Activity Analysis for
Continuous Productivity Improvement in Construction

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.

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Abstract

In the construction industry, onsite labour is one of the most variable and costly factors which affect project profits. Due to the variable nature of construction labour and its correlation with profits, construction managers require a comprehensive understanding of the activities of workers onsite. For project success, it is important that workers are spending the majority of their time installing materials which advance the project. This material installation time is known in the construction industry as "direct-work" or "tool time". Site management should continuously seek to improve the direct-work rate through the life of the project. A review of the literature indicates that no workface assessment method exists in the literature which provides: (1) a detailed description of worker activities, and (2) a continuous productivity improvement process to help management identify productivity inhibitors affecting site labour, to develop a plan to reduce or eliminate these issues, and to measure improvements as a result of these changes. In response to this need, this research has focused on the development of a workface assessment method called activity analysis. Activity analysis is a continuous productivity improvement process which efficiently measures the time expenditure of workers onsite and identifies productivity inhibitors that management must reduce or eliminate to provide workers with more time for direct-work activities. Six case studies were conducted to verify the feasibility of the activity analysis process. Further, cyclical data from two major construction firms was collected and statistically analyzed to validate the hypothesis that activity analysis can improve direct-work rates. It has been concluded that activity analysis, as a continuous productivity improvement process, is both feasible and when continually applied to a construction site, can significantly improve direct-work rates through the life of a project.

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Chapter 1: Introduction

1.1 Productivity and Workface Assessment

In a competitive construction environment, it should be the goal of all construction companies to decrease costs in attempts to increase market competitiveness and profits. Kerry O'Brien, a productivity consultant from Toronto, Ontario, states that of all the factors which influence project profits, onsite labour costs are the most influential (K.E. O'Brien & Associates, Inc., 2008).

To reduce costs, it is important to identify areas of high and low productivity. Though there is no universally accepted definition of productivity, it is generally understood that productivity is the relationship between inputs and outputs. Inputs include costs associated with labour, equipment and materials. Indirect costs such as training and overhead should be considered, however they are often ignored because they are often fixed. Outputs consist of physical elements that advance the construction project. Low productivity is a result of too many inputs and too few outputs; that is, project costs are high with few deliverables completed.

There are two primary purposes for measuring productivity: to control project cost and schedule, and obtain data for planning future projects (H. R. Thomas & Mathews, 1986). There are several metrics site management may use to describe productivity. One of the most common is factor productivity, which considers the ratio between costs of labour, equipment, and materials, and outputs such as tons of steel erected or cubic metres of concrete placed. This metric is often termed unit rate, since it describes cost to install one unit of output. This has been modified into another metric called labour productivity which only considers labour as the input. A third common metric is the productivity factor which is the ratio of scheduled values of work hours with the actually performed values per unit output. These metrics have been criticized because they are often calculated months after the work has been completed once reports from the superintendents are received. When productivity is measured in this way, areas of low productivity are identified in the site office well after the issue first occurred onsite. By this time the project could be well off schedule and budget.

Workface assessment techniques have been developed in an attempt to identify productivity issues immediately, without waiting for cost information or work completed reports. Continuous observation was an early technique, but has been abandoned due to the discomfort of craft workers. In response to this, methods such as work sampling, foreman delay surveys, craftsman questionnaires and five minute ratings were developed. These methods offer site management an opportunity to identify problem areas in a much timelier manner than the productivity metrics described earlier (Liou & Borcherding, 1986; The Business Roundtable, 1982).

1.2 Research Need

Work sampling was identified in the 1980's as an effective technique that would gain widespread industry acceptance. Thirty years later, the method is still only being used by a handful of contractors. The work sampling method is strong and provides detailed, accurate information. However, the method has not been accepted by industry, because there is no easily accessible guide on how to perform work sampling. Further, work sampling identifies productivity issues, but does not determine the root causes or provide management with an outline how to plan and implement improvements. Contractors need a process to continually assess workface issues, identify root causes, and implement improvements so that labour costs can be reduced, thus increasing contractor profits and/or improving the contractor's competitiveness.

The construction industry requires a continuous productivity improvement process which utilizes a strong workface assessment technique. The process should provide a method for quickly assessing productivity levels, be able to identify productivity issues, propose and implement improvements to increase productivity, and reassess the productivity levels to quantify the effects of the improvements. The process needs a cyclical framework, so that productivity improvements can be realized throughout the life of the project. Currently, no such process exists in the construction industry.

1.3 Scope and Objectives

The primary objective of this research is to provide a comprehensive construction productivity improvement process that when applied helps contractors identify productivity issues on their project, and provide a framework for determining the cause of the issues and potential solutions. The process is to be cyclical so that a second study evaluates the degree of improvement realized by the first set of improvements. The results of the second study are also used to create a second set of improvements. The ultimate goal is for the contractor to be able to reduce site labour costs.

It is recognized that contractors will modify the process to suit their site specific needs. No process, method or program can be developed that considers every single construction scenario. For this reason, it is an objective to develop this process in a general base form that can be altered or enhanced as required.

The process will be developed for medium to large construction sites in all sectors of the construction industry. In this light, the process needs to be general enough so that it may be applied to all sectors. Though the process is applicable to small construction projects, the benefits realized may not outweigh the costs of full implementation; however aspects of the process can employed at a relatively low cost.

1.4 Research Methodology

The methodology to achieve the research objectives is as follows:

- Complete a detailed review of the literature focusing on construction productivity, productivity improvement methods, workface assessment techniques, and work sampling from its origins in industrial engineering until its current application in the construction industry.
- Interview construction industry experts representing major contracting firms, owner companies, and vendors in North America working in power, petro-chemical, refinery sectors and the like. Two of the interviewees are construction productivity experts who lead their respective construction firm's productivity department.
- Develop a comprehensive process, called activity analysis, for assessing activity levels at the workface and continually improving productivity. The new process is formulated using findings from productivity researchers and consultants through published literature, and the opinions and insights from the interviews.
- Perform six case studies involving multi-day site visits on construction projects made available by the construction experts who were interviewed. Two of the projects were visited by this author. Four of the projects were visited by research team members who reported their data to this author for analysis. This confirms that the process for collecting the data is adequate.
- Improve the process according to lessons learned from the case studies.
- Collect and analyze data from two major construction firms on a large set of construction projects who utilize continuous productivity improvement processes.
- Comment on the applicability of the process to other construction projects.
- Provide conclusions and recommendations regarding future research.

1.5 Structure of Thesis

Five chapters have been written to present the research objectives and methodology, the relevant background information related to activity analysis, the details of the activity analysis process, the case studies and statistical validation, and conclusions and recommendations.

Chapter 1 discusses the construction industry's need for a current workface assessment method that incorporates a continuous productivity improvement process. The scope, objectives and methodology to support the research need have been presented.

Chapter 2 summarizes the background information necessary to develop a foundation of knowledge for the research. The background presents: (1) an introduction to construction productivity including definitions and supporting equations, (2) construction improvement including learning curves, Hawthorne effect, and active changes, and (3) workface assessment methods such as foreman delay surveys, craftsman questionnaires, five minute ratings, and work sampling. The intimate link between work sampling and activity analysis is identified. To reflect this relationship a much more detailed literature review of work sampling is provided.

Chapter 3 presents the activity analysis process including a thorough explanation of its details. Included is the continuous productivity improvement cycle which highlights all five steps of activity analysis: planning the study, sampling, analyzing the data, planning improvements, and implementing improvements. Each step describes the actions that must be taken, and provides examples where appropriate.

Chapter 4 reports on the validation for the process which is comprised of two principle parts. The first is the six case studies performed at construction sites throughout the United States. Each case study describes the project visited, the sampling efforts, the results, and what the results indicate. Further, the statistical error of each study is calculated and reported. The second part of the validation process is the statistical analysis of data collected from two major international construction companies.

Finally, Chapter 5 highlights the major findings from the research in a section dedicated to conclusions. Further, a recommendations section discusses the potential for future research on this topic.

Chapter 2: Literature Review

2.1 Construction Productivity

The construction industry has found it difficult to develop a universally accepted definition of productivity. In general, productivity is considered the relationships between inputs and outputs (H. R. Thomas & Mathews, 1986). Inputs, measured in dollars, include labour, tools and equipment, and materials. Outputs are deliverables that contribute to the completion of the project, whether it is cubic metres of concrete placed, tons of steel erected, or length of pipe welded. As will be shown in the following equations and definitions, the ultimate goal is to reduce inputs and increase outputs, thereby improving productivity.

Factor Productivity

Factor productivity reports productivity as the number of units of output that can be produced using one dollar of input resources. These input resources include labour, equipment, and material, as shown in the following equation.

$$\text{Factor productivity} = \frac{\text{Units of physical output}}{\text{Labour \$+Equipment \$+Material \$}}$$

The metric for this equation is units per dollar (units/$), and therefore a higher factor productivity is the goal since more is being created from the same number of dollars. This is accomplished by either increasing the physical output holding the inputs constant, or decreasing the cost of labour, equipment, or material while maintaining the same output. Often there is little opportunity to reduce the costs of equipment and material significantly from project to project; therefore managers tend to concentrate more on labour costs which led to the development of labour productivity.

Labour Productivity

Labour productivity ignores the cost of equipment and material, because in the short term these are difficult inputs to change. Further, the cost of labour is affected by factors such as craft, experience, geographic location, etc. For this reason, labour productivity also ignores the actual cost of labour, and instead considers the number of hours to produce one unit of output. This is indicated in the following equation. (Groover, 2007; Thomas Jr., 1981)

$$\text{Labour productivity} = \frac{\text{Labour hours}}{\text{Unit of physical output}}$$

In this form, a smaller labour productivity value is desirable since labour hours (an input) are used as the numerator in the equation. This is in contrast to factor productivity, where a higher value was the goal.

Productivity Factor

Productivity factor is the comparison between anticipated labour productivity and actual labour productivity. A 2004 report by McDonald and Zack for the American Association of Cost Engineers provided an equation for productivity factor (McDonald & Zack, 2004):

$$\text{Productivity factor} = \frac{\text{Actual productivity}}{\text{Baseline or planned productivity}}$$

This can be clarified by the following equation:

$$\text{Productivity factor} = \frac{\text{Actual unit rate}}{\text{Planned unit rate}} = \frac{\text{Acutal work}-\text{hours per unit of output}}{\text{Planned work}-\text{hours per unit of output}}$$

In this form, a productivity factor less than one is ideal since the actual work-hours per unit is less than the planned work-hours per unit of output. It is noted, that some contractors report productivity factor as the reciprocal: planned over actual. In this form, a productivity factor greater than one is ideal.

When calculating activity durations, historical unit rates from previous projects are used. As the project progresses it is important to measure actual labour productivity and compare to the unit rate to determine if the project is on schedule. A productivity factor, calculated as per the equation provided, greater than one indicates more work-hours are needed than anticipated. This could potentially lead to cost overruns and schedule delays.

Activity Level

Activity level is the percent of time craft spend on a particular activity such as direct-work, preparatory-work, material-handling, waiting, etc. For construction managers the direct-work rate is most important because it quantifies the amount of time workers are actively installing materials toward the completion of the project. The direct-work rate can be calculated using a statistical work measurement method known as work or activity sampling. Observations of work are categorized, and the direct-work rate is calculated as the number of direct-work observations divided by the total number of observations.

$$\text{Direct} - \text{work rate} = \frac{\text{Observations of direct}-\text{work}}{\text{Total number of observations}}$$

This equation results in a percentage, which indicates the proportion of time craft is spending completing units of output. However, unlike the other three metrics, activity level does not actually consider the number of units produced. This is true for all activity level percentages.

2.1.1 Factors Affecting Labour Productivity

If productivity is to be increased, it is important to understand the factors which affect it. Articles by Randolph Thomas of the Pennsylvania State University list factors which affect labour productivity:

1. Type of project;
2. Scope and size of project;
3. Complexity of project;
4. Stage of project;
5. Type of craft;
6. Geographical location of project;
7. Weather conditions;
8. Special site conditions;
9. Layout of project (including congestion issues);
10. Construction methods (example of onsite fabrication versus prefabrication offsite);
11. Safety and housekeeping;
12. Labour skill level;
13. Absenteeism and labour turnover rates;
14. Distribution of workforce (journeyman to apprentice ratio, use of helpers);
15. Length of workday including schedule of breaks and overtime; and
16. Use of automated tools over manual tools (H. R. Thomas & Mathews, 1986; H. R. Thomas, 1991).

Note that each factor is not completely independent of others. For instance, the scope and type of project affects the complexity of the project. Further, the stage and scope of the project will affect the types of craft onsite at any given time. Generally, the early stages of projects contain more civil related crews who work in excavation, concrete, and steel. However, in later stages when the building frame has been constructed, the majority of the crafts become electricians and pipefitters.

The list of factors affecting labour productivity has been organized so that the factors which construction site management can affect are isolated. Factors 1 through 8 cannot be changed by the management team. Obviously contract specifics like scope and type of project are set. Further, stage is a natural progression, and the type of crafts onsite will be determined by the stage of the project. When attempting to improve productivity, factors 9 through 16 must be considered. How to identify which factors are adversely affecting site productivity is discussed in the activity analysis process in Chapter 3.

An article by Rojas and Aramvareekul in 2003 presented the results of an industry survey which identified factors which affect labour productivity. This list included factors that were identified by Thomas in 1986 and 1993, but also others which were not:

17. Capability of supervisors to manage work;
18. Materials management;
19. Lack of quality leading to rework;
20. Change orders; and
21. Economic climate (Rojas & Aramvareekul, 2003).

The article points out that change orders can have significant impacts on labour productivity. In three case studies, the average loss of productivity due to changes in scope amounted to 30% (Rojas & Aramvareekul, 2003). Further, Rojas and Aramvareekul argue that good economic climates encourage construction and leads to managers hiring workers with less skill due to labour shortages (Rojas & Aramvareekul, 2003). Again it is important to notice that no factor is unaffected by others, which is witnessed by the connection between economic climate and skill level of craft workers.

Again it must be determined which factors on labour productivity can be affected by construction management. From the second list it is identified that factors 17 to 19 may be controlled, but the economic climate and change in scope of work are out of the hands of construction managers.

2.2 Productivity Improvement

There are three important mechanisms which cause direct-work rate improvements in the construction industry: the learning curve, the Hawthorne effect, and direct improvements to the construction processes. The improvement due to the learning curve is limited as will be shown in the following discussion. The improvement due to the Hawthorne effect is artificial and temporary, and is caused from the situation of being observed. Only direct changes to construction processes will lead to true, long lasting improvements. It is this last mechanism that activity analysis aims to utilize for overall labour productivity improvement. However, improvements due to the learning curve and the Hawthorne effect must be recognized and isolated when performing activity analysis. For this reason, a background description of all three mechanisms is presented.

2.2.1 Learning Curve

Learning curve is the theory that as workers become familiar with an activity, they will become more proficient at it (H. R. Thomas, 2009). Though counterintuitive, Randolph Thomas proposed the following general learning curve in a recent article in the ASCE *Practice Periodical on Structural Design and Construction* (H. R. Thomas, 2009).

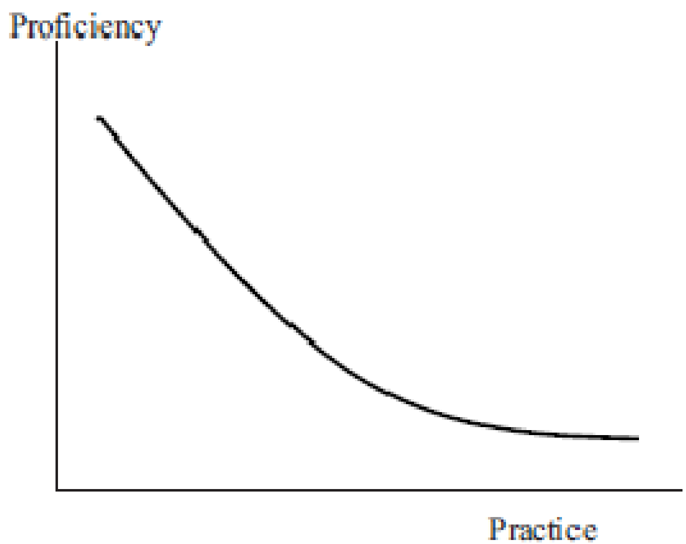


Figure 1: General hypothetical learning curve

In this representation, proficiency is defined as work-hours per unit completed, therefore lower values of proficiency means less work-hours to produce the same unit. Thomas noted that though a concave curve is the hypothetical representation, any shape is possible.

In 1994, Lutz, Halpin, and Wilson proposed a hypothetical representation of learning curve similar to Thomas', except that this early curve provided more information and specifically detailed the effect of learning on construction projects. It highlights that as the cumulative quantity of units produced increases, the production rate decreases. The production in this sense is the number of work-hours per unit produced. The curve has been included for the reader's reference (Lutz, Halpin, & Wilson, 1994).

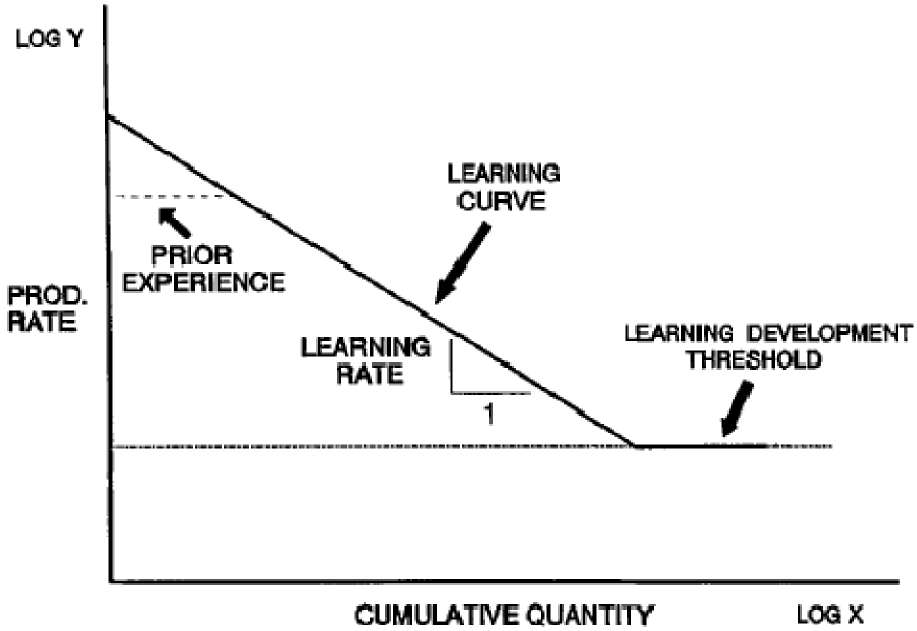


Figure 2: Construction specific hypothetical learning curve

The curve shows three distinct regions: a possible prior experience level, a learning curve, and a learning development threshold. This threshold is common to all curves because it acknowledges that at this point units are being produced as fast as possible, and no further man-hour savings may be realized without changing the actual work method.

The learning curve was first noted in the aircraft industry in the 1930's (Everett & Farghal, 1994; H. R. Thomas, 2009). T.P. Wright reported in a 1936 article, that during the course of assembling airplanes, a 20% reduction of required man-hours was realized each time the cumulative output doubled (Lutz et al., 1994). For industries such as aviation, automobile, power, petroleum, steel production, and electronics, the reduction due to learning has been reasoned to be between 10% and 40% (Lutz et al., 1994).

In a 1986 article in the ASCE *Journal of Construction Engineering and Management*, Thomas, Mathews, and Ward set out the reasons for a decrease in duration of repetitive activities:

1. Increased worker familiarity;
2. Improved coordination of both equipment and crews;
3. Better job organization;
4. Greater engineering support;
5. Better management and supervision of daily activities;
6. More efficient construction methods;

7. More efficient materials management; and
8. Stabilized design with fewer modifications and rework (H. R. Thomas, Mathews, & Ward, 1986).

In a recent summary article in the ASCE *Practice Periodical on Structural Design and Construction*, Thomas suggested that three factors are required for learning on construction projects:

1. Work must be sufficiently complex to facilitate learning,
2. Repetitive units must be constructed; and
3. A stable work environment must be created by management (H. R. Thomas, 2009).

Thomas states that a stable work environment would be a non-congested site with no disruptions. This and the factor of repetitive units were identified by a United Nations report in 1965, which Thomas referenced. However, the complexity factor was first identified by V. Frantezolis and confirmed by Thomas through his experience. Thomas states that he has seen no quantifiable improvements due to repetition in activities like masonry, reinforcing steel and caisson operations because these are not complex tasks (H. R. Thomas, 2009). Thomas continues to argue that it is uncommon for all these factors to be present, and therefore no true learning actually exists on projects (H. R. Thomas, 2009) .

Much literature regarding learning in the construction industry has focused on modeling this effect with equations. In 1986, Thomas studied five equations as shown in the following figure that was taken directly from the article (H. R. Thomas et al., 1986).

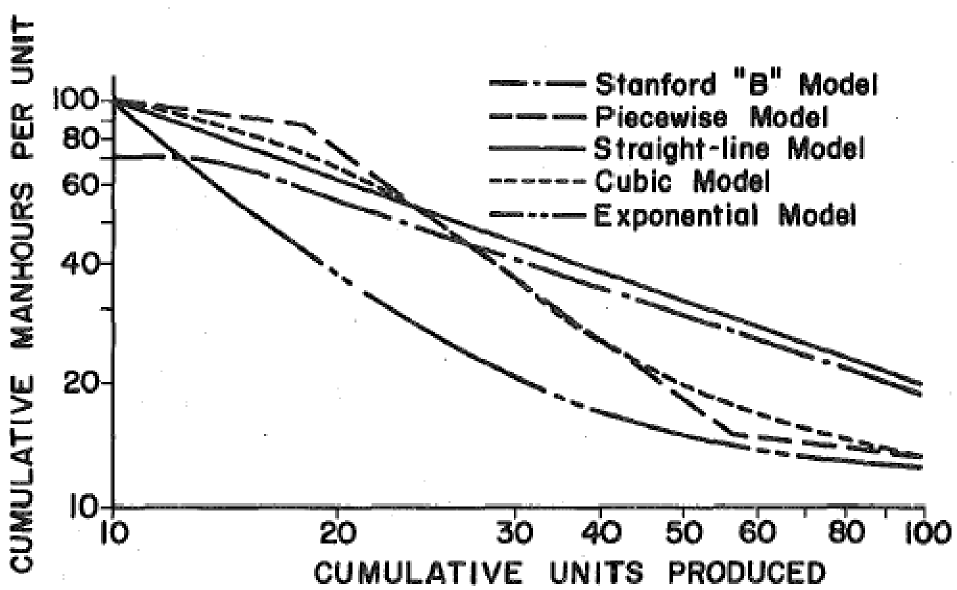


Figure 3: Five learning curve models

Thomas, Mathews and Ward compared all five models using data from 65 activities. It was determined that the optimal model for representing a learning curve in construction was the cubic model (H. R. Thomas et al., 1986). However, the authors state that no one learning curve model exists that would satisfy all situations (H. R. Thomas et al., 1986).

In a later study by Everett and Farghal in 1994, 12 equations to model the learning effect were studied. Each model could be categorized as linear, quadratic or cubic. It was ultimately determined that the optimal model was the log x, y cubic model as shown (Everett & Farghal, 1994).

$$y = a + b(\log x) + c(\log x)^2 + d(\log x)^3$$

This differed from the equation Thomas et al. identified as optimal, however this specific model was not considered in the 1986 study. Everett and Farghal also determined that the difference in cubic models were not significant, however all cubic models better represented the data than quadratic and linear models (Everett & Farghal, 1994).

Everett and Farghal attempted to extend this work by determining which of the 12 models most accurately predicted future points on the learning curve. The cubic function, which was determined to be most accurate at modelling existing data, was poor at predicting future points. It was determined that the log x, log y function was optimal at predicting the future (Everett & Farghal, 1994).

$$\log y = a + b(\log x)$$

The authors neglected the Stanford "B", piecewise, and exponential models which were studied by Thomas et al.

2.2.2 Hawthorne Effect

It has been identified that productivity may arbitrarily increase during studies due to workers being aware that they are being observed. The theory related to this phenomenon is that worker output increases when interest is shown from supervisors (Herzberg, Mausner, & Bloch Snyderman, 1959). Termed the Hawthorne effect, this theory applies to observers conducting productivity studies. Herzberg summed up this concept succinctly:

> No manipulation of working conditions or incentives affected productivity as much as the sheer exposure of the work group to observation (Herzberg et al., 1959).

The Hawthorne investigations (or studies) are the collective name given to studies conducted at the Hawthorne Works of the Western Electric Company in Chicago (Roethlisberger & Dickson, 1966). The initial study, conducted from 1924 to 1927, was funded by the National Research Council and attempted to determine the effects of light conditions on efficiency (Roethlisberger & Dickson, 1966). Two groups completing the same activities were isolated. The control group worked under normal conditions, while a test group was subjected to varying lighting conditions. It was determined that the production rate of both the control and test group rose through the study (Pugh, Hickson, & Hinings, 1985; Roethlisberger & Dickson, 1966).

Beginning in 1927, researchers from the Harvard Business School aimed to determine the relationship between work conditions and worker characteristics such as morale and fatigue (Roethlisberger & Dickson, 1966). The studies had three distinct phases with the intent of determining which factors contributed to employee effectiveness. In the first phase, six female workers were isolated in an experiment known as the Relay Assembly Test Room (Pugh et al., 1985). The workers were subjected to more than ten changes in working conditions including a special payment scheme, introduction of rest periods, shorter work-hours, refreshments, etc. (Pugh et al., 1985). After every change, the observers noted that output increased. Then the working conditions were returned to normal (i.e. the women worked eight hours per day, six days per week with breaks, and no financial incentives), and yet the output still increased (Pugh et al., 1985). From this study the observers concluded that physical conditions did not improve the output nearly as much as the benefit of developing and working in a social group (Pugh et al., 1985).

To further study the effect of a wage incentive on performance, a second group was studied. Known as the Second Relay Assembly Group, the group was given an incentive to increase output (Landsberger, 1968). This incentive was similar to the first group, but the increase in output was less. Authors have proposed theories on this increase and why the second study did not see the same increase. One proposed theory is the concept of a social group among all workers (i.e. those involved in the study and those not). Landsberger suggests that the rest of the workers were jealous towards the study and its incentives, and for this reason, workers in the test group did not increase their output as much as possible (Landsberger, 1968).

The third study, known as the Mica Splitting Test Room, was created to study both incentives and the effects of rest periods. The workers were subjected to changes, however less drastic than the original Relay Assembly Test Room (Landsberger, 1968). As anticipated the productivity increased, however near the middle of the study it began to decline. Observers attribute this to a decrease in morale despite shorter work hours (Landsberger, 1968).

The observers were confused by the results of the study. However, they felt confident to say that the increase in productivity of the first Relay Assembly Test Room could be attributed to a change in supervision where concern was shown for worker's conditions and morale (Landsberger, 1968).

Much of the work in the Hawthorne investigations have been heavily criticized by psychology and organizational theory researchers. These critics have attacked the premises of which the theories are based on, the methodology of the studies, and the conclusions on industrial workers (Wren, 1979). These critics are willing to attest to the fact that it was the Hawthorne investigations which spurred a change in management thought and an increase in research on human relations.

Though critics have attacked the findings of the Hawthorne investigations, any theories developed are far from conclusive. No researcher has ultimately proved or disproved that additional supervision increases productivity. Therefore we must acknowledge that a Hawthorne effect may exist when observing labour on construction sites. As seen in the Hawthorne investigations, a temporary increase in productivity may occur when workers are aware they are being studied. This biases any results from work sampling. It is of concern that the Hawthorne effect has not been discussed by previous authors on work sampling. The activity analysis process developed here outlines strategies to avoid or reduce the Hawthorne effect. Still, it has been argued by some construction productivity experts, that the Hawthorne effect is not a bad thing if it can reliably cause improvements on construction projects which have limited durations, as opposed to manufacturing operations with long durations.

2.2.3 Active Changes

Much research has been published on innovation in the construction industry, as well as improving construction processes. However, little information on effectively implementing these changes on a construction site has been published. It seems that a lot of researchers were content with identifying a construction need, research the subject, and propose solutions, but fall one step shy of proposing an implementation plan.

In an attempt to identify the factors that support successful implementation of change on construction sites, Sanders and Eskridge interviewed 12 construction related firms including design-build contractors, utility and other public owners, and suppliers. The focus of the study was on improving company operations as a whole, and not construction site specific, which is the focus of this research. However, with the identified lack of information on implementing change on construction sites, parallels were drawn when applicable.

Planning the implementation of a change was stressed by Sanders and Eskridge. It is essential that the current stage be benchmarked, and the future expectations be defined and communicated with all employees (Sanders & Eskridge, 1993). Benchmarking is an important function that cannot be overlooked. It is impossible to understand how you have improved without understanding what you improved from. It is proposed that milestones be set, and activities be identified and assigned to individuals with defined due dates (Sanders & Eskridge, 1993).

Another key factor to successfully implementing changes is a formal measurement and evaluation procedure (Sanders & Eskridge, 1993). The purpose of measuring and evaluating is to track the progress of implementation. The authors provided subjective means for measuring progress, but stressed that the measurement technique should be tailored to the company. It seems clear that the method used for benchmarking, should also be the method for evaluating. This will provide a solid metric for measuring the success of the project.

From Sanders and Eskridge's research, a five step process may be identified, though not specifically offered in the article. In general, the steps to the successful implementation of changes are:

1. Benchmark current process/activities;
2. Analyze the results of the benchmark;
3. Plan changes;
4. Implement changes; and
5. Evaluate changes.

The development of the activity analysis process utilized aspects of this outline, but it will be shown in Chapter 3 that the model enhances this outline into a complete process.

2.3 Workface Assessment Methods

There are several workface assessment methods. Of the most common are foreman delay surveys, craftsman questionnaires, five minute ratings, and work sampling.

2.3.1 Foreman Delay Survey

Foreman delay surveys are daily reports by the foreman which summarize issues which are adversely affecting productivity of their crew (Oglesby, Parker, & Howell, 1989). These productivity issues are beyond the control of the foreman, and therefore reflect management's effectiveness at planning work, and allocating tools, equipment and materials (Rogge & Tucker, 1982; The Business Roundtable, 1982).

At the end of each period, the foreman estimates the number of hours his crew was delayed. The foreman delay survey provided in the following figure was modified from Oglesby et al. After the time lost to each delay has been estimated, the foreman multiples the lost time by the number of members in a crew to determine the overall time the crew lost to that delay. This is summarized in the following equation:

$$\text{Labour hours delayed} = \text{Number of hours x Number of crew members}$$

These specific delays can be summed; however the relevant information is the amount of time lost on each specific delay, so that major delays may be targeted first.

Foremen have the best knowledge of productivity issues affecting their crews. Foreman delay surveys give the foreman an opportunity to communicate these issues through a succinct list of items so that steps may be taken to correct these issues. If management effectively minimizes these issues, it is logical that the number of work-hours would decrease.

The benefits of the foreman delay survey include:

- A simple method to measure and interpret results;
- Data acquisition is quick and at a low cost;
- Can canvas the entire jobsite;
- Provides specific delay information;
- Data collected is current and up-to-date; and
- Delays can be separated by crew and/or craft (The Business Roundtable, 1982).

Disadvantages of foreman delay surveys include:

- More paperwork for foremen;
- Foremen may be concerned of repercussions from management; and
- Potential for inaccurate results due to estimations (Oglesby et al., 1989; H. R. Thomas & Mathews, 1986).

Date: ____________________ Name: ____________________

Number in crew: ____________ General Foreman: ____________________

Foreman's name: ____________________

Problems causing delay	Manhours lost				
	Number of hours	X	Number of workers	=	Labor hours
Changes/redo (design error or change)	______	X	______	=	______
Changes/redo (prefabrication error)	______	X	______	=	______
Changes/redo (field error or damage)	______	X	______	=	______
Waiting for materials (warehouse)	______	X	______	=	______
Waiting for materials (vendor delay)	______	X	______	=	______
Waiting for tools	______	X	______	=	______
Waiting for construction equipment	______	X	______	=	______
Construction equipment breakdown	______	X	______	=	______
Waiting for information	______	X	______	=	______
Waiting for other crews	______	X	______	=	______
Waiting for fellow crew members	______	X	______	=	______
Unexplained or unnecessary move	______	X	______	=	______
Other: ____________	______	X	______	=	______
____________	______	X	______	=	______

Comments: ____

____

____

Figure 4: Example foreman delay survey template

2.3.2 Craftsman's Questionnaire

Craftsman's questionnaires were first developed in the 1960's, around the same time as foreman delay surveys. Similar to foreman surveys, craftsman's questionnaires attempt to quantify time lost through asking the opinion of someone intimately involved at the workface. In 1989 Oglesby et al., stated that simply asking the opinion of craft workers helped to identify weaknesses of the work process, create ideas how to solve productivity issues, and disclose workers' frustration over lack of tools, equipment and materials (Oglesby et al., 1989). It was the last benefit that Oglesby et al. believed was most beneficial since it helped create a stronger site to management relationship.

Formal craftsman questionnaires aim to identify inefficiencies at the workface. Questions of typical craftsman questionnaires focus on issues with materials, tools, equipment, scaffolds, rework, crew interferences, information flow, inspection, and employee relations programs. The survey is meant to be anonymous so that workers can openly express their opinions. Typically, the only demographic questions asked are trade and area of site. In this way inefficiencies are identified and may be improved upon. Further, the surveys also provide management with the ability to do job-to-job comparisons of working conditions, methods, and materials management. Often the surveys also identify demotivating policies.

One Construction Industry Institute research team recently worked to evolve old craftsman questionnaires into a more sophisticated assessment tool called the Voice of the Worker (VOW). In one study, the research team found improvements in the areas of construction equipment, project management, tools and consumables, supervisory direction, materials, and engineering drawing management within a two month period of initially completing a VOW assessment.

Benefits of craftsman's questionnaire include:

- Data is simple to collect and analyze;
- Can canvas the entire site;
- Results can be separated by craft or area; and
- Provides craft with a voice on important subjects (Oglesby et al., 1989).

