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Relationship Between The Ratio Of Direct And Support Work With Productivity For Slab Formwork

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Relationship Between The Ratio Of Direct And Support Work With Productivity For Slab Formwork

by

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Abstract

Construction companies have yet to establish universal benchmarks. With the advent of the World Wide Web, it has become easier to share information both internally and externally. Productivity metrics are very popular amongst many industries, especially in the construction realm. However, throughout benchmarking history, there has been a lack of consistency in regard to definitions, data collection, and data organization.

Studies that utilize work sampling have been frequently employed by construction company initiatives to monitor the distribution of certain categories of productive and non-productive time of a certain construction trade. Traditionally, these studies have focused on maximizing the amount of direct work or “tool-time” in order to optimize productivity. This theory has recently been challenged, whereby the climax of productivity will occur based on a distinct ratio between direct work and supportive work.

The proposed framework aims to develop a database and benchmarking system of activity analysis category ratios and associated productivity values for concrete formwork installation using Google Fusion Tables (GFT). The sixteen-week work sampling activity analysis has been executed on a large commercial construction project in western Canada.

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Chapter One: Introduction

Chapter one will cover topics to introduce the reader to the remainder of the thesis. Background for both construction productivity and database and benchmarking efforts are covered. The problem statement is presented in question format, with the solution proposed in the format of objectives and sub-objectives. A succinct summary of the research approach and methodology followed by expected deliverables, and finally the structure of the entire thesis will conclude chapter one.

1.1 Background

1.1.1 Construction Productivity

The construction industry has had marginal growth, if any, in terms of labour productivity throughout the last half century. It has more so displayed a stagnant to negative trend in productivity, which, when compared to all non-farm industries does not bolster the reputation of the construction industry as an evolving and productive industry.

In Figure 1.1 (BLS 2013) labour productivity in the United States is computed as output in dollars over input in work hours. Various deflators are used to account for a five-decade period of inflation. Regardless of the deflator applied to the construction labour productivity there is an average rate of decline at which a linear trend line exhibits a .32% decline per year, as opposed to the upward positive trend for all nonfarm industries at 3.06% per year (Teicholz 2013). The contrast between the construction industry and the remainder of industries is alarming.

A more detailed account of labour productivity trends in Canada can been seen from Figure 1.2 (Statistics Canada 2013) in comparison to the Canadian Economy. The graph displays trends that are similar to the United States statistics. During the displayed years, construction labour productivity (noted as NAICS 23) decreased an average of .7% per year, while the Canadian economy as a whole increased an average of 1.7% per year (Industry Canada 2012). The labour productivity for Figure 1.2 has also been computed with an output in dollars divided by an input in work hours.

Figure 1.1: Index of Construction Labour Productivity: 1964-2012 Based On Various Deflators In Comparison To Labour Productivity In All Nonfarm Industries. (BLS 2013)

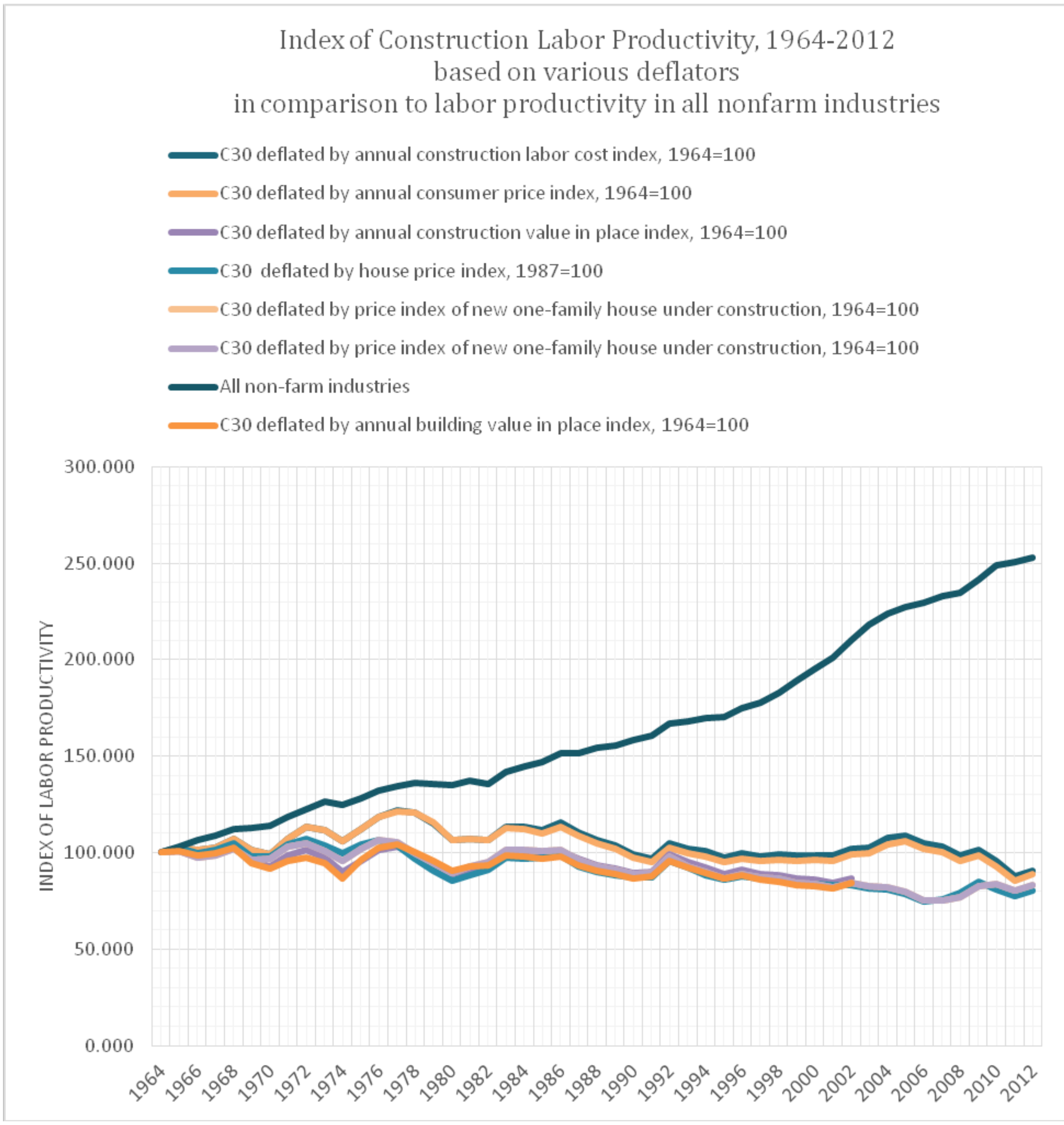
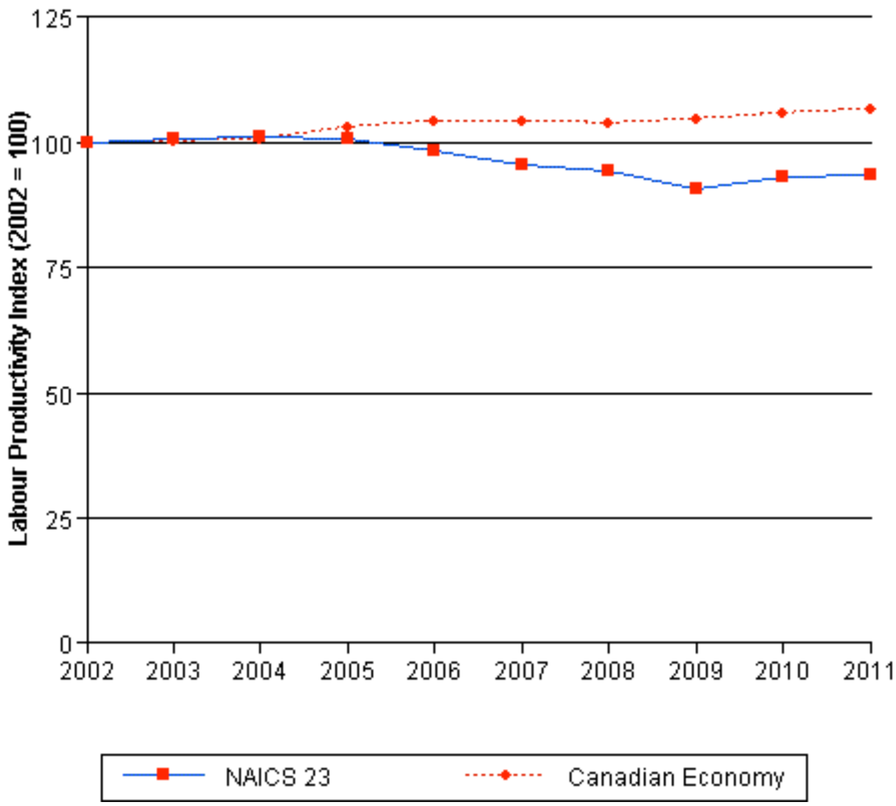


Figure 1.2: Labour Productivity Index: 2002-2011 Construction (Statistics Canada 2013)



The bleak outlook of construction labour productivity, despite countless efforts in past research dedicated to solving this problem, must continue to be diligently investigated and reassessed in accordance with advances in technology. In general terms, the labour component of a construction project comprises as much as 40% to 50% of the total direct capital cost (Ranasinghe 2012). Therefore, the reversal of the current downward trend in labour productivity by even a fraction of a percent would translate into large savings for the construction industry. "To improve construction productivity and performance, it must be measured" (Nasir et. al

2012). A universal method of measuring and benchmarking construction productivity has yet to be established.

1.1.2 Databases and Benchmarking

A universal and collaborative database and benchmarking system (DBBMS) has yet to be established for the construction industry due to various internally and externally influenced reasons. External reasons being derived from the industry's current outlook as a single entity, and internal reasons being derived from the general outlook of individual construction companies based on their own structure and self-interested outlook. The most fundamental barriers to the establishment of a collaborative DBBMS that could be utilized by the construction industry throughout the developed world are as follows:

- External
    - Lack of initiative to collaborate externally and across boundaries.
    - Lack of standards in definitions that transcend language barriers.
- Internal
    - Resistance to change.
    - Resistance to technology.
    - Resistance to investment of funds.
    - Lack of confidence in privacy measures.
    - Lack of precedence by competitors.
    - Lack of confidence in research.

Many predecessors have accomplished niche DBBMS applications at best, those that are exclusive to certain trades, geographic regions, or company types. Some common issues surrounding the current database and data management system paradigm include:

- Data is not easily accessible to all members and stakeholders.
- Current databases have a lack of visualizations to accompany and deliver data in a user-defined way.
- In-house databases are often incompatible with sharing data outside of the company.
- Lack of standards for sharing data across the industry and national boundaries.
- Data management and sharing via Internet include costly fees in order to join a data-hosting site, or become a member of a hosting organization.

The demand for an efficient construction database and benchmarking system is currently worldwide. Nasir et al. (2012) highlights the need for a data management system that is especially available to all stakeholders, and which spans across various regions of Canada. The motivation for the research presented in this paper is derived from Canada.

The mandate for the above-mentioned database and benchmarking system to be web-based is also essential. Nasir et al (2012) further emphasizes the use of an online tool or web based application for collaboration among all involved stakeholders, whereby data may be collected, organized, assimilated, archived, and kept secure indefinitely. Hence in this thesis the author has developed a pilot online database and benchmarking system using a sample set of construction data pertinent to a building construction project by utilizing Google Fusion Tables (GFT), developed by Google Inc. The associated methodology for testing the pilot database will act as a framework for future DBBMS evaluation.

The synthesis of two schools of thought on productivity improvement has additionally provided impetus for this research. The first being labour activity measurement through a detailed form of work sampling known as activity analysis, whereby ratios of direct work to supportive work associated with the best productivity are presented for a given trade. The second is benchmarking all activity analysis results through the development of a cloud-based database using Google Fusion Tables. Overall, this research presents the development of a framework for a methodology of creating and testing a pilot database and benchmarking system to ultimately aid in the improvement of productivity, as well as the production of direct to support ratio values that coincide with a more favourable productivity for a selected construction trade.

1.2 Research Questions

The definition of the main problems that this research attempts to address is articulated in the format of a series of questions:

1. How can the construction industry better understand the implications of the synergy between construction activity proportions in terms of productivity?
2. How can the construction industry establish and apply an efficient database and benchmarking system tool as a central source for productivity metrics?

The development of the main research questions has created an array of corresponding secondary questions that will be addressed in the following section on objectives:

1.1 What initiatives has the construction industry taken in order to improve productivity?

1.2 What are the types of observation methods used by companies to garner productivity related data?

1.3 What standard definitions have been utilized when conducting data collection?

1.4 How is productivity related data evaluated and in what context?

2.1 What initiatives has the industry taken to establish a DBBMS for productivity metrics?

2.2 What initiative has the industry taken to streamline collaboration internally and externally through web-based technology?

2.3 What has been the experience of the industry in utilizing databases and cloud-based technology?

2.4 What are the barriers to implementation of a DBBMS tool amongst the industry?

1.3 Research Objectives

The dual main objectives of the presented research are as follows:

1. Determine a relationship between the proportions of activity analysis categories and the associated productivity for a selected trade in order to act as a benchmark for future research.
2. Develop a framework for a methodology for forming and testing a cloud-based database and benchmarking system tool for productivity metrics.

The corresponding sub-objectives presented herein are as follows:

1.1 Investigate the history of productivity initiatives that have been taken by the industry.

1.2 Investigate and assess that various methods that have been used to collect pertinent productivity related metrics.

1.3 Compare the various definitions used by industry and academia in regard to productivity related measurements.

1.4 Investigate and compare the various methods used to evaluate productivity related data.

2.1 Identify the initiatives that the industry has taken to establish a DBBMS for productivity metrics.

2.2 Identify the initiatives and perceptions of the industry in regard to collaboration internally as well as externally through web-based technology.

2.3 Understand the perceptions of the industry in regard to utilizing databases and cloud-based technology.

2.4 Identify the barriers to implementation of a DBBMS tool amongst the industry.

1.4 Summary of Research Approach

The objective of this research is the combination of two research approaches. The first is collecting data at a construction site for a specific trade using work-sampling observations, and assimilating the data based on the relationship between the ratio of the activities observed and actual productivity. It is imperative to collect enough work sampling observations to sustain a designated level of accuracy as well as to establish a benchmarked baseline of the activity proportions for the construction trade being observed. This objective will be accomplished by applying an established framework (Tsehayae et al. 2012) for data collection and analysis, and to obtain metrics on a selected construction trade, which has yet to be observed within the constraints of the applied framework. The aim of this research approach is to pledge the accumulated data as a contributory source of information for future studies of similar scope.

The second approach of this research entails executing a pilot program of the application of Google Fusion Tables (GFT) as a database and benchmarking system for the project management, IT, and business personnel involved with the site being used to conduct research. Following the pilot program, GFT will be assessed on a standalone basis and also compared to the company's current extranet through surveys. The aim for this research approach is to test the application of GFT on pertinent metrics for a long-term application within the construction industry.

1.5 Summary of Research Methodology

The commencement of research was marked by a thorough literature review that spanned the spectrum of productivity, work sampling, benchmarking, and database related topics. Following the literature review, ethics approval was secured, and construction site access clearance was promptly obtained. Prior to the commencement of data collection, all involved parties that were part of the participating construction company were briefed on the operation in order to build rapport and establish a "buy-in".

Data collection began in July 2013 and was conducted by utilizing a method of work sampling known as activity analysis, which will be further discussed in later chapters. The duration of data collection spanned from July to November 2013. One week of data collection was dedicated for the researcher to familiarize themselves with the construction site, methods, and personnel. A preliminary data collection phase focused on collecting data on all concrete and formwork trades for multiple structural elements including suspended slabs, foundation walls, columns, stairs, ramps, and miscellaneous walls. Following the initial data collection phase, a phase of data collection targeted on the most consistently scheduled and uniform trade in terms of means and methods of construction was selected and committed to for comprehensive monitoring and analysis for the remainder of the data collection duration. The targeted data collection phase was focused on suspended slab formwork.

Parallel to data collection, a framework for the methodology for creating and testing a cloud-based database and benchmarking system tool for productivity metrics was evaluated through the implementation of a pilot program that utilized Google Fusion Tables (GFT), the database component of the Google Drive web-based program. The pilot program included the introduction, and a tutorial of GFT to thirteen employees of the participating company who were actively involved with the site where research was being conducted. Following the pilot program, a pair surveys were administered to the participants to assess GFT in terms of six fundamental categories:

1. Ease of Use
2. Future Feasibility
3. Innovative Features
4. Collaboration
5. Security and Privacy
6. Compatibility

The first survey was administered to assess the above categories in relation to the participating companies current extranet. The second survey was administered to assess the same categories for GFT exclusively.

1.6 Deliverables

The deliverables that this research presents are broken down into two separate areas:

1. Activity Analysis and Productivity
2. Database and Benchmarking System

1.6.1 Activity Analysis and Productivity

1. Comparison of definitions developed throughout the history of work sampling and activity analysis.
2. Proposed standard definitions for future research.
3. Data set on activity analysis categories and their corresponding productivity values for suspended slab formwork.
4. Correlation results for the activity analysis categories and productivity values within the data set delivered.
5. Development of a customized template for conducting activity analysis based on the researchers methodology.
6. Development of a productivity predictor model for industry use composed of the categories of work activities monitored.

1.6.2 Database and Benchmarking System

1. Development of a format for a file organizational structure and relevant productivity related inputs recommended within a cloud-based database.
2. Development of a framework for a methodology for creating and testing a cloud-based DBBMS for application in the construction industry.

3. Survey results based on the categories of Ease of Use, Future Feasibility, Innovative Features, Collaboration, Security and Privacy, and Compatibility evaluating the following:
    a. Google Fusion Tables
    b. Google Fusion Tables vs. Current Company Extranet

1.7 Structure of Thesis

Chapter One – Introduction

Chapter one has provided an introduction to the background involved with the presented line of research, problem statement, objectives and sub-objectives, summary of research approach and methodology, expected deliverables, and the remaining structure of the thesis to follow.

Chapter Two – Literature Review

Chapter two will provide a thorough literature review that covers productivity and associated studies, activity analysis and the variation of the categories that have been used correspondingly over time, benchmarking, the evolution of databases and the different types evident within the construction industry. The latter part of this chapter will cover Google Fusion Tables, its features, competitors, justification for use, and general barriers to implementation.

Chapter Three – Methodology and Theoretical Framework

Chapter three will provide a model of the summary of research work undertaken and describe the two-pronged approach of the presented thesis. The methodology for data collection through activity analysis will be covered, as well as the theoretical framework for the database and benchmarking portion of the research.

Chapter Four – Data Analysis

Chapter four will provide a thorough and detailed analysis of two research approaches. The sixteen-week data set will be featured and assimilated in terms of minimum, maximum, range, average, and standard deviation. A correlation analysis of all of the respective activity analysis categories will also be included, with accompanying charts and figures, as well the results from a multivariate linear regression. Finally, the results obtained from the set of surveys administered following the DBBMS pilot program will be included and discussed.

Chapter Five – Conclusions and Recommendations

This concluding chapter will provide the reader with a summary of the research that was conducted. Conclusions will be asserted, as well as the limitations that the author has encountered. Finally, the contributions of this research as well as recommendations for future research will mark the finale of this chapter.

Chapter Two: Literature Review

Chapter two will discuss the comprehensive literature review that was conducted in conjunction with the presented research. The contents of this chapter will cover the appropriate definitions and history of productivity, activity analysis, benchmarking, and databases. In addition to the above, the preceding framework in this field will be discussed, as well as factors effecting productivity. The culmination of this chapter will also cover Google Fusion Tables (GFT) and its justification for this research based upon preceding literature.

2.1 Productivity

Productivity, regardless of the variation of the definition, is a buzzword that is associated with various industries and is not endemic to the construction industry alone. When any type of improvement is implemented, productivity is assessed before and after the improvement. When any type of assessment or audit is being conducted, questions that arise are: How productive is this operation? What hinders the productivity of this operation? What can be done to increase the productivity of this operation?

2.1.1 History

The history of productivity studies within a construction context dates back to studies conducted towards the end of the nineteenth century by Frank Gilbreth. As a pioneer of productivity improvement, Gilbreth who was a bricklayer at the time, carried out experiments on a building site whereby he aimed to minimize the amount of movements a bricklayer made for each brick laid. Although these early studies were originally conducted in the construction industry, they prospered in the manufacturing industries up until after the Second World War, at which point a large demand for building with a small amount of invested capital initiated a renewed effort aimed at productivity research (S. Peer 1986).

The Project Management Specialization at the University of Calgary has been conducting its own productivity improvement initiatives since as early as 2003 (Choy 2004, Da Silva 2006, Hewage 2007, Liu 2008, Zhang 2008, Ranasinghe 2012, Jeyamathan 2012). The main focus of the productivity studies at the University of Calgary has been centered on “tool-time” analysis. “Tool-time” is a synonym for direct, output producing, work that is conducted on a construction project. Tool-time analysis is typically conducted while taking into account various other categories of activity observed on a construction site such as supportive, waiting, and idle, all of which would fall under "non-tool-time" (Ruwanpura et al. 2006). The categories of observed activities throughout time will be discussed in depth in the following section. The corresponding philosophy associated with the work to date conducted on productivity at the University of Calgary has aimed to maximize tool-time activities and minimize non-tool-time activities.

Furthermore, productivity studies have evolved since their introduction in the late 1800's and vary greatly depending on the industry, company, project, and academic research initiatives. Both the construction industry and academia have yet to establish a universal standard for productivity studies. However, there has been a significant effort by organizations such as the Construction Industry Institute (CII), which has dedicated a part of their research towards productivity improvement, through data collection and benchmarking, in order to put forward standards that will be discussed later in this chapter.

2.1.2 Definitions

The largest discrepancy amongst construction productivity studies is the lack of a uniform definition associated with productivity. Ranasinghe (2012) asserts this dilemma amongst the industry as follows: "Since there is no single standard method to interpret productivity, people use their own methods to measure the productivity and interpret information to suit their individual requirements" (Ranasinghe 2012). The concept of productivity can be ambiguous at times, and interpreted differently depending on the stakeholder, construction company, project, job conditions, as well as variations based on the hierarchy of the construction company personnel analyzing the information.

"In nationally developed statistics it is commonly stated as constant in-place value divided by inputs, such as worker-hours. For the owner of an existing or contemplated plant or other property or equipment, it may be the cost per unit of output produced by the facility. For the contractor, a rough measure often is the amount or percentage which costs are below (or above) the payment received from the owner". (Oglesby et. al 1989)

Other terms within the construction industry referring to productivity include "production rate", "unit rate", "performance factor", "cost factor", and "efficiency" (Ruwanpura et al. 2006). The most rudimentary definition of productivity that can be applied to multiple industries can be elucidated as the ratio of output to input. This can be represented as:

$$\text{Productivity (P)} = \frac{Output\ (O)}{Input\ (I)}$$

………………………………………………………Equation 2-1

Whereas inputs may include labour, materials, information, equipment, tools, time, and capital, while output includes a tangible quantity produced such as kilometers of pipe placed, or cubic meters of concrete poured, as well as an output based in dollars or profit (Ruwanpura et al. 2006).

2.2 Observation Types

The subsequent step in any endeavour assessing a chosen productivity related metric involves proper observations and data collection, regardless of the variation of the definition of productivity used. Throughout the literature review there have been many observation types demonstrated, each possessing advantageous applications in certain scenarios. The current section will cover the most frequently utilized observation types involved in productivity studies. The observation types to be discussed will include:

- Direct Observation
- Time Study
- Work / Activity Sampling
    - Field Ratings
    - Productivity Ratings
    - 5-Minute Rating
    - Activity Analysis
- Visual
    - Time-Lapse Photography
    - Continuous Video Monitoring
- Survey
    - Foreman Delay
    - Craftsmen Questionnaire

2.2.1 Direct Observation

The direct observation method entails continuous monitoring of construction activity by a trained individual. The observations are done throughout the day and would constitute the observer to actively watch and classify the results into one of three categories based on the amount of minutes a worker has allocated towards a given category for each daily observation cycle. Traditionally, the three categories noted during this observation type include direct work, contributory work, or not working (Noor 1998). The advantages of direct observations would be demonstrated for the monitoring of a unique construction operation that typically does not have any previous historical data available. Disadvantages for this method include the difficulty for one observer to "continuously" monitor more than one small group of people, the added cost of maintaining an observer on the construction site on a full-time basis, the vast amount of data generated and the time required to assess and analyze this data, as well as the overwhelming presence a worker may feel when an observer is hovering over them throughout an entire work shift (Noor 1998). The amount of disadvantages for direct observation generally render this method not viable for consistent application.

