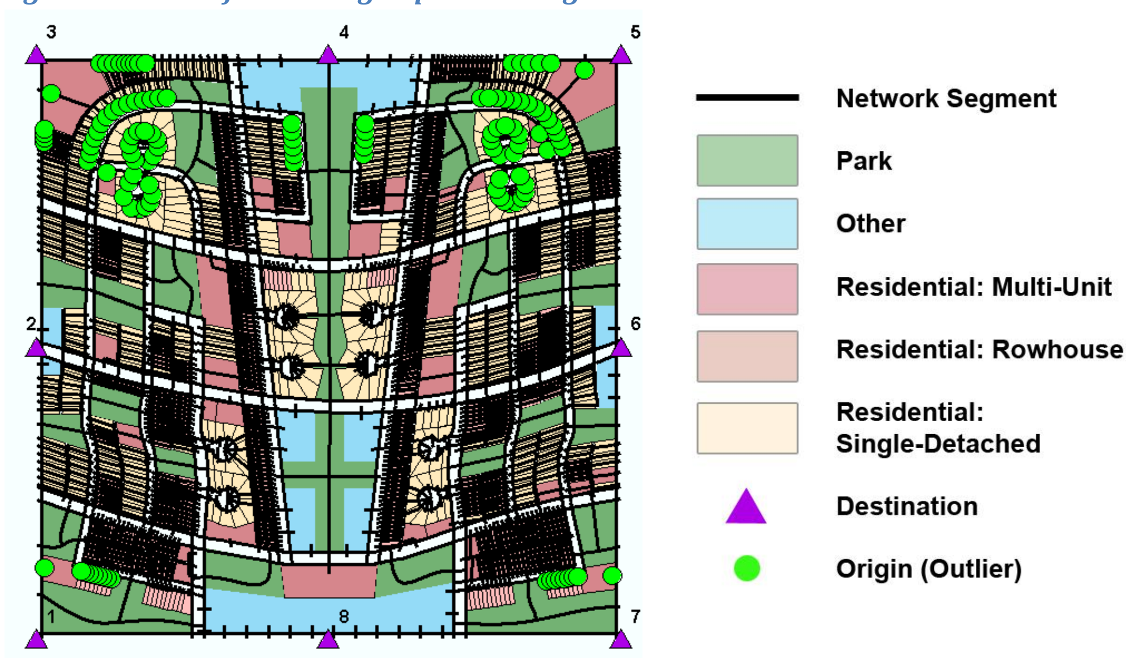
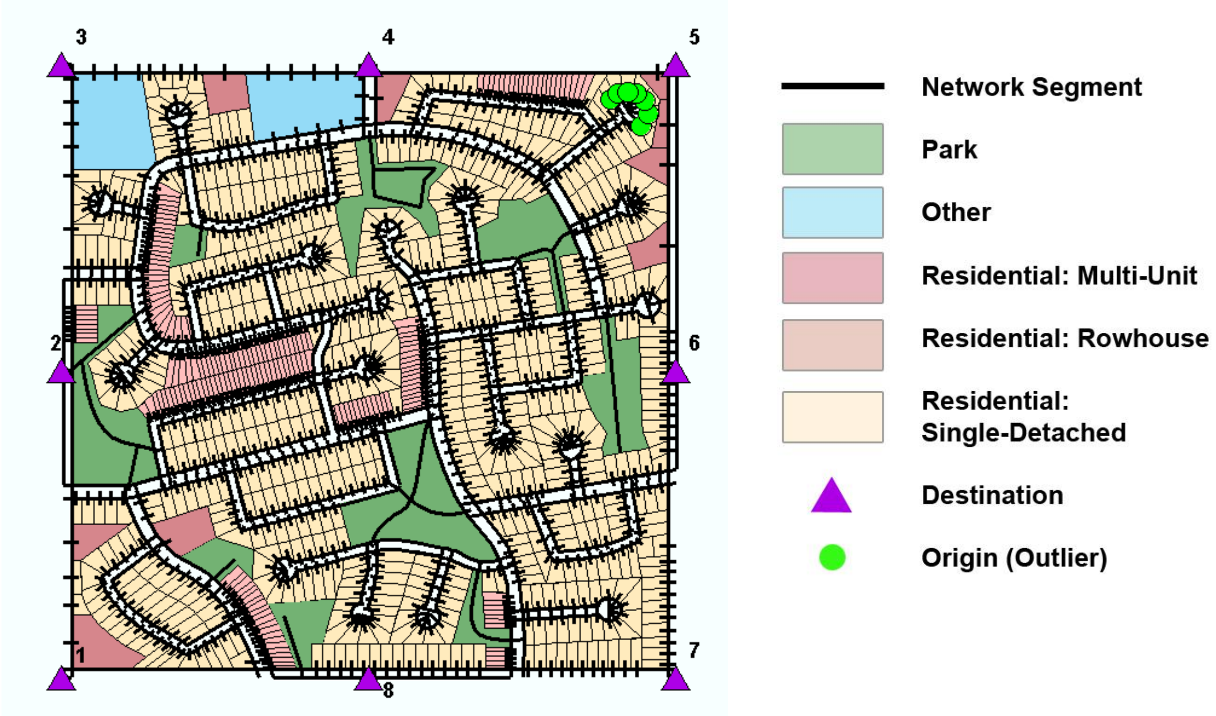