Disadvantages of craftsman's questionnaire include:

- Craft may be concerned about repercussions of management; and
- Lower management may resent surveys (Oglesby et al., 1989).

2.3.3 Five Minute Rating

An older workface assessment method that is rarely used is the five minute rating technique. The method is used to create awareness of delays in a job, measure the effectiveness of a crew and indicate problem areas which require further study (Oglesby et al., 1989). The technique rates a crew's performance over a defined interval as either effective or non-effective (i.e. delay). This creates an awareness of the magnitude of delays and provides a measure of the effectiveness of a crew (H. R. Thomas & Daily, 1983).

During the interval, which ranges from 30 seconds to several minutes, the percentage of time actively working is estimated for each crew member using a form (Figure 5). The form has been modified from Oglesby et al. and has been provided for the reader's reference. As the form indicates, each crew member is rated as effective or not, all at the same time. If the observer determines the amount of time spent working by the individual is greater than 50%, the entire interval is rated as effective and receives a mark (Oglesby et al., 1989; H. R. Thomas & Daily, 1983). If the time spent working is less than 50%, the entire interval is rated as ineffective and receives no mark. Immediately after one interval has ended the next interval begins. This process continues for the length of the study period. Several studies of the same crew should be completed in a day.

The overall effectiveness of the crew is calculated as shown in the following equation:

$$\text{Percent crew effectiveness} = \frac{\text{Total number of effective intervals}}{\text{Number of intervals x Number of crew members}}$$

Benefits of the five minute rating include:

- Data collection is relatively simple and easily understandable;
- Very quick estimate of the general work behaviour; and
- Identifies areas that require further analysis (Oglesby et al., 1989; H. R. Thomas & Daily, 1983).

Disadvantages to the method include:

- Does not distinguish cause of delays;
- Difficult to accurately observe all crew members;
- Cannot canvas entire site; and
- Statistical reliability is very low (Oglesby et al., 1989; H. R. Thomas & Daily, 1983).

Date July 9, 2009
Job Erecting precast panels
Contractor N & E Corp.
Superintendent
Foreman

Time	IRONWORKER	IRONWORKER	CARPENTER	CARPENTER	CARPENTER	WELDER	
START	1	2	3	4	5	6	
10:13	✓						*Crew waiting for panel to be hoisted*
:14	✓	✓	✓	✓	✓		*Landing panel, welder waiting to*
:15	✓	✓	✓	✓	✓		*tack rebar*
:16		✓	✓	✓	✓		*Install upper bolts from braces*
:17		✓		✓	✓		*Install braces*
:18			✓	✓	✓		*Align panels*
:19			✓	✓	✓		*Align panels*
:20			✓	✓	✓		*Align panels*
:21	✓	✓	✓				*Unhook crane*
:22	✓	✓	✓				*Unhook crane*
:23						✓	*Weldertacks rebar, crew waits for next*
:24						✓	*panel to be hoisted*
:25						✓	
	5	6	8	7	7	3	*Effective unit totals*

Total Man Units 78

Effective 36

Effectiveness 46 %

Figure 5: Example five minute rating template

2.3.4 Work Sampling

Randolph Thomas, the foremost academic on work sampling in construction, defined the method as "a productivity measurement technique used for the quantitative analysis, in terms of time, of the activities of men or equipment" (H. R. Thomas & Holland, 1980). The method estimates the proportion of time craft workers are spending on activities such as installing materials, planning work, waiting, travelling, etc. (Aft, 2000; Liou & Borcherding, 1986; Picard, 2004)

Work sampling is a statistical technique where an observer collects a series of random observations from the worker population (Aft, 2000; Jenkins & Orth, 2003; Picard, 2004; Stoyanoff & Bowles, 1972). For each observation, the observer instantaneously determines the activity of the worker, and then records it in one of several activity categories. The categories included in the most general work sampling study are direct-work, preparatory-work, tools-and-equipment, material-handling, waiting, traveling, and personal-time. The proportion of time spent in each category is then determined by the percentage of observations of that activity from all of the observations. For example, if 331 direct-work observations are collected from 1000 observations, it is known that workers on that project spend an average of 33.1% of their time installing materials. Further, the statistical accuracy of this measurement can be determined from the number of samples collected.

Benefits of work sampling include:

- Provides detailed information similar to continuous observation studies, but in less time and at a smaller cost;
- Ability to canvas an entire construction site;
- No disruption of the work activities of craft or foreman;
- Craft more likely to accept work sampling compared to continuous observation; and
- Desired level of accuracy possible through statistical techniques (Jenkins & Orth, 2003; K.E. O'Brien & Associates, Inc., 2008; Picard, 2002; Picard, 2004; Stevens, 1969; Stoyanoff & Bowles, 1972; H. R. Thomas & Daily, 1983).

Disadvantages of work sampling include:

- Less efficient on sites where craft are spaced further apart;
- Provides no information on specific crews;
- Observations need to adhere to stringent levels of accuracy; and
- Potential for individuals to behave differently (i.e. the Hawthorne effect) (The Business Roundtable, 1982; H. R. Thomas & Mathews, 1986).

2.4 Work Sampling

Work sampling was developed by industrial engineers in the 1930's. The method slowly gained popularity, eventually being applied to the construction industry. The following presents a detailed background of work sampling, including major contributions to the body of knowledge.

2.4.1 Work Sampling in Industrial Engineering

Work sampling was originally developed in 1927 as the snap-reading method by Leonard Tippett as a work measurement tool to control inputs (Groover, 2007). Until this point, direct time studies were the primary work measurement tool used by industrial engineers. A direct time study is a stopwatch technique where the time of each subtask is measured and then summed to calculate the total time for the entire task (Groover, 2007). The purpose for the direct time studies was two-fold. Firstly, the results would help to refine time standards used to plan work. Secondly, the results indicated whether productivity was on course. If a timed task took longer than the time standard, the productivity was not acceptable. Accordingly, managers could take actions to correct the situation.

Tippett, a British statistician working in a cotton factory, identified several issues with the direct time study when trying to measure lost productivity of looms. Firstly, timing the operation of looms requires constant attention, meaning that only one observer could monitor a few looms. The cotton factory where Tippett worked had 200 looms (Tippett, 1934) . Developing accurate results regarding delays in operation for the entire factory would be long and laborious. Secondly, Tippett identified that loom operators were continuously changing activities such as repairing yarn, replacing yarn, lifting cloth, repairing looms, sweeping looms, and supervising loom operation. Because the movement between these activities is fluid, it can be difficult to accurately time each activity. Finally, Tippett identified the potential for operators to work abnormally because of the knowledge of being constantly observed (Tippett, 1934). As previously discussed, this phenomenon is known as the Hawthorne effect. To resolve these issues, Tippett developed the snap-reading method.

2.4.1.1 History of Work Sampling

The snap-reading method was conceived in 1927, but not published until 1935. Tippett described the snap-reading method as a series of instantaneous observations of looms and operators at random time intervals. These snap-readings are similar to taking a picture, no information before or after this instant in time is provided. Only observations from that instant picture can be used. Tippett understood that due to the law of averages, if the sample were collected randomly, with each loom and operator having an equal likelihood of being sampled, the sample should be representative of the entire population. As a large number of samples are collected, the sample average tends to move closer to the unknown population average.

The study published by Tippett illustrated two studies that he completed simultaneously at the textile factory. It was the purpose of this study to determine the amount of time that the looms were delayed. Further, the activities of the loom operators would be quantified. Table 1 summarizes the delays of the 200 looms studied by Tippett (Tippett, 1934).

Table 1: Summary of Tippet's 1934 Study of Looms

Loom Delay Category	Percent of Observations
Weft replenishment	8.5%
Weft break	1.7%
Warp break	3.4%
Pull back	2.6%
Cloth lifting	1.6%
Loom repairs & sweeping	1.8%
Weaver absent	2.1%
Miscellaneous	0.3%
In Operation	78.0%

Through the snap-reading method, Tippett was able to quantify these delays. By determining which delays are having significant impacts on production, managers were able to target these delays. In the results provided, replacing the weft was the primary cause of the loom not operating. The weft is the yarn which is weaved between parallel lines of yarn termed warp. Replacing the weft is a mandatory task to the operation of the loom, however with this information the managers may attempt to reduce the amount of time this task takes. By reducing this time, the loom should be in operation for a longer period of time.

During the same study, Tippett applied the snap-reading method to the operators. In the study, the operators were categorized into one of four categories as listed in the following table. The table also presents the results from the study (Tippett, 1934).

Table 2: Summary of Tippet's 1934 Study of Operators

Activity Category	Percent of Observations
Attending to weft	46.8%
Attending to warp	18.1%
General supervision	19.2%
Miscellaneous	15.8%

It is noted that the amount of detail between the loom study and the operator study differs a great deal. In the loom study, the managers had a detailed breakdown of the delays that are inhibiting production. The operator category does not include any delay categories. Though the information provided is valuable to managers, it is not detailed enough to point out problem areas to be corrected such as the loom study did.

In Tippett's article, he identifies the three advantages of the snap-reading method. Firstly, he states that the snap-reading method provides a better average for the entire facility than the direct time study (Tippett, 1934). The snap-reading method samples the entire facility. Much more labour would be required for the direct time study technique to collect data from all looms in the facility. Therefore, for the same amount of effort, the snap-reading method samples all looms and so is considered more accurate when considering the entire facility. The second advantage identified by Tippett was the lack of interference with the operators (Tippett, 1934). The continuous nature of the direct time study requires the operators to be monitored, thus making them uncomfortable and more likely to act abnormally. This would bias the results meaning that the calculated averages for the study would not accurately represent the true nature of the entire population. In contrast observers using the snap-reading method quickly sample work at each loom, and move onto the next loom. Each loom is observed through every random sampling round, but is not constantly watched. This method is less likely to cause the operators to act abnormally. The third advantage is the ease of the method (Tippett, 1934). In the direct time study, it can be difficult to identify the exact moment one activity becomes another due to the fluid nature of the work. Inaccurate times will lead to inaccurate results.

The procedure behind Tippet's snap-reading method has largely stayed the same from this point on. In 1940 a New York University professor, Robert L. Morrow, who often is accredited with bringing the method to America, changed the name to ratio-delay survey (Heiland & Richardson, 1957). This reflected Morrow's vision to use the method to establish delay allowances for time standards. Later in 1952, the term "work sampling" is used in an article in *Factory Management & Maintenance* by C.L. Brisley and

H.L. Waddell (Heiland & Richardson, 1957). This name change was to reflect the nature of the method as a sampling technique to determine work levels.

2.4.1.2 Application of Work Sampling in Industrial Engineering

The strength of work sampling is its ability to provide management with accurate, real-time information on the activities of the workforce. Once the method had been introduced to the industry in America, it began to gain in popularity. Researchers such as Ralph Barnes, Robert Heiland, and Wallace Richardson began studying and publishing results. Example studies included laundry at the University of Iowa and farm implement plants in the Midwest during the 1940's. Barnes published results on the reliability, validity and practicability of work sampling to manufacturing operations in 1950. Large manufacturers, such as Eastman Kodak, adopted the method and actively applied it to its operations (Barnes, 1957). In response to this rapid growth of the method, researchers identified that though articles and reports had been published, no comprehensive book had yet been published to guide industrial engineers on how to apply the method (Heiland & Richardson, 1957). Heiland and Richardson collaborated on a book titled Work Sampling, which was published in 1957. At the same time Barnes published a text of the same name, also in 1957.

In 1972 the United States General Accounting Office (GAO) published results in its summer issue of the *GAO Review*, stressing work sampling benefits to the manufacturing industry. A study had been completed on the behalf of the United States Department of Defense who had contracted out the production of airplanes. Nine observers collected 17,052 samples from a sample size of 206 representing a population of 1402 workers, over the course of ten days (Stoyanoff & Bowles, 1972). Though not the employer, the Department of Defense had a vested interest in the productivity levels of its contractor. The type of contract was not specified; however in the general sense a less productive crew meant an increase in cost to the Department of Defense, and a deliverable time behind schedule. The results of the study are reproduced in Table 3 (Stoyanoff & Bowles, 1972)

Table 3: Summary of GAO Study Work Categories

Work Category		Percent of Observations
Direct Productive	Direct-work	43.0%
Indirect Productive (30.9%)	Walking	12.5%
	Job Preparation	7.9%
	Talking	6.3%
	Planning & Analysis	4.2%
Non-productive (25.6%)	Idle Time	8.6%
	Personal	6.8%
	Unobserved	6.2%
	Unavoidable Delay	2.0%

Managers determined that the level of idle time and unobserved observations was unacceptable. An "unobserved" observation characterizes the time workers are away from the workface and are therefore not observed. It assumes that time spent away from the workface is unproductive. The GAO calculated that the savings from the elimination of idle time and the unobserved percentage through more effective management would amount to $2 million per year (Stoyanoff & Bowles, 1972). Further, it was determined that 165 man-days were needed to complete the study, totalling a mere $19,000.

The GAO study is important to the development of work sampling because it quantified the potential benefits of corrective actions based on the results of a study. Further, the study demonstrated that work sampling could develop a labour activity profile, detect inefficient methods and practices, and potentially set work performance standards.

2.4.1.3 Industrial Engineer's Perspective on Work Sampling

By the time of the GAO study, work sampling in industrial engineering had been well developed. So much so that industrial engineering writings identified the following advantages of work sampling:

- Compared to time studies which require continuous observation, work sampling costs less and requires less time in terms of labour hours to complete.
- Time studies can only monitor one or two operators or machines at one time; work sampling has the added benefit of monitoring several subjects at one time.
- When work sampling studies are completed across several days or weeks, short term abnormalities are avoided. An example of an abnormality would be one crew member becoming

sick for an entire week. A short direct time study would view high direct-work rates because everyone working especially hard to compensate.

- The work sampling method is more representative to the actual conditions than the direct time study.
- Due to the simplicity of work sampling, training observers is relatively short.
- Work sampling is less tedious than the constant observation which is required in the direct time study.
- Work sampling is less interruptive and uncomfortable for the operators than direct time study, because in work sampling the operator is viewed once, and then the observer moves on.
- Work sampling is suitable to activities with lots of tasks at a low repetition rate. Work such as this is difficult to measure using direct time studies.
- Work sampling has a quantifiable level of statistical reliability. Further, more accurate results may simply be obtained by collecting more samples.

The preceding list was a compilation of resources from L.H.C. Tippett (1934), Lawrence S. Aft (2000), and Mikell P. Groover (2007). Further, these resources compiled a list of disadvantages to work sampling. These included:

- Work sampling is less accurate at setting time standards when compared to other methods such as direct time study, predetermined motion time systems, and standard data systems.
- When the purpose of the study is to measure the activity of one worker or machine, work sampling is less practical. A direct time study would be completed much quicker.
- Efficiency becomes a concern in operations where workers or machines are not densely populated. For instance, it may not be economical to walk across the plant to collect 2 or 3 samples in each work sampling observation period.
- Work sampling lacks the detail that can be provided by studies such as the direct time study.
- Because work sampling does not specify results for each employee, differences between employees are not provided. This could be useful information for management.
- The work sampling method only categorizes productive work, it does not specify if the worker is using the correct method.
- Work sampling is to be completed at random times throughout the work day. To be economical, it is imperative that the observer uses the non-observation time productively.

The list of advantages and disadvantages for the use of work sampling in industrial engineering are extensive. Adaptation of working sampling to the construction industry began in the 1970’s due to this list of advantages, and despite the disadvantages. By nature, most construction activities have low repetition rates over longer periods of time than manufacturing activities. Being able to measure these low repetition activities was seen as the main benefit to work sampling. Work sampling was viewed as the next great tool that managers could use to effectively control labour input on a site. Construction productivity researchers like Randolph Thomas, John Borcherding, and Richard Tucker began to observe these studies and work to increase the benefit of work sampling to the contractors. Their efforts are discussed next.

2.4.2 Work Sampling in Construction

It is unknown when work sampling was first applied to the construction industry; however a paper on activity sampling was published by the Great Britain Building Research Station in 1969. It is noted here that activity sampling and work sampling are essentially identical methods. The Building Research Station was a government funded agency with the purpose of investigating construction materials and methods for residential buildings. In these efforts, the Research Station used activity sampling extensively, collecting 3,000 to 5,000 observations weekly on several building sites in Britain (Stevens, 1969).

The Research Station was using work sampling to obtain four pieces of information:

1. Movement of workers around a site;
2. Labour expenditure;
3. Duration of each task; and
4. Amount of non-productive time (Stevens, 1969).

The Research Station's use of activity sampling in construction reflects the reasons for which industrial engineers utilized work sampling. For example, setting time standards (the duration for each task) using work sampling was an industrial engineering concept.

2.4.2.1 Randolph Thomas' Contributions

Eventually, the uses for work sampling evolved to better suit the construction industry. In the 1980's Randolph Thomas of the Pennsylvania State University took the lead on work sampling research in the construction industry. For over a decade he was the foremost researcher and publisher of articles regarding work sampling. Thomas' journal articles focused on three main areas: summarizing attributes of a successful work sampling study, discussing specific aspects of studies, and comparing work sampling with other productivity measurement techniques.

In 1980, Thomas published his first journal article on work sampling. The article compared the results of eight work sampling efforts completed on new construction and maintenance projects in the power industry. The comparison of the studies was not intended as a discussion of productivity results on different projects, but instead to highlight attributes of a successful work sampling study.

Also in the 1980 article, Thomas stated that work sampling does not provide the basic information necessary for productivity improvement (H. R. Thomas & Holland, 1980). Thomas argues that results collected in the work sampling study will highlight problem areas, but cannot ascertain the precise reason for the problem (Thomas Jr., 1981). Thomas uses a case study in a 1981 article to illustrate how problem areas can be identified by comparing crews with each other. It has been Thomas' contention, and many authors since, that results illustrate the effectiveness of management (or lack thereof) and not the performance of craft workers (Thomas Jr., 1981).

Thomas compared specific crews with each other to determine which crews had reasonable direct-work rates and which others were struggling according to this comparison. By analyzing the data in this way, Thomas argued that specific crews with specific issues could be identified so that improvements could be realized. An issue with comparing crews is that this method of analysis does not indicate problems affecting the entire site. For example, it may be true that one crew has issues with material-handling compared to another crew; however in reality both crews may have issues with material-handling. Instead it is important to have targets with which to compare activity rates to understand which are reasonable, and which are of concern.

In 1982, Thomas' focus shifted from one-off work sampling studies to work sampling programs to be used to communicate productivity problems from the site to management (Thomas Jr., Holland, & Gustenhoven, 1982). In this discussion, Thomas numbered the four principles of a successful work sampling program:

1. Careful planning and implementation;
2. Careful monitoring of the program, and program changes to suit project changes;
3. Strong leadership so the first two principles are adhered to; and
4. Measure success of program by number of issues identified (Thomas Jr. et al., 1982).

In this light, Thomas warned of two issues of work sampling programs. The first is that often work sampling programs lose effectiveness with time (Thomas Jr. et al., 1982). To combat this, Thomas created principle number two: that as the project changes the program needs to respond and change accordingly. Secondly, Thomas warned that with time work sampling programs become more of an audit tool instead of a tool to highlight problems (Thomas Jr. et al., 1982). Thomas was unable to provide a comment to ensure this does not occur, simply reinforcing that when used as an audit, work sampling becomes antagonistic, and fighting ensues between management and labour.

Also, at this time, a document on construction productivity by the Business Roundtable, which Thomas was commissioned to complete, was published. The report was mainly focused on measuring productivity in the construction industry. In the appendix Thomas defined work sampling, and provided brief descriptions of certain aspects of the work sampling method (The Business Roundtable, 1982).

Thomas continued to publish articles on work sampling through the mid 1980's. The discussions in these articles centered on sources of error in work sampling, and the use of results as a predictor for crew output. These were noteworthy discussions and so have been included as separate sections.

In 1986, Thomas produced another report on the tools for measuring construction productivity. The report was written for the Construction Industry Institute, and included sections on work sampling, craftsman questionnaires, and foreman delay surveys. Also at this time a significant text titled <u>Productivity Improvement in Construction</u> was written by Clarkson Oglesby, Henry Parker and Gregory Howell. This text included work sampling as a chapter.

In 1991, Thomas published his final article regarding work sampling, ending his 11 year contribution to this topic. The final article was an about face on work sampling, with Thomas appearing not to support its use anymore. This may explain Thomas' lack of publication on work sampling between 1986 and 1991. The purpose of the article was to put an end to the "work sampling as an indicator of labour productivity" debate. As mentioned, this was a noteworthy debate which is summarized in the following section.

2.4.2.2 The Controversial Crew Approach

Before the work of Randolph Thomas, the typical method for work sampling was by what is known as the tour approach. In the tour approach, an observer samples on a random route throughout the construction site so that every worker may be included in the study. This approach gives the site management a good understanding of its effectiveness at planning for the entire site (The Business Roundtable, 1982). Thomas disapproves of the tour approach for two reasons. Firstly, he argues that walking the entire site means that the observer is unable to become familiar with craft workers, their workface, and their daily tasks (Thomas Jr., 1981). In one example, Thomas observed that two ironworkers were absent from the workface for up to two hours. He argues that if the observer is unfamiliar with these ironworkers, they would go uncounted and should have been included in a category titled "No Contact". The "No Contact" category means that workers were not sampled. Secondly, Thomas argues that because the tour approach includes samples from both critical and non-critical activities, management may assume that critical activities are progressing faster than actual because the inclusion of non-critical activities can distort the results (H. R. Thomas & Holland, 1980). To address these issues, Thomas proposed a new sampling technique called the crew approach.

First presented in 1980, the crew approach studies only the activities of a few crews, usually those with critical path tasks (The Business Roundtable, 1982; Thomas Jr., 1981; H. R. Thomas & Holland, 1980). In using this approach, the observer only samples a few crews, and therefore becomes familiar with the craft workers allowing the use of a "No Contact" category. Using the crew approach usually means a more specific objective, with narrowly defined categories, which will help to more readily identify the delays and their causes (The Business Roundtable, 1982). Thomas does admit that one drawback to this system is that only three to five crews can be sampled by one observer. It would be costly and impractical for management to have enough observers to cover the entire site in this manner.

Thomas also proposes a third approach. As the principle author of the Business Roundtable report on construction productivity in 1982, Thomas suggested a modified crew approach. In this approach, an observer would use the crew approach on several crews, all from the same craft. The observer would select one crew for each specific task that particular trade was completing at that time. For instance, if electricians were being studied, one crew pulling cable, one crew laying conduit, one crew connecting a panel, etc., would all be selected. Then these crews would be sampled, and the activity rates from the entire craft would be inferred based upon these results, despite the whole craft not actually being sampled (The Business Roundtable, 1982).

Becoming familiar with workers (whether by the crew approach or the modified crew approach) is controversial, because much literature states that it is important to receive worker buy-in and one major tenant to getting this buy-in is from the anonymity of the work sampling study. Workers are often concerned that an audit of their work is occurring in the study, and are concerned the results will be used for employment decisions. Before the study begins, management must stress with workers that the study is not an audit, and for this reason no worker names will be recorded. However, if an observer can recall someone is away from the workface, they have the ability to recall who is usually away, which could in theory be used for firing. Further on this topic, Thomas assumes the "No Contact" category should be classified as unproductive. This is not always true since a worker may be away from the workface collecting material, tools, or equipment.

Work sampling is believed to be less obtrusive than continuous stopwatch studies conducted in industrial engineering. It is imperative for workers to feel comfortable with the presence of the observer, and if they feel the observer is attempting to determine specifically who is wasting time they will modify their behaviour to not get “caught”. This relates to the Hawthorne effect, and is a serious concern. For this reason it is important to provide anonymity to the workers during the study, and therefore the activity analysis process will utilize the tour approach.

2.4.2.3 The Predictor of Labour Productivity Debate

Researchers have attempted to find a relationship between work sampling results and labour productivity. The following debate is not directly related to the author’s research; however it is a significant and interesting part of the limited work sampling literature.

In 1984, Thomas argued that work sampling could not be used as a predictor of labour productivity because work sampling does not consider output (Thomas Jr., 1981). We recall that labour productivity has been previously defined by the equation:

$$\text{Labour Productivity} = \frac{\text{Labour hours}}{\text{Unit of physical output}}$$

Compared to direct-work rate which is defined by the following equation:

$$\text{Direct} - \text{work rate} = \frac{\text{Observations of direct}-\text{work}}{\text{Total number of observations}}$$

Direct-work activities are defined as the act of exerting physical effort directed towards an activity or physically assisting in these activities. An example supporting Thomas’ argument is the case of two welders. Both welders could be observed to be completing direct-work activities 40% of the their work day, however welder one could complete twice as many welds than welder two, and therefore would have a labour productivity half of welder two. Note that according to the labour productivity equation, a smaller value is better.

In 1986, John Borcherding and Fwu-Shiun Liou contested Thomas’ argument stating that work sampling could be used to predict unit rate productivity. Work completed by the pair and published in a journal article stated that they had verified work sampling as an effective predictor of productivity, proved that work sampling information can be a predictor in a productivity projection model, and verified prediction power of the projection model that they developed (Liou & Borcherding, 1986). A working labour productivity projection model would be extremely beneficial to site managers since labour productivity is the primary productivity index used. However, real changes cannot be made because unit rates are often calculated much too late (Liou & Borcherding, 1986). Therefore, if work sampling results could predict labour productivity early, then necessary corrective actions could be taken earlier resulting in greater benefits.

Five years later in 1991, Thomas contests Borcherding's and Liou's claim. The article by Thomas statistically examines the data of seven work sampling studies that had been used as the basis for both his and Liou's journal articles. He concludes that there is no correlation between direct-work rates and labour productivity (H. R. Thomas, 1991). Further, he concludes that if a relationship between direct-work rates and labour productivity truly existed as Liou and Borcherding suggest, then the data points to greater productivity in the winter than the summer, and during the last stage of a project (80% to 100% completion) than any other stage (H. R. Thomas, 1991). This is illogical since in both Canada and the United States, productivity is generally higher in summer months and at early stages in construction when civil crafts are working without any barriers. Thomas continues, stating that winter months and last stages of construction as the highest times of labour productivity has been disproved by research, common knowledge in the construction industry, common sense, and documented statistics (H. R. Thomas, 1991).

2.4.2.4 The Erroneous Statistical Error Discussion

In his 1982 article, Thomas made another major contribution through his discussion regarding the sources of error in work sampling. Generally, error can be considered as random or systematic. Systematic error is the bias that consistently occurs in a study. Thomas attempted to list the sources of systematic error, which he labelled as bias or omission errors:

1. Human limitations (i.e. not all corners of a site can be observed);
2. Variations between observers;
3. Procedural deficiencies which do not anticipate all possible issues that could arise while sampling;
4. Observer bias;
5. Observer fatigue;
6. Identification of population in the study or not; and
7. Abnormal worker behaviour (i.e. the Hawthorne effect) (Thomas Jr. et al., 1982).

These issues were considered in the development of the activity analysis process. It would be extremely difficult to quantify these errors. Therefore, the response is to attempt to minimize these errors as much as possible through a diligent sampling procedure.

Sampling (random) error is the range of deviation of the measured mean from the true mean (Thomas Jr. et al., 1982). If the same characteristic were sampled multiple times, the range of results would develop the sampling error. Sampling errors are quantifiable using statistical equations. However, in many statistical sampling techniques, like work sampling, the planners select a random error to limit to, and determine the number of samples required. Many construction and industrial engineering journals provide the following equation for determining sample size based on desired error, and anticipated category percentages (Aft, 2000; Groover, 2007; Picard, 2004; Stevens, 1969; Thomas Jr. et al., 1982; H. R. Thomas & Daily, 1983; H. R. Thomas, Guevara, & Gustenhoven, 1984; H. R. Thomas, 1991):

$$n = \frac{(Z_{\alpha/2})^2 p(1-p)}{d^2}$$

where $Z_{\alpha/2}$ is the standard normal variable corresponding to a confidence level of α, p is the anticipated category percentage, and d is the error between the true percentage and the estimated. For a confidence level of 95%, $\alpha = 0.05$, and corresponds to a $Z_{\alpha/2} = 1.96$. If the anticipated percentage p is unknown, a value of 50% (0.5) may be used as a worst case scenario ensuring the number of samples will be overestimated. As stated, the general acceptable values for these variables in the construction industry are $p = 0.5$, $Z_{\alpha/2} = 1.96$, and $d = 0.05$, which results in a total minimum sample size of 384 observations (Oglesby et al., 1989; Picard, 2004).

Determining an adequate sample size is critical to the accuracy of the work sampling study. As more samples are collected, the results become more accurate as sampling error is reduced. However, there is a balance between statistical accuracy and the cost to collect samples. In most industries an error of ± 5% at a confidence level of 95% is generally acceptable.

The sample size equation is applicable to sampling exercises when the characteristic being sampled follows a binomial distribution; however work sampling is multinomial. In sampling, a binomial distribution applies to two attributes. Either the observation falls into one attribute, or it doesn't and therefore is the other attribute. Binomial distribution would be valid for productive or unproductive categories, and direct-work or not direct-work categories. Work sampling generally has more than two categories, since if the observation is not direct-work, it can be one of several other categories, and so is multinomial. The result for each category is subjected to the 95% confidence level and so has the potential to be wrong one time out of 20. However, there are several categories where the results all have a probability of being wrong once out of 20 times. Therefore, the probability of reporting one result wrong in the entire study is significantly greater than one in 20.

One solution proposed to address this issue was to use a confidence level of 1 – α/k, where k is the number of categories in the study (Thompson, 1987). For example, if the confidence level is 95% for the entire study and there are seven categories, then each category would be held to 5%/7 which equals a confidence level of 99.3% for each individual category. In this scenario, the number of observations increases from 384 to 724. However, the percentage for all seven categories cannot be 50%, and so this method overestimates the number of samples required (Thompson, 1987).

A second solution to determining the sample size for multinomial distributions was developed by S.K. Thompson in 1987. For a given confidence level, the following equation is calculated at varying number of categories m (regardless of the number of categories k in the study), to find the maximum number of observations n in the worst case scenario (Thompson, 1987).

$$n_0 = \max\left\{\frac{Z_{\left(1-\frac{\alpha}{2m}\right)}^{2}\frac{1}{m}\left(1-\frac{1}{m}\right)}{d^2}\right\}$$

For a 95% confidence and error of d = 0.05, the result is m = 3, and n = 510 observations. This means regardless of the category percentages, the confidence will always be greater than 95%.

In 1987, S.K. Thompson provided a table of sample size based on the preceding equation considering an error of ±5% (d = 0.05), for several confidence levels. The table appeared in the article "Sample size for estimating multinomial proportions" in *The American Statistician*. The values have been verified and reproduced here (Thompson, 1987; Thompson, 1992).

Table 4: Sample Size for Varying Confidence Levels and Error d = 0.05

α	d^2n_o	n_o(d=0.05)	m
0.5	0.44129	177	4
0.4	0.50729	203	4
0.3	0.60123	241	3
0.2	0.74739	299	3
0.1	1.00635	403	3
0.05	1.27359	510	3
0.025	1.55963	624	2
0.02	1.65872	664	2
0.01	1.96986	788	2
0.005	2.28514	915	2
0.001	3.02892	1212	2
0.0005	3.35304	1342	2
0.0001	4.11209	1645	2

This discussion indicates that equations for determining sample size of work sampling studies, which have been repeatedly reproduced in work sampling documents, is less accurate than believed. The activity analysis process produced in Chapter 3 utilizes this second more accurate equation.

2.4.2.5 Recent Literature on Work Sampling in Construction

After Thomas' final article in 1991, no literature on work sampling was written until work by productivity consultants began being published in 1996. Hans Picard, a productivity consultant working in North America, published an article describing partnerships the Tennessee Valley Authority (TVA) Fossil and Hydro Power established with two major contractors who completed the work. Due to utilizing only two contractors for all outages, improvements in productivity were possible across the system. It was reported that work-hour savings on TVA outages were as high as 20% (Picard & Seay Jr., 1996). A plot in the article indicated the improvement in direct-work rates beginning in the spring of 1993 until fall 1995 in which the direct-work rate increased from 50.3% to 67% (Picard & Seay Jr., 1996). The averages were calculated from 5 to 10 studies for every half year, representing several outage projects on TVA power plants.

A second article published by Picard identified the major causes of non-productive time. The list included insufficient planning and coordination, inefficient work practices, site logistics issues, inadequate supervision, unavailability of tools, materials or equipment, and lack of cooperation between crafts (Picard & Seay Jr., 1996). It is important to note that the bulk of these factors are management related and not caused by labour. This concept was first identified in literature by academics in the 1980's.

In the article Picard also provided important criteria for a productivity improvement program based on his experiences. This succinct list of criteria included:

1. Management buy-in;
2. Labour buy-in;
3. Outage team including observers, owner and contractor;
4. Challenging and measureable performance expectations with incentives;
5. Communication of expectations and results;
6. Analysis of labour usage with cost and schedule performance; and
7. Learn from experience (Picard & Seay Jr., 1996).

It is important to note that some academic researchers are still applying work sampling. A study was completed for a major pharmaceutical company by James Jenkins of Purdue University in 2002. During that study he concluded that work sampling results would indicate productivity inhibitors for management to resolve in an attempt to improve productivity. Jenkins proposes the use of third party observers, since the results have a better opportunity of being unbiased (Jenkins & Orth, 2003). Other literature has supported this position, however from an operational standpoint. It was viewed that using construction management personnel was not an effective means, because the assigned observer would be too busy with regular duties to add on the task of conducting and analyzing work sampling data. Currently the few work sampling studies being conducted in the construction industry are being completed by third party observers whether by productivity consultants like Picard, or independent productivity departments of major construction companies.

The last significant contribution to work sampling was a brief note in a manual published in 2008 by Kerry O'Brien, a productivity consultant in Toronto. Similar to Picard, O'Brien travels North America, not only performing productivity reviews of construction sites, but also educating site personnel on productivity issues. O'Brien stresses that direct-work rates will increase through the reduction of material-handling and “get-ready” activities (K.E. O'Brien & Associates, Inc., 2008). For this reason, the manual recommends actions to reduce the time spent handling material, onsite planning, getting tools, etc., with no information provided on how to perform work sampling studies.