2.2.2 Time Study

The time study method, originated by Frank Gilbreth, was a pioneering observation method that would later evolve into work and activity sampling. Time study was originally introduced in the manufacturing industry to tally the amount of time a distinct process would take (Gilbreth 1911). Time-study methods, also referred to as work-study and motion study, are advantageous in uses for cyclic processes. A disadvantage of time-study includes the inability to distinguish between categories of activity for individual workers (Da Silva 2006).

2.2.3 Work / Activity Sampling

Work sampling entails the measuring of time allocated for selected work and non-work categories of a given construction project, trade, or task through instantaneous and non-intrusive observations performed at random intervals to a predetermined amount of statistical accuracy. The following sub-sections will discuss the frequently used types of work sampling.

2.2.3.1 Field Ratings

Field ratings are one of four types of work sampling observation methods. This method consists of obtaining “snap-shot” or instant observations of the workers being monitored throughout a given duration. The observation points are categorized into two fundamental categories; working and not-working. Foremen are typically omitted from these observations. Field ratings are advantageous when observing a project of a large magnitude, which would easily yield the required amount of calculations to be statistically accurate (Oglesby et al 1989). The disadvantage of field ratings is that the distribution of observations in only two categories limits the level of sophistication when analyzing data.

2.2.3.2 Productivity Ratings

Similar to field ratings, productivity ratings accumulate data based on the instant observations of the worker or crew being monitored. Productivity ratings are generally categorized into three fundamental categories; effective, contributory (essential), and idle (not useful) (Oglesby et al 1989). Productivity ratings allow for the dissemination of data into a slightly more detailed structure than field ratings, whereby the definitions for the categories used can be modified depending on the construction trade or task being monitored.

2.2.3.3 5-Minute Rating

The method of work sampling known as the 5-minute rating is synonymous with its name. The process for this method is conducted by observing a worker or crew for a five-minute period. Following the observation, the data recorded for that worker or crew is categorized as either effective or delay, depending on what that worker or crew were doing for over 50% of the time observed (Oglesby et al 1989). The 5-minute rating is advantageous when only small amounts of time are available for observation durations. Furthermore, the five-minute rating can gauge the effectiveness of an entire crew, and is not limited by the nature of the work, whether it is cyclic or repetitive (Noor 1998). Disadvantages of the 5-minute rating include a lack of depth of information collected, as well as the inability to ascertain the root cause of an issue.

2.2.3.4 Activity Analysis

The most comprehensive version of work sampling is referred to as activity analysis. Activity analysis is different from conventional work sampling methods in that it has much more depth to its categories and therefore has a superior analysis potential. Activity analysis typically consists of seven categories including direct work, preparatory work, tools and equipment, material handling, waiting, travel, and personal (CII 2010). Activity analysis is advantageous on construction sites that require a more detailed depiction of the relative productivity status without investing in the personnel for full-time direct observations. Some disadvantages of activity analysis include the inability of an observer to monitor craft workers that are far from one another, as well as the requirement of the observations to be categorized in a meticulous manner based on the given definitions, in order to sustain a strict consistency in results (CII 2010). Since activity analysis is the most thorough form of work sampling, it will be the selected method of data collection for this research. A more detailed analysis of the history, as well as the definitions of work activities throughout time will be presented in the section following observation types.

2.2.4 Visual

2.2.4.1 Time Lapse Photography

One of the two visual methods of collecting observation data, time-lapse photography, entails employing a camera to take pictures of a distinct location based on certain intervals, usually every three to four seconds (Da Silva 2006). Time-lapse photography is advantageous when monitoring a repetitive task that can easily be identified by photographs, and has a low probability of uncertainties. Furthermore, time-lapse photography also removes the necessity of employing an actual person on the site to collect data. Disadvantages of this method include potential technical malfunctions, as well as the frame of the picture being limited to the angle that the camera is installed (Da Silva 2006).

2.2.4.2 Continuous Video Monitoring

The employment of continuous video monitoring, like time-lapse photographs, removes the need of having to have an actual person on site doing manual data collection. Advantages of continuous video monitoring include being able to save data acquired for viewing at any time, as well as the capacity to control the video cameras functions from a remote location, whereas zooming and pivoting the frame can be adjusted as needed. Disadvantages of continuous video monitoring include reliance on technology, whereby a malfunction may not always be evident at the moment that it occurs (Da Silva 2006).

2.2.5 Surveys

Surveys are a more intimate way of collecting data in reference to productivity studies on a construction site. They are often not used exclusively, and are commonly an adjunct to the raw data collection being conducted on the project through manual observation of the workers and crews. The two most frequently applied surveys are the foreman delay survey and the craftsman questionnaire.

2.2.5.1 Foreman Delay

The foreman delay survey is intended to capture the foreman's perspective on what delays may be associated with the productivity related data being collected on the site. Foreman delay surveys act as supplementary information for researchers, especially if the construction company they are collaborating with is withholding actual productivity values for confidentiality purposes. Foreman delay surveys exhibit flaws in their subjectivity, whereby; the responses of the foreman may be biased based on a personal agenda (Da Silva 2006).

2.2.5.2 Craftsman Questionnaire

The craftsman questionnaire is a form of the aforementioned delay survey, except it is administered to the craftsmen. The biggest concern with the craftsman questionnaire is that it is vulnerable to strong biases derived from the craftsmen, who are often unaware of the influential forces, derived from higher management, that play a part in their daily operations (Ranasinghe 2012).

2.3 Activity Analysis

This section will cover activity analysis in more depth including its evolution from work sampling, as well as the development of the categories that activity analysis is composed of throughout time.

2.3.1 History

An efficient way for collecting data without interfering with the construction activities has been a necessity since construction productivity studies have begun. A data collection method that meets this criterion is called work sampling (WS) and has been frequently coupled with construction productivity studies. Activity analysis has been recently created as a more detailed version of WS.

The origin of WS in productivity studies was derived in 1927 by an industrial engineer named Leonard Tippett, who had initially referred to the procedure as the "snap-reading method" due its instantaneous observation nature (Tippet 1935). The snap-reading method, similar to current WS methods was executed at random time intervals and was accumulated to the point where statistical accuracy could be ensured.

In 1952, the snap-reading term evolved into "work sampling", coined by C. L. Brisley and H. L. Waddell in an article in *Factory Management and Maintenance* (Gouett et al 2011). Following the early years of WS adaptation, it began to gain increased popularity in conjunction with the mid-twentieth century. Academic H. R. Thomas was at the forefront of the WS movement through the 1980's (Gouett et al 2011). In recent years, there have been collective guidelines published on WS. Two seminal guidelines include the Association for the Advancement of Cost Engineering International's *Direct Labour Productivity Measurement – As Applied In Construction And Major Maintenance Projects* (Picard 2004) and CII's *Guide to Activity Analysis* (CII 2010).

2.3.2 Definitions

The work and non-work categories for WS have fluctuated throughout history but nonetheless exhibit similarities. Throughout the application of WS studies, a constant factor and main work category has been referred to as direct work or tool-time (Ruwanpura et al. 2006). This category is generally composed of the amount of direct, physical, and output producing work. In other words, the time a worker spends in producing a tangible output such as square meters of formwork installed, or linear meters of conduit installed (Ruwanpura et al. 2006).

The non-work or unproductive work category is the opposite of direct work, and has traditionally included everything besides direct work, which may be comprised of supportive work and delay time. As previously mentioned, the work and non-work definitions have fluctuated throughout the history of WS, and often have been broken down into further categories or sub-categories.

The precedence set in productivity studies at the University of Calgary has also displayed a fluctuation in the work activity categories utilized throughout time. Table 1 covers the work conducted by Ruwanpura (2006), Da Silva (2006), Hewage (2007), Liu (2008), and Zhang (2008). It is evident through this table that the tool-time category maintains consistency throughout time, due mainly in part to its fundamental meaning of “output producing work”. Although the research produced by Hewage did not necessitate the grouping of categories into more rudimentary terms, Ruwanpura, Da Silva, Liu, and Zhang all provided combined categories for easier evaluation of information. The supportive category was the commonly grouped category amongst the previously mentioned four authors. Although each researcher’s supportive category entails some differences, it is evident that the supportive aspect of a construction task has been distinguished from direct work. The remainder of the combinatory categories amongst the set of research includes waiting, idle, and ineffective work, all of which are considered wasted time, and are often the main source of scrutiny when assessing ways to improve productivity.

Recent research conducted at the University of Calgary has yielded a slightly varied approach to productivity studies. Table 2 exemplifies the work undertaken by Jeyamathan (2012), and Ranasinghe (2012). Jeyamathan has substituted the common nomenclature of direct work or tool-time in favour of a category labeled “value added”. Furthermore, the remaining two synthesised categories are called “contributory” and “non-value added” (Jeyamathan 2012). The one unique aspect of this format is that all three categories (value added, contributory, and non-value added) vary with the type of construction task being conducted, which is evident in Table 2, whereby Table Formwork, Loose Formwork, and Edge of Slab all have differences in their grouped categories. The commonalities evident across each grouped category have been highlighted for viewing convenience.

Table 1: Productivity Studies at the University of Calgary Category Matrix (2006-2008)

Category Matrix

Ruwanpura (2006)	
Tool-Time	
Supportive	Search for Materials
	Move Materials
	Travel
	Measure
	Safety
	Instructions
	Check Drawings
	Interruption
	House Keeping
	Discuss
	Inspection
	Equipment
Waiting	Waiting for Materials
	Search for Materials
	Equipment
	Watching
Idle	Idle
	Extra Breaks
	Socialize
	Leave
	Washroom
	Warm up

Da Silva (2006)	
Tool-Time	
Supportive	Search for Materials
	Move Materials
	Travel
	Measure
	Safety
	Instructions
	Check Drawings
	Interruption
	House Keeping
	Discuss
	Inspection
	Equipment
Waiting	Waiting for Materials
	Search for Materials
	Equipment
	Watching
Idle	Idle
	Extra Breaks
	Socialize
	Leave
	Washroom
	Precedents

Hewage (2007)
Work (Tool) Time
Looking for Materials
Socializing
Moving
Instructions
Idle
Other

Liu (2008)	
Tool-Time	
Supportive	Material
	Tools
	Equipment
	Measure
	Safety
	Instruction
	Precedent
	House Keeping
	Discussion
	Inspection
	Drink/ Washroom
Ineffective	Idle
	Extra Breaks
	Socializing

Zhang (2008)	
Tool-Time	
Supportive	Waiting for Materials
	Searching for Materials
	Carrying Materials
	Waiting for Tools
	Searching for Tools
	Carrying Tools
	Double Handling
	House Keeping
	Measure
	Safety
	Instructions
	Precedent
	Interruption
	Discussion
	Inspection
	Washroom
Idle	Idling
	Extra Breaks
	Socializing

Table 2: Productivity Studies at the University of Calgary Category Matrix (2012)

Category Matrix						
Jeyamathan (2012)						**Ranasinghe (2012)**
Table Formwork		**Loose Formwork**		**Edges of Slab and Beam Formwork**		
Value added	Measurement	Value added	Measurement	Value added	Measurement	Working
	Alignment/ Level Forms		Alignment/ Level Forms		Alignment/ Level Forms	Walking
	Making of Form		Making of Form		Making of Form	Material Handling
	Formwork Inspection/ Testing		Formwork Inspection/ Testing		Formwork Inspection/ Testing	Idling
	Mechanical Transport		Lift/Lower Materials		Cut & Chop Materials	Socializing
	Study/Inspect Drawings		Study/Inspect Drawings	Contributory	Crew Communication	Waiting
	Crane Handling/ Moving parts using crane		Crane Handling/ Moving parts using crane		Static Lift/Hold	Instructions
Contributory	Crew Communication		Cut & Chop Materials		Form Oil/Grease	Housekeeping
	Static Lift/Hold	Contributory	Crew Communication		House Keeping	Safety
	Form Oil/Grease		Static Lift/Hold		Labour-Intensive/ Manual Transport	
	House Keeping		Form Oil/Grease		Crane Handling/ Moving parts using crane	
	Access/Move on Ladder		House Keeping		Study/Inspect Drawings	
	Lift/Lower Materials		Access/Move on Ladder		Lift/Lower Materials	
Non-Value Added	Non-process time		Labour-Intensive/ Manual Transport		Mechanical Transport	
	Labour-Intensive/ Manual Transport		Mechanical Transport	Non-Value Added	Non-process time	
		Non-Value Added	Non-process time		Access/Move on Ladder	

In addition to the categories for activity analysis derived from academia, a graphical representation of the breakdown of work, non-work, and other categories throughout the history of WS publications and initiatives can be seen in Figure 2.1: The categories used in work sampling in different study periods and presented in research., a model by Jie Gong (Gong et al. 2011), which has been modified to include CII's activity analysis categories to be explained subsequently.

Figure 2.1: The categories used in work sampling in different study periods and presented in research.

[Removed, copyright clearance not obtained, please refer to Gong et al. 2011 – Figure 1]

As exemplified by Figure 2.1, prior to 1985 WS studies were as rudimentary as only recording differences in data collection between direct work and unproductive work. This later evolved to include more categories in order to give project managers and foremen a glimpse into how time was being distributed throughout a given project, trade, or task. Gong's research used a three-tier metric in order to separate supportive work from idle (Gong et al. 2011). Contemporary research guidelines by CII have yielded seven categories for analysis and have subsequently renamed their seven-tier WS method “activity analysis” (CII 2010).

As alluded to previously, standard definitions for activity analysis categories ought to be uniform to promote consistency in future research and alignment with past research. Therefore, the CII definitions for Direct Work, Preparatory Work, Tools and Equipment, Material Handling, Waiting, Travel, and Personal Time will be used. In order to maintain this standard without any loss in translation the CII’s definitions for the above categories are here forth presented verbatim (CII 2010):

1. **Direct work** is the act of either exerting physical effort to perform an activity or of physically assisting in these activities. Direct work often involves the installation of materials, but it also includes the physical effort of support groups.
2. **Preparatory work** includes activities related to receiving assignments and determining the requirements of the work prior to performing it. Preparatory work includes stretching activities, safety talks, and start card processes. Preparatory work also includes any explanations or planning of the work at the workface. Such discussions can take place between craft workers or between supervisors and craft workers.
3. **Tools and Equipment** includes activities associated with obtaining, transporting, and adjusting tools or equipment in preparation for direct work.
4. **Material Handling** includes the transportation of materials from one part of the facility to another, but does not include moving items within the general area of the task or into their final positions.

5. **Waiting** covers periods of waiting or idleness, even if workers are attentive to ongoing work by others.
6. **Travel** includes walking or riding empty-handed or without tools, materials, or technical information.
7. **Personal** category includes idleness and time taken away from work during normal work- hours. This excludes normally scheduled breaks and lunch periods.

These seven categories will be further utilized to provide a detailed account of how time is being used for a given construction trade. However, for the purpose of alignment these categories will be further aggregated as follows: Direct work remains direct work, preparatory work, tools and equipment, and material handling will combine to form supportive work, and finally, waiting, travel, and personal time will combing to form delay time.

An additional category that was included for detailed analysis is "out of sight". Although not labeled as an official category in the proposed standard of the seminal guides, Picard explicitly states that the observer or analyst "also records the number of craft workers not observed on site ('un-accounted for')" (Picard 2004). Here forth is the definition of the out of sight category as applied in this research:

8. **Out of Sight** category is logged when observing a crew of a predetermined size and any one or group of crew members are unable to be observed for any one or group of observations due to those workers being unable to be found or their activity being obstructed or hidden from the observer.

Overall, activity analysis provides a more detailed glimpse into the utilization of time of an observed entity. Through the duration of this research, the direct work category remains aligned with the precedence in WS, although the six remaining categories are distributed and defined differently, whereas preparatory work, tools and equipment, and material handling combine alternatively to make up supportive work, while waiting, travel, and personal time combined make up delay time. The established definitions of each of the aforementioned categories will be reiterated in the following chapter as the proposed standard going forward.

2.3.3 Activity Categories Effecting Productivity

Based upon the given definitions and the variation of categories found within the work sampling and activity analysis domain, it is now necessary to delve deeper into the aforementioned categories that have been found to have significant impacts on productivity throughout the literature review. The sub-categories of this section will discuss the categories of tool-time and direct work, supportive and contributory, material handling, ineffective, and idle and waiting.

2.3.3.1 Tool-Time and Direct Work

The function of tool-time or direct work in productivity studies as the principal indicator of a productive construction operation has been dominant throughout time. This theory has resonated throughout the history of productivity research at the University of Calgary by Choy (2004), Da Silva (2006), Ruwanpura (2006), Hewage (2007), Liu (2008), Zhang (2008), Ranasinghe (2012), and Jeyamathan (2012). The synthesis of this theory is that there is a strong correlation between direct work and productivity. The correlation coefficient between direct work and productivity has been noted to be as high as 0.764 for the deck formwork crew (Liu 2008). From an intuitive outlook, it seems valid that the greater amount of tool-time, or in other words, output producing work, the greater the associated productivity should be. However, the core of discussion in the body of this research will highlight an alternate theory, whereby the role of the ratio between all activity analysis categories and their relationship to productivity will be examined instead.

2.3.3.2 Supportive and Contributory

Choy (2004), Da Silva (2006), Liu (2008), and Jeyamathan (2012) have all asserted that the supportive or contributory category in a given construction trade has a subordinate effect on construction productivity and can therefore be minimized in favour of increasing the direct or tool-time category which would therefore translate into a higher productivity. Although the supportive and contributory categories presented by Da Silva and Jeyamathan are not completely aligned, as can be seen in Table 1 and Table 2, the principle behind their theory is analogous.

2.3.3.3 Material Searching & Handling

The handling and searching of material has been linked as a source of productivity loss by Da Silva (2006), and Zhang (2008). Moreover, in his general recommendations, Da Silva advocated, "productivity improvements should focus on the mitigation of manually moving materials" (Da Silva 2006). Zhang's research stems off of Da Silva's framework and presents a list of "Ineffective Material Handling Activities"; these activities are emphasized as the source of productivity loss and encompass the following categories (Zhang 2008):

- Waiting for Materials

- Searching for Materials
- Double Handling
- Improper Storage
- Workface Materials Congestion
- Surplus/Waste/Housekeeping
- Improper Positioning of Toolbox

Furthermore, a survey of 14 construction managers conducted by Hewage (2007) has also yielded the material and tools handling category as being believed to be the cause of deficiencies in productivity. Hewage attributed this to a lack of an efficient inventory system, as well as the effects of a congested work site (Hewage 2007).

2.3.3.4 Ineffective

The ineffective category as highlighted by Liu (2008), includes worker idle time, extra breaks, and socializing. The ineffective category has been a popular category of focus amongst both the industry and academia when presenting initiatives to improve productivity by reducing a certain category. Indeed, it is difficult to dispute that “ineffective” time can have a positive effect on productivity. However, in order to fully understand the effects of ineffective time on productivity, each one of the sub-categories that it is composed of must be individually scrutinized. For example, work conducted by Da Silva (2006), refrains from advocating the reduction of socializing on the construction site because it can help promote a friendly atmosphere and actually influence productivity in a positive way (Da Silva 2006). This theory also aligns with the research conducted on motivational issues by Ruwanpura and Hewage (Hewage et al. 2005).

2.3.3.5 Idle and Waiting

Similar to the ineffective category, time observed in the idle and waiting categories has been noted to have a negative impact on productivity (Ruwanpura 2006, Da Silva 2006, Zhang 2008). Unlike the socializing category, the idle and waiting categories do not contain any latent motivational implications. The most common sub-category amongst the "idle" main category throughout the literature is "extra breaks". Other sub-categories, which compose both the idle and waiting categories, can be further seen in Table 1 (Page 28).

2.3.4 Framework Review & Application

The culmination of the literature review has made the author and readers familiar with the common terminology and core concepts that compose the presented research. This section will be dedicated to highlighting a distinct journal paper that has presented a proposed framework for data collection and analysis that this research will be aligned with in order to encourage consistency in any potential future work. *A Research Framework for Work Sampling and its Application in Developing Comparative Direct and Support Activity Proportions for Different Trades* by A.A. Tsehayae and A.R. Fayek (2012) has provided the following pillars for research alignment:

1. Utilize Construction Industry Institute (CII) standard definitions for activity analysis.
2. Utilize work sampling data collection techniques.
3. Compare data results to actual productivity of the observed time frame.

Since the dawn of WS studies, it has been unfittingly postulated that the higher the amount of direct work the greater the productivity will be. Whereas, delay and supportive work, or any non-direct or non-productive work must be minimized in order to optimize productivity. This notion has been challenged on several occasions and justified with data sets. The first instance of contestation was by H.R. Thomas who elucidated that there is a lack of correlation between only direct work and productivity (Thomas 1991). A following instance of contestation was by Abraham Tsehayae who concluded that a certain amount of support work is essential to optimize productivity (Tsehayae et al. 2012). Figure 2.2, extracted from the aforementioned framework illustrates the synergy between various types direct and support work proportions and their relative effects on productivity for a residential framing crew (Tsehayae et al. 2012).

Figure 2.2: Effect of Direct and Support Proportions on Productivity (Tsehayae et al 2012)

[Removed, copyright clearance not obtained, please refer to Tsehayae et al. 2012 – Figure 2]

2.4 Benchmarking

Once a means of collecting and assimilating data can be established, an effort to benchmark results throughout the duration of the research ought to be supported. Benchmarking is an involved term, and like productivity fluctuates depending on the ethos of each construction company that implements it.

2.4.1 Definitions

Benchmarking has been defined as "a continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as representing best practices for the purpose of organizational improvement" (Spendolini 1992; Nasir et al. 2012).

Benchmarking can further be broken down into three distinct forms, internal benchmarking, project benchmarking, and external benchmarking. Internal and external benchmarking are similar in nature. Internal benchmarking involves evaluating a companies selected metrics against those of another company in the same industry, while external benchmarking involves evaluation against industries other than ones own. Project benchmarking, which the presented research focuses on, is the evaluation of metrics at the micro or project level, whereby comparisons are conducted against other similar projects of size, type, scope, complexity, or trade (Mohamed 1996).

2.4.2 History

Productivity benchmarking has been an elusive element for construction companies around the world. With the advent of the Internet many companies have attempted web-based database and benchmarking efforts since the 1990's. Moreover, benchmarking programs have been scarce and not uniform throughout the construction industry. In fact, there were no substantial public benchmarking programs in the construction industry until 1993, at which point the CII benchmarking and metrics program was established. (Nasir et al. 2012; CII 2000) Currently, benchmarking programs are beginning to take shape in countries such as Australia, Brazil, Chile, Denmark, the United Kingdom, the United States, Hong Kong, Singapore, and the Netherlands (Costa et al. 2006).

Recently, Canada has established benchmarking initiatives through two different fronts. The heavy industrial construction sector of Alberta, represented by the Construction Owners Association of Alberta (COAA) has partnered with CII since 2005 to improve mainly oil sands projects throughout Alberta (COAA 2009). Additionally, the Construction Sector Council (CSC) has partnered with five universities from Canada to develop the Labour Productivity and Project Benchmarking program, initiated in 2008. The CSC program has a focus on the infrastructure sector and implements standard definitions from the recognized CII benchmarking and metrics program (Nasir et al. 2012).

The reason that benchmarking history has recently thrived and has been mostly concentrated in the last two decades is attributed to the advent of the World Wide Web. A key feature amongst the aforementioned benchmarking programs is their ability to be accessible at any given moment, from any given location, contingent on a satisfactory connection to the Internet. The web-based tools associated with the data entry for these programs varies with each benchmarking initiative and has yet to be governed by one universal standard. The research presented in the following chapters will present a framework for the employment and testing of a universal web-based tool that can cater to contemporary benchmarking efforts.

2.5 Databases

Databases are a pivotal part of any type of data collection. Without an organized database, data becomes lost and therefore wasted. Databases must be further managed and maintained in order to stimulate continuous improvement efforts. The following sections will not delve into the technical terms and functionality associated with databases, but will maintain a focus on the application in the construction realm.

2.5.1 History

The earliest literature available on the application of databases in the construction industry is two significant journal papers published in 1989 and 1991 authored by Larry M. Rayburn and R.M.W Horner and B.T. Talhouni, respectively.

