COMPARISON OF CONSTRUCTION LABOR PRODUCTIVITY BETWEEN
U.S. AND CHINA: USING ON-SITE PRODUCTIVITY MEASUREMENT METHODS

BY

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Submitted to the graduate degree program in
the Department of Civil, Environmental, and Architectural Engineering
and the Graduate Faculty of the University of Kansas
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy.

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ABSTRACT

One of the main entry barriers faced by U.S. construction firms for entering the booming Chinese construction market is the acquisition of accurate labor productivity data in China. The accuracy of labor productivity data can mean the difference between the success or failure of a construction project. Due to the sheer diversity and complexity of international construction practices, minimal research has been performed on comparative labor productivity between the U.S. and China. In this study, on-site measurement research was conducted in the U.S. and China to assist U.S. construction firms in competing in the Chinese market by comparing the Chinese construction labor productivity with the U.S. labor productivity. The labor productivity data were collected randomly at jobsites located in Kansas, U.S., and in Chongqing, China (Chongqing is the largest and most populated municipality of China's four provincial-level municipalities) by using time studies method. Various statistical analysis methods were applied to analyze and compare the collected productivity data from both countries. Comparative review of productivity data will help enhance U.S. construction firms' competitiveness in the Chinese market and improve project management capabilities in China. In addition, the results of a productivity comparison will provide U.S. construction firms the advancement of knowledge in the Chinese construction industry and support benchmarking and continuous improvement of efficiency and productivity with greater worker safety and satisfaction in the U.S., China, or global construction markets.

ACKNOWLEDGMENTS

I would like to give my best appreciation to my dear parents and fiancée. Especially, I would like to dedicate this dissertation to you who have been my best friends and supporters in my life. I wish you would know how much strength you are adding to me as a person. Your unconditional loves and supports provide me with such a strong foundation that gives me courage to push myself further and deeper. Thank you for believing in me and loving me without any doubts.

I specially would like to thank Dr. Yong Bai for guiding me and supporting me throughout the whole process of finishing this dissertation. I especially appreciate your support that you constantly provided me, and your appreciation of my effort to seek the best way to put what I have learned from my research into words. My special thanks are also extended to my advisory committee members, Dr. Wai Kiong (Oswald) Chong, Dr. Steven D. Schrock, Dr. Thomas E. Mulinazzi, and Dr. Yaozhong Hu, for their invaluable advice and words of encouragement.

I would also like to thank Dr. Guiwen Liu and Prof. Wenhua Hou, who are faculty members of the Chongqing University's Faculty of Construction Management and Real Estate, for their tremendous amount of effort in helping me to organize and schedule site visit to building construction jobsites in Chongqing, China for this research. Last but not least, I would like to express gratitude to several employees of the KU Facilities Operations (William Siebenaler), JE Dunn Construction (Matt Burger & Jim Huckleberry), McCownGordon Construction (Fred Lowe), and other contractors who helped me so much by providing me information and access to each individual building construction sites in the U.S. and China.

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CHAPTER 1: INTRODUCTION

1.1 Background

In 2008, U.S. construction spending totaled $1.5 trillion, with over 6 million employed, contributing 10% to the gross domestic product (GDP) of $14.4 trillion (AGC, 2009). As for China in 2008, direct Chinese construction spending contributed a total of Renminbi (RMB) 1,707 billion Yuan (US$250 billion) or 5.7% to the total GDP of RMB 30,067 billion Yuan (US$4.4 trillion), up 7.1% over the previous year (see Figure 1) (NBS, 2009). The construction industry is an important sector of both countries' economies. Investment in plant and facilities, in the form of construction activity, provides the basis for the production of products and the delivery of services (Chapman and Butry, 2009). It is clear that the construction industry is vital to the continued growth of a country's economy and has impact on nearly every aspect of it. Therefore, construction project performance has always been an important concern of project owners, constructors, management professionals, and design professionals. Project cost and schedule performance have largely depended on the quality of project planning and work area readiness preparation, and the resulting productivity of the work process made possible in project execution (Picard, 2004). Labor productivity has always been one of the greatest risk factors and source of cost and schedule uncertainty to owners and contractors alike.

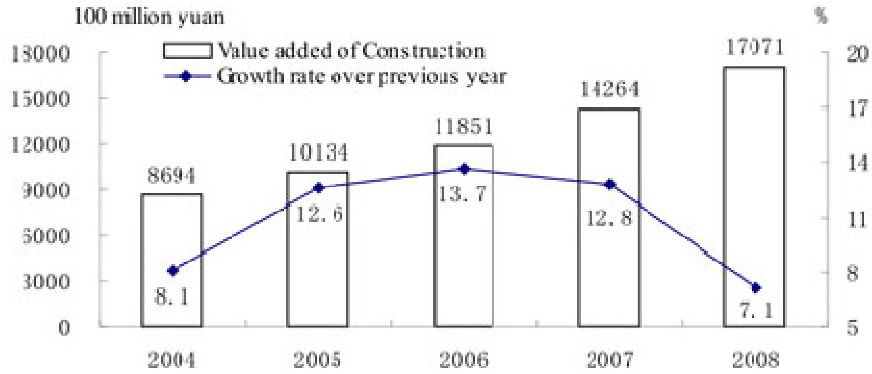


Figure 1. Value-Added of Construction Industry of China and Its Growth from 2004 to 2008 (NBS, 2009)

In both the developed and developing countries, U.S. and China as specific examples, the construction industry is a highly diverse sector. It encompasses all sorts of buildings: residential, commercial, and industrial; all sorts of civil engineering projects: streets and highways, bridges, water and sewer lines, dams and power plants, and so forth; and all sorts of trades in each of the foregoing: carpentry, concrete, electrical, excavation, flooring, framing, masonry, roofing, painting, plumbing and so forth (OECD, 2008). The industry has played a fundamental role in the process of economic development in the U.S. and China. As construction is a labor-intensive industry, small and medium-sized businesses are the mainstay of some segments of the construction sector in a country's economy. Construction is also diverse with respect to matters relevant in competition policy. Competition in the construction sector is usually highly localized, but the competition for the award of some large projects can be national or even transnational in geographic scope. For U.S. construction firms entering the booming Chinese construction market, the entry barriers derive from the possibility of U.S. construction having to acquire the technology, the accumulation of experiences from previous Chinese construction, and the achievements reached by research and development of Chinese constructors. Furthermore, the decision to enter a new foreign market is of critical importance for a firm's profit making and sustainable growth (Chen, 2005).

Minimal work has been done on the labor productivity comparisons between the U.S. and China due to limitations of data and the complexity of international standards. As projects, particularity in the construction industry, result in product heterogeneity, it is impossible to produce homogeneous products of construction works through mass manufacturing (OECD, 2008). Therefore, in large part due to its impact on competitiveness and its influence on the success of a project, construction firms in the U.S. and China need to take a detailed look at the productivity of its workers.

1.2 Problem Statement

In China, the construction industry has played a powerful role in sustaining economic growth, in addition to producing structures that improves industrial productivity and quality of life over the recent years. According to the Engineering News-Record (ENR) Top 225 Global Contractors 2008, there were four Chinese construction firms which were ranked in the top ten and a total of fourteen Chinese construction firms which were ranked in the top one hundred in the world, compared to only nine firms were ranked in the top one hundred in 2000. As for the ENR Top 225 International Contractors, China has become the country with the highest number of contractors being ranked in 2007 with a total of 51 firms, compared to only 34 firms in 2000. The difference between the ranking of the Top 225 Global Contractors and the Top 225 International Contractors is that the global contactors are ranked by its construction contracting revenue both from its home country and abroad, and the international contractors are ranked by the revenue generated only outside its own home country (Huang, 2009). Table 1 shows the number of ranked Chinese construction firms between 2000 and 2007.

Table 1. Number of Chinese Construction Firms Ranking between 2000 and 2007

	The Top 225 Global Contractors					The Top 225 International Contractors				
Year	1-10	11-50	51-100	101-225	1-225	1-10	11-50	51-100	101-225	1-225
2000	0	4	5	8	17	0	2	7	25	34
2001	0	5	6	8	19	0	4	9	27	40
2002	0	5	5	8	18	0	3	12	28	43
2003	0	5	6	8	19	0	5	8	34	47
2004	0	8	5	9	22	0	4	5	40	49
2005	2	5	5	11	23	0	3	9	34	46
2006	4	3	4	14	25	0	2	12	35	49
2007	4	4	6	13	27	0	4	9	38	51

Source: ENR–The Top 225 Global Contractors and the Top 225 International Contractors (2000-2007).

Compared to the construction industry in the U.S., the construction industry in China is far less developed in its legal framework, industrial structure, technological level, and international market share (Xu et al., 2005). For these reasons, a significant U.S. export to China is in construction which includes professional services in architectural, construction, and engineering. Today, many projects in China are constructed by various local firms as well as joint ventures between Chinese and U.S. companies. Given the involvement of the Chinese companies in almost all construction projects, a trade war could dramatically reduce opportunities for U.S. construction firms.

However, at this time, the China's National Housing Reform provides enormous opportunities for U.S. firms. According to the U.S. Embassy in Beijing, China expects to build between 486 million and 549 million square meters of floor space annually in the first 20 years in the 21st century. U.S. firms will surely have a major role to play because Chinese firms are often lacking experience with large-scale projects such as skyscrapers, and many new building technologies, equipment and materials which come from the U.S. In this regard, to satisfy project owners and funding agencies and to fulfill specifications, it is imperative for U.S. firms to obtain the immediate data on construction cost and productivity which need to be readily available for cost estimating, bidding and scheduling purposes.

Meanwhile, the construction activities in China are generally more labor intensive, physically demanding, and time consuming compared to the extensive mechanization of construction in the highly developed U.S. construction industry. It is widely known that labor productivity is extremely difficult to measure due to the heterogeneity of the construction industry’s products and inputs (Koch and Moavenzadeh, 1979; Koehn and Ahmed, 1998). There is also no common definition of labor productivity in the industry. Even when definitions are consistent, approaches to measuring input and output vary so greatly that valid comparisons between projects in the U.S. and China are almost impossible. As a result, the most important element associated with the efficient operation of a project in the U.S. and China remains in labor productivity, which is quantitatively the most abundant but unstudied resource in both countries’ construction industries. Furthermore, there is a need for better measurement approaches that apply more specifically to the work at task level.

This research is based on the labor productivity for building construction in a developing country, China, compared to that of a highly-developed country, the U.S. The comparative labor requirements for the U.S. and China had been investigated and the on-site data for this research were obtained from metropolitan areas – Chongqing, China and Kansas, U.S. Chongqing is the largest and most populated municipality of China’s four provincial-level municipalities. At this time, the civil/construction industry in China, as in many developing countries, is undergoing a transformation and rapidly adopting new technologies. This is particularly the case in the Chongqing region. The results will assist U.S. firms during planning and construction processes to achieve the desired quality, cost effectiveness, and duration of construction projects in the Chinese competitive market. Comparative review of collected productivity data will help enhance the U.S. firms' competitiveness in the Chinese market and improve project management capabilities in China. Furthermore, the results from productivity measurements will provide U.S. firms with the advancement of knowledge in the Chinese construction industry and support benchmarking and continuous improvement of efficiency and productivity with greater worker safety and satisfaction in the U.S., China, or global construction markets.

CHAPTER 2: RESEARCH OBJECTIVES, SCOPE, AND METHODOLOGY

2.1 Research Objectives

In response to the industry needs, the primary goal of this research was to conduct an accurate measurement of on-site construction productivity in the U.S. and China for a comparison of labor productivity at task level. To realize this goal, the following objectives were needed to be accomplished:

1. To address the history, status quo, and trends in the construction productivity in the U.S. and China;
2. To conduct on-site data collection for labor productivity in the U.S. and China;
3. To analyze and compare the effectiveness of the construction productivity from the collected data;
4. To identify the appropriate contents or factors that provide the competitive advantages in the Chinese, U.S., and global construction markets; and
5. To provide a summarization of research and guidelines for future development of on-site construction productivity measurements.

It is widely accepted that productivity measurement plays an important role in the construction management process. Productivity measurement provides the necessary data to analyze factors for project owners, constructors, and management professionals to control construction progress, estimate the cost of future construction projects, and determine its competiveness in the global market. In achieving these objectives, the researcher hoped that it could help the U.S. construction firms stay competitive and profitable in the Chinese and global markets.

2.2 Research Scope

According to Construction Industry Institute (CII), it has been appropriately stated that an accurate measurement of productivity provides construction owners/constructors with a means of controlling their project by (CII, 2009):

1. Determining how effectively their projects are being managed;
2. Determining adverse trends quickly so as to facilitate timely corrective action;
3. Determining the effects of changed methods or conditions;
4. Identifying the reasons for differences in productivity from one project to the next;
5. Providing the means for assessing the effects of productivity improvement programs.

In this study, the researcher reviewed present construction productivity measurement procedures and data analysis techniques and devised a study measuring labor productivity in three work categories (fire protection sprinkler system, heating, ventilation, and air conditioning system, and masonry) of building construction at the task level in the U.S. and China. In addition, this research emphasized the level of activities that U.S. and Chinese construction firms frequently undertake in building construction.

2.3 Research Methodology

The research objectives were achieved by using the following steps: Literature review – A comprehensive literature review was conducted to provide the previous research studies related to the construction productivity and to understand the current U.S. and Chinese construction industry. The review synthesized the findings from previous literature in textbooks, journal papers, research reports, conference proceedings, theses, dissertations, and Internet publications, relationship to productivity measurement in the U.S., overview of the Chinese market, and methods of productivity data analyses. The review enabled the researcher to better understand the current status of the field research and to perform studies in both accuracy and practicability.

Data collection – The researcher conducted on-site construction productivity measurements in the U.S. and China. The data were collected from observation and recompiled to a spreadsheet format that is suitable for statistical data analysis by using computer software, such as Statistical Package for the Social Sciences (SPSS). The secondary research data were also obtained from *RS Means Building Construction Cost Data*, which is a standard industry reference used in construction cost estimation for comparison to the direct work rate data from on-site measurements.

Data analyses and comparison – The data analyses were conducted by using the statistical software package, SPSS 16.0, for determining the productivity rate characteristics, labor control effectiveness, work environment/technology factors, and labor productivity. Various statistical analysis methods, including descriptive statistics, analysis of variance (ANOVA), correlation, and nonparametric tests, were also used for modeling throughout the research. Based on the data analyses' results, it will provide U.S. firms with the advancement of knowledge in the Chinese construction industry and support benchmarking and continuous improvement of efficiency and productivity with greater worker safety and satisfaction in the U.S., China, or global construction markets.

Conclusions and recommendations – Based on the results of the data analyses and comparison, conclusions and recommendations were provided for this research project. The conclusions included the characteristics of the labor productivity, production effectiveness, competitiveness of each country's construction industry, and evaluation for advancement. In addition, corrective actions and future research were recommended for other researchers who are interested in further research on this topic and for U.S. construction firms which are interested in staying competitive and conducting profitable business in China.

2.4 Dissertation Organization

The organization of this dissertation is in the following. Chapter 1 provides an overview of this research and identifies the problems. Chapter 2 presents the research objective, scope, and methodology that were used in this research. Chapter 3 reports the major findings from literature in construction productivity, measuring productivity of construction industry in U.S., overview of construction industry in China, and methods of productivity data analyses. Chapter 4 describes the selected building construction projects in the U.S. and China, presents data collection procedures in different work categories, and defines data analysis that were used in the following chapter. Chapter 5 shows the results from on-site data analyses for U.S. and China. Chapter 6 conducts data comparison between U.S. and China. Chapter 7 concludes the results for this research and provides recommendations for future research.

CHAPTER 3: LITERATURE REVIEW

This chapter presents previous approaches related to the determination of construction productivity which influence the cost and schedule of construction projects in the U.S. and China and the overview of construction industry of China. The chapter begins with a brief description of some research performed in construction productivity. Previous measurement models which have been identified within the construction industry and the applicability of these models to strategic decision are followed along with a discussion of the evaluation and selection of the decision making theories which are used to describe the evaluation process.

3.1 Introduction to Construction Productivity

In spite of some awareness of problems in construction productivity, there have been only limited studies in response to the industry's need. Clearly there is a lack of agreement and understanding concerning this critical issue. Productivity has profound effects on not only the construction industry, but on society at large. And construction labor productivity remains one of the least understood factors in the U.S. economy (Allmon et al., 2000). As a reflection of this, the U.S. Bureau of Labor Statistics (BLS) maintains productivity indices for all significant sectors of the economy except for the construction sector due to a lack of "suitable data" (Haas et al., 1999). Furthermore, it is difficult to define a standard productivity measure because companies use their own internal systems, which are not standardized (Park et al., 2005).

In the U.S. construction industry, productivity is being defined as "to measure the effectiveness with which management skills, workers, materials, equipment, tools and working space are employed at, or in support of, work-face activities to produce a finished building, plant, structure or other fixed facilities at the lowest feasible cost" (Oglesby et al., 1989; Liu and Song, 2005). In the construction productivity field, there is a need for measures of productivity at three levels: (1) *task* – which refers to specific construction activities; (2) *project* – which is the collection of tasks required for the construction of a new facility or renovation of an existing facility; and (3) *industry* – which represents the total portfolio of projects (Chapman and Butry, 2009).

In the construction productivity measurement field, the scope of research studies focuses in three different ways: (1) *the multifactor productivity model* (also known as total factor productivity) – which defines productivity as the ratio between total outputs and total inputs, and is employed in the construction sector to evaluate the efficiency in the use of resources; (2) *the project-specific model* (also known as total productivity) – which defines productivity as the ratio between the outputs expressed in a physical unit and the inputs expressed in dollars, and focuses on the individual project without meeting the requirements of macroeconomic analysis; and (3) *the activity-oriented model* (also known as labor productivity) – which codes the producers, calculating the project cost and monitoring the field activity, and is determined to be the most commonly used definition in the industry (Liu and Song, 2005).

Dozzi and AbouRizk (1993) defined labor productivity as measured at an activity level, and because construction activities are normally labor intensive, productivity at the activity level is frequently referred to as labor productivity, which measures the input as labor hours and the output as installed quantities. As shown in the equation below, labor productivity is the ratio of the quantity of input to the quantity of output (Song and AbouRizk, 2008).

$$\text{Productivity} = \frac{\text{Labor Hours}}{\text{Completed Work (Unit)}} \tag{3.1.1}$$

When it is defined in a detail manner, the labor productivity is measured in actual work hours per installed quantity and the lower productivity values indicate better productivity performance (Park et al., 2005). Productivity also has another definition, including performance factors production rate, and unit person hour rate (Hewage and Ruwanpura, 2006). Generally in construction, productivity is stated as an in-place value divided by inputs, such as work hours (Oglesby et al., 1989). Although most project owners and contractors adhere to the definition of productivity as dollars of output per dollars of input or an increase in sales, this definition is not widely accepted (Adrian, 2004). Therefore, by substituting dollars for person-hours of input, labor productivity is the ratio of physical output per unit of work hour requirements as shown in the equation below (Goodrum and Haas, 2002).

$$\text{Productivity} = \frac{\text{Physical Output(Units)}}{\text{Labor Hours}} \tag{3.1.2}$$

3.2 Measuring Productivity of Construction Industry in the U.S.

Productivity is a way of measuring how much a sector in the construction industry produces given an amount of resources or how much resources are needed when producing a given number/volume of a product. The reason for measuring productivity is to understand the production processes and learn about capacity of machinery and workers (Ingvaldsen et al., 2004). Measuring productivity is to quantify how efficiently resources are used and to provide the performance ability of companies/project owners/contractors in a competitive market. Figure 2 presents the graphic illustration of productivity measures.

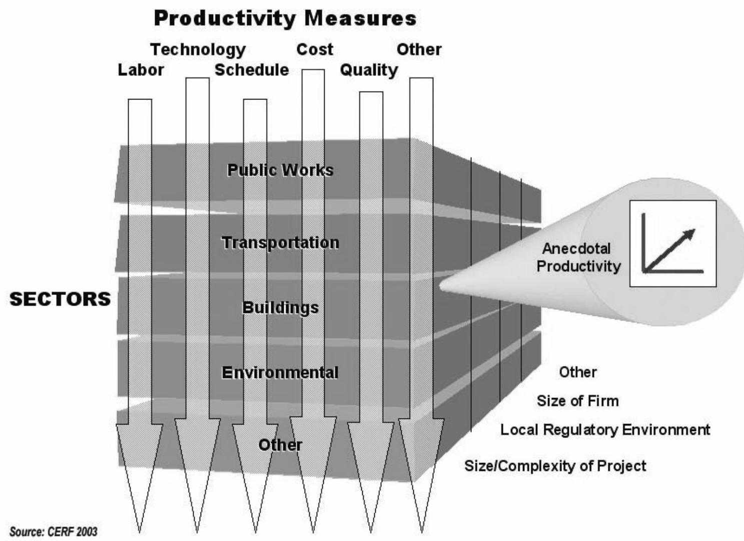


Figure 2. Graphic Illustration of Productivity Measures

Since the 1960s, the studies in the U.S. have focused on the possibilities of bias in the price series used to deflate nominal output in construction productivity measurement (Harrison, 2007). It led to a conclusion by Dacy (1965) that the cost index, which is a weighted average of labor and non-labor inputs, had been used by the U.S. Department of Commerce (DOC) to measure construction prices and had greatly overstated the rise in prices and deflated the construction output. Based on the study by Dacy, Gordon (1968) proposed a new cost index for construction output and prices which deflects had been removed from the deflator used by the U.S. DOC at the time; and he concluded the growth of construction output was underestimated by 34 percent between 1919 and 1948 and by 40 percent between 1948 and 1965. As a result, the U.S. DOC had made some improvement in the measurement of construction output and prices after discovering a substantial portion of productivity improvement in construction had been overlooked (Harrison, 2007).