Chapter 3: Activity Analysis Process

3.1 Continuous Productivity Improvement Process

A significant productivity text by Oglesby, Parker and Howell in 1989 outlined five steps of an improvement process for construction operations. The steps are reproduced here:

1. Gather data;
2. Analyze data;
3. Identify the problem;
4. Develop a new or revised method; and
5. Implement the new method (Oglesby et al., 1989).

This is a succinct methodology that has been supported by other academics. Productivity consultant Hans Picard utilized a similar three step approach when discussing work sampling:

1. Determine proportion of time lost on non-productive activities;
2. Analyze factors that cause non-productive activities or delays; and
3. Identify opportunities to reduce these activities or delays (Picard, 2004).

Picard has condensed the five step program of Oglesby et al., omitting the implementation step, though this is an obvious step that should be included, or else all previous work is useless.

An important step is missing from both outlines regarding productivity improvement. It is critical that the workface be reassessed to ensure that the changes implemented have caused improvements. Jenkins and Orth extended this concept to completing work sampling studies at regularly scheduled intervals so that any productivity improvements may be validated (Jenkins & Orth, 2003).

To reflect the contributions of Oglesby, Picard, and Jenkins, the following is an outline of the steps that were developed for the activity analysis process.

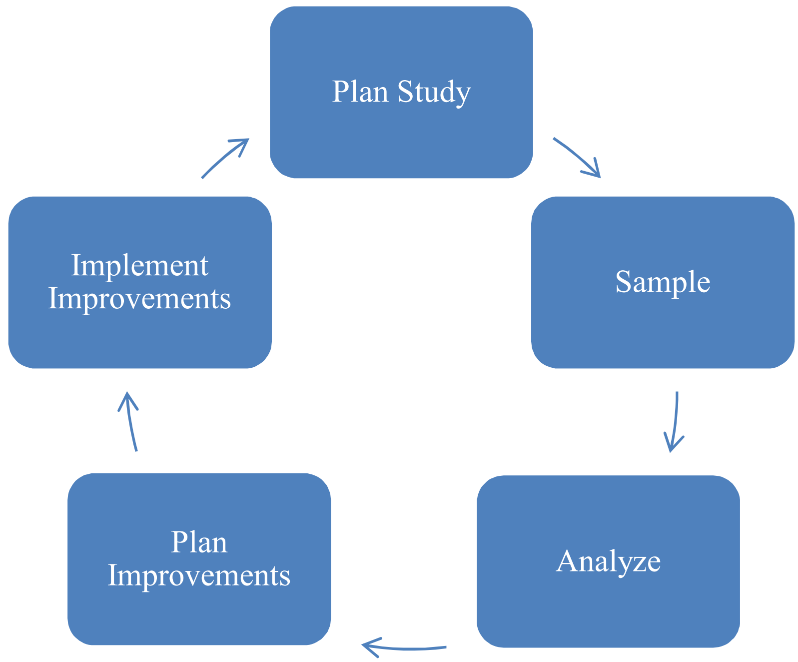


Figure 6: Activity analysis continuous improvement process

The process as outlined in the preceding figure begins at the plan study step. At this point, all details for conducting the actual study are decided. Elements include developing the objectives of the study, defining the population, the activity categories, the routes and times, etc. Next, the actual study is performed in the sample step. The third step is to tabulate and analyze the collected data. In the "analyze" step all data is combined and analyzed in several different ways which will result in activity proportions based on craft, area of site, and time of day. The analyze step also identifies potential productivity barriers. The fourth and fifth step is to plan and implement the improvements. These improvements are based on the productivity barriers indentified in the previous step and other notes made by the observer during the study. The steps of the process are described in greater detail in the following sections.

Notice, the outline is a continuous improvement process as indicated by the connection of the implement improvement step with the plan study step. The purpose of this is twofold. Firstly, as Jenkins argues, it should be proven that changes implemented caused an increase in the direct-work rate. Liou and Borcherding stated this best in a 1986 journal article:

> "In order to improve productivity, . . . one has to measure labor performance against some sort of standard before and after improvement measures have been introduced to reveal the usefulness of the corrective action." (Liou & Borcherding, 1986)

By comparing the first study with the second, the results of the changes can be determined. Secondly, since a second study has been conducted, the results can be used to identify further productivity barriers that may have arisen since the first study, or were not identified earlier. This creates the cyclical process of conducting the study, analyzing the results, implementing improvements, conducting another study to validate changes, and using the results for further improvement. The schedule of conducting studies should not be predetermined; instead it should reflect the needs of the construction project. For example, if the initial study determined low direct-work rates, it is important that a second study be conducted relatively quickly, as it is important to determine early if direct-work rates have improved. However, if the improvements required are minimal and may have minor change on direct-work rates another visit may not be required for several months.

3.1.1 Setting Targets

It is important for construction managers to set targets for all activity categories so that the site does not attempt to increase direct-work rates beyond feasible levels by arbitrarily trying to minimize all other activities. Further, it has been reported that improvement programs lose effectiveness when goals are not set and considered regularly. It is argued that targets should be ambitious, yet realistic. Having direct-work rates of 100% are impossible, and so are personal activity rates of 0%. The purpose of activity analysis is not to obtain these percentages; instead, its purpose is to reduce or remove barriers so that direct-work rates will increase, and personal activity rates decrease.

Targets need to consider several of the factors which affect productivity that were discussed earlier. For instance, it is important to consider the craft, project type, stage of the project and weather when setting targets. For this reason, the author stresses that targets must be reviewed regularly and revised accordingly. For instance, direct-work rates of crafts such as bricklayers, insulators, labourers, painters, and teamsters are generally high ranging between 42% and 46%, because the activities are simpler and require less planning than other activities like pipefitting, electrical work, and carpentry which have direct-work rates ranging between 27% and 29% (Oglesby et al., 1989). It is unrealistic to set the same targets for pipefitters as painters since the work differs greatly, and either the targets are not achievable for the pipefitter, or are not ambitious for the painter.

Targets should also change with the stage of the project. On a "greenfield" construction project, the direct-work rates at the beginning have the potential to be very high. This is because activities such as excavation, formwork, and even structural steel erection can be complex, however have limited barriers. These activities result in the creation of structural elements. As the project continues the distribution of crafts onsite shifts from predominately civil trades to pipefitters and electricians. Structural elements, which were constructed with little to no obstructions, become the obstructions for pipefitters and electricians making their work even more complex. For this reason, more planning is required which reduces direct-work rates.

Further, weather can have significant impacts on direct-work rates. It is unrealistic, for any particular month of the year, to set the same targets for an ironworker in Ontario, and one in Texas. The ironworker in Ontario contends with cold conditions and snow during winter months. The worker in Texas deals with extreme heat in the summer months which slow his production.

The following is a list of factors which should be considered when setting activity targets. Note that the list is not exhaustive and that the construction manager may include other factors which are beyond his control. Factors within his control should not be considered when setting targets, because these are the factors which will change if direct-work rates are determined to be low.

1. Type of project;
2. Scope and size of project;
3. Complexity of project;
4. Stage of project;
5. Type of craft;
6. Geographical location of project;
7. Weather conditions; and
8. Special site conditions beyond management control.

Setting targets can be a difficult task. The construction industry experts interviewed have comprehensive databases of activity rates for several categories from thousands of studies of hundreds of projects. The database is sorted by type of project and geographic location. During the development of the activity analysis process, it was determined that contractors should begin to develop these databases, and record the results of every study. The other purpose of a database is to compare results of previous studies of the project, and results of similar projects at similar stages. This is discussed further in the next section regarding baselining.

3.1.2 Baselining Results

Baselining is the act of recording the activity rates of the initial study. Further, other project data and characteristics should be included. The main purpose of baselining is to have a common datum, so that as the project progresses, the results of succeeding studies can be compared. For instance, if the direct-work rate was initially measured to be 25% before any changes were made, the results of the second study would indicate the effect of the changes. However, it is important to consider pertinent project characteristics when making these comparisons. Drastic changes in the site are possible if a long time has passed between cycles. To continue the example, assume the second study resulted in a direct-work rate of 26%. This appears to be a near negligible change in the direct-work rate. However, if it is determined through the project characteristics that the site is now more congested, and the work is more complex than the initial baselined study, then an increase of 1% in direct-work rate is good, since without the changes it could be expected to have declined.

The two contractors on the research team for this thesis who were completing work sampling, baselined projects for which the observers visited multiple times. Both contractors always compared the cycle to the baseline, regardless of the cycle number. Cycle 2 is compared to the baseline (cycle 1), and cycle 3 is compared to the baseline. To compare to the baseline, the analyst can either take the relative change, or the absolute change. For example, if the direct-work rate is determined to be 26%, and the baseline is 25%, it can be reported as a relative improvement of 4%, or an absolute improvement of 1%. Continuing the example, if the third cycle direct-work rate is 22%, it is a relative decrease of 12%, and an absolute decrease of 3% from the baseline. The fact that it gives a standard value for all future cycles is why a baseline is used.

When baselining and recording the activity analysis results it is important to include the following items so that comparisons may be drawn in the future:

- General project information:
    - Type;
    - Scope of work;
    - Size;
    - Level of complexity;
    - Location;
    - Number of workers per craft on site;
    - Percent union versus direct hire; and
    - Projected total installed cost.
- Project performance to date:
    - Stage of project; and
    - Cost performance;

- Schedule performance.
  - Study information:
  - Study dates;
  - Weather during study period;
  - Crafts involved in study;
  - Direct-work, preparatory-work, tools-and-equipment, material-handling, waiting, travel, and personal activity percentages (for entire study and hourly for typical day);
  - Pie charts and time series stacked bar chart; and
  - Deviation from activity percentage targets.

It has been recommended that this information be recorded immediately after the activity analysis results are calculated while the information is current and readily available. Often recording at a later date leads to incomplete or inaccurate information.

3.2 Step 1: Plan Study

3.2.1 Define Objectives of Study

The first step of planning an activity analysis study is to develop the objectives of the study. This objective should reflect the information that management wishes to determine from the data (H. R. Thomas & Holland, 1980). For instance, a common objective which was used for the field trials was to:

> Quantify the time expended by craft on productive and non-productive activities so that productivity improvements may be determined and implemented.

This is a general objective and so general categories are created to reflect this. Example categories which reflect this general objective would be: direct-work; preparatory-work; material-handling; tools-and-equipment; waiting; travel; and personal. These categories will be defined in the following sections.

The process has been developed so that a more specific objective can define a narrower study. For instance, management may want to determine what specific factors are causing delays. In this situation, the activity category of waiting in the general study is replaced by waiting-for-materials, waiting-for-tools, waiting-for-instructions, etc. A more narrowly defined study can produce very specific results, however it can be difficult to sample, and requires a comprehensive knowledge of construction methods.

3.2.2 Define Population for the Study

With the objective of the study determined, the study population may be defined. The population should be defined according to craft, shift, and job location. It is essential to understand the objective of the study to determine which craft workers should be included in the study. To reflect the common objective stated above, the population may be defined as the entire site. This means that all craft workers will be included. It is important to note at this point that foremen and superintendents are not to be included in the study, since they do not complete direct-work activities, and therefore they are excluded as to not skew the results.

In contrast, a more specific objective could lead to a population of electricians in a specific work area. Recall at this point, that it was determined that a tour approach was selected as the sampling methodology as discussed in Chapter 2. This was to protect the anonymity of craft workers. It is important to ensure that the population is not too small that the workers become uncomfortable because the observer is sampling from them too often. It is important to be able to highlight productivity issues with specific studies, such as electricians in an area of the site; however it must be balanced with worker comfort. As mentioned, if the workers feel they are being directly targeted, they will modify their behaviour and distort results.

It must also be recognized that depending on the site layout, including every worker as a member of the sampling population may be infeasible and uneconomical (Picard, 2004). This was confirmed with a construction productivity expert. On one particular site, the expert stated that he does not sample the laydown yard because there are only a few workers there compared to the several hundred working in close proximity on the project. The walk to the laydown yard was not reasonable simply for the inclusion of a few samples out of several hundred. Statistically, this means that the results should not apply to those workers not included. However, it may be reasonably assumed that these workers would have similar activity percentages as those workers of the same craft which were included in the study, within the specified error and confidence determined by the number of samples collected.

3.2.2.1 Craft Identifiers

Once the population has been determined, it is important that the craft workers have a distinguishing mark so that their trade may be identified during sampling. Craft identifiers are necessary if the results are to be broken down by trade. It has already been discussed that activity targets should be set for each craft individually. Therefore, to strive for these targets, it is essential that results be broken down by craft. An experienced observer may be able to discern a workers' trade by his/her activities. For example, pipefitters actively install piping. However, activity categories other than direct-work do not lend themselves to identifying the trade of the worker. For instance, if a worker is walking to the tool room with nothing in their hands or a specific tool belt on, it is impossible to determine their trade. Further, having to spend time determining the trade of each worker encumbers the activity analysis process. The method is meant to be quick. Having a distinguishing mark on the hard hat of the worker makes determining their trade much easier.

One such identifier is a colour coding system. One horizontal band of coloured electrical tape around a hard hat, determined by a key like the one below, means that a worker's trade can be determined quickly from any vantage point. The coloured tape system can be extended to identify journeymen and foremen. Journeymen could have two horizontal bands. This gives the observer the opportunity to breakdown the results beyond simply trade, but also by trade and experience level. Continuing this, foremen could have vertical stripes on the hard hat. If an observer sees an employee with a vertical stripe, they will immediately know they are not to be sampled. An example colour scheme is provided in the following table.

Table 5: Example Craft Identifier - Colour Scheme

Color	Craft
Red	Pipefitter
Blue	Boilermaker
Gray	Electrician
Green	Ironworker
Black	Carpenter
Orange	Labourer
Brown	Operator
Black/White	Millwright
Orange/White	Concrete finisher

It has been noted, that in some scenarios it can be difficult to identify the colour of the tape on some hard hats. This occurs when colours are similar in dark areas of a construction site. During one field trial, it was determined that in the lower levels of a building, it was difficult to determine a boilermaker from an ironworker because both dark blue and dark green were used respectively. It was determined that this system is further compounded by dark coloured hard hats, and the customization which craft workers often make to their hard hats.

Another craft identification technique is the use of numbers. Similar to the colour scheme, each craft has a specific number. In this case it is important that several numbers be placed on the hard hat, so the number can be viewed from any vantage point. An issue with this method of identifying craft workers is that the numbers need to be large enough to be spotted amongst other stickers from a distance of 15 to 30 metres. Furthermore, the number must not become worn.

Table 6: Example Craft Identifier: Numerical Scheme

Number	Craft
1	Pipefitter
2	Boilermaker
3	Electrician
4	Ironworker
5	Carpenter
6	Labourer
7	Operator
8	Millwright
9	Concrete finisher

3.2.3 Define Activity Categories

Activity categories should be customized for every project and should reflect the objectives set for the study (Picard, 2004; H. R. Thomas & Mathews, 1986). The level of specificity desired by the objective will determine the number of categories necessary. For instance, the general objective of determining how the craft works are spending their time requires fewer categories than if the objective was to determine specific areas of delay. The more categories selected, the more comprehensive the data is; however this is more cumbersome for the observer and therefore prone to errors. It has been recommended that only eight to ten categories be selected, though it has been suggested that this be a minimum and 15 to 20 is a realistic maximum (Groover, 2007; Stevens, 1969; The Business Roundtable, 1982). For the process presented in this thesis, seven categories were chosen.

Much literature regarding work sampling has offered suggestions as to the categories which should be chosen, and how they should be defined. In general, each study published contained roughly the same activity categories of direct-work, preparatory-work, tools-and-equipment handling, material-handling, waiting, traveling and personal (K.E. O'Brien & Associates, Inc., 2008; Oglesby et al., 1989; Picard, 2004; H. R. Thomas & Daily, 1983; H. R. Thomas & Mathews, 1986). These categories were selected for the activity analysis process. There were cases when some of these categories were further divided. For instance the study completed by Thomas and Mathews in 1986, divided the personal activity category into two separate categories: personal breaks; and late starts and early quits (H. R. Thomas & Mathews, 1986).

The classification of activity categories has often been discussed. Most literature has agreed to separate direct-work as its own classification, though it may be known as effective or direct installation, and it is sometimes called “tool time”. The second classification is supportive work (also known as essential contributory work, or indirect work). This classification generally consists of preparatory-work, tools-and-equipment, and material-handling. However a major contractor actively using work sampling has considered the travel activity category as supportive since workers need to walk to areas to collect items. The final classification is delay, but it has also been known as non-productive, ineffective, or idle. The remaining activity categories of waiting, travel, and personal are usually included here. Another major contractor using work sampling only considers two classifications: productive and non-productive. The productive class includes the activity categories of direct-work, preparatory-work, tools-and-equipment, and material-handling. The remaining categories of waiting, travel, and personal are considered non-productive. It is interesting to note the different classification of the travel activity category between the contractors. One considers travel supportive, while the other considers it non-productive.

Regardless of the categories and how they are defined, it is imperative that all studies have comprehensive definitions for each activity category, which consider all states of being of craft workers which could be witnessed by the observer (The Business Roundtable, 1982). It is shown in the category description, that each possible state for each craft is considered and written down. Well detailed activity category definitions ease the observation efforts, and creates consistency which is important so that observer bias may be limited (The Business Roundtable, 1982).

In 1980, Thomas identified the key question that should be asked when defining activity categories:

> “Do the categories provide the manager with the type of information needed in order to take appropriate action?” (H. R. Thomas & Holland, 1980)

The following are definitions of activity categories used in the activity analysis process. These definitions were created after the thorough literature review and detailed conversations with productivity experts of both major contractors who actively employ the method of work sampling. Photos have been included to depict a typical scenario which would be recorded as the activity category being defined.

3.2.3.1 Direct-work

Direct-work is the act of exerting physical effort directed towards an activity or physically assisting in these activities. Direct-work often involves workers installing materials, but also includes the physical effort of support groups. Specific examples of direct-work include:

- Labourers sweeping, removing trash, cleaning forms, placing concrete, assisting with excavations, distributing water and assisting other crafts with direct-work.
- Carpenters erecting or dismantling scaffolding, erecting or stripping formwork, erecting or dismantling temporary structures, installing doors and finishes, or assisting with concrete pours.
- Pipefitters or boilermakers fitting, grinding or welding an installation, connecting a pump or other equipment, installing blinds, actively involved in hydro test or physically assisting with these activities.
- Teamsters driving trucks to laydown yards to pick-up materials, delivering materials, or transporting personnel.
- Ironworkers erecting, bolting, welding, or positioning steel, rigging material, flagging an operator, actively involved in general traffic flagging/control or physically assisting with these activities. Ironworkers positioning, tying, or placing reinforcing bars or physically assisting with these activities.
- Concrete finishers actively engaged or assisting in a concrete pour, finishing concrete, covering or protecting concrete, or grouting.
- Operators lifting or transporting materials, or actively positioning equipment, boom or hook.
- Oilers actively engaged in maintenance of equipment, assisting with the placement of equipment, providing flagging or rigging support.
- Millwrights installing, aligning, or adjusting equipment, or installing or adjusting shims.
- Electricians installing temporary power, installing raceway, pulling wire, installing duct banks, pulling or terminating cable, or testing systems.
- Painters mixing paint, preparing surfaces, or applying coating material.
- Insulators laying out patterns, shearing metal, fitting components, or installing insulation.

- Sheet metal workers laying out patterns, cutting or shaping metal, fabricating activities, welding, fitting, or installing ductwork.
- Any craft actively engaged in performing fire watch, confined space hole watch, providing tool or rod room attendant services, etc.
- Any craft physically and actively assisting another crafts direct-work.

The following three figures illustrate example direct-work activities. In Figure 7, two workers are placing concrete via a bucket. The workers are actively installing materials to advance the project. In Figure 8, two operators are completing direct-work activities. At first glance the driver of the truck may be classified as material-handling. However, an "operator" moving materials is a direct-work activity since he is completing his primary job in his craft which is to transport material from one location to another. This follows the definition for direct-work. The photo in Figure 9 illustrates an electrician installing an outlet.

Figure 7: Example of direct-work - placing concrete

Figure 8: Example of direct-work - operators moving material

Figure 9: Example of direct-work - electrician installing outlet

3.2.3.2 Preparatory-work

Preparatory-work includes those activities related to receiving assignments and determining requirements prior to performing tasks. Preparatory-work includes stretching activities, safety talks and start card processes. Preparatory-work also includes discussions to explain or plan the task at the work location. These discussions can take place between craft workers or between supervisors and craft workers. Specific examples of preparatory-work include:

- Receiving instructions at the gang box or foreman's station (craft personnel must be attentive).
- Receiving drawings, specifications or other task related and necessary information.
- Using radios for work related reasons.
- Inspecting the work area with supervision, safety or other craft workers to determine task requirements.
- Discussing material, tool, or equipment needs.
- Actively participating in stretching and safety talks.

In the following photo, two craft workers are using the drawings to plan their work; therefore this would be recorded as two preparatory-work observations. Had one of the workers been a foreman, only one preparatory-work observation would have been recorded since foremen are not included in the study.

Figure 10: Example of preparatory-work - planning work

3.2.3.3 Tools-and-equipment

This category includes activities associated with obtaining, transporting, and adjusting tools or equipment in preparation of performing direct-work activities. Specific examples include:

- Locating a grinder or other tool in a gang box and transporting it to the task area.
- Running welding leads to the work area or adjusting the welding machine.
- Connecting electrical supply or air supply to tools or construction equipment.
- Obtaining and transporting slings, shackles or similar tools.
- Putting on safety harnesses, face shields, cleaning safety glasses, or physically adjusting personal protective equipment (PPE).
- Adjusting the location of a scissor lift or other equipment in the immediate vicinity of work.

Figures 11 and 12 are presented to illustrate tools-and-equipment activities. In Figure 11, a carpenter moves a bucket of scaffolding clamps. The clamps are considered tools since they are not permanently installed on the project. Figure 12 is of a worker adjusting a boom lift in the immediate work area. Adjusting equipment is considered a tools-and-equipment activity. If both of these situations are observed on the site, each would be recorded as one tools-and-equipment observation.

Figure 11: Example of tools-and-equipment - transporting scaffold clamps


Figure 12: Example of tools-and-equipment - adjusting boom lift

3.2.3.4 Material-handling

This category includes transporting materials from one part of the facility to another, but does not include moving items in the general area of the task or into their final position. Examples of activities included are:

- Craft workers, other than operators and teamsters, transporting bulk materials from the laydown area to the project work areas. Material-handling by operators and teamsters is considered a direct-work activity because it is their primary job.
- All craft persons physically carrying steel, pipe, insulation, etc. from one location to another.

Figure 13 illustrates a material-handling activity. In this photo two bricklayers are assisting in transporting bricks to the workface. Providing that both are not riggers, the photo would be recorded as two material-handling observations. Had the bricklayers been riggers, and they were guiding the bricks as they were lifted by a crane, the observation would be direct-work, since the riggers are completing their primary job. It should be noted that the bricklayers are not wearing sufficient personal protective equipment (PPE) for the job. Such observations should be noted, and an appropriate suggestion made.

Figure 13: Example of material-handling - moving bricks

3.2.3.5 Waiting

The activity category of waiting is defined as periods of waiting or idleness, even if attentive to ongoing work by others. Examples include:

- Waiting for instruction or job assignments from foreman or other supervisor.
- Waiting for a truck, crane, or bus to arrive to transport material or personnel.
- Waiting to gain access to work area or for another craft to finish work.
- A pipefitter waiting for a welder to complete a weld.
- Electricians waiting for a cable pull to begin.
- A rigger waiting for a crane hook to return for the next lift.

- A concrete worker waiting for a bucket to return with the next load of concrete.
- A teamster waiting for truck to be loaded or unloaded.
- An oiler waiting for an opportunity to maintain equipment or assist an operator.
- An operator waiting for an item to lift or move.
- Any craft worker waiting at the clock to clock out.

Figure 14 illustrates a common scenario where waiting observations are often recorded. The photo depicts a crew tying a reinforcing bar cage. As five workers tie the reinforcing bars, another stands and watches. The five workers tying the reinforcing would be recorded as five direct-work observations. The idle worker would be classified as one waiting observation. This observation is made since the worker is attentive to work and is waiting for work. If the worker had been inattentive to the work of others, one personal observation would have been recorded.

Figure 14: Example of waiting – idle, but attentive to work of others

3.2.3.6 Travel

Travel activities include walking or riding empty handed or without tools, materials, or technical information. Specific examples of travel include:

- Any craftsperson walking or riding with empty hands (carry normal tool belt tools, such as a carpenter with a hammer or an ironworker with a spud wrench, is considered travel).
- An operator of any equipment using the equipment to travel from one site location to another or around the perimeter of the site.
- Workers traveling to and from work areas during normal working hours.

Figure 15 illustrates two travel observations. In the photo, two workers are walking. Note that it is impossible to categorize the craft of these workers, and therefore a craft identifier is required. It could be that at this site electricians wear blue hard hats, and so the photo would be recorded as two electricians traveling.

Figure 15: Example of travel - workers walking

3.2.3.7 Personal

The personal category includes time taken or idleness during normal work hours and normally not attentive to work (this excludes normal breaks and lunch periods). Specific examples of personal activities include:

- Rest periods or coffee breaks during normal work hours.
- Smoke breaks or snack breaks during normal work hours.
- Rest room or water breaks during normal work hours.
- Obvious socializing and non attentiveness to work in the area.
- Sleeping during normal work hours.
- Donning or doffing or adjusting personal clothing.

Figure 16 illustrates an example of a personal activity observation. Two workers sit and rest along a track. The observation could have been considered as waiting; however the workers do not appear to be attentive to the work progress. Additionally, they are sitting which indicates resting. Therefore, the observation would be recorded as two personal activity observations provided that this observation was not made during a scheduled break period.

Figure 16: Example of personal - sitting/resting

3.2.4 Plan Study Specifics

In this stage, several aspects of the study are determined including the statistical accuracy desired, the corresponding sample size, length of the study, tour routes, and workday study windows. The determination of sample size is critical to the accuracy of the results. Due to its importance, a separate subsection is devoted to how the sample size for the activity analysis process was determined.

The length of a study is determined by the sample size. The number of samples required per workday hour (e.g. 10 to 11am) may be equally divided by the number of days on site. For instance, if the sample size is 300 observations in one hour, and it is realistically determined that only 100 observations can be taken per hour, three days of observation will be required. It is recommended that for greater accuracy, more days than necessary be spent sampling. To continue the example, if the observer can spend five days sampling, collecting 100 samples per hour, then 500 samples will be collected for each hour after the five days. This increases accuracy because of the greater number of samples. Further, because more days are included, the results will be more representative of the whole situation on site. An environmental condition may be affecting the site for one or more of those three days, if samples are collected over five days, the results will be more representative despite the condition. It has been recommended in the literature that sampling be from one to three weeks (The Business Roundtable, 1982). This would create very accurate and representative results, but may not be feasible or economical.

Sampling routes need to be planned before the sampling period begins. It is important that each route cover the majority of the site, however it is preferable that it covers the whole site. It is important to the statistical accuracy of the sampling method that each worker has an equal opportunity of being witnessed. To do this, the observer needs to travel to the workface of each worker. It is suggested that the observer speak with construction management to discuss workface locations so that all can be included in each route (Jenkins & Orth, 2003). Several routes are required, and should be selected randomly so that craft workers cannot anticipate the time of an observation and modify their behaviour accordingly (Aft, 2000; Jenkins & Orth, 2003). The productivity expert of one consultant advised that when the same route is used over and over, craft workers have the opportunity to signal fellow workers of an impending observation. This is the Hawthorne effect and is a serious consideration for any activity analysis study. Using random routes will help to reduce or eliminate this statistical bias (Groover, 2007). With a random route, the craft worker will be unaware of any pattern. When a route is randomly selected, it is also suggested that the start location be randomly selected (Stevens, 1969). More tips and techniques to reduce the Hawthorne effect are discussed in the section regarding executing the study.

Another important aspect to be planned is the study window times. The literature has been divided on this subject. Some sources believe that work times spent on irregular activities, such as start up and clean up, should not be sampled because they are not indicative of the true work behaviour (Oglesby et al., 1989). One productivity expert stated that he does not complete a study during the first 30 minutes of a work day, 15 minutes before and after any break, and 30 minutes before the end of the work day. He feels he has other work assessment tools that can capture these ramping up and down periods in the day. Other literature states that not including these periods of typically low direct-work rates artificially inflates the overall direct-work rate, and thus all working periods of the day should be included in the study (Stevens, 1969; Thomas Jr. et al., 1982). The activity analysis process collects observations for all periods of the day for which the workers are receiving compensation. An hourly breakdown of the workday is included in the results so that the ramping up and down periods is separated from the direct-work rate peaks at mid-morning and mid-afternoon.

3.2.4.1 Minimum Sample Size Determination

For the activity analysis results to be accurate, it is critical that an appropriate sample size be selected. When the field trials were conducted for this thesis, the sample size determination equation which had been provided by several work sampling articles was used (Aft, 2000; Groover, 2007; Picard, 2004; Stevens, 1969; Thomas Jr. et al., 1982; H. R. Thomas & Daily, 1983; H. R. Thomas et al., 1984; H. R. Thomas, 1991):

$$n = \frac{(Z_{\alpha/2})^2 p(1-p)}{d^2}$$

Using a 95% confidence interval and an error of 5%, the minimum number of samples was determined to be 384 as per the following calculations.

$$n = \frac{(Z_{\alpha/2})^2 p(1-p)}{d^2} = \frac{(1.96)^2 0.5(1-0.5)}{0.05^2} = 384$$

This value is confirmed by Oglesby et al. in the 1989 productivity improvement text. Further, it seemed redundant to sample 384 times for worker populations less than the sample size. For this reason, a finite population correction factor was applied (Thompson, 1987; Thompson, 1992):

$$n = \frac{1}{\frac{1}{n_0}+\frac{1}{N}}$$

Where n_0 is the value calculated from an infinite population, and N is the size of the population. For instance consider $n_0 = 384$ (as previously determined) and a population size of N = 300.

$$n = \frac{1}{\frac{1}{n_0}+\frac{1}{N}} = \frac{1}{\frac{1}{384}+\frac{1}{300}} = 165$$

This was the method used in the field trials to determine sample size. However, the accuracy of the equation is based on a binary distribution. As discussed in Chapter 2 on the background of sample size determination, activity analysis follows a multinomial distribution because there are more than two categories. For this reason the following equation is applicable (Thompson, 1987).

$$n_0 = \max\left\{\frac{Z_{\left(1-\frac{\alpha}{2m}\right)}^{2}\frac{1}{m}\left(1-\frac{1}{m}\right)}{d^2}\right\}$$

From the sample size table in the literature review, it is known that for a 95% confidence and an error of 5%, a total of 510 samples are required. Further, it has been determined that the finite population correction factor is not applicable, since the actual population is not finite. The characteristic being sampled is not the workers, but instead the workers' behaviour at any one time (for example every minute, hour, etc.). It is this constantly changing behaviour of hundreds of workers that is being sampled. It is not infinite, but it is large enough that the true population is unknown. For the analysis presented in the next chapter, the actual error according to this new equation will be reported.

The required number of samples is calculated for a one hour period, such as 8 to 9 am. However, it may be impossible for one observer to obtain the required sample size in one hour of one day, so sampling for that one hour period (8 to 9 am) may be evenly distributed over several study days, and then the results summed up. Stacking, or summing up several days of observations for each period, increases accuracy.

3.2.5 Select and Train Observers

Selecting and training observers for the activity analysis study is critical to its success. A good observer has five qualities:

1. Have a comprehensive knowledge of construction;
2. Committed activity category definitions to memory;
3. Be able to easily identify crafts;
4. Adhere to the concept of instantaneous observation (the snap); and
5. Be free of bias.

When analyzing the activity analysis results, the observer has the greatest knowledge of the conditions onsite. Because of this, the observer will be the best analyst in identifying productivity problems and recommending solutions. In order to have this knowledge and be able to recommend solutions, a thorough knowledge of construction is required (Jenkins & Orth, 2003). Further, it is imperative that the observer knows both the categories and craft identifiers since it will make the study less cumbersome, and help the observer adhere to the instantaneous observation required. Often referred to as the snap, it must be as random as possible, but more importantly the observer must identify the craft and the activity category as soon as the worker is first seen (Stevens, 1969). Identifying the activity category at first sight minimizes the worker's opportunity to change his behaviour. Also the instantaneous observation will help the observer to not reason about the activities of a worker, which is another key to activity analysis (Oglesby et al., 1989). Reasoning what the worker was about to do, or just did, distorts the results since they are not representative of what was truly witnessed by the observer. This leads to the important characteristic of the observer being free of bias (Picard, 2004). The observer must not feel guilty for anonymously recording workers in one of the non-productive categories. In contrast, the observer must not be of the opinion that workers are lazy, and so infers that the worker is being unproductive. Both these conditions distort results.

3.2.6 Host Craft Information Session

The final step when planning the activity analysis study is to host a craft information meeting, where the objectives and process of the study are explained to the workers in detail. Much of the literature agrees on this point. It is important to achieve acceptance from the employees so that the presence of the observer is not seen as a direct audit against them, thus giving them reason to modify their behaviour (Aft, 2000; Groover, 2007; Thomas Jr. et al., 1982). As mentioned previously, if the workers feel they are being directly targeted, they will modify their behaviour. It has been witnessed that workers will purposely carry a tool wherever they go because they know getting tools is considered productive, but walking without tools is not. This is the Hawthorne effect in its worst form. Additionally, it strains the relationship between management and site craft labour.

There are three key factors that should be stressed at the information meeting. Firstly, the observer should inform workers that it is not continuous observation, and no stopwatches will be used. It is productivity consultant Kerry O'Brien's belief that methods like activity analysis are accepted more readily than continuous observation techniques which often use stopwatches (K.E. O'Brien & Associates, Inc., 2008). Secondly, the study methods, expected results, and benefits to the workers should be explained (The Business Roundtable, 1982; Thomas Jr. et al., 1982). It is generally believed that workers take pride in their work. If a study has the potential to help them work better, it is more likely to be positively received. Finally, it must be stressed that the data collection process is completely anonymous; therefore there is no way to make any employment decisions (Picard, 2004). The workers must understand that the productivity of the entire site is being measured, not the craft workers individually.