In *Productivity Database and Job Cost Control Using* Microcomputers, Rayburn sets forward a rudimentary framework for utilizing databases in construction for project cost control through a labour cost estimating system, whereby over time a historical record of labour productivity would be established in order to help with bidding future projects (Rayburn 1989).

In *Application of Database Management Systems In Productivity Analysis*, Horner et al. places an emphasis on the importance of gathering a vast amount of variables associated with productivity in order to be able to analyze productivity accurately in future applications (Horner et al. 1991). Horner et al. further propose an elementary framework for the collection of such variables by breaking them down into six core categories each of which are then sub-categorized based on the extent of the application:

1. Project Data
2. Output Data

3. Input Data
4. Factors effecting productivity data.
5. Productivity data.
6. Productivity analysis data.

2.5.2 Definitions

There are various depths to the definition associated with databases, most of which can be omitted due to limit of the scope of this research, whereas the computer science related details will not be interpreted. However, the most fundamental definition of a database is "a collection of interrelated data items that are managed as a single unit" (Oppel 2004). Furthermore, in an application based on the construction industry a database has been similarly described as "a collection of interrelated data stored together. The essential feature of a database is that it allows the researcher to treat data as a central source" (Horner et al. 1991). The research presented will refer to a database in terms of its fundamental function of accumulating data into one accessible source through the use of a computer-aided tool.

2.5.3 Types

Database types, and the ways in which they are implemented, vary across industries, which also holds true for the construction industry's implementation. The advent and mass implementation of the Internet in the late 1990's has opened the door for databases to evolve alongside this leap in technology. The most important factor that the Internet has influenced is a platform for collaboration amongst the industry (Wilkinson 2005). Instead of correspondence and data being shared on an individual party-to-party basis, it can now be harboured in a central location for all parties to contribute to or view. Furthermore, databases can be created, hosted, and accessed through various platforms, which are further described in the following sub-sections.

2.5.3.1 Software (Microsoft Access)

Databases have been popular amongst research related to productivity studies. Zhang (2008) introduced the utilization of database software, Microsoft Access, for material management in order to support the improvement of productivity. The database that was implemented in this research collected the following inputs (Zhang 2008):

- Activity Schedule
- Inventory
- Supplier Information
- Crane Schedule
- Storage Information
- Workface Information

The database created by Zhang, was also structured in order to have the capacity to be connected to the World Wide Web, through the use of Active Server Pages (ASP). Microsoft Access in conjunction with ASP, allowed for multiple users to access the database from multiple locations and generate web pages from the data. The database was also purported to be cost-effective and maintain data integrity and security (Zhang 2008). This database setup can be seen as the precursor to more advanced, user-friendly, and efficient databases to be covered subsequently.

Ranasinghe continued the research paradigm of using Microsoft Access as a database for the construction industry in 2012. Ranasinghe utilized this method in conjunction with his *Task*

Based Productivity Loss Control and Improvement framework. Furthermore, Ranasinghe developed his database in order to be operated by a *Construction Productivity Improvement Officer*. The intended inputs and outputs of the proposed database were as follows (Ranasinghe 2012):

- Inputs
  - Product Details
  - Activity Information
  - Tool-Time observations
  - Activity Process
  - Productivity Updates
  - Activity Analysis
- Outputs
  - Tool-time reports
  - Process observation reports
  - Productivity trend charts
  - Overall productivity performance
  - Time bound tool-time & process reports

2.5.3.2 Intranet

An intranet can be defined as a collaborative technology whereby only employees within a company have rights to access and input information in its hosted database. A more formal definition is as follows:

> "A private network contained within an enterprise. It uses IP and its main purpose is normally to share company information and computing resources among employees" (Wilkinson 2005).

2.5.3.3 Extranet

An extranet is similar to an intranet, however it also grants limited or full access to various parties associated with a project who are not directly members of the company that administers the extranet. An example of this would be an architectural firm that grants limited access to their extranet for a general contractor to view revised contract drawings. A more formal definition is as follows:

> "An extranet is a private network that uses the Internet and the public telecommunication system to securely share a business's information or operations with authorized suppliers, vendors, partners, customers, or other businesses. An extranet can be viewed as an extension of a company's intranet for users outside the company. (Wilkinson 2005).

Extranets can also be referred to any of the terms found on the following list, which is featured in Paul Wilkinson's *Construction Collaboration Technologies: The Extranet* Evolution (Wilkinson 2005):

1. Collaborative Extranet
2. Concurrent Engineering (CE) Environment
3. Construction Management System
4. Construction Portal
5. Construction Project Extranet (CPE)
6. Construction Project Network (CPN)
7. Data Management System
8. Document Pool
9. Drawing Management System
10. Enterprise Portal

11. Online Collaboration and Project Management (OCPM) Technology
12. Online File Storage
13. Project Collaboration Network (PCN)
14. Project Collaboration Service
15. Project Extranet
16. Project Hosting
17. Project Management Platform
18. Project Management Systems-Application Service Providers (PM-ASP)
19. Project Portal
20. Project Website
21. Virtual Project
22. Web-Based Project Management Systems (WPMS)

Furthermore, extranets may be hosted and managed by an in-house IT department and data storage center. Alternatively, extranets can be hosted and managed by a third party website and data storage center. Occasionally, the hosting and managing of extranets and the data involved can be executed by a collective effort of an in-house IT department and third party service providers, with each individual company utilizing a unique set-up based on their requirements.

2.5.3.4 Cloud Database and Storage

A recent trend that has emerged in regard to data storage is the concept of cloud storage. This does not mean that your information is literally stored in the sky inside the constraints of a large amorphous white or grey cloud. Cloud storage is a very basic concept that involves storing any type of virtual data in a remote data storage center that is typically hosted by a third-party. Cloud storage is further made possible with an Internet connection. Regardless of your location, if there is an Internet connection you are able to access your saved data in the cloud, as well as add additional data.

The dawn of cloud computing has helped to open up new frontiers for the evolution and streamlining of databases, as well as benchmarking data. The application of cloud storage in the construction industry should intuitively be accepted as the standard for virtual data storage due to the transient nature of the business, whereby regardless of the project site you are located at, you may easily access any required metric by way of cloud. Other noteworthy characteristics for application within the construction industry include the absence of any major capital investment, no obligation for establishing IT personnel to manage and maintain the system, the opportunity for collaboration with clients, and the level of access authorization management available (Stoller 2011). An additional benefit of cloud storage is that it can be used either in conjunction with current intranet and extranet applications or independently. The research presented in this thesis will explore the application of cloud storage for the development of a framework for using and testing a database and benchmarking system for construction productivity metrics.

2.6 Google Drive and Google Fusion Tables

2.6.1 Introduction

The construction industry generates a substantial amount of meaningful data that ought to be collected, assessed, and used as a source of learning. Databases and benchmarks become a limited source of learning without widespread collaboration between companies, regions, and nations. The dawn of the new millennium brought about an influx of new information technology that has acted as a catalyst for the demand in collaborative applications that facilitate group work among different people (Wilkinson 2005).

Databases have two main means for data storage, in-house storage and outsourced storage, also known as storage on the "cloud". In-house storage is data stored via a company owned and managed data storage center. Outsourced storage is data stored in a location outside of the company's space and requires a monthly fee based on the amount of storage space used. This data can be further accessed through two typical methods, through in-house software or through a web-based project management system, both can be classified as extranets. To reiterate, an extranet can be defined as an Internet powered private network that is administered by a company in order to share specific information with authorized parties such as suppliers, vendors, subcontractors, clients, or various other stakeholders. Extranets are "intranets" that grant limited access to those not directly employed by the governing company (Wilkinson 2005).

Currently, new opportunities are being generated for efficient and free database services that are challenging the established intranet and extranet paradigm. Google Drive (GD) is a data storage, viewing, and editing cloud-based service that is compatible with various widespread file types. Google Fusion Tables (GFT) is one of the many types of files supported on Google Drive, and is a file type that has also been exclusively created by Google. In addition to GFT files, GD supports a spectrum of files including Microsoft Excel, Microsoft Word, and Adobe Acrobat. Files stored on GD are able to be shared with selected parties and allow the creator of the file to grant editing rights to selected users. The privacy settings of GD files that have been set to "public" can be found via Internet search engines (Gallaway and Starkey 2013).

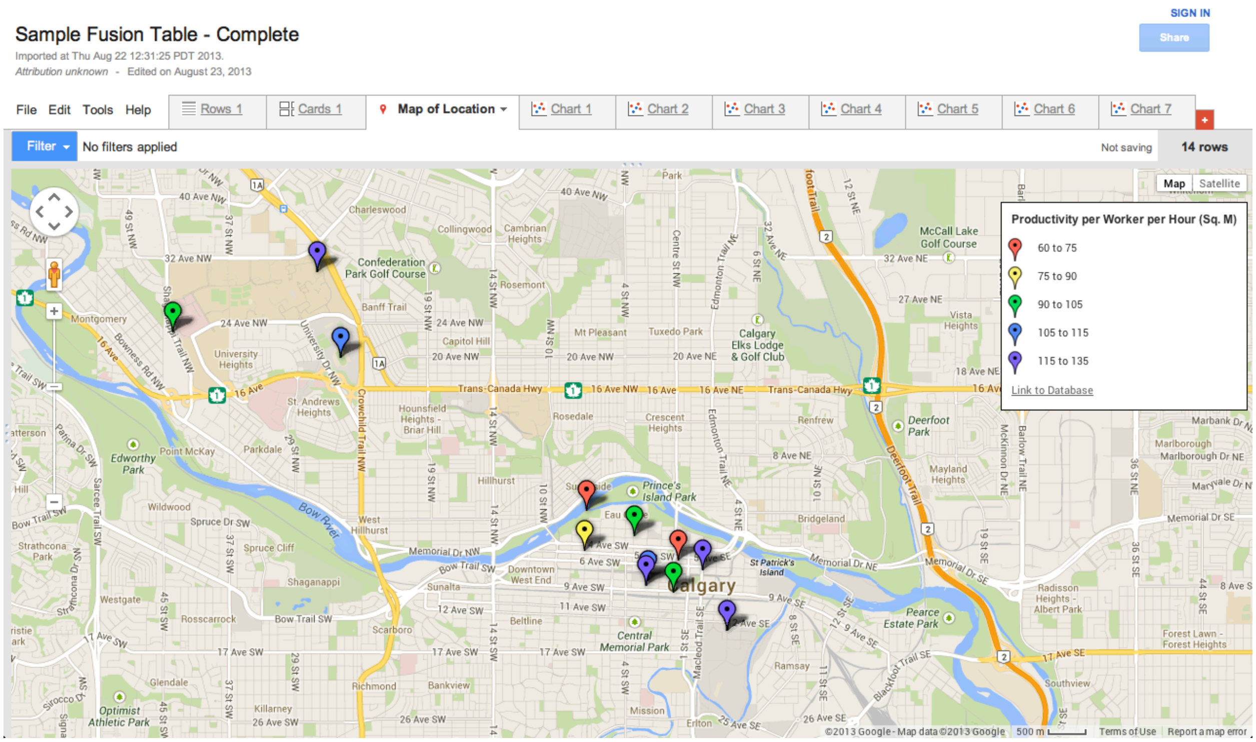
Following its launch in 2009, GFT has been since evolving based on the input it has been gathering from its users. Overall, GFT provides a user-friendly, collaborative, and interactive database tool that is available to the public on an international scale at no charge. GFT provide the user options to publish their data on another site, make it publically available and discoverable by search engines, or keep it private. GFT can be classified as outsourced data storage that is accessed through a web-based format. Furthermore, the service has been gaining attention and has been utilized in various applications since its launch. "The service was originally designed for organizations that are struggling with making their data available internally and externally, and for communities of users that need to collaborate on data management across multiple enterprises." (Gonzalez et al. 2010a and Gonzalez et al. 2010b)

2.6.2 Key Features

With the proper employment of GFT, the main issues associated with current benchmarking and database models can be alleviated. Key features of GFT are listed below:

- GFT is a service provided by Google at no charge.
- Sharing data with various parties can be done effortlessly by granting either editing or viewing access to the selected stakeholders. These editing privileges facilitate collaboration by allowing the merging of additional data.
- Adjusting the file to either a private or public setting can control the privacy of data. Once a dataset is public, it can be viewed by anyone.
- Public datasets can further be discovered when searched with search engines, further facilitating collaboration among the industry.
- Locations in a dataset are automatically detected, geo-coded, and rendered on an interactive Google map. GFT can detect locations in the form of street addresses, points, lines, or polygons. (Figure 2.2)

Figure 2.3: Sample GFT to Represent Productivity Information in Different Locations (Google 2014)



- Publishing data allows for the delivery of interactive visualizations provided by GFT with any pertinent party, without necessitating a Google username and password. The published data is shared via link and automatically reflects any changes made to the original file.
- Analysis of a dataset is aided by various user-friendly and modifiable visualizations that include maps, bar charts, pie charts, line graphs, scatter plot graphs, and area graphs.
- The attribution of data allows the creator to properly attribute the source of information and add any other metadata that is essential to be united with the file indefinitely.
- Entire datasets can be imported from various compatible files like Microsoft Excel. Data can also be exported from a GFT file contingent on the security settings.
- Since GFT is a cloud-based service, installation of software is not required.

- Filters allow the sorting of datasets that are overwhelming in size. Multiple filters can be applied simultaneously.
- GFT is compatible with an Application Programming Interface (API), where programmers are able to manipulate GFT and integrate its features with any website accordingly (Halevy and Shapley 2009).

The following chapter will provide a framework for a methodology for the formation and testing of a cloud-based DBBMS that is catered to productivity studies within the construction industry. The cloud-based database and benchmarking system selected for the pilot program will be Google Fusion Tables. The alternatives considered, as well as the justification for the use of GFT will be discussed in the following sections.

2.6.3 Alternatives Considered

The market for cloud-based databases that can be applied in the construction industry is vast. There are a multitude of options that exist if a company has no reservations about making a monetary investment. Some paid options include Fusion Live, EADOC, Procore, Microsoft Dynamics CRM, Aconex, Jonas, and Projectmates (Rodriguez 2014). However, in the free cloud-based database domain there is one other main provider that can conceivably cater to the construction industry, Microsoft.

Microsoft's version of cloud storage is Microsoft SkyDrive (renamed as OneDrive). Similar to Google, to register for the SkyDrive a user needs to have a Microsoft account. However it is possible to register for the Microsoft account via major e-mail accounts such as Yahoo!, MSN, or Hotmail. SkyDrive provides 7 GB free file storage initially with the option of purchasing 50 GB for $25USD/year. SkyDrive has similar features to Google Drive and provides many productivity tools to enhance document management. SkyDrive supports different types of file types including Microsoft Word, PowerPoint, Excel, and One Note. The user is able to work with most office tools online (referred to as Word Online, Excel Online, etc.). One innovative feature in SkyDrive is that the user can access the folders and files in their PC (contingent on an internet connection) remotely even when the files are not in the SkyDrive folder. Even though Microsoft developed SkyDrive, it provides compatibility with a Mac with the installation of an additional app. During the period of the research conducted herein, SkyDrive was in the development stage. Therefore most of the enhanced features were not available to the customers. Therefore, due those limitations, the research scope was limited only to GD and GFT. Further justification for the use of GFT based upon the alignment of its offered features with industry demand will be highlighted in the following section.

2.6.4 Justification for GFT

The research conducted by Hewage (2007) was mainly focused on the IT application of the informational kiosk called iBooth. However, a significant contribution of his research was also the collection of insight from the construction industry on currents voids in IT and suggested features in forthcoming IT (Hewage 2007). Cloud-based databases are considered a form of information technology, and GFT in particular, is justified for its application in the presented research based on its alignment with the IT survey results conducted by Hewage. The summarized results that follow, have been obtained through the interview of fourteen construction managers and represent the features that were suggested to be manifested in field based IT applications (Hewage 2007):

- Economically feasible

- Tested and proved in a site setting
- Training and support to be provided
- Real-time information available to required parties
- Able to be catered to various projects
- Should be part of an industry wide technology and communication standard
- Created as a joint effort between vendors, researchers, and industry
- Should not disrupt current activities
- Offers maintenance and upgrades
- Benefits should be noticed in a short amount of time
- Provide an advantage in bidding applications
- Should be able to replace manual paperwork and data entry

Additional literature in academia further justifies the use of GFT as a relevant cloud-based database option for conducting a pilot study on. Zhang (2008) stresses the need of functions that allow the importing of files from commonly used software into a database, as well as the need for integration with existing intranets, extranets, and existing commercial software (Zhang 2008); all of which GFT provides.

2.7 Barriers to Implementation

The survey discussed in the previous section also tested the barriers to implementation of IT within the construction industry. The surveys were conducted from two alternate perspectives, construction managers and developers. The set of surveyed developers included over fifty results from both Canada and the United States. The responses from both entities have been included below (Hewage 2007):

- Barriers to Implementation (Construction Managers Perspective)

- Will not implement until all options are analyzed
- Require demonstrations and continuous support to feel comfortable with IT
- Must see results from the implementation by their competitors first
- Thorough field testing must be conducted before implementation
- The reluctance to share information with industry

- Barriers to Implementation (Developers Perspective)
  - Lack of industry wide standards
  - Lack of manager interest
  - Unclear needs and poor technology integration
  - Lack of managers understanding of the expected output

2.8 Chapter Summary

This chapter has been able to cover a wide range of topics associated with the research presented. The definitions and history of productivity, activity analysis, benchmarking, and databases were covered in terms of past academic contributions and industry related literature. The sub-sections of this chapter was able to highlight the various forms of data collection observation methods, the various categories of work noted to have impacts on productivity, the different types of databases applied within the construction industry and academia, and the alternatives considered for the pilot study of a cloud-based database. Also highlighted within the contents of this chapter, were a background on GD and GFT, its key features, and justification for research. The final part of this chapter included general barriers to information technology implementation as noted in preceding literature.

Chapter Three: Methodology and Theoretical Framework

Chapter three will entail a model of the summary of research work undertaken. The methodology utilized during activity analysis and productivity related data collection will be thoroughly covered. Additionally, the theoretical framework for the methodology of composing and testing a cloud-based database and benchmarking system will be presented.

3.1 Research Work Undertaken

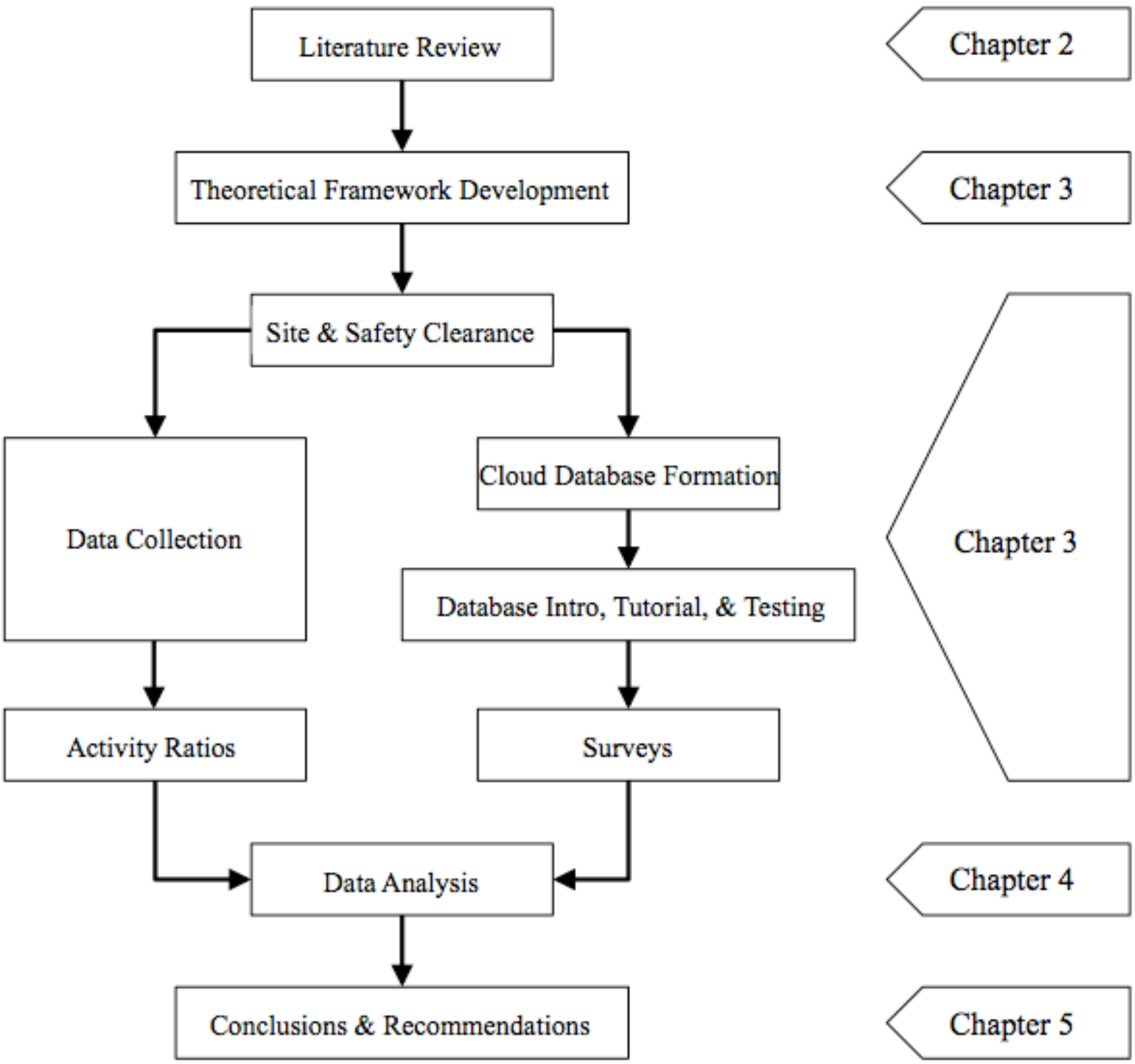
The research work presented herein has a two-pronged approach, both of which run in parallel with each other. Figure 3.1 exemplifies what will be articulated in the following paragraphs. Following the comprehensive literature review, a theoretical framework was developed for the methodology of preparing and testing a cloud-based database and benchmarking system for productivity related data within the context of the commercial construction industry. After clearance was granted from the University's ethics board, construction site and safety clearance was soon thereafter granted as well and both research approaches were ready to be commenced.

The two-pronged approach of the research entailed simultaneous research on one common construction site and project. The first "prong" (left-hand side of Figure 3.1) of the research was considered to be the "active" portion of the work because it entailed obtaining raw data on activity analysis categories directly from within the operational construction site. This active prong approach is considered to be the backbone of the research based upon its contributions, to be discussed in succeeding chapters.

The second "prong" (right-hand side of Figure 3.1) of the research was considered to be the "passive" portion of the work because it entailed project management related activities, and harnessed all of its data from within the field office in the form of surveys. This passive prong approach is considered to be the supplementary part of the research based upon its limitations, to be discussed in succeeding chapters.

Both stages of the research yielded data to be evaluated accordingly. Chapter four will include the data analysis encompassing both prongs of research. Chapter five will be the final chapter and include conclusions, contributions, limitations, and recommendations based upon the entire body of research presented herein.

Figure 3.1: Summary of Research Work Undertaken



3.2 Methodology: Activity Analysis and Productivity

3.2.1 Introduction

This active part or “prong” of the research is based on the study of a participating company’s concrete slab formwork installation trade over the span of sixteen weeks. Specific details about the company, location, and project will be omitted in order to honour the privacy of the company and maintain confidentiality. The construction project was a commercial structure located in Calgary, Canada and the data collection spanned from July 2013 until the end of November 2013. The construction work trade being focused on will also be fully defined and justified as to why it was the trade selected for observations within this section on methodology. Furthermore, the activity analysis and productivity research methodology section is additionally broken down into four significant components, established standards, pre-data collection, data collection, and post data collection.

3.2.2 Standards Established

In order to stay aligned with past and projected future research, it is imperative to establish a nomenclature that provides consistency. As mentioned in the literature review, there are various definitions in the industry available for both productivity and WS categories. The following sub-sections will provide the researcher’s acknowledged standards for the measurements of productivity as well the activity analysis categories that raw field observation data was grouped in.