In 1981, Stokes (1981) tried to explain the divergence between construction and total non-farm private sector productivity with the fact that construction productivity had risen by 2.4 percent annually from 1950 to 1968 but had then fallen by 2.8 percent annually from 1968 to 1978; and in contrast, total non-farm private sector productivity had also risen by 2.4 percent annually from 1950 to 1968 but had then risen by 1.2 percent annually from 1968 to 1978 (see Figure 3).

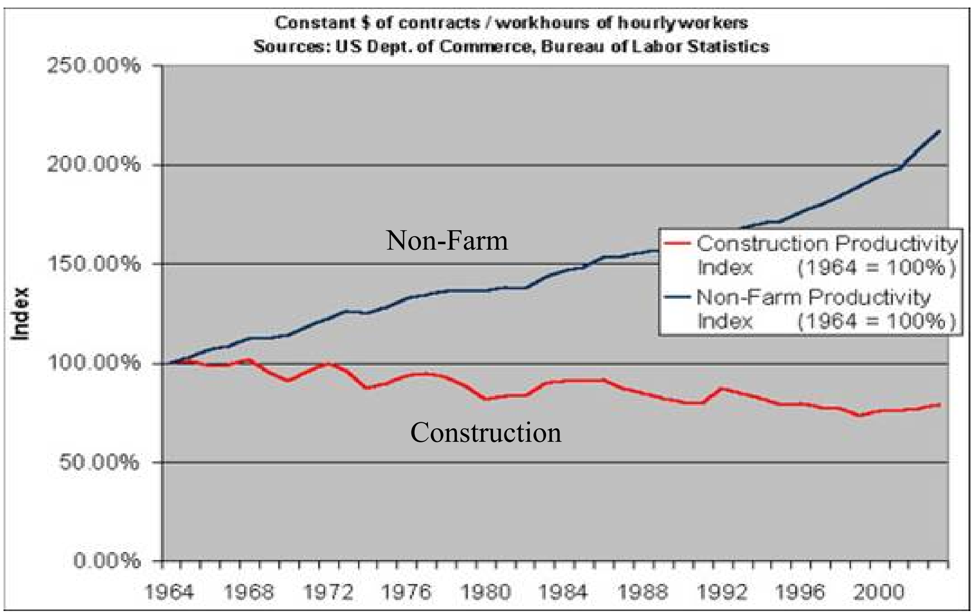


Figure 3. Graph of Productivity Index for Construction Industry and All Non-Farm Manufacturing Industry, including Construction Industry, from1964 to 2003 (Teicholz, 2004)

As shown in Figure 3, the productivity index for the construction industry has been in decline since 1960s. And there were seven factors being used to explain the decline in construction productivity (Harrison, 2007): (1) the measurement of real output; (2) shifts in the composition of construction industry output; (3) changes in capital per worker; (4) demographic changes in the workforce; (5) economies of scale; (6) regional shift; and (7) changes in work rules or practices. But these factors could only support a part of the reasons. In the end, it was concluded that deflation, using input cost indexes, overstated the rise in final prices and the inappropriate use of input cost indexes was an inadequate explanation of the construction productivity decline beginning in 1968 (Stokes, 1981; Harrison, 2007).

Allen (1985) attempted to further examine the sources of the productivity decline in construction between 1968 and 1978; and he determined the productivity should have declined by 8.8 percent during the period, which accounts for 41 percent of the actual decline. The biggest factor for the decline was the reduction in skilled labor intensity resulting from a shift in the mix of output from large scale commercial, industrial, and institutional projects to single-family houses; furthermore, other important factors included declines in the average number of employees per establishment, capital-labor ratio, percent of unionized workers, and the average age of workers (Allen, 1985). While the results emphasizing real factors, not mismeasurement, were encouraging, a considerable part of the productivity decline remained unexplained and the possibility of nominal output being over-deflated was accounted for the remaining part of the decline (Harrison, 2007). Allen (1985) claimed that the difference between the cost index deflator of the Bureau of Economic Analysis (BEA) and his proposed alternative deflator accounted for an additional 51 percent of the reported productivity decline in construction productivity observed in the statistics produced by the U.S. BLS, which explaining 92 percent of the productivity decline between 1968 and 1978.

However, Pieper (1989) challenged Allen's (1985) explanation of the construction productivity decline between 1968 and 1978; and Pieper argued that the real factors could not be accounted for the construction productivity decline and that his proposed alternative deflator and his argument on the BEA cost index deflator relying on only cost-indexes were misleading (Harrison, 2007). Furthermore, Pieper (1989) argued that the alternative deflator being proposed by adjusting the BEA deflator was based on assumptions with no supporting evidence; and he concluded that the construction productivity decline could not be explained with the mismeasurement hypothesis awaiting for hard evidence. In response to Pieper's (1989) criticism, Allen (1989) partially responded that the BEA deflator was not mainly a cost index and acknowledged that the deflators were used to deflate the output of other segments of the construction sector besides single family houses and highways, which together accounted for only one-third of construction sector output (Harrison, 2007). In conclusion, there were some errors in Allen's original calculations due to both real factors and mismeasurement and his research could only explain 56 percent of the decline in construction productivity, not 92 percent as originally claimed (Allen, 1989; Harrison, 2007).

After the controversy between Allen and Pieper over the causes of the construction productivity decline, U.S. government agencies and research professionals had abetted inactivity in research on construction productivity. This lack of information about productivity since 2000 has led to the frustration with the unwillingness and inability of the U.S. BLS to produce construction sector productivity statistics; and in response, the U.S. construction industry began to pursue its own initiatives to measure productivity with an alternative procedure (Harrison, 2007). The procedure is known as activity-oriented model or labor productivity, and it is measured at the activity level to determine construction productivity. However, Harrison (2007) concluded the most obvious disadvantages to this approach, in comparison with a more traditional aggregate approach, are that it requires all tasks to be summed up with the possibility for many tasks being omitted; and in addition, it requires large amounts of high quality data for a good completion and it may prohibit this approach to be implemented on a large scale project with such requirements.

In 2000, Allmon et al. (2000) presented a study on activity-level analysis in the U.S. construction industry and the research data were obtained from *RS Means Building Construction Cost Data*, which is a standard industry reference used in construction cost estimation for comparison to the direct work rate data, which are from 72 projects in Austin, Texas over a 25-year period from 1970s to 1990s. The scope was to select a wide range of specific tasks that represent different trades and differing levels of technological intensities for tracing the benchmark values for these tasks based on the labor cost and output productivity trends. Allmon et al. (2000) described the factors being considered in the study: "The direct work rate is a percentage of time on such productive actions as erecting formwork, tying reinforcing steel, and placing concrete. Other work activities, such as transporting materials and tools or getting instructions, are considered support time. Finally, when the work force may be waiting or taking a break, this considered idle time." The researchers concluded that the combined data indicated the construction productivity had increased in the 1980s and 1990s due to the depressed real wages and technological advances; and the data also indicated that management practices were not a leading contributor to construction productivity changes over time. And in most cases, increasing the direct work rate increases construction productivity (Allmon et al., 2000).

More studies related to the measurement in the activity-level construction productivity conducted in 2002. Goodrum et al. (2002) studied the divergence in aggregate and activity estimates of U.S. construction productivity, which described the methodology of activity-level analysis and revealed the three principal advantages over the traditional aggregate analysis in the estimation of productivity (Harrison, 2007). First, the problems of output measurement associated with aggregate data are avoided with the changes in physical output of construction which do not rely on construction price indices to measure real output for either labor or multifactor productivity. For example, the cubic meters of concrete placed. Second, for the measure of activity-level labor productivity, input is measured by the number of labor hours which gives further independence in the use of cost-index deflators. Third, input and output are easier to compare over time at the activity level. For example, when the activity involves the installation of aluminum strip siding, 6-inch aluminum trays, or 2-ply reinforced curing paper, the characteristics of the final output tend to remain the same (Goodrum et al., 2002). For this research study, the data were collected from *RS Means Building Construction Cost Data*, *Richardson's Process Plant Construction Estimating Standards*, and the *Dodge Cost Guides* (DCG), which are often used by construction industry professionals for project cost estimation, for years between 1976 and 1998 on 200 construction activities that had undergone a diverse range of technical changes (Goodrum et al., 2002). Goodrum et al. (2002) recognized that there is a weakness in using just two points in time for measuring the change in productivity and it is expected that fluctuations in the change in productivity would occur in a year-by-year analysis. However, Goodrum et al. (2002) explained that the research was designed to focus on the long term trends in construction productivity by examining the changes in productivity from 1976 to 1988. As a result, the study estimated that productivity had on the average improved, with 107 activities having improved, 63 activities remaining unchanged, and 30 activities being declined. As for multifactor productivity, it had also been estimated with a similar pattern (Goodrum et al., 2002; Harrison, 2007). Goodrum and Haas (2002) further investigated the relative impact of different types of equipment technology to support their proposition that the industry was experiencing a steady increase in construction productivity at the activity level. The relationship between changes in equipment technology and partial factor productivity was examined through an analysis of variance (ANOVA) and regression analyses. It is found that activities that experienced a significant change in equipment technology also witnessed substantially greater long-term improvements in partial factor productivity than those that did not experience a change (Goodrum and Haas, 2002).

The latest research in the U.S. on productivity in the construction industry focused on establishing a common set of productivity metrics and definition for companies/project owners/contractors to track productivity (Park et al., 2005; Harrison, 2007). Like other papers published in the U.S. since 2000, one important distinction from measuring productivity is between partial factor productivity and multifactor productivity. Partial factor productivity is the relationship between output and one input (labor or capital); and multifactor productivity relates output with all of the inputs that can be measured (Harrison, 2007).

Song and AbouRizk (2008) suggested the following selection criteria to be established to determine the appropriate productivity measurement method:

1. The output measurement needs to have high correlation with the labor hours and needs to be quantifiable.
2. The output measurement needs to be independent from factors that have influence on the productivity, such as site conditions and labor skills.
3. The output measurement needs to be easy to track and cost effective to implement.

There are a number of labor productivity measurement methods being presented in the following sections. These techniques involve the continuous observation or the intermittent observation of a worker or a work crew involved in a task. A review of the advantages and disadvantages of the technique are summarized in each section.

3.2.1 Time Studies (Stopwatch) Method

A time study, also called a stopwatch study, is defined as the process of determining the time required by a skilled, well-trained operator working at a normal pace doing a specific task; and the purpose of time studies is to set time standards in the production area and to record the incremental times of the various steps or tasks that make up an operation (Oglesby et al., 1989; Meyers, 1992). Time studies were the fundamental approaches to productivity improvement developed by Frederick W. Taylor in 1880 and it had a tremendous impact on U.S. housing construction practices.

Time studies require a minimum of equipment, including a stopwatch and an interval timer or link timers, and are a fast way to record a specified sequence of events involving at the most only a few workers or machines (Oglesby et al., 1989). There are several types of stopwatches being used: (1) snapback; (2) continuous; (3) three watch; (4) digital; (5) time-measured unit (TMU); and (6) computer (Meyers, 1992).

There are two observation studies using stopwatches to obtain the standard times of activities for labor productivity measurement: direct observation and work study. In the direct observation method, the period of observation is continuous throughout the workday by a trained observer to record to the nearest minute the time that the workers spend on direct work, indirect work, and ineffective work. In the work study method, the period of observation is unlike the continuous observation method, which does not span the full length of the workday. Work study is suited to operations that have a definable cyclic period and the length of these periods of observation corresponds to the work cycle of the operation monitored; furthermore, the results of the work study measurement can be used to determine the most appropriate working method and possible alternative working methods (Noor, 1998).

However, there are limitations to time studies. Oglesby et al. (1989) stated the several constraints in stopwatch studies and the heavy demands for observer's time which limits their usefulness in the following:

1. With no chances for hindsight, the observer must decide the point in time at which one cycle stops and another begins. Also, to eliminate deficiency and differences of opinion in interpretation about cycles, the same evaluation to a series of studies should be made by a single observer or several trained observers.
2. It is inherently difficult for a single observer to cover activities accurately when it involves a substantial period of observation over different cycles. A maximum of five workers in a crew per observer is recommended by Geary (1962). If more than one crew or more than one trade is to be monitored, then the observation can only be accomplished with more observers or another method of recording.
3. A stopwatch study must be based on the information gathered by the observers plus detailed notes which precisely recorded each activity and site condition. Only if the report included such information, it could be used in evaluating any situations. However, the presence of an observer a detailed study of his/her or their activities is a recipe for labor discontent.
4. The physical limitations or biases of the observer for recording a large amount of data in a short time can affect his/her objectivity and with them will come a tendency to alter the data. To avoid this natural tendency, the observer must strictly follow the rule with no reevaluation, hindsight, or second thoughts once the observation has been made.

5. Stopwatch studies require an observer for almost every person or machine being observed which can be prohibitively expensive. Therefore, it is seldom employed today on U.S. construction sites. However, stopwatch studies of limited scope can still be an extremely useful tool when one or perhaps a few elements or components are to be observed. The technique is inherently simple and requires only a small outlay for equipment to gather data for productivity improvement.

3.2.2 Work Sampling Method

Work sampling is the process of making periodic observations of workers. One of the pioneers of work sampling was Tippett (1935) who used a virtual snapshot in cotton mills to record the activities of each of the workers under study at the time of the observation (Noor, 1998). In essence, work sampling can be used to establish crew sizes or to determine the effectiveness of a specific crew size at the workplace (Adrian, 2004).

Work sampling is a statistical technique that can be used for analyzing the construction work process and the application has proven effective on hundreds of construction projects, achieving labor cost savings of 20 to 30 percent (Picard, 2004). It is also used to determine the proportion of direct work from indirect work, and ineffective work; analyze factors that cause indirect and ineffective work; and identify opportunities to reduce indirect and ineffective work. Direct work can be defined as productive actions, picking up tools at the area and measurement on the area where the work is taking place, holding materials in place, inspecting for proper fit, putting on safety equipment, and all cleanup; indirect work can be defined as supervision, planning or instruction, all travel, carrying or handling materials or tools, and walking empty-handed to get materials or tools; and ineffective work can be defined as waiting for another trade to finish work, standing, sitting or any non-action, personal time, and late starts or early quits (Allmon et al., 2000).

In order to avoid systematic errors in observations, there are three statistical concepts being used: (1) confidence limit, (2) limit of error, and (3) category proportion (Adrian, 2004). Confidence limit is a measure of the dependability of the inferences. If the confidence limit is 95 percent, it means that the inference can be relied on 95 percent of the time. The limit of error is a measure of the accuracy of the inferences. If the limit of error is five percent and the observed nonproductive percentage is 20 percent (obtained by work sampling), the range of nonproductive will be somewhere between 15 and 25 percent of the time. The category proportion is the characteristic portion of the work sampling being measured (productive vs. nonproductive), which determines the size of sample (number of observations) needed to meet the confidence limit and limit of error (Adrian, 2004).

As the number of observations, N, increases, the more accurately will work sampling results approximate actual conditions and the sampling error will diminish (Picard, 2004). In planning of work sampling, the absolute number of observations required can be computed with this equation (Thomas and Daily, 1983):

$$N = \frac{Z^2 P(1-P)}{S_a^2} \tag{3.2.1}$$

in which N is the total number of work sampling observations; P is the observed percentage (obtained by work sampling); S is the limit of error; and Z is the number of standard deviations σ (for the 95 percent confidence level, the value of Z=1.96 as shown in Table 2 and Figure 4). The N value can also be obtained from the confidence limit table shown in Table 3.

Table 2. Table of Confidence Level Z (Meyers, 1992)

Confidence Level (%)	Z
99.5	3.25
99	2.575
95	1.96
90	1.645
80	1.245
75	1.151

Table 3. Number of Observations Based on Confidence Limit (Adrian 2004)

Sample sizes required for 95% confidence limits						Sample sizes required for 90% confidence limits					
Category Proportion (%)	Limits of error					Category Proportion (%)	Limits of error				
	1	3	5	7	10		1	3	5	7	10
50, 50	9600	1067	384	196	96	50, 50	6763	751	270	138	68
40, 60	9216	1024	369	188	92	40, 60	6492	721	260	132	65
30, 70	8064	896	323	165	81	30, 70	5681	631	227	116	57
20, 80	6144	683	246	125	61	20, 80	4328	481	173	88	43
10, 90	3456	384	138	71	35	10, 90	2435	271	97	50	24
1, 99	380	42	15	8	4	1, 99	268	30	11	5	3

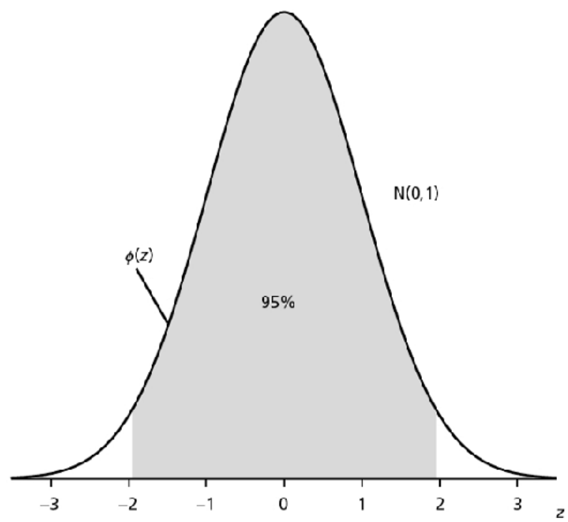


Figure 4. Standard Normal Cumulative Distribution

In addition, there are modified forms of the work sampling method which are known as the group timing technique (GTT) and the five-minute rating technique (Noor, 1998). GTT is suitable for operations that are repetitive and have a short cycle time. The observations with an interval length of about 30 seconds to three minutes can be repeated at different periods of each work day to evaluate the performance of each crew member (Thomas and Daily, 1983; Noor, 1998). As for the five-minute rating method, the observation with an interval length between 30 seconds to several minutes (depending on the size of the crew) should be used to monitor each crew member with a minimum of five minutes or a duration in minutes equal to the size of the crew, whichever is greater (Thomas and Daily, 1983; Noor, 1998). This technique, which can be applied to all operations, is recommended to be applied between four to eight times a day and can be used to evaluate the effectiveness of a work crew without depending on whether the operations are cyclic or not (Sprinkle, 1972; Noor, 1998). Noor (1998) also stated that the GTT and five-minute rating technique record the activity of each crew member at the instant of the observation and are far less time-consuming than the traditional work sampling method. Overall, Picard (2004) concluded the main advantages of the work sampling method are as follows:

1. Random observations are made of overall project work activity of groups of workers, collectively observed at randomly selected areas and times, not of specific individual workers.
2. Sampling causes less anxiety and tension among workers than continuous observation (such as with a stop watch).
3. There is no, or minimal, interference with the worker's normal activities.
4. Observers with minimal specialized training can conduct random work sampling.
5. The number of observations can be adjusted to meet desired levels of accuracy.
6. Work sampling is an effective means of collecting useful facts during project execution that are not normally collected by other methods.
7. Work sampling is less expensive than continuous observation techniques.

3.2.3 Delay Survey Methods

Since the late 1970s, more attention has been given to the use of delay surveys. The most popular form of delay surveys are known as the "worker delay survey/craftsmen's questionnaire surveys" and "foreman delay survey", which have been carried out on a regular basis for identifying the sources of problems from the views of workers and monitoring the performance of workers (Noor, 1998).

The foreman delay survey is completed by the foremen or first line supervisors on the project. Each foreman estimates the total amount of time lost by each crew during each day because of specifically noted sources. When multiplied by the number of workers in a crew, the magnitude of the problem will be determined for appropriate response by the management. As for the worker delay survey, it generates essentially the same information as is generated by the foreman delay survey, but is completed by each of the workers. This is the least popular of the two survey forms due to the high cost involved to maintain confidentiality and anonymity for the workers who are disturbed from their work to complete the forms in privacy (Noor, 1998).

However, a note of caution should be offered concerning the delay surveys. It is human nature to blame others for the problems. Look for consistency of reporting between foremen or workers. Outliers may have to be excluded from consideration due to the subjectivity of the survey responses.

3.2.4 Audio-Visual Methods

For many years, the audio-visual methods like time-lapse film with 1- to 5-second intervals and time-lapse video with various time intervals have been used to record construction field operation for productivity analysis, improvement of construction operations, training of workers, and for evident in construction claims and contract disputes (Everett et al., 1998; Noor, 1998). It is a recording technique that can be used effectively to document a lengthy building construction process by using special cameras/video camcorders and the recording can be viewed in a much shorter period of time with the appearance of actions being rather fast and jerky. This technique can also provide a permanent record of the activities on pictures or film which can be reviewed at any stages of construction process to recognize problems, such as flow of workers and materials, equipment utilization and balance, and safety and working conditions (Christian and Hachey, 1995; Noor, 1998).