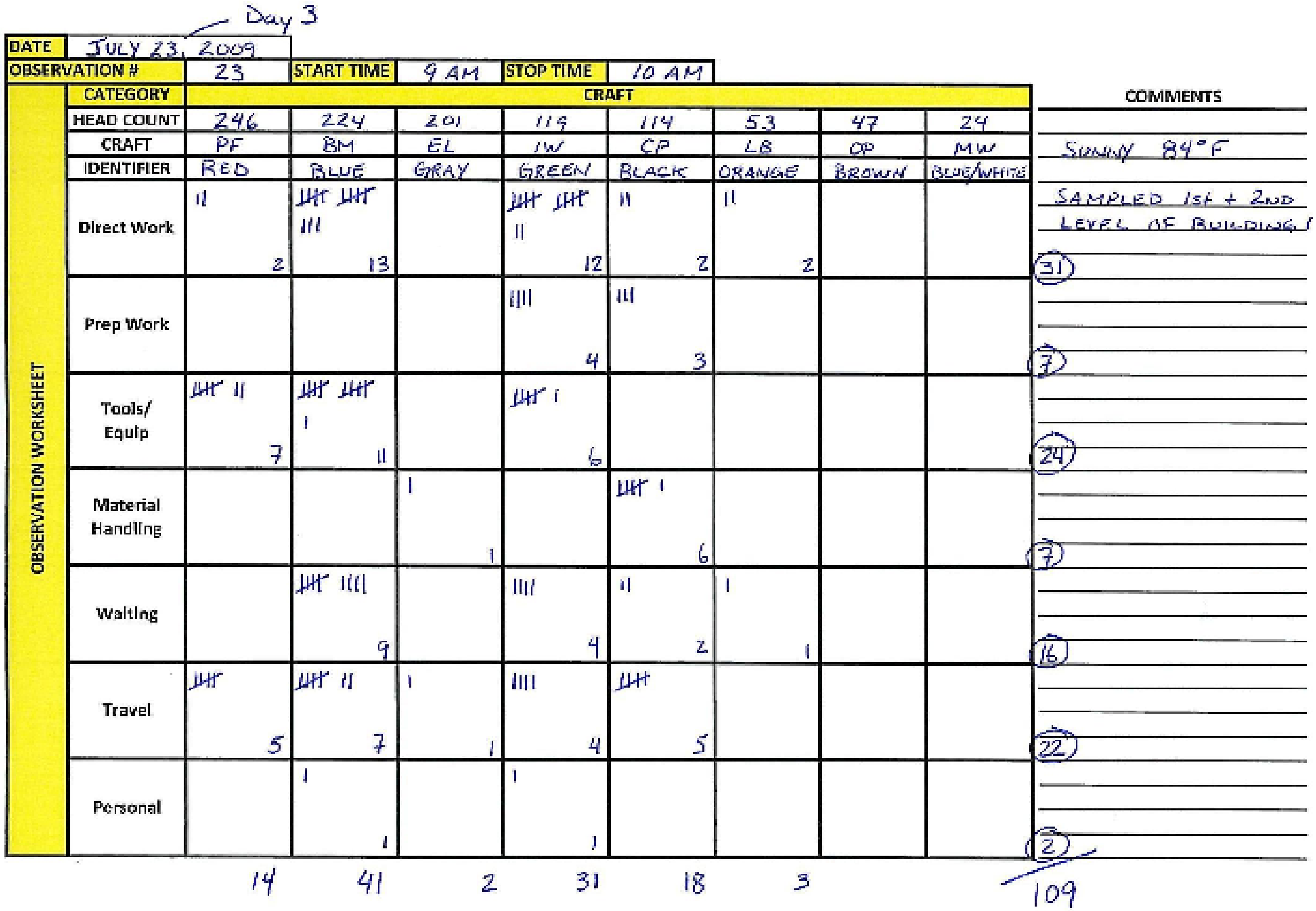
3.3 Step 2: Sample

The details of how the craft workers are sampled are presented in this section. The section also includes a discussion on how to avoid the Hawthorne effect to get unbiased results, and presents the data collection template for the reader's reference.

3.3.1 Execute Study

Before the beginning of the work day, the observer should prepare enough blank data collection sheets for each one hour period of study. The data collection form (Figure 17) contains spaces to insert the date, time of each one hour observation period, and spots for each craft's name, identifier and number of workers. The form also contains a right hand column, where the observer can make comments. Other information that could be recorded here includes temperature, location studied, and other pertinent details as the study progresses. These comments will prove valuable when identifying potential productivity problems.

Just before the first study period of the day, the observer goes to the random start location, of a randomly selected route. The observer then walks along the pre-defined route, characterizing the activity of each worker seen. As the observer approaches a craft worker, they instantaneously identify the craft and activity category of the craft. This is done from a distance of between 15 to 30 metres, since this is close enough to make an accurate recording, but not close enough to cause worker discomfort. It is critical that the observation be made at first sight of the worker, and the observer must not reason about what the worker was doing, nor wait a second to see what he does next. This is extremely important to ensure accuracy of the results.



Day 3

DATE	JULY 23, 2009								
OBSERVATION #	23	START TIME	9 AM	STOP TIME	10 AM				
CATEGORY	CRAFT								COMMENTS
HEAD COUNT	246	224	201	119	114	53	47	24	
CRAFT	PF	BM	EL	IW	CP	LB	OP	MW	SUNNY 84°F
IDENTIFIER	RED	BLUE	GRAY	GREEN	BLACK	ORANGE	BROWN	BLUE/WHITE	SAMPLED 1st + 2ND LEVEL OF BUILDING
Direct Work	2	13		12	2	2			31
Prep Work				4	3				7
Tools/ Equip	7	11		6					24
Material Handling			1		6				7
Waiting		9		4	2	1			16
Travel	5	7	1	4	5				22
Personal		1		1					2
	14	41	2	31	18	3			109

OBSERVATION WORKSHEET

Figure 17: Example activity analysis sampling template

When the activity and craft is identified, the observer places a mark in the box which cross corresponds to the craft and activity. Figure 17 illustrates a completed form for a one hour study period, with several marks. The observer should take every effort not to stand, characterize the activity, record on the form, and then walk away. This can cause discomfort on the part of the worker. Instead, it is recommended that the observer should collect the observations, and then walk past the workers or into a nearby quiet area out of sight, and record what was observed. This can be difficult at first; but the experience of the field trials was that with time this becomes possible. However, it is important that if accuracy cannot be ensured by recording away from the workface, the observer must record as soon as the work is characterized so that the results will accurately represent the true activities onsite. Ultimately, the accuracy of the data cannot be sacrificed to alleviate the workers momentary discomfort.

The sites visited during the field trials were large and complex. During the one hour study period the observer was not able to complete an entire route. In this scenario the observer begins to use the next data collection form at the beginning of a new one hour study period. This hourly segmentation gives management the opportunity to analyze the distribution of work activities by hour. If the route can be completed in an hour (that is the entire site is observed), the observer finishes the route, and prepares for the next study. In this scenario it is important to use random start times and not simply the top of the hour, so that the results are representative of the entire study period. For example, consider a route that takes 40 minutes to complete. If this route always started at 11:00 am and finished at 11:40 am, the 20 minutes before lunch will never be sampled. This period before lunch is often a time of high personal activity rates which is of concern to management. The study should instead begin at a different random time for each day of study so that the last 20 minutes before lunch gets included in the sample.

When inclement weather occurs, the study should pause through the duration of the weather event. During these times, observations collected will not be representative of the true work activities. Often work activities themselves will be postponed until the weather has passed. These inclement weather periods should be recorded. If enough samples cannot be collected during the remaining days of the study, an extra day may be necessary at the end of the study period to ensure enough observations for statistical accuracy.

It has been the experience of the observers that craft will be inquisitive about the study. The observer should openly communicate with the craft workers. It was Thomas' belief in 1982 that this open communication would lead to greater support for the study on behalf of the workers (Thomas Jr. et al., 1982). The observer should reinforce with the workers that the study is anonymously determining the overall productivity of the site, and ultimately the effectiveness of management, and that the study is in no way an audit on the workers individually or as a group.

3.3.1.1 Minimizing the Hawthorne Effect

Much of the literature describes workers changing their behaviour due to the study being performed. This unfortunately distorts the results and so defeats the purpose of performing the study in the first place. This is the Hawthorne effect, and has been discussed in detail in the literature review. However, a few articles have argued that using a method similar to activity analysis did not result in craft workers significantly modifying their behaviour. In 1981, Thomas indicated that there were no detectable adverse relations (Thomas Jr., 1981). In 1986, Thomas discussed what he termed the “hump effect”. He defined it as a natural increase in measured direct-work rates during the first few days of the study, which then declines to the normal rate despite the study continuing (H. R. Thomas & Mathews, 1986). In the study presented in the paper, the direct-work rate returned to normal after 5 days. In 1989, Oglesby et al. made the strongest argument that the Hawthorne effect did not significantly distort results, stating that that trained observers could record 85 to 90% of their observations before they were seen (Oglesby et al., 1989).

Despite arguments contesting the Hawthorne effect, it is impossible to state with certainty that workers do not change their behaviour when an observer is present. For this reason, each observer is informed of actions for trying to avoid any change in worker behaviour. The actions include hosting craft information sessions, using random routes, and using strategic observation techniques.

Host Craft Information Session

As discussed, craft workers can potentially react negatively towards any workface assessment study, especially those which employ the use of observers, since the observers are viewed as outsiders auditing them and their work. This concept of the study being an audit can be partially alleviated by communicating the purpose of the study at an information session before work has began. It should be stressed with workers that activity analysis identifies productivity inhibitors so that site management can correct these problems, thereby improving productivity. If the craft workers can see how an accurate study benefits their work day, they are less likely to change their behaviour.

Use Random Routes, Start Locations, and Times

Randomization is another way to limit the amount of bias in the activity analysis results. It may be expected that craft workers may modify their behaviour when they know a study is ongoing, despite the fact that they have been informed that it is not an audit against them, and that the results will benefit them in their daily work. However, it is believed that to arbitrarily increase their direct-work rate is not sustainable, and that the workers are less likely to change behaviour when the observer is not present. For this reason it is important to ensure that workers cannot predict an impending observation. To do this, the observer should travel a predefined route which has been randomly selected from several routes. Also, the observer should try to vary the start location, and the start time if reasonable. It is noted that if the study takes longer than an hour, then it is impossible to vary the start time since the observer should be constantly making observations. In this scenario the random routes and start locations should be enough to ensure that craft workers cannot predict an observation.

Strategic Observation Techniques

There are a few techniques that can be used while sampling to reduce the Hawthorne effect. Firstly, the observer should attempt to observe a crew before any member of the crew realizes the observer is there. The observation should be made within 15 to 30 metres of the workers. In general, it can be determined that a worker has become aware of the presence of the observer if eye contact is made. In this case, the observer should not record any observations because the worker has the opportunity to change his work activity. The observer should make the observation before this point.

Secondly, the observer should not record observations while standing watching the work activities. Recording facing the workers will obviously not change the result of this particular observation, however it can cause discomfort for the workers, and they are more likely to change their behaviour for the next observation. The observer should make a mental note of the crafts and work activities, and then quickly find a quiet place to record the observation. This is a difficult task, and should not be attempted unless the observer can ensure accuracy of results.

The observer should also try and find areas where crews can be observed without their knowledge. These areas need to be in the 15 to 30 metre distance to ensure accuracy, however there are several areas within this distance that can be used. Good examples are through doorways, or on platforms above workers on an open staircase. This technique is not about spying on workers, but instead observing without causing them discomfort.

Finally, an effective technique which has been determined is to walk past a workface mentally noting all the craft workers including their trade and activity, and then recording once out of sight. This is a very quick and effective technique, however inexperienced observers will find this difficult at first. Again it is important that if the observer cannot ensure accuracy he should not use this technique. However with time, the observer will be able to use the technique, and activity analysis studies will be much faster because of it.

3.4 Step 3: Analysis

When all one hour observation periods have been completed, the results are tabulated, the distribution of time spent on activities is calculated, graphic presentations of the total overall results and the hourly breakdown are developed, and the results are analyzed looking for productivity inhibitors.

To illustrate the process of tabulating and calculating the results, data from a field trial will be worked through. The study was comprised of 10 one-hour shifts over a three day period, thus there were 30 one hour observation periods. The particular study used for this example included pipefitters, boilermakers, electricians, ironworkers, carpenters, labourers, operators, and millwrights. The completed data collection form in Figure 17 was taken from this study. The calculations will show how to calculate percentages for the entire site; however the same principles can easily be applied to each craft individually. For further detail of these calculations, refer to Appendix A.

3.4.1 Calculating Total Overall Results

To calculate the total activity percentages for the entire study, the steps to follow include:

1. Summing observations per activity on the observation worksheets;
2. Inputting the observation counts into a spreadsheet according to hour and activity;
3. Summing total activity observations across all hours and days;
4. Summing total observations; and
5. Calculating study activity percentages.

Summing observations per activity on the observation worksheet

The number of observations in each box on the example observation worksheet (Figure 17) is summed. The sum is placed in the bottom right hand corner of the box. These values are added to determine the number of observation for a specific activity across all crafts. For instance, consider the number of direct-work observations for the one-hour period shown in Figure 17.

$$DW_{Day\ 3,9-10} = 2 + 13 + 12 + 2 + 2 = 31$$

The activity sums are placed on the far right of the form, which have been circled. These values are then summed to determine the number of observations for the study period. Continuing the example:

$$Total\ hourly\ observations = 31 + 7 + 24 + 7 + 16 + 22 + 2 = 109$$

Therefore, a total of 109 samples were collected for that particular one-hour period. Often the observer will quickly complete this step immediately after one study and before another, to indicate his progress. If 120 samples are required for every one-hour study period, the observer needs to collect observations faster, or another day of sampling will be required.

Inputting observation sums into a spreadsheet according to hour and activity

A spreadsheet is created to tabulate all activity sums for each data collection form. The spreadsheet is sorted by day, hour, and activity. The circled values in the example data collection form are put in the circled spaces of the example spreadsheet in the following figure. The data from all 30 data collection forms have been put into the sheet.

	Time	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30	Activity Totals	Percent of Obs.
Direct Work	Day 1	17	61	33	43	38	N/A	40	40	41	35	17	365	26.94%
	Day 2	4	10	26	31	25	N/A	35	37	32	22	13	235	
	Day 3	14	34	31	31	53	N/A	47	45	28	42	30	355	
Prep Work	Day 1	43	23	22	20	8	N/A	32	11	10	11	11	191	11.11%
	Day 2	33	2	10	15	14	N/A	14	10	6	4	4	112	
	Day 3	14	11	7	16	4	N/A	19	7	3	5	5	91	
Tools/Equip	Day 1	46	32	21	22	26	N/A	9	20	26	21	47	270	19.29%
	Day 2	34	12	14	17	20	N/A	16	19	21	18	41	212	
	Day 3	23	26	24	18	9	N/A	14	18	18	19	33	202	
Mat'l Hand	Day 1	1	10	6	9	18	N/A	16	15	8	9	4	96	8.38%
	Day 2	3	4	12	13	10	N/A	13	7	16	12	4	94	
	Day 3	6	8	7	4	16	N/A	16	13	17	15	5	107	
Waiting	Day 1	3	12	15	16	12	N/A	12	12	23	14	11	130	12.44%
	Day 2	22	27	25	10	13	N/A	10	3	12	10	16	148	
	Day 3	18	19	16	16	18	N/A	13	17	16	17	13	163	
Travel	Day 1	24	19	16	21	15	N/A	19	13	19	21	27	194	16.95%
	Day 2	23	21	26	20	22	N/A	15	19	27	22	19	214	
	Day 3	28	10	22	13	21	N/A	17	18	16	30	18	193	
Personal	Day 1	4	5	10	11	5	N/A	7	1	8	6	8	65	4.88%
	Day 2	0	8	14	9	11	N/A	1	2	6	4	7	62	
	Day 3	1	4	2	7	9	N/A	2	9	6	5	1	46	
	Hourly	361	358	359	362	367	N/A	367	336	359	342	334	3545	Total

Figure 18: Example activity analysis spreadsheet

Summing total activity observations across all hours and days

When all values for every data collection form is inserted into the spreadsheet, the sum of each activity category by day is calculated. For a three day study with seven activity categories, a total of 21 daily activity category sums will be calculated. As shown in the following calculation, the number of direct-work observations for the first day was 365.

$$DW_{Day\ 1} = 17 + 61 + 33 + 43 + 38 + 40 + 40 + 41 + 35 + 17 = 365$$

These values are reported in the second column from the right.

Summing total observations

Next all 21 daily activity sums are summed to determine the total number of observations for the entire study.

$$Total\ Observations = 365 + 235 + 355 + 191 + 112 + 91 + 270 + 212 + 202 + 96 + 94 + 107 + 130 + 148 + 163 + 194 + 214 + 193 + 65 + 62 + 46 = 3545$$

A total of 3,545 observations were collected in the three days of observation.

Calculating study activity percentages

Finally, each activity percentage is calculated by summing the three daily activity categories and dividing by the total number of observations. This calculation can be represented by the following equation.

$$\text{Activity percentage} = \frac{\text{Day 1 activity total+Day 2 activity total+Day 3 activity total}}{\text{Total number of observations}}$$

An example calculation for the direct-work percentage is given as follows:

$$\text{Direct} - \text{work rate} = \frac{365+235+355}{3545} = 26.9\%$$

The site visited uses ten hour shifts, therefore approximately 2.7 hours of each craft workers day is spent directly installing materials to advance the project. The remaining activities are calculated in the same way, and are reported in the right hand column of the spreadsheet.

The typical method for presenting activity percentages is in a pie chart. The pie chart helps to illustrate the proportion of a craft worker’s time spent in each category, and how reducing one category means there is more free time to complete direct-work activities. The pie chart for the example using the results in the spreadsheet is presented here.

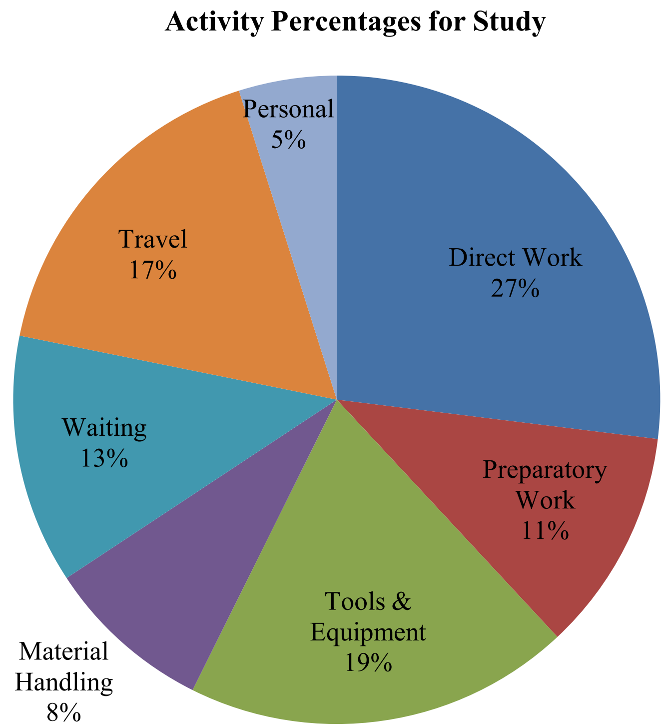


Figure 19: Pie chart illustrating overall activity results

3.4.2 Calculating Hourly Results

Hourly activity percentages are calculated next to provide management with an idea of how direct-work rates ramp up in the morning and after lunch, and how the activities ramp down before lunch and the end of the day. These results are graphically represented by a time series stacked bar chart. Generally the time series bar chart shows lower direct-work rates during the first hour of the day while workers plan work, and collect items such as tools, equipment and materials. In the second hour, the direct-work rate generally increases substantially. Further, direct-work rates at the end of the day are less than the daily average since workers are putting away tools and equipment. These are vital pieces of information for site management.

The steps required to calculate the hourly activity percentages for the study are as follows:

1. Summing observations per activity on the observations worksheet;
2. Inputting the observation counts into a spreadsheet according to hour and activity;
3. Summing total hourly observations across all activities; and

4. Calculating hourly activity percentages.

The calculation of hourly activity categories uses the same spreadsheet as the overall activity percentages; therefore steps 1 and 2 usually have already been performed and will not be repeated here. When calculating the overall activity percentages, the sums of rows were used. In contrast, the sums for hourly activity percentages are of the columns as described next.

Summing total hourly observation across all activities:

To determine hourly activity percentages, the number of observations collected for each hour during the three days of study is required. Because there are three days of study, and seven categories, each hour has 21 values from data collection forms. These values are summed along the column and recorded in the bottom row as shown in the example spreadsheet. For the study hour of 7 to 8 am, 361 observations were collected over the three days of study. This is illustrated by the following calculation:

$$Hourly\ Total = 17 + 4 + 14 + 43 + 33 + 14 + 46 + 34 + 23 + 1 + 3 + 6 + 3 + 22 + 18 + 24 + 23 + 28 + 4 + 0 + 1 = 361$$

Calculating hourly activity percentages

Next hourly activity percentages are calculated similar to the overall activity percentages, except instead of calculating only seven percentages, there are 70 hourly percentages (seven activity categories in a ten hour work-day).

$$\text{Hourly activity percentage} = \frac{\text{Day 1 hourly activity+Day 2 hourly activity+Day 3 hourly activity}}{\text{Total number of hourly observations}}$$

An example calculation for the direct-work rate at the 7 to 8 am study hour is given as follows:

$$\text{Direct} - \text{work rate} = \frac{17+4+14}{361} = 9.70\%$$

It is convenient to develop a separate table to summarize these results.

Table 7: Example Hourly Activity Percentages

	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30
Direct Work	9.7%	29.3%	25.1%	29.0%	31.6%	N/A	33.2%	36.3%	28.1%	28.9%	18.0%
Prep Work	24.9%	10.1%	10.9%	14.1%	7.1%	N/A	17.7%	8.3%	5.3%	5.8%	6.0%
Tools/Equip	28.5%	19.6%	16.4%	15.7%	15.0%	N/A	10.6%	17.0%	18.1%	17.0%	36.2%
Mat'l Hand	2.8%	6.1%	7.0%	7.2%	12.0%	N/A	12.3%	10.4%	11.4%	10.5%	3.9%
Waiting	11.9%	16.2%	15.6%	11.6%	11.7%	N/A	9.5%	9.5%	14.2%	12.0%	12.0%
Travel	20.8%	14.0%	17.8%	14.9%	15.8%	N/A	13.9%	14.9%	17.3%	21.3%	19.2%
Personal	1.4%	4.7%	7.2%	7.5%	6.8%	N/A	2.7%	3.6%	5.6%	4.4%	4.8%

This data is then used to develop the time series stacked bar chart.

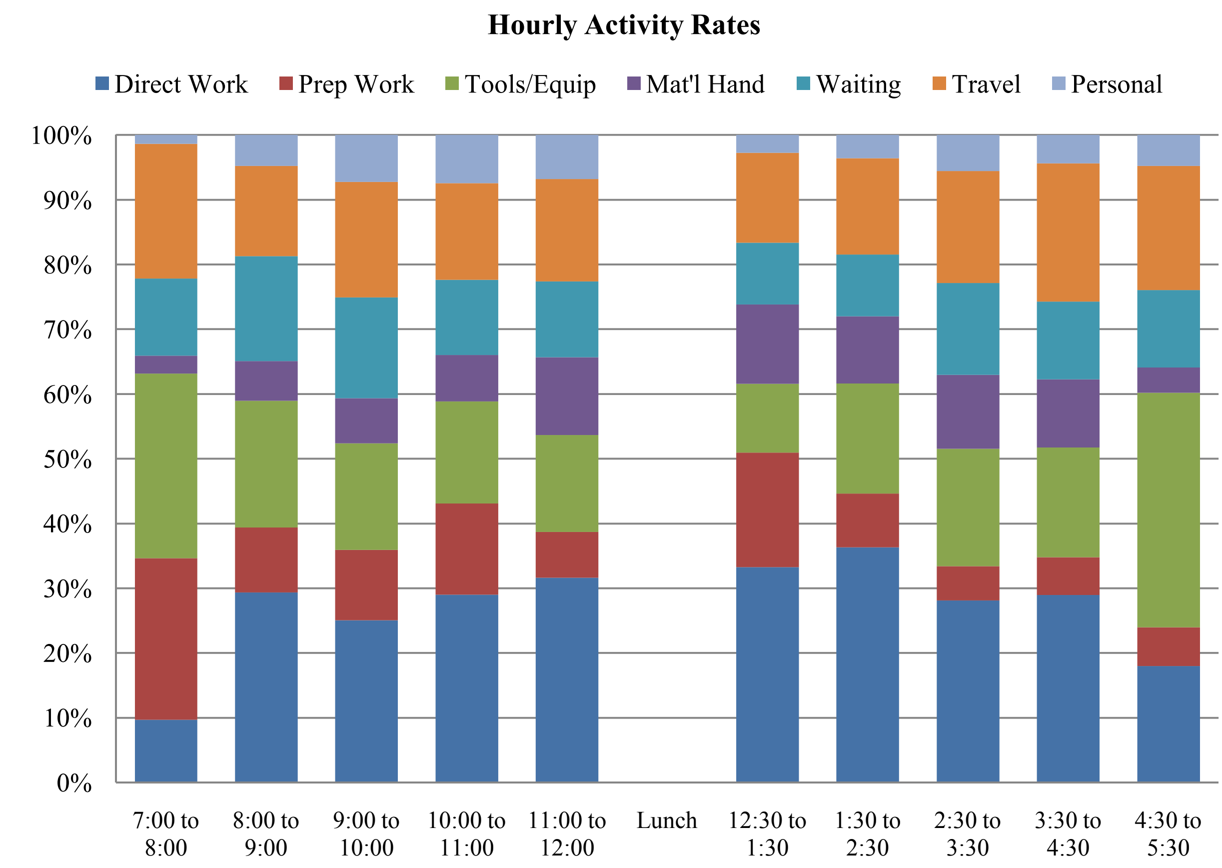


Figure 20: Time series stacked bar chart illustrating hourly distribution of activity results

In some cases, management may prefer other graphical representations. For instance a rollercoaster chart has been commonly used. The following is an example rollercoaster chart which presents the same data as in Figure 20.

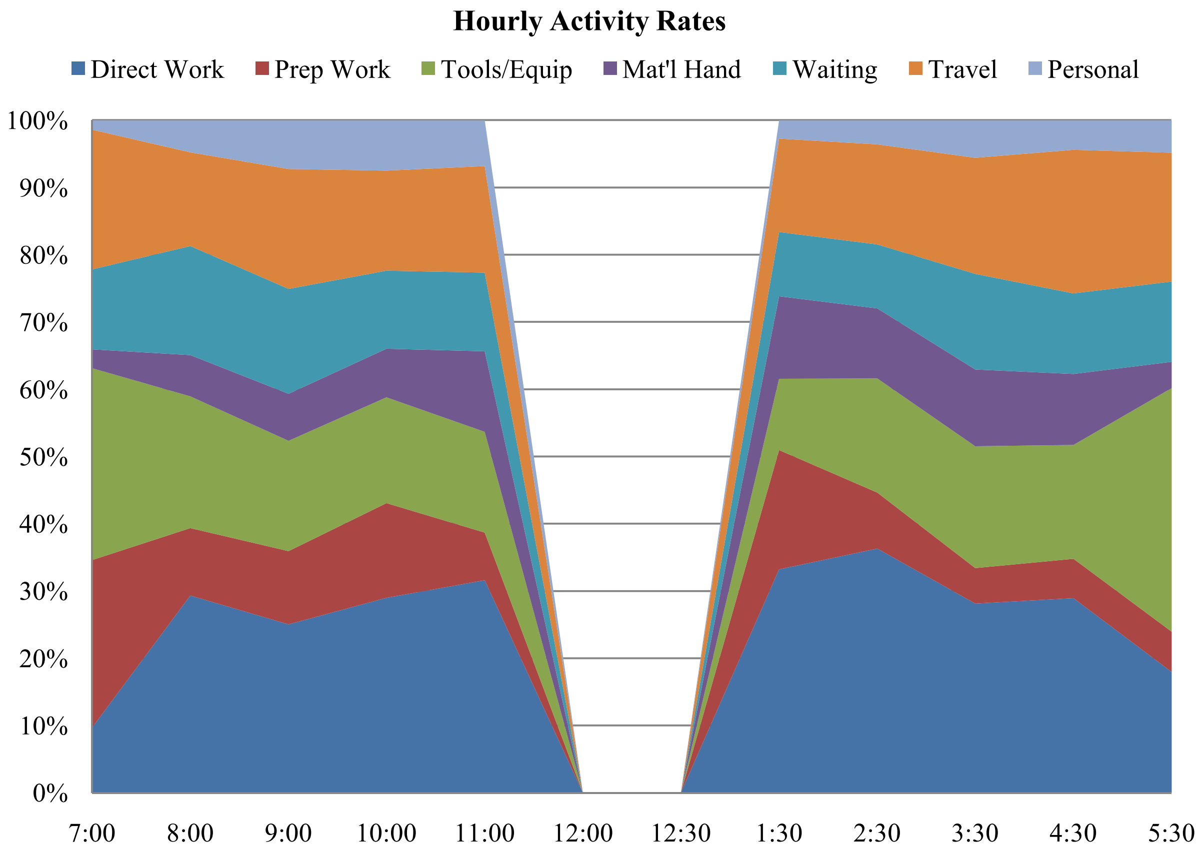


Figure 21: Rollercoaster chart illustrating hourly distribution of activity results

Both charts illustrate some typical concepts of site labour. Firstly, there is the typical low direct-work rate at the beginning of the day. The direct-work rate peaks by mid-morning and then declines toward lunch. The personal activity rate is higher just before lunch. The direct-work rate is slow the hour immediately after lunch, and then peaks mid-afternoon. This particular study included a mid-afternoon dip in the direct-work rate which is not typical but possible. These are some of the key areas that both types of representation offer which gives management an idea of what needs to be controlled. However, it is felt that the rollercoaster chart erroneously gives the impression of activity rates at time periods less than one hour because of its continuous nature. Whereas the time series stacked bar chart better represents the discrete nature of the data collected.

3.4.3 Interpreting the Data

Correctly interpreting the results of studies is one of the most difficult parts of activity analysis because conditions differ from one project to another. However, it is an important step, since the data will indicate issues on site which management can take immediate action to remove constraints or obstacles that are interfering with work (Picard, 2002; Picard, 2004).

Thomas suggested that the observer would be the best person to analyze and interpret the data. The observer has developed an intimate knowledge of the issues affecting the whole site since he has been observing for several days or weeks (Thomas Jr. et al., 1982). Picard supports this position offering a question the observer should ask while collecting data: "What can be done to improve productive utilization, reduce wasted time, minimize travel, and streamline workflow?" (Picard, 2004). It is for this reason that the data collection form created for this thesis work includes areas for the observer to make general comments.

When interpreting the data, the observer must remember that the purpose of activity analysis is to remove productivity barriers so that the direct-work rate may increase. It is preferable that non-productive activities decrease so that amount of direct-work can increase. However, if preparatory-work, tools-and-equipment, and material-handling percentages are greater than targets, then these percentages should also be reduced thus making more time for direct-work activities. These inhibitors that are to be reduced or eliminated should be developed into a specific action items list presented to management in report form, and potentially through a presentation (Jenkins & Orth, 2003; Picard, 2004).

The recommendations regarding specific excessive activity rates were developed through the extensive literature review and interviews with several construction industry experts. These experts are actively involved in labour productivity issues for their respective companies. These experts have been an excellent resource for this research.

At this time, the author acknowledges that the following discussion of potential productivity issues as a result of specifically high activity percentages is not exhaustive. Further, if the specific cause of an undesirably high activity percentage is not determined through the first activity analysis study, a second may be required, or another workface assessment method such as foreman delay surveys should be used to augment the results from the study.

3.4.3.1 Excessive Preparatory-work Activity Percentages

Some preparatory-work activities are essential, while other are unnecessary. The unnecessary tasks should be eliminated, while the essential activities may still be excessive and could be reduced. Some tasks that should not be reduced for safety reasons include safety talks and stretching activities. These are critical activities that need to be maintained for a well functioning and safe construction site.

High preparatory-work rates are caused by two issues: a lack of information, and a lack of experience. Both these factors result in craft workers spending extra time determining which tools, equipment and materials are required for the job, and too much time planning how to execute the work assignment.

Lack of information

When management does not issue detailed work packages that include an outline of the work tasks, and the required tools, equipment and materials, much of this planning has to be done at the workface. If work packages are being provided upfront, the level of detail of these packages should be analyzed, and increasing the level of detail should be considered.

Lack of experience

High preparatory-work rates are sometimes caused by inexperience of craft workers. Inexperienced workers often consult with more experienced workers to answer questions regarding the work tasks. These periods of instruction are considered preparatory-work activities. A study provided to the author by one of the construction experts, reported that the use of two journeymen instead of a journeyman and a sub-journeyman reduced preparatory-work rates by 15%.

3.4.3.2 Excessive Tools-and-equipment Activity Percentages

High tools-and-equipment activity percentages are usually caused by a poor tool management program, broken tools and equipment, or a poor layout of gang boxes and tool rooms. All these issues are related.

Poor tool management program

It is the purpose of the tool management program to allow a craft worker to leave the workface, obtain a tool or piece of equipment, and return to the workface in a short period of time. When high tools-and-equipment percentages occur, the following questions should be asked about the tool management program:

- Are there enough tool room attendants?
- Should more tool rooms be added at strategic locations?
- Can more gang boxes be added?
- Are the gang boxes adequately stocked?
- Are there processes in place to monitor the condition of tools and equipment in both the gang box and tool room?