3.2.2.1 Productivity

The measurement of productivity in this research is aligned with the most rudimentary definition that exists, an output over an input. From Equation 3-1, the equation as applied to this research is further elaborated by an output being in a certain quantity, that being meters squared since we will be focusing in on construction formwork installation, with an input being in labour hours, or in other words, the amount of time associated with that construction trade as is logged by the project management personnel. This is further illustrated in equation 3-1:

$$\text{Productivity (P)} = \frac{Output\ (O)}{Input\ (I)} = \frac{Quantity\ (m^2)}{Labour\ Hours\ (hr)}$$

…………………………………Equation 3-1

From here on in productivity will be referred to based on the above equation.

3.2.2.2 Activity Analysis Categories

In the previous chapter, the author discussed and highlighted the definitions of an array of categories that have been used in conjunction with data collection for productivity related studies, as well as the evolution of those definitions throughout time. In order to promote a continuum amongst academic research endeavours, a standard must be agreed upon. As the methodology of this research on activity analysis category ratio proportions is aligned with the framework put forward by Tsehayae et al. (2012), the categories used for activity analysis and their definitions will also remain uniform with those of which have been proposed by the framework, and were originally published the CII (2010). They are based on both a seven-category and three-category grouping and are listed as follows (refer to section 2.32 for full definitions):

- Seven-Category
    - Direct Work
    - Preparatory Work
    - Tools & Equipment
    - Material Handling
    - Waiting
    - Travel
    - Personal

- Three-Category
    - Direct Work
    - Supportive Work = Preparatory Work + Tools & Equipment + Material Handling
    - Delay = Waiting + Travel + Personal

3.2.3 Pre-Data Collection

3.2.3.1 Project Manager Buy-In

Following a university sanctioned ethics approval but prior to collecting data several meetings were held with the project management personnel in charge of the construction site where data was to be collected. The meetings entailed an introduction to the research that included definitions, methodology, and overall objective of the research. It was imperative to build rapport with the parties who were granting access to the construction site and facilities.

Naturally, there were many questions that arose from the project management team about the logistics, ethics, and confidentiality of the research, all of which had to be addressed before any clearance was granted for data collection. Following the meetings, there was also a buffer period where the project management team had to relay the meeting minutes back to their superiors. Once everyone was on board, research was able to commence.

3.2.3.2 Foremen Buy-In

Foremen buy-in was accomplished after project management and executive approval was granted. Foremen generally are not in a position to dispute research being conducted due to their position within the hierarchy of the company, but in good faith, and as an ethical and informative measure, there were meetings held with the foreman of each construction crew located on the construction site where research was being conducted. A total of five foremen were briefed on the research operation, one foreman for concrete, and one foreman for each of the main types of formwork being installed on the site; foundation walls, miscellaneous walls, columns, and suspended slab.

Also, the importance of the notification of research for the foreman is critical since they are out on the construction site everyday and also act as main sources for information throughout the research process. Additionally, foremen are easier to get a hold of when an exigent question may arise about the past, present, or future operations on the construction site. Furthermore, foremen are equally as important in the research process as any other project management or executive party.

3.2.3.3 Walk-thru and Site Safety

As with any construction site, safety is an on-going concern. Prior to entry onto the site a safety orientation was required, which included watching a video on safety measures necessary in different scenarios. Following the safety orientation a brief exam was administered in order prove proficiency in basic safety procedures. Proper personal protection equipment (PPE) was administered before being allowed to enter the construction site. The PPE equipment required included safety glasses, a hard hat, a reflective safety vest, and a pair of safety grade steel-toe boots. Gloves and earplugs remained optional.

Once fully prepared to enter the live construction site, the site safety director conducted a guided walk-thru which emphasized areas that were low risk, high risk, and off-limits. Muster points where all persons on the construction site would meet in the case of an emergency were also stressed. Interns further explained the daily operations involved on the construction site during ensuing tours.

3.2.4 Data Collection

3.2.4.1 Duration, Conditions, and Site Details

The duration of the data collection spanned sixteen "observed" weeks from July to the end of November. Although the actual span of the researcher's presence on the construction project was longer, the amount of "observed" weeks was sixteen due to data collection being limited to neutral weather conditions. The temperature during data collection ranged from 25^{o} C in July to 0^{o} C in November. Additionally, the researcher's definition of "neutral weather conditions" will be discussed in an upcoming section.

A typical workweek consisted of five days from Monday to Friday, four days were nine-hour days and one day was an eight-hour day for a total of forty-four hours. The working day began at 07:00 and ended at 16:30, thirty minutes was allocated for a lunch break. Major Canadian statutory holidays were observed and work did not occur on these days. On occasion there was work that occurred on Saturdays, however, data collection was limited to work that occurred between Monday and Friday with the exclusion of any overtime. The layout of the site was on a square plot, with at least three points of access at all times.

3.2.4.2 Data Collection Observation Type

The observation type selected for the duration of data collection was activity analysis. This method was selected for multiple reasons. Firstly, activity analysis is the more detailed format of work sampling, and allows for an extensive evaluation of work categories, as opposed to other methods, which typically only feature two or three categories to classify work activities. Additionally, as mentioned previously, in order sustain a continued effort in research, and to promote the accumulation of more data sets in the future, the method chosen is in line with CII (2010) and the acknowledged framework of Tsehayae et al. (2012). Furthermore, from a logical assessment, activity analysis is also the most viable option due to its minimum disruption on the workforce being observed, as well as the level of statistical accuracy that can be achieved within a given threshold in lieu of committing an entire workday to a direct or continuous observation method.

3.2.4.3 Data Collection Tools

Data Collection was originally conducted manually with a clipboard, paper collection template, and pencil. This method was very tedious and had a larger risk of error when the data was later transferred to a Microsoft Excel spreadsheet for analysis. This obsolete manual method of data collection was superseded by a streamlined method with the use of a Microsoft Surface RT tablet as a data collection tool. The tablet came equipped with Microsoft Excel, so uploading data for analysis was a simple and time saving process. However, using electronic tablets on a construction site could be risky due to the presence of dirt, dust, and other air borne debris, hence a case for the tablet was used to increase the durability of the device if exposed to harmful conditions or if dropped. The utilization of tablets on the construction site was also foreshadowed by Hewage (2007) and further justifies their use for data collection:

> “Tablet PCs provide better visibility and can be used as a full function computer at the open site environment. There are many ruggedized models available for construction and military use. It is possible to have touch screen functions with these devices. Tablet PCs are very popular in manufacturing industry and with the military because of their light weight, high intensity touch screens, portability, rugged body, and hand writing recognition.” (Hewage 2007)

3.2.4.4 Data Collection Templates and Inputs

The templates for data entry that were used in conjunction with the tablet were composed with Microsoft Excel and specifically crafted for the data collection application of this research. Automation within Microsoft Excel was utilized to the advantage of the researcher, whereby the data entry inputs were automatically totalled at the conclusion of every 30-point observation cycle, and further automatically calculated in terms of percentage per category. Additionally, the Microsoft Excel conditional formatting function was applied, and a predetermined alert in the form of a solid red cell would appear on the spreadsheet if the total amount of observations in any one column or “observation interval” would not equal the numerical value that has been entered into the crew size input cell.

The format of the template itself had to be adjusted several times, and was finalized with the fourth revision. The stimulus behind the revisions in the template was based on maximizing efficiency in data entry, whereby the aim was for the researcher to make the least amount of finger swipes or clicks on the tablet in order to accumulate data. An efficient data collection template file, over time, will yield time saved for the researcher, which could in turn be used to accumulate additional data. The final version of the template that was used for data collection can be found in Appendix C.

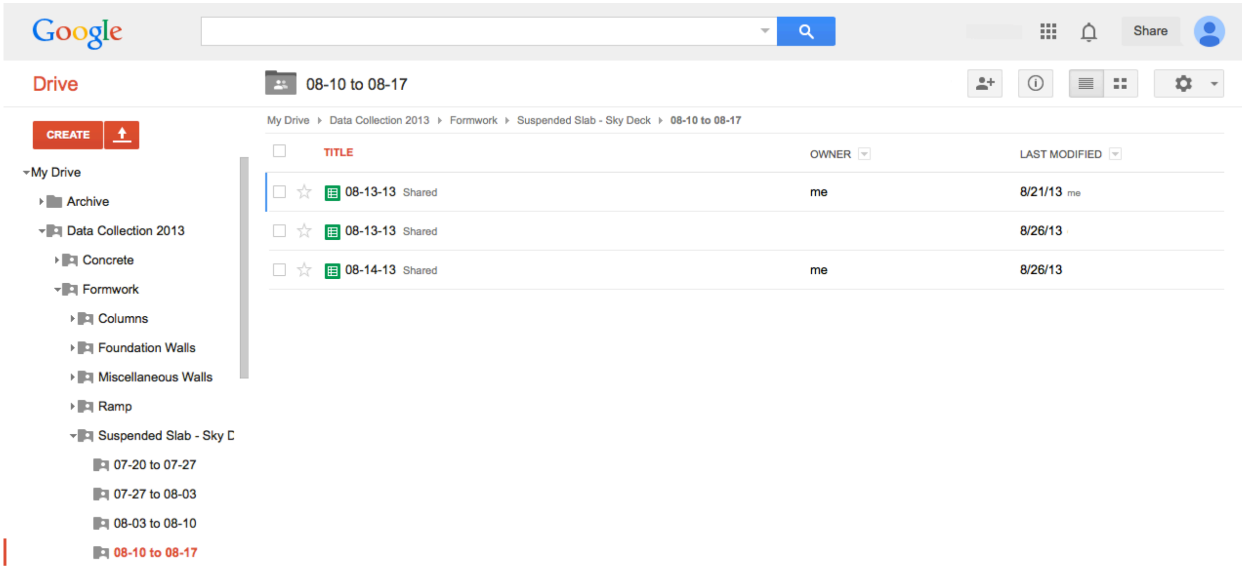
Inputs included in the template include:

- Date, Day, Time
- Temperature, Weather, Site Conditions
- Interval of Observations
- Crew Size
- Location
- Data entry table, totals, and percentage of category per observation cycle
- Notes and Remarks

3.2.4.5 Data Storage

Data storage was done on several sources in order to prevent any type of significant data loss. The primary source was using the cloud storage function of Google Drive. A comprehensive directory of data sets organized by construction trade and week of observation was created on Google Drive (Figure 3.2). The secondary source was on the hard drive of the tablet used to collect data on the construction site.

Figure 3.2: Data collection folder arrangement in Google Drive (GD) (Google 2014)



At the end of each data collection week, the observer uploaded the Microsoft Excel files to the Google Drive. A uniform format was followed for the file names saved on the tablet device, as well as on GD. All the data was compiled in to one central folder created on GD, then based on the construction trade that folder separated into two, concrete and formwork. Those two sub folders were again divided based on different building elements; columns, foundation walls, suspended slabs, and miscellaneous walls. Finally, the building elements were further divided into separate weeks of observation, respectively.

The advantage of using this cloud storage service is that it is free of charge, accessible from any location with an Internet connection, and its spreadsheet file format is cross compatible with Microsoft Excel. Google Fusion Tables, which is another file format hosted by Google Drive, will be discussed at length as it will serve the function of a pilot database in the latter part of this research.

3.2.4.6 Sample Size, Accuracy, and Confidence Level

In order to achieve statistically significant results a certain amount of data points must be collected. In respect to the research conducted, each "data point" was considered a single observation within a single interval. Intervals were either set to either 30 seconds, or one minute, depending on the size of the crew being observed or the distance between each of the workers being observed. Longer intervals were allotted for large crew sizes, or a crew with workers spaced very far apart. This technique was employed to give the observer enough time to document each worker in a crew before the next interval; it also promoted a steady and regulated tempo in observation. Each observation cycle included data from 30 consecutive intervals. For example, if a crew of three workers were observed for one observation cycle, regardless of the interval, the amount of data points that would be generated would be 90. In other words, one data point per worker per interval for thirty intervals would equal 90 data points.

Generally speaking, the more accumulated data points, the greater the accuracy that will be produced when analyzing data. However, the data collection phase of this research necessitated a feasible amount of data points required in order to act as a benchmark for the sample size. The sample size is further governed by three factors, accuracy or limit of error, confidence level, and category proportion. Clarkson H. Oglesby et al. covers the construction industry accepted standard for these factors as follows:

> "For sampling construction operations, there is a general industry consensus that a confidence level of 95 percent and a limit of error of plus or minus 5 percent give a good indication of the overall effectiveness of an organization or operation. As noted, the "working" portion of activities usually falls within the range of 40 to 60

percent of the whole of most activities. Given these limits, the minimum sample size is 384" (Oglesby et al 1989).

The following Equation 3-2 has been extracted from the above authors' seminal work *Productivity Improvement in Construction* (Oglesby et al 1989):

$$N = \frac{K^2[P(1-P)]}{S^2}$$ **……………………………………..…………………….Equation 3-2**

N = The required sample size or number of observations
K = The number of standard deviations associated with a confidence level of 95
S = Accuracy: Limit of Error (plus or minus), in percent
P = Category proportion in percent

The following Equation 3-3 exhibits the outcome based on the recommended values:

$$384 = \frac{2^2[.40(1-.40)]}{5^2}$$ **……………………………………………………….Equation 3-3**

Furthermore, 384 observations are required to sustain the aforementioned degree of accuracy and limit error on a daily basis. When a five-day workweek is factored in, the weekly total becomes 1,920 observations, bringing a sixteen-week grand total to 30,720 observations. These amounts were honoured during data collection and often exceeded as a safety precaution.

3.2.4.7 Neutral Weather Conditions

The data collection was carefully conducted during neutral weather conditions, to continue to conform to the paradigm that promotes future research. The researcher's defined limits for neutral weather conditions are graphically depicted in a modified version of a figure derived from the work conducted by Moselhi et al. (2010).

Figure 3.3: Labour Productivity of formwork as function of temperature and humidity – Modified to include range of parameters for data collection (Moselhi et al. 2010)

[Removed, copyright clearance not obtained, please refer to Moselhi et al. 2010 – Figure 2a and 2b]

The shaded areas underneath the curves demarcated by the diagonal lines represent the range for temperature and humidity within which the data collection observations were carried out. The temperature range was limited to approximately 25^{o} C to 0^{o} C. The relative humidity range was limited to approximately 35% to 65%. As figure 3.3 portrays, the ranges within which the data collection was conducted are within favourable boundaries and are at or above the 0.5 threshold, whereby a normalized productivity with the value of 1 would equate to the most optimum condition (Moselhi et al 2010).

3.2.4.8 Adverse Weather Conditions

During adverse weather conditions data collection was halted due to the intrinsic barriers to productivity. This was done in order to neutralize the data collection and limit it to satisfactory weather conditions only. Adverse weather conditions were considered anything that hampers productivity such as heavy rain, heavy snow, freezing temperatures below zero, or hot temperatures above 25^{o} C. If data were being collected at the time of an adverse condition, it would be paused indefinitely until the condition had concluded. Adverse weather also had a negative impact while utilizing tablets for data collection, since they are generally not resistant to heavy precipitation.

3.2.4.9 Randomization

The randomization of the beginning times and location of observations is critical to promote statistical accuracy (Oglesby et al. 1989). This was achieved in the presented research by using the Microsoft Excel function “=RANDBETWEEN” to create a random number generator from one to one hundred, whereby each number had an associated start time. The randomly generated start time was then abided by each day. An important characteristic of randomizing start times was also to deter labourers from anticipating uniform start times, whereby they may change their habits if being observed at the same time each day over a long period of time (CII 2010). Furthermore, additional times that were omitted due to a traditionally believed drop in productivity include exactly after the work day began, prior to lunch, after lunch, and before the work day ended (CII 2010). The buffer period allotted for each of these periods was fifteen minutes.

When conducting activity analysis on a large construction site where the entire site as a whole is monitored, regardless of the construction task or trade, it is viable to also factor in random starting locations. However, random start locations could not be used due to the focus on one construction trade during each set of observations. The locations were therefore governed by the daily location of the crew being observed.

3.2.4.10 Observing Tactics

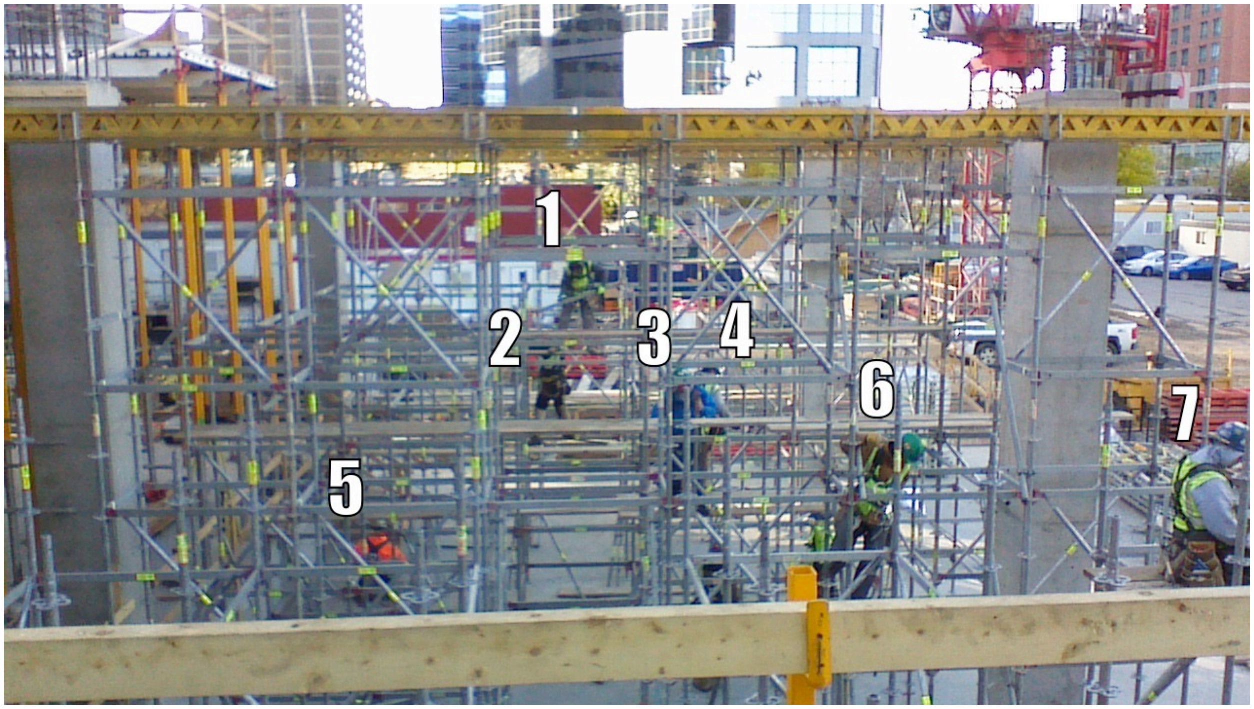
The work sampling and activity analysis methodology was conducted based on the standards put forward by the two previously mentioned seminal guides (CII 2010, Picard 2004). However, some key observation tactics that were utilized during the data collection are worth mentioning.

In regard to positioning when collecting observations of work in progress, locations were always selected in order to maximize the distance between the observer and the workers in order to minimize interference. Figure 3.4 depicts the typical distance that was taken by the researcher when conducting activity analysis observations. If figure 3.4 were an actual "observation" point, both of the workers would be classified in the direct work category. The observer changed their position periodically while remaining in the same general observation area in order to deter the notion that they are observing aggressively. When the observer shifts positions within an observation area, workers feel more comfortable, compared to a worker who notices the same observer in the same observation spot multiple times. Observation sets, although primarily consecutive, were never collected from the exact same area for longer than 30 minutes.

Figure 3.4 Observers positioning and spacing during data collection

An equally important tactic is to maintain observation integrity when each reading is recorded. In other words, the observer should not care about the activity the worker was conducting just before the observation, nor should the observer care about the activity the worker will be doing directly after the observation (CII 2010). The main purpose is to obtain data on the worker at the exact moment of the observation point, just as if a photograph of that moment was taken. This observational integrity will make the data collected more uniform, and allow the observer to collect data as a neutral party without doing any unnecessary evaluation of the construction trade being monitored. Figure 3.5 depicts an observation point of seven workers, although some of the activities are difficult to decipher from the photograph, it becomes less challenging when the observer is located on the actual construction site. Based on figure 3.5, one observation point or interval will yield seven data points.

Figure 3.5: Observation point of seven workers



3.2.4.11 Preliminary Collection

Several days were dedicated to studying the plans and construction site to familiarize the observer with the current routine and construction methods. The initial week of observations was a trial week and disregarded for data analysis. The reason for disregarding the first week was due to the observer's learning curve for data collection as well as the time allocated for introductions. Moreover, time was allocated to answer questions from approaching laborers, lead hands, and foremen as well as to gain an understanding of the site from a field perspective. The omitted week was necessary to gain bearings on the procedure of activity analysis, to solve unforeseen questions and problems associated with data collection, as well as to finalize the data entry template.

After the first omitted week, the following six weeks were dedicated to collecting data on multiple construction trades because it was still unclear at that point of research which trades would remain the most consistent and uniform throughout the entire sixteen week duration. Initially the two main trades emphasized were concrete and formwork. Those two trades each further broke down into columns, foundational walls, slabs, and miscellaneous walls. The first six weeks of data collection acted as a projection of the work to come and was emblematic of the consistency and uniformity of the work being conducted.

3.2.4.12 Targeted Collection

The entire concrete trade was rendered unsatisfactory to monitor for the entire duration of the study due to the lack of consistency in concrete shipments. There were major delays constantly in between concrete truck shipments and made data collection difficult and tainted. If it were not for the delays, the uniformity of the concrete operation would have made for an exemplary trade for data collection.

The formwork trade was mostly consistent based on workload, however the separate construction tasks either lacked uniformity or were mainly executed with a crane operator. Miscellaneous wall formwork was diverse in nature and varied greatly based on the size of the wall, the amount of laborers, and the methods used. Foundation wall formwork was uniform in construction method, but had large gaps in between installation, and did not have a long enough overall duration to monitor. Formwork for columns was installed by one lead hand or foreman with the assistance of a crane operator and was not feasible to monitor.

The remaining construction crew for the formwork trade was suspended slabs. Suspended slabs were both uniform in operation and consistent; their duration endured the entire sixteen weeks of data collection and was scheduled to continue beyond the duration limits of the research. Furthermore, suspended slab formwork is a recurring construction activity within the industry that did not have any comprehensive productivity metrics published on it that were within the constraints of the applied framework and was therefore the most viable construction task for targeted data collection of data points through activity analysis.

In favor of maintaining complete transparency throughout the research, the explanation of exactly what suspended slab formwork installation entailed will be further described. However, trade names of material will still be withheld due to privacy concerns. The suspended slab formwork operation was multi-faceted. There were often at least four separate crews of three or more laborers working on this operation at any given moment. The four crews were often distributed in to two groups of crews based on their positioning in reference to the slab being formed.

One group of crews would be below the formwork and installing formwork underneath the slab to be formed. The operation below the slab was executed with a mechanical lift and prefabricated, interlocking forms, which were braced by adjustable aluminum extrusions. One laborer would operate the lift, while the others would prepare and handle the majority of the materials and tools during this procedure. This process was fairly uniform and did not have many variations in installation throughout the duration of the observation period. However, in some areas that the aluminum extrusions were unable to reach, a scaffold had to be erected instead (Figure 3.5).

The other group of crews would be above the formwork or installing formwork above the slab being formed, which would include edges, and miscellaneous jogs and changes in elevation (Figure 3.4). The operation above the slab was executed by manually cutting pieces of plywood that would be fastened to the prefabricated interlocking forms accordingly. This operation also typically consisted of a less cohesive and more spaced worker formation. This formation was in part due to the work area being designated as a fall zone, which required each worker to be wearing a harness that was tied off to an adequate bearing point. The procedure of formwork installation above the slab had more variation involved, but typically employed fewer laborers. Both groups of crews were monitored equally to sustain a balance throughout data collection. The removal of suspended slab forms, following the pouring and curing of concrete was omitted from data collection observations.

3.2.4.13 Obtaining Actual Productivity Values for Comparison

In order to be able to compare activity analysis results, actual values on productivity had to be obtained. Prior to the commencement of data collection, there was an agreement with the project management team that they would release actual productivity values on a weekly basis to the researcher. The productivity values were in a very raw format when received and had to be further calculated. The values received were quantity and work hours to date for each classified construction task, therefore the totals had to be calculated based on a weekly distribution and finally compared to the associated week of activity analysis data.