As described above from an owner's point of view, Everett et al. (1998) further discussed the usage of time-lapse film and video that has the equivalent value to the contractors, designers, and even the craft workers for faulty claims and legitimate contractor claims against the owner. Overall, its benefits accrue to all parties and possibly prevent problems from occurring. The technique has been proven to resolve claims and disputes and has been used for education, public relations, fund raising, media applications, and construction project management.

However, there are some difficulties with the applications of this technique. First, it has high initial costs and requires technical competence for picture quality – as there is a possibility of a loss of data due to equipment failure, technical incompetence, weak illumination, and human error (Noor, 1998). Second, the use of a camera/video camcorder is restrictive in the coverage area – as the movement in the entire construction process being captured in time-lapse film. It is impractical to use the data to recognize the performance of individual craft workers or a piece of equipment (Kim, 2008). Finally, some construction sites may not have access to the Internet for transmissions of high-resolution, full motion live pictures to distant office locations because the intent is to send up-to-date data to the project owner, project manager, architect, and engineer for properly visualizing the actual status of the project (Everett et al., 1998).

To overcome the limitations of existing on-site audio-visual methods, there is one of the latest developed systems called the Wireless Real-time Productivity Measurement (WRITE) System available (Kim et al., 2009). The major components of the system include a digital camera, a video camera, a data processor, and AC transformer, a computer, and wireless modems. The statistical analysis results proved that the developed system generated identical productivity measurements compared to the results from the stopwatch method. The system has several unique features: (1) there is no disruption to the construction operations; (2) the on-site construction productivity can be determined in real-time; and (3) the collected data can be shared by all parties via the Internet at any time (Kim et al., 2009). These advantages can help enhance the capability of the project owner, project manager, architect, or engineer to manage the project.

3.2.5 Secondary Data

The secondary data for the productivity data analyses were collected by using historical data and references from *RS Means Building Construction Cost Data*. These manuals provide unit labor costs, unit equipment costs, and physical output data based on the most used, quoted, and respected unit price guide available to the construction industry for the purpose of cost estimating, budgeting, and scheduling. While the manuals are a valuable source on productivity for contractors and project managers, there are some weaknesses in the time-series data. For instance, Goodrum and Haas (2002) argued that the figures in the manuals are from the lead constructors, who are not required to construct a project using their estimations and offer inflated estimates of construction costs and have limitations in accuracy. Despite these weaknesses, there is still precedence among project owners, architects, engineers, and constructors to use these manuals as a source for cost estimation and expected levels of productivity.

3.3 The Overview of Construction Industry in China

3.3.1 Market Overview

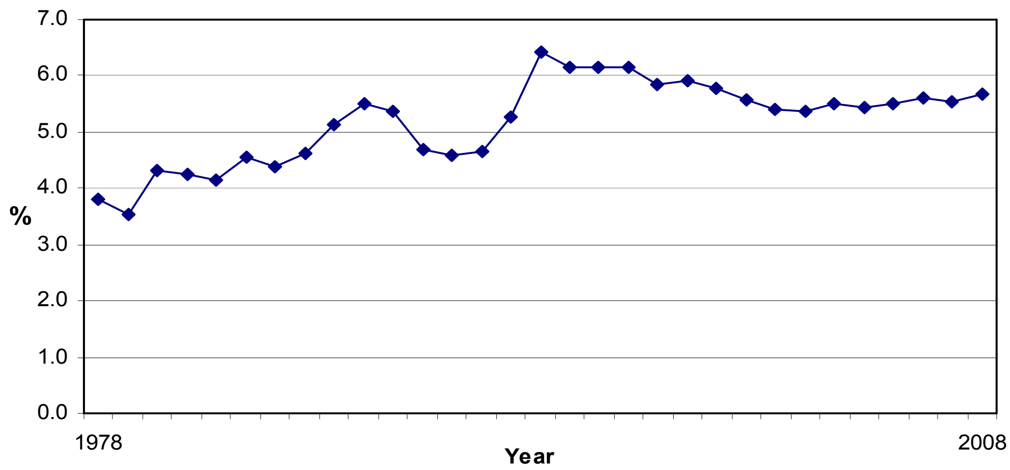
Before the early 1980s, the construction industry in China was characterized by a high level of government control and was utilized as a vehicle to support the centrally planned economy (Bajaj and Zhang, 2003). Also, it was not recognized officially as a separate economic sector contributing to GDP in China (Lu and Fox, 2001). It was not until the Open Door Policy at the beginning of 1980, then a rapid and dramatic change in the Chinese construction industry started to take place. The Open Door Policy enabled China to gradually move away from a sluggish centrally controlled economy to a new dynamic, market oriented mechanism (Bajaj and Zhang, 2003). As a result, over the past three decades, since China opened its market to the world, the Chinese construction industry has grown dramatically (Xu et al., 2005). In other words, the strong economic growth after the Open Door Policy has lead to the rapid development of urban infrastructure and housing construction in China, stimulating enormous construction activities (Guan et al., 2001), and rendering the construction market in China one of the most attractive in the world (Bond and Crosthwaite, 2001).

At present, the Chinese construction industry has contributed significantly to the country's economy. The proportion of the construction industry in China's GDP was 4.30% in 1980, continuously increasing to 5.7% in 2008 (NBS, 2009). Statistics show that the percentage contribution of the Chinese construction industry to China's GDP has been growing at an average annual rate of nearly 9.88% since 1979 (see Table 4, Figures 5 and 6). However, the share of the Chinese construction industry in GDP is still low compared to the developed countries, which implies a strong potential for further growth of the construction industry.

Table 4. Composition of China's Gross Domestic Product (1978-2008)

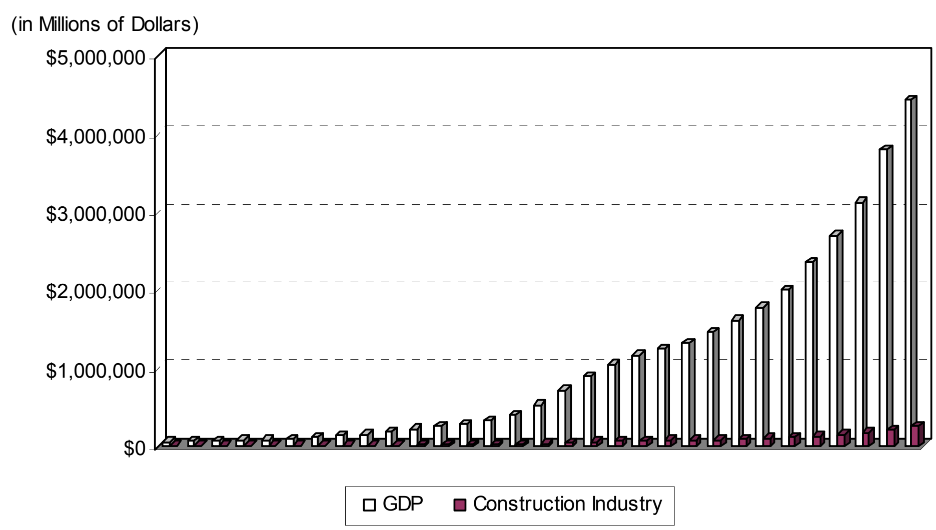
Year	Gross Domestic Product (%)	Primary Industry	Secondary Industry	Industry	Construction	Tertiary Industry
1978	100	28.2	47.9	44.1	3.8	23.9
1979	100	31.3	47.1	43.6	3.5	21.6
1980	100	30.2	48.2	43.9	4.3	21.6
1981	100	31.9	46.1	41.9	4.2	22.0
1982	100	33.4	44.8	40.6	4.1	21.8
1983	100	33.2	44.4	39.9	4.5	22.4
1984	100	32.1	43.1	38.7	4.4	24.8
1985	100	28.4	42.9	38.3	4.6	28.7
1986	100	27.2	43.7	38.6	5.1	29.1
1987	100	26.8	43.6	38.0	5.5	29.6
1988	100	25.7	43.8	38.4	5.4	30.5
1989	100	25.1	42.8	38.2	4.7	32.1
1990	100	27.1	41.3	36.7	4.6	31.6
1991	100	24.5	41.8	37.1	4.7	33.7
1992	100	21.8	43.4	38.2	5.3	34.8
1993	100	19.7	46.6	40.2	6.4	33.7
1994	100	19.8	46.6	40.4	6.2	33.6
1995	100	19.9	47.2	41.0	6.1	32.9
1996	100	19.7	47.5	41.4	6.2	32.8
1997	100	18.3	47.5	41.7	5.9	34.2
1998	100	17.6	46.2	40.3	5.9	36.2
1999	100	16.5	45.8	40.0	5.8	37.7
2000	100	15.1	45.9	40.4	5.6	39.0
2001	100	14.4	45.1	39.7	5.4	40.5
2002	100	13.7	44.8	39.4	5.4	41.5
2003	100	12.8	46.0	40.5	5.5	41.2
2004	100	13.4	46.2	40.8	5.4	40.4
2005	100	12.2	47.7	42.2	5.5	40.1
2006	100	11.3	48.7	43.1	5.6	40.0
2007	100	11.1	48.5	43.0	5.5	40.4
2008	100	11.3	48.6	42.9	5.7	40.1

Source: China Statistical Yearbook 2009.



Note: Data adopted from China Statistical Yearbook 2009.

Figure 5. Construction Industry as a Proportion of China's GDP 1978-2008



Note: Data adopted from China Statistical Yearbook 2009.

Figure 6. The Chinese Construction Gross Output to China's GDP 1978-2008

According to Bajaj and Zhang (2003), China's construction industry is very big by world standards. It is huge and widespread. In 2008, it employed 3.15 million people and had a total of 71,095 of enterprises (NBS, 2009). Furthermore, the gross output value of construction has grown from US $752,747 millions in 2007 to US $914,864 millions in 2008 with a growth rate of 21.5% (NBS, 2009). According to the World Factbook 2008, the Chinese construction industry's annual output (US $4.2 trillion) has surpassed Germany (US $3.8 trillion) and is ranked among the world top two on a purchasing power parity basis after the U.S.

In China, the construction industry has become the main engine of the economic growth over decades of development (Fung et al., 2006; Hinton and Tao, 2006; Li et al., 2009). With the booming market of recent years, the successful bid to host the 2008 Olympic Games in Beijing, and entry into the World Trade Organization (WTO) on December 11, 2001, China has sped up a series of gradual reforms of legal and regulatory systems in the construction industry which offers a profitable investment opportunity for both local and foreign firms (Fung et al., 2006). The Beijing Capital International Airport Terminal 3 (the second largest airport passenger terminal building of the world), the Beijing National Stadium (the Bird's Nest), the Beijing National Aquatics Center (the Water Cube), and the Shanghai World Financial (the third tallest building in the world) are some of the landmark buildings, with foreign firms involved in their construction (Huang, 2009). With this in mind, fierce competition in the Chinese construction market requires firms to improve competitiveness and to determine how organizations can become innovative and stronger from their current competitive positions (Li et al., 2009).

3.3.2 The World Trade Organization (WTO) Commitment

China formally became a member of the WTO on December 11, 2001. Prior to China's entry into the WTO, foreign contractors were only allowed to tender for the World Bank, the Asian Development Bank, and other multilateral or donor-funded projects (Xu et al., 2005). Regulations that allow foreign contractors and foreign design firms to register as wholly foreign owned "construction enterprises" and "construction engineering design enterprises," respectively, were both effected on December 1, 2002 (MOC, 2002a, b). The scope of services is limited in foreign funded projects and those domestic funded projects that require special technologies because the Chinese construction market and construction enterprises are largely under the protection and control of the government.

However, during the negotiation between China and other WTO member countries regarding China's entry into the WTO, China was required to open its construction market to foreign companies such as those in Japan and the U.S. (Lam and Chen, 2004; Xu et al., 2005; Zeng et al., 2005). Furthermore, in the WTO entry negotiations concerning the construction industry, China presented itself as a developing country, persisted in the basic principles of mutual benefits and a win-win strategy, and promised to implement the commitments. China became a WTO member country as it aimed to achieve the maximum protection in the development of China's construction industry. As a result, China's construction industry has opened its doors to the outside world in a progressive and limited way as listed below (Chui, 2006):

1. Commitments to prospect, design and consulting services
    A. Limitation in market access.

(1) Unbound for cross-border deliveries of plan designs, other types of cross-border deliveries are required in cooperation with Chinese design institutes.

(2) Only wholly foreign-owned enterprises are permitted after the first five years of China's accession to the WTO. Joint ventures (JV) with a foreign majority ownership are no longer permitted.

B. Limitation on national treatment.

(1) Foreign service providers must be certified architects, engineers or enterprises engaging in construction, design, engineering and urban planning in their resident countries.

2. Commitments to construction

A. Limitation in market access. Wholly foreign-owned enterprises are permitted after the first three years of China's accession to the WTO. But wholly foreign-owned enterprises can only undertake the following four types of construction projects:

(1) Construction projects wholly financed by foreign investments and/or grants.

(2) Construction projects financed by loans from international financial institution awarded through international tendering according to the terms of the loans.

(3) Chinese-foreign jointly constructed projects with a foreign investment equal to or more than 50 percent; or on Chinese-foreign jointly constructed projects with a foreign investment less than 50 percent but technically difficult to be implemented by Chinese construction enterprises alone.

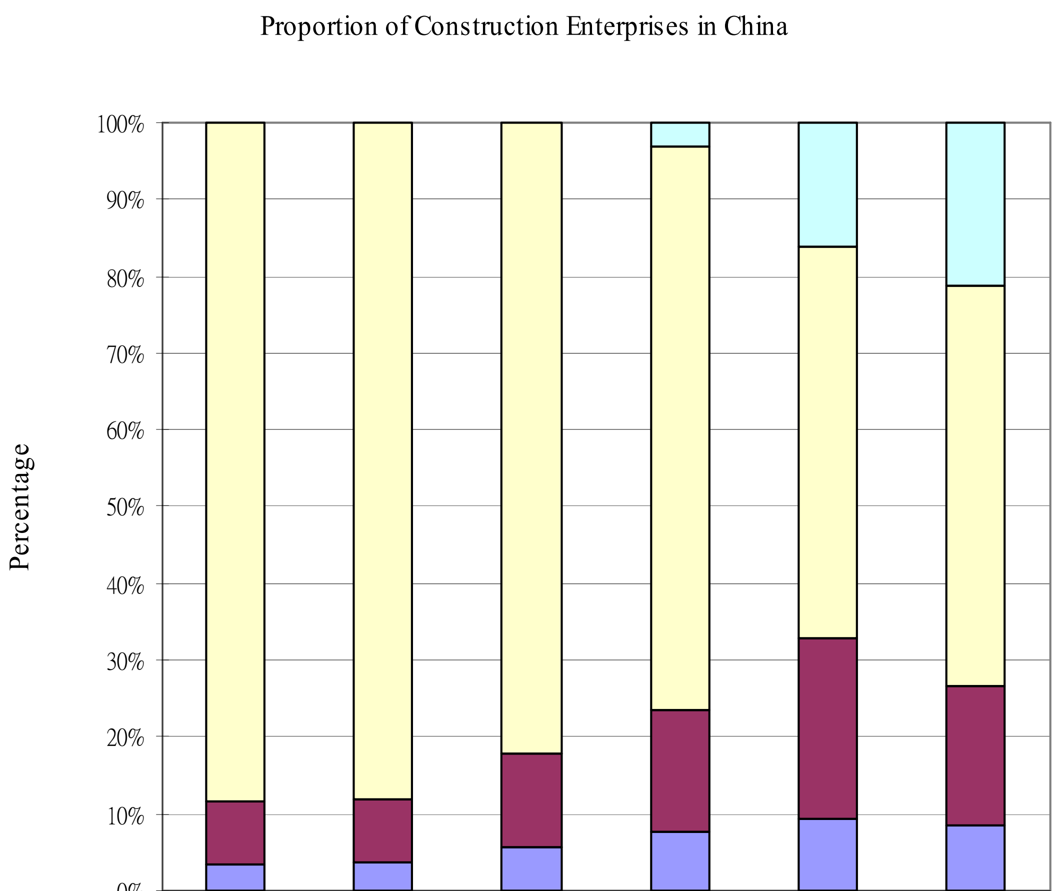
(4) Chinese-invested construction projects difficult to implement by Chinese construction enterprises alone can be jointly undertaken by Chinese and foreign construction enterprises with approval from the provincial government.

3. Commitments to national treatment. There is little difference in requirements in registered capital between the present Sino-foreign JV enterprises and Chinese enterprises. The limitations had been abolished within first three years of China's entry into the WTO.
4. Commitments to related countries. Apart from the above two-part commitments, commitments made in bilateral talks upon joining the WTO with Japan are also adaptable to all WTO member countries.
   A. According to the principle of national treatment, China needs to do its best to lower the standard minimum amount of registered capital for wholly foreign-owned construction enterprises and Sino-foreign JV and cooperation construction enterprise.
   B. In the regulations, China needs to put the contracting performance of the parent companies into consideration when fixing the new qualification level for wholly foreign-owned construction enterprises.
   C. China will retain the present regulations that stipulate foreign construction enterprises can contract construction work without establishing a business presence in China until the new regulations allowing wholly foreign-owned construction enterprises in China come into effect.
   D. China will publicize a notice before the deadline for the present regulations. Even if the regulations are abolished, construction contracts approved beforehand will be implemented.

3.3.3 Changes of Ownership of Construction Enterprises

There are three major types of construction enterprises in China: state-owned enterprises (SOE), urban collective-owned enterprises (UCO), and rural construction teams (RCT) (Chen, 1998; Low and Jiang, 2003; Tam et al., 2004; Cheah and Chew, 2005; Zeng et al., 2005). The SOEs are under the direct management and financial control of the central government, while the UCOs are owned by a clan of people (in reality they are owned by states) (Chen, 1997).

According to Chui and Bai (2007), all large construction firms in China were SOEs under the traditional planned economy system. However, since the adoption of the reform and opening policies in 1978 and as a result of China's accession to the WTO in 2001, China's economy has gradually been transformed from a centrally-planned to a market-oriented setting (Tam et al., 2004; Cheah and Chew, 2005; Zeng et al., 2005). Furthermore, the opening up of China's market invites more liberal participation by foreign contractors and consultants who were previously limited to undertake only World Bank and Asian Development Bank projects, foreign direct investment projects, specialized technology projects, and "authorized" form of joint ventures (Lam and Chen, 2004; Cheah and Chew, 2005). Consequently, the Chinese construction industry has undergone a rapid change, and the dynamic of its ownership also has changed simultaneously. In fact, for construction, the issuance of Decree 113 and 114 essentially hastened this process two year earlier than it was legally required under the WTO Accession Treaty (Ren and Khong, 2004). The growing presence of foreign enterprises rightfully adds to a fourth category of the construction enterprises in China. Coupled with the government's drive for integration in the global economy, international alliances and joint ventures are gradually being forged between Chinese and foreign contractors to undertake both domestic and international construction projects (Luo, 2001; Shen et al., 2001; Xu and Chew, 2004; Xu et al., 2004). For example, as shown in Figure 7, as at 1980, the proportion of others (including public-listed sharing-holding, foreign-funded enterprises) was 0%, with that of SOE at 3.48%, UCO at 8.04%, and RCT at 88.50% while as at 2001, the proportion of others has reached 21.12%, with that of SOE at 8.57%, UCO at 17.93%, and RCT at 52.38%. This example represents a great change in the form of ownership of construction enterprises in China.



Year	1980	1985	1990	1995	2000	2001
Others	0%	0%	0%	3.14%	16.02%	21.12%
RCT	88.50%	88.11%	82.02%	73.26%	51.15%	52.38%
UCO	8.04%	8.28%	12.21%	15.83%	23.55%	17.93%
SOE	3.48%	3.61%	5.77%	7.77%	9.28%	8.57%

Source: China Statistical Yearbook 2005.

Figure 7. Changes of Ownership of Construction Enterprises (Chui and Bai, 2009)

3.3.4 Industry Development Research

In academia, research topics related to the Chinese construction industry have gradually received more academic interest in the English-language literature since the introduction of China's economic Open Door Policy in 1980; however, there are a few studies which have reported on the development of the industry and the comparison of the industry to other developed countries after China's entry into the WTO in 2001 (Xu et al., 2005). In fact, researchers have reported difficulties in making an absolute comparison between the construction industries of developing and developed countries due to the differences in politics and economy (Cox and Townsend, 1998; Xiao and Proverbs, 2002; Xu et al., 2005). And there seems to be no comprehensive review to summarize and critique existing research on the competitiveness in construction productivity (Flanagan et al., 2007).

According to the argument from Porter (1990), competitiveness research is defined by using productivity. And there are various measurements for construction productivity which can be categorized into three types: total factor productivity, total productivity, and labor productivity (Arditi and Mochtar, 2000). Productivity has captured the cornerstone of research on achieving excellence in the construction industry (Arditi, 1985; Chau and Walker, 1988; Arditi and Mochtar, 2000; Allmon et al. 2000; Flanagan et al., 2007). Xu et al. (2005) described the fundamental concept of productivity as the ratio of output to input, though many factors affect this ratio, such as labor, machinery, and management. But in the Chinese construction industry, output per employee is the measurement of productivity (CEIN, 2003; SSB, 2000; Xu et al., 2005).