Broken tools and equipment

The tool management program should monitor and remediate broken tools. A formal process needs to be instituted to assess the conditions of tools regularly, and have them repaired or replaced as required. When a craft worker receives a broken tool, two scenarios exist. Firstly, he struggles with tool while performing his work, needing to constantly adjust it or make minor repairs at the workface. The second option is that the worker returns the tool. If the tool originated from the tool room, it should be noted that the tool is broken and should not go back out to the worksite until repaired or replaced. However, if the tool came from the gang box, it may not be recorded, and eventually another worker will select that tool and have the same issues, thus wasting more time. It should be site policy that all broken tools be brought to the tool room, recorded and have the item replaced in the gang box as soon as possible.

Poor layout of gang boxes and tool rooms

Again related to the tool management program is the concept of a poor layout of gang boxes and tool rooms. The main consideration in this scenario is how far craft workers have to travel to obtain a tool. When observed going to the tool room or gang box empty handed, a travel observation is recorded; when returning to the workface with the tool, a tools-and-equipment observation is recorded. Ideally tools and equipment should be readily available in gang boxes near the workface, or closer tool rooms.

3.4.3.3 Excessive Material-handling Activity Percentages

Material-handling is another essential activity. Materials need to be received, stored, retrieved when needed, and then transported to the workface. Excessive material-handling activity percentages can be caused by poor site layout, disorganized material laydown yards, and damaged or incorrect materials.

In 1999, the Construction Industry Institute published an implementation resource titled "Procurement and Materials Management: A Guide to Effective Project Execution". This is an excellent resource, which includes an entire chapter dedicated to site materials management.

It is noted that material-handling activity rates do not always appear excessive, because material handling is often the responsibility of a materials department. Further, materials are often transported to the site by operators driving forklifts or trucks. When an operator transports material, the activity is categorized as direct-work since this is the operator's primary activity. The following issues should still be considered by site management.

Poor site layout

Site layout has a major impact on labour productivity, as illustrated by its inclusion as a cause of excessive tools-and-equipment, material-handling, and travelling activity percentages. With respect to excessive material-handling, a poor site layout means workers have to travel long distances to obtain materials. The walk to the material laydown yard is categorized as a travel activity; however the walk back with material in hand is categorized as a material-handling activity. Management should consider having small material storage areas near the workface. Having materials close at hand will greatly reduce the material-handling activity rate. These small storage areas need to be well controlled so that materials can be tracked. The area needs to remain uncluttered and safe.

Disorganized laydown yards

Disorganized laydown yards have been the topic of much literature in the construction industry. Research has focused on the costs due to excessive work-hours spent searching for specific materials, and costs due to materials ultimately deemed lost. In terms of excessive material-handling rates, the use of many work-hours to find materials is concerning. If laydown yards were organized, materials could be located quickly. Solutions vary in technological sophistication from simple mapping of laydown yards, to full automation using barcodes, radio frequency identification tags, and global positioning systems.

Another interesting solution to disorganized laydown yards is to simply store less material. Kerry O'Brien, a productivity consultant, recommends just-in-time material delivery, so that very few materials actually need to be stored (K.E. O'Brien & Associates, Inc., 2008). This requires a strong relationship with suppliers, and a detailed material delivery schedule which is synchronized with the construction schedule.

Damaged or incorrect materials

Another contributor to poor labour productivity is damaged or incorrect materials. When a worker receives a material that is either damaged or incorrect, the worker must return the material and ensure another gets ordered. In terms of productivity, this disturbs the work sequence and causes waiting and extra planning as a new task for the crew is identified. In terms of the material-handling rate, having to return material just picked up increases the rate.

3.4.3.4 Excessive Waiting Activity Percentages
In some instances, waiting is unavoidable. For example electricians waiting for a cable pull. However, most often waiting is caused by poor planning on behalf of management and poor crew balance, and is therefore avoidable.

Poor planning by management

Poor planning is the most common cause of excessive waiting activity rates. In some cases crews find themselves waiting on other crews. Crews often have to wait for other crews to complete work that is a prerequisite for their work. Or the crew may simply need another crew to vacate space they physically require. In other cases, crews may be waiting for scaffolding. Planning for scaffolding is a major task on large construction sites. If carpenters receive requests for a scaffold late, other crews may be waiting significant amounts of time while the scaffolding is being assembled, especially when no other task can be completed at that time.

Poor crew balance

Achieving the correct crew balance can be a difficult task; however incorrect balances will significantly increase waiting activity percentages. Often workers must wait for something to do either because the work area is simply too congested, or there is simply not enough work for every member in the crew all the time. It was observed on one of the field trials that a prefabrication crew consisting of five welders, only ever utilized at most four workers, however often only two would be observed to be actively working. One option is to utilize fluid crew sizes where foremen can request or offer spare labour for the day. This can be a difficult system to effectively employ, however it can substantially reduce waiting activity percentages.

Other causes of waiting

Other common causes of waiting include waiting for job instructions or waiting on tools, equipment, or material.

3.4.3.5 Excessive Travel Activity Percentages
Excessive travel activity rates can be caused by a poor site layout, or workers purposely avoiding the workface.

Poor layout

When workers have to consistently travel long distances to items that they regularly use, this increases the travel activity percentage. For instance, when there are few tool rooms and gang boxes, and they are in a poor layout, workers have to travel greater distances to obtain tools and equipment. Obviously, this is related to the discussion on poor tool management programs. In this case, it could be considered a double negative since far tool rooms and gang boxes means an increase to both tools-and-equipment and travel activity percentages.

Workers avoiding the workface

A productivity expert from a major construction company has observed that in some cases workers chose to take “the long way back” to the workface. This is often caused by long work weeks, or low worker morale.

3.4.3.6 Excessive Personal Activity Percentages

Controlling personal activity percentages is a difficult task for management. There are cases when personal activities are necessary, such as in extreme heat. In hot conditions workers need to frequently rest, seek shade, and take water breaks. If this is paid time, it will be recorded by the observer as personal activities. This is more likely to occur when there are no scheduled breaks in the workday with the exception of lunch. One particular site indicated that workers were to take water breaks “as required”. In this case, it is difficult for managers to control workers abusing this system, because it is hard to define “as required”.

Management should focus on areas which are controllable. Management should focus on late starts and early quits at the beginning of the day, around lunch, and at the end of the day. Better planning and a greater presence onsite during these times should limit the number of craft purposely starting slowly, or waiting to clock-out. Also, workers should not be permitted to smoke (and similar activities) onsite during work hours since their productivity is reduced in this time and it is considered to be a personal activity.

3.5 Step 4: Plan Improvements

The most significant inhibitor of implementing improvements is negative perceptions of change. The process of planning improvements has three steps: list probable causes, analyze alternatives, and create a plan for improvement implementation.

List probable causes

For true improvement, it is important that changes be made at the root cause of problems. It is not sufficient to merely correct a problem, since if the root exists the problem will most likely re-occur. The scope and extent of a problem is identified based on the activity analysis results. The results of the study have identified the productivity issues. In this step, the reasons why this issue has occurred must be identified.

For instance, a problem may be improper crew balance. Causes of improper crew balance can be poor communication between management and site labour indicating needs and over-manning situations. Or, the poor crew balance could be a result of poor planning of work tasks. For example, at one moment less labour is needed, but in the near future more will be required, so the labourer remains on the crew in an inactive state until that time. The cause is most likely a combination of these scenarios.

For each cause, several solutions should be developed through experience, expert insights, and creative brainstorming. In this stage, no potential solution should be dismissed until properly analyzed in the next stage.

Analyze alternatives

Each potential solution must be evaluated according to potential cost and anticipated benefits. The evaluation should also consider probability of success, limitations, stage of the project, duration of implementation, required resources, and necessary methods. Also, the effect of this change on other tasks and activities should be considered.

For instance consider a high material-handling activity rate due to a very large, unorganized and complex project. The site could consider implementing a more advanced materials management program which utilizes radio-frequency identification tags and possibly global positioning systems. The cost for such an implementation and the training for staff to learn software may be high. If the system is being installed retroactively, the duration remaining in the project may result in costs and confusion outweighing benefits.

Create a plan for improvement implementation

A successful plan is very detailed with all potential obstacles considered and with an outline how to handle each. The conceptual design of the solution is important; however the components of the solution need also to be comprehensively designed. Considerations to include in the plan are the financial issues, a schedule, project culture, limitations, permitting process, etc.

3.6 Step 5: Implement Improvements

Consulting the productivity industry experts, the following list of activities need to be undertaken to implement the improvements which were planned:

1. Obtain real commitments from all levels of management;
2. Study each action element of the plan;
3. Define a schedule and timeline for each element;
4. Investigate cost of implementation including development, purchasing, maintenance, etc.;
5. Consider human resource issues (for example training and support on new implementations); and
6. Update forms and documents related to changed work processes.

Chapter 4: Validation of Activity Analysis

As outlined in the research methodology section of this thesis, the validation of activity analysis is comprised of two parts. First, case studies on six projects were completed to verify that the activity analysis process as outlined in Chapter 3 is logistically feasible. The second portion of the validation process was the collection of data from contractors who complete the activity analysis cycle on projects. This was done in order to test the validity of the hypothesis that activity analysis can improve direct-work rates.

4.1 Case Studies

Activity analysis studies were completed on six construction projects located in the United States: three in Texas, and one in each of Louisiana, Kentucky, and Illinois. The industrial sector of each project varied between power, petroleum and petrochemical. Several details of the projects will be provided, including the results of the studies, and the interpretations of the data.

The contribution of colleagues in performing activity analysis studies at these six projects is noted at this time. For logistical reasons, colleagues from the University of Kentucky, and the University of Texas at Austin also collected data. The author personally visited and completed activity analysis studies on two projects. All data from each project visited, was sent to this author for analysis.

Also it is noted here that project information and data has been sanitized to protect the interests of the contractors who permitted project visits. It is important that exact details of their operation not be released because of its proprietary nature. For this reason, no contractor or project names will be provided, nor the exact location of any project. This allows the author to present some project specifics, including all results from studies while still maintaining the contractor's anonymity.

4.1.1 Project A

Project A was the construction of a 750 MW pulverized coal-fired unit with a steam turbine generator, both utilizing strict environmental controls. This project, located in Kentucky, began construction in July 2006, with completion anticipated to be reached in 2010. The contractor was responsible for both the design and construction of the new unit. The author visited this site in July 2009 to perform an activity analysis study.

The labour breakdown on this project at the time of the visit is shown in the following table:

Table 8: Labour Breakdown of Project A

Trade	Number of Craft
Pipefitter	246
Boilermaker	224
Electrician	201
Ironworker	119
Carpenter	114
Labourer	53
Operator	47
Millwright	24
Concrete Worker	4

According to the breakdown, a total of 1032 workers were present on the construction site. All workers were included in the study. The contractor utilized a colour scheme for denoting the craft of a worker. Therefore, the author could identify the craft throughout the study for more detailed observations.

For the study of 1032 workers, a total of 342 samples per hour of study was determined to be required according to the binomial distribution and the finite population correction factor. However, as discussed in Chapter 3, these were incorrect assumptions. Instead the multinomial distribution should have been used without considering the finite population correction factor. For a 95% confidence level, and an error of 5.0%, a total of 510 samples are required per hour, regardless of the number of craft workers on site.

The following table summarizes the number of samples collected for every observation hour. The true confidence level for each hour period is reported. The true confidence level was calculated using the actual number of samples collected, an error of 5.0%, and the actual measured proportions for each hour. The error associated with each proportion was calculated using the binomial distribution because the proportion indicates what percentage of observations has that attribute or not. This was completed for all seven categories. Then the confidence levels were summed. This was done according to the following logic. Assume the direct-work rate has a 95% confidence level, which is the probability of the proportion being incorrect once out of 20 times. Assume the preparatory-work rate also has a confidence of 95%, and therefore a probability of being incorrect once out of 20 times. It is unlikely that out of the 20 studies, both the direct-work rate and preparatory-work rate will incorrectly be estimated simultaneously. It is more likely that out of the 20 studies one proportion will be incorrect while the second proportion is correct, and eventually the second proportion will be incorrect while the first is correct. Therefore the probability of one incorrect proportion occurring becomes twice out of 20 studies. This corresponds to a confidence level of 90%.

Table 9: Project A Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
7:00 – 8:00	361	91.26%
8:00 – 9:00	358	92.69%
9:00 – 10:00	359	93.55%
10:00 – 11:00	362	93.76%
11:00 – 12:00	367	93.83%
Lunch	-	-
12:30 – 1:30	367	93.38%
1:30 – 2:30	336	91.33%
2:30 – 3:30	359	92.92%
3:30 – 4:30	342	91.37%
4:30 – 5:30	334	90.01%
Total	**3545**	**99.99%**

The confidence levels for Project A are not drastically worse than the 95% confidence level that was originally intended. This is due to the observer collecting more samples than the original minimum sample size of 342 samples. It is important to note that though the individual hour confidence levels are less than 95%, the confidence level for the overall study is slightly less than 100%. This is because sample size does not consider duration of the study, and therefore for the overall results to have a confidence of 95% and an error of 5%, only 510 samples are required. The observer collected nearly seven times this number of samples, and so the overall results are considered very accurate.

The results of the study at Project A are summarized in the following table.

Table 10: Activity Rates and Error Estimates for a 95% Confidence Level for Project A

Activity Category	Percentage	Error
Direct-work	26.94%	1.46%
Preparatory-work	11.11%	1.03%
Tools-and-equipment	19.29%	1.30%
Material-handling	8.38%	0.91%
Waiting	12.44%	1.09%
Travelling	16.95%	1.24%
Personal	4.88%	0.71%

The table also presented the true error. Sample size determination is a balance between error and confidence. If the error was maintained at 5.0%, the confidence level would be nearly 100% as reported in the Table 10. However, the author determined it would be more meaningful to report the error of each proportion based on a 95% confidence level which was originally intended. The error indicates that for Project A, the overall study determined the direct-work rate was 26.94% ± 1.46% with a confidence of 95%.

Activity analysis data uses two primary plots. The first is a pie chart (Figure 22) which illustrates the overall activity percentages determined from the study. The pie chart illustrates how large the proportion of each activity really is, and how other activities need to be reduced to increase the direct-work rate. The second plot (shown in Figure 23) is an hourly distribution of activity percentages for a typical work day. This chart, called the time series stacked bar chart, is used to compare how activity percentages vary throughout the day.

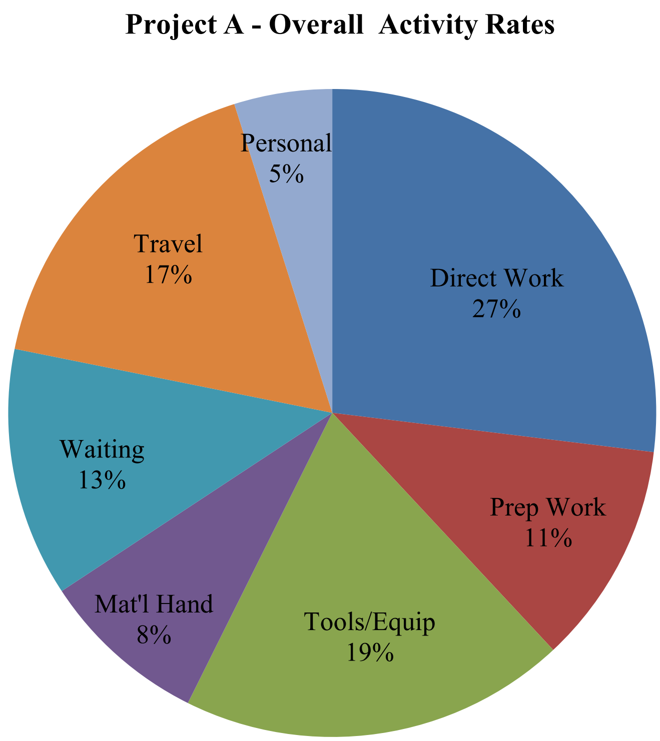


Figure 22: Overall activity rates for Project A

The first note from this plot is that the direct-work rate appears to be less than ideal. In a typical ten-hour work shift, the average worker only spends 2.69 hours actually installing materials. This is less than optimal. Therefore the analyzer considers the other categories, identifies which ones appear high, and attempts to identify causes which can be reduced or eliminated thereby increasing the amount of time available for direct-work activities.

The preparatory-work rate is 11%, which in the experience of the author appears reasonable. To avoid rework, workers need time to fully plan their work so it can be executed smoothly and efficiently. However a tools-and-equipment activity percentage of 19% is much too high. As identified in Chapter 3, the main causes of increased tools-and-equipment activity percentages are poor or nonexistent tool management programs, broken tools or equipment, and poor layout of gang boxes and tool rooms. At the time of visit, an eight storey structure was under construction. The high tools-and-equipment activity rate may be a result of workers having to go all the way down to the main floor, walk over to the tool room, and return back to the workface. This results in a high tools-and-equipment activity rate because it is a long distance to walk back with tool in hand. Note that this issue is also reflected in the high travel activity percentage. The travel percentage is higher than average. The high tools-and-equipment activity percentage may be alleviated if small tool rooms were constructed on each floor of the building so that workers would not have to travel to the ground floor to obtain or return tools.

The pie chart also highlights a higher than typical material-handling activity percentage. It is often difficult to reduce material handling, because often large areas of land are required to house stockpiles of material, and so it is logical to have the laydown yard further away from the workface. Project A was no exception. If the entire laydown yard cannot be closer, splitting the yard into two smaller areas and moving closer to the workface may be considered. Another possible solution is to consider the number of times workers are handling materials. The typical material handling process is to unload a delivery truck, record important information regarding the material, find a place in the laydown yard, move the material there, then locate it later, and finally transfer it to the workface. These are significant activities which add to material-handling percentages. Further, if the material is blocking a material that is required, it must be moved away and then replaced, thus increasing the amount of handling. It is a good practice, if possible, to only handle materials once.

Finally, the pie chart indicates that the waiting activity category is minimal. At 13%, the amount of waiting was one of the lowest for all six studies. Though there were many workers on the site, it was not congested. The majority of waiting appeared to be for one of only two elevators. Also, the amount of personal activities observed was the lowest of all six projects. This indicates that site management is doing a good job of controlling late starts and early quits, and have a general presence onsite.

Next the analyzer considers the hourly distribution of site activities. As mentioned, the time series stacked bar chart is used to illustrate this.

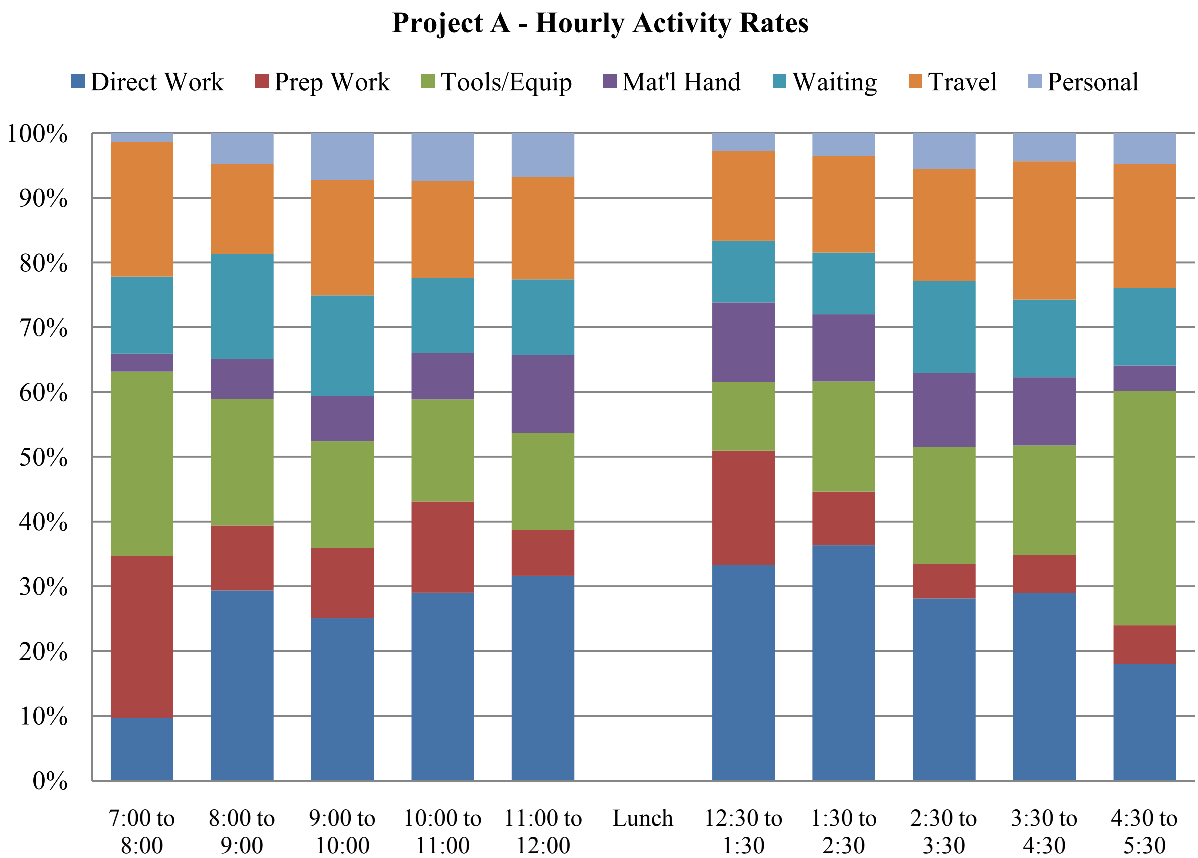


Figure 23: Hourly distribution of activities at Project A

The hourly distribution chart indicates a slow start to the work day. This is indicated by a direct-work rate in the first hour less than 10%. The chart also indicates that at the beginning of the day the preparatory-work, tools-and-equipment, and travel activity percentages are higher than the overall average. This is logical since at the beginning of the day workers need to plan their work, get tools, and get to the workface. However, it would be ideal if these activities at the beginning of the day were minimized, so that the direct-work rate could ramp up faster.

4.1.2 Project B

Project B was the second site visited during the field trials. The site, located in Illinois, was visited in July of 2009. The project was the construction of two sulphur recovery units, two tail gas treating units, two amine recovery units, and a sour water stripper at an existing oil refinery. The oil refining capacity was not expanded. The design-build contract began in October 2008 and was expected to be completed November 2010.

When Project B was visited in July 2009, a total of 139 workers were onsite. The number of craft workers per trade was broken down as follows:

Table 11: Labour Breakdown of Project B

Trade	Number of Craft
Labourer / Concrete Worker	31
Operator	25
Pipefitter	24
Carpenter	17
Ironworker	14
Teamster	10
Electrician	9
Boilermaker	9

With 139 workers included in the study, a total of 110 observations per hour was initially determined as the required sample size to obtain an absolute accuracy of 5%, with a confidence of 95%. Unfortunately this is far below the 510 samples that was later determined based on the multinomial distribution. Due to this large discrepancy in sample sizes, the confidence level for each individual study hour is poor. The accuracy of the results of each hour can easily be questioned. However, it is noted that because the whole study only requires 510 observations for accuracy, the overall results for the entire study have a high degree of confidence.

Table 12: Project B Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
6:00 – 7:00	126	38.05%
7:00 – 8:00	203	69.02%
8:00 – 9:00	208	71.18%
9:00 – 10:00	183	64.27%
10:00 – 11:00	222	74.30%
11:00 – 12:00	201	69.15%
Lunch	-	-
1:00 – 2:00	163	58.72%
2:00 – 3:00	173	62.36%
3:00 – 4:00	199	66.64%
Total	**1678**	**99.99%**

For a study such as this, it would be recommended that a second study be completed where more than 510 samples are collected each hour to obtain accurate hourly results. The results for the entire study are presented in the following table, including the error calculated for the typical 95% confidence level.

Table 13: Activity Rates and Error Estimates for a 95% Confidence Level for Project B

Activity Category	Percentage	Error
Direct-work	31.35%	2.22%
Preparatory-work	13.05%	1.61%
Tools-and-equipment	7.87%	1.29%
Material-handling	3.58%	0.89%
Waiting	15.38%	1.73%
Travelling	15.97%	1.75%
Personal	12.81%	1.60%

The results are illustrated using the typical pie chart shown in Figure 24.

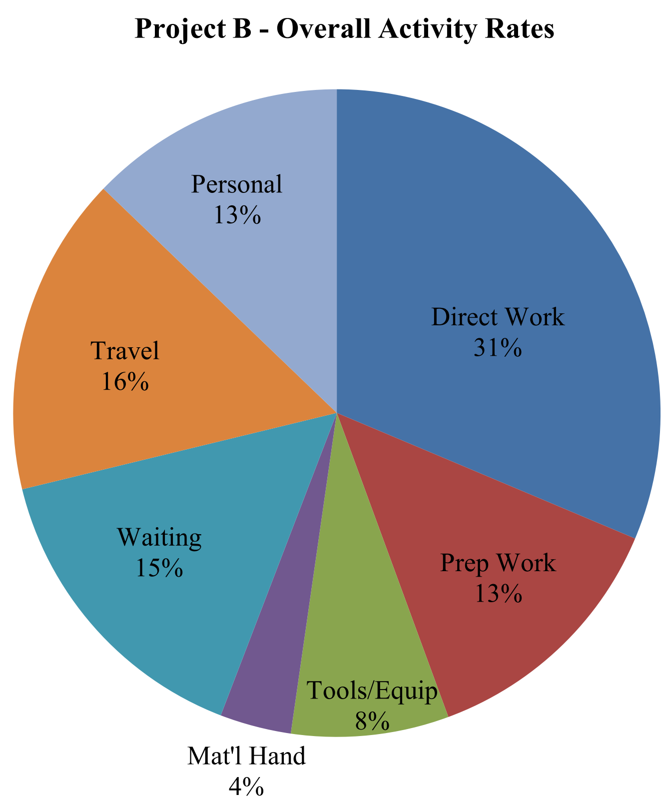


Figure 24: Overall activity rates for Project B

It would appear from the pie chart that the preparatory-work rate, tools-and-equipment rate, and material-handling rate are within typical values. Further, tools-and-equipment at 8% is generally considered low. Waiting and travel activity percentages are also low compared to the six case studies. Though these categories are considered within typical ranges, management should consider reducing these percentages by better logistics and work packages.

The personal activity percentage is quite high at 13%. On a typical eight-hour shift at Project B, more than an hour of personal activities is taken each day by every worker. With 139 workers onsite, 144 man-hours were lost to personal activities each day. This is a large number of hours lost. It is difficult to specifically identify the cause of this high percentage because the author was not the observer onsite. However, management should consider increasing their presence onsite during key times that are highlighted by the time series stacked bar chart presented in the following figure.

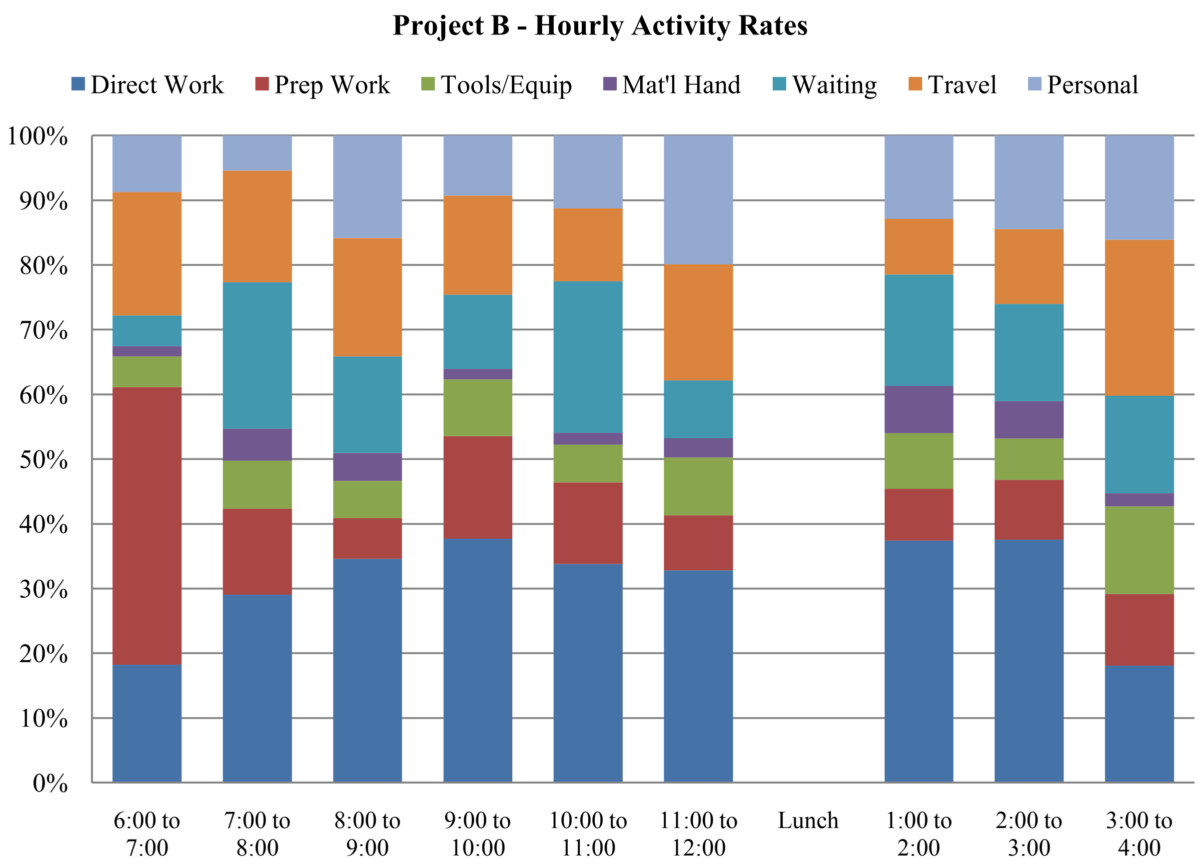


Figure 25: Hourly distribution of activities for Project B

The chart indicates that the personal activity percentage is fairly constant throughout the day, except for an increase between 8 and 9 am. At this point in the day, the craft workers have been working for two hours, and appear to be taking an undesignated break. Management should ensure more supervisors are present at this time.

The chart also indicates a very high preparatory-work percentage during the first hour of the day. Often preparatory-work rates in the morning are high since workers have to plan their work, participate in safety talks, and do any necessary stretching. Still management should consider if there is a way to decrease this percentage safely, in an attempt to increase the direct-work rate.

Further, the direct-work rate seems to ramp up slowly at the beginning of the day, but very quickly after lunch which is good.

It must again be noted at this point that this discussion is predicated on the hourly results reflecting the true work behaviour on site. However, as shown in Table 13 there is little confidence that the hourly results are accurate. In a situation such as this, it would be recommended that before site management takes action based on this discussion, the study be repeated.

4.1.3 Project C

The third project visited was the expansion of a large refinery by a major construction company in Texas. Construction began in the fall of 2007, and is scheduled to be completed in 2010. Once finished the output will increase by 325,000 barrels/day; thus making the refinery the largest in the United States.

Project C was visited in August 2009. At the time of sampling, the project was ahead of schedule and consisted of mainly mechanical, structural and civil trades. During the study, a total of 209 workers were sampled from. The distribution of trades from the study population was not recorded.

Using the binomial distribution and the finite population correction factor, the minimum sample size was erroneously calculated to be 149 samples for each hour, well below the multinomial value of 510 per hour. The number of observations recorded for each hour is summarized in the following table. Also included is the confidence level for each hourly study period based on the number of observations, and an accuracy of 5.0%.

Table 14: Project C Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
7:00 – 8:00	322	87.10%
8:00 – 9:00	158	67.50%
9:00 – 10:00	675	99.09%
10:00 – 11:00	329	91.52%
11:00 – 12:00	168	60.04%
Lunch	-	-
12:30 – 1:30	171	57.48%
1:30 – 2:30	152	52.64%
2:30 – 3:30	151	51.21%
3:30 – 4:30	154	70.15%
4:30 – 5:30	196	69.15%
Total	**2476**	**99.99%**

Similar to Project B, the confidence levels for Project C in most study hours are insufficiently low, however it is very high for the study as a whole. In three instances the observer collected more than 300 samples which resulted in higher confidence levels. Specifically these where the first, third, and fourth study hours which resulted in confidence levels of 87.1%, 99.1%, and 91.5% respectively. These hours represented times when the observer had the opportunity to collect more than one day of data. Only one day of data was collected for the other hours due to events such as orientation and training for the observer, rain, site safety meetings, and heavy lifts. When these events occurred, either the observer could not sample, or the work was not representative of the true work activities, which as described earlier is an important principle of activity analysis.

The results of the study are presented in the following table:

Table 15: Activity Rates and Error Estimates for a 95% Confidence Level for Project C

Activity Category	Percentage	Error
Direct-work	42.12%	1.94%
Preparatory-work	12.83%	1.32%
Tools-and-equipment	11.95%	1.28%
Material-handling	2.05%	0.56%
Waiting	11.14%	1.24%
Travelling	13.23%	1.33%
Personal	6.68%	0.98%

It is interesting to note that the direct-work rate for Project C was the highest of all projects visited. Further, the material-handling and personal activity percentages were much lower than typical. To have high direct-work rates it is important to minimize activities such as these to provide more time for actually installing materials.

However we provide another stipulation from the results reported in the preceding table. Because the observer did not have the opportunity to evenly collect samples, the hours where more samples were collected will distort the overall results. For example, if the morning direct-work rates are typically higher than the afternoon, and more samples were collected at this time than the afternoon, then the overall results will report higher direct-work rates than are necessarily typical. This is a concern that should be mitigated by creating hourly sample sizes within 10% of each other. Unfortunately, due to aforementioned events which prohibited the observer from sampling and due to other schedule constraints of the observer, he was unable to extend his stay and follow this general 10% rule of thumb.

As typical, the results are illustrated to aid in the understanding of the activities on site.