Furthermore, during the conclusion of every workweek, which would end on the Friday of each calendar week, the researcher's data would be uploaded on to GFT for secure storage. The following week, typically Thursday or Friday, the senior project manager would send raw data from the previous week, which would constitute as a lag period of one-week for the researcher. In the case of targeted research on suspended slab formwork, the values sent by the project manager would entail the quantity that has been installed to date in square meters (M^2) as well as the amount of hours that have been logged to date for that construction task in hours (Hrs.). Each successive week of values sent from the project manager would therefore consist of the quantity and hours to date, also known as *total* hours. The task of the researcher was, through simple arithmetic, to determine the difference between each set of weekly quantities and hours from that of the previous week. Once the researcher calculated this information, the final step would be to align the true weekly quantity of formwork installed and the associated amount of hours dedicated towards that week, with the corresponding week of activity analysis data points.

The importance of obtaining actual productivity information for the research presented is paramount. Productivity information is typically considered classified information, and has sometimes been completely withheld from past researchers (Ranasinghe 2012). In order to truly assess the impact of activity analysis categories on a construction site, actual productivity values must be garnered. Although the presented research was able to obtain weekly values on actual productivity, planned productivity information remained confidential and unattainable.

Furthermore, the best approach of obtaining pertinent information from management would be to build and maintain a positive and amicable relationship with the involved parties. Often, authorization to release this information is generated from the next higher tier of executive management. The fact that ethical clearance has been obtained can be used as leverage to ensure to the construction company that confidentiality will be maintained. An alternate method could also consist of signing a confidentiality agreement with the construction company. Moreover, proprietary data is difficult to attain from any construction company, but with the proper assertiveness the likelihood is increased.

3.2.5 Post-Data Collection

3.2.5.1 Discussion and Review with Project Managers

After each month of activity analysis and productivity comparison was conducted, a formal meeting was held with the project management team. This meeting was intended to showcase short-term results as well as foment discussion amongst the construction company's personnel. The discussion and review of data with the project managers was beneficial on many levels. First, meetings and transparency of data built the confidence and trust of the involved company personnel. Second, many inquiries were spawned during these sessions by the project managers and additionally allowed them to embrace an alternate perspective of assessing the success of a construction trade or crew. During the final meeting, the attendance of the meeting tripled from that of the first meeting, which indicated that the research generated interest beyond the core project management team.

3.3 Theoretical Framework: Testing a Cloud-Based Database and Benchmarking System

3.3.1 Introduction

The portion of the presented work that ran parallel to data collection on the construction site was the development and implementation of a theoretical framework for a methodology to form and test a cloud-based database and benchmarking system (DBBMS). The overall measure that the DBBMS is tested on is its applicability within the construction industry as a project management tool for productivity metrics. As previously alluded to, the cloud-based DBBMS to be formed and tested as part of the pilot program for this theoretical framework will be Google Fusion Tables (GFT).

The utopian and long-term contributory aim of this presented framework is the promotion of the development and use of a free and collaborative DBBMS throughout the construction industry on a global scale. However, the summary of contributions that this theoretical framework aims to instantly provide is listed as follows:

1. Testing the applicability of GFT as a DBBMS in terms of the featured categories.
2. Comparing and contrasting the GFT pilot DBBMS against the participating construction company's current extranet and data management system.
3. Understand the perceptions of the participating company in regard to the applicability of GFT as a cloud-based DBBMS and project management tool.
4. Identify the barriers to implementation of GFT as a DBBMS tool.

3.3.2 Methodology

The theoretical framework for the methodology presented will first develop a pilot cloud-based DBBMS through the use of GFT. Once the pilot database has been created, it will be introduced to the project management staff of the participating company through a tutorial and a demonstration highlighting key features and functions. The knowledge of the highlighted features and functions would be required to complete a succeeding phase of exercises in respect to the pilot DBBMS. There will be an allocated period for the participants to learn, test, and explore the features and functions of GFT. Certain rudimentary exercises will be assigned to each individual participant to gauge their proficiency with GFT. The attempt of the exercises will also act as a prerequisite to a pair of administered surveys. The completion of the surveys will mark the conclusion to the pilot program and theoretical framework.

The sub-sections of the methodology to follow will discuss the steps that are required to follow the presented theoretical framework. A succinct explanation of each step that composes the methodology sub-sections is presented herein:

1. Selection of Cloud-Based DBBMS – Provides criteria for the selection of the cloud-based DBBMS tool.
2. Pilot Program – Describes the steps for forming a cloud-based DBBMS pilot program that is catered to productivity studies.
3. Presentation & Tutorial – Chronicles the procedure of introducing the selected DBBMS with a presentation, tutorial, and demonstrations.
4. Administered Exercises – Explains the exercises administered as part of the pilot program.
5. Surveys and Assessment – Provides the types of surveys, and the six main categories that the surveys assessed following the exposure of the participants to the pilot program.

3.3.2.1 Selection of Cloud-Based DBBMS

Based on the prevailing literature review (Chapter 2), which has covered the industries demand in IT, as well as the historical precedent regarding database applications within the construction industry, the selection of GFT as the cloud-based DBBMS to be utilized for the pilot program included the following fundamental criteria:

1. No initial or residual cost
2. Collaborative without global boundaries
3. Security and privacy control
4. Compatible with common file types

5. Extensive charts, graphs, and visualizations
6. User friendly and customizable based on project
7. Can integrate with current intranet/extranet
8. Sufficient storage limit
9. Automatic upgrades
10. Trusted source (Google)
11. Location mapping feature
12. Maintains a database for publically available files
13. Multiple users can work on same file simultaneously

3.3.2.2 Pilot Program

Following the selection of an appropriate cloud-based DBBMS that is applicable to the construction industry, the development of the pilot program was able to commence. The pilot program was carried out on the same construction site where activity analysis data collection was being conducted. The aligning of the participating company (further referred to as company X) and project site for both parts of the research allow the researcher to gain a better understanding of the daily activities of the project management personnel who are involved with the pilot program. The procedures related to the formation of the pilot program were as follows:

1. Determine the amount of people who will be participating in the program.
2. Investigate the daily extranet usage patterns of the participants of Company X.
3. Form a database file, populated with hypothetical productivity data that the participants are exposed to throughout a typical workweek for viewing purposes. Data column titles included:
    a. Project Name
    b. Location
    c. Project Cost

d. Duration

e. Number of Laborers

f. Construction Trade

g. Productivity per. hour (m^2)

h. Direct Work (%)

i. Support Work (%)

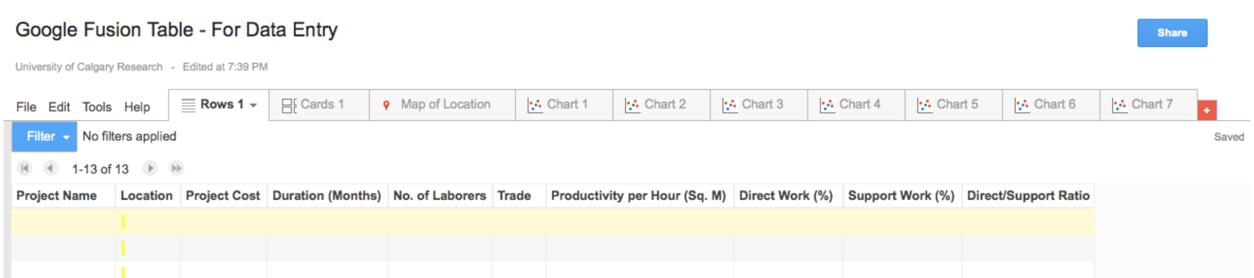
j. Direct/Support Ratio

4. Form a blank database file with column names that match the hypothetical productivity data for editing purposes (Figure 3.6)

5. Create usernames and passwords and grant editing rights to the blank database file to all participants.

6. Create a database file with hypothetical data that has public viewing rights and is therefore searchable through Google.

Figure 3.6: Blank GFT database file with column names for editing purposes (Google 2014)



3.3.2.3 Presentation

An introduction to GD and GFT was presented to thirteen project management employees who are actively involved with the site where data is being collected on. The senior project manager, senior superintendent, senior estimator, information technology district systems administrator, and business analyst, were all part of the set of surveyed employees, all of which who use the company extranet as part of their daily functions. The introduction included a brief history of GD and GFT, a tutorial of basic functions including adding data and searching for data in the publically available database of GFT files, a demonstration of key features, and a preview of the application of GD and GFT for current activity analysis data collection being conducted on site in order to showcase a real-world example. Experimentation with GFT, as well as the file that the participants were granted editing rights to was highly encouraged.

3.3.2.4 Exercises

Following the presentation, two exercises were assigned to all members as a prerequisite to completing a set of surveys. Exercises were carefully planned to familiarize the participants with fundamental features of GD and GFT that are crucial to managing and maintaining a database system. A two-week period was granted for attempting the exercises and the experimentation with the pilot DBBMS.

Exercise 1: Add a row of data to the Fusion Table template file that each user had been granted access to. Each participant was assigned a unique row of data to enter. Note: Each participant was set up with a separate username and password for Google in order to be able to use the editing feature of GFT.

Exercise 2: Answer a basic question about a certain sample public dataset that must be found through a search of public Google Fusion Tables. Each participant was assigned a unique question to answer.

3.3.2.5 Surveys

Following the attempt at the exercises, the employees were asked to complete a set of online surveys hosted by a GD file format called “forms”. The first survey was a standalone assessment of the applicability of GD and GFT as a tool for construction data management and was based on a five-grade Likert scale from “Strongly Disagree” to “Strongly Agree” (Likert 1932). Inclinations were based on a three-tier scale: Negative, Neutral, and Positive, whereby the negative inclination scale is a composition of “Strongly Disagree” and “Disagree”, the neutral scale was aligned with the Likert scale of “3”, and the positive inclination scale was composed of “Agree” and “Strongly Agree” (Table 3). The results in terms of both the Likert and the inclination scale will be further highlighted in the following chapter.

Table 3: Survey 1 – Inclinations and Likert Scale

Survey 1 - Google Fusion Tables				
Negative		Neutral	Positive	
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Likert Scale				
1	2	3	4	5

The second survey was a comparative assessment of GFT vs. Company X’s current extranet and was based on a five-grade Likert scale from “Strongly Prefer GFT” to “Strongly Prefer Company X’s Current Extranet” (Likert 1932). Inclinations were based on a three-tier scale: GFT, Neutral, and Current Extranet, whereby the GFT inclination scale is a composition of “Strongly Prefer GFT” and “Prefer GFT”, the neutral scale was aligned with the Likert scale of “3”, and the Current Extranet inclination scale was composed of “Prefer Company X Extranet” and “Strongly Prefer Company X Extranet” (Table 4). Likewise, the results in terms of both the Likert and the inclination scale will be further highlighted in the following chapter.

Table 4: Survey 2 – Inclinations and Likert Scale

Survey 2 - Comparative				
GFT		Neutral	Current Extranet	
Strongly Prefer GFT	Prefer GFT	Neutral	Prefer Company X Extranet	Strongly Prefer Company X Extranet

Likert Scale				
1	2	3	4	5

The purpose of both surveys was to evaluate their respective metrics against six fundamental categories:

1. Ease of use
2. Feasibility
3. Innovation and Features
4. Collaboration
5. Security and Privacy
6. Compatibility

For each survey, the summation of the results of all questions for each category was further organized based on the inclination that they depicted. Each survey had two opposed inclinations, as well as a neutral designation. Additionally, each surveys included a section for leaving additional comments. Answering all of the questions was required, with the exception of the additional comment section, which was optional. All participants were able to see a summary of the total survey results after their completed submission. Please refer to Appendix B for a full list of questions found on each of the surveys.

3.4 Chapter Summary

The culmination of this chapter has provided the reader with a comprehensive understanding of the two-pronged approach to the research undertaken. The methodology for the "active" activity analysis data collection was covered and justification for the targeted collection of suspended slab formwork was provided. Furthermore, the "passive" theoretical framework for the methodology of forming and testing a cloud-based database and benchmarking system for application within the construction industry was discussed and broken down in its respective steps. The following chapter will cover the analysis of data generated from the entire body of the presented research.

Chapter Four: Data Analysis

Chapter 4 will include a detailed evaluation of the results generated by the sixteen-week activity analysis study of suspended slab formwork. The evaluation will consist of correlation analysis and multivariate linear regression. Also the results and responses generated from the surveys that were administered following the DBBMS pilot program will be featured herein.

4.1 Activity Analysis and Productivity

4.1.1 Introduction

As discussed previously, the focus of the activity analysis and productivity data evaluation hereon in will be based upon suspended slab formwork installation, whereby all quantity values "Q" will refer to the installed quantity of formwork in meters squared per hour. The interpretation of each activity analysis category for slab formwork in terms of the applied CII definitions (Chapter 2) will be featured in the succeeding section.

The evaluation of the activity analysis study will be based on both a seven-category and a three-category data set as described in the *Standards Established* section of Chapter 3 and in alignment with the *Framework Review and Application* section of Chapter 2. Both data sets will be assessed on a weekly and average scale. Correlation analysis between categories will be discussed at length. The out of sight category could be considered as an additional category for both the seven-category and three-category breakdown but has not been included when referring to each of the aforementioned breakdowns because of its redundant effect on forthcoming calculations.

The culmination of this section will feature a multivariate linear regression analysis conducted using both the 3-category and 7-category activity definitions. The more statistically valid model will then be presented as a productivity predictor tool for use within the industry for suspended slab formwork.

4.1.2 Activity Analysis Category Interpretation

The categories for activity analysis that have been established as the standard for this research are not endemic to a certain trade, and are more so generally defined in order to encompass the work activities throughout the entire construction industry. Furthermore, the ambiguous content of the standardized definitions provides an interpretative void that the researcher must fill based on the construction trade being monitored. The following list will address the interpretation of the original seven standard categories put forth by this research in terms of individual tasks that were observed during the targeted data collection of suspended slab formwork.

1. **Direct work** – Installing forms, scaffolds, and aluminum extrusions. Handling forms, materials, and tools within immediate work area. Using tools and materials within immediate work area. Assembling the parts that compose the aluminum extrusion assembly.
2. **Preparatory work** – Giving and receiving assignments, directions, drawings, explanations, specifications, or any other information relevant to the task. Planning task to be conducted by visual assessment of work area. Inspecting work as it progresses and making measurements. Since foremen were omitted from data collection observations, preparatory work data points would be recorded for only the laborers if a foreman were briefing them on a duty.
3. **Tools and Equipment** – Obtaining, transporting, adjusting, and using tools related to the targeted construction task outside of the immediate work area. Typical tools utilized during data collection consisted of circular saws, power drills, electrical and power feed equipment, mechanical scissor lift, and PPE that included a safety harness for tying off.
4. **Material Handling** – Obtaining, transporting, adjusting, searching for, and handling material related to the targeted construction task outside of the immediate work area.

Typical material utilized during data collection consisted of modular forms, aluminum extrusions, scaffolding segments, plywood, hardware such as screws and nails, and form oil or grease.

5. **Waiting** – An attentive form of waiting or idleness. This included waiting for task duties to be assigned, waiting to gain access to a work area or ladder, waiting to use a tool, waiting for material to be relocated or dropped off by a crane, waiting while worker on mechanical scissor lift lowers lift to receive materials, waiting on surveyor to check work.
6. **Travel** – Walking throughout or out of the construction site without material, tools, or technical documents.
7. **Personal** – This category included inattentive waiting, extra breaks beyond what was allocated, smoking or snacking, washroom breaks, socializing, and changing or adjusting personal clothing.

Additional definitions are provided for extended clarity in the research terminology:

8. **Out of Sight -** Category was recorded when observing a crew of a predetermined size and any one or group of crew members are unable to be observed for any one or more observation intervals due to those workers being unable to be found or their activity being obstructed or hidden from the observer.
9. **Immediate Work Area –** Recognized as the area within 15 Feet (4.5 Meters) of where the direct work assignment is being conducted (CII 2010).

4.1.3 Weekly Breakdown

The weekly breakdowns are exemplary of the percentage of the total observations recorded of each category in a given week. This value was produced by dividing the total amount of observation data points for a given category in a week by the total sum of observations for that same week. The summation of each week's categories is equal to 100%. Each week is composed of the traditional Monday thru Friday five-day workweek and is labeled based on the calendar date of the Saturday following the end of the workweek. For example, "to July 27" covers workdays Monday July 22nd to Friday July 26th. Table 5 presents the raw data set that has been used for analysis throughout the remainder of this chapter.

Table 5: Activity Analysis 16-Week Data Set

	Productivity (Q/HR)	Direct	Prep	Materials	Tools	Support	Waiting	Personal	Travel	Delay	Out of Sight	D/S Ratio
to July 27	0.7823	40.51	16.28	5.3	4.65	26.23	21.21	5.26	6.14	32.61	0.65	1.544
to Aug 3	0.8164	45.06	16.34	10.03	5.32	31.69	6.26	5.12	10.67	22.05	1.19	1.422
to Aug 10	0.2825	33	32.89	10.33	5.22	48.44	6.89	2.67	9	18.56	0	0.681
to Aug 17	0.6576	31.19	31.14	11.84	6.21	49.19	5.12	2.93	9.86	17.91	1.7	0.634
to Aug 31	0.3710	26.8	42.33	10.03	4.34	56.7	6.02	3.14	5.7	14.86	1.65	0.473
to Sept 7	0.3075	25.52	44.08	8.49	6.49	59.06	4.75	3.44	6.45	14.64	0.77	0.432
to Sept 14	0.2638	41.9	12.86	23.81	2.86	39.53	1.43	9.52	7.62	18.57	0	1.060
to Sept 21	0.2283	36.85	35.94	6.16	6.69	48.79	5.76	3.27	5.17	14.2	0.15	0.755
to Sept 28	0.2667	28.31	22.9	18.25	4.98	46.13	13.16	5.09	7.3	25.55	0	0.614
to Oct 5	0.2280	30.52	41.1	9.86	4.87	55.83	4.4	2.32	5.71	12.43	1.21	0.547
to Oct 12	0.2232	32.96	45	9.26	0.83	55.09	6.48	2.27	3.19	11.94	0	0.598
to Oct 19	0.4314	35.76	11.09	13.52	2.85	27.45	27.64	8.3	0.85	36.79	0	1.303
to Oct 26	0.3853	39.4	20.83	9.58	6.55	36.96	12.26	8.87	2.5	23.63	0	1.066
to Nov 9	0.0338	37.52	33.18	10.31	0.7	44.19	8.6	2.4	5.81	16.82	1.47	0.849
to Nov 16	0.4256	32.98	31.9	20.6	1.55	54.05	2.14	1.19	9.4	12.73	0.24	0.610
to Nov 30	0.1332	31.85	32.22	18.52	1.67	52.41	4.26	1.48	8.7	14.44	1.3	0.608

4.1.3.1 (7) Category Analysis

Figure D.1 in Appendix D exhibits the 7-category sixteen-week activity analysis breakdown for each week of observations. The weeks are not consecutive, and gaps in between weeks are attributed to a stoppage or pause in work, or adverse or non-neutral weather conditions. Each category has also been evaluated based on the following values: Minimum, Maximum, Range, Mean, and Standard Deviation. Table 6 provides the aforementioned values based on each of the seven categories.

Table 6: (7) Category – Accompanying Statistics

(7) Category	Minimum	Maximum	Range	Mean	Standard Deviation
Direct Work	26	45	19	34	5.55
Preparatory Work	11	45	34	29	11.30
Material Handling	5	24	19	12	5.29
Tools & Equipment	1	7	6	4	2.08
Waiting	1	28	27	9	7.02
Personal	1	10	9	4	2.62
Travel	1	11	10	7	2.74

The direct work category has the largest percentage of observations on average at 34% with a standard deviation of 5.55. Traditionally direct work takes up the largest percentage of a set of observations.

The preparatory work category has a much larger range (34%), and therefore a larger standard deviation (11.30). Its average or mean (29%) value is very close to that of direct work due to the nature of suspended slab formwork installation, whereby it is imperative to properly prepare in order to execute the work, as opposed to a much more mundane task with less preparatory work involved such as pouring concrete, which would have a much greater inclination towards direct work.

The material-handling category has the fourth largest deviation (5.29) due to the large size of the site and the distribution of the formwork installation throughout this large plane. A

12% average for material handling also designates that this is the third most utilized category for the given construction task.

The tools and equipment category has the smallest range (6%), deviation (2.08), and mean (4%). Tools and equipment is often hypothesized to have low accompanying statistics due to the established definition that includes “activities associated with obtaining, transporting, and adjusting tools or equipment” (CII 2010). A minimum amount of time is utilized on obtaining and transporting tools because they are strategically stationed by the foremen and/or project management team in order to decrease the amount of time necessary for “obtaining” and “transporting”, which would in turn allow the saved time to be distributed to the remaining categories. Adjusting tools or equipment was typically conducted when there was an equipment failure or malfunction, which was a rare occurrence.

The waiting category has the second largest standard deviation of 7.02 and the second largest range of 27%. The variation in waiting was attributed to the site congestion derived from having multiple construction trades working simultaneously. Any large construction site will often have interferences, where a certain construction trade would receive preference over another due to the unique circumstances of the schedule, trade, or overall project. Therefore, the waiting category fluctuated based on the time of day, adjacent trades, and preferred activities. There was also some fluctuation that was attributed to waiting based on a suspended slab formwork activity, such as waiting for material, or waiting for direction.

Both personal and travel time were similar in all recorded metrics. Personal and travel times are generally not considered to be value adding activities and are therefore minimized to the smallest possible amount, in order to attempt to optimize the quantity producing categories such as direct work and supportive work. The traditional notion of bringing these two mentioned categories to the bare minimum will be further discussed and disputed in the sections on correlations.

4.1.3.2 (3) Category Analysis

Figure D.2 in Appendix D exhibits the 3-category sixteen-week activity analysis breakdown for each week of observations. The weeks are not consecutive, and gaps in between weeks are attributed to a stoppage or pause in work, or adverse or non-neutral weather conditions. The three-category analysis is an alternative and more traditional method for analyzing work-sampling observations. These three categories were formed based on the following combinations of the seven-category activity analysis. Direct work is consistent and does not change in either form. Support or supportive work is a combination of the preparatory work, material handling, and tools and equipment categories. The delay category is a combination of the waiting, personal, and travel categories.

Each category has also been evaluated based on the following values: Minimum, Maximum, Range, Mean, and Standard Deviation. Table 7 provides the aforementioned values based on each of the three categories.

Table 7: (3) Category – Accompanying Statistics

(3) Category	Minimum	Maximum	Range	Mean	Standard Deviation
Direct Work	26	45	19	34	5.55
Supportive Work	26	59	33	46	10.52
Delay	12	37	25	19	7.27

The direct work category is the most uniform out of the three and therefore has the smallest range (19%) and smallest standard deviation (5.55). The direct work average percentage (34%) is now the second largest due to the supportive work category being a combination of the three aforementioned sub-categories. Hence, due to the combinatory element of supportive work, it also has the largest range (33%), mean (46%), and standard deviation (10.52). The delay category has a mean of 19% and is higher than expected because it combines waiting, personal, and travel time. Although delay time is aimed to be decreased or completely diminished by project managers and foremen, it is an inevitable vice found on all construction projects.