As for the weaknesses of the Chinese construction industry, it can be described as follows: due to most Chinese construction enterprises not having sufficient exposure to and adoption of advanced construction technologies, the technology index is below other sectors in China and other developed countries, with an excessive average number of construction enterprises' employees being unskilled workers who previously were farmers and have no proper training for construction (Xu et al., 2005). Figure 8 shows the distribution of education levels of Chinese construction employees. In addition, there are too much work on construction sites being done manually instead of by machinery with skilled workers. In China, advanced equipment is used only for large or major projects (Hinton and Tao, 2006). Finally, a lack of appropriate knowledge in engineering design, project management, information systems, application of computer software, construction laws, codes, standards, and drawings from management personnel and workers also result in problems in construction productivity, scheduling, quality, and safety on site.

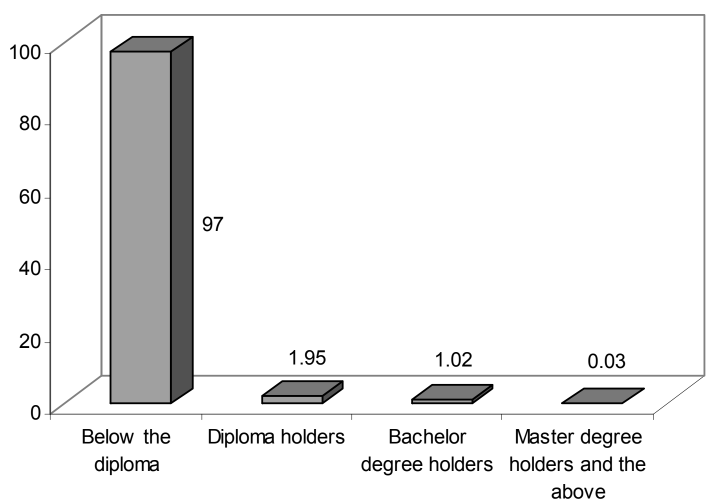


Figure 8. Distribution of Education Level of Chinese Construction Employees (He, 2000)

China is a socialist country with differences in the social political system and culture comparing to other developed countries, as exposed in its construction industry. Although the

Chinese construction industry is slowly evolving toward becoming a developed country and being an international construction market, the industry is unlikely to be the same as that of the U.S. in its industrial mechanism within the next 20 to 30 years. To improve and sustain its competitiveness, it is important for the Chinese construction industry to research, study, and resolve its own weaknesses, and, meanwhile, to learn the construction service rules of the WTO before integrating with the global market and reforming its industry (Xu et al., 2005).

3.3.5 Chinese Construction Industry vs. U.S. Construction Industry

Table 5 shows the GDP and percentage of construction in the GDP of the Chinese and U.S. construction industries from 1978 to 2007. It shows that the Chinese construction industry's contribution to GDP increases from 3.79% of GDP in 1978 to 5.6% of GDP in 2007, while U.S. construction industry's contribution to GDP decreases from 4.86% of GDP in 1978 to 4.42% of GDP in 2007.

Table 5. The GDP and percentage of construction of the Chinese and U.S. Construction Industry from 1978 to 2007 (Huang, 2009)

Year	GDP (Millions of Dollars)		Percentage of Construction (%)	
	China	U.S.	China	U.S.
1978	53,215	2,294,705	3.79	4.86
1979	59,308	2,563,327	3.54	4.95
1980	66,359	2,789,504	4.30	4.67
1981	71,410	3,128,436	4.23	4.21
1982	77,713	3,255,009	4.15	3.96
1983	87,046	3,536,667	4.54	3.95
1984	105,227	3,933,168	4.39	4.18
1985	131,621	4,220,262	4.64	4.37
1986	150,003	4,462,824	5.12	4.65
1987	176,038	4,739,471	5.52	4.60
1988	219,603	5,103,790	5.38	4.56
1989	248,063	5,484,351	4.67	4.46
1990	272,523	5,803,067	4.60	4.28
1991	317,978	5,995,927	4.66	3.84
1992	393,043	6,337,744	5.26	3.67
1993	515,824	6,657,407	6.41	3.73
1994	703,618	7,072,225	6.15	3.88
1995	887,500	7,397,650	6.13	3.88
1996	1,039,074	7,816,862	6.16	3.99
1997	1,152,891	8,304,342	5.85	4.06
1998	1,232,150	8,746,997	5.91	4.28
1999	1,309,154	9,268,410	5.77	4.39
2000	1,448,388	9,816,969	5.57	4.44
2001	1,600,805	10,127,976	5.41	4.64
2002	1,756,682	10,469,601	5.37	4.61
2003	1,982,814	10,960,770	5.52	4.53
2004	2,333,990	11,685,901	5.44	4.61
2005	2,674,707	12,421,885	5.51	4.87
2006	3,093,774	13,178,376	5.62	4.90
2007	3,642,772	13,807,539	5.60	4.42
Average Growth Rate (%)	9.88	3.02	--	--

Note: Adapted from the China Statistic Yearbook 2008, the U.S. Bureau of Economic Analysis, and the U.S. Department of Commerce.

Table 6 shows the comparison of the value added and gross output value of the Chinese and U.S. Construction Industries from 1978 to 2007, based on purchasing power parity (PPP). In 2007, the PPP factor from Chinese currency (Yuan) to U.S. dollar was 3.6, according to the World Development Indicators 2009 (Huang, 2009). Tables 5 and 6 indicate the faster growing construction industry in China with a low starting point compared to the U.S. construction industry. It also shows the relative competitiveness of the construction industry in China and the U.S. over the recent years. In addition, based on a causal relationship between construction and economic growth, China shows a stronger growing construction industry (which the growth needs to contribute in a range of 5-8% to GDP) comparing to U.S. construction industry, in which the contribution is within 3-5% to GDP (Turin, 1969; Turin, 1973). Using the relationships derived by Turin (1973), Edmonds (1979) postulated that a minimum of 5% contribution to GDP by the construction industry is a prerequisite for continuous economic growth (Han and Ofori, 2001). However, Porter (1990) concluded that the U.S. construction industry has sustained a strong position globally despite high factor costs in the market because of a favorable structure for determinants of competitive advantages. These determinants include the factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry (Porter 2000; Xu et al. 2005).

Table 6. Comparison of Value Added and Gross Output Value of the Chinese and U.S. Construction Industry from 1978 to 2007, based on PPP (Huang, 2009)

Year	Value Added of Construction (Millions of Dollars)		Construction Gross Output (Millions of Dollars)	
	China	U.S.	China	U.S.
1978	3,839	111,475	--	239,311
1979	3,994	126,992	--	270,705
1980	5,431	130,330	7,970	272,446
1981	5,753	131,802	--	288,532
1982	6,131	128,811	--	282,272
1983	7,517	139,777	--	311,917
1984	8,797	164,450	14,365	360,817
1985	11,608	184,636	18,753	389,555
1986	14,603	207,664	20,543	408,246
1987	18,494	218,235	24,329	448,731
1988	22,500	232,728	28,983	461,650
1989	22,056	244,824	32,749	474,626
1990	23,872	248,465	37,361	477,648
1991	28,197	230,152	39,597	441,439
1992	39,306	232,471	55,275	464,659
1993	62,954	248,305	90,376	497,737
1994	82,352	274,432	129,259	541,979
1995	103,579	286,973	160,938	571,727
1996	121,871	311,684	230,063	629,410
1997	128,378	337,558	253,513	676,027
1998	138,493	374,387	279,500	730,787
1999	143,670	406,602	309,802	798,611
2000	153,397	435,914	347,156	861,470
2001	164,769	469,535	426,710	899,778
2002	179,596	482,277	514,644	906,899
2003	208,077	496,212	641,219	956,756
2004	241,508	539,216	806,151	1,064,927
2005	281,494	605,450	959,781	1,180,146
2006	329,197	646,015	1,154,366	1,246,340
2007	389,281	610,842	1,417,881	1,245,874
Average Growth Rate (%)	9.96	1.38	22.77	5.97

Note: Adapted from the China Statistic Yearbook 2008, the U.S. Bureau of Economic Analysis, and the U.S. Department of Commerce.

3.4 Methods of Productivity Data Analyses

3.4.1 Frequency Analysis

The analysis of data often begins with a frequency analysis which helps in describing or explaining a situation. It is particularly useful for describing discrete categories of data, which may be time dependent or space dependent or otherwise. The frequency analysis involves structuring a frequency distribution by arranging the observed or measured data in classes or groups and by identifying the different class frequencies with a lower limit and an upper limit. With frequency distributions being classification dependent, the frequency analysis needs to be exhaustive in the sense that all data must be categorized.

For every set of data, there are various measures of central tendency including the mean, standard deviation, mode, and median. In most statistical analysis cases, the mean (μ) gives an estimate of the central tendency of the mass of data and the standard deviation (σ) gives an estimate of the closeness of the data to the mean. Nowadays, with any spreadsheet computer programs (e.g., Microsoft Excel, Microsoft Access), it is fairly easy to automate the calculation of cumulative frequency distributions with different mathematical expressions that give the best match with the data. In addition, it provides interval analysis, confidence belts, and graphics.

One can start the frequency analysis by having the data to be ranked in ascending order. The following is an equation of the cumulative frequency:

$$F_c = \frac{M}{(N+1)} \tag{3.4.1}$$

where M is the rank number and N is the number of data, F_c indicates the cumulative frequency (%). As the minimum value of M is zero and the maximum is N, the value of F_c ranges between

0 and 1 or 100%, i.e. the frequency of non-exceedance (%), or the percentage of data with values smaller than the value considered. The value 1- F_c indicates the frequency of exceedance F_e.

When the data and its frequencies are shown on a graphic diagram, the data tend to form a curved line despite the existence of scatter. Figure 9 illustrates an example of a cumulative frequency distribution. The curved line indicates the type of frequency distribution and the scatter is assumed to stem from random variation (Oosterbaan, 2002).

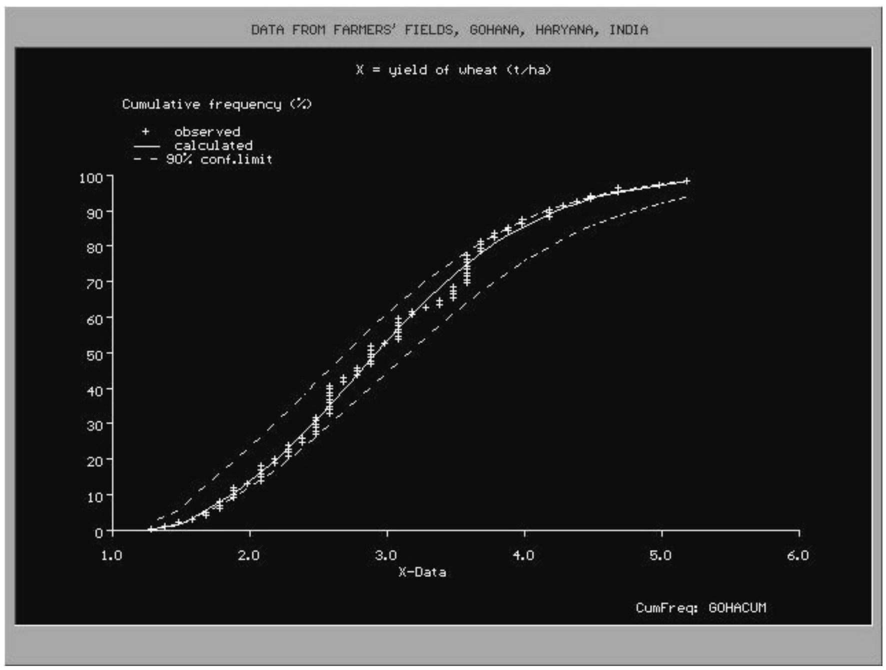


Figure 9. Graphic Illustration of Cumulative Frequency Distribution (Sharma et al., 1997)

Oosterbaan (2002) stated, "To present the cumulative frequency distribution as a mathematical equation, one may try to fit the cumulative frequency distribution to a known cumulative probability distribution. If successful, the known equation is enough to report the frequency distribution and a table of data will not be required. Further, the equation helps interpolation and extrapolation. When extrapolating a cumulative frequency distribution, this fact should be explicitly mentioned, because extrapolation may be a source of errors. One possible error is that the frequency distribution does not follow the selected probability distribution any more beyond the range of the observed data."

3.4.2 Analysis of Variance (ANOVA) Models

One of the most common activities in processing productivity data is to study the variation associated with the measurement and to determine the important sources of that variation. This is called an analysis of variance (ANOVA). It is a parametric test that assumes the distribution is known or the sample is large, so that a normal distribution may be assumed; equal interval or ratio scales should be used for measurements (Fellows and Liu, 2008). Its procedures separate or partition the variation observable in a response variable into two basic components: variation due to assignable causes (experimental factors or measured covariates) and to random variation (uncontrolled effects, including chance causes and measurement errors) (Mason et al., 2003). The key to performing an ANOVA is to identify the structure represented by the data. In the ANOVA models, there are one-way layouts and two-way layouts where the factors are either crossed or nested. To perform the analysis, it is necessary to enter the data for each of the factors and levels into a statistical analysis program, such as SPSS, and then interpret the ANOVA table and other output.

3.4.2.1 One-Way ANOVA

One-way ANOVA has a single factor with several levels and multiple measurements at each level. With the one-way layout, the mean of the measurements can be calculated within each level of available factor and the residuals will show the variation within each level. The grand mean can also be obtained from averaging the means of each level; and as follows, the deviation of the mean of each level from the grand mean can be used to determine the level effects (Mason et al., 2003). As results, the variation can be compared within levels to the variation across levels. The following is an equation of the one-way model:

$$y_{ij} = m + a_i + e_{ij} \tag{3.4.2}$$

where y is the response variable for the j^{th} data value in the i^{th} level; m is the common value (grand mean); a_i is the level effect (the deviation of each level mean from the grand mean); and e_{ij} is the residual or the error of the j^{th} data value in the i^{th} level.

Furthermore, an estimation of the one-way layout can be performed one of two ways. First, the total variation can be calculated within-level variation and across-level variation. In general, these can be summarized in an ANOVA table as shown below and test can be made to determine if the factor levels are significant by the one-way value-splitting.

Table 7. ANOVA Table for One-Way Case

Source	Sum of Squares	Degrees of Freedom	Mean Square
Factor Levels	$J\sum a_i^2$	I-1	$J\sum a_i^2 \big/ (I-1)$
Residuals	$\sum_i \sum_j e_{ij}^2$	I(J-1)	$\sum_i \sum_j e_{ij}^2 \big/ I(J-1)$
Corrected Total	$\sum_i \sum_j y_{ij}^2 - IJm^2$	IJ-1	

Source: NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, accessed on 09/02/2009.

The use of the value-splitting is to break each data value into its component parts. Once the component parts are determined, it is then a trivial matter to calculate the sums of squares and form the F-value for the test. The first step is to calculate the mean values to get the level means. The level mean from each associated data value can then be subtracted to get the residuals. The next step is to calculate the grand mean from the individual level means and to subtract the grand mean from each individual level mean to obtain the level effects. With the data values split and the overlays created, the sums of squares, the degrees of freedom and the mean squares can be calculated. The last step is to calculate the F-value and perform the test of equal level means. The F-value is just the level mean square divided by the residual mean square.

Thus, the one-way ANOVA is most useful to compare the effect of multiple levels of one factor and to have multiple measurements at each level. The factor can then be either discrete (different sites, etc.) or continuous (different times, etc.).

3.4.2.2 Two-Way ANOVA

When there are two factors with at least two levels and one or more observations at each level, two-way crossed or nested ANOVA would be used for the analysis of data. In case of every level of factor, *a*, occurring with every level of factor, *b*, the two-way crossed layout would be used to estimate the effect of each factor (Main Effects) as well as any interaction between the factors. If there are *k* observations at each combination of *i* levels of factor *a* and *j* levels of factor *b*, then the two-way layout would have an equation of the form:

$$y_{ijk} = m + a_i + b_j + (ab)_{ij} + e_{ijk} \qquad (3.4.3)$$

The equation shows that the k^{th} data value for the j^{th} level of factor b and the i^{th} level of factor a is the sum of five components: the common value (grand mean, m), the level effect for factor a, the level effect for factor b, the interaction effect ab, and the residual e. In the equation, "ab" does not mean multiplication, but instead, it is the interaction between the two factors.

Like in the one-way case, the estimation for the two-way layout can be done by calculating the variance components. For this method, the data are in a two dimensional table with levels of factor a in columns and the levels of factor b in rows. The replicate observations fill each cell. The common value, the row effects, the column effects, the interaction effects and the residuals can be determined by using a value-splitting technique, which is similar to one-way value splitting. The sums of squares can be calculated and summarized in an ANOVA table as shown below.

Table 8. ANOVA Table for Two-Way Crossed Case

Source	Sum of Squares	Degrees of Freedom	Mean Square
Rows	$JK\sum a_i^2$	I-1	$JK\sum a_i^2 \big/ (I-1)$
Columns	$IK\sum b_j^2$	J-1	$IK\sum b_j^2 \big/ (J-1)$
Interaction	$K\sum_i \sum_j (ab)_{ij}^2$	(I-1)(J-1)	$K\sum_i \sum_j (ab)_{ij}^2 \big/ (I-1)(J-1)$
Residuals	$\sum_i \sum_j \sum_k e_{ijk}^2$	IJ(K-1)	$\sum_i \sum_j \sum_k e_{ijk}^2 \big/ IJ(K-1)$
Corrected Total	$\sum_i \sum_j \sum_k y_{ijk}^2 - IJm^2$	IJK-1	

Source: NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, accessed on 09/02/2009.

The two-way crossed ANOVA is useful when it is necessary to compare the effect of multiple levels of two factors and to combine every level of one factor with every level of the other factor. In addition, it is able to estimate the effects of interaction between the two factors with multiple measurements at each level. On the other hand, there are situations which prevent constraints from crossing every level of one factor with every level of other factor. A two-way nested ANOVA would be used for the analysis of data when fewer than all levels of one factor occur within each level of the other factor. If factor *b* is nested within factor *a*, then a level of factor *b* can only occur within one level of factor *a* and there can be no interaction. This gives the following equation:

$$y_{ijk} = m + a_i + b_{j(i)} + e_{ijk} \tag{3.4.4}$$

This equation indicates that each data value is the sum of a common value (grand mean, *m*), the level effect for factor *a*, the level effect of factor *b* nested factor *a*, and the residual. It is important to note that the two-way nested ANOVA is not capable to estimate the interaction between the two factor because each level of one factor can only present with one level of the other factor.

For a nested case, it is typical to use the variance components methods to perform the analysis. The common value, the row effects, the column effects and the residuals can be determined by using a value-splitting technique. The sums of squares can be calculated and summarized in an ANOVA table as shown below.

Table 9. ANOVA Table for Two-Way Nested Case

Source	Sum of Squares	Degrees of Freedom	Mean Square
Rows	$JK\sum a_i^2$	I-1	$JK\sum a_i^2 \big/ (I-1)$
Columns	$IK\sum b_j^2$	$I(J$-1)	$IK\sum b_j^2 \big/ I(J-1)$
Residuals	$\sum_i \sum_j \sum_k e_{ijk}^2$	IJ(K-1)	$\sum_i \sum_j \sum_k e_{ijk}^2 \big/ IJ(K-1)$
Corrected Total	$\sum_i \sum_j \sum_k y_{ijk}^2 - IJm^2$	IJK-1	

Source: NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, accessed on 09/02/2009.

The two-way nested ANOVA is useful when it is necessary to combine all the levels of one factor with all of the levels of the other factor. It is also most useful for cases when there is a random effects situation. It is a random effects model when the levels of a factor are chosen at random rather than selected intentionally.

3.4.3 Regression Analysis

Regression modeling is one of the most widely used statistical modeling techniques (Mason et al., 2003). But regression analyses are generally limited by the number of influencing factors that can be included and their capability of measuring the combined effect of the influencing factors (Song and AbouRizk, 2008). As ANOVA models being special types of regression models as described in the previous section, the remainder of this section will introduce and briefly discuss some of well-established regression analyses that are useful for different model building situations. In fact, there are many forms of regression analysis: linear versus non-linear, two-variable versus multi-variable, and ratio method versus least-squares method (Oosterbaan, 2002). Regression analysis is a function of variables x and β which gives the following equation:

$$y = f(x, \beta) \tag{3.4.5}$$

In the regression equation, the variables included are the unknown parameters β (this may be a scalar or a vector of length k), the independent variables x, and the dependent variable y. These variables stand in a causal relation to one another. The regression analysis was developed to detect the presence of a mathematical relation between two or more variables subject to random variation, and to test if such a relation, whether assumed or calculated, is statistically significant.

3.4.3.1 Linear Regression

Linear regression by the ratio method presupposes that the dependent scatter between the variables changes linearly with their values. For example, linear two-variable regression by the ratio method can be done when the scatter of the data depends on the magnitude of Y and X values, and Y = 0 when X = 0. When independent scatter occurs, it is supposed to be normally distributed, and the least-squares method can be used. For example, the linear two-variable regression by the least squares method can be done in two ways: regression of “Y upon X” and “X upon Y”.

According to Oosterbaan (2002), there are many methods of transforming data to obtain a linear relation. The most well known methods are the logarithmic transformations. In this case, it is necessary to study the scatter of transformed data before deciding whether to use the ratio or least squares method. Conceptual transformations, based on a theory of how one variable influences the other, can also be used. In this section, the least squares method will be further discussed.