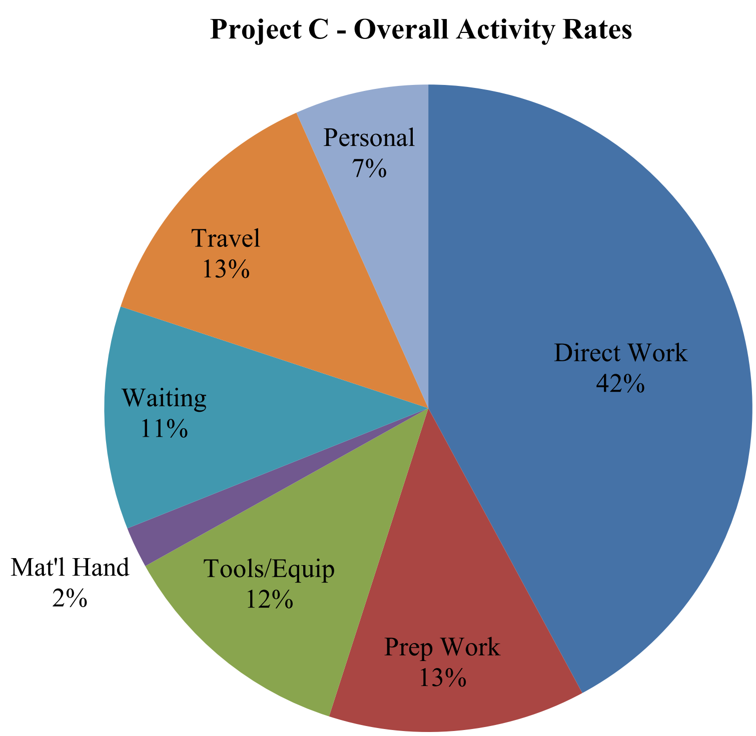


Figure 26: Overall activity rates for Project C

It is noted that this site has a very high direct-work rate. This is most likely reflected by site management having a permanent productivity employee onsite. This site does a good job of monitoring its work activities through work sampling, and attempting to improve where possible.

Despite having high direct-work rates, the tools-and-equipment and preparatory-work rates are both higher than what would be considered acceptable. Unfortunately, the author is again hampered by the fact he was not the observer onsite. The preparatory-work levels may be adequate if the project is extremely complex and are currently in later stages of construction. However, if management deems this percentage as too high, the level of detail in work packages should be considered and enhanced if necessary.

The excessive tools-and-equipment percentage could be caused by a poor tool management program which is not providing fully functioning tools. The layout of the site may need to be considered. The travel activity percentage also appears to be slightly high. Workers may be travelling long distances to tool rooms and gang boxes which is recorded as a travel observation when walking there empty handed, and a tools-and-equipment observation when returning.

All three unproductive categories appear to be a little higher than would be desirable in the eyes of construction managers, though each was close to the average for all six case studies. Despite this, it should be the goal of management to continually attempt to decrease these percentages thereby leaving more time for direct-work activities. It is noted that direct-work rates are high, though there is room to improve.

The time series stacked bar chart for Project C is presented next so that the distribution of work activities throughout the day may be considered. It is again noted at this time that the confidence levels for several of these hour periods are quite low, and a second study should be considered before site management acts upon recommendations based on the hourly results.

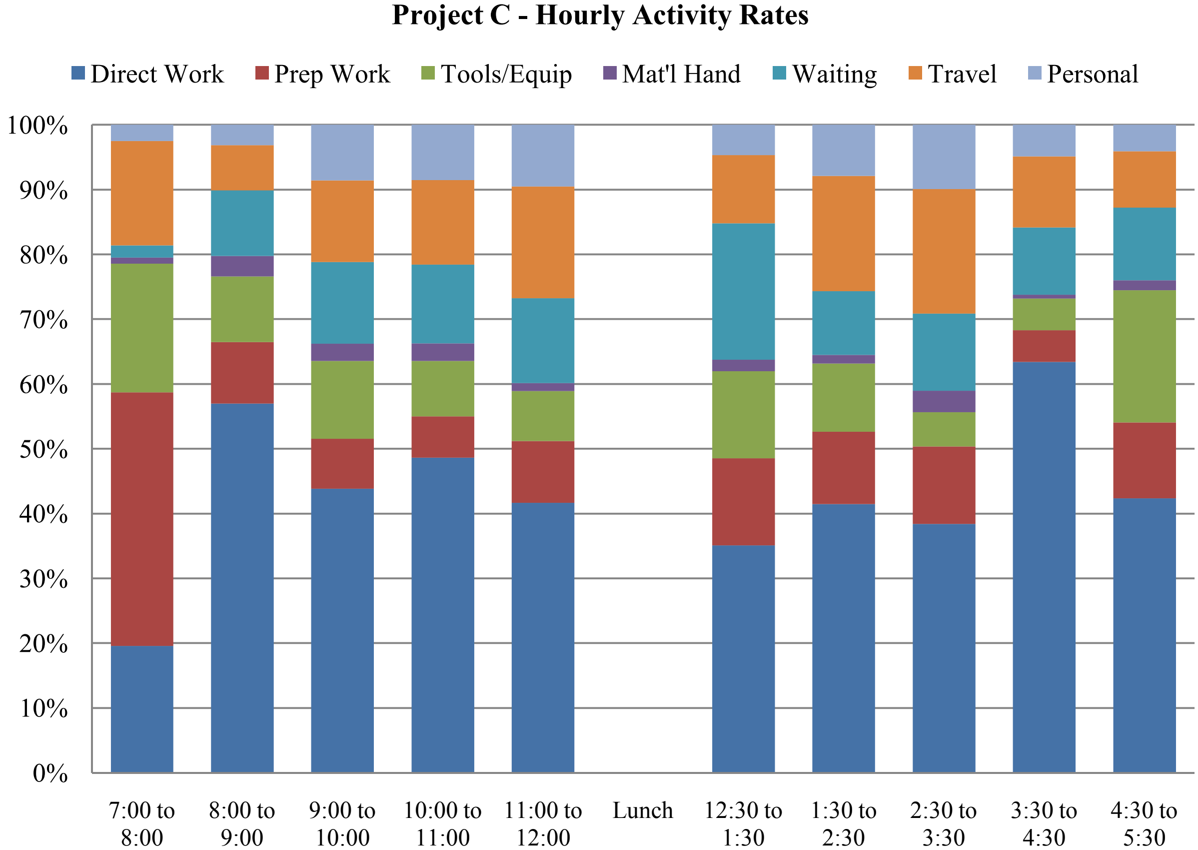


Figure 27: Hourly distribution of activities for Project C

The hourly distribution of work activities for Project C indicates many good concepts. First, the direct-work rate ramps up very quickly at the beginning of the day and after lunch. Further, high levels of direct-work are maintained throughout the day, spiking during the second last hour of the work day. This seems to indicate that workers have the notion to push and work harder to get all their work done for the day.

Other good aspects seen in this time series stacked bar chart is that the workers do not appear to be starting late or quitting early for the work day, nor the lunch break. Also there is very little waiting at the beginning of the day. This means management is getting work assignments to employees quickly. However, this is not reflected in the waiting activity percentage after lunch. Management should consider this period after lunch and determine if there are any techniques being used at the beginning of the day which are not being applied immediately after lunch.

4.1.4 Project D

The fourth project visited was also located in Texas. The project is the upgrade of an existing power plant to include new dual cycle natural gas turbines and heat recovery power generation units. The Project D contractor completed the engineering and procurement for this project. The site was visited in August 2009 by the author. At the time of the visit, engineering was not entirely complete; however construction was more than two thirds complete. The anticipated completion date at this time was mid April 2010.

The activity analysis study for Project D only considered pipefitters. During the four days on site, there were 283 pipefitters, all of which were included in the study. The author as observer was able to determine the pipefitters by blue electrical tape on the hardhat of each worker. For a population of 283, a minimum size of 183 samples was erroneously calculated. Again, there is a large difference between the sample size calculated and 510 samples, therefore it is expected that the confidence levels would be quite low. This is reflected in the confidence levels as summarized in the following table.

Table 16: Project D Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
6:30 – 7:30	208	71.34%
7:30 – 8:30	204	69.47%
8:30 – 9:30	213	74.20%
9:30 – 10:30	216	72.94%
10:30 – 11:30	214	73.81%
11:30 – 12:00	194	64.58%
Lunch	-	-
12:30 – 1:00	139	39.25%
1:00 – 2:00	223	78.02%
2:00 – 3:00	222	74.12%
3:00 – 4:00	207	69.98%
4:00 – 5:00	211	72.44%
Total	**2251**	**99.99%**

The lowest confidence levels are the half hours around the lunch break. These two half hours were considered their own study periods. Fewer observations were collected during these half hour study periods due to less time to sample. Though the hourly confidence levels are quite low, thus causing concern for the hourly results depicted in the time series stacked bar chart, the overall confidence was quite high since 2251 observations were collected, where as only 510 was required for a 95% confidence level.

The results for the entire study are summarized in the following table. Because over four times the number of samples was collected, the error for each activity category is quite small. As previously discussed the error percentage was calculated using the binomial distribution, the calculated activity percentages, and a 95% confidence level.

Table 17: Activity Rates and Error Estimates for a 95% Confidence Level for Project D

Activity Category	Percentage	Error
Direct-work	28.39%	1.86%
Preparatory-work	15.73%	1.50%
Tools-and-equipment	11.51%	1.32%
Material-handling	4.35%	0.84%
Waiting	15.90%	1.51%
Travelling	13.02%	1.39%
Personal	11.11%	1.30%

The data was then illustrated through the use of a pie chart as shown in Figure 28.

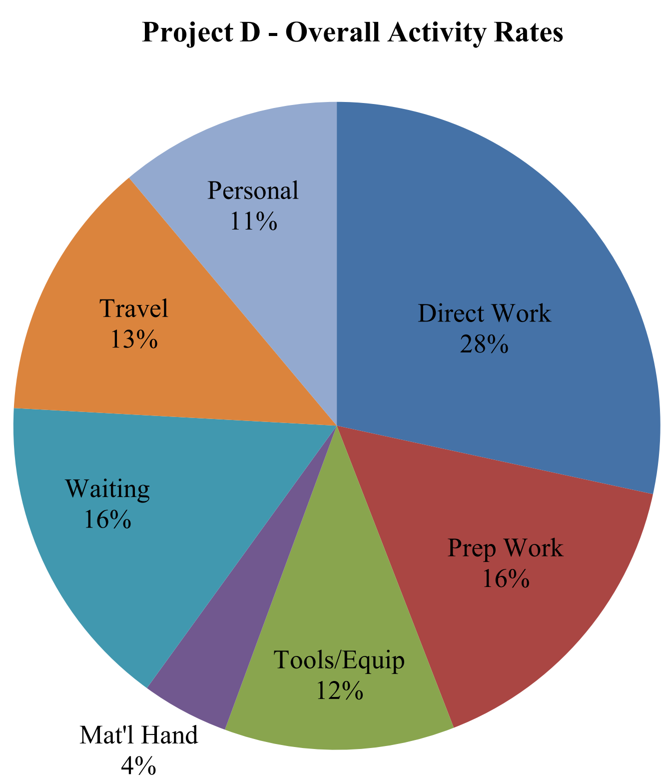


Figure 28: Overall activity rates for Project D

The pie chart indicates that the preparatory-work rate at Project D is very high and deserves management's attention. As mentioned in Chapter 3, high preparatory-work rates are generally caused by a lack of information to craft workers, or a lack of experience. It was noted that the construction project was in one of the most complex stages, as most of the structural work was complete, and the majority of the piping was being installed at this time. The structural work was causing excessive interferences. In general it would be expected that preparatory-work rates would be high for pipefitters, with smaller direct-work rates, however not to the extent as indicated by the results. The observer did have the opportunity to view typical work packages. These seemed fairly detailed, though it is not the position of the observer to determine how much is enough detail. It would be recommended that even more comprehensive work packages be issued to lower the preparatory-work percentage. Also, the contractor may need to consider hiring more experienced workers to work at this critical time of the construction process.

The tools-and-equipment activity percentage, as well as material-handling percentage was typical. Further, the travel activity percentage could be considered low.

Both the waiting and personal activity percentages were excessive. Often, waiting is a cause of poor planning; however for Project D the high waiting activity percentage appeared to be caused by improper crew balances. It was observed on several occasions that workers were waiting because there was a lack of work. This is intimately tied to poor planning, however if a system was employed that would allow foremen to offer extra labour, the site would be more productive and direct-work rates would increase.

It is acknowledged that at Project D controlling personal activities was difficult. When the site was visited in August 2009, the conditions were extremely hot. The policy of the site was to take breaks as required, and drink lots of water. Water jugs were well placed throughout the site. Much of the personal observations could be attributed to these hot conditions. Management would be encouraged to supervise these breaks and ensure that workers are not abusing the system; however this will be very difficult.

With the total site results considered, the analysis shifts focus to the hourly distribution of work activities. The time series stacked bar chart for Project D is presented in the following figure. Recall that the confidence levels for these hourly results are significantly less than intended, and so recommendations presented here assume the results are accurate. Before action is taken it would be recommended that the study be repeated.

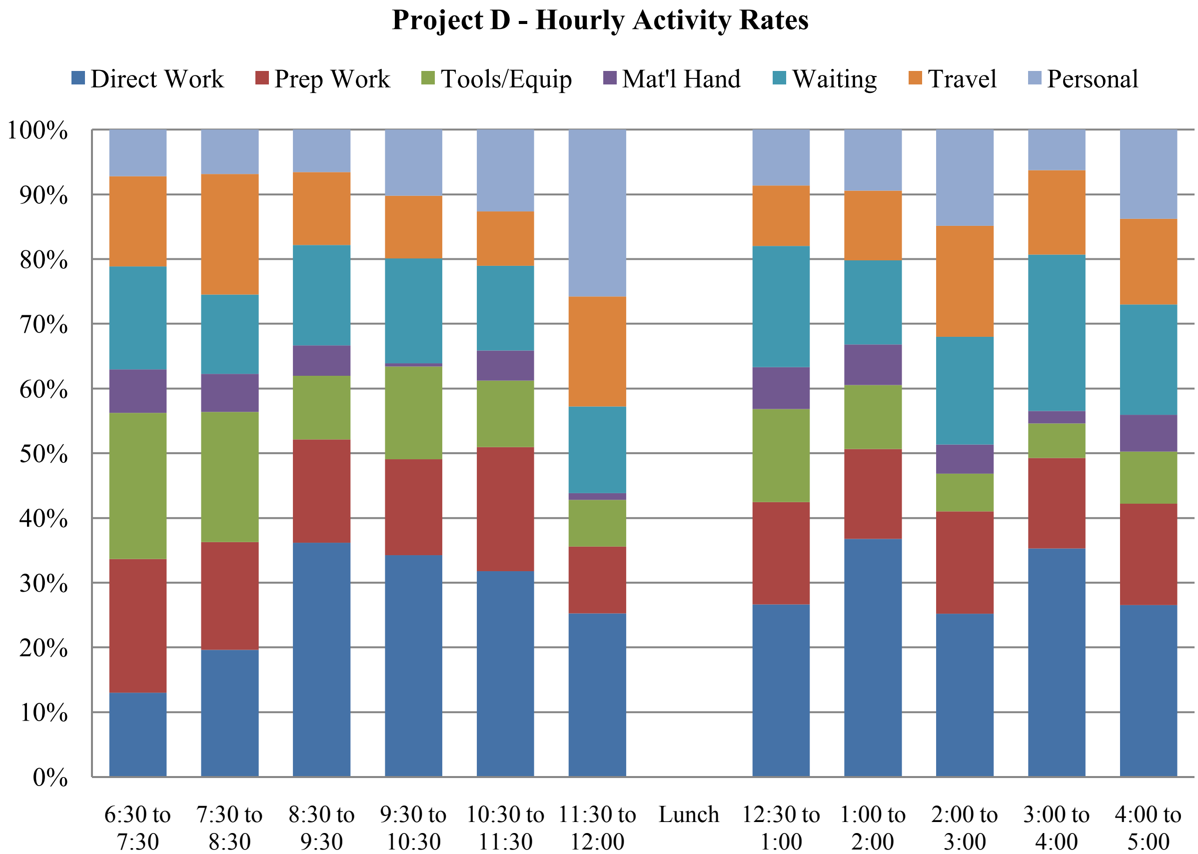


Figure 29: Hourly distribution of activities for Project D

Several key issues may be readily identified from the hourly distribution of Project D. Firstly the pipefitters slowly ramp up direct-work levels at the beginning of the day. By the second hour of the study, the direct-work rate is still below 20%. Because it ramps up so slowly, the direct-work rate peaks in the third hour and then already starts to decline for lunch. This is the second major issue that the plot indicates; workers taking lunch early. The personal activity percentage immediately before lunch is much too excessive. Supervisors should increase their presence on site during this time.

Another concern is the consistently high preparatory-work rates throughout the day. It would be expected to see large preparatory-work rates at the beginning of the day, and right after lunch. This should then decrease in the second hour since the work has already been planned. A consistently high preparatory-work rate throughout the day indicates the craft workers are getting confused, and have to repeatedly consult drawings.

Other concerns include the dip in direct-work rates in the afternoon, though it is acknowledged that a mid-afternoon decrease occurs on some construction projects. Also, there is a large jump in the waiting activity percentage during the second last hour of the work-day.

4.1.5 Project E

The fifth construction site visited was the expansion of a petrochemical plant on the Gulf Coast in Texas. The plant produces chemical and polymer grade propylene, as well as other products created during the processes. The contactor for Project E was the engineer, procurer and construction contractor for the entire project.

At the time of the visit the foundation of the structure was complete, and structural steel was 33% complete. Work was focused on the erecting the remaining structural steel, and constructing piping, electrical, and setting of equipment. The project started in November 2008, and was set to be completed at the end of April 2010. When visited in September 2009 the project was 25% complete and considered on schedule.

A total of 300 workers were onsite when visited. The trades onsite reflected the main focus of structural steel and piping. The breakdown of workers was as follows:

Table 18: Labour Breakdown of Project E

Trade	Number of Craft
Ironworkers	76
Pipefitters	76
Operators	33
Carpenters	26
Riggers	25
Electricians	21
Welders	17
Labourers	17
Boilermakers	9

Despite knowing the distribution of trades, it was not possible to identify the craft while sampling. For this reason all workers were considered in the study. For 300 workers, a minimum sample size per hour was determined to be 189 using the binomial distribution. Again this is much less than the true minimum sample size of 510. The following table summarizes the number of observations per hour and the associated confidence level. As shown, the observer collected many more samples than the initial minimum sample size estimate, which increased confidence levels from what they would have been had only the minimum been collected. It is also interesting to note that four of the study hours surpassed or neared the intended 95% confidence level, despite three of the four hours collecting less than 510 samples. This is because the 510 minimum sample size is determined by the worst case scenario where three categories have proportions of 33%, and all others are at 0%. However, the hourly results did not follow this worst case scenario so the confidence level increased.

Table 19: Project E Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
6:30 – 7:30	227	76.32%
7:30 – 8:30	266	81.36%
8:30 – 9:30	467	95.17%
9:30 – 10:30	239	75.35%
10:30 – 11:30	525	97.44%
11:30 – 12:00	198	67.67%
Lunch	-	-
12:30 – 1:00	227	73.32%
1:00 – 2:00	389	94.53%
2:00 – 3:00	219	73.26%
3:00 – 4:00	221	73.95%
4:00 – 5:00	421	94.97%
Total	**3399**	**99.99%**

The observer assigned to Project E, observed the site for two days. After these two days of sampling, the results were calculated and presented here.

Table 20: Activity Rates and Error Estimates for a 95% Confidence Level for Project E

Activity Category	Percentage	Error
Direct-work	30.19%	1.54%
Preparatory-work	8.50%	0.94%
Tools-and-equipment	6.68%	0.84%
Material-handling	4.62%	0.71%
Waiting	20.51%	1.36%
Travelling	23.57%	1.43%
Personal	5.94%	0.79%

From the table we identify high percentages in terms of both waiting and travel activities. This is a troubling result, since 50.01% of all workers' time is spent in non-productive activities. Information like this allows managers to target specific areas for improvement.

Project E - Overall Activity Rates

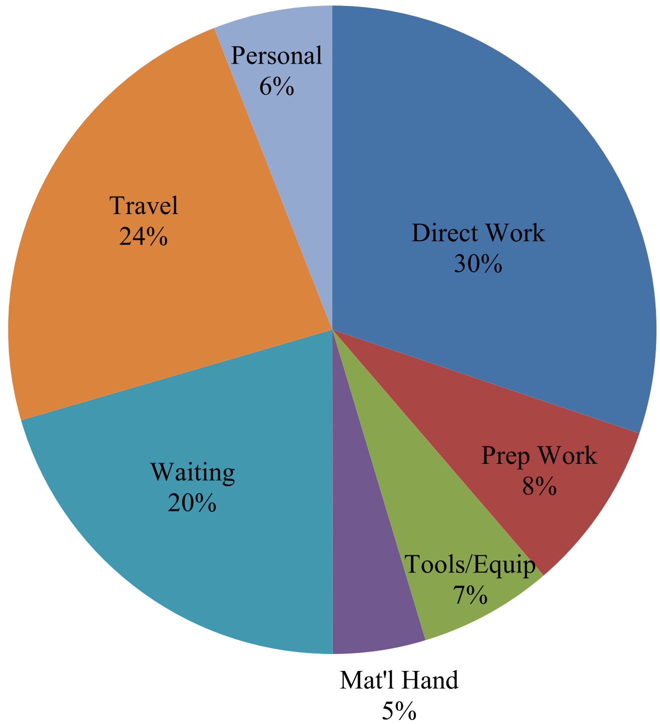


Figure 30: Overall activity rates for Project E

It is clear that the majority of a worker's time is spent in three activities: direct-work, waiting and traveling. A direct-work rate of 30.19% is considered average, especially when it is the first study completed on a site. Further, the site exhibited lower than average preparatory-work, and tools-and-equipment percentages, and the material-handling percentage is average. Though these activities are considered productive, it is good to have low percentages so that more time may be spent in direct-work activities.

Obviously, the most troubling result is the extremely high percentages of travel activities and waiting activities. These were the highest observed percentages for all six studies. A waiting activity percentage of 20.51% means that in a typical ten-hour work shift at this site, slightly more than 2 hours is lost to waiting. Further, another 2.5 hours is lost to traveling. When combined with a personal activity percentage of 5.94%, a little more than half the day is lost to these three unproductive activities.

As identified in Chapter 3, high waiting percentages is often a result of poor planning. It was recorded by the observer that the site was very congested. Congested sites cause waiting because often workers are forced to wait for one crew to vacate a space so that they may occupy it and complete their work. The second major cause of waiting is the over-manning of crews. No comment was made by the observer of this, however it should be considered. Other causes of waiting are for tools and equipment. The observer did not comment on long lines at tool rooms; however this often occurs on large construction sites. An observer records this as a waiting observation, since they are not travelling to the tool room, nor returning with tools, but instead are waiting in a line. The analyzer did note that the site was completing work packages, which would result in diminished preparatory-work rates. Ideally, this less preparatory-work percentage would be spent in direct-work activities. It is possible that the workers are receiving well detailed work packages, however simply do not have enough work, and therefore must wait for more job instructions.

The high travelling activity percentage is also troubling. The first major consideration is site layout. Site managers should consider the location of areas that are often visited by workers. For example, if the tool room is in an inconvenient location or the material laydown yard is in the furthest back corner, high travel activity percentages will result. Unfortunately, the author was unable to visit this site, and so it is difficult to assess if these are issues. However it was noted by the colleague who did visit, that the site was congested. It may be impossible to add additional tool rooms, or merely move them closer to the workface. Another consideration may be workers purposely avoiding the workface. This may occur as a result of a lack of work which ties into a possible waiting issue. It should be considered by site management.

After analyzing issues with the overall activity percentages, the analyst then concentrates on the hourly breakdown of work to determine any concerning trends. The hourly breakdown chart is shown in the following figure.

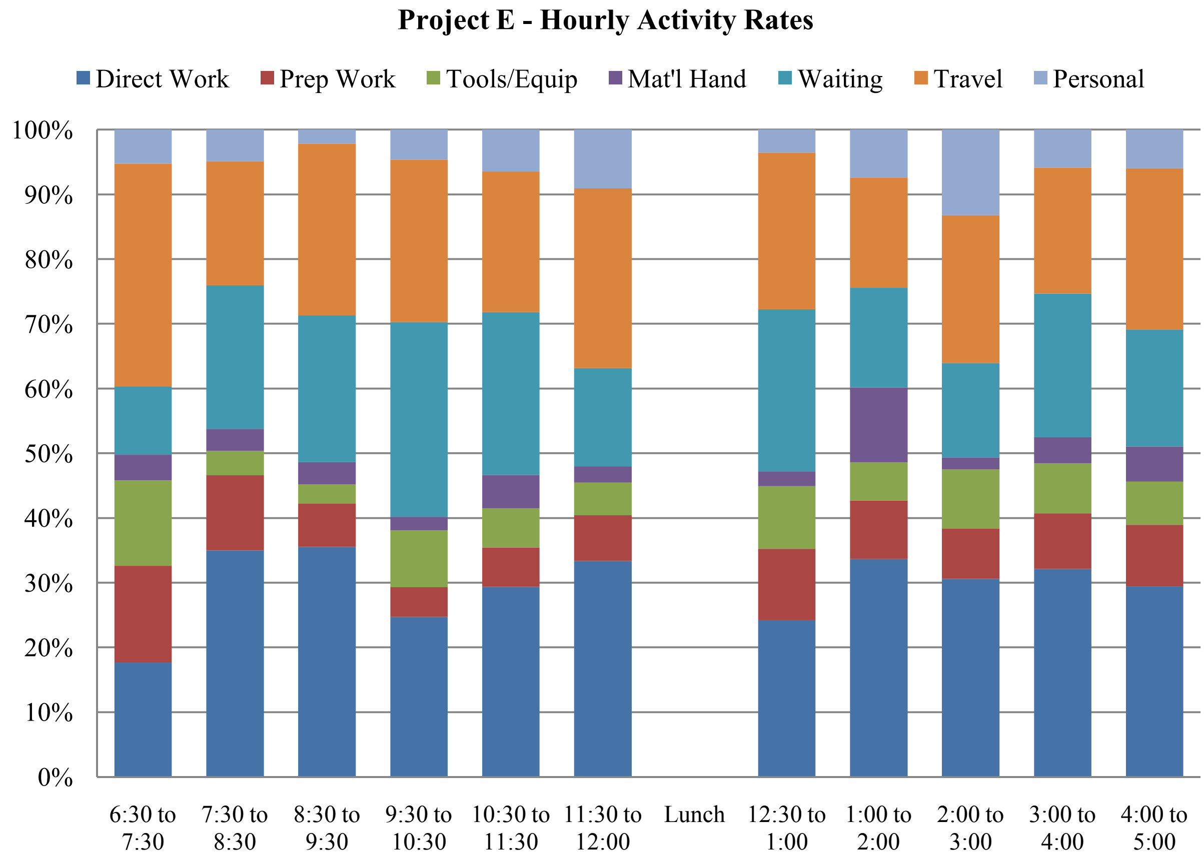


Figure 31: Hourly distribution of activities for Project E

The analyzer will first notice the high travel activity percentage right at the beginning of the work day. It is obvious that travelling is excessive right at the beginning as workers walk to the workface, to the tool room, or to the material laydown yard. The tools-and-equipment activity percentage is also highest at the beginning of the day, which is typical of most construction projects since workers need to get tools. It appears that the direct-work rate does ramp up fairly quickly in the morning.

The mid-morning dip in direct-work rate is typical, however the reason here is not necessarily typical. Often the dip is caused by an increase in personal activities. However, this does not appear to be the case. Instead, it appears an increase in the waiting activity percentage is driving the direct-work rate down. Further study needs to be completed to determine why there is so much waiting at this particular time.

The traveling and personal activity percentages increased slightly before lunch which is typical as workers begin to take lunch earlier than the prescribed time. Better site management can decrease this; however the time is not excessive. Further, after lunch personal activities are low meaning that many workers are not extending their lunch into the work hours.

The rest of the afternoon appears fairly flat. Once the workers get up to a direct-work rate of 30% it appears that they sustain it. There is a minor dip in the direct-work rate during the afternoon. The dip is created by more workers taking personal activity time in the afternoon. This often happens when there is no afternoon break time.

4.1.6 Project F

The final project visited was another petrochemical plant in the Gulf Coast area, specifically Louisiana. This particular plant is designed to produce alumna products from recycled aluminum.

At the time of visit in late September 2009, 70% of piping and structural steel were completed. The main focus of the work at this time was commissioning, however there were still piping work assignments to be completed. It is interesting to note that the site used extensive work packaging for piping assignments.

A total of 161 pipefitters were onsite in September 2009. Only pipefitters were included in the study. For 161 workers, a minimum sample size of only 123 was required according to the binomial distribution to achieve an error of 5%, well below the true minimum sample size of 510. Fortunately, as shown in the following table, the observer collected many more samples than the original estimate. Also, the proportions of each category, provided for the confidence level to be higher than would be anticipated had the worst case scenario existed.

Table 21: Project F Number of Observations per Hour

Work Hour	Number of Observations	Confidence Level
7:00 – 8:00	271	83.16%
8:00 – 9:00	248	78.54%
9:00 – 10:00	312	88.72%
10:00 – 11:00	239	78.45%
11:00 – 12:00	322	89.29%
Lunch	-	-
12:30 – 1:30	318	90.44%
1:30 – 2:30	282	89.86%
2:30 – 3:30	279	85.66%
3:30 – 4:30	250	85.49%
4:30 – 5:30	278	80.82%
Total	**2799**	**99.99%**

These observations were then tabulated and the activity percentages for each activity analysis category were calculated. These results from the study of Project F are presented.

Table 22: Activity Rates and Error Estimates for a 95% Confidence Level for Project F

Activity Category	Percentage	Error
Direct-work	28.12%	1.67%
Preparatory-work	11.54%	1.18%
Tools-and-equipment	10.93%	1.16%
Material-handling	7.57%	0.98%
Waiting	13.97%	1.28%
Travelling	22.97%	1.56%
Personal	4.89%	0.88%

These results are illustrated, like all other studies, with a pie chart.

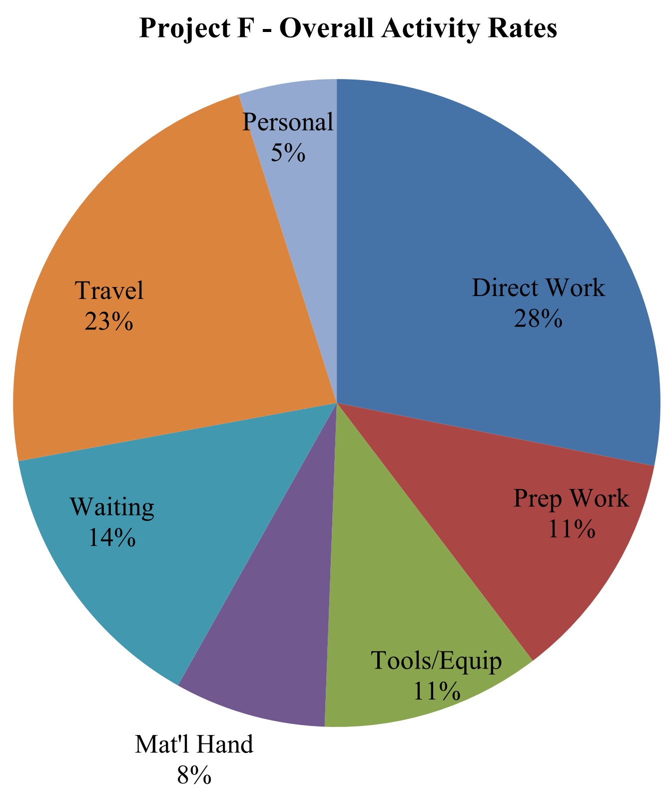


Figure 32: Overall activity rates for Project F

The first percentage to jump out at the analyst is the very high value of travel activity. At 23%, nearly 2.5 hours of the average workers' time is spent walking the site without tools, equipment, or materials. For a site of 161 workers, this is 370 hours per day lost to travel activities. Management needs to consider the layout of the site. Unfortunately, the author was not the observer onsite; however, it is also noted that other percentages related to travel such as material-handling, and tools-and-equipment are high. This indicates that workers are travelling long distances to laydown yards, tool rooms, and gang boxes. If possible, management should move these items closer. Further, if this is a vertical site, the addition of elevators may help alleviate this issue.

The material-handling and tools-and-equipment activity percentages are excessive, which would reflect poor materials management, and tools management programs.

The waiting activity percentage could also be considered high, though was not much greater than the average of the six case studies. Management should consider their planning techniques and crew balances. Further, congestion and interferences of groups may need to be considered.

Personal activities accounted for 4.9% of workers time which is very low for the typical construction site. The hourly distribution of work activities illustrates this low personal activity percentage. The personal activity percentage in the morning is nearly negligible, while the afternoon it increases. This is most likely due to heat in the afternoon, and workers becoming tired from a ten-hour work-day. It is also noted that there appears to be no discernable increase in personal activity percentages before lunch and the end of the work-day which is common on construction projects.