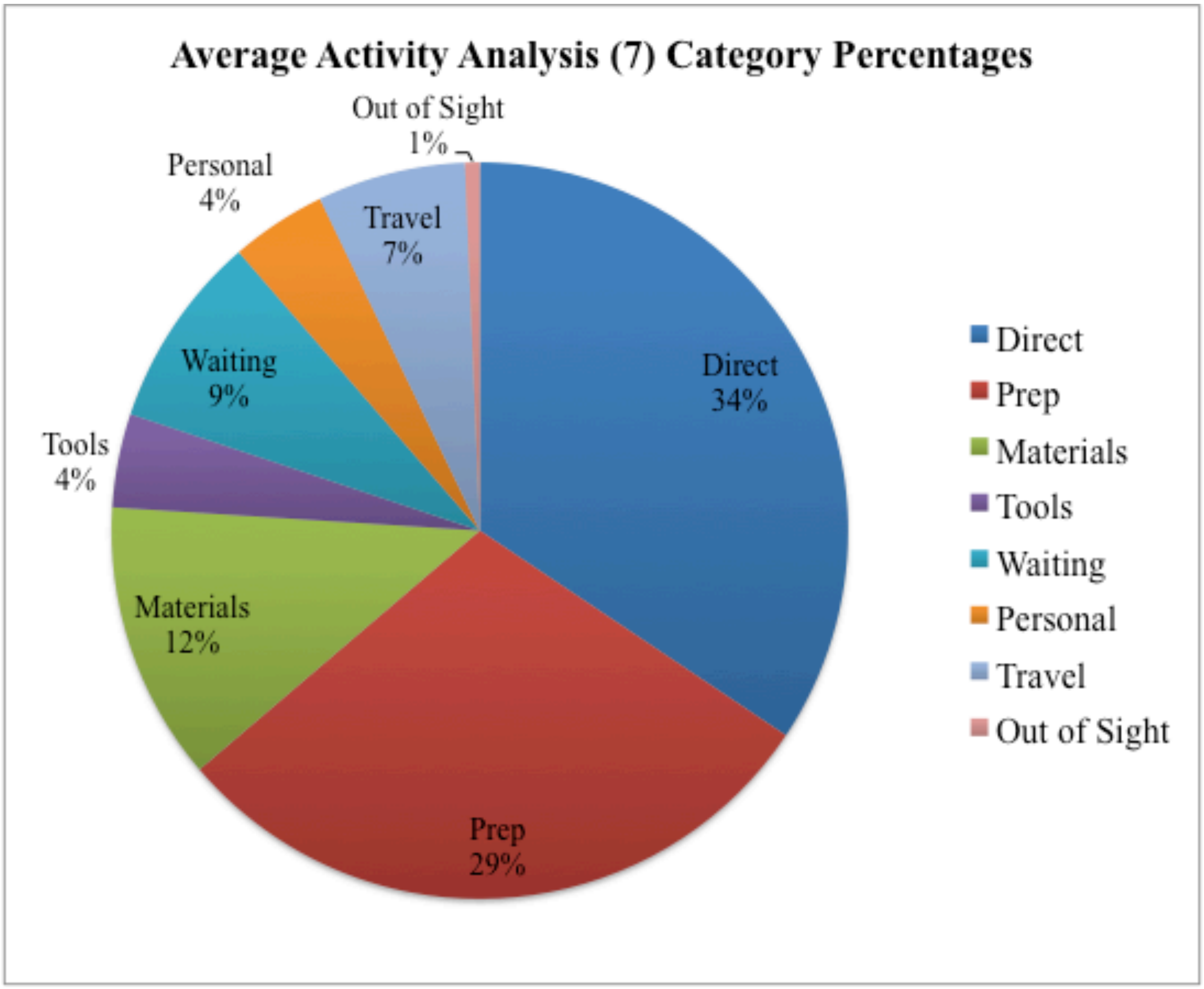
4.1.4 Average Breakdown

The average breakdown is executed in two forms, activity analysis of seven and three categories, respectively. The out of sight category is included in the seven-category analysis for informational purposes, however it is excluded in the three-category analysis.

4.1.4.1 (7) Category Analysis

Figure 4.1 exhibits the average of the seven-activity analysis categories accumulated over the sixteen-week data collection duration. The direct work category, utilized 34% of the time, and is the largest of the seven. The preparatory work category is very close to direct work at 29%, and exemplifies the duality of supportive work required as an adjunct to direct work. Both materials and handling (12%) and tools and equipment (4%) show an inevitable utilization of time for these categories; although a relatively small percentage, these ought to be scrutinized and evaluated based on their correlation to productivity.

Figure 4.1 Pie Chart –Activity Analysis Average Percentages (7) Category

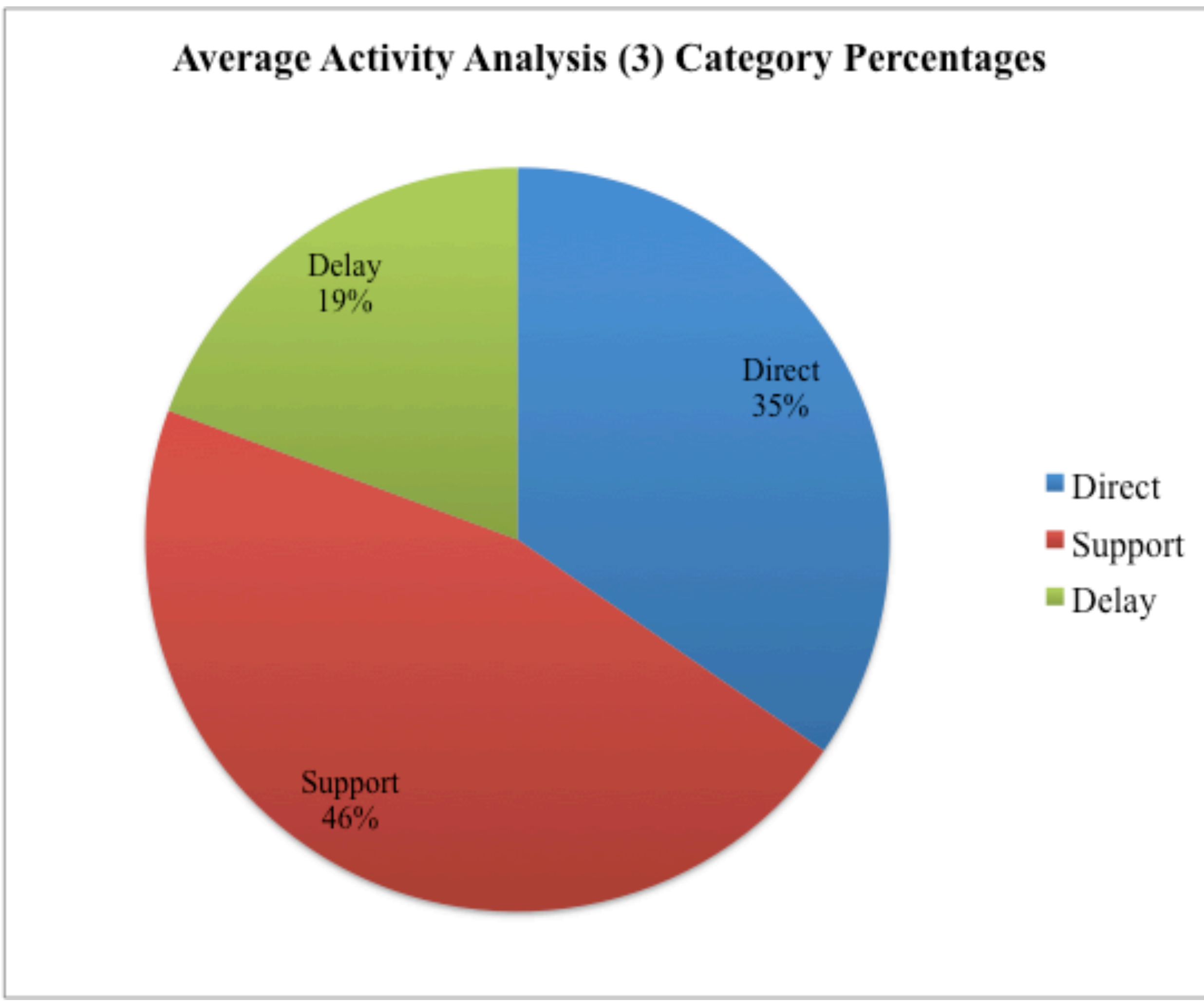


The waiting, personal, and travel categories are all beneath ten percent respectively. Although these three categories are often targeted to be completely eliminated from a construction operation, they may have a positive correlation to productivity and will be discussed later in this chapter. The out of sight category, included for informational purposes is negligible and acted as a buffer for workers outside of the observer's field of vision.

4.1.4.2 (3) Category Analysis

Figure 4.4 exhibits the average of the three-activity analysis categories accumulated over the sixteen-week data collection duration. The direct work category and the supportive work category represent a ratio of .76 on average. Ratios of direct work to support work and their associated productivities will be discussed at the conclusion of this chapter.

Figure 4.2: Pie Chart –Activity Analysis Average Percentages (3) Category



The percentage of supportive work, which is comprised of preparatory work, material handling, and tools and equipment, almost takes up half of the time utilized during data collection due to its definition encompassing the above-mentioned sub-categories. The delay category, likewise, is composed of three sub-categories waiting, personal, and travel time, and at initial evaluation may look larger than anticipated for any construction operation at 19%.

4.1.5 Correlation Analysis

4.1.5.1 Introduction

Correlation analysis has been selected as the appropriate and most traditional method for data analysis between two respective variables. The letter "R" will designate the correlation coefficient.

> "A value of R equal to +1 implies a perfect linear relationship with a positive slope, while a value of R equal to -1 results from a perfect linear relationship with a negative slope. It might be said then that sample estimates of R close to unity in magnitude imply good correlation or linear association between X and Y, while values near zero indicate little or no correlation." (Walpole et al. 1993)

Further validation for the correlation analysis will be presented in terms of the significance level, denoted by the symbol α (alpha).

> "The classical way of accomplishing this is to specify a value α and then require the test to have the property that whenever the null hypothesis is true its probability of being rejected is never greater than α. The value α, called the level of significance of the test, is usually set in advance, with commonly chosen values being α = .1, .05, .005." (Ross 2009)

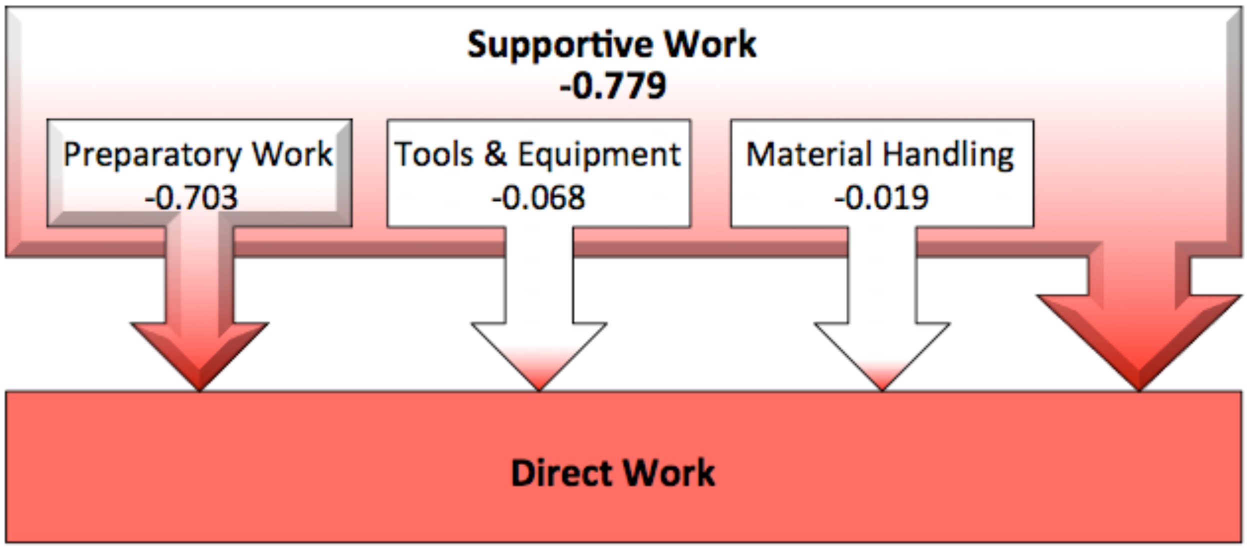
Furthermore, based on the relatively small size of the data set the α has been chosen to be .150. The full table of correlation coefficients and associated P-values can be found in Appendix E.

4.1.5.2 Direct Work vs. Support Work

The following correlation data analysis has been conducted based on multiple pairs of variables. The correlation coefficient values will be discussed between the direct work category and supportive work, preparatory work, material handling, tools and equipment, delay, waiting, personal, and travel time respectively. Relationships will be indicated by two means, visually and numerically. Arrows towards direct work, generated from the respective categories will illustrate the relationship visually based on the amount of the color red at the end of each arrow. Therefore, a stronger relationship is indicated by a greater amount of red starting from the tip of the arrow. Additionally, relationships above .500 are further emphasized with extruded bevelled edges. The second and numerical means of illustrating relationships is based upon the value inside each respective category rectangle, which is always compared to the chief category of direct work. There were sixteen data points factored into the results, one corresponding with each week of observations.

Figure 4.3 exhibits the correlation coefficients between direct work and the given categories. The supportive work category rectangle is illustrated as a larger rectangle because it is considered a main category. Additionally, the remaining three smaller rectangles within supportive work designate that they are sub-categories that make up the supportive work main category.

Figure 4.3: Direct Work vs. Support Work Correlation Coefficients

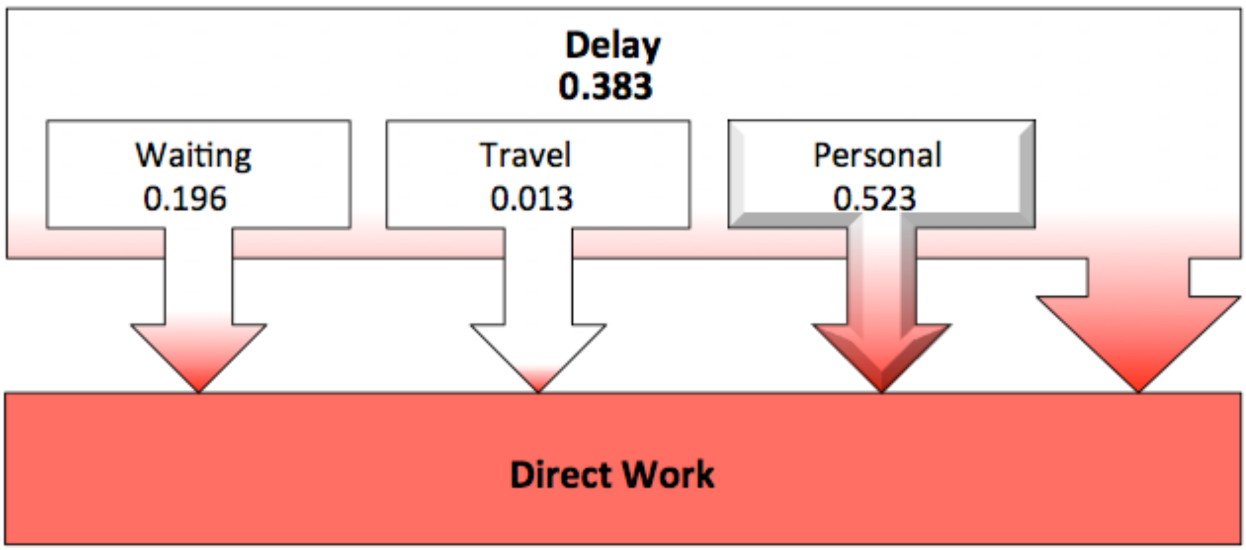


The strongest relationship is found between direct work and supportive work (R = -0.779, P = 0.0003). This inverse correlation is associated with a raise in direct work when supportive work is decreased. If the aim of a foreman or project manager is to solely increase the direct work, it can be inferred that this may be accomplished by decreasing supportive work directly. Since supportive work is a composition of the three sub-categories preparatory work, material handling, and tools and equipment, the next step is to assess which sub-category has the largest standalone correlation to direct work. The relationships between direct work and both material handling and tools and equipment are negligible. The remaining inverse relationship is between direct work and preparatory work (R = -0.703, P = 0.002) which designates that this sub-category should be given priority if the foreman or project manager's aim is to adjust supportive work for suspended slab formwork installation.

4.1.5.3 Direct Work vs. Delay

Figure 4.4 exhibits the correlation coefficients between direct work and the given categories.

Figure 4.4: Direct Work vs. Delay Correlation Coefficients

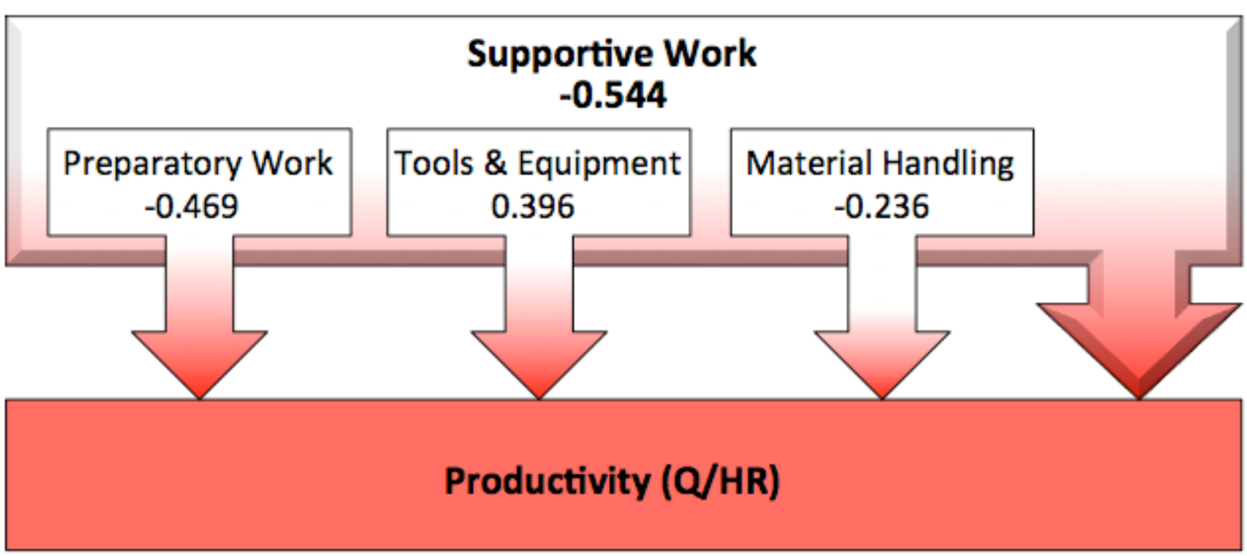


Although, there is a lack of a significant relationship between direct work and delay (R = 0.383, P = 0.143), there is a fascinating and counterintuitive relationship evident between direct work and personal time. The positive relationship between direct work and personal time (R = 0.523, P = 0.038) asserts that an increase in direct work, will correspond with a simultaneously increase in personal time. The logic behind this relationship is as follows; when workers are pressured to do more direct and quantity producing work, which is often the most laborious and arduous task, they will thus utilize more time for personal time such as water breaks and socializing. This logic follows the observer's experience on the site. This result is contrary to popular belief, whereby personal time must be completely eradicated in order for direct work to increase. However, both the work of Hewage et al. (2005) and Da Silva's (2006) recommendations refrain from advocating for the reduction of socializing on the construction site, as it may be an important factor in regard to motivation. The relationships between direct work and both waiting and travel are negligible.

4.1.5.4 Productivity vs. Support Work

The following correlation coefficient values to be discussed will be between the actual productivity and supportive work, preparatory work, material handling, tools and equipment, delay, waiting, personal, and travel time respectively. The format of the following figures and their contents in respect to main categories and sub-categories are indicated in the same manner as the previous figures. Additionally, as discussed previously, productivity is defined as the quantity of suspended slab formwork installed over hours in meters squared per hour. This data was obtained on a weekly basis from the project management team. Figure 4.5 exhibits the correlation coefficients between productivity and the given supportive categories.

Figure 4.5: Productivity vs. Support Work Correlation Coefficients

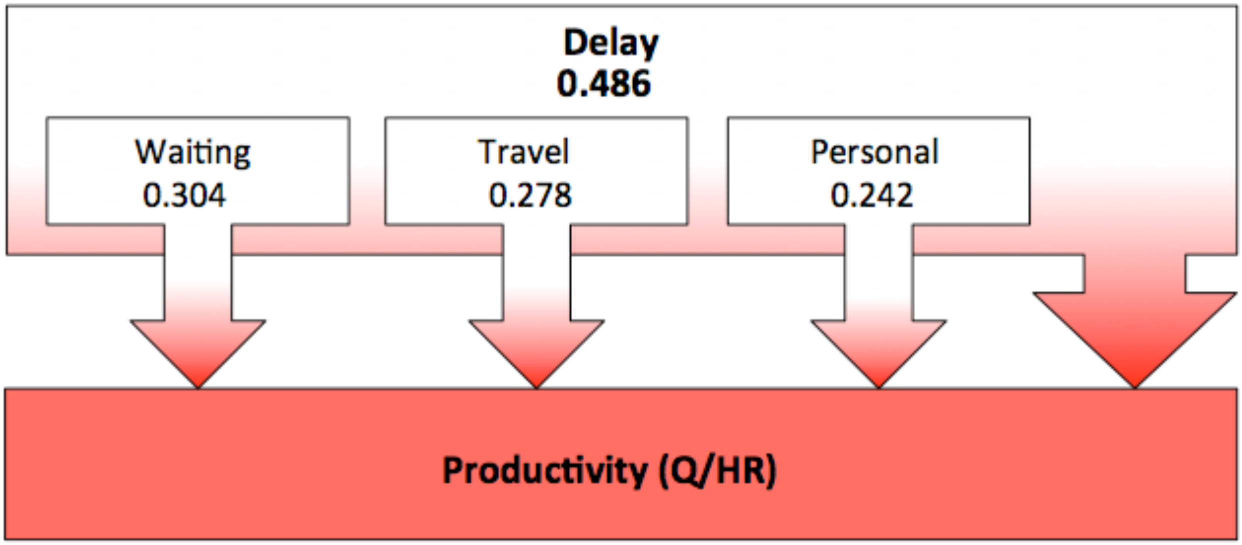


The strongest correlation, which exemplifies a moderate relationship, is the inverse relationship of support work to productivity (R = -0.544, P = 0.029). Therefore, based on the sixteen data points, productivity tends to increase when support work decreases or vice versa. Similar results for deck formwork have also been evinced by previous research, whereby R was found to be -0.369 (Liu 2008). When the main supportive work category is further broken down into the remaining three sub-categories of preparatory work, material handling, and tools and equipment it can be seen that there is a fair degree of an inverse relationship between productivity and preparatory work (R = -0.469, P = 0.067). Therefore, productivity tends to increase when preparatory work diminishes, which could be attributed to an excessive amount of time being utilized for preparatory work instead of direct. The tools and equipment category also displays a fair degree of relationship (R = 0.396, P = 0.129), meaning that when tools and equipment are maintained accordingly, productivity tends to increase. The material-handling category has little or no relationship to productivity.

4.1.5.5 Productivity vs. Delay

Figure 4.6 exhibits the correlations coefficients between productivity and the given delay categories.

Figure 4.6: Productivity vs. Delay Correlation Coefficients



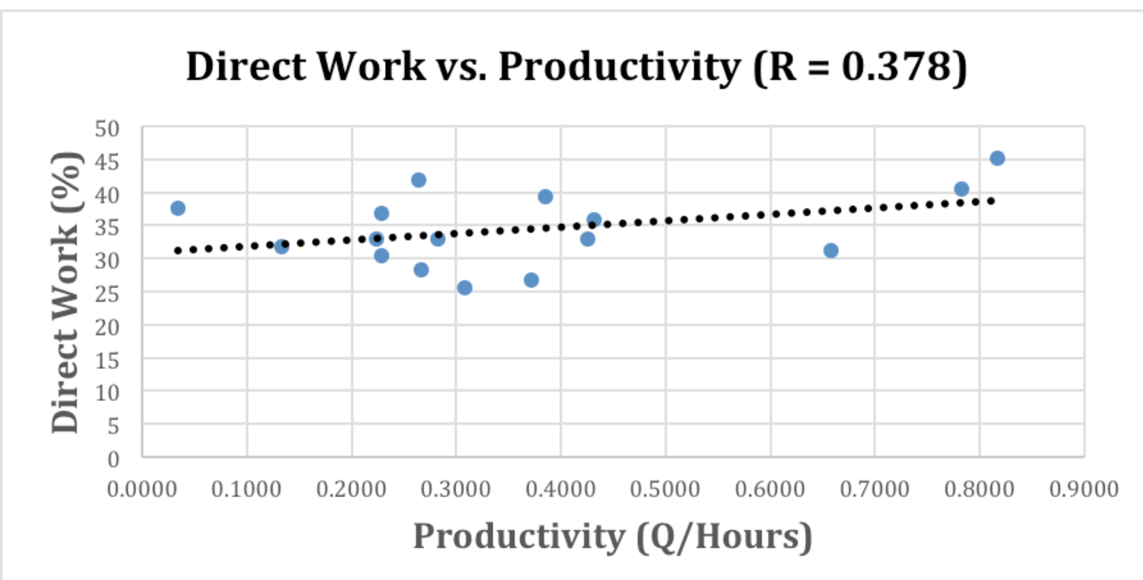
There is a lack of significant correlations between productivity and delay. Overall, the highest correlation of R = 0.486 (P = 0.056) denotes that when productivity increases, delay tends to increase as well. This can be attributed to the similar principle discussed between the correlations of personal time and direct work, whereby the more output generated, the higher of a rate of time utilized in the delay categories. Preceding research by Liu (2008) shows this value to be exactly the same for deck formwork except the correlation depicted is negative (R = -0.486). The three sub-categories of delay time, which are travel, personal, and waiting, all have a nominal relationship to productivity. Since it would be a controversial topic to relay to the construction industry that some time allocated towards delay is necessary for productivity to increase, these outcomes must be taken subjectively and a substantial set of data must be acquired before advancing these sensitive results.