According to NIST (2006), linear least squares regression is the most widely used modeling method for a broad range of situations that are outside its direct scope. If it is used directly with an appropriate data set, linear least squares regression can be used to fit the data with any function of the form:

$$f(x;\beta) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \tag{3.4.6}$$

in which each explanatory variable in the function is multiplied by an unknown parameter; there is, at most, one unknown parameter with no corresponding explanatory variable; and, all of the individual terms are summed to produce the final function value. In statistical terms, any function that meets these criteria would be called a "linear function." The term "linear" is used, even though the function may not be a straight line, because if the unknown parameters are considered to be variables and the explanatory variables are considered to be known coefficients corresponding to those "variables," then the problem becomes a system (usually overdetermined) of linear equations that can be solved for the values of the unknown parameters. To differentiate the various meanings of the word "linear," the linear models being discussed here are often said to be "linear in the parameters" or "statistically linear," Linear models include a fairly wide range of shapes. For example, in a simple quadratic curve,

$$f(x;\beta) = \beta_0 + \beta_1 x + \beta_{11} x^2 \tag{3.4.7}$$

is linear in the statistical sense (see Figure 10 for illustration). A straight-line model in *log(x)*,

$$f(x;\beta) = \beta_0 + \beta_1 \ln(x) \tag{3.4.8}$$

or a polynomial in *sin(x)*,

$$f(x;\beta) = \beta_0 + \beta_1 \sin(x) + \beta_2 \sin(2x) + \beta_3 \sin(3x) \tag{3.4.9}$$

is also linear in the statistical sense because they are linear in the parameters, though not with respect to the observed explanatory variable, *x*.

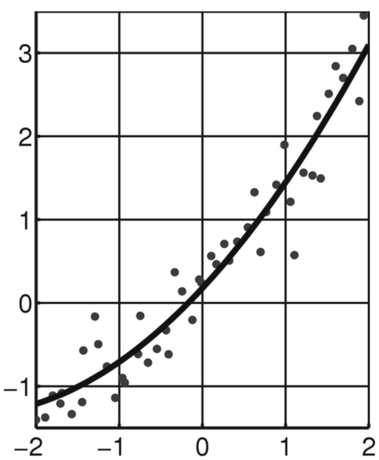


Figure 10. Graphic Illustration of Fitting a Quadratic function

According NIST (2006), the main disadvantages of linear least squares are limitations in the shapes that linear models can assume over long ranges, possibly poor extrapolation properties, and sensitivity to outliers. Nevertheless, linear least squares regression has earned its place as the primary tool for process modeling because of its effectiveness and completeness. Though there are types of data that are better described by functions that are non-linear in the parameters, many processes in science and engineering are well-described by linear models. This is because either the processes are inherently linear or because, over short ranges, any process can be well-approximated by a linear model. The estimates of the unknown parameters obtained from linear least squares regression are the optimal estimates from a broad class of possible parameter estimates under the usual assumptions used for process modeling. Practically speaking, linear least squares regression makes very efficient use of the data. Good results can be obtained with relatively small data sets. Finally, the theory associated with linear regression is well-understood and allows for the construction of different types of easily-interpretable statistical intervals for predictions, calibrations, and optimizations. These statistical intervals can then be used to give answers to scientific and engineering questions.

3.4.3.2 Non-Linear Regression

Non-linear regression is a form of regression analysis in which observational data are modeled by a function which is a non-linear combination of the model parameters and depends on one or more independent variables. According NIST (2006), it extends linear regression for use with a much larger and more general class of functions. Almost any function that can be written in closed form can be incorporated in a non-linear regression model. Unlike linear regression, there are very few limitations on the way parameters can be used in the functional part of a non-linear regression model. For example, in a base form of a non-linear model,

$$y = f(x;\beta) + \varepsilon \tag{3.4.10}$$

in which the functional part of the model is not linear with respect to the unknown parameters, β_0, β_1,…, and the method of least squares is the most widely used to estimate the values of the unknown parameters. Some examples of non-linear models obtained from NIST (2006) include:

$$f(x;\beta) = \frac{\beta_0 + \beta_1 x}{1 + \beta_2 x} \tag{3.4.11}$$

$$f(x;\beta) = \beta_1 x^{\beta_2} \tag{3.4.12}$$

$$f(x;\beta) = \beta_0 + \beta_1 \exp(-\beta_2 x) \tag{3.4.13}$$

$$f(x;\beta) = \beta_1 \sin(\beta_2 + \beta_3 x_1) + \beta_4 \cos(\beta_5 + \beta_6 x_2) \tag{3.4.14}$$

However, the non-linear least squares procedure shares the same disadvantages with the linear least squares regression including a strong sensitivity to outliers. In fact, the presence of one or two outliers in the data analysis can seriously affect the outcomes of a non-linear analysis. Unfortunately, there are fewer model validation tools for the detection of outliers in non-linear regression than there are for linear regression. In addition, the major effort of switching from linear least squares to non-linear least squares regression is the need to use iterative optimization procedures to compute the parameter estimates. According to NIST (2006), with functions that are linear in the parameters, the least squares estimates of the parameters can always be obtained analytically while that is generally not the case with non-linear models. The use of iterative procedures requires the researcher to provide starting values for the unknown parameters before the computer software can begin the optimization. The starting values must be reasonably close to the as yet unknown parameter estimates or the optimization procedure may not converge. Bad starting values can also cause the software to converge to a local minimum rather than the global minimum that defines the least squares estimates.

On the contrary (NIST, 2006), the biggest advantage of non-linear least squares regression over many other techniques is the broad range of functions that can be fit. Although many scientific and engineering processes can be described well using linear models or other relatively simple types of models, there are other processes that are inherently non-linear models which describe the asymptotic behavior of a process well. Like the asymptotic behavior of some processes, other features of physical processes can often be expressed more easily using non-linear models than with simpler model types. Non-linear least squares regression also has some of the same advantages that linear least squares regression has over other methods. One common advantage is efficient use of data. Non-linear regression can produce good estimates of the unknown parameters in the model with relatively small data sets. Another advantage that non-linear least squares shares with linear least squares is a fairly well-developed theory for computing confidence, prediction and calibration intervals to answer scientific and engineering questions. In most cases the probabilistic interpretation of the intervals produced by non-linear regression are only approximately correct, but these intervals still work very well in practice.

3.4.4 Correlation

The Correlation is one of the most common and most useful statistic. A correlation is a single number that describes the degree of relationship between two variables. It is a bivariate analysis that measures the strengths of association between two variables. In statistics, the value of the correlation coefficient varies between +1.0 and -1.0. When the value of the correlation coefficient lies around ±1.0, then it is said to be a perfect degree of association between the two variables. As the value goes towards 0, the relationship between the two variables will be weaker. In other words, a correlation of +1.0 means that if one variable will expand, the other variable will also expand. In case the correlation between the two variables is -1.0, the two are inversely proportional to each other. In other words, the correlation means that if one variable expands, then the other will be lessened or become smaller. To make the value of the correlation coefficient easier to understand, the value of the correlation coefficient is squared. That square of the correlation coefficient is equal to the percentage with which the variation of one variable is related to the variation of the other variable. After the correlation coefficient *r* is squared, the decimal point can be ignored. While using the correlation technique, it is important to understand that it only works on linear relationships and not on curvilinear (where the relationship does not follow a straight line) relationships. In statistics, there are three types of correlation: Pearson Correlation, Kendall's Tau Correlation and Spearman Correlation.

3.4.4.1 Pearson Correlation

Pearson Correlation is widely used in statistics to measure the degree of the relationship between the linear related variables in which both variables should be normally distributed (SSI, 2009a). The following formula is used to calculate the Pearson Correlation:

$$r = \frac{N\sum xy - \sum (x)(y)}{\sqrt{N\sum x^2 - \sum (x^2)][N\sum y^2 - \sum (y^2)]}} \qquad (3.4.15)$$

where r = Pearson Correlation coefficient; N = number of value in each data set; $\sum xy$ = sum of the products of paired scores; $\sum x$ = sum of x scores; $\sum y$ = sum of y scores; $\sum x^2$= sum of squared x scores; and $\sum y^2$= sum of squared y scores.

3.4.4.2 Kendall's Tau Correlation

Kendall's Tau Correlation is a nonparametric test that does not assume any assumptions related to the distributions – like Pearson Correlation (SSI, 2009a). The following formula is used to calculate the value of Kendall's Tau Correlation:

$$\tau = \frac{n_c - n_d}{\frac{1}{2}n(n-1)} \tag{3.4.16}$$

where τ = Kendall's Tau Correlation coefficient; n_c = number of concordant; and n_d = number of discordant.

$$\frac{1}{2}n(n-1) \tag{3.4.17}$$

is the total number of possible pairing of observations.

3.4.4.3 Spearman Correlation

Spearman Correlation is a nonparametric test. It was developed by Karl Spearman, thus it is called the Spearman Correlation. It is a measure of the correlation between two variables. It is widely used in the research as a measure to quantifiable data. The Spearman Correlation test does not assume any assumptions about the distribution and is used when the Pearson test gives misleading results (SSI, 2009a). The following formula is used to calculate the Spearman Correlation:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{3.4.18}$$

where ρ = Spearman Correlation coefficient; d_i = the difference between the ranks corresponding values X_i and Y_i; and n = number of value in each data set.

3.4.5 Chi-Square Test

The chi-square (χ^2) is a nonparametric statistical test commonly used to compare observed data in which the sampling distribution of the test statistic is a chi-square distribution when the null hypothesis is true, or any in which this is asymptotically true. It means that the sampling distribution can be made to approximate a chi-square distribution as closely as desired by making the sample size large enough.

In a chi-square test, a value is obtained from the data by utilizing the chi-square procedures, which are then compared to the critical value from a chi-square distribution table (see Table 10), which are calculated in reference to the degrees of freedom parallel to that of the data of chi square test. If the resultant value of chi-square test is greater than or equal to the critical or the table value, then the null hypothesis is discarded. If, on the other hand, the resultant value is less than the critical or table value, then the null hypothesis is said to be true and it is accepted. The chi-square is always testing what researchers call the null hypothesis, which states that there is no significant difference between the expected and observed result.

Table 10. Chi-Square Distribution (Fisher and Yates, 1995)

Degrees of Freedom (*df*)	Probability (*p*)										
	0.95	**0.9**	**0.8**	**0.7**	**0.5**	**0.3**	**0.2**	**0.1**	**0.05**	**0.01**	**0.001**
1	0.004	0.02	0.06	0.15	0.46	1.07	1.64	2.71	3.84	6.64	10.83
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.60	5.99	9.21	13.82
3	0.35	0.58	1.01	1.42	2.37	3.66	4.64	6.25	7.82	11.34	16.27
4	0.71	1.06	1.65	2.20	3.36	4.88	5.99	7.78	9.49	13.28	18.47
5	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09	20.52
6	1.63	2.20	3.07	3.83	5.35	7.23	8.56	10.64	12.59	16.81	22.46
7	2.17	2.83	3.82	4.67	6.35	8.38	9.80	12.02	14.07	18.48	24.32
8	2.73	3.49	4.59	5.53	7.34	9.52	11.03	13.36	15.51	20.09	26.12
9	3.32	4.17	5.38	6.39	8.34	10.66	12.24	14.68	16.92	21.67	27.88
10	3.94	4.86	6.18	7.27	9.34	11.78	13.44	15.99	18.31	23.21	29.59
	Nonsignificant								**Significant**		

The chi-square test is one of the most important tests in nonparametric statistical analysis. It is used to compare observed and expected frequencies of a variable, which has three or more categories, and to test whether more than two population proportions can be considered to be equal (Fellows and Liu, 2008). It also requires numerical values to be used, not percentages or ratios. In fact, the chi-square should not be calculated if the expected value in any category is less than 5. The following formula is used to calculate chi-square (χ^2):

$$\chi^2 = \chi(o\text{-}e)^2/e \qquad (3.4.19)$$

That is, chi-square is the sum of the squared difference between the observed (o) and expected (e) data (or the deviation, d), divided by the expected data in all possible categories. To calculate χ^2, first determine the number expected in each category and then calculate χ^2 by using the formula as shown above. The followings are the procedure for interpreting the χ^2 value:

1. To determine degrees of freedom (*df*) – Degrees of freedom can be calculated as the number of categories in the problem minus 1.

2. To determine a relative standard to serve as the basis for accepting or rejecting the hypothesis – The relative standard commonly used in research is $p > 0.05$. The p value is the probability that the deviation of the observed from that expected is due to chance alone (no other forces acting).
3. To refer to the chi-square distribution table (see Table 10). Using the appropriate degrees of freedom, the value closest to the calculated chi-square should be located in the chi-square distribution table. And the closest p (probability) value associated with the chi-square and degrees of freedom should be determined.

The followings are the step-by-step procedure for testing hypothesis and calculating chi-square:

1. To state the hypothesis being tested and the predicted results and to gather the data by conducting the proper testing.
2. To determine the expected numbers for each observational class.
3. To calculate χ^2 using the formula.
4. To use the chi-square distribution table to determine significance of the value.
   A. To determine degrees of freedom and locate the value in the appropriate column.
   B. To locate the value closest to the calculated χ^2 on the degrees of freedom *df* row.
   C. To move up the column to determine the p value.
5. To state the conclusion in terms of the hypothesis.
   A. If the p value for the calculated χ^2 is $p > 0.05$, accept the hypothesis. 'The deviation is small enough that chance alone accounts for it. A p value of 0.6, for example, means that there is a 60% probability that any deviation from expected is due to chance only. This is within the range of acceptable deviation.

B. If the p value for the calculated χ^2 is $p < 0.05$, reject the hypothesis, and conclude that some factor other than chance is operating for the deviation to be so great. For example, a p value of 0.01 means that there is only a 1% chance that this deviation is due to chance alone. Therefore, other factors must be involved.

Though the nonparametric test like the chi-square test does not require the need of evenly distributed data, but it still has its limitations. While performing the chi-square test, researcher should make sure that the data or the representative sample should be random. Individual distribution of the chi-square test should be independent of each other. The sample size should be adequate in the chi-square test. The distribution basis in chi-square test must be decided before the data are collected. And last but not least, the sum of the observed frequencies should be equal to the sum of the expected frequencies.

3.4.6 Kruskal-Wallis Test

The Kruskal-Wallis test was developed by William Kruskal and W. Allen Wallis jointly and is named after them. The Kruskal-Wallis test is a nonparametric (distribution free) test. It is used for testing and comparing equality of population medians among three or more groups of sample data. The Kruskal-Wallis test is used when assumptions of ANOVA are not met (SSI, 2009b). As described in a previous section, ANOVA is a statistical data analysis technique that is used when the independent variable groups are more than two and the distribution of each group is assumed to be normally distributed. In the Kruskal-Wallis test, there is no assumption about the distribution; therefore, it is a distribution free test. If normality assumptions are met, then the Kruskal-Wallis test is not as powerful as ANOVA.

In the Kruskal-Wallis test, the null hypothesis assumes that the samples are from identical populations and alternative hypothesis assumes that the samples come from different populations. Generally, the samples drawn from the population are random and the cases of each group are independent. The measurement scale for the Kruskal-Wallis test should also be ordinal.

The followings are the step-by-step procedure for the Kruskal-Wallis test:

1. To arrange the data of both samples in a single series in ascending order.
2. To assign rank to them in ascending order. In the case of a repeated value, assign ranks to them by averaging their rank position.
3. Once this is complete, ranks or the different samples are separated and summed up as R_1 R_2 R_3, etc.
4. To calculate the value of the Kruskal-Wallis test, apply the following formula:

$$\begin{aligned} K &= \frac{12}{N(N+1)} \sum_{i=1}^{g} n_i \left(\bar{r}_{i\cdot} - \frac{N+1}{2} \right)^2 \\ &= \frac{12}{N(N+1)} \sum_{i=1}^{g} n_i \bar{r}_{i\cdot}^2 - 3(N+1) \end{aligned} \tag{3.4.20}$$

where K = Kruskal-Wallis Test; and N = total number of observations in all samples.

$$\bar{r}_{i\cdot} = \frac{\sum_{j=1}^{n_i} r_{ij}}{n_i} \tag{3.4.21}$$

where n_i = the number of observations in group i; and r_{ij} = the rank (among all observations) of observation j from group i.

The Kruskal-Wallis test statistic is approximately a chi-square distrubution, with K-1 degree of freedom where n_i should be greater than 5. If the calculated value of Kruskal-Wallis test is less than the chi-square distribution table value, then the null hypothesis will be accepted. If the calculated value of Kruskal-Wallis test, H, is greater than the chi-square distribution table value, then the null hypothesis will be rejected and the sample will come from a different population.

3.4.7 Box Plots and Scatter Plots

A box plot is a useful way of graphically illustrating the distribution of data based on the lower adjacent value, lower quartile (Q1), median (Q2), upper quartiles (Q3), and upper adjacent value (see Figure 11). More importantly, box plots depict differences between measurements or values without making any assumptions of the underlying statistical distribution. Results from the distribution plot of project data are illustrated in Chapter 6.

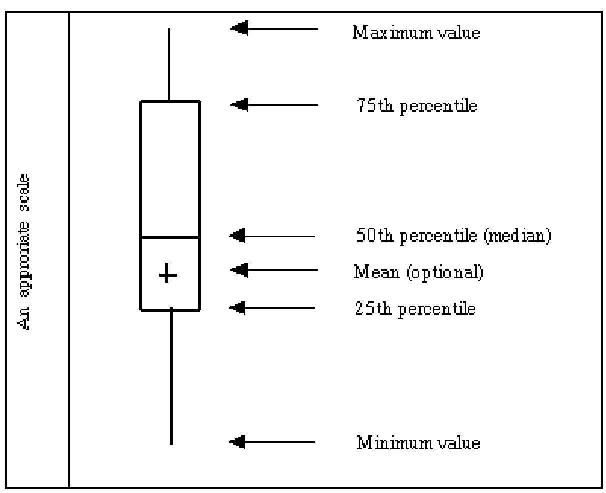


Figure 11. Annotated Sketch of the Distribution Plot (Schwarz, 2008)

A scatter plot provides a graphical display of the relationship between two variables. The variable that might be considered an independent variable is plotted on the X-axis and the dependent variable is plotted on the Y-axis. Scatter plots are especially useful to provide a pictorial representation of the degree and direction of correlation. For instance, brick size and productivity for laying a brick are intuitively positively correlated. However, there is not necessarily a cause and effect relationship between two variables. Both variables could be related to a third variable that explains their variation or there could be some other cause. Nevertheless, it is useful in the early stages of analysis to explore data before actually calculating a correlation coefficient or fitting a regression line/curve. Figure 12 illustrates an annotated sketch of the scatter plot.

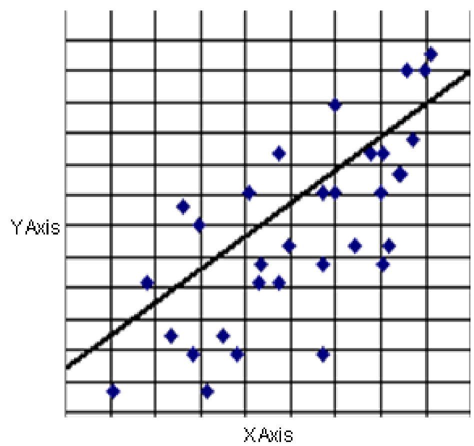


Figure 12. Annotated Sketch of the Scatter Plot

3.5 Summary of Literature Review

During the 1980s and 1990s, the research and development activities concerning construction mainly focus on quality, health and safety, environmental matters, etc. and less on productivity. As the global society has grown and changed, the U.S. and China economies have become increasingly more dynamic and complex. Continuous up-to-date studies on productivity are necessary for U.S. firms to keep the competitive edge in the construction industry and to enhance their competitiveness in the global construction markets, especially in China. In the U.S. and China, the U.S. Census Bureau and the National Bureau of Statistics (NBS) of China serve their construction industries with information. This information is mainly based on GDP and other macro economy figures, and, thereby, of limited value for operational decision-making by U.S. construction firms.

For an evaluation of performance in the construction industry, it is necessary to have activity-oriented productivity information. It is widely known that labor productivity is extremely difficult to measure due to the heterogeneity of the construction industry's products and inputs. The difference in presented measurement methods, which include time studies (stopwatch), work sampling, delay survey, audio-visual, and secondary data, emphasizes how wide the field of productivity studies is. Although this can take a long time of cooperation before reaching a common method of productivity measurement in the industry, such research studies are needed to be conducted independently using the same set of ground rules.

While little literature has been found on the impact of the Open Door Policy and the entry into the WTO on the Chinese construction industry, a few studies have reported on the development of the Chinese industry to assist the U.S. construction firms to become more familiar with the highly competitive Chinese market. In fact, the inadequate legal framework and mechanism, low productivity, relatively unsophisticated construction equipment and technologies, and low international construction market share with limited types of projects are considered by international standards the reasons the Chinese construction industry is still being a weak sector of the overall economy (Huang, 2009). Kwak (2002) conducted a study analyzing concession projects by foreign construction firms in Asia, including China, which showed about

30 percent of the projects had serious problems and resulted in substantial financial losses, cancellation, delay, and suspension of the projects. As a result, a few U.S. construction firms doing business in China are successful due to the lack of productivity information in deciding how to estimate, schedule, construct and operate the project as well as how to have a successful bid in the Chinese market. The overview of the Chinese construction industry in this chapter provides further information for better understanding of the market in both accuracy and practicability.