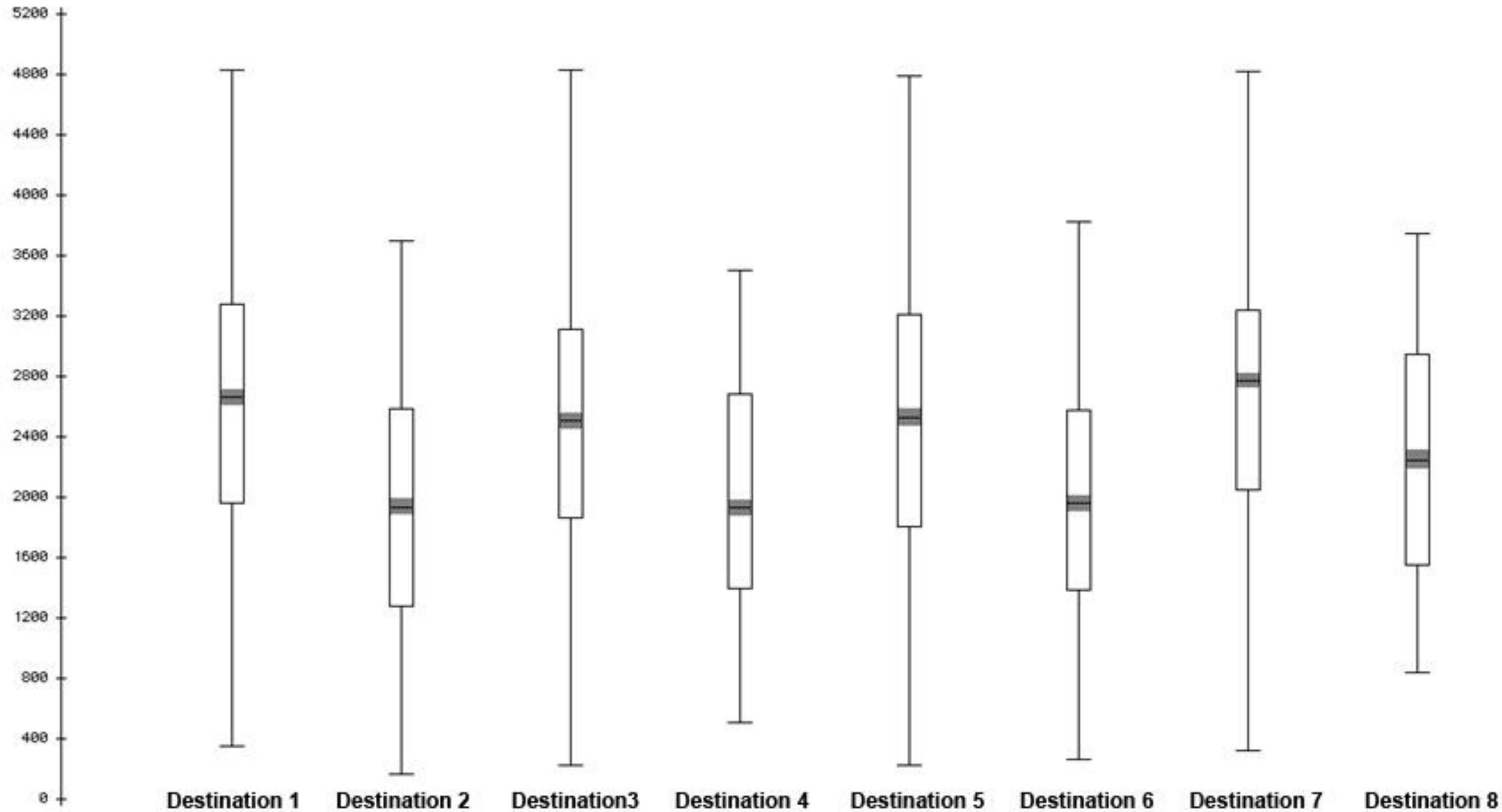
Fig. N.5: Outliers for walking trips to the edge in the Loop and Cul-de-Sac model



As can be seen from Fig. N.4 and Fig. N.5 above, the longest trips to the eight edge points for pedestrians in both models had origins located towards the corners of the model space. This is consistent with what one would expect, since origins closest to the centre would have shorter trips (on average) to equally distributed points along the edge. In the case of the Loop and Cul-de-Sac model, the rough location of the outliers is almost identical to that seen for "bike trips to centre", although here they are located on the interior cul-de-sac (from where it harder to get out to the edge) rather than the exterior arterial road (from where it would be harder to get to the centre). The outliers in the New Urbanist model were more widely distributed, with outliers near each of the four corners as well as a few on the lops near destination 4.

For trips to the edge, it is likely that some of the eight destination points may have been more difficult to reach than others, which can be obscured by the use of a single value for "average trip length to edge". To test this, another set of box plots were created for trip lengths to each destination to help identify those that are most difficult to get to (see Fig. N.7 and Fig. N.7 below). This method could be used to help determine how to modify development plans to improve travel times to key locations on the network.

Fig. N.6: Walking trips to each of the eight edge destinations in the New Urbanist Model



Note: Results based on one trip per dwelling unit.

Table N.1: Descriptive statistics for New Urbanist walking trips to edge by destination

Descriptive Statistics	Overall (in feet) *(Averaged trip to edge for all eight points)*	By Edge Destination (in feet)							
		Dest. 1	**Dest.2**	**Dest.3**	**Dest. 4**	**Dest. 5**	**Dest. 6**	**Dest. 7**	**Dest. 8**
Mean	2,317.0	2,655.0	1,961.3	2,473.9	1,994.0	2,496.7	1,979.9	2,695.6	2,279.8
Median	2,299.3	2,663.8	1,939.9	2,510.7	1,935.0	2,532.5	1,961.5	2,775.9	2,253.6
Minimum	2,075.6	358.3	174.3	232.0	509.5	229.8	263.9	323.4	842.8
Maximum	2,620.9	4,832.7	3,705.2	4,830.9	3,511.5	4,791.1	3,826.2	4,825.5	3,747.6
Lower quartile	2,226.3	1,968.6	1,282.3	1,863.4	1,399.4	1,812.3	1,392.4	2,050.9	1,554.9
Upper quartile	2,401.1	3,278.2	2,591.9	3,120.4	2,685.9	3,215.1	2,576.4	3,244.0	2,949.1
Standard deviation	125.6	983.4	842.2	951.1	753.9	985.7	834.1	953.6	792.9
Range	545.3	4,474.4	3,530.9	4,598.9	3,002.0	4,561.3	3,562.3	4,502.1	2,904.8

Note: Measured on a one trip per dwelling unit basis. Boxplots created in ActivStats; descriptive statistics in Excel.