4.1.5.6 Direct Work vs. Productivity

Both direct work and productivity have each been compared to the six sub-categories that make up supportive work and delay time, however they have yet to be compared to each other to gauge the potential existing relationship. The following fundamental correlations will be evaluating the correlation coefficient between direct work and productivity, as well as the ratio of direct work and support work to productivity, respectively.

The traditional belief since the beginning of work sampling studies is that direct work and productivity has a very strong correlation, whereby in order to increase productivity, direct work must be increased to it's maximum threshold. Contrary to popular belief, the results generated from work sampling of suspended slab formwork installation has proved otherwise. Figure 4.7 exhibits the data points from the sixteen-week study plotted in a scatter chart.

Figure 4.7: Marked Scatter Chart – Direct Work vs. Productivity



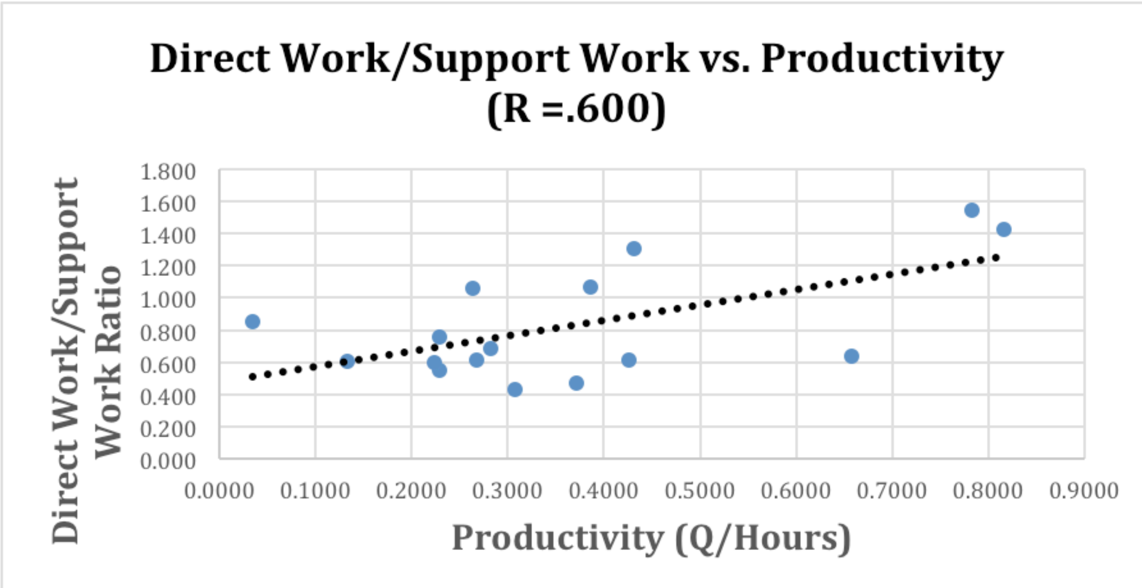
The relationship between direct work and productivity only indicates a fair degree of correlation (R = 0.378, P = 0.149). Although preceding research, which was similar in nature, featured analysis of the same metric for the deck formwork trade that yielded R values as high as 0.764, it did not take external factors such as weather into account (Liu 2008). In order to evaluate the magnitude of this relationship it must be juxtaposed against the correlation coefficients of further metrics. The following comparison will provide insight on the importance of the direct work to support work dynamic in relation to productivity.

4.1.5.7 Direct Work/Support Work vs. Productivity

In line with the objectives and sub-objectives presented earlier in this thesis, the significance of the relationship between productivity and the ratio of direct work to support work will be elucidated. As shown on Figure 4.8, the relationship between the aforementioned factors is considered to have a favourable correlation coefficient (R = 0.600, P = 0.014) (Walpole 1993).

The highlighted relationship between the ratio of direct work to support work and productivity is considerably higher than that of solely direct work to productivity. These results are aligned with the predecessors of similar research (Thomas 1991, Tsehayae et al 2012). H. Randolph Thomas used data mainly from nuclear power plants to make the assertion that direct work is only a random variable and is not a predictor of productivity (Thomas 1991). Abraham Assefa Tsehayae et al. used data on a residential framing crew to assert that direct work is not the only predictor of productivity and should be coupled with supportive work to obtain optimum results (Tsehayae et al. 2012).

Figure 4.8: Marked Scatter Chart – Direct Work/Support Work vs. Productivity



Furthermore, based on the above results (Figure 4.8), the equation associated with the best-fit line is provided as follows:

$$Y = 0.9528x + 0.4772$$ **…………………………………………………………...Equation 4-1**

In order to obtain an equation in terms of the ratio of direct to supportive work as the independent variable, which would furnish a dependent variable of productivity (P), we rearrange equation 4-1 into:

$$\text{Productivity} = \frac{\frac{\text{Direct (\%)}}{\text{Support (\%)}} - 0.4772}{0.9528}$$ **…………………..………………………...Equation 4-2**

Equation 4-2, which is derived from the fundamental linear regression method can be further applied as a productivity predictor model for suspended slab formwork within the given constraints.

The provided data set on suspended slab formwork installation is now engrained as a benchmark for this trade. The results further substantiate past research, as well as establish a new standard for the indicated trade. The importance of the strength in correlation between the direct work and support work ratio to productivity is evident and will be further analyzed in the forthcoming multivariate linear regression analysis.

4.1.6 Multivariate Linear Regression Model

4.1.6.1 Introduction

Multivariate linear regression was utilized to conduct the next tier of data analysis. This was the selected method for two main reasons. Firstly, in order to remain aligned with the governing framework proposed by Tsehayae et al. (2012). Secondly, according to Ross (2009):

> "The response of an experiment can be predicted more adequately not on the basis of a single independent input variable but on a collection of such variables".

Furthermore, a logarithmic transformation was applied to the data to transform it into linear form, based on the assumption that the relationship between direct work, supportive work, and delay is non-linear (Ross 2009).

The following section will present the results of a multivariate linear regression that has been conducted on the weekly activity analysis categories gathered from the data collection phase. The analysis will be conducted on the three-category activity only. Multivariate linear regression for the seven-category activity analysis has not been executed due an inadequate sample size in terms of independent variables. Both the coefficient of determination and the adjusted coefficient of determination will be further elaborated on.

4.1.6.2 3-Category Results

The multivariate linear regression on the three-category activities (direct work, supportive work, delay) was executed using the software program SPSS Version 21, for Windows (Manufactured by IBM). Following the application of a natural logarithmic transformation the following equation was yielded:

$$\text{Productivity} = \frac{e^{26.894}}{Direct^{2.942}Support^{3.804}Delay^{1.141}}$$ …………………………...**Equation 4-3**

However, the model generated had a correlation coefficient of only R = 0.473 (R^2 = 0.224). Additionally, the “adjusted coefficient of determination” ($\overline{R}^2$) value was calculated in order to account for the sample size of the data set, and the amount of parameters being tested (Dillon et al 1984). In our case, we had four parameters, which were, direct work, supportive work, delay, and the constant “e”. The adjusted R^2 value was a meagre $\overline{R}^2$ = 0.030 with an overall P equal to 0.367. Therefore, the adjusted coefficient of determination value, as well as the significance level renders this model for productivity not statistically justified.

Based on further statistical inferences, it is recommended to have a sample size, or number of cases of twenty times the amount of independent variables within a model in an ideal scenario, and four to five times the amount at minimum (Tabachnick et al. 1983). Furthermore, in order to make a commitment to a multivariate linear regression derived model for use as a productivity predictor within the construction industry, a much greater sample set is required to achieve statistically significant results.

4.2 Database and Benchmarking System

4.2.1 Introduction

The culmination of the cloud-based DBBMS pilot program was marked by the completion of a set of surveys. The two separate surveys were titled as follows:

1. Survey 1: Google Drive and Fusion Table Survey
2. Survey 2: Google Fusion Tables vs. Company X Extranet

As previously mentioned both surveys were each assessed based on six categories, ease of use, feasibility, innovation, collaboration, security and privacy, and compatibility. The results from both surveys will be thoroughly discussed in terms of their conjoint categories in the contents of this section. A complete list of survey questions can be found in Appendix B.

The employees who were surveyed represented a broad range of experience in the construction industry. The following two figures (4.9 and 4.10) portray the amount of experience of the participants within the industry, as well as their years of experience with the surveyed Company X, respectively.

Figure 4.9: Participants of pilot program years working in the construction industry

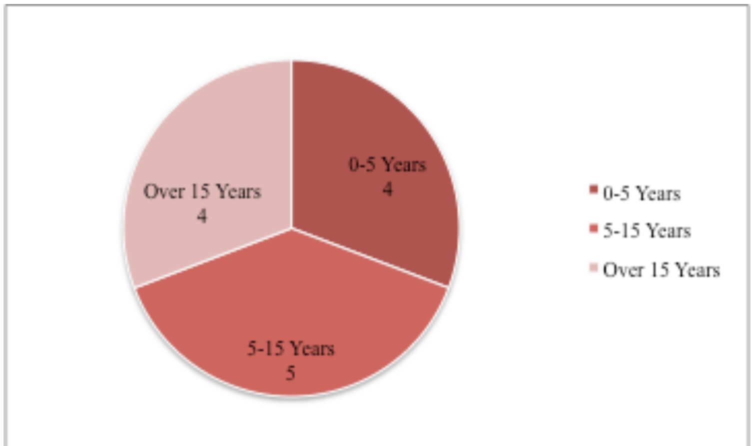


Figure 4.10: Participants of pilot program years working with Company X

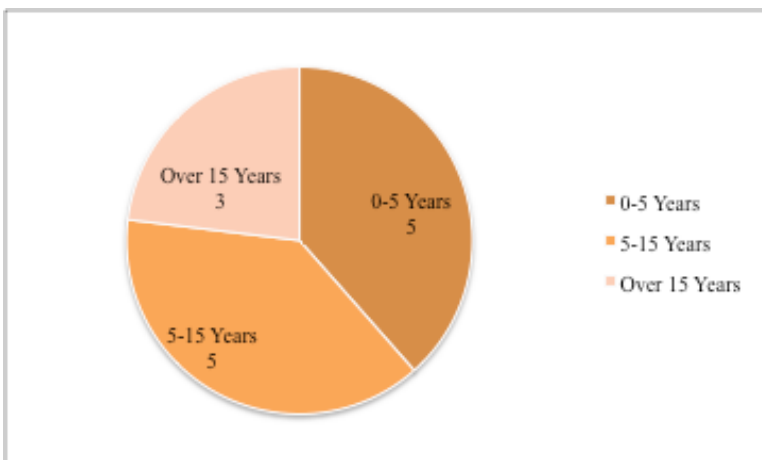


Table 8 provides the breakdown of the results in a tabulated form for reference during the discussion of the subsequent sections, which cover the analysis of each category, respectively. The shaded cells provide the percentage of responses that fall within the original 5-grade Likert scale for each corresponding category. The white cells, or those that are not shaded, provide the percentage of responses that fall within the 3-grade inclination scale.

Table 8: Summary of Results

		GD & GFT (Survey 1)					GFT vs. Extranet X (Survey 2)				
Inclination		Negative		Neutral	Positive		GFT		Neutral	Current Extranet	
Scale		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Strongly Prefer GFT	Prefer GFT	Neutral	Prefer X	Strongly Prefer X
Categories	Ease of Use	3.9		32.7	63.5		11.1		66.7	22.2	
		0	3.9	32.7	50.0	13.5	0	11.1	66.7	22.2	0
	Feasibility	15.4		18.0	66.7		41.7		0	20.8	
		0	15.4	18.0	64.1	2.6	4.2	37.5	37.5	20.8	0
	Innovative Features	0		12.8	87.2		91.7		0	8.3	
		0	0	12.8	66.7	20.5	29.2	62.5	0	8.3	0
	Collaboration	11.5		17.3	71.2		20.8		41.7	37.5	
		0	11.5	17.3	65.4	5.8	0	20.8	41.7	33.3	4.2
	Security & Privacy	2.6		23.1	74.4		12.5		41.7	45.8	
		0	2.6	23.1	74.4	0	0	12.5	41.7	37.5	8.3
	Compatibility	3.9		34.6	61.5		16.7		66.7	16.7	
		0	3.9	34.6	57.7	3.9	0	16.7	66.7	16.7	0

4.2.2 Ease of Use

The Ease of Use category for Survey 1 had approximately one-third of responses in the neutral field, and two-third of responses in the positive field. The largest positive inclination under this category was for the question "The general layout of GD & GFT is intuitive and easy to navigate". The Ease of Use category for Survey 2 had a slight preference towards the current extranet. The "logging in" metric in Survey 2 had the strongest inclination towards the current company extranet. This slight preference could be attributed to an already established level of comfort and proficiency with their current extranet due to frequent usage.

4.2.3 Feasibility

The Feasibility category for Survey 1 had approximately 18% of responses in the neutral field and 67% of responses in the positive field. The question that was deemed most feasible (largest positive inclination) was a tie between “GFT can be implemented as a complimentary tool for executing meetings & presentations” and “GFT can be implemented as an accessory to our current extranet”. The quick and unrivaled access to pertinent data by GFT through any device with an Internet signal propels it to the forefront of data delivery. The least feasible (largest negative inclination) was for question “GFT can be implemented as a replacement to the current database features of our extranet”. Since GFT is still in its nascent stages of development, it is difficult to agree with shifting paradigms based on the limited exposure of the responders. For Survey 2, the current extranet was favored “as a database application”; however GFT was favored “for the use of graphs and charts”.

4.2.4 Innovation

The Innovative Features category for Survey 1 had over 87% of responses in the positive field, as well as 92% of responses favoring GFT over the current extranet in Survey 2. The question that had the largest influence from Survey 1 was “The visualizations (charts & graphs) offered by GFT deliver the data in a comprehensible manner”. The corresponding influence for Survey 2 was a tie between the “Maps” and “Visualizations” metric. The GFT geo-coding feature that automatically detects locations in a dataset and plots them on a map was an innovation that did not have a counterpart on Company X’s extranet.

4.2.5 Collaboration

The Collaboration category had approximately 71% of responses in the positive field for Survey 1. The question contributing the most to this inclination was “Collaboration within the company is facilitated with data entry allowed by all users with editing privileges”, whereby everyone surveyed selected “Agree”. This was one of the highlighted features offered by GFT whereby only those users who have been granted editing rights by the creator of the file can edit given data, alternatively collaboration is also further encouraged through the users who have only been granted viewing rights as well. The question that contributed the most to the negative inclination was “Making a GFT publically available will facilitate collaboration among the entire industry”. This was due to reservations by the responders about sharing their own data with an external and public audience. Survey 2 had an inclination slightly towards the current extranet for the collaboration category; the surveyed metric that this was most evident on was “Among Internal Users”.

4.2.6 Security and Privacy

The Security and Privacy category was the most critical category based on the quantitative results as well as the additional comments noted at the culmination of the survey. In Survey 1, 74% of responses were in the positive range. The question that had the largest influence on the positive inclination was “The share settings allow for viewing or editing access to be easily granted to specific users”. However, based on Survey 2, the “User Access Control” & “File Attribution” metrics for the current extranet were favored over GFT at a ratio of almost 4:1. The additional comments referred to privacy and security on four separate occasions. During discussions it was noted that the level of comfort was not high due to GFT being a cloud-based service that is only password protected. Moreover, the basic layout of the privacy features on GFT can also give an impression of a lack of security.

4.2.7 Compatibility

The Compatibility category for Survey 1 had approximately 35% of responses in the neutral field and approximately 62% of responses at the positive inclination. The largest contributing question to this positive range was “The file types supported by GFT are compatible with current standard file types used within our office”. The files that GFT is cross compatible with include .csv, .tsv, .txt, .xls, and .kml. Survey 2 had balanced results for this category and consequently did not depict any inclination.

Twelve out of thirteen participants were able to successfully add data to the GFT template file and all participants were able to answer their assigned question found in a predetermined public GFT.

4.2.8 Additional Comments

Although the additional comment area in the set of surveys was optional, it generated some valuable insight on the application of GFT as a free cloud-based DBBMS within the industry. Some of the key responses are highlighted below:

1. Like the ability to update and customize graphs, but would like to see more security control.
2. With more practice and background information, I could see this being an asset to the construction world. The privacy issue worries me as for someone being able to hack into the system and get Company X's confidential info.
3. The idea of Google Drive and how it works is a great idea, but I’m hesitant on the security of it. We'll just have to see if it can be secure enough for our clients and solicit their approval for storing data.

4. This really does look like a great tool that we can use, internally or externally for our company. Very easy to use, manipulate, and manage and a great tool to have when doing a presentation with a client.
5. Will be good for internal use but may be a struggle to use on a global basis in the industry.
6. The capabilities of GFT will be effectively extended into the construction industry through collaboration with organizations such as the Construction Standards Institute (CSI), in order to develop standard data metric definitions for use by industry stakeholders.

The majority of the key comments reverberate an overall emphasis on security and privacy concerns. This is a key source of trepidation in any IT implementation and has been documented in research in past surveys of foremen in the construction industry (Hewage 2007). Another source of reservation is centered on the application of the pilot DBBMS on a global scale, which has been a residual issue since the onset of web-based DBBMS. The concluding comment addresses the reinforcement of GFT throughout the industry by suggesting collaboration and alignment with organizations that govern standards related to data metrics.

4.3 Chapter Summary

The culmination of this penultimate chapter has provided a detailed analysis of the dual-faceted research. The data set that is composed of the sixteen weeks of observations has been included and helps illustrate the distribution of the activity analysis categories throughout the data collection. Averages, ranges, and standard deviations were included for all categories.

Correlation analysis results were included with an emphasis on direct work and productivity. A case for the synergy between direct work and supportive work as opposed to only direct work as a predictor of productivity was additionally made, with a corresponding best-fit equation that can be applied within the industry. Furthermore, a multivariate linear regression derived model with independent variables of direct, support, and delay, was discussed and evaluated for application.

Finally, the results from the set of surveys that were administered following the cloud-based DBBMS pilot program were discussed. The results were organized based on the six main categories of analysis. Additional comments, and their relation to preceding research efforts were also covered.

Chapter Five: Conclusions & Recommendations

Chapter 5 will include a description of the dual faceted research presented in a summarized form. Conclusions that have been derived from the preceding chapter, as well as through the overall experience of the researcher will be presented. Research contributions will be explicitly stated, along with limitations that governed the achieved work. Finally, recommendations for future research will mark the conclusion of the chapter.

5.1 Research Summary

5.1.1 Introduction

The impetus for the presented research has been generated in part from the misalignment in productivity related and activity analysis definitions throughout the construction industry. Research efforts, although written in the same language, have been lost in translation due to the constant altercations, modifications, or interpretations in terminology. This research aimed to aide in defeating this problem in nomenclature by following and tracking the predecessors and covering their work carefully, while collecting pertinent productivity related data and evaluating it accordingly.

Additionally, the construction industry has been considered a late bloomer in terms of information technology. This research has correspondingly explored the depths of the collaborative construction technology domain in terms of database and benchmarking tools and their applications. Furthermore, the dichotomy of the research presented has been steered by the ultimate objective of improving the overall labour productivity in the construction sector.

5.1.2 Activity Analysis and Productivity

The commencement of research was marked by the beginning of data collection on a commercial construction project in Calgary, AB. Data was collected by means of a modified method of work sampling called activity analysis. Weather, humidity, and site condition constraints were set in order to neutralize the data set for future research. The activities that data was collected on included direct work, preparatory work, material handling and searching, tools and equipment, waiting, personal, and travel and were based on the standard definitions established by the Construction Industry Institute (2010). The weekly data was coupled with productivity values from corresponding weeks.

Following the conclusion of data collection, a thorough analysis was conducted on the obtained information. A correlation analysis was conducted on all activities in relation to productivity and direct work. Results showcased a stronger relationship between that of the ratio of direct and support work to productivity, than just from the relationship between direct work and productivity. Based on the results, a productivity predictor model was generated in terms of the independent variable of direct/support work. Multivariate linear regression was also conducted, but was proved to not be statistically significant based on the sample size obtained.

5.1.3 Database and Benchmarking System

The commencement of the pilot program occurred mid-way through activity analysis and productivity data collection. The pilot program was created and tested amongst the project management personnel that were involved with the project where field data collection was being conducted. The pilot program consisted of an introduction, demonstration, and tutorial for the selected free cloud-based DBBMS, Google Fusion Tables. A set of tasks was assigned to the participants as an objective that would help later ascertain their understanding of the tool through the use of surveys.

Following a fourteen-day trial period a set of surveys was administered to the participants to garner their opinions of the applicability of GFT as a DBBMS tool for the construction industry. The surveys consisted of an individual assessment of GFT, as well as an assessment compared to the participating companies current extranet. Both surveys were aligned in terms of the categories that they evaluated. These categories were ease of use, future feasibility, innovation features, collaboration, security and privacy, and compatibility.

5.2 Conclusions

5.2.1 Activity Analysis and Productivity

Based on the evaluated data, it has been established that direct work has a lower correlation to productivity than does the ratio of direct work and support work to productivity. However, this holds true for the targeted construction trade only. Nonetheless, the results presented in this work serve as a benchmark and will act as a catalyst for future research.

Statistically, the difference that was found between the two main correlations was 0.221, whereby the relationship between direct work and productivity had a correlation coefficient of R=0.378, while the relationship between the ratio of direct work to support work and productivity had a correlation of R=0.600, which is considered above noteworthy. Other notable correlations were found between direct work and support work (R=-0.779); direct work and preparatory work (R=-0.703); direct work and personal time (R=0.523); as well as productivity and support work (R=-0.544).

In terms of most favourable ratios of direct work to supportive work that effect productivity, three of the top four weeks were in the range of 1.303 to 1.544, or an average of 1.423. The most productive week based on the best productivity rate "Q" occurred at the ratio of 1.422, which was the second highest ratio recorded during data collection. For informational purposes, in terms of least favourable direct to support work ratios based on the data collection results, the lowest three productivities were associated with ratios of 0.849, 0.608, and 0.598

respectively, averaging to 0.685. For example, a 0.685 ratio could be 20% direct work and 29% support work, or 30% direct work and 44% support work, etc.

Based on the associated correlation analysis, a productivity predictor model was generated. The model is intended to yield the productivity (dependent variable) that is a function of the direct to support work ratio (independent variable). Although this model can theoretically be implemented by the industry, the range of values within the featured data set governs its input parameters. The necessity for comprehensive data sets will be discussed later in this chapter.

5.2.2 Database and Benchmarking System

Based on the tabulated results, additional comments, and participant feedback during and after the GFT pilot exercises, various strengths and weaknesses have become evident. The highest ranked category between both surveys in favor of GFT was innovation. The innovative features such as the array of graphs and charts available as well as the interactive map component are unmatched by other databases (Appendix F). Another category that displayed notable strengths in favor of GFT represented by both surveys was feasibility. This category was favored based on the potential of GFT being used as an accessory to the current extranet, as well as a complimentary tool for executing meetings and presentations, mainly in conjunction with its robust visualizations.

Ease of Use, collaboration, and security and privacy were three categories that ranked in favor of GFT in the standalone survey, but did not surpass the current extranet in the comparative survey. Ease of use is a staple of Google applications; however the slight preference of the current extranet over GFT in this category could be attributed to an inherent resistance in new technology.

The collaboration category was favorable for GFT due to the ease of which multiple users could be granted viewing and editing privileges, as well as the convenience of the publish feature. However, one-third of responders did not agree that making a GFT publically available will facilitate collaboration among the entire construction industry, and there was also slight resistance to the potential collaboration within the industry on an international scale. Database and benchmarking collaboration among the industry is an inherent aspect of improving productivity; the reluctance to share competitive information such as productivity data throughout an industry is a hurdle that ought to be overcome in order to progress.