Since the construction productivity is defined as the ratio between an output value and an input value that is used to determine the output, one of the challenges in analyzing construction productivity statistically is that there are different units of measurement in productivity for each construction activity. But in statistics, there are different analysis methods which can be applied for modeling and analyzing the observed data from on-site measurements. Based on the knowledge obtained from the reviews of frequency analysis, ANOVA, regression analysis, correlation analysis, Chi-Square test, Kruskal-Wallis test, etc., remarks about the importance of this research and some specific points to be addressed in this research were developed. In the following chapter, the plan of work provides more details regarding the research strategy, general principles, implementation plan, and timeline of this study.

CHAPTER 4: DATA COLLECTION

This chapter details the methodology used in performing the research. It discusses the formation of the process which has been developed. The step-by-step procedures for collecting task-level productivity data and documenting the factors affecting labor productivity can provide a consistent database for communications and comparisons between projects in the U.S. and China, as well as data for further research on the factors affecting productivity. In this study, productivity data were collected from two construction projects in the U.S. and three projects in China. The projects were constructed in the 2009-2010 time frame. Due to resource constraints in both countries, only work items that are labor intensive in building construction were selected by the researcher. The data collection form and work scope coding used for on-site measurements can be found in Appendix A.

4.1 Project Descriptions

In the U.S., two ongoing construction projects were accessed during the study. Both projects were located on the University of Kansas west campus. One was a new building for the School of Pharmacy; the other was the new Bioscience and Technology Business Center. The new School of Pharmacy facility was a $45.5 millions project that was started in late May 2009, approximately 60 percent was completed when the study was initiated, and it was completed in late July 2010 (see Figures 13 to 15). The project involved the construction of a 10,220 square meter four-story building plus a level of basement and exterior glass-and-brick-faced structure. The structure had a mainly curtain wall façade. The second construction project, the Bioscience and Technology Business Center, was a $7.25 millions project that was started in early Oct. 2009.

Approximately 20 percent was completed when the study was initiated, and it was completed in early July 2010 (see Figures 16 to 18). The 1,858 square meter two-story facility had mainly glass-and-brick-faced exterior walls. The scope of work at the jobsites included collecting data from the fire protection sprinkler system, heating, ventilating, and air conditioning (HVAC) system and masonry.

Figure 13. Site Photo of the School of Pharmacy Building (Feb. 2010)

Figure 14. Site Photo of the School of Pharmacy Building (May 2010)

Figure 15. Digital Image of the School of Pharmacy Building

Figure 16. Site Photo of the Bioscience & Technology Business Center (Feb. 2010)

Figure 17. Site Photo of the Bioscience & Technology Business Center (May 2010)

Figure 18. Digital Image of the Bioscience & Technology Business Center

In China, three construction projects were accessed during the study in 2009 and 2010: One was a new school building on the Chongqing University's campus; the other was a project with two high-rise office buildings in the downtown district of the City of Chongqing; and last but not least, a four-story shopping mall located in an urban area of the City of Chongqing. The new school building was a US$4.79 millions project that was started in June 2009, approximately 30 percent was completed when the study was initiated, and was completed in July 2010 (see Figures 19 to 21). The school project included a 19,933 square meter nine-story, brick-faced building facility for garage, administrative office, classroom, and laboratory space. The reinforced concrete structure has mainly concrete blocks and bricks for internal partitioning. The scope of works included collecting data from the fire protection sprinkler system, HVAC system, and masonry.

The second construction project, two 28-story office buildings plus one level of basement with a total of 75,970 square meter of floor area for garage and office space (see Figures 22 and 23) was started in October 2008. The new buildings had a total construction cost of US$12.05

millions, approximately 60 percent was completed when the study was initiated. Most of the exterior walls are glass-and-metal siding with internal partitions made of reinforced concrete and concrete blocks. The scope of works for this project included collecting data from the fire protection sprinkler system and masonry. The third construction protect, a four-story shopping mall with a total of 80,000 square meter of floor area for retails (see Figures 24 and 25) was started in 2008. The study was initiated when the project was approximately 90 percent completed. The scope of works for this project included collecting data from the fire protection sprinkler system, HVAC system, and masonry.

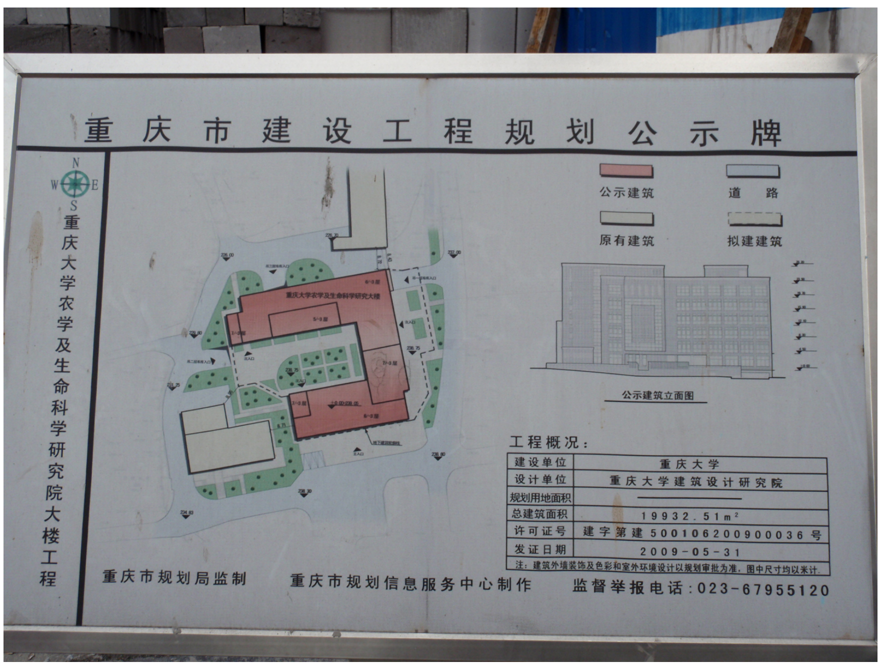


Figure 19. Site Plan of the School Building Project at Chongqing University

Figure 20. North Entrance of the School Building Project at Chongqing University (Oct. 2009)

Figure 21. North Entrance of the School Building Project at Chongqing University (June 2010)

Figure 22. Site Plan of the High-Rise Office Building Project in Chongqing

Figure 23. Site Photo of the High-Rise Office Building Project in Chongqing

Figure 24. Site Photo of the Shopping Mall Project in Chongqing

Figure 25. Site Photo of the Shopping Mall Project in Chongqing

4.2 Data Collection Procedure

Data were collected through observations during daily site visits to the building construction projects in Chongqing, China from October 2009 to November 2009 and from May 2010 to June 2010, and in Lawrence, Kansas, from February 2010 to April 2010. The data collection procedures were established in collaboration with the construction firms' personnel, staff members of Design & Construction Management Office in the University of Kansas, and faculty members of Chongqing University's Faculty of Construction Management and Real Estate. The selection of projects' jobsites and work items for observation were investigated. Figure 26 delineates each step of the procedures shown with the level of frequency and output where applicable. For each candidate project proposed for this study, the researcher prescreened each project and specifically excluded the early phase of the work and the startup phase of the project since the stage of construction could affect labor productivity. The following items were also included for consideration: (1) Data collection methodology; (2) Safety protocol for site visit; (3) Research assistants training and availability for on-site observations; (4) Selection of work items to be observed; and (5) Site visit schedule for each project.

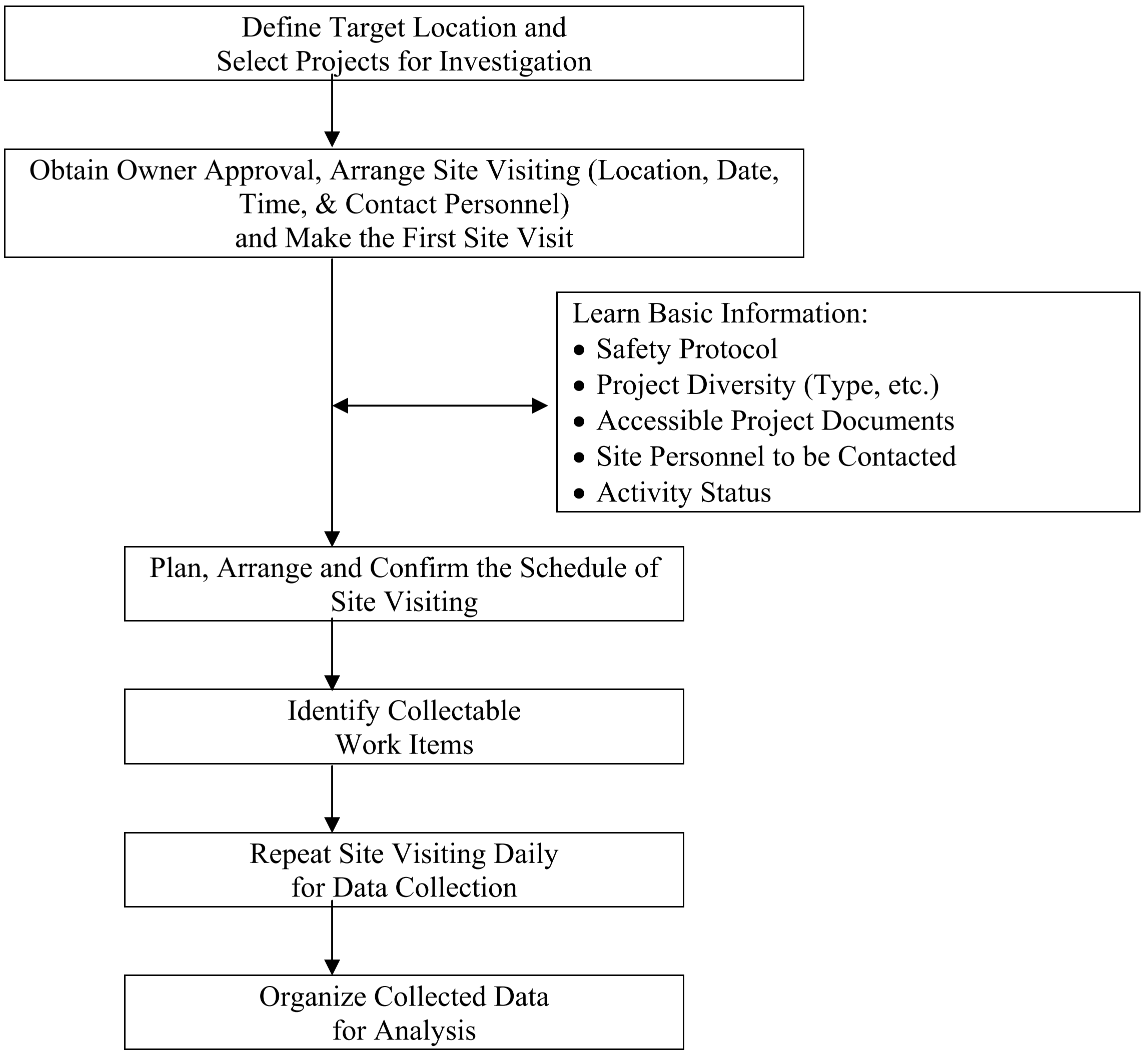


Figure 26. Site Visit and Data Collection Process

Data collection focused on a task-level productivity measurement per 10-minute work cycle, specifically, the on-site measurement was accomplished by randomly selected a worker in a single shift and the documentation of the factors that may have affected work. It was important to determine the process of a work activity from the beginning until it was finished in a work cycle because any large variation in a job task would have complicated the data collection procedures. Since the daily work process and the work environment were equally important, the job task had to be accessible for physical and visual inspection. The daily measurement during the work shift involved counting work hours, quantities and quality of work items installed and then documenting other factors regarding the job site. Discussions with the workers, especially the crew/foremen, were held frequently to obtain information regarding the progress and problems encountered by the workers. Continuous variables were measured daily, which include crew size, worker's age and experience, temperature, weather condition, interference, and so forth. It required the observers to be familiar with the site conditions and have a good working relationship with the crew, foremen and superintendents.

Data collection was based on visual observations, physical measurements, reviews of construction documents, and brief discussions with the workers, crew or foremen. Data collection forms were provided to the observers (the researcher and his research assistants in the U.S. and China) for recording the data and other factors that may have affected the productivity. The data collection form is illustrated in Appendix A. The form was used to specify the scope of each work item for which data were collected and to note different factors that may influence the production rate of each work item at task-level (see Table 11). It provided guidance to ensure consistent observations and data collection. Work elements included in the scope of work were those that most directly represent actual production of the work item and are the primary concerns in estimating construction time. To accommodate variability in the scope of work and task-level factors among work items, each data collection form is unique for a given work item.

Table 11. Work Item Scope: Included vs. Not Included

	Scope	
Work Item	**Included**	**Not Included**
Fire Protection System – Fire Protection Sprinkler System	Installation of pipes, supports, moving equipment/material, installation of valves/heads, on-site preparation/cleaning before work, and breaks	Material fabrication and transportation/cleaning site after work/inspection & testing
Building Mechanical System – Heating, Ventilating, and Air Conditioning (HVAC) System	Installation of ductwork/equipment, supports, moving equipment/material, on-site preparation/cleaning before work, and breaks	Material fabrication and transportation/cleaning site after work/inspection & testing
Masonry – Brickwork	Placement of brick works, on-site preparation/cleaning before work, and breaks	Cleaning site after work/ transportation of bricks from jobsite yard to work location/material handling/mixing mortar

4.2.1 Fire Protection Sprinkler System

In this research, the installation of a fire protection sprinkler system at different jobsites in the U.S. and China was observed and recorded. The portion of a sprinkler system above ground is considered the fire protection sprinkler system. A fire protection sprinkler system is a system of overhead piping designed in accordance with local fire protection engineering standards in each country. It is a network of hydraulically designed piping installed in an overhead area of a building, and to which sprinklers are connected in a systematic pattern. The system is supplied from a water supply connected to the city main. On the selected jobsites in the U.S. and China, the wet-pipe systems were installed with components including the automatic sprinklers, steel piping, couplings, flange adapters, fittings, hole cut, valves, strainers, suction diffuser, expansion joints, etc. Examples of fire protection sprinkler system installation in which the procedures are similar in both countries are illustrated in Appendix C.

In U.S., fire protection workers who are responsible for installation, alteration, extension or addition of all piping, material and equipment inside a building were required to be licensed. In China, workers who have the same responsibility were not required to be certified or licensed.

4.2.2 Heating, Ventilation, and Air Conditioning System

A Heating, Ventilation, and Air Conditioning (HVAC) System is referred to as the climate control in a building. Three functions are closely interrelated, as the system controls the temperature, humidity, and indoor air quality within a building in addition to providing for smoke control, maintaining pressure relationships between spaces, and provide fresh air for occupants. In modern building designs, the design, installation, and control systems of these functions are integrated into a single "HVAC" system. In this research, the installation of a HVAC duct system was the part of an overall HVAC system observed and recorded in the U.S. and China. The duct system is often called "ductwork," which is used to deliver and remove air, for example, supply air, return air, exhaust air. The duct system components which were observed included branch duct take-off fittings, air volume control dampers, smoke/fire dampers, return air plenums, terminal units, etc. Duct sealing was also included as a part of the HVAC duct system. It is the sealing of leaks in air ducts in order to reduce air leakage, optimize efficiency, and control entry of air pollutants into the building.

In the U.S., HVAC workers, who are responsible for installation, alteration, or addition of a HVAC system, were required to have five years of training and be certified as a professional. In China, workers who have the same responsibility were not required to be professionally trained, certified or licensed.

4.2.3 Masonry

Brickwork is masonry construction in which units of baked clay or shale of uniform size, small, enough to be placed with one's hands, are laid in courses with mortar joints to form walls. Where the bricks are to remain fully visible, as opposed to being covered up by plaster or stucco, this is known as face-work or facing brickwork. In this research, observations focused on all brickwork which is produced by a bricklayer, using bricks and mortar to build up a brick structures such as walls. The size of bricks being used by U.S. bricklayers is 5.72 cm (2.25") by 9.21 cm (3.63") by 19.37 cm (7.63") with three core holes. The size of bricks being used by Chinese bricklayers is 5.3 cm (2.09") by 10.6 cm (4.17") by 23.5 cm (9.25") with no core hole. Occasionally, brick was cut into various shapes to fill in spaces at corners and other locations where a full brick did not fit. Under these circumstances, the brick is measured as one full brick in the data collection. Examples of bricklaying in which the procedures are similar in both countries are illustrated in Appendix D.

In the U.S., masonry workers are required to have three-year training to be certified as a bricklayer or mason. In China, workers who have the same responsibility were not required to be professionally trained or certified.

4.3 Data Analyses

The overall process of applying statistical methods is to identify the causes of differences, if any, after comparing the data collected from the U.S. and China and to illustrate the methodology of data presentation. The factors were identified by visually inspecting scatter plots and distribution plots and by using descriptive statistics. An analysis of variance (ANOVA), frequency analysis, correlation, Chi-Square test, and Kruskal-Wallis test were then employed to analysis the data by using the Statistical Package for Social Scientists (SPSS).

Descriptive statistics are commonly used to summarize a data set in a simple and understandable way, rather than being used to support inferential statements about the measurements or values that the data are thought to represent. In this research, general project data are presented with numerical and graphics analysis. The data gathered were analyzed to present the number of work items in each category and its corresponding work cycle time. Results of the detailed project data sets are illustrated in Chapter 5.

CHAPTER 5: DATA ANALYSES

5.1 Introduction

This chapter describes the productivity data of projects which were collected by using the stopwatch and work sampling methods in the U.S. and China. The data were analyzed using statistical methods to determine if they contain factor(s) that are related to labor productivity in each country. As has been previously mentioned, the purpose of this research is to compare the labor productivity in the U.S. and China. Therefore, all data were ensured to be collectable and analyzable. The data are presented under the following headings: productivity data set in the U.S., and productivity data set in China. The productivity data set section summarizes the descriptive data in each country. Each workforce activities are distinguished, essentially, in three major categories: direct work (D) – using tools or effort at a designated work location to perform an assigned task that makes a direct, productive contribution to completing the work scope; indirect work (I) – support activities that are not directly contributing to completing a job; and non-working (N) – all unexplained non-utilization or personal idle time. Each of these categories has its sub-categories with code definitions are shown in the Table 12.

Table 12. Work Scope Coding Used for On-Site Data Collection

Direct Work (D):	Indirect Work (I):	Non-Working (N):
D1 – Measure space for exact position before installation D2 – Prepare materials for the activity (material measuring, cutting, lifting, taping, modifying, etc.) D3 – Hands-on activity (installing, sealing, finishing, etc.) D4 – Check and adjust position/alignment of new installation	I1 – Read blueprint drawing I2 – Prepare space for direct work (observing, initial measuring, cleaning, clearing, marking, cutting opening, etc.) I3 – Walk back/relocate with tools/materials (equipment, hand/power tools, accessories, etc.) I4 – Walk back/around empty handed (searching for tools/materials/accessories, etc.) I5 – Discuss with foremen/co-worker for direct work I6 – Receive tools/materials/assistance from other workers I7 – Assist co-worker I8 – Re-adjust previous installation I9 – Get electrical power for tools/equipment I10 – Seal outlet/opening of installment for temporary protection	N1 – Chat with others N2 – Personal reasons (phone calls, smoking, restroom, etc.) N3 – Break time N4 – Early Leave for Lunch

5.2 Productivity Data Set in the U.S.

In this study, the on-site labor productivity data were collected from two projects. Construction labor measurements from fire protection sprinkler systems, HVAC systems, and brickwork were used for this data analysis process. Pertinent statistics for the three categorical data sets are summarized, as shown in Table 13. The data sets contain data covering a total of 239.3 work hours from a total of 1,436 observations (10-minute work cycles). Comparison of work hours for all three work categories is shown below (see Table 13) and the actual measured percentages for each work category are shown in pie chart format (see Figures 27 to 38).

Table 13. Data Set Summary Statistics for Categories in the U.S.

Category	No. of Observations	Direct Work Hours	Indirect Work Hours	Non-Working Hours	Total Work Hours
Fire Protection Sprinkler System	442	27.11	37.41	9.15	73.67
HVAC System	407	32.79	26.35	8.69	67.83
Brickwork	587	66.23	22.21	9.40	97.83

Data collected from the jobsites in the U.S. indicate that between 37 and 67 percent is for direct work hours. In addition, the time proportions are illustrated which includes the direct work hours (37-67 percent), indirect work hours (23-50 percent) and non-working (10-13 percent) hours. The following pie charts (see Figures 27, 31, and 35) show the distributions of each work category at task-level where the elements are categorized into three proportions based on the collected data.

When comparing proportions within the direct work hours, indirect work hours, and non-working hours of each work category, the measuring elements (refer to Table 12 for definitions) are used for additional pie charts to illustrate the proportions of each sub-category.