As can be seen in Fig. N.6 and Table N.1 above, destination 4 (in the top-middle of the model) had the lowest median trip length to an edge destination for pedestrians in the New Urbanist model, while destination 7 (in the bottom right corner) had the greatest.

There is a clear pattern in the box plots that shows that even numbered destinations, located in the middle of each of the bounding roads, were easier to get to than the odd numbered destinations located in the corners. This pattern makes sense because corner destinations could only have homes in 25% of the space around them, while destinations on the middle of the bounding roads could have homes in 50% of the space around them. In the case of destination 4 (a “middle of the edge” instead of corner destination), it would have had the shortest median trip length because of the trail that ran from the bottom of the model and across the rest of the neighbourhood to end right at it, providing a valuable shortcut for pedestrians to this destination (see Fig. 44 on p. 136). Of the even-numbered destinations, destinations 2 and 6 also fared well (and had slightly better mean trip lengths than destination 4), likely because of the sidewalk they are near that bisects the model space. Destination 8, which lacked any direct pedestrian paths to it perpendicular to the road it was located on, had the worst trip values of the “middle of an edge” destinations. While this may be the result of that missing connection, Destination 8 may have also suffered if a greater number of dwelling units were located further from it (in terms of Euclidean distance). To determine if this might be the case, an analysis of average proximity (weighted by dwelling units) between destinations and origins was performed (Table N.2 below).

Table N.2: Proximity of dwelling units to edge destinations in the New Urbanist model

	Average proximity between dwelling units and destination point (in feet)
Destination 1	2,034.7
Destination 2	1,542.4
Destination 3	1,971.8
Destination 4	1,535.9
Destination 5	1,974.6
Destination 6	1,557.7
Destination 7	2,056.7
Destination 8	1,597.7

Since there was a greater average Euclidean distance between destination 8 and the model's dwelling units than destinations 2, 4 or 6, this would have been a contributing factor when it came to trip lengths. Determining how much of the difference in trip lengths comes from differences in proximity to the destination points versus differences in the network leading up to them is more complicated. In a case such as this, directness ratios for trips to each of the edge points could be used to isolate the effects of network on trip lengths, independent of proximity.

Fig. N.7: Walking trips to the eight edge destinations in the Loop and Cul-de-Sac model

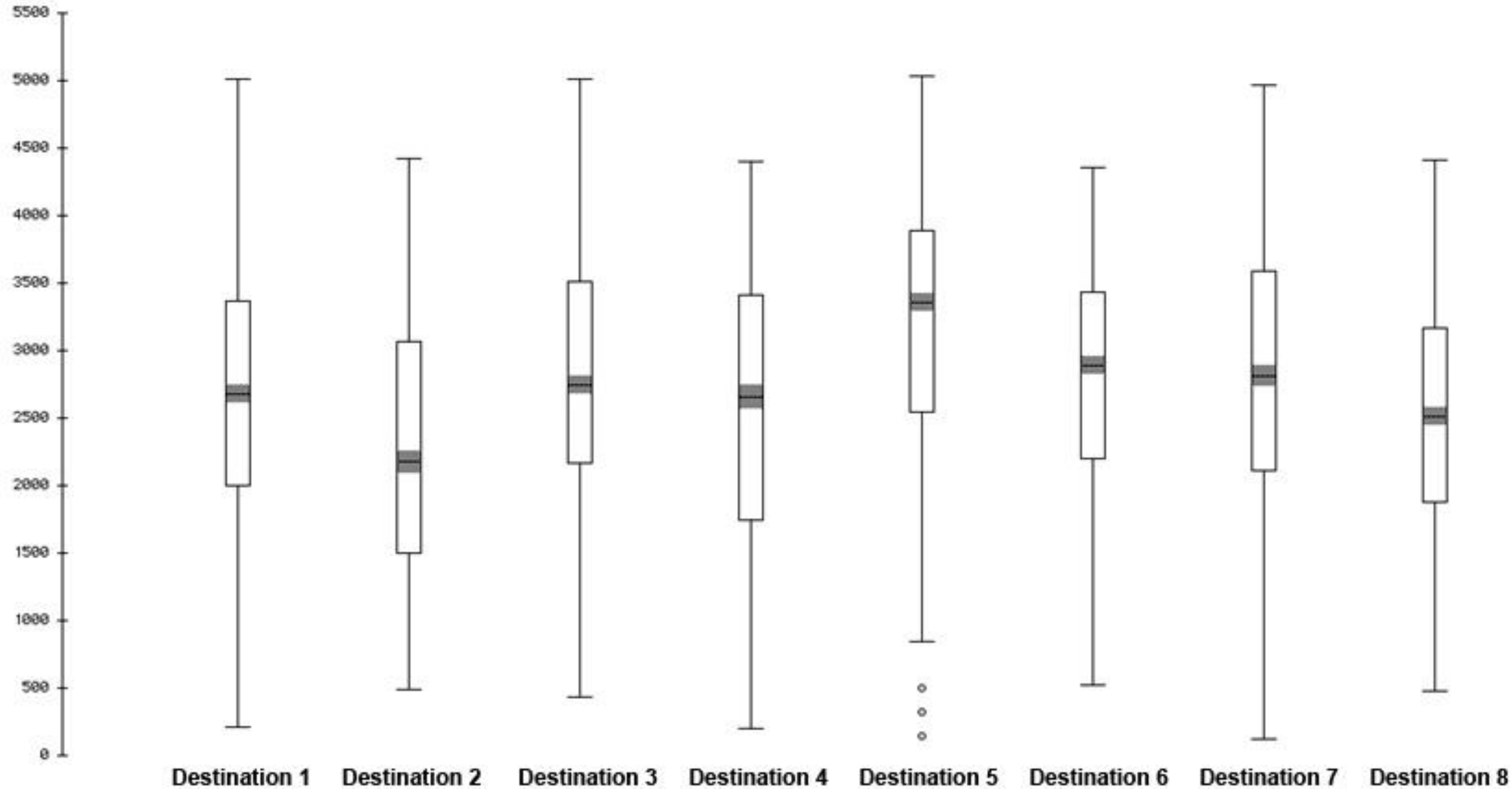


Table N.3: Descriptive statistics for Loop and Cul-de-Sac walking trips to edge by destination