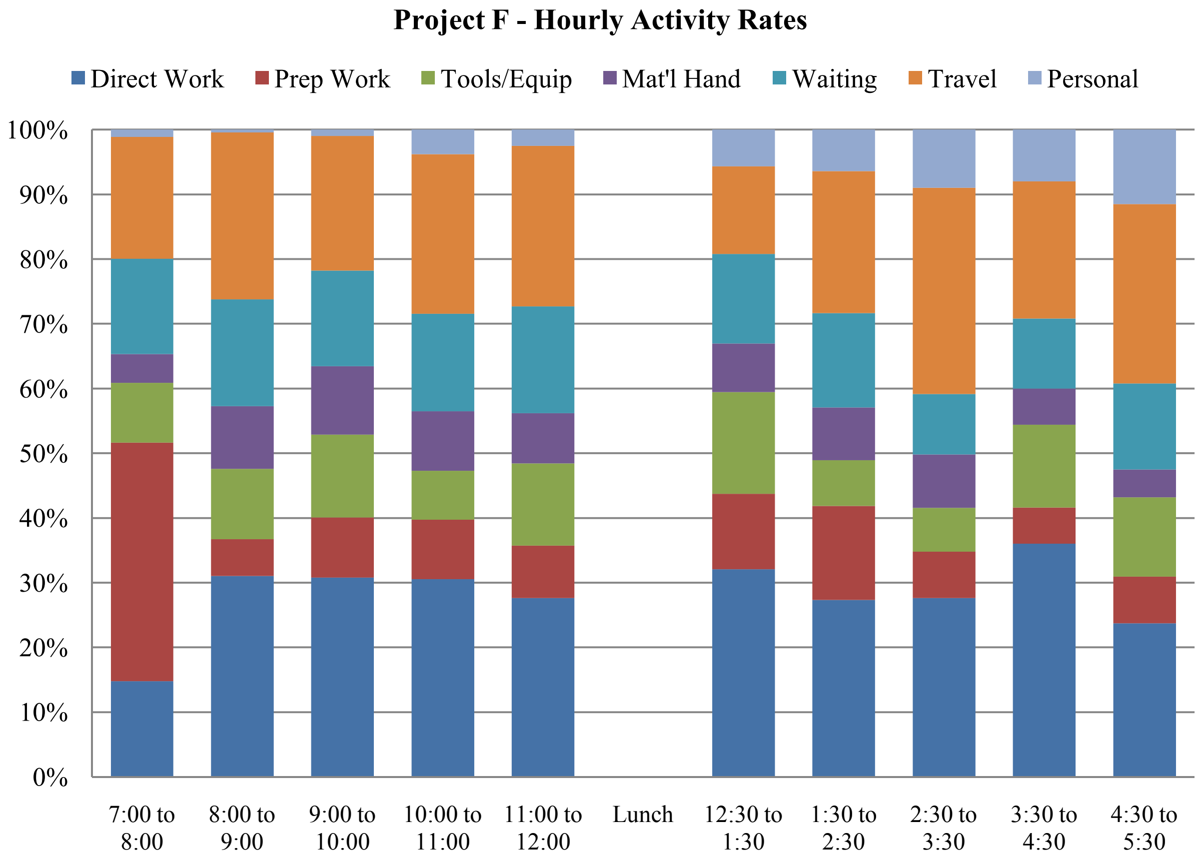


Figure 33: Hourly distribution of activities for Project F

Though the hourly distribution for Project F is a model for the control of personal-time, the control of travel activity is weak. Of most concern is the third last study hour between 3:30 and 4:30 pm, where over 30% of the site was observed traveling empty handed. Management needs to control this time period more effectively. This increase of travel time caused the mid-afternoon decrease in the direct-work rate.

4.1.7 Summary of Lessons Learned

The six case studies have illustrated that the workface assessment methodology integral to the activity analysis process is successful. However, the trials have lead to several lessons learned which are presented here as a reflection on the case studies.

Importance of sample size

Before the field trials, the minimum sample size was determined according to the binomial distribution equation which was published by several researchers. However, through research after the studies, it was determined that because more than two categories existed, a multinomial distribution was to be used where the worst case scenario required a much greater minimum sample size. The problem was further compounded by the notion that sampling a site of 110 workers 384 times per hour seemed redundant. Because of this, the finite population correction factor was utilized which in many cases significantly reduced the number of samples. As the number of samples decreased, the error increased. This was shown by poor confidence levels in most of the studies. It is generally accepted that the industry uses a 5.0% error rate and a confidence level of 95%. Through the analysis of the case studies it has been determined that sample size needs to be a minimum of 510 samples per observation period regardless of workforce size.

Benefit of worst case scenario and taking more samples

Some hourly confidence levels were higher than anticipated despite estimating the sample size with the binomial distribution and finite population correction factor. This occurred for two reasons. Firstly, the worst case scenario determined the minimum sample size by assuming only three categories, each at 33%. However, activity analysis uses seven categories, each with a significant proportion. If these values could be used to determine the minimum sample size, fewer samples would be necessary. This leads to the second reason why confidence levels increased; observers collected more samples than were required. Despite only collecting more samples than the erroneously calculated minimum sample size, and less than the worst case estimate of 510 samples, the confidence intervals improved significantly compared to had only the erroneous sample size been collected.

Leave an open schedule

As the hourly breakdown of observations have indicated there are real chances of delays to the sampling procedure whether by inclement weather such as rain, entire site meetings such as safety talks, or irregular activities like heavy lifts. It would be recommended for future observers to incorporate at the very least one day grace, if not two, into a visit to ensure that if an unforeseen event occurs, the minimum sample size can be collected for all study hour periods. Further, it helps to ensure that no study period distorts the total overall results.

Difficulty in sampling

Sampling using the activity analysis process can be difficult, and takes practice. At the beginning of the field trials it was determined that new observers are slow to correctly identify work activities and craft identifiers. Craft identifiers can be especially difficult to determine in dark areas of construction sites. However, it is believed that in general there is a quick learning curve, as most observers were finding by the end of the first field trial that sampling was becoming much easier. Observers were quickly learning that much information could be extracted from the body orientation, what was in his hands, what he was looking at, etc.

A second identified difficultly in sampling was that the process is physically demanding. On most construction sites, the observer needs to continuously walk the site only breaking at scheduled break times observed by the workforce. For a first time observer who is use to site management duties, this can be exhausting. Further, the observer needs to prepare for studies outside of the typical work hours since the whole of the work hours needs to be spent sampling.

Benefit of comments to identify productivity issues

The difficulty in analyzing data when someone other than the observer does the analysis has been recognized. In this light, it has been made clear that results from activity analysis really do reflect the conditions onsite which are witnessed by the observer. By recording comments on the side of the template, the observer (now the analyst) can think of examples of waiting, traveling, and personal activities, or the like. Causes of productivity issues are easier to identify when the analyst has intimate knowledge of the site and has made comments as to specific events.

Communication with workers during sampling

For most studies, no widespread craft information session was held. Instead foremen were told of the study, and some foremen chose to disclose this information with craft workers, while others did not. It is encouraged that observers be open and honest with craft workers. The craft worker may see the study as an audit. The observer should share the observation template with the worker so that he sees the anonymity that is inherent in this study. Further, it should be stressed that the purpose of the study is to identify productivity inhibitors that will be reduced or removed as a result of the study. Often the worker will have suggestions on how to improve the site. These should be recorded in the comments section of the template, and considered when analyzing the results.

4.1.8 Summary of Case Studies

The case studies have proved valuable to verifying and improving the activity analysis process. The lessons learned are minor in nature, but will help to enhance the overall study, and ensure statistical accuracy. Unfortunately, the cyclical nature of the activity analysis process could not be employed due to time constraints. Also, though it is stressed throughout the document not to, the analysts were forced to compare projects with each other. Further, because these were the first trials of activity analysis, no database existed to compare or set targets to strive for. However, it is stressed that the workface assessment part of the activity analysis process has been verified and improved upon.

The validation of the continuous improvement portion of the activity analysis process is completed using results from similar studies performed by two major contractors. Multiple workface assessment studies were performed on the projects submitted. The statistical analysis of these submitted projects, and the results of the analysis are reported in the next section.

4.2 Validation of Continuous Productivity Improvement Data

4.2.1 Data Sources

For the purpose of validating the continuous productivity improvement portion of the activity analysis process, data was collected from two major construction contractors from the United States. Both contractors have productivity departments which assess site productivity and provide improvement recommendations to construction managers. Both contractors utilize work sampling, however their application differs. These contractors are two of a very limited number of construction companies actively using work sampling. Further, the difference in applications reflects the fragmented use of work sampling in the construction industry.

Contractor A's Contribution

In the interview with a representative of Contractor A's productivity department, it was determined that the corporate office does not force construction sites to be subjected to a review by the department. Instead construction managers must decide that they want their site measured in terms of productivity, and invite the productivity department to visit. Once onsite, a representative conducts both a work sampling study and issues foreman delay surveys for the week or two that he is onsite. The representative then analyzes the work sampling data in conjunction with the surveys and presents an overview of the labour activity levels by craft, area, time of day, etc. and presents a comprehensive list of productivity inhibitors for management to consider and correct.

Contractor A provided much to the development and analysis of the activity analysis process. Beyond providing insight into onsite productivity and work sampling, Contractor A provided both online and in person work sampling training. Further, Contractor A was able to provide two projects for two of the case studies. The contractor also provided data for sites to which work sampling studies were completed multiple times. The purpose of this data is to examine the hypothesis of whether a continuous improvement process like activity analysis can be used to improve direct-work rates on a construction site. The author as developer of activity analysis, is grateful for Contractor A's contribution to this research.

Contractor B's Contribution

Contractor B has a substantially larger productivity department than Contractor A, however in similar fashion the department must be invited to a site to monitor and report on the activities of the workforce. A senior representative with the group introduced the author to the database of work sampling results Contractor B has developed through years of study. The database assists Contractor B to set activity target rates for construction projects based on several factors including type of construction and facility, location, stage of project, etc. However, the program developed by Contractor B is more than a database. The program calculates activity percentages for observers. Further, the program will compare current results with any previous results to monitor any changes to activity levels.

Contractor B provided thorough insight into their work sampling practices, and its compilation of a database and calculation program. The author is grateful for these insights. Further, Contractor B was able to provide a significant number of projects where multiple iterations of work sampling were completed. This data was combined with Contractor A's to examine the potential of continuous productivity improvement processes such as activity analysis.

4.2.2 Statistical Analysis of Data

The data provided by Contractors A and B represents 16 construction projects, of which 42 work sampling studies were completed. On all 16 projects at least two work sampling studies have been conducted. Seven projects had a third study completed and three had four studies completed during the course of the project. The two contractors provided the percent improvement in direct-work rates when compared to the initial first study. It is the goal to improve direct-work rates and so the two contractors measure their improvement in this way. The data collected from both Contractor A and B are summarized in Table 23 and illustrated in Figure 34.

Table 23: Percent Direct-Work Rate Improvement Compared to Initial Study

Project	Study 2	Study 3	Study 4
A	-5.1%		
B	-3.6%	17.4%	24.6%
C	3.0%		
D	4.5%	23.1%	
E	4.8%	-4.4%	
F	7.4%	3.4%	6.3%
G	8.3%		
H	12.2%		
I	12.7%		
J	19.9%	16.2%	13.1%
K	24.9%	22.0%	
L	25.3%	46.9%	
M	30.7%		
N	30.9%		
O	36.9%		
P	57.4%		
Size (n)	16	7	3
Average (x)	16.89%	17.81%	14.65%
Standard Deviation (s)	16.67%	16.30%	9.23%

It is important to reiterate that the percentages represent the percent improvement in direct-work rates in comparison to the first study. The following is a theoretical example for Project J.

- Assume the direct-work rate was measured to be 28% in an initial study.
- Assume the direct-work rate was measured to be 33.57% in the second study. When compared to the initial 28%, the percent improvement is 19.9% as summarized in the table.

$$Percent\ Improvement = \frac{Second\ DW - Initial\ DW}{Initial\ DW} = \frac{33.57\% - 28.0\%}{28.0\%} = 19.9\%$$

- Assume the direct-work rate was measured to be 32.54% in the third study. Again, comparing to the initial direct-work rate of 28% results in a percent improvement of 16.2%.

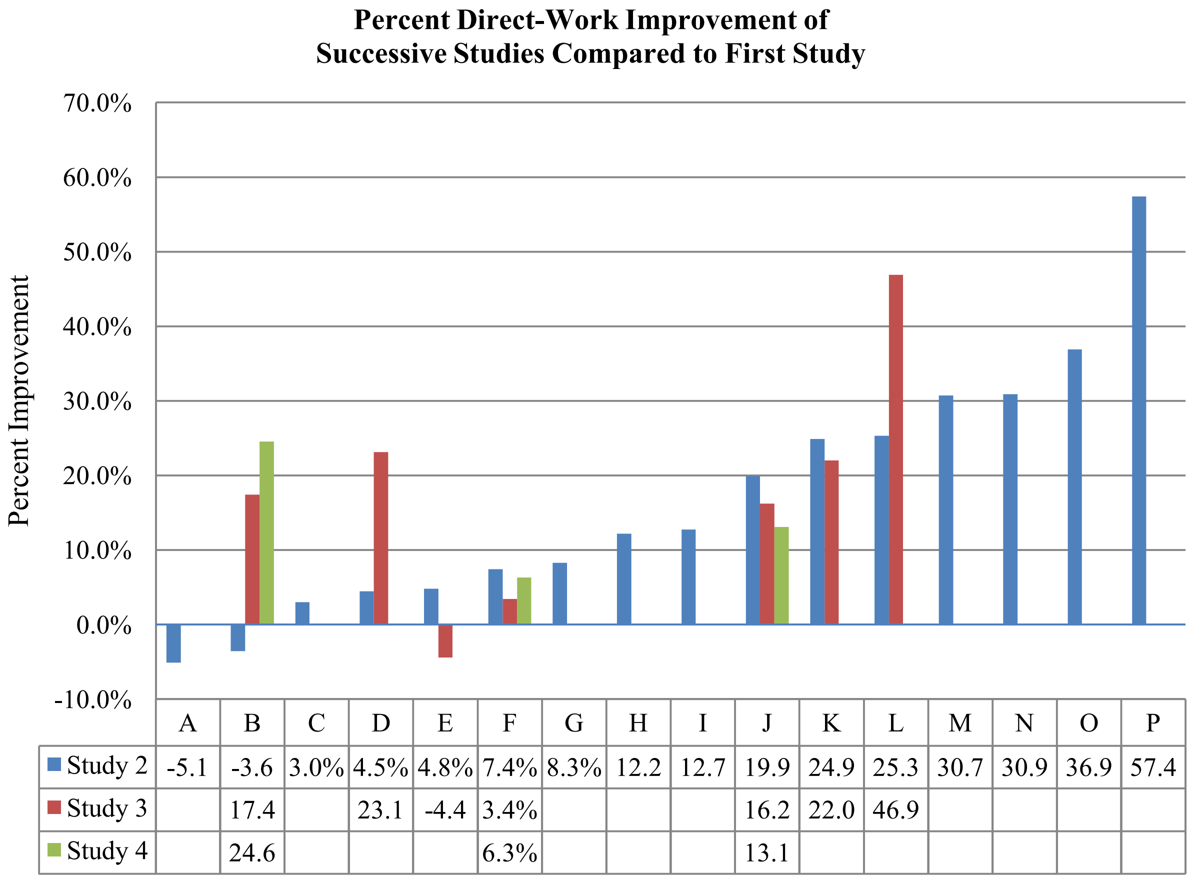
$$Percent\ Improvement = \frac{Third\ DW - Initial\ DW}{Initial\ DW} = \frac{32.54\% - 28.0\%}{28.0\%} = 16.2\%$$

- Finally a fourth study is completed, with a measured direct-work rate of 31.67%. The fourth direct-work rate is compared to the initial study, which results in percent improvement from the first study of 13.1%.

$$Percent\ Improvement = \frac{Fourth\ DW - Initial\ DW}{Initial\ DW} = \frac{31.67\% - 28.0\%}{28.0\%} = 13.1\%$$

This is a theoretical example, because the absolute direct-work rate for all of the studies is unknown. Both contractors wish to protect proprietary information related to their business for competitive reasons. Regardless, it is the actual percent improvement which is important because it shows the potential of direct-work rate improvements through the use of a continuous productivity improvement process such as activity analysis.

A plot of all percent direct-work rate improvement data has been created to illustrate improvements. The points are grouped by project, and coloured according to the study number. Because all rates are compared to the first, the plot quickly illustrates which projects continued to increase its direct-work throughout the course of the project, and which declined.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Study 2	-5.1	-3.6	3.0%	4.5%	4.8%	7.4%	8.3%	12.2	12.7	19.9	24.9	25.3	30.7	30.9	36.9	57.4
Study 3		17.4		23.1	-4.4	3.4%				16.2	22.0	46.9				
Study 4		24.6				6.3%				13.1						

Figure 34: Percent direct-work rate improvement of 16 projects

As the plot indicates, the direct-work rates of two projects (A & B) declined from the first to the second study. Further, direct-work rates from the third study declined on four of seven projects (E, F, J & K) when compared to the second study. Of those (Project E) actually declined less than the first study. Of the three projects where a fourth study was conducted, only one declined compared to the third study (Project

J). It is important to note at this point that it is generally accepted that direct-work rates decrease as the stages of a construction project progress when site management do not take an active role in improving direct-work rates. This is due to two reasons both related to the sequence of trades. At the beginning of a project, civil and structural trades are performing work in a relatively open space. As the structure nears completion, trades such as pipefitters and electricians take over. While performing their work, structural elements completed by the civil and structural trades such as floors, columns, beams and walls, become interfering objects. Second, it is generally understood that work of civil and structural trades is less complex than the work of boilermakers, pipefitters, millwrights, and electricians who work during later stages of the project. To maintain direct-work rates during these more complex stages, active processes such as activity analysis are necessary.

A statistical analysis was performed to examine whether the apparent correlation of significant improvements with Contractor A's and B's efforts using a continuous improvement process is statistically valid. To perform this, the average of each study was calculated. The average, standard deviation and number of data points are summarized in Table 23. A plot was generated to illustrate the average, median, range, 25th percentile and 75th percentile of each set of data (Figure 35). Because the averages are all above zero, it is understood that the second, third and fourth studies in general improved beyond the first study.

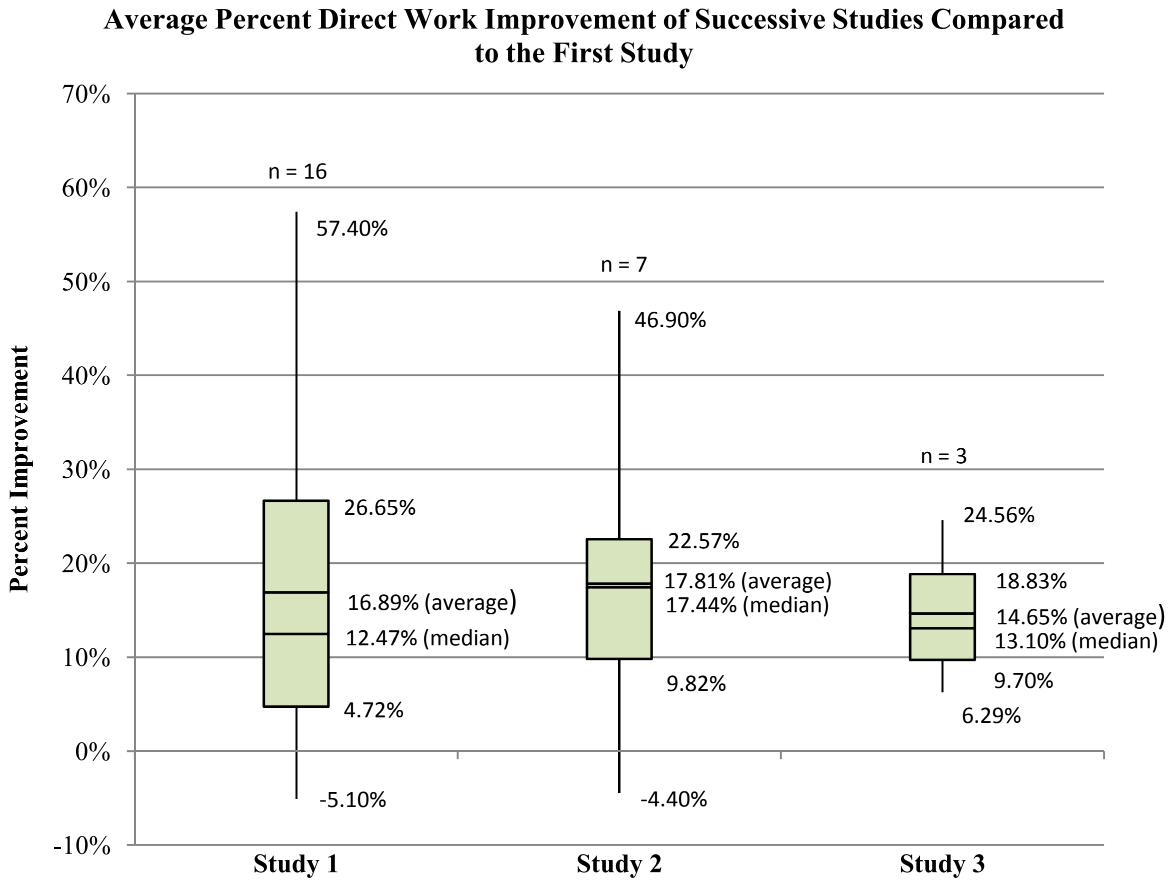


Figure 35: Average direct-work rate improvement by study number

Compare Study 2 to Study 1

A t-test was used to determine if the average improvement for Study 2 was significantly different than zero. If the average is significantly different, it shows that the direct-work rates of Study 2 were significantly greater than the direct-work rate of Study 1.

The data for the study:

Number of data points: $n_2 = 16$

Average improvement for sample: $x_2 = 0.1689$

Standard deviation for sample: $s_2 = 0.1667$

Error for 95% confidence: $\alpha = 0.05$

The significance test becomes:

Hypothesis test:

H_0: $\mu_0 = 0 \rightarrow$ the change between studies 1 and 2 is 0%

H_1: $\mu_0 \neq 0 \rightarrow$ the change between studies 1 and 2 is not 0%

The null hypothesis is rejected if $t_{obs} > t_{crit}$

$$t_{crit} = t_{n_2-1;\,\alpha} = t_{16-1;\,0.05} = t_{15;\,0.05} = 1.7531$$

$$t_{obs} = \frac{x_2 - \mu_0}{\frac{s_2}{\sqrt{n_2}}} = \frac{0.1689-0}{\frac{0.1667}{\sqrt{16}}} = 4.0532$$

$$t_{obs} = 4.0532 > t_{crit} = 1.7531$$

∴ the null hypothesis is rejected

From this analysis, it is determined that the improvements from Study 1 to Study 2 are significant at a 95% confidence level.

Compare Study 3 to Study 1

Another t-test was used to determine if the average improvement for Study 3 was significantly different than zero. If the average is significantly different, it shows that the direct-work rates of Study 3 were significantly greater than the direct-work rate of Study 1.

The data for the study:

Number of data points:	$n_3 = 7$
Average improvement for sample:	$x_3 = 0.1781$
Standard deviation for sample:	$s_3 = 0.1630$
Error for 95% confidence:	$\alpha = 0.05$

The significance test becomes:

Hypothesis test:

H_0: $\mu_0 = 0 \rightarrow$ the change between studies 1 and 3 is 0%

H_1: $\mu_0 \neq 0 \rightarrow$ the change between studies 1 and 3 is not 0%

The null hypothesis is rejected if $t_{obs} > t_{crit}$

$$t_{crit} = t_{n_3-1;\,\alpha} = t_{7-1;\,0.05} = t_{6;\,0.05} = 1.9432$$

$$t_{obs} = \frac{x_3 - \mu_0}{\frac{s_3}{\sqrt{n_3}}} = \frac{0.1781-0}{\frac{0.1630}{\sqrt{7}}} = 2.8909$$

$$t_{obs} = 2.8909 > t_{crit} = 1.9432$$

∴ the null hypothesis is rejected

From this analysis it is determined that the improvements from Study 1 to Study 3 are significant at a confidence of 95%.

Compare Study 4 to Study 1

A third t-test was used to determine if the average improvement for Study 4 was significantly different than zero. If the average is significantly different, it shows that the direct-work rates of Study 3 were significantly greater than the direct-work rate of Study 1.

The data for the study:

Number of data points: $n_4 = 3$

Average improvement for sample: $x_4 = 0.1465$

Standard deviation for sample: $s_4 = 0.0923$

Error for 95% confidence: $\alpha = 0.05$

The significance test becomes:

Hypothesis test:

H_0: $\mu_0 = 0 \rightarrow$ the change between studies 1 and 4 is 0%

H_1: $\mu_0 \neq 0 \rightarrow$ the change between studies 1 and 4 is not 0%

The null hypothesis is rejected if $t_{obs} > t_{crit}$

$$t_{crit} = t_{n_4-1;\,\alpha} = t_{3-1;\,0.05} = t_{2;\,0.05} = 2.9200$$

$$t_{obs} = \frac{x_4 - \mu_0}{\frac{s_4}{\sqrt{n_4}}} = \frac{0.1465-0}{\frac{0.0923}{\sqrt{3}}} = 2.7482$$

$$t_{obs} = 2.7482 < t_{crit} = 2.9200$$

∴ the test fails to reject the null hypothesis

From this analysis it is determined that the improvements from Study 1 to Study 4 are not significant at a confidence level of 95%.

The study was then extended to determine at what confidence level the improvements in direct-work rate found in Study 4 can be considered to be significantly different than zero. To find this, we set the critical t-value to the observed t-value of 2.7482.

Find the confidence level $(1 - \alpha)$

$$t_{obs} = t_{crit} = t_{n_4-1;\,\alpha} = t_{2;\,\alpha} = 2.7482$$

From a t table we find that:

$$t_{2;\,0.05} = 2.920;\ t_{2;\,0.10} = 1.886$$

The conservative confidence level of 90% is used.

$$t_{obs} = 2.7482 > t_{crit} = 1.886$$

∴ at a confidence level of 90%, the average improvement in direct-work rates found in Study 4 compared to Study 1 is significantly different than zero

The analysis for Study 4 shows that at a 95% confidence level, the improvement was not statistically significant. This is because the number of projects where a fourth study was conducted was a meagre 3. When the confidence level is lowered to 90% the improvement from Study 1 becomes statistically significant. It is noted that the actual confidence level is greater than 90% and less that 95%.

4.2.3 Summary of Continuous Improvement Validation

The preceding analysis has shown that continuous productivity improvement using a process similar to the activity analysis process is viable. The following is a brief summary of the statistical analysis.

It has been shown that for the 16 projects submitted by the two contractors; the average difference in the direct-work rate of 16.9% of second study compared to the first study is statistically significant at the 95% confidence level.

Further, it has been shown that for the seven projects where three studies have been completed, the average increase in the direct-work rate of 17.8% of the third study compared to the first is statistically significant at a 95% confidence level.

Finally, it was determined that the average increase in the direct-work rate of 14.6% from the three projects where four studies were completed was not statistically significant at a 95% confidence level. This was due to few projects where the fourth study was completed. However, the improvement from the fourth study compared to the first becomes significant at a 90% confidence level.

This shows that there is potential to progressively improve direct-work rates throughout a project. It is acknowledged that the improvement from the fourth cycle to the first cycle was not as large as the improvement from the third cycle to the first. This indicates a decrease in direct-work rates in the fourth study. A fourth study was only performed on three projects, so it cannot be said for certain that this is the trend. However, it is logical that as the study progresses direct-work rates may decrease. This is because the later stages of a project are more complex, and so a slight decrease in direct-work rates would be expected. A continuous productivity improvement process such as activity analysis, strives to continually increase direct-work rates, or at the very least minimize its decrease at late, more complex stages of a project.

Unfortunately, time was a limitation to this study, and so activity analysis could not be applied to the case study projects multiple times. It would have been more valuable to perform activity analysis on a regular basis on sites, instead of using data collected from a similar continuous improvement process. It would have also been more valuable to continue the study to fifth and sixth cycles to determine if the decrease in direct-work rates in the fourth study is a trend or simply a case of too few studies skewing the information.

Chapter 5: Conclusions & Recommendations

5.1 Conclusions

In attempts to increase both profits and market competitiveness, construction firms are in the constant pursuit of ways to reduce costs. Of the input costs on typical construction projects, labour costs are the most variable. Common site metrics for productivity include labour productivity and productivity factors. However, these require cost and production information which is reported well after the work has been completed, leaving management without timely information for which to improve site productivity.

Workface assessment methods such as foremen delay surveys, craftsmen questionnaires, the five minute rating technique and work sampling attempt to provide more timely information regarding the labour situation which exists on site. Of the four methods, work sampling provides management with the ability to understand how workers spend the work day with a good level of statistical accuracy. Work sampling can report the amount of time workers spend installing materials, preparing to work, waiting, walking empty handed, etc. Information about the expenditure of time is a valuable metric for construction managers; however work sampling is not widely used in the construction industry.

Work sampling is not regularly employed by most construction sites, possibly because no readily available guide exists detailing how to complete a work sampling study on a construction site. Further, work sampling is a workface assessment method merely reporting activity levels. It does not identify productivity issues. The construction industry needs a process for quantifying activity levels of labour, identifying productivity issues, determining the causes of these issues, and assisting managers in planning and implementing changes to improve site productivity. Further, this process must be cyclical so that productivity continues to increase throughout the life of the project.

In response to these needs, activity analysis has been developed. Activity analysis is a continuous productivity improvement process which determines the overall activity rates of craft workers and the distribution of activity rates throughout a typical workday. The rates are analyzed to identify productivity inhibitors, which are reduced or eliminated in an attempt to improve the direct-work rate. Several studies are completed throughout a project life to continually improve the direct-work rate.

In summary, it can be concluded based on the research presented in this thesis that:

1. Activity analysis is feasible to conduct; and
2. Activity analysis correlates with improved direct-work rates.

The feasibility of activity analysis was verified through six case studies performed at industrial construction sites in the United States. The application of activity analysis on these projects indicates its ability to quantify activity rates of workers, identify productivity issues, and determine causes. The case studies also provided the opportunity to enhance the data collection and analysis process through reflection on lessons learned.

Data from 16 projects was collected from contractors who performed activity analysis on their site. Multiple studies were completed on each project submitted. The data was analyzed to statistically show that the direct-work rate of each cycle improved when compared to the initial baseline. This indicates a correlation between activity analysis and improved direct-work rates.

5.2 Recommendations for Future Research

Future work on activity analysis centres around three main potential areas of research which will be discussed here: (1) full application of activity analysis to a construction firm; (2) a study on the costs of activity analysis versus the financial benefits of employing the method; and (3) the relationship and potential integration of activity analysis with other workface assessment methods. It is acknowledged here that there are limitless areas of research related to activity analysis, since little research in this area has been published recently. The three potential areas are considered close extensions of this work, and are of interest to the author.

Full application of activity analysis

As mentioned previously, one of the great limitations of this study has been time constraints. The activity analysis process has not been applied fully to specifically validate the construction productivity improvement process as outlined in activity analysis. Instead this research shows that the continuous productivity improvement process is effective. This finding has been extended to include activity analysis. It would be of great value if the entire activity analysis process could be validated through monitoring direct-work rates through sampling and implementing improvements through the life of a construction project.

Cost benefit analysis of activity analysis deployment

Related to the full application of activity analysis, a study on the financial aspects of the deployment of the activity analysis process would be intriguing. It is anticipated that the costs of deploying a basic form of activity analysis on a project would not be costly. An observer is required to run the process and spreadsheet software to make the calculations. However, to include the development and maintenance of a comprehensive database, as discussed in Chapter 3, in the cost would be beneficial since it is anticipated this could be costly, but would have enormous benefits. Few construction companies may have the resources to develop this database. These costs would be considered against estimates of real dollars saved throughout the project that can be attributed to activity analysis identifying productivity issues, and helping managers implement improvements. It is estimated by the author that the financial benefits will greatly outweigh the costs; however actually being able to quantify this is critical.

Integration of other workface assessment methods

A third interesting area of research would be the relationship between activity analysis and other workface assessment methods such as foreman delay surveys, and craftsman questionnaires. It is recognized that each method has its own advantages and disadvantages. It has been recommended that activity analysis be used in conjunction with, at the very least, foremen delay surveys. However no specific relationship has been determined. Further, it may be possible to integrate these other methods into activity analysis, thereby enhancing the productivity improvement capabilities. For instance, combining results of activity analysis with foremen delay surveys may assist the analyst in determining more specific causes of productivity issues, and specific areas of the site it is affecting. Activity analysis does this, however it could be enhanced with the addition of other workface assessment methods.

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Appendix A: Sample Calculations

The following is intended to illustrate calculations of the overall activity rates of a study and the hourly distribution of activity rates. Also included are sample calculations for error and confidence levels. The example calculations are for Project A as described in Chapter 4.

Calculating Overall Activity Rates

As stated in Chapter 3, there are five steps to calculating overall activity rates for a study. The calculations presented here start at Step 3, because summing observations on the activity analysis template as shown in Figure 17 and inputting into a spreadsheet, such as Figure 18, is relatively simple.

1. Sum observations per activity on the observations worksheet;
2. Input the observation counts into a spreadsheet according to hour and activity;
3. Sum total activity observations across all hours and days;
4. Sum total observations; and
5. Calculate study activity percentages.

Step 3: Sum hourly activity counts

Once the data has been inputted, the number of observations of a particular category for a particular day is summed. For instance, the sums of the direct-work observation are:

$$DW_{Day\ 1} = 17 + 61 + 33 + 43 + 38 + 40 + 40 + 41 + 35 + 17 = 365$$

$$DW_{Day\ 2} = 4 + 10 + 26 + 31 + 25 + 35 + 37 + 32 + 22 + 13 = 235$$

$$DW_{Day\ 3} = 14 + 34 + 31 + 31 + 53 + 47 + 45 + 28 + 42 + 30 = 355$$

These sums are reported in the second column from the right, and repeated for all activities and days.