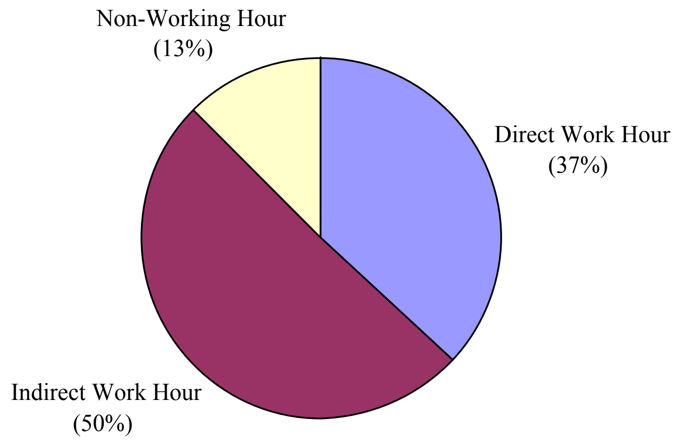


Figure 27. Chart of Proportions of U.S. Labor Hours in Fire Protection Sprinkler System

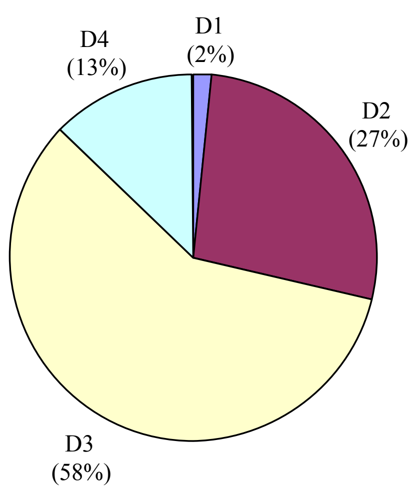


Figure 28. Chart of Direct Work Proportions within Direct Work Hours in Fire Protection Sprinkler System

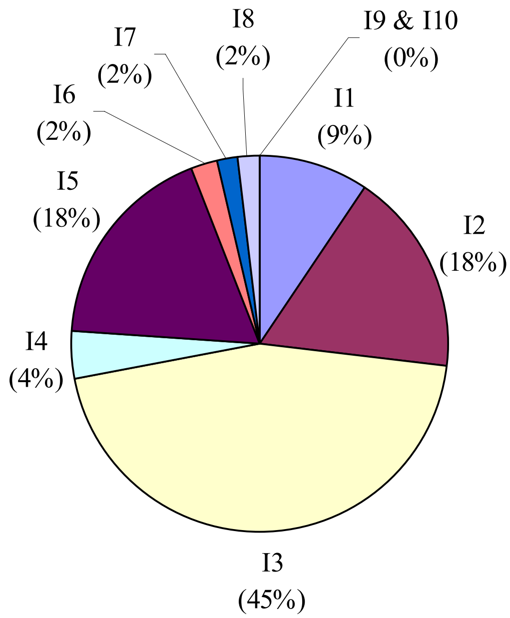


Figure 29. Chart of Indirect Work Proportions within Indirect Work Hours in Fire Protection Sprinkler System

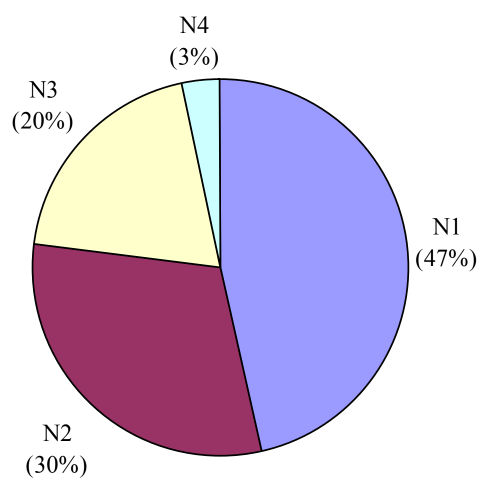


Figure 30. Chart of Non-Working Proportions within Non-Working Hours in Fire Protection Sprinkler System

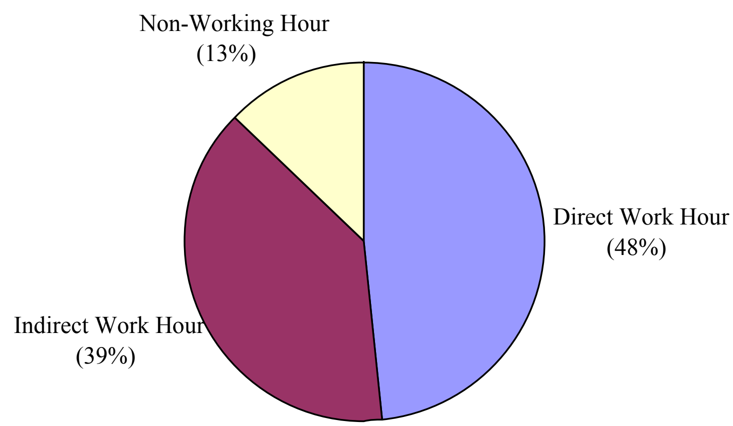


Figure 31. Chart of Proportions of U.S. Labor Hours in HVAC System

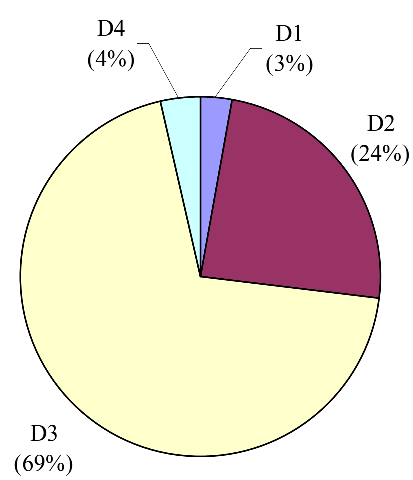


Figure 32. Chart of Direct Work Proportions within Direct Work Hours in HVAC System

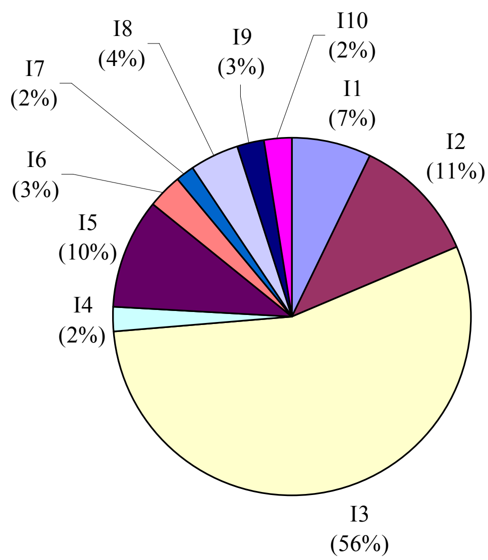


Figure 33. Chart of Indirect Work Proportions within Indirect Work Hours in HVAC System

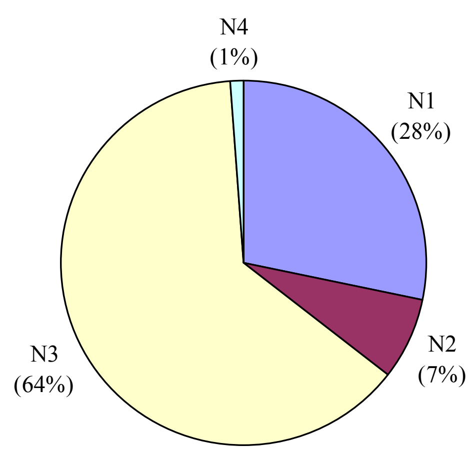


Figure 34. Chart of Non-Working Proportions within Non-Working Hours in HVAC System

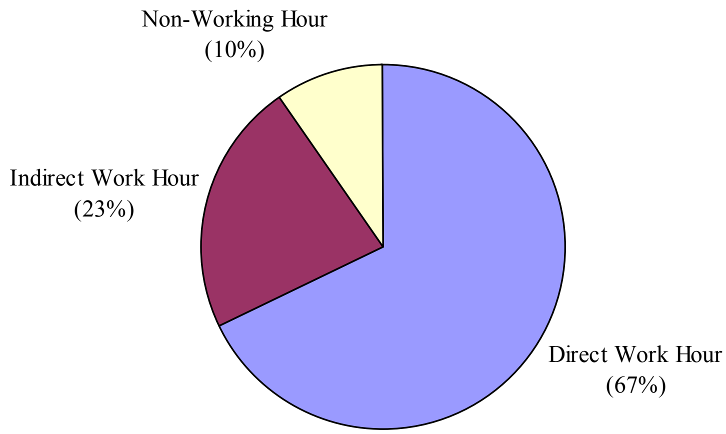


Figure 35. Chart of Proportions of U.S. Labor Hours in Brickwork

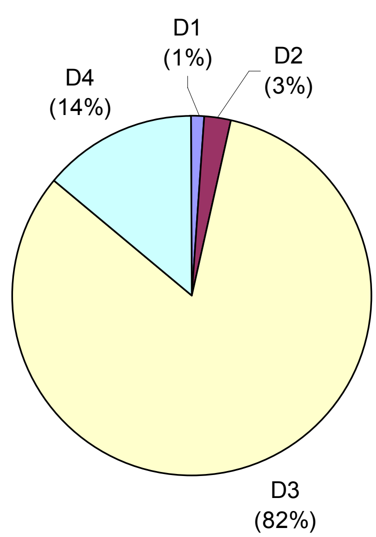


Figure 36. Chart of Direct Work Proportions within Direct Work Hours in Brickwork

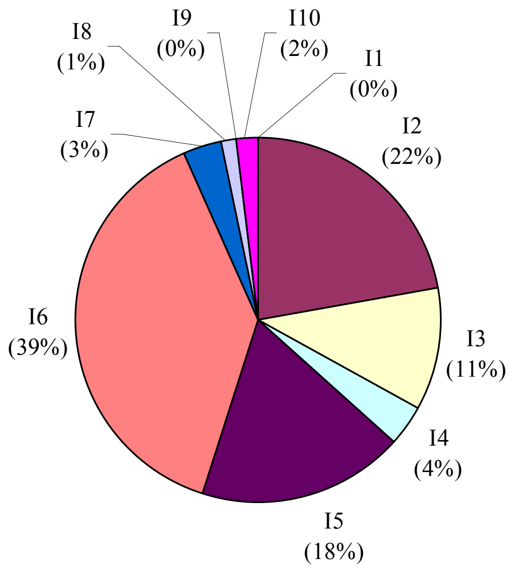


Figure 37. Chart of Indirect Work Proportions within Indirect Work Hours in Brickwork

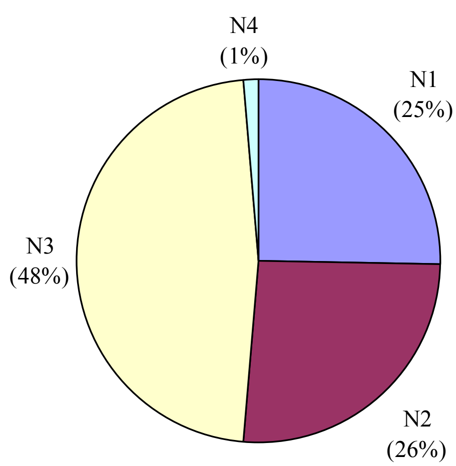


Figure 38. Chart of Non-Working Proportions within Non-Working Hours in Brickwork

In this research, a total of 239.3 work hours of on-site data measurement were investigated to determine the work proportions of each work category, as shown in Figure 39. All data were analyzed so that the researcher could identify the direct work hours, indirect work hours, and non-working hours for each operation. The work category which had the highest direct work hours compared to the other two work categories was brickwork which showed fewer indirect work hours and non-working hours. Comparing the other two work categories, which include fire protection sprinkler system and HVAC system, it shows a slightly different output with the HVAC system being higher than the fire protection sprinkler system. From the results of analyzing the sub-categories of each operation, the researcher could identify more differences between three work categories, as shown in Table 14.

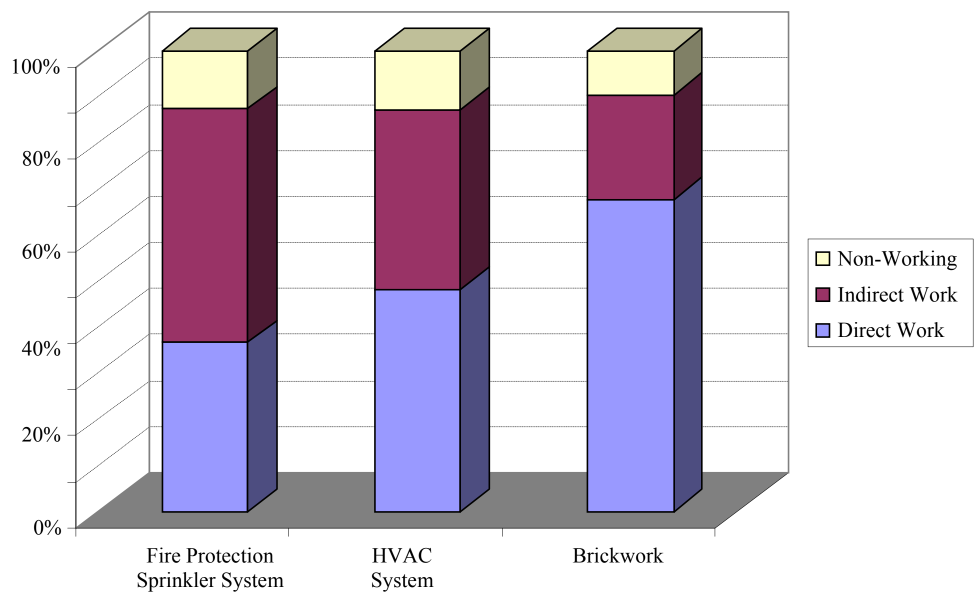


Figure 39. Comparing Proportions of U.S. Labor Hours by Work Category

Table 14. Summary of Work Proportions for Each Work Category in the U.S.

		Work Proportions (%)		
		Fire Protection Sprinkler System	HVAC System	Brickwork
Direct Work Hours	D1	2	3	1
	D2	27	24	3
	D3	58	69	82
	D4	13	4	14
	Total	100	100	100
Indirect Work Hours	I1	9	7	0
	I2	18	11	22
	I3	45	56	11
	I4	4	2	4
	I5	18	10	18
	I6	2	3	39
	I7	2	2	3
	I8	2	4	1
	I9	0	3	0
	I10	0	2	2
	Total	100	100	100
Non-Working Hours	N1	47	28	25
	N2	30	7	26
	N3	20	64	48
	N4	3	1	1
	Total	100	100	100

Correlation coefficients were computed to determine whether U.S. workers' age and experience were significantly related to their work performance (productive vs. nonproductive time) and labor productivity for work at task level in all three work categories. The results of the correlational analyses presented in Table 15 and Figure 40 show that age and experience were significantly correlated, but neither one was significantly related to work performance nor labor productivity. In general, the results indicate that U.S. workers who are older tend to have more work experience. However, U.S. workers' age and experience are not significantly related to their work performance and productivity.

Table 15. Correlations among Labor Productivity, Work Time, Worker's Age and Experience in the U.S.

		Workers' Age	Workers' Experience	No. of Observations
Fire Protection Sprinkler System	Labor Productivity	0.009	-0.500	442
	Direct Work Time	0.037	-0.060	
	Indirect Work Time	-0.056	-0.025	
	Non-Working Time	0.027	0.043	
	Workers' Age	-	0.920**	
HVAC System	Labor Productivity	0.065	0.036	407
	Direct Work Time	0.050	0.024	
	Indirect Work Time	-0.089	-0.073	
	Non-Working Time	0.050	0.065	
	Workers' Age	-	0.905**	
Brickwork	Labor Productivity	-0.071	-0.074	587
	Direct Work Time	-0.030	-0.050	
	Indirect Work Time	0.039	0.055	
	Non-Working Time	-0.005	0.005	
	Workers' Age	-	0.967**	

** Correlation is significant at the 0.01 level (2-tailed).
Note: In this research, U.S. workers' age ranged from 20 to 63 years old with work experience between 0 and 45 years.

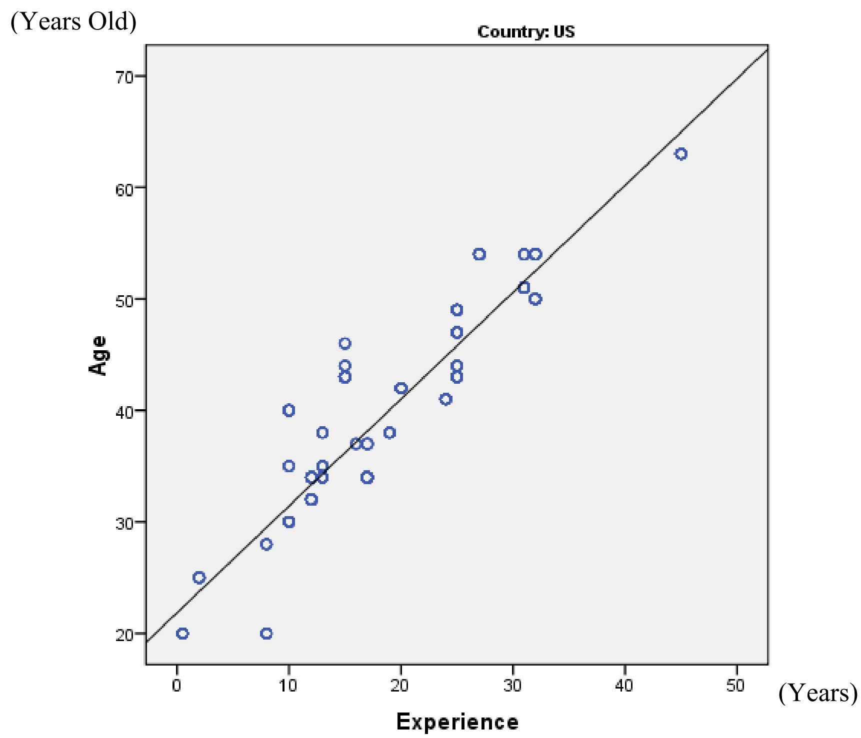


Figure 40. Correlation between Workers' Age and Experience in the U.S.

Correlation coefficients were computed to determine whether time of the day (morning vs. afternoon) and on-site temperature were significantly related to their work performance (productive vs. nonproductive time) and labor productivity for work at task level in all three work categories. The results of the correlational analyses presented in Table 16 show that time of the day and on-site temperature were not significantly correlated, and neither one was significantly related to work performance nor labor productivity.

Table 16. Correlations among Labor Productivity, Work Time, Daytime, and On-Site Temperature in the U.S.

		Daytime (AM/PM[1])	On-Site Temperature[2]	No. of Observations
Fire Protection Sprinkler System	Labor Productivity	-0.090	0.118*	442
	Direct Work Time	0.079	-0.021	
	Indirect Work Time	-0.083	-0.028	
	Non-Working Time	0.008	0.069	
HVAC System	Labor Productivity	0.060	-0.034	407
	Direct Work Time	0.079	-0.155**	
	Indirect Work Time	0.062	0.173**	
	Non-Working Time	-0.193**	-0.015	
Brickwork	Labor Productivity	0.122**	0.040	587
	Direct Work Time	-0.004	-0.122**	
	Indirect Work Time	0.049	0.086*	
	Non-Working Time	-0.055	0.070	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
1: AM (8:00 am - 12:00 pm); PM (12:30 pm - 3:30 pm).
2: On-Site Temperature ranged from 6 to 28 °C.

5.3 Productivity Data Set in China

In this study, the on-site labor productivity data were collected from three projects. Construction labor measurements from fire protection sprinkler systems, HVAC systems, and brickwork from the construction projects were used for this data analysis process. Pertinent statistics for the three categorical data sets are summarized, as shown in Table 17. The data sets contain data covering a total of 238.0 work hours from a total of 1,428 observations (10-minute work cycles). Comparison of work hours for all three work categories is shown below (see Table 17) and the actual measured percentages for each work category are shown in pie chart format (see Figures 41 to 52).

Table 17. Data Set Summary Statistics for Categories in China

Category	No. of Observations	Direct Work Hours	Indirect Work Hours	Non-Working Hours	Total Work Hours
Fire Protection Sprinkler System	446	26.72	41.68	5.94	74.34
HVAC System	404	23.90	39.11	4.33	67.34
Brickwork	578	67.14	26.01	3.18	96.33

Data collected from the jobsites in China indicate that between 35 and 70 percent is for direct work hours. In addition, the time proportions are illustrated which includes the direct work hours (35-70 percent), indirect work hours (27-59 percent) and non-working (3-8 percent) hours. The following pie charts (see Figures 41, 45, and 49) show the distributions of each work category at task-level where the elements are categorized into three proportions based on the collected data.

When comparing proportions within the direct work hours, indirect work hours, and non-working hours of each work category, the measuring elements (refer to Table 12 for definitions) are used for additional pie charts to illustrate the proportions of each sub-category.