Descriptive Statistics	Overall (in feet) *(Averaged trip to edge for all eight points)*	By Edge Destination (in feet)							
		Dest. 1	Dest. 2	Dest. 3	Dest. 4	Dest. 5	Dest. 6	Dest. 7	Dest.8
Mean	2,708.4	2,674.6	2,279.5	2,844.8	2,534.1	3,231.2	2,775.7	2,825.6	2,501.4
Median	2,670.0	2,684.4	2,178.6	2,750.9	2,662.5	3,360.2	2,894.4	2,815.3	2,514.8
Minimum	2,318.8	222.0	489.4	442.9	207.7	154.6	528.9	126.4	484.2
Maximum	3,417.6	5,020.9	4,424.8	5,019.8	4,404.2	5,041.2	4,365.0	4,972.9	4,418.3
Lower quartile	2,529.2	2,008.7	1,506.8	2,174.5	1,750.4	2,553.4	2,200.3	2,119.6	1,884.8
Upper quartile	2,851.3	3,376.8	3,070.0	3,511.3	3,421.2	3,898.6	3,434.5	3,595.8	3,177.0
Standard deviation	221.2	973.8	914.2	934.1	1,016.5	946.1	849.6	1,054.5	950.0
Range	1,098.8	4,798.9	3,935.4	4,576.9	4,196.5	4,886.6	3,836.1	4,846.5	3,934.1

Note: Measured on a one trip per dwelling unit basis.Boxplots created in ActivStats; descriptive statistics in Excel

In the Loop and Cul-de-Sac model, the same pattern of even numbered destinations being easier to reach than odd numbered destinations reappears. Destination 5 (in the top right corner) was the most difficult destination to get to, and also had a few outliers in the bottom end of its range, the only destination in these two models that did. Fig. N.8 below shows these “short trip” outliers, which were the closest origin points on the network to Destination 5 and all multi-unit buildings.

Fig. N.8: Outlier origin points for walking trips to Destination 5 in the Loop and Cul-de-Sac model

Looking at the proximity of dwelling units (Table N.4, below), even though Destination 5 had the longest mean and median trip lengths, it did not have the greatest average Euclidean distance to the model’s dwelling units – Destination 3 did. This indicates that differences in the network, not density distribution, are the cause of the longer trip lengths to this point.

Table N.4: Proximity of dwelling units to edge destinations in the Loop and Cul-de-Sac model

	Average proximity between dwelling units and destination point (in feet)
Destination 1	1,975.5
Destination 2	1,541.1
Destination 3	2,040.5
Destination 4	1,583.7
Destination 5	2,030.4
Destination 6	1,577.1
Destination 7	2,019.6
Destination 8	1,544.5

APPENDIX O: COMPARISON OF TRIP-BASED VS. NETWORK-BASED RANKS OF DESIGN VARIABLES

Both trip-based and network-based measures of have regularly been used by other researchers to assess the potential relationship between neighbourhood design (here limited to network layout) and travel. It was therefore of interest to the researcher to know how rankings based on network measures (which were used for the evaluation of overall active transportation potential on p. 186) would compare to those arising from trip-based measures. Tables O.1, O.2 and O.3 below compare the model ranks for each of the different connectivity, continuity and modal separation measures used in this study.

What becomes immediately evident from looking at the following tables is that while in some cases a model/mode combination might have the same ranking for all types of trip-based and network-based measures used to assess a given variable (for instance, the Loop and Cul-de-Sac had the same rank for all measures of connectivity for cyclists), this is the exception rather than the rule. While in most cases the ranks hovered within one or two ranks for the variable in question (for instance, all connectivity measures for biking in the Fused Grid model resulted in a rank between 2 and 3), in others, the difference was greater – a notable example of which was for connectivity cyclists in the New Urbanist model, for which the two network based measures (intersection density and metric reach) produced a rank of 5 but for which the trip-based directness ratio ranked only 2. Thus, not only do models vary in how they rank *between* variables, the measure used can affect how they rank *within* variables.

Table O.1: Comparison of trip-based vs. network-based connectivityrankings

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Trip-Based Connectivity Measures for Pedestrians					
Average trip length rank	4	1	2	5	3
Directness ratio rank	5	1	4	3	2
Network-Based Connectivity Measures for Pedestrians					
Alpha index rank	5	1	2.5	2.5	4
Intersection density rank	4	2	3	5	1
Metric reach rank	4	1	2	5	3
Trip-Based Connectivity Measures for Cyclists					
Average trip length rank	3	1	2	4	5
Directness ratio rank	4	1	3	2	5
Network-Based Connectivity Measures for Cyclists					
Alpha index rank	5	1	2.5	2.5	4
Intersection density rank	3	1	2	5	4
Metric reach rank	3	1	2	5	4
Trip-Based Differential Connectivity for Pedestrians vs. Motorists					
Differential connectivity rank – by trip distance	1	2.5	5	4	2.5
Network-Based Differential Connectivity for Pedestrians vs. Motorists					
Differential connectivity rank – by metric reach	1	3	4	2	5
Differential connectivity rank – by intersection density	2	1	3	4	5
Trip-Based Differential Connectivity for Cyclists vs. Motorists					
Differential connectivity rank – by trip distance	1	2	4	3	5
Network-Based Differential Connectivity for Cyclists vs. Motorists					
Differential connectivity rank – by metric reach	1	3	4	2	5
Differential connectivity rank – by intersection density	2	1	3	4	5

The greatest difference between ranks in Table O.1 above was for pedestrian differential connectivity in the Greenway model, which had a rank of 2.5 when using trip-based measures to assess differential connectivity but a rank of 5 for network-based measures. Since there is no doubt that the Greenway model offers substantial connectivity improvements for pedestrians over cars (given the nature of the two different networks used), this is almost certainly the result of the frame choice which favoured cars when it came to trip lengths, but does help to show what an impact frame choice can have.