Step 4: Sum activity totals

All 21 activity totals are then summed to determine the total number of observations collected for the study.

$$Total\ Observations = DW_{Day\ 1} + DW_{Day\ 2} + \ \dots + P_{Day\ 3}$$

$$Total\ Observations = 365 + 235 + 355 + 191 + 112 + 91 + 270 + 212 + 202 + 96 + 94 + 107 + 130 + 148 + 163 + 194 + 214 + 193 + 65 + 62 + 46 = 3545$$

	Time	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30	Activity Totals	Percent of Obs.
Direct Work	Day 1	17	61	33	43	38	N/A	40	40	41	35	17	365	26.94%
	Day 2	4	10	26	31	25	N/A	35	37	32	22	13	235	
	Day 3	14	34	31	31	53	N/A	47	45	28	42	30	355	
Prep Work	Day 1	43	23	22	20	8	N/A	32	11	10	11	11	191	11.11%
	Day 2	33	2	10	15	14	N/A	14	10	6	4	4	112	
	Day 3	14	11	7	16	4	N/A	19	7	3	5	5	91	
Tools/Equip	Day 1	46	32	21	22	26	N/A	9	20	26	21	47	270	19.29%
	Day 2	34	12	14	17	20	N/A	16	19	21	18	41	212	
	Day 3	23	26	24	18	9	N/A	14	18	18	19	33	202	
Mat'l Hand	Day 1	1	10	6	9	18	N/A	16	15	8	9	4	96	8.38%
	Day 2	3	4	12	13	10	N/A	13	7	16	12	4	94	
	Day 3	6	8	7	4	16	N/A	16	13	17	15	5	107	
Waiting	Day 1	3	12	15	16	12	N/A	12	12	23	14	11	130	12.44%
	Day 2	22	27	25	10	13	N/A	10	3	12	10	16	148	
	Day 3	18	19	16	16	18	N/A	13	17	16	17	13	163	
Travel	Day 1	24	19	16	21	15	N/A	19	13	19	21	27	194	16.95%
	Day 2	23	21	26	20	22	N/A	15	19	27	22	19	214	
	Day 3	28	10	22	13	21	N/A	17	18	16	30	18	193	
Personal	Day 1	4	5	10	11	5	N/A	7	1	8	6	8	65	4.88%
	Day 2	0	8	14	9	11	N/A	1	2	6	4	7	62	
	Day 3	1	4	2	7	9	N/A	2	9	6	5	1	46	
	Hourly	361	358	359	362	367	N/A	367	336	359	342	334	3545	Total

Step 5: Calculate activity percentages

Then each activity percentage may be calculated by summing the three days of activity totals, and dividing by the total number of observations, as per the following equation.

$$\text{Activity percentage} = \frac{\text{Day 1 activity total} + \text{Day 2 activity total} + \text{Day 3 activity total}}{\text{Total number of observations}}$$

The following are the calculations for the seven activity percentages for Project A:

$$\text{DW\%} = \frac{\text{DW}_{\text{Day 1}} + \text{DW}_{\text{Day 2}} + \text{DW}_{\text{Day 3}}}{\text{Total observations}} = \frac{365+235+355}{3545} = 26.94\%$$

$$\text{PW\%} = \frac{\text{PW}_{\text{Day 1}} + \text{PW}_{\text{Day 2}} + \text{PW}_{\text{Day 3}}}{\text{Total observations}} = \frac{191+112+91}{3545} = 11.11\%$$

$$\text{TE\%} = \frac{\text{TE}_{\text{Day 1}} + \text{TE}_{\text{Day 2}} + \text{TE}_{\text{Day 3}}}{\text{Total observations}} = \frac{270+212+202}{3545} = 19.29\%$$

$$\text{MH\%} = \frac{\text{MH}_{\text{Day 1}} + \text{MH}_{\text{Day 2}} + \text{MH}_{\text{Day 3}}}{\text{Total observations}} = \frac{96+94+107}{3545} = 8.38\%$$

$$\text{W\%} = \frac{\text{W}_{\text{Day 1}} + \text{W}_{\text{Day 2}} + \text{W}_{\text{Day 3}}}{\text{Total observations}} = \frac{130+148+163}{3545} = 12.44\%$$

$$\text{T\%} = \frac{\text{T}_{\text{Day 1}} + \text{T}_{\text{Day 2}} + \text{T}_{\text{Day 3}}}{\text{Total observations}} = \frac{194+214+193}{3545} = 16.95\%$$

$$\text{P\%} = \frac{\text{P}_{\text{Day 1}} + \text{P}_{\text{Day 2}} + \text{P}_{\text{Day 3}}}{\text{Total observations}} = \frac{65+62+46}{3545} = 4.88\%$$

These percentages are reported in the far right column of the spreadsheet.

Calculating Actual Errors for Activity Percentages

With the activity percentages calculated, the actual error of each percentage may be calculated using the binomial distribution. Seven error calculations are completed, each considering only one category which creates two attributes. For instance, when considering the category of direct-work, the observation either was direct-work (one attribute) or was not direct-work (the other attribute). The equation for error using the binomial distribution is as follows:

$$d = \sqrt{\frac{(Z_{\alpha/2})^2 p(1-p)}{n}}$$

where d is the error, $Z_{\alpha/2}$ = 1.96 corresponding to a confidence level of 95%, p is the activity percentage being considered, and n is the total number of observations. For this particular case, the total number of observations is 3545.

The error for each activity percentage is calculated as follows:

$$d_{DW} = \sqrt{\frac{(Z_{\alpha/2})^2 DW\%(1-DW\%)}{n}} = \sqrt{\frac{1.96^2(0.2694)(1-0.2694)}{3545}} = 1.460\%$$

$$d_{PW} = \sqrt{\frac{(Z_{\alpha/2})^2 PW\%(1-PW\%)}{n}} = \sqrt{\frac{1.96^2(0.1111)(1-0.1111)}{3545}} = 1.035\%$$

$$d_{TE} = \sqrt{\frac{(Z_{\alpha/2})^2 TE\%(1-TE\%)}{n}} = \sqrt{\frac{1.96^2(0.1929)(1-0.1929)}{3545}} = 1.299\%$$

$$d_{MH} = \sqrt{\frac{(Z_{\alpha/2})^2 MH\%(1-MH\%)}{n}} = \sqrt{\frac{1.96^2(0.0838)(1-0.0838)}{3545}} = 0.912\%$$

$$d_{W} = \sqrt{\frac{(Z_{\alpha/2})^2 W\%(1-W\%)}{n}} = \sqrt{\frac{1.96^2(0.1244)(1-0.1244)}{3545}} = 1.086\%$$

$$d_{T} = \sqrt{\frac{(Z_{\alpha/2})^2 T\%(1-T\%)}{n}} = \sqrt{\frac{1.96^2(0.1695)(1-0.1695)}{3545}} = 1.235\%$$

$$d_{P} = \sqrt{\frac{(Z_{\alpha/2})^2 P\%(1-P\%)}{n}} = \sqrt{\frac{1.96^2(0.0488)(1-0.0488)}{3545}} = 0.709\%$$

Each error reports the interval for which the activity percentage is valid at a specified confidence level. For instance, the direct-work rate at Project A is 26.94% ± 1.460% at a confidence of 95%. Because the sample size for the study is large, all errors are smaller than the typical construction industry rate of 5.0%.

The activity percent errors were reported for each case study in Chapter 4. Specifically, these results for Project A were reported in Table 10.

Calculating Actual Confidence Level of Study Results

In Chapter 4, the actual confidence level for each study was reported as greater than 99%. The confidence level for each activity rate may be determined using the same equation as previous. However, in this calculation, $Z_{\alpha/2}$ is isolated and the error is set to 5.0%.

$$(Z_{\alpha/2}) = \sqrt{\frac{d^2n}{p(1-p)}}$$

The value of $Z_{\alpha/2}$ corresponds to a value of confidence which is determined by $(1 - \alpha)$.

The entire study follows a multinomial distribution because there are more than two categories. Unfortunately, there is little information regarding how to find the true confidence of multinomial distributions. Due to this, the overall confidence of the study is calculated by summing the seven α values and determining the confidence by $(1 - \alpha_{total})$.

As an example of the logic assumed here, consider a study being completed where the direct-work rate has a 95% confidence level. The probability of the proportion being incorrect is once out of 20 times. Assume the preparatory-work rate also has a confidence of 95%, and therefore a probability of being incorrect once out of 20 times. It is unlikely that out of the 20 studies, both the direct-work and preparatory-work rates will incorrectly be estimated simultaneously. It is more likely that out of the 20 studies, one proportion will be incorrect while the second proportion is correct, and eventually the second proportion will be incorrect while the first is correct. Therefore the probability of one incorrect proportion occurring conservatively becomes twice out of 20 studies. This corresponds to a confidence level of 90%.

For Project A the confidence level for the direct-work rate of 26.94% is calculated as follows:

$$(Z_{\alpha/2})_{DW} = \sqrt{\frac{d^2n}{DW\%(1-DW\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.2694(1-0.2694)}} = 6.710$$

From a spreadsheet software it is determined that $\alpha = 1.94\text{x}10^{-11}$ for a value of 6.710.

As the value of $Z_{\alpha/2}$ increases the value of α decreases; therefore the confidence level increases. Typical cumulative standard normal distribution tables only report up to $Z_{\alpha/2} = 3.99$ which corresponds to a value $\alpha = 0.00006$ and a confidence of 99.994% which is very high. The confidence level corresponding to higher values of $Z_{\alpha/2}$ can be determined using statistical software; however this is redundant for this work. When $Z_{\alpha/2}$ is greater than 3.99 a value of $\alpha = 0.00006$ will be used. The confidence level calculation for the remaining activity levels is as follows:

$$(Z_{\alpha/2})_{PW} = \sqrt{\frac{d^2n}{PW\%(1-PW\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.1111(1-0.1111)}} = 9.473$$

For calculations use $\alpha_{PW} = 0.00006$ because $Z_{\alpha/2} = 9.473 > 3.99$.

$$(Z_{\alpha/2})_{TE} = \sqrt{\frac{d^2n}{TE\%(1-TE\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.1929(1-0.1929)}} = 7.545$$

For calculations use $\alpha_{TE} = 0.00006$ because $Z_{\alpha/2} = 7.545 > 3.99$.

$$(Z_{\alpha/2})_{MH} = \sqrt{\frac{d^2n}{MH\%(1-MH\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.0838(1-0.0838)}} = 10.744$$

For calculations use $\alpha_{MH} = 0.00006$ because $Z_{\alpha/2} = 10.744 > 3.99$.

$$(Z_{\alpha/2})_{W} = \sqrt{\frac{d^2n}{W\%(1-W\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.1244(1-0.1244)}} = 9.020$$

For calculations use $\alpha_{W} = 0.00006$ because $Z_{\alpha/2} = 9.020 > 3.99$.

$$(Z_{\alpha/2})_{T} = \sqrt{\frac{d^2n}{T\%(1-T\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.1695(1-0.1695)}} = 7.935$$

For calculations use $\alpha_{T} = 0.00006$ because $Z_{\alpha/2} = 7.935 > 3.99$.

$$(Z_{\alpha/2})_{P} = \sqrt{\frac{d^2n}{P\%(1-P\%)}} = \sqrt{\frac{0.05^2 \text{ x } 3545}{0.0488(1-0.0488)}} = 13.818$$

For calculations use $\alpha_{P} = 0.00006$ because $Z_{\alpha/2} = 13.818 > 3.99$.

For all seven categories, it was determined that the confidence for the entire study was greater than typically reported in cumulative standard normal distribution tables.

Continuing the calculations for all $\alpha = 0.00006$:

$$\propto_{total} = \propto_{DW} + \propto_{PW} + \propto_{TE} + \propto_{MH} + \propto_{W} + \propto_{T} + \propto_{P}$$

$$\propto_{total} = 7(0.00006) = 0.00042$$

$$Confidence = (1 - \propto_{total}) = (1 - 0.00042) = 99.958\%$$

The confidence for the entire study is conservatively calculated to be 99.958%. In Chapter 4, many of the confidence intervals for the case studies are reported as 99.99% because spreadsheet software was used and considers greater confidence than these manual calculations. By either calculation, the results are considered very accurate.

Calculating Hourly Activity Percentages

As stated in Chapter 3, the steps to calculate hourly activity percentages which leads to the development of the time series stacked bar chart is as follows:

1. Sum observations per activity on the observations worksheet;
2. Input the observation counts into a spreadsheet according to hour and activity;
3. Sum total hourly observations across all activities; and
4. Calculate hourly activity percentages.

As before, the example calculations begin at step 3, because the inputting of observation counts into a spreadsheet is not complicated. The spreadsheet used to calculate overall results is also used for hourly activity percentages.

Step 3: Sum hourly observation counts

The total number of observations collected in every hour across all days of study needs to be determined. This is a simple calculation which is illustrated using the following example for the study hour of 7 to 8 am.

$$Hourly\ Total = 17 + 4 + 14 + 43 + 33 + 14 + 46 + 34 + 23 + 1 + 3 + 6 + 3 + 22 + 18 + 24 + 23 + 28 + 4 + 0 + 1 = 361$$

These values were taken from the third column of the spreadsheet, which corresponds to the 7 to 8 am study hour. This calculation is repeated for all study hours and is reported in the bottom row of the spreadsheet.

Step 4: Calculate hourly activity percentages

The hourly activity percentages can then be calculated similar to the entire study, except the focus is on a specific hour. This calculation is again illustrated using the 7 to 8 am study hour.

$$\text{DW\%}_{7-8} = \frac{17+4+14}{361} = 9.70\%$$

This value is then reported in a new spreadsheet as shown. The layout of this spreadsheet is similar to the large spreadsheet which summarizes all data with study hours at the top and activities along the left column. No days are reported since the hourly activity percentage includes all study days.

	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30
Direct Work	9.7%	29.3%	25.1%	29.0%	31.6%	N/A	33.2%	36.3%	28.1%	28.9%	18.0%
Prep Work	24.9%	10.1%	10.9%	14.1%	7.1%	N/A	17.7%	8.3%	5.3%	5.8%	6.0%
Tools/Equip	28.5%	19.6%	16.4%	15.7%	15.0%	N/A	10.6%	17.0%	18.1%	17.0%	36.2%
Mat'l Hand	2.8%	6.1%	7.0%	7.2%	12.0%	N/A	12.3%	10.4%	11.4%	10.5%	3.9%
Waiting	11.9%	16.2%	15.6%	11.6%	11.7%	N/A	9.5%	9.5%	14.2%	12.0%	12.0%
Travel	20.8%	14.0%	17.8%	14.9%	15.8%	N/A	13.9%	14.9%	17.3%	21.3%	19.2%
Personal	1.4%	4.7%	7.2%	7.5%	6.8%	N/A	2.7%	3.6%	5.6%	4.4%	4.8%

The remaining hourly activity percentages for the 7 to 8 am study hour are calculated as below.

$$\mathrm{PW\%}_{7-8} = \frac{43+33+14}{361} = 24.93\%$$

$$\mathrm{TE\%}_{7-8} = \frac{46+34+23}{361} = 28.53\%$$

$$\mathrm{MH\%}_{7-8} = \frac{1+3+6}{361} = 2.77\%$$

$$\mathrm{W\%}_{7-8} = \frac{3+22+18}{361} = 11.91\%$$

$$\mathrm{T\%}_{7-8} = \frac{24+23+28}{361} = 20.78\%$$

$$\mathrm{P\%}_{7-8} = \frac{4+0+1}{361} = 1.39\%$$

These calculations are repeated for all study hours as shown in the previous table.

Calculating Actual Confidence Level of Hourly Results

In general, the error of each hourly activity rate is not of great concern, since the purpose is to produce the time series stacked bar chart, which shows how work is distributed throughout the day. However, the confidence level for each individual hour of study is of importance, since it describes the accuracy of the results. The calculation is similar to that presented in this Appendix for the entire study; however there are two primary differences. Firstly, the calculation uses much smaller sample sizes, since each hour is considered individually. Secondly, since the confidence of each hour is calculated separately, a total of ten confidence levels are calculated.

The confidence level for each hourly activity percentage may be determined using the same equation as before.

$$(Z_{\alpha/2}) = \sqrt{\frac{d^2 n}{p(1-p)}}$$

The overall confidence of the hour is calculated by summing the seven α values and determining the confidence by $(1 - \alpha_{total})$.

The example calculations will consider the 7 to 8 am study period. The α value of each hourly activity percentage is as follows:

$$(Z_{\alpha/2})_{DW} = \sqrt{\frac{d^2 n}{DW\%(1-DW\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.0970(1-0.0970)}} = 3.210$$

From a standard normal distribution table α_{DW} = 0.00133 for a value of 3.210.

$$(Z_{\alpha/2})_{PW} = \sqrt{\frac{d^2 n}{PW\%(1-PW\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.2493(1-0.2493)}} = 2.195$$

From a standard normal distribution table α_{PW} = 0.02816 for a value of 2.195.

$$(Z_{\alpha/2})_{TE} = \sqrt{\frac{d^2 n}{TE\%(1-TE\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.2853(1-0..2853)}} = 2.104$$

From a standard normal distribution table α_{TE} = 0.03540 for a value of 2.104.

$$(Z_{\alpha/2})_{MH} = \sqrt{\frac{d^2 n}{MH\%(1-MH\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.0277(1-0.0277)}} = 5.789$$

For calculations use α_{MH} = 0.00006 because $Z_{\alpha/2}$ = 5.789 > 3.99.

$$(Z_{\alpha/2})_{W} = \sqrt{\frac{d^2 n}{W\%(1-W\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.1191(1-0.1191)}} = 2.933$$

From a standard normal distribution table α_{W} = 0.00336 for a value of 2.933.

$$(Z_{\alpha/2})_{T} = \sqrt{\frac{d^2 n}{T\%(1-T\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.2078(1-0.2078)}} = 2.341$$

From a standard normal distribution table α_{T} = 0.01921 for a value of 2.341.

$$(Z_{\alpha/2})_{P} = \sqrt{\frac{d^2 n}{P\%(1-P\%)}} = \sqrt{\frac{0.05^2 \text{ x } 361}{0.0139(1-0.0139)}} = 8.114$$

For calculations use $\alpha_P = 0.00006$ because $Z_{\alpha/2} = 8.114 > 3.99$.

Continuing the calculations for all α_{total}:

$$\propto_{total} = \propto_{DW} + \propto_{PW} + \propto_{TE} + \propto_{MH} + \propto_{W} + \propto_{T} + \propto_{P}$$

$$\propto_{total} = 0.00133 + 0.02816 + 0.03540 + 0.00006 + 0.00336 + 0.01921 + 0.00006$$

$$\propto_{total} = 0.08758$$

$$Confidence = (1 - \propto_{total}) = (1 - 0.08758) = 91.24\%$$

The confidence for the first study hour (7 to 8 am) is conservatively calculated to be 91.24%. This calculation needs to be repeated for all ten study hours. The hourly confidence levels have been reported for all case studies in Chapter 4.

Appendix B: Summary of Case Study Data

Project A

	Time	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30	Activity Totals	Percent of Obs.
Direct Work	Day 1	17	61	33	43	38	N/A	40	40	41	35	17	365	26.94%
	Day 2	4	10	26	31	25	N/A	35	37	32	22	13	235	
	Day 3	14	34	31	31	53	N/A	47	45	28	42	30	355	
Prep Work	Day 1	43	23	22	20	8	N/A	32	11	10	11	11	191	11.11%
	Day 2	33	2	10	15	14	N/A	14	10	6	4	4	112	
	Day 3	14	11	7	16	4	N/A	19	7	3	5	5	91	
Tools/Equip	Day 1	46	32	21	22	26	N/A	9	20	26	21	47	270	19.29%
	Day 2	34	12	14	17	20	N/A	16	19	21	18	41	212	
	Day 3	23	26	24	18	9	N/A	14	18	18	19	33	202	
Mat'l Hand	Day 1	1	10	6	9	18	N/A	16	15	8	9	4	96	8.38%
	Day 2	3	4	12	13	10	N/A	13	7	16	12	4	94	
	Day 3	6	8	7	4	16	N/A	16	13	17	15	5	107	
Waiting	Day 1	3	12	15	16	12	N/A	12	12	23	14	11	130	12.44%
	Day 2	22	27	25	10	13	N/A	10	3	12	10	16	148	
	Day 3	18	19	16	16	18	N/A	13	17	16	17	13	163	
Travel	Day 1	24	19	16	21	15	N/A	19	13	19	21	27	194	16.95%
	Day 2	23	21	26	20	22	N/A	15	19	27	22	19	214	
	Day 3	28	10	22	13	21	N/A	17	18	16	30	18	193	
Personal	Day 1	4	5	10	11	5	N/A	7	1	8	6	8	65	4.88%
	Day 2	0	8	14	9	11	N/A	1	2	6	4	7	62	
	Day 3	1	4	2	7	9	N/A	2	9	6	5	1	46	
	Hourly	361	358	359	362	367	N/A	367	336	359	342	334	3545	Total

	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30
Direct Work	9.7%	29.3%	25.1%	29.0%	31.6%	N/A	33.2%	36.3%	28.1%	28.9%	18.0%
Prep Work	24.9%	10.1%	10.9%	14.1%	7.1%	N/A	17.7%	8.3%	5.3%	5.8%	6.0%
Tools/Equip	28.5%	19.6%	16.4%	15.7%	15.0%	N/A	10.6%	17.0%	18.1%	17.0%	36.2%
Mat'l Hand	2.8%	6.1%	7.0%	7.2%	12.0%	N/A	12.3%	10.4%	11.4%	10.5%	3.9%
Waiting	11.9%	16.2%	15.6%	11.6%	11.7%	N/A	9.5%	9.5%	14.2%	12.0%	12.0%
Travel	20.8%	14.0%	17.8%	14.9%	15.8%	N/A	13.9%	14.9%	17.3%	21.3%	19.2%
Personal	1.4%	4.7%	7.2%	7.5%	6.8%	N/A	2.7%	3.6%	5.6%	4.4%	4.8%

Project B

	Time	6:00 7:00	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	1:00 2:00	2:00 3:00	3:00 4:00	Activity Totals	Percent of Obs.
Direct Work	Day 1	0	29	32	36	40	35	N/A	38	46	18	274	31.35%
	Day 2	23	30	40	33	35	31	N/A	23	19	18	252	
Prep Work	Day 1	0	16	6	14	18	11	N/A	6	13	16	100	13.05%
	Day 2	54	11	7	15	10	6	N/A	7	3	6	119	
Tools/Equip	Day 1	0	6	5	7	8	9	N/A	10	6	20	71	7.87%
	Day 2	6	9	7	9	5	9	N/A	4	5	7	61	
Mat'l Hand	Day 1	0	7	5	3	4	5	N/A	7	10	3	44	3.58%
	Day 2	2	3	4	0	0	1	N/A	5	0	1	16	
Waiting	Day 1	0	33	19	14	33	10	N/A	24	21	21	175	15.38%
	Day 2	6	13	12	7	19	8	N/A	4	5	9	83	
Travel	Day 1	0	21	27	11	14	15	N/A	9	9	19	125	15.97%
	Day 2	24	14	11	17	11	21	N/A	5	11	29	143	
Personal	Day 1	0	2	12	8	13	16	N/A	14	11	21	97	12.81%
	Day 2	11	9	21	9	12	24	N/A	7	14	11	118	
	Hourly	126	203	208	183	222	201	N/A	163	173	199	1678	Total

	6:00 7:00	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	1:00 2:00	2:00 3:00	3:00 4:00
Direct Work	18.3%	29.1%	34.6%	37.7%	33.8%	32.8%	N/A	37.4%	37.6%	18.1%
Prep Work	42.9%	13.3%	6.3%	15.8%	12.6%	8.5%	N/A	8.0%	9.2%	11.1%
Tools/Equip	4.8%	7.4%	5.8%	8.7%	5.9%	9.0%	N/A	8.6%	6.4%	13.6%
Mat'l Hand	1.6%	4.9%	4.3%	1.6%	1.8%	3.0%	N/A	7.4%	5.8%	2.0%
Waiting	4.8%	22.7%	14.9%	11.5%	23.4%	9.0%	N/A	17.2%	15.0%	15.1%
Travel	19.0%	17.2%	18.3%	15.3%	11.3%	17.9%	N/A	8.6%	11.6%	24.1%
Personal	8.7%	5.4%	15.9%	9.3%	11.3%	19.9%	N/A	12.9%	14.5%	16.1%

Project C

	Time	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30	Activity Totals	Percent of Obs.
Direct Work	Day 1			86			N/A						86	42.12%
	Day 2			62			N/A						62	
	Day 3	63	90	78	74		N/A	60	63	58	104	83	673	
	Day 4			70	86	70	N/A						226	
Prep Work	Day 1			2			N/A						2	12.83%
	Day 2			23			N/A						23	
	Day 3	126	15	17	10		N/A	23	17	18	8	23	257	
	Day 4			10	11	16	N/A						37	
Tools/Equip	Day 1			14			N/A						14	11.95%
	Day 2			29			N/A						29	
	Day 3	64	16	14	15		N/A	23	16	8	8	40	204	
	Day 4			24	13	13	N/A						50	
Mat'l Hand	Day 1			9			N/A						9	2.05%
	Day 2			3			N/A						3	
	Day 3	3	5	3	8		N/A	3	2	5	1	3	33	
	Day 4			3	1	2	N/A						6	
Waiting	Day 1			22			N/A						22	11.14%
	Day 2			32			N/A						32	
	Day 3	6	16	20	25		N/A	36	15	18	17	22	175	
	Day 4			11	15	22	N/A						48	
Travel	Day 1			20			N/A						20	13.23%
	Day 2			19			N/A						19	
	Day 3	52	11	22	27		N/A	18	27	29	18	17	221	
	Day 4			24	16	29	N/A						69	
Personal	Day 1			20			N/A						20	6.68%
	Day 2			8			N/A						8	
	Day 3	8	5	18	13		N/A	8	12	15	8	8	95	
	Day 4			12	15	16	N/A						43	
	Hourly	322	158	675	329	168	N/A	171	152	151	164	196	2486	Total

	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30
Direct Work	19.6%	57.0%	43.9%	48.6%	41.7%	N/A	35.1%	41.4%	38.4%	63.4%	42.3%
Prep Work	39.1%	9.5%	7.7%	6.4%	9.5%	N/A	13.5%	11.2%	11.9%	4.9%	11.7%
Tools/Equip	19.9%	10.1%	12.0%	8.5%	7.7%	N/A	13.5%	10.5%	5.3%	4.9%	20.4%
Mat'l Hand	0.9%	3.2%	2.7%	2.7%	1.2%	N/A	1.8%	1.3%	3.3%	0.6%	1.5%
Waiting	1.9%	10.1%	12.6%	12.2%	13.1%	N/A	21.1%	9.9%	11.9%	10.4%	11.2%
Travel	16.1%	7.0%	12.6%	13.1%	17.3%	N/A	10.5%	17.8%	19.2%	11.0%	8.7%
Personal	2.5%	3.2%	8.6%	8.5%	9.5%	N/A	4.7%	7.9%	9.9%	4.9%	4.1%

Project D

	Time	6:30 7:30	7:30 8:30	8:30 9:30	9:30 10:30	10:30 11:30	11:30 12:00	Lunch	12:30 1:00	1:00 2:00	2:00 3:00	3:00 4:00	4:00 5:00	Activity Totals	Percent of Obs.
Direct Work	Day 1							N/A				17	20	37	28.39%
	Day 2	5	25	33	34	35	16	N/A	16	40	21	33	13	271	
	Day 3	9	4	25	24	16	19	N/A	16	21	27	23	23	207	
	Day 4	13	11	19	16	17	14	N/A	5	21	8			124	
Prep Work	Day 1							N/A				2	7	9	15.73%
	Day 2	23	14	23	14	19	6	N/A	4	8	13	19	12	155	
	Day 3	16	17	6	8	13	10	N/A	9	13	19	8	14	133	
	Day 4	4	3	5	10	9	4	N/A	9	10	3			57	
Tools/Equip	Day 1							N/A				1	5	6	11.51%
	Day 2	13	16	9	13	7	1	N/A	10	11	7	5	5	97	
	Day 3	15	17	8	8	7	7	N/A	6	4	5	5	7	89	
	Day 4	19	8	4	10	8	6	N/A	4	7	1			67	
Mat'l Hand	Day 1							N/A				2	8	10	4.35%
	Day 2	3	10	2	0	7	0	N/A	5	5	4	2	1	39	
	Day 3	5	0	3	0	3	2	N/A	0	6	2	0	3	24	
	Day 4	6	2	5	1	0	0	N/A	4	3	4			25	
Waiting	Day 1							N/A				13	19	32	15.90%
	Day 2	13	13	12	11	14	7	N/A	2	15	17	23	10	137	
	Day 3	14	2	9	10	5	6	N/A	13	8	13	14	7	101	
	Day 4	6	10	12	14	9	13	N/A	11	6	7			88	
Travel	Day 1							N/A				5	12	17	13.02%
	Day 2	11	17	12	11	7	8	N/A	4	6	11	11	4	102	
	Day 3	10	13	7	8	7	9	N/A	2	7	20	11	12	106	
	Day 4	8	8	5	2	4	16	N/A	7	11	7			68	
Personal	Day 1							N/A				2	7	9	11.11%
	Day 2	3	2	4	4	11	15	N/A	2	6	21	5	14	87	
	Day 3	4	8	6	11	15	20	N/A	4	7	9	6	8	98	
	Day 4	8	4	4	7	1	15	N/A	6	8	3			56	
	Hourly	208	204	213	216	214	194	N/A	139	223	222	207	211	2251	Total

	6:30 7:30	7:30 8:30	8:30 9:30	9:30 10:30	10:30 11:30	11:30 12:00	Lunch	12:30 1:00	1:00 2:00	2:00 3:00	3:00 4:00	4:00 5:00
Direct Work	13.0%	19.6%	36.2%	34.3%	31.8%	25.3%	N/A	26.6%	36.8%	25.2%	35.3%	26.5%
Prep Work	20.7%	16.7%	16.0%	14.8%	19.2%	10.3%	N/A	15.8%	13.9%	15.8%	14.0%	15.6%
Tools/Equip	22.6%	20.1%	9.9%	14.4%	10.3%	7.2%	N/A	14.4%	9.9%	5.9%	5.3%	8.1%
Mat'l Hand	6.7%	5.9%	4.7%	0.5%	4.7%	1.0%	N/A	6.5%	6.3%	4.5%	1.9%	5.7%
Waiting	15.9%	12.3%	15.5%	16.2%	13.1%	13.4%	N/A	18.7%	13.0%	16.7%	24.2%	17.1%
Travel	13.9%	18.6%	11.3%	9.7%	8.4%	17.0%	N/A	9.4%	10.8%	17.1%	13.0%	13.3%
Personal	7.2%	6.9%	6.6%	10.2%	12.6%	25.8%	N/A	8.6%	9.4%	14.9%	6.3%	13.7%

Project E

	Time	6:30 7:30	7:30 8:30	8:30 9:30	9:30 10:30	10:30 11:30	11:30 12:00	Lunch	12:30 1:00	1:00 2:00	2:00 3:00	3:00 4:00	4:00 5:00	Activity Totals	Percent of Obs.
Direct Work	Day 1	40	93	80	59	101	66	N/A	55	131	67	71	124	887	30.19%
	Day 2			86		53		N/A						139	
Prep Work	Day 1	34	31	26	11	14	14	N/A	25	35	17	19	40	266	8.50%
	Day 2			5		18		N/A						23	
Tools/Equip	Day 1	30	10	9	21	23	10	N/A	22	23	20	17	28	213	6.68%
	Day 2			5		9		N/A						14	
Mat'l Hand	Day 1	9	9	10	5	8	5	N/A	5	45	4	9	23	132	4.62%
	Day 2			6		19		N/A						25	
Waiting	Day 1	24	59	58	72	82	30	N/A	57	60	32	49	76	599	20.51%
	Day 2			48		50		N/A						98	
Travel	Day 1	78	51	56	60	74	55	N/A	55	66	50	43	105	693	23.57%
	Day 2			68		40		N/A						108	
Personal	Day 1	12	13	9	11	10	18	N/A	8	29	29	13	25	177	5.94%
	Day 2			1		24		N/A						25	
	Hourly	227	266	467	239	525	198	N/A	227	389	219	221	421	3399	Total

	6:30 7:30	7:30 8:30	8:30 9:30	9:30 10:30	10:30 11:30	11:30 12:00	Lunch	12:30 1:00	1:00 2:00	2:00 3:00	3:00 4:00	4:00 5:00
Direct Work	17.6%	35.0%	35.5%	24.7%	29.3%	33.3%	N/A	24.2%	33.7%	30.6%	32.1%	29.5%
Prep Work	15.0%	11.7%	6.6%	4.6%	6.1%	7.1%	N/A	11.0%	9.0%	7.8%	8.6%	9.5%
Tools/Equip	13.2%	3.8%	3.0%	8.8%	6.1%	5.1%	N/A	9.7%	5.9%	9.1%	7.7%	6.7%
Mat'l Hand	4.0%	3.4%	3.4%	2.1%	5.1%	2.5%	N/A	2.2%	11.6%	1.8%	4.1%	5.5%
Waiting	10.6%	22.2%	22.7%	30.1%	25.1%	15.2%	N/A	25.1%	15.4%	14.6%	22.2%	18.1%
Travel	34.4%	19.2%	26.6%	25.1%	21.7%	27.8%	N/A	24.2%	17.0%	22.8%	19.5%	24.9%
Personal	5.3%	4.9%	2.1%	4.6%	6.5%	9.1%	N/A	3.5%	7.5%	13.2%	5.9%	5.9%

Project F

	Time	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30	Activity Totals	Percent of Obs.
Direct Work	Day 1	40	77	96	73	89	N/A	102	77	77	90	66	787	28.12%
Prep Work	Day 1	100	14	29	22	26	N/A	37	41	20	14	20	323	11.54%
Tools/Equip	Day 1	25	27	40	18	41	N/A	50	20	19	32	34	306	10.93%
Mat'l Hand	Day 1	12	24	33	22	25	N/A	24	23	23	14	12	212	7.57%
Waiting	Day 1	40	41	46	36	53	N/A	44	41	26	27	37	391	13.97%
Travel	Day 1	51	64	65	59	80	N/A	43	62	89	53	77	643	22.97%
Personal	Day 1	3	1	3	9	8	N/A	18	18	25	20	32	137	4.89%
	Hourly	271	248	312	239	322	N/A	318	282	279	250	278	2799	Total

	7:00 8:00	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	Lunch	12:30 1:30	1:30 2:30	2:30 3:30	3:30 4:30	4:30 5:30
Direct Work	14.76%	31.05%	30.77%	30.54%	27.64%	N/A	32.08%	27.30%	27.60%	36.00%	23.74%
Prep Work	36.90%	5.65%	9.29%	9.21%	8.07%	N/A	11.64%	14.54%	7.17%	5.60%	7.19%
Tools/Equip	9.23%	10.89%	12.82%	7.53%	12.73%	N/A	15.72%	7.09%	6.81%	12.80%	12.23%
Mat'l Hand	4.43%	9.68%	10.58%	9.21%	7.76%	N/A	7.55%	8.16%	8.24%	5.60%	4.32%
Waiting	14.76%	16.53%	14.74%	15.06%	16.46%	N/A	13.84%	14.54%	9.32%	10.80%	13.31%
Travel	18.82%	25.81%	20.83%	24.69%	24.84%	N/A	13.52%	21.99%	31.90%	21.20%	27.70%
Personal	1.11%	0.40%	0.96%	3.77%	2.48%	N/A	5.66%	6.38%	8.96%	8.00%	11.51%