The security and privacy category had a positive inclination for the standalone GFT survey due to the attribution feature, as well as the efficient setting for toggling between public and private access. However, this category had the largest preference for company x's current extranet over GFT. The responders believed that the user access control and file attribution functions of their current extranet remained superior to GFT. Several comments addressed concerns with security for internal users as well as clients, yet remained optimistic that security would be revamped in future versions of GD.

Although, the pilot program was focused on GFT, the research was successful in developing a coherent methodology for creating and testing any cloud-based DBBMS within the construction industry. The structure of the methodology was logically presented and was influenced by the preceding literature and database and benchmarking initiatives. The six categories utilized for analysis were selected by the author as the most pertinent for the evaluation of a pilot program in terms of its applicability within the construction industry.

5.3 Research Contributions

5.3.1 Activity Analysis and Productivity

The contributions found within the contents of this research in terms of activity analysis and productivity have been listed below:

1. Activity Analysis Category Definition Matrix, which has covered the range of productivity studies conducted at the University of Calgary since 2003.
2. Standardized activity analysis categories in terms of slab formwork installation.
3. 16-week data set for the slab formwork trade that includes activity analysis metrics with corresponding productivity values.
4. Correlation analysis results for the activity analysis categories in relation to productivity and in relation to direct work, respectively.
5. Productivity predictor model in terms of the independent variable of direct/support work.

5.3.2 Database and Benchmarking System

The contributions found within the contents of this research in terms of a cloud-based database and benchmarking system tool have been listed below:

1. Development of a framework for a methodology for creating and testing a cloud-based DBBMS for application in the construction industry.
2. Surveyed results based on the categories of Ease of Use, Future Feasibility, Innovation Features, Collaboration, Security and Privacy, and Compatibility evaluating:
    a. Google Fusion Tables
    b. Google Fusion Tables vs. Current Company Extranet

5.4 Limitations

5.4.1 Activity Analysis and Productivity

There were various limitations during the activity analysis data collection phase. The majority of limitations fall under the site-specific details of the construction site that was observed. In other words, this research was limited to an individual commercial construction project in Calgary, Alberta executed by an individual construction company during neutral weather conditions. Also, the construction trade targeted was the only suitable trade to be monitored based on the researchers criteria. Furthermore, the duration of the research was limited to a seventeen-week collection of data with one week omitted due to the necessity for the researcher to become fully assimilated with the construction site, operations, and data collection techniques.

Data collection was limited to a passive approach, and there was a lack of implementation of best practices by the participating construction company. The reason for the trepidation in implementation was attributed to two factors. The first factor was that following the final results meeting with the project management team, the weather began to decline and drop below zero degrees Celsius, which does not fall under the neutral weather criteria established for this research. The second factor was a lack of complete buy-in from the entire project management team. Although, distinct metrics, correlations, and suggestions for improvement were presented, the project management team never administered an action plan. This hesitation can be attributed to either a lack of confidence in the data accumulated or it can be attributed to an inherent resistance to change.

5.4.2 Database and Benchmarking System

Limitations experienced during the database and benchmarking research track were similar to those mentioned during the activity analysis research. The results obtained were limited to the perspective of one construction company. Likewise, the duration of the pilot program was limited to several weeks, and may not have provided sufficient time for users to completely explore the constraints of GFT and GD.

Limitations also revolved around the type of data used, the amount of data the database could handle, as well as the lack of a real-world application assessment. Furthermore, the pilot program was created without input for exact tasks required by potential personnel who would utilize the proposed database and benchmarking system, it was more so limited to hypothetical tasks that have a more general appeal.

5.5 Recommendations for Future Research

5.5.1 Activity Analysis and Productivity

Research that will follow should be as best aligned with the standard terms and definitions used for productivity, as well as the activity analysis categories. Since there has been a significant amount of fluctuation in terms in this exact research, the standards proposed by the seminal texts should be abided by.

Once alignment has been accomplished, the following step would be to evaluate a common or popular construction trade, task, or activity, regardless of whether or not there has been a precedent in research. Following the selection of the trade, task, or activity, as many variables as possible must be monitored for potential use in a future database or for comparison against published data. Some of these variables include, weather, time, crew size, project type, project size, geographic locations, duration of project, complexity of work, project price, cost, and profit, and any other notable variables or anomalies. Additionally, in terms of data collection, following the alignment of definitions, the template for data collection ought to be adjusted based on the tablet or device utilized to collect data. Consideration should be given towards minimizing the amount of finger movements or screen touches required to log data, in order to optimize the time of researcher on the construction site.

An important aspect of potential future research would be the full collaboration with a participating company, one that has committed to the evaluation of preliminary results followed by the implementation of best practices based upon benchmarked values. Further commitment by a participating company could also include the sharing of planned productivity, in addition to actual. Obtaining planned productivity would provide a useful metric in terms of the establishment of a potential database, either internally or externally.

Furthermore, the duration of the presented research is considered to be short-term; it would be beneficial to obtain comprehensive data over a long-term period, preferably from the start to finish of a given project. In favour of amassing statistically significant results, the approach to data collection could also be modified. Consideration of comparing daily activity analysis categories to their respective daily productivities would allow for a larger overall data set in the same amount of time. This, of course is contingent on either the participating company granting access to this data, or allowing the researcher to take manual measurements of the work conducted for the day. Furthermore, the prime goal is to increase the sample size in order to strengthen the productivity predictor models generated from future research.

5.5.2 Database and Benchmarking System

The pilot cloud-based database and benchmarking system study presented was administered on one large-scale construction company. Feedback from companies of various sizes, and various specialties is necessary to begin to craft a consensus on the piloted tool (GFT), or likewise any other alternate tool tested. The trial and experimentation period for the pilot program spanned fourteen days following the introductory presentation. Comments in the surveys acknowledged the potential of the tool but believed that a more comprehensive and long-term pilot program must be established to fully understand the functions and possible applications.

Additionally, future pilot studies could further test parameters such as file size limitations, the application of the tool in conjunction with actual data and in a real-world setting, as well as the feedback obtained from two separate parties or companies based on the use of the tool for actual external collaboration.

In order to introduce a new technology to any audience certain standards and templates must be established. Along with standards for sharing data, an administrator protocol will be paramount for maintaining and managing data and granting access to authorized personnel. If the participating construction company employs a construction productivity improvement officer (Ranasinghe 2012), or similar person, the cloud-based DBBMS could also serve as a complimentary tool for the employee to use as part of their daily productivity evaluations.

In regard to the continuation of testing GFT, full utilization of the Application Programing Interface (API) features were out of the scope of this research, however, with proper programmers and developers the possibilities are endless by integrating GFT with any website or company extranet. An additional future recommendation would similarly be focused on full integration of the tool with current intranet and extranet systems.

Furthermore, the benchmarking that this research focuses on is the comparisons of activity analysis categories and their associated productivity amounts. These distinct metrics are important for either project managers or estimators to establish productivity predictors depending on the category or ratio of categories acting as independent variables. If the framework is diligently pursued with a focus on the aforementioned metrics, slowly, but surely a comprehensive database of benchmarked values will be available to the participating construction company to use at their disposal.

Potential future applications of a cloud-based DBBMS should not exclude the creation of a database that caters to estimators and project managers data requirements accordingly, either private for internal use, or public for industry input. Furthermore, the proposed theoretical framework for a methodology for creating and testing a DBBMS has provided a blueprint for future endeavors. Ultimately, the goal of this research in respect to future recommendations is to influence an economical and innovative route for the establishment of an international and public cloud-based database and benchmarking tool.

References

BLS. (2013, March 11). About the Construction sector. *U.S. Bureau of Labor Statistics*. Retrieved January 12, 2014, from http://www.bls.gov/iag/tgs/iag23.htm

COAA. (2009, February 1). The Alberta Report: COAA Major Projects Benchmarking Summary. *COAA: Benchmarking*. Retrieved January 14, 2014, from http://www.coaa.ab.ca/Portals/ConstructionPerformance/documents/Alberta-Report-09.pdf

Construction Industry Institute. (2010). *Guide to Activity Analysis: Implementation Resource 252-2a*. United States: Construction Industry Institute.

Costa, D.B., Formoso, C.T., Kagioglou, M., Alarcon, L.F., and Caldas, C.H. (2006). "Benchmarking initiatives in the construction industry: Lessons learned and improvement opportunities". Journal of Management Engineering, Vol. 22(4): 158–167.

Dillon, W. R., & Goldstein, M. (1984). *Multivariate analysis: methods and applications*. New York: Wiley.

Gallaway, T. O., & Starkey, J. (2013). "Google Drive". The Charleston Advisor, Vol. 14(3), 16-19.

Gilbreth, F. B. (1911). *Motion Study: A Method for Increasing The Efficiency of The Workman*. New York: D. Van Nostrand Company.

Gong, Jie, Borcherding, John D. and Caldas, Carlos H., (2011), "Effectiveness of craft time utilization in construction projects." Construction Management and Economics, Vol. 29(7), pp. 737-751.

Gonzalez, H., Halevy, A., Jensen, C. S., Langen, A., Madhavan, J., Shapley, R., & Shen, W. (2010a). “Google fusion tables: data management, integration and collaboration in the cloud”. In Proceedings of the 1st ACM symposium on Cloud computing (pp. 175-180). ACM.

Gonzalez, H., Halevy, A. Y., Jensen, C. S., Langen, A., Madhavan, J., Shapley, R., Shen, W., Goldberg-Kidon, J. (2010b). “Google fusion tables: web-centered data management and collaboration”. In Proceedings of the 2010 ACM SIGMOD International Conference on Management of data (pp. 1061-1066). ACM.

Google. (2014, January 14). Sample Fusion Table - Complete. *Google Fusion Tables*. Retrieved January 14, 2014, from https://www.google.com/fusiontables/DataSource?docid=16Gv3-CbQyl_BfNga2szCITJbMEJMhqObYwrLec8#rows:id=1

Halevy, A., & Shapley, R. (2009). Google Fusion Tables. User Experience http://googleresearch.blogspot. com/2009/06/google-fusion-tables. Html (Aug. 30, 2013)

Hewage, K. N., & Ruwanpura, J. Y. (2005). *Most important Worker Motivational Issues that impact Productivity of Alberta Construction Projects.* Paper presented at the 6th Construction Speciality Conference, Toronto.

Horner, R. M. W., & Talhouni, B. T. (1991). “Application of database management systems in productivity analysis”. Computers & structures, Vol. 41(6), pp. 1141-1147.

Industry Canada. (2012, July 18). Labour Productivity Construction (NAICS 23). *Canadian Industry Statistics*. Retrieved January 14, 2014, from http://www.ic.gc.ca/cis-sic/cis-sic.nsf/IDE/cis-sic23proe.html#pro2

Likert, R. (1932). A Technique for the measurement of attitudes. *Archives of Psychology, 21*(140), 5-54.

Moselhi, O., & Khan, Z. (2010). Analysis Of Labour Productivity Of Formwork Operations In Building Construction. *Construction Innovation: Information, Process, Management*, *10*(3), 286-303.

Nasir, H., Haas, C., Rankin, J., Fayek, A.R., Forgues, D., and Ruwanpura, J. (2012) "Development and Implementation of a Benchmarking and Metrics Program for Construction Performance and Productivity Improvement." Canadian Journal of Civil Engineering, Special Issue on Construction Engineering and Management, Vol. 39(9), pp. 957-967.

Noor, I (1998) "Measuring construction labour productivity by daily visits". In: *Proceedings of the 42nd annual meeting of AACE, American Association of Cost Engineers,* Cincinnati, Ohio, Prod.05.01 – 06.

Oglesby, Clarkson H., Henry W. Parker, and Gregory A. Howell. (1989) Productivity Improvement In Construction. New York: McGraw-Hill, Print.

Oppel, Andrew J. (2004), "Databases demystified" McGraw-Hill/Osborne, New York ; Toronto.

Picard, H. E. (2004, January 1). Direct Labor Productivity Measurement - As Applied In Construction and Major Maintenance Projects. *AACE International Recommended Practice No. 22R-01*. Retrieved January 13, 2014, from http://www.aacei.org/non/rps/22R-01.pdf

Rayburn, L. M. (1989). Productivity Database and Job Cost Control Using Microcomputers. *Journal of Construction Engineering and Management*, *115*(4), 585-601.

Rodriguez, J. (2014). Top Saas Construction Products. *About.com Construction*. Retrieved March 14, 2014, from http://construction.about.com/od/New-Software/tp/Top-Saas-Construction-Products.htm

Ross, S. M. (2009). *Probability and statistics for engineers and scientists* (4th ed.). Amsterdam: Elsevier.

Ruwanpura, J., Hewage, K., Da Silva, S. P., & Smith, D. (2006, Fall). Tool Time Analysis to Improve Construction Productivity in Alberta. *Canadian Civil Engineer*, *23*, 18-22.

Sherif Mohamed, (1996) "Benchmarking and improving construction productivity", Benchmarking for Quality Management & Technology, Vol. 3(3), pp. 50-58

Statistics Canada. (2013, December 6). Table 383-0012 Indexes of labour productivity and related variables, by North American Industry Classification System (NAICS), seasonally adjusted. *Statistics Canada*. Retrieved January 13, 2014, from http://www5.statcan.gc.ca/cansim/pick-choisir?lang=eng&p2=33&id=3830012

S. Peer (1986) An improved systematic activity sampling technique for work study, Construction Management and Economics, 4:2, 151-159

Spendolini, M.J. (1992). The benchmarking book. AMACOM, American Management Association, New York.

Stoller, J. (2011). Construction and the cloud. On - Site, 55(6), 48. Retrieved from http://ezproxy.lib.ucalgary.ca/login?url=http://search.proquest.com/docview/910461139?accountid=9838

Tabachnick, B. G., & Fidell, L. S. (1983). *Using multivariate statistics*. New York: Harper & Row.

Teicholz, P. (2013, March 14). Labor-Productivity Declines in the Construction Industry: Causes and Remedies (Another Look) Viewpoint #67. *AECbytes*. Retrieved January 14, 2014, f rom http://www.aecbytes.com/viewpoint/2013/issue_67.html

Thomas, H. (1991). ”Labor Productivity and Work Sampling: The Bottom Line.” Journal of Construction Engineering and Management, Vol. 117(3), pp. 423–444.

Tippett, L. H. C. (1935), “3—Statistical Methods In Textile Research. Part 3—A snap-reading method of making time-studies of machines and operatives in factory surveys.” Journal of the Textile Institute Transactions, Vol.26(2), pp. T51-T70.

Tsehayae, A. A., & Fayek, A. R. (2012). A Research Framework for Work Sampling and its Application in Developing Comparative Direct and Support Activity Proportions for Different Trades. *Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress 2012* (pp. 1420-1429). Indiana: ASCE.

Walpole, R. E., & Myers, R. H. (1993). *Probability and statistics for engineers and scientists* (5th ed.). New York: Macmillan.

Wilkinson, Paul. (2005), “Construction collaboration technologies: the extranet evolution” Taylor & Francis, London ; New York.

Appendix A

(Ethics clearance removed for e-thesis submission)

Appendix B

The following appendix includes the set of questionnaires utilized for the cloud-based database and benchmarking pilot program survey.

Google Drive & Fusion Table Survey

Please select your answers only after you have attempted the objectives distributed at the tutorial.

* Required

1. How many years have you been working in the construction industry? *

❑0-5 years ❑5-15 years ❑Over 15 years

2. How many years have you been working for Company X? *

❑0-5 years ❑5-15 years ❑Over 15 years

3. Ease of Use*

a. I was able to easily log on and find my shared file folder.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. I was able to easily add data to Fusion Table.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

c. I was able to easily search for and find data in a published Fusion Table.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

d. The general layout of GD & GFT is intuitive and easy to navigate.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

4. Feasibility *

a. GFT can be implemented as an accessory to our current extranet.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. GFT can be implemented as a replacement to the current database features of our extranet.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

c. GFT can be implemented as a complimentary tool for executing meetings & presentations.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

5. Innovation & Features *

a. The visualizations (charts & graphs) offered by GFT deliver the data in a comprehensible manner.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. The maps feature with geocoded data conveniently indicates locations based on any selected metric.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

c. The filter feature can be used to quickly access specific data.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

6. Collaboration *

a. Collaboration within the company is facilitated with data entry allowed by all users with editing privileges.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. The publish data feature allows for an easy way to communicate data with various partners.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

c. Making a GFT publically available will facilitate collaboration among the entire industry.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

d. GFT can become an international database for construction metrics with proper administration.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

7. Security & Privacy *

a. The share settings allow for viewing or editing access to be easily granted to specific users.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. The visibility options allow for easy configuration between public and private access.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

c. Each GFT file can easily be attributed with proper information to the original creator.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

8. Compatibility *

a. The import & export options allow for easy conversion between file types.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

b. The file types supported by GFT are compatible with current standard file types used within our office.

❑ Strongly Disagree ❑ Disagree ❑ Neutral ❑ Agree ❑ Strongly Agree

9. What is the Name or Number of the Project you added to the GFT Database? *

10. Any additional comments?

Google Fusion Tables vs. Company X Extranet

Please select your answers only after you have attempted the objectives distributed at the tutorial.

Please select your answer based on the criteria for each question.

"Extranet" means the web-based project management system you use on a daily basis in order to view, analyze, organize, or manage any type of job related data.

* Required

1. Ease of Use*

a. Logging In

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

b. Adding Data

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

c. Finding Data (Filtering)

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

2. Future Feasibility *

a. As a Database Application

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

b. For the use of Graphs & Charts

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

3. Innovative Features *

a. Maps

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

b. Visualizations

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

4. Collaboration *

a. Among Internal Users

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

b. Among External Users

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

5. Security & Privacy *

a. User access control

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

b. File attribution

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

6. Compatibility *

a. Import & Export

❑ Strongly Prefer GFT ❑ Prefer GFT ❑ Neutral ❑ Prefer Company X Extranet

❑ Strongly Prefer Company X Extranet

7. What is the Name or Number of the Project you added to the GFT Database? *

8. Any additional comments?

Appendix C

The following appendix includes the finalized template utilized to record data on the construction site being observed.

	Date:					Day:			Time:				Interval:			
A																
No.	Category	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Direct Work															
2	Prep Work															
3	Material Handling / Searching															
4	Tools & Equipment															
5	Waiting															
6	Personal															
7	Travel															
8	Out of Sight															

Temperature:				Weather:				Site Conditions:					Crew Size:			Location:	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total	%	Remarks
															0		
															0		
															0		
															0		
															0		
															0		
															0		
															0		
															0		

Appendix D

The following appendix includes bar charts for the activity analysis weekly breakdown percentages for both the (7) category and (3) category set.

Figure D.0.1: Bar Chart – Weekly Breakdown Percentages – (7) Category Analysis

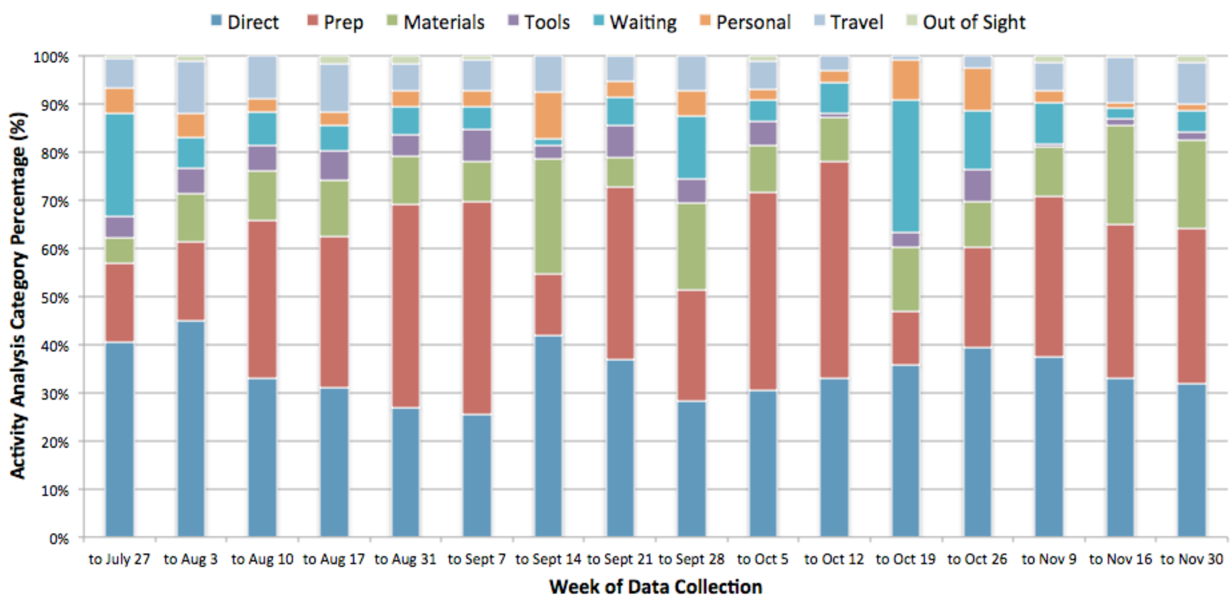
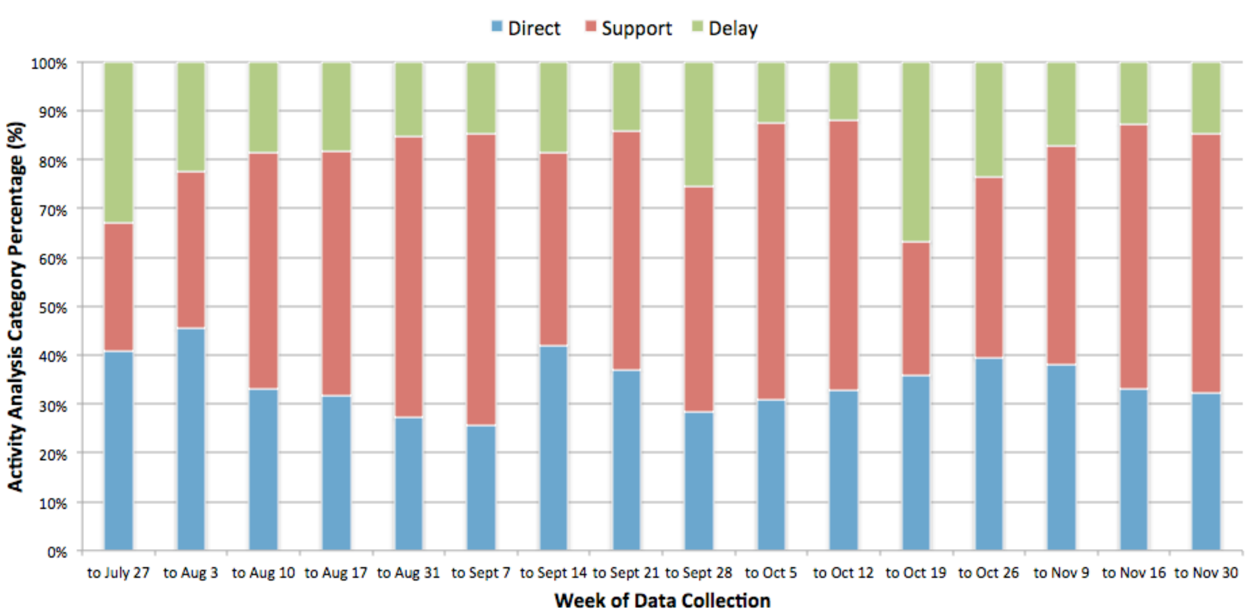


Figure D.0.2: Bar Chart – Weekly Breakdown Percentages – (3) Category Analysis



Appendix E

The following appendix includes correlation coefficients (R) and P-values, for all analysis conducted within the presented research.

	Correlation Coefficient (R)	P-value
	Direct	
Productivity	0.378	0.149
Support	-0.779	0.0003
Prep	-0.703	0.002
Materials	-0.019	0.943
Tools	-0.068	0.801
Waiting	0.196	0.466
Personal	0.523	0.038
Travel	0.013	0.961
Delay	0.383	0.143

	Correlation Coefficient (R)	P-value
	Productivity	
Direct	0.378	0.149
Support	-0.544	0.029
Prep	-0.469	0.067
Materials	-0.236	0.379
Tools	0.396	0.129
Waiting	0.304	0.253
Personal	0.242	0.366
Travel	0.278	0.296
Delay	0.486	0.056
Direct:Support	0.600	0.014

Appendix F

The following appendix includes visualization functions, namely scatter and area charts, which represent several of many more available when using GFT (Google 2014).