For trip-based continuity (Table O.2 below), ATN/ATN POCs were omitted as it is unlikely this type of conflict point acts as near as much a source of risk (real or perceived) as conflict points involving cars. An equally weighted trip-based POC measure was also created for each model, recognizing that no one type of POC could, on its own, describe overall continuity for pedestrians or cyclists in the models.

Table O.2: Trip-based vs. network-based continuity measure rankings for pedestrians

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Trip-Based Continuity Measures for Pedestrians					
ATN/Driveway POCs per mile	3	1	2	4	5
ATN/Road POCs per mile	1	4	3	2	5
Overall continuity (average of ATN/Driveway and ATN/Road ranks)	2	2.5	2.5	3	5
Network-Based Continuity Measures for Pedestrians					
Pedestrian/Car POC density (ranks based on equal weight given to ATN/Driveway and ATN/Road POC categories)	1.5	2.5	3	3	5
Ratio of ATN-only to regular road intersections	2	1	3	4	5
Trip-Based Continuity Measures for Cyclists					
Road/Road POCs per mile	1.5	3	4	1.5	5
ATN/Road POCs per mile	1	3	4	2	5
Overall continuity (average of Road/Road and ATN/Road ranks)	1.25	3	4	1.75	5
Network-Based Continuity Measures for Cyclists					

Cyclist/Car POC density (Includes road/road and road/trail POCs)	2	5	3.5	1	3.5
Ratio of ATN-only to regular road intersections	2	1	3	4	5

The most interesting result above was that for cyclists, the network-based cyclist/car POC density had the Loop and Cul-de-Sac model ranked as best, while for the trip-based measures it only ranked third. This suggests that when making trips to the specific destination points used in this study, bike trips tended to hit a disproportionately high number of these POCs.

For modal separation (Table O.3 below), how ranks are assigned for trip-based measures is dependent on what is termed "best", which could be the model that has:

1) The greatest portion of trips occurring on completely separated pathways (trails and/or sidewalks);
2) The greatest proportion of trips occurring on completely separated pathways (trails and/or sidewalks) or those with medium separation (bike lanes); or
3) The least proportion of the trip occurring on pathways shared with cars (either just on regular roads or including alleys and driveways).

For Table O.3 below, the first option was chosen. Since there is nothing to stop cyclists on roads with bike lanes from choosing to travel directly in traffic any more so than there is to stop them from doing so where the "modally separated facility" is a separate trail instead, the "Cyclists on trails only" scenario for the Greenway has been used for the purposes of ranking the models (for both trip-based and network-based measures).

It is noted that a shortcoming of this approach is that the other GIS models did not force cyclists to choose to use trails in place of roads where available, nor pedestrians to choose continuous sidewalks instead of alleys. Since ranks thus produced for pedestrians and cyclists still produce results consistent with what one would expect from a visual inspection of the network layouts (see Appendix I) and the amount of modally separated pathways provided in each model (see p. 174), it is felt that this approach is sufficient within the time constraints of this study.

Table O.3: Comparison of ranks for trip-based vs. network-based measures of modal separation

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway
Pedestrians					
Ranks using trip-based measures (rank by proportion of trip made on paths offering complete separation from cars)	2	1	3	4	5
Ranks using network-based measures (rank by coverage of pathways providing complete separation from cars)	2	1	3	4	5
Cyclists					
Ranks using trip-based measures (rank by proportion of trip made on paths offering complete separation from cars)	1	2	3	4	5
Ranks using network-based measures (rank by coverage of pathways providing complete separation from cars)	1	3	2	4	5

As can be seen in Table O.3 above, the trip-based and network-based measures of modal separation produced identical rankings for pedestrians, while for cyclists, there was a reversing of the ranks between the Loop and Cul-de-Sac model and the Fused Grid. This reversal in the latter case is not surprising, since the Fused Grid lays out trails in a systematic matter to enhance connectivity, while in the Loop and Cul-de-Sac model, many of the trails are confined to a single park and do not provide a connective function, even if they represent a greater proportion of the network's coverage overall.

To further examine this result, a comparison of the proportion of the network that is made up of modally separated pathways for cyclists (i.e. trails and bike lanes) and the average proportion of trip lengths that occurred on them was made (Tables O.4 and O.5 below).

Table O.4: Comparing presence vs. use of trails for cyclists

	Grid	Loop and Cul-de-Sac	Fused Grid	New Urbanist	Greenway – Cyclists on Trails Only

Proportion of network made up of trails	5.6%	12.2%	7.5%	15.7%	96.7%
Proportion of trip made on trails	2.3%	6.9%	9.2%	20.1%	97.2%

Cycling trips made in the Loop and Cul-de-Sac and Grid models made disproportionately *low* use of their trails, while trips made in the three alternative models made disproportionately *high* use of theirs. Unlike the two traditional models, the alternative models all emphasize locating trails in such a way as to attempt to improve connectivity and reduce trip lengths (which was reflected in the model designs). The results in Table O.4 above indicate that they can be quite successful in this regard.

This pattern also appeared when looking at the length of trips occurring on bike lanes: in the Fused Grid model, travel along bike lanes accounted for 51.8% of trips by length even though they represented only 32.8% of the network coverage, while in the New Urbanist model, they accounted for 61.8% of the average trip despite comprising only 40.2% of the network by length (see Table O.5 below). This result would reflect the fact that, except in the Grid model, the destination points were located on arterial and collector roads with bike lanes, making travel on them inevitable. By locating bike lanes on these roads, the models were able to locate infrastructure where it would offer the most benefit (given the locations of destinations in the GIS models). The Loop and Cul-de-Sac model had the least increase between the proportion of the cyclist network made up of bike lanes and the proportion of trip made on bike lanes; this likely reflects the fact that in that model, one would have to travel further along local roads in order to reach the higher-order ones.

Table O.5: Comparing presence vs. use of bike lanes for cyclists

	Grid	**Loop and Cul-de-Sac**	**Fused Grid**	**New Urbanist**	**Greenway – Cyclists on Trails Only**
Proportion of cyclist network made up of bike lanes	N/A	49.8%	32.8%	40.2%	N/A
Proportion of trip made on bike lanes	N/A	62.1%	51.8%	61.8%	N/A

APPENDIX P: CONTINUITY – POCs ENCOUNTERED BY EDGE AND CENTRE

Table P.1: Trip-based continuity (POCs encountered) by edge and centre for pedestrians

	Grid				Loop and Cul-de-Sac				Fused Grid				New Urbanist				Greenway			
	Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge	
	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile
ATN/ATN	8.2	31.9	14.7	33.4	10.6	29.5	12.6	24.6	10.8	37.8	33.0	72.8	14.0	54.2	26.5	60.5	36.2	136.7	51.3	113.5
ATN/Road	4.0	15.4	7.0	15.9	2.7	7.6	4.0	7.8	3.1	10.9	5.4	12.0	3.6	13.8	6.5	14.8	1.3	4.9	1.6	3.5
ATN/Driveway	10.7	41.4	18.3	41.5	29.0	80.6	28.9	56.3	16.1	56.2	18.2	40.1	5.9	23.0	3.8	8.7	0.0	0.0	0.0	0.0

Table P.2: Trip-based continuity (POCs encountered) by edge and centre for cyclists

	Grid				Loop and Cul-de-Sac				Fused Grid				New Urbanist				Greenway			
	Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge	
	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile
ATN/ATN	0.0	0.1	0.8	1.9	1.4	3.8	1.3	2.6	1.9	6.4	3.1	6.7	3.5	13.5	2.1	4.6	9.9	42.7	31.1	71.4
ATN/Road	8.6	32.7	14.6	32.8	9.3	25.3	11.7	22.3	6.5	22.4	10.3	22.5	6.1	23.5	12.8	28.9	2.5	10.6	3.6	8.2
ATN/Driveway	1.0	3.8	1.0	2.2	1.0	2.7	1.0	2.0	0.6	1.9	0.6	1.2	0.3	1.0	0.3	0.6	0.2	1.0	0.1	0.3
Road/Road	4.0	15.4	6.6	14.9	4.6	12.5	5.1	9.7	2.9	10.1	4.8	10.5	3.5	13.6	7.1	16.0	2.0	8.8	2.0	4.6

Table P.3: Trip-based continuity (POCs encountered) by edge and centre for motorists

	Grid				Loop and Cul-de-Sac				Fused Grid				New Urbanist				Greenway			
	Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge		Centre		Edge	
	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile	Avg. count	Per mile
ATN/Road	8.6	32.8	14.9	33.3	10.7	28.2	13.0	24.3	7.9	23.5	11.4	23.3	7.5	26.1	14.5	30.8	3.1	12.1	6.3	12.8
ATN/Driveway	1.0	3.8	1.0	2.2	1.0	2.6	1.0	1.9	0.6	1.6	0.6	1.1	0.3	0.9	0.3	0.5	0.2	0.8	0.2	0.4
Road/Road	4.0	15.4	7.0	15.6	5.3	13.9	5.8	10.9	4.4	13.2	6.0	12.2	4.4	15.3	8.8	18.7	3.0	11.7	4.9	9.9

APPENDIX Q: TRIP-BASED MODAL SEPARATION – BY EDGE AND CENTRE

Table Q.1: Trip-based modal separation by edge and centre for cyclists

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway	
	Centre	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**
Low separation - parking (biking in mixed traffic with cars and pedestrians) (i.e., driveways and alleys)	2.4%	1.4%	2.0%	1.4%	3.6%	5.0%	7.7%	8.5%	9.7%	3.4%
Medium separation (biking in bike lanes)	N/A	N/A	45.7%	78.5%	48.2%	55.4%	50.9%	73.1%	N/A	N/A
Low separation - roads (biking in mixed traffic with cars)	97.4%	94.0%	45.1%	13.4%	37.7%	31.5%	11.5%	9.2%	58.7%	38.5%
High separation (biking with pedestrians only) (i.e. trails, sidewalks, front door connections and through underpasses)	0.2%	4.5%	7.3%	6.7%	10.5%	8.1%	29.9%	9.3%	31.6%	58.0%

Table Q.2: Trip-based modal separation by edge and centre for pedestrians

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway	
	Centre	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**	**Centre**	**Edge**
No separation – parking (driveways and alleys)	11.4%	11.0%	22.1%	14.2%	16.4%	13.0%	12.2%	9.0%	0.0%	0.0%
No separation – higher order roads (crossing arterials or collectors)	N/A	N/A	2.4%	3.6%	1.5%	2.7%	6.8%	5.7%	1.3%	1.4%
No separation – local roads (crossing local roads)	9.8%	10.7%	3.0%	1.9%	3.8%	3.9%	1.6%	2.2%	0.6%	0.7%
Complete separation (sidewalks, trails, frontdoor connections and walking through underpasses)	78.8%	78.3%	72.5%	80.2%	78.4%	80.5%	79.4%	83.1%	98.1%	97.9%
Sum – crossing roads	9.8%	10.7%	5.4%	5.5%	5.3%	6.6%	8.4%	7.9%	1.9%	2.1%
Sum – no separation	21.2%	21.7%	27.5%	19.7%	21.7%	19.6%	20.6%	16.9%	1.9%	2.1%

Table Q.3: Trip-based modal separation by edge and centre for motorists

	Grid		Loop and Cul-de-Sac		Fused Grid		New Urbanist		Greenway – Cyclists on Roads	
	Centre	**Edge**	**Centre**	**Edge**	**Centre**	**Centre**	**Edge**	**Centre**	**Edge**	**Centre**
Complete separation (no cyclists on roads)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
No separation (cars, cyclists and pedestrians travelling in same space – i.e. alleys and driveways)	2.4%	1.4%	1.9%	1.3%	10.8%	15.2%	16.0%	13.4%	10.9%	5.6%
Partial separation (driving on roads with bikes in bike lanes)	N/A	N/A	56.3%	86.9%	71.1%	70.1%	59.1%	80.1%	N/A	N/A
Low separation (driving on roads in mixed traffic with bikes)	97.6%	98.6%	41.8%	11.8%	18.2%	14.7%	24.8%	6.5%	89.1%	94.4%

APPENDIX R: SUMMARY TABLES OF RESULTS FOR THE ALTERNATIVE MODELS

Fused Grid Model

Table R.1: Fused Grid land use & efficiency results

Variable	Value	Rank
Diversity (land use mix) (average rank of "Other" and "Park")	6% Other, 11% Park	2.25
Buildable area as a percent of model area *(model space – road network area)*	81.9%	4
Road network area (roads, alleys and bike lanes)	18.1%	4
Other active transportation network area (sidewalk and trails)	6.2%	3
Total paved network area (roads, alleys, bike lanes, sidewalks and trails)	24.3%	3
Total infrastructure (road network + parks) in square feet per dwelling unit	2,044.5	3
Total paved network area in square feet per dwelling unit	1,443.7	3

Note: Network efficiency not included because of the inability to effectively rank the data – see p. 225 for results.

Table R.2: Fused Grid density results

Variable	Value	Rank
Gross density	7.3 dwelling units/acre	3
Gross theoretical residential population density per acre (based on actual number of dwelling units in model)	18.3 people/acre	3
Gross density potential for single-detached homes (based on 5,750 sq. ft. lots)	6.2 homes/acre	3.5

Table R.3: Network measures for the Fused Grid, by mode

	Pedestrians		Cyclists	
	Value	**Rank**	**Value**	**Rank**
Coverage (by mode, per acre, in feet)	433.1	2	128.4	2
Connectivity – alpha index	0.20	2.5	0.20	2.5
Connectivity – intersection density (including alleys, per acre, for each mode)	0.52	3	0.52	2
Connectivity – metric reach (miles)	2.0	2	2.0	2
Connectivity – differential connectivity by intersection density	1.53	3	1.53	3
Connectivity – differential connectivity by metric reach	1.40	4	1.40	4
Continuity – POC density: ATN/Road (# per acre)	1.1	3	N/A	N/A
Continuity – POC density: ATN/Driveway (# per acre)	4.4	3	N/A	N/A
Continuity – Overall rank (pedestrian: average rank of ATN/Driveway and ATN/Road)	N/A	3	N/A	N/A
Continuity – POC density: Cyclist/Car (# per acre)	N/A	N/A	0.5	3.5
Continuity – ratio of ATN-only intersections to regular road Intersections	0.54	3	0.54	3
Modal separation – by coverage (proportion of network providing complete separation from cars)	80.3%	3	7.5%	2
Legibility – by directional distance (in miles)	1.98	3	1.98	2

Table R.4: Trip-based measures for the Fused Grid, by mode

	Pedestrians		Cyclists	
	Value	**Rank**	**Value**	**Rank**
Average trip length (equally weighted trips to edge & centre, in feet)	1,953.1	2	1,972.6	2
Directness ratios (equally weighted trips to edge & centre)	1.34	4	1.35	3
Differential connectivity based on trip distances Active:Car (equally weighted edge & centre)	0.89	5	0.90	4
ATN/Driveway POCs per mile	46.4	2	N/A	N/A
ATN/Road POCs per mile	11.6	3	22.5	4
ATN/ATN POCs per mile	59.2	2	6.6	3
Road/Road POCs per mile	N/A	N/A	10.3	4
Overall trip-based continuity (average of applicable ranks)	N/A	2.5[1]	N/A	4[2]
Trip-based modal separation (rank by proportion of equally weighed trips to edge and centre made on paths offering complete separation from cars)	79.1%	3	9.2%	3[3]

[1]: *Average of ATN/Driveway and ATN/Road ranks*

[2]: *Average of Road/Road and ATN/Road ranks*

[3]: *When using the "cyclists on trails only" scenario for the Greenway model*

New Urbanist Model

Table R.5: New Urbanist land use & efficiency results

Variable	Value	Rank
Diversity (land use mix) (average rank of "Other" and "Park")	8% "Other", 21% "Park"	4.75
Buildable area as a percent of model area *(model space – road network area)*	78.1%	2
Road network area (roads, alleys and bike lanes)	21.9%	2
Other active transportation network area (sidewalk and trails)	7.8%	1
Total paved network area (roads, alleys, bike lanes, sidewalks and trails)	29.7%	1
Total infrastructure (road network + parks) in square feet per dwelling unit	2,459.9	2
Total paved network area in square feet per dwelling unit	1,478.7	2

Note: Network efficiency not included because of the inability to effectively rank the data – see p. 225 for results.

Table R.6: New Urbanist density results

Variable	Value	Rank
Gross density	8.8 dwelling units / acre	4
Gross theoretical residential population density per acre (based on actual number of dwelling units in model)	22.0 people / acre	4
Gross density potential for single-detached homes (based on 5,750 sq. ft. lots)	5.9 homes / acre	1.5

Table R.7: Network measures for the New Urbanist model, by mode

	Pedestrians		Cyclists	
	Value	**Rank**	**Value**	**Rank**
Coverage (by mode, per acre, in feet)	546.8	4	251.0	5
Connectivity – alpha index	0.20	2.5	0.20	2.5
Connectivity – intersection density (including alleys, per acre, by mode)	1.00	5	0.95	5
Connectivity – metric reach (in miles)	3.67	5	3.67	5
Connectivity – differential connectivity by intersection density	1.69	4	1.69	4
Connectivity – differential connectivity by metric reach	1.25	2	1.25	2
Continuity – POC density: ATN/Road (# per acre)	1.8	2	N/A	N/A
Continuity – POC density: ATN/Driveway (# per acre)	1.7	4	N/A	N/A
Continuity – overall rank (pedestrian: average rank of ATN/Driveway and ATN/Road)	N/A	3	N/A	N/A
Continuity – POC density: Cyclist/Car	N/A	N/A	1.0	1
Continuity – ratio of ATN-only intersections to regular road intersections	0.70	4	0.62	4
Modal separation – by coverage (Proportion of network providing complete separation from cars)	84.4%	4	15.7%	4
Legibility – by directional distance (in miles)	3.06	3	3.06	3

Table R.8: Trip-based measures for the New Urbanist model, by mode

	Pedestrians		Cyclists	
	Value	**Rank**	**Value**	**Rank**
Average trip length (equally weighted trips to edge & centre, in feet)	1,838.4	5	1,857.2	4
Directness ratios (equally weighted trips to edge & centre)	1.36	3	1.38	2
Differential connectivity based on trip distances Active Mode : Car (equally weighted edge & centre)	0.92	4	0.93	3
ATN/Driveway POCs per mile	14.0	4	N/A	N/A
ATN/Road POCs per mile	14.4	2	26.9	2
ATN/ATN POCs per mile	58.2	3	7.9	2
Road/Road POCs per mile	N/A	N/A	15.1	1.5
Overall trip-based continuity (average of applicable ranks)	N/A	3[1]	N/A	1.75[2]
Trip-based modal separation (rank by proportion of equally weighed trips to edge and centre made on paths offering complete separation from cars)	80.9%	4	20.1%	4[3]

[1]*: Average of ATN/Driveway and ATN/Road ranks*

[2]*: Average of Road/Road and ATN/Road ranks*

[3]*: When using the "cyclists on trails only" scenario for the Greenway model*

Greenway Model

Table R.9: Land use & efficiency results

Variable	Value	Rank
Diversity (Land Use Mix) (average rank of "Other" and "Park")	6% "Other", 16% "Park"	3.25
Buildable area as a percent of model area *(model space – road network area)*	86.7%	5
Road network area (roads, alleys and bike lanes)	13.3%	5
Other active transportation network area (sidewalk and trails)	5.7%	5
Total paved network area (roads, alleys, bike lanes, sidewalks and trails)	19.0%	5
Total infrastructure (Road Network + Parks) in square feet per dwelling unit	2,016.7	4
Total paved network area in square feet per dwelling unit	1,296.4	5

Note: Network efficiency not included because of the inability to effectively rank the data – see p. 225 for results.

Table R.10: Greenway density results

Variable	Value	Rank
Gross density	6.4 dwelling units / acre	2
Gross theoretical residential population density per acre (based on actual number of dwelling units in model)	16.0 people / acre	2
Gross density potential for single-detached homes (based on 5,750 sq. ft. lots)	6.6 homes / acre	5

Table R.11: Network measures for the Greenway model, by mode

	Pedestrians		Cyclists	
	Value	Rank	Value	Rank
Coverage (by mode, per acre, in feet)	237.5	1	237.5	4
Connectivity – alpha index	0.36 (with closed frame)	4	0.29	4
Connectivity – intersection density (including alleys, per acre, by mode)	0.33	1	0.74	4
Connectivity – metric reach (miles)	2.42 (with frame)	3	3.53	4
Connectivity – differential connectivity by intersection density	1.53	3	1.53	3
Connectivity – differential connectivity by metric reach	2.03	5	2.97	5
Continuity – POC density: ATN/Road (# per acre)	0.3	5	N/A	N/A
Continuity – POC density: ATN/Driveway (# per acre)	0.0	5	N/A	N/A
Continuity – overall rank (pedestrian: average of ATN/Driveway and ATN/Road)	N/A	5	N/A	N/A
Continuity – POC density: Cyclist/Car	N/A	N/A	0.5	3.5
Continuity – ratio of ATN-only intersections to regular road intersections	2.08 or perfect	5	3.76 or perfect	5
Modal separation – by coverage (proportion of network providing complete separation from cars)	96.6%	5	96.7% (cyclists assumed to use trail only)	5
Legibility – by directional distance	7.83 (with frame)	5	9.07	5

Table R.12: Trip-based measures for the Greenway model, by mode

	Pedestrians		Cyclists	
	Value	**Rank**	**Value**	**Rank**
Average trip length (equally weighted trips to edge & centre, in feet)	1,890.4	3	1,761.6	5
Directness ratios (equally weighted trips to edge & centre)	1.46	2	1.31	5
Differential connectivity based on trip distances Active:Car (equally weighted edge & centre)	0.95	2.5	0.89	5
ATN/Driveway POCs per mile	0.0	5	N/A	N/A
ATN/Road POCs per mile	5.1	5	9.1	5
ATN/ATN POCs per mile	120.4	1	61.7	5
Road/Road POCs per mile	N/A	N/A	6.1	5
Overall continuity (Average of applicable ranks)	N/A	5[1]	N/A	5[2]
Trip-based modal separation (rank by proportion of equally weighed trips to edge and centre made on paths offering complete separation from cars)	97.2%	5	97.2%	5[3]

[1]: *Average of ATN/Driveway and ATN/Road ranks*

[2]: *Average of Road/Road and ATN/Road ranks*

[3]: *When using the "cyclists on trails only" scenario for the Greenway model*