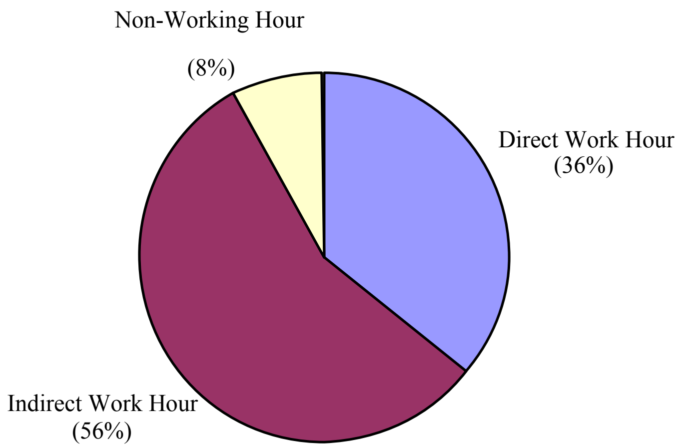


Figure 41. Chart of Proportions of Chinese Labor Hours in Fire Protection Sprinkler System

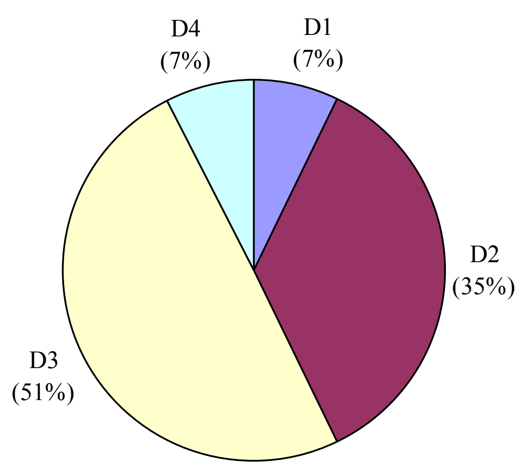


Figure 42. Chart of Direct Work Proportions within Direct Work Hours
in Fire Protection Sprinkler System

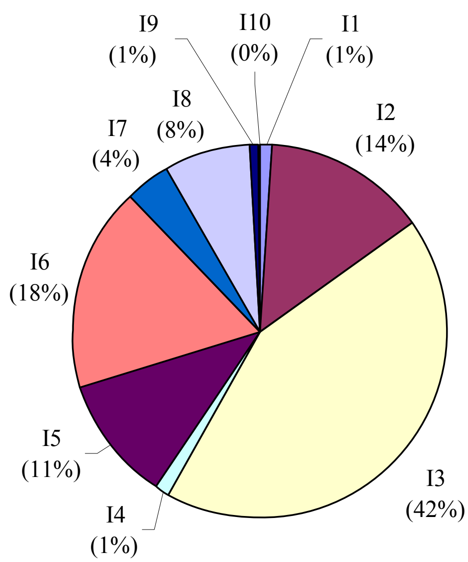


Figure 43. Chart of Indirect Work Proportions within Indirect Work Hours in Fire Protection Sprinkler System

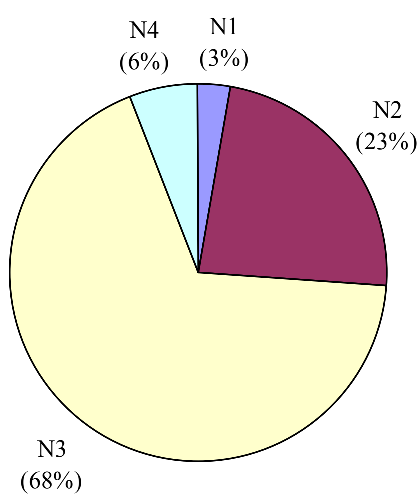


Figure 44. Chart of Non-Working Proportions within Non-Working Hours in Fire Protection Sprinkler System

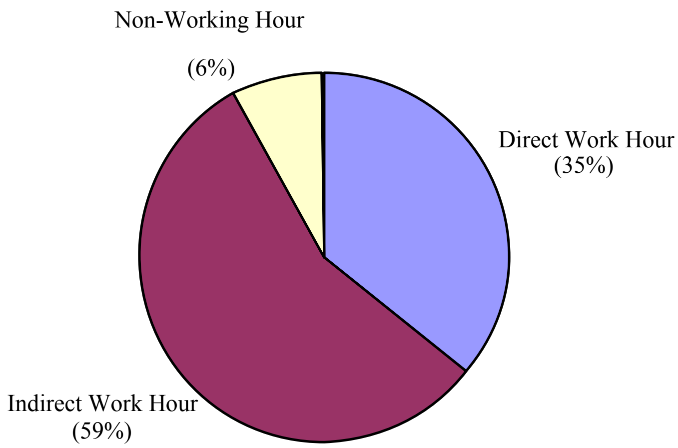


Figure 45. Chart of Proportions of Chinese Labor Hours in HVAC System

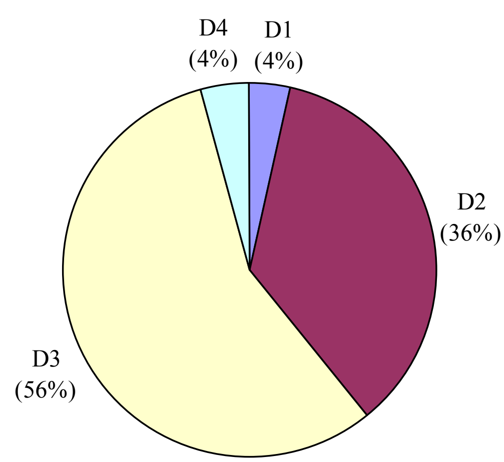


Figure 46. Chart of Direct Work Proportions within Direct Work Hours in HVAC System

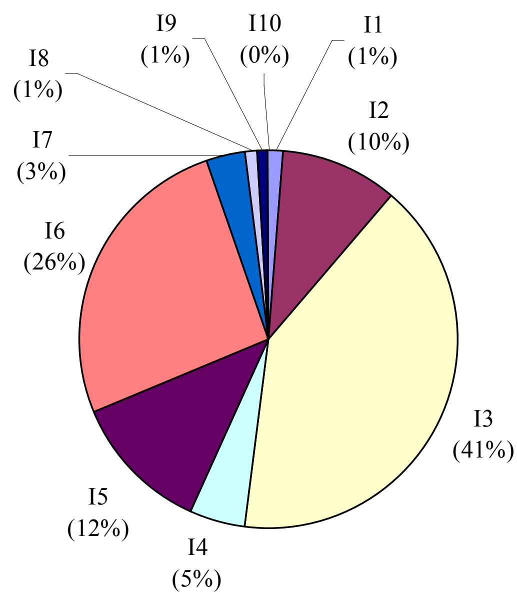


Figure 47. Chart of Indirect Work Proportions within Indirect Work Hours in HVAC System

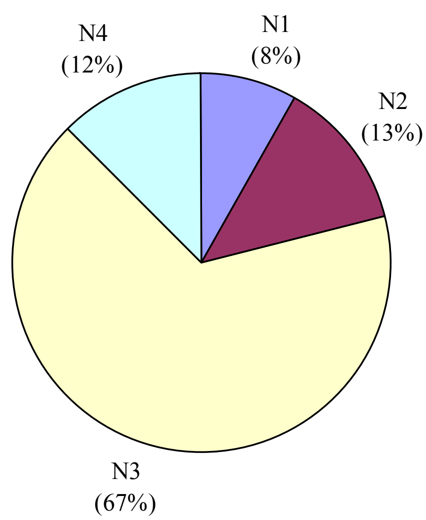


Figure 48. Chart of Non-Working Proportions within Non-Working Hours in HVAC System

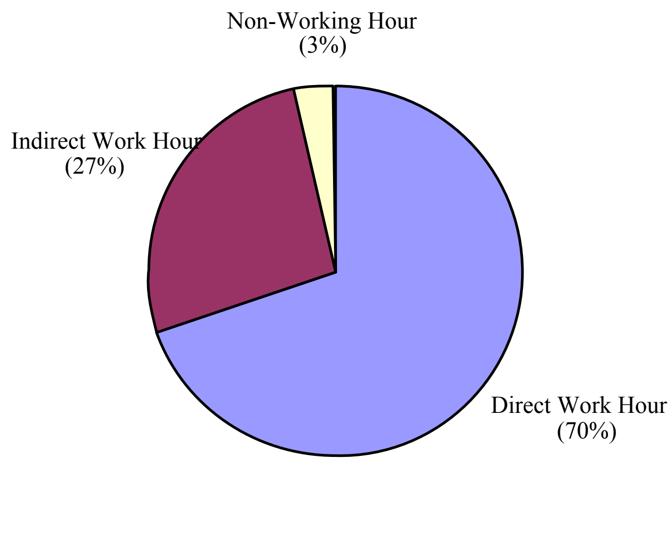


Figure 49. Chart of Proportions of Chinese Labor Hours in Brickwork

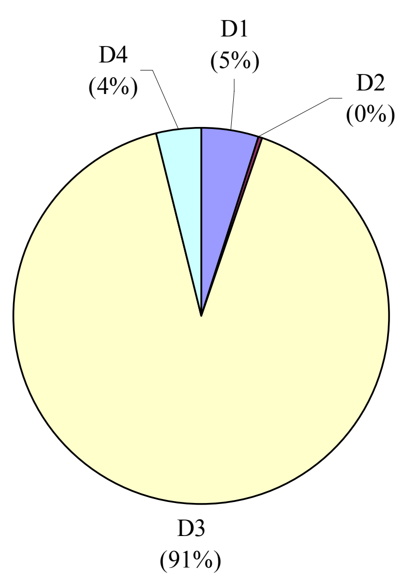


Figure 50. Chart of Direct Work Proportions within Direct Work Hours in Brickwork

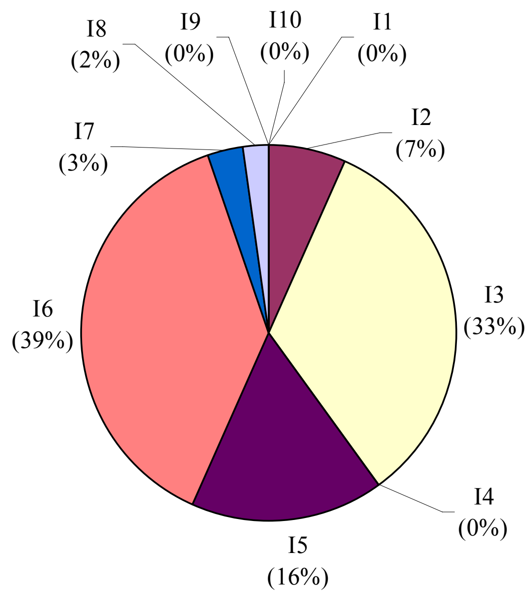


Figure 51. Chart of Indirect Work Proportions within Indirect Work Hours in Brickwork

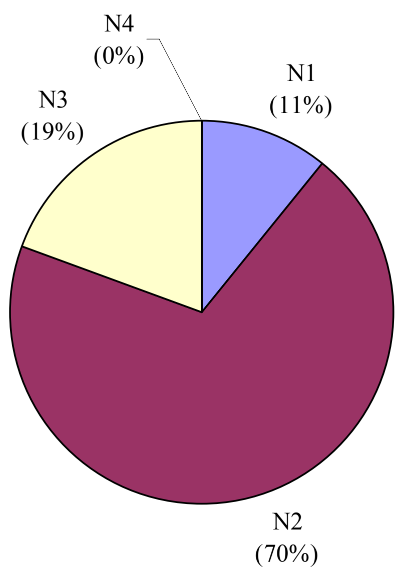


Figure 52. Chart of Non-Working Proportions within Non-Working Hours in Brickwork

In this research, a total of 238.0 work hours of on-site data measurement were investigated to determine the work proportions of each work category, as shown in Figure 53. All data were analyzed, so that the researcher could identify the direct work hours, indirect work hours, and non-working hours for each operation. The only work category which had higher direct work hours comparing to the other two work categories was brickwork which showed fewer indirect work hours and non-working hours. Comparing the other two work categories, which include fire protection sprinkler systems and HVAC systems, it shows similar output from the collected data. From the results of analyzing the sub-categories of fire protection sprinkler systems and HVAC systems, the researcher could identify differences between these two work categories, as shown in Table 18.

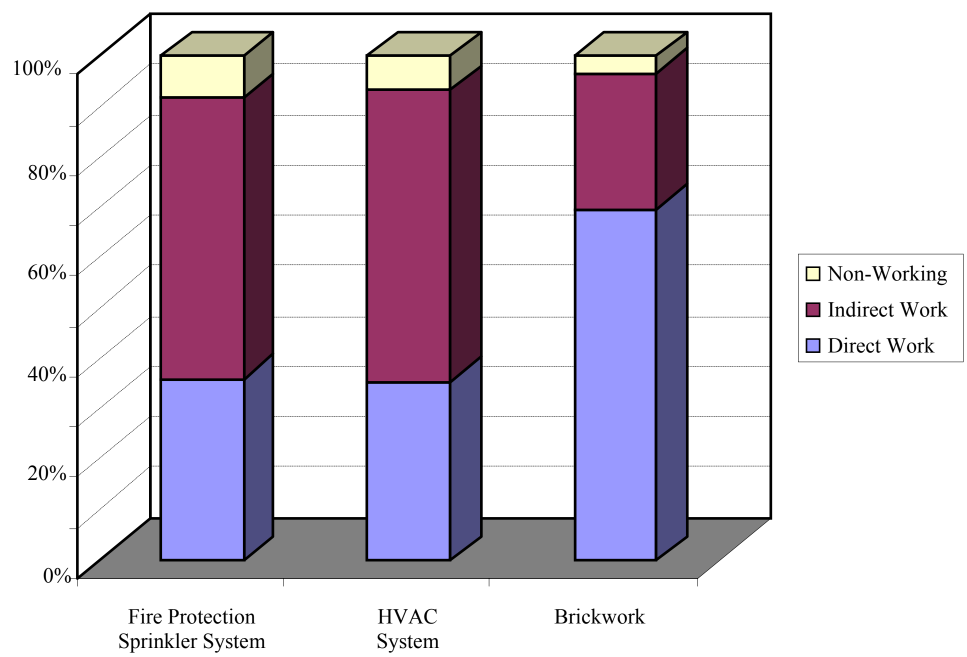


Figure 53. Comparing Proportions of Chinese Labor Hours by Work Category

Table 18. Summary of Work Proportions for Each Work Category in China

		Work Proportions (%)		
		Fire Protection Sprinkler System	**HVAC System**	**Brickwork**
Direct Work Hours	D1	7	4	5
	D2	35	36	0
	D3	51	56	91
	D4	7	4	4
	Total	100	100	100
Indirect Work Hours	I1	1	1	7
	I2	14	10	33
	I3	42	41	0
	I4	1	5	16
	I5	11	12	39
	I6	18	26	3
	I7	4	3	2
	I8	8	1	0
	I9	1	1	0
	I10	0	0	0
	Total	100	100	100
Non-Working Hours	N1	3	8	11
	N2	23	13	70
	N3	68	67	19
	N4	6	12	0
	Total	100	100	100

Correlation coefficients were computed to determine whether Chinese workers' age and experience are significantly related to their work performance (productive vs. nonproductive time) and labor productivity for work at task-level in all three work categories. The results of the correlational analyses presented in Table 19 and Figure 54 show that age and experience were not significantly correlated, and neither one was significantly related to work performance or labor productivity. In general, the results indicate that Chinese workers who are older may not have more work experience, unlike the U.S. workers. In the meantime, Chinese worker's age and experience are not related to their work performance and productivity.

Table 19. Correlations among Labor Productivity, Work Time, Worker's Age and Experience in China

		Workers' Age	Workers' Experience	No. of Observations
Fire Protection Sprinkler System	Labor Productivity	0.004	0.020	446
	Direct Work Time	0.137**	0.144**	
	Indirect Work Time	-0.030	-0.024	
	Non-Working Time	-0.162**	-0.182**	
	Workers' Age	-	0.769**	
HVAC System	Labor Productivity	0.152**	0.185**	404
	Direct Work Time	0.114*	0.001	
	Indirect Work Time	-0.164**	-0.007	
	Non-Working Time	0.092	0.010	
	Workers' Age	-	0.254**	
Brickwork	Labor Productivity	-0.172**	-0.069	578
	Direct Work Time	0.022	0.011	
	Indirect Work Time	-0.009	-0.010	
	Non-Working Time	-0.037	-0.004	
	Workers' Age	-	0.470**	

** Correlation is significant at the 0.01 level (2-tailed).
*   Correlation is significant at the 0.05 level (2-tailed).
Note: In this research, Chinese workers' age ranged from 18 to 57 years old with work experience between 0 and 26 years.

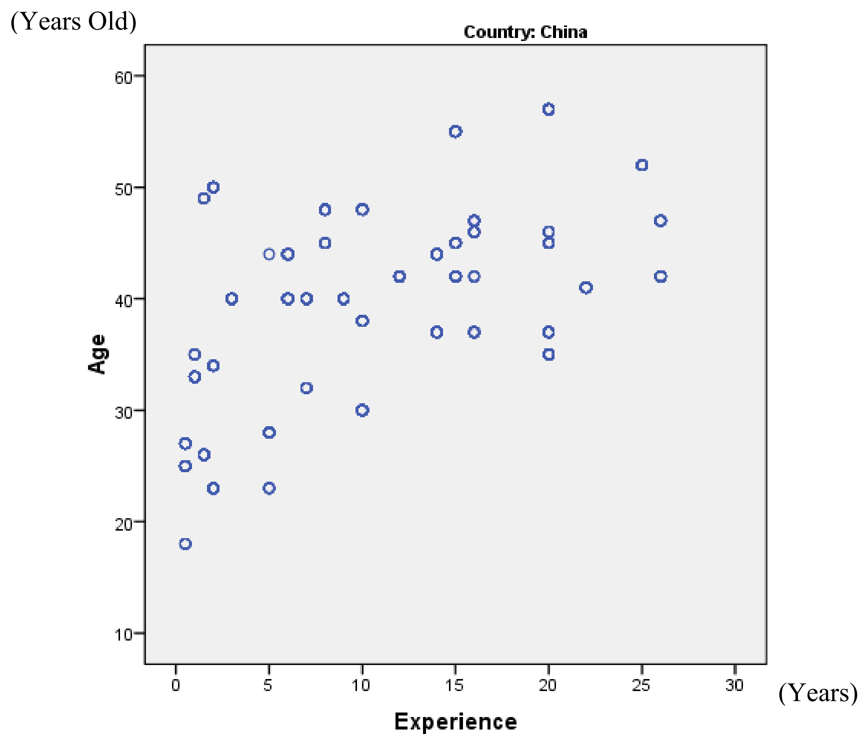


Figure 54. Correlation between Workers' Age and Experience in China

Correlation coefficients were computed to determine whether time of the day (morning vs. afternoon) and on-site temperature are significantly related to their work performance (productive vs. nonproductive time) and labor productivity for work at task-level in all three work categories. The results of the correlational analyses presented in Table 20 show that time of the day and on-site temperature were not significantly correlated, and neither one was significantly related to work performance or labor productivity.

Table 20. Correlations among Labor Productivity, Work Time, Daytime, and On-Site Temperature in China

		Daytime (AM/PM[1])	On-Site Temperature[2]	No. of Observations
Fire Protection Sprinkler System	Labor Productivity	-0.102*	0.058	446
	Direct Work Time	0.023	-0.186**	
	Indirect Work Time	0.004	0.093*	
	Non-Working Time	-0.042	0.137**	
HVAC System	Labor Productivity	0.004	-0.162**	404
	Direct Work Time	0.060	-0.142**	
	Indirect Work Time	0.020	0.063	
	Non-Working Time	-0.138**	0.132**	
Brickwork	Labor Productivity	-0.018	-0.094*	578
	Direct Work Time	-0.043	-0.010	
	Indirect Work Time	0.030	0.015	
	Non-Working Time	0.038	-0.014	

** Correlation is significant at the 0.01 level (2-tailed).
*   Correlation is significant at the 0.05 level (2-tailed).
1: Daytime: AM (8:30 am - 12:00 pm); PM (1:00 pm - 6:00 pm).
2: On-Site Temperature ranged from 18 to 33 °C.

CHAPTER 6: DATA COMPARISON BETWEEN U.S. AND CHINA

This chapter describes the comparison of characteristics of building construction projects in the labor productivity data sets collected on-sites in the U.S. and China. These analyses were used to identify the relationship between the labor productivity, workers' age, and experience that can be used to establish and model the production rates and measurements for helping to enhance U.S. construction firms' competitiveness in the Chinese market and improve project management capabilities in China.

6.1 Workers' Age

As shown in Table 21, the summary statistics demonstrate the overall characteristics of workers' age. The mean values for all workers' age were nearly identical with respective standard deviations of 9.95 for U.S. workers and 9.66 for Chinese workers. The variance and the standard deviation show the magnitude of data dispersion. As shown in Figure 55, the box plot illustrates the distribution of data based on the collected data, which include lower adjacent value (minimum), lower quartile (Q1), median (Q2), upper quartiles (Q3), and upper adjacent value (maximum). The box plot provides a revealing summary of the data. Since half of the workers were between the hinges (between Q1 and Q3), it shows that half the U.S. workers were between 34 and 49 years old whereas half the Chinese workers were between 30 and 45.8 years old. Overall, it appears that the U.S. workers were generally older than the Chinese workers.

Table 21. Descriptive Statistics of Workers' Age in the U.S. and China

	No. of Observation	Mean Age	Standard Deviation	Minimum	Maximum	Q1	Q2	Q3
U.S	1436	39.9	9.95	20	63	34	38	49
China	1428	39.1	9.66	18	57	30	40	45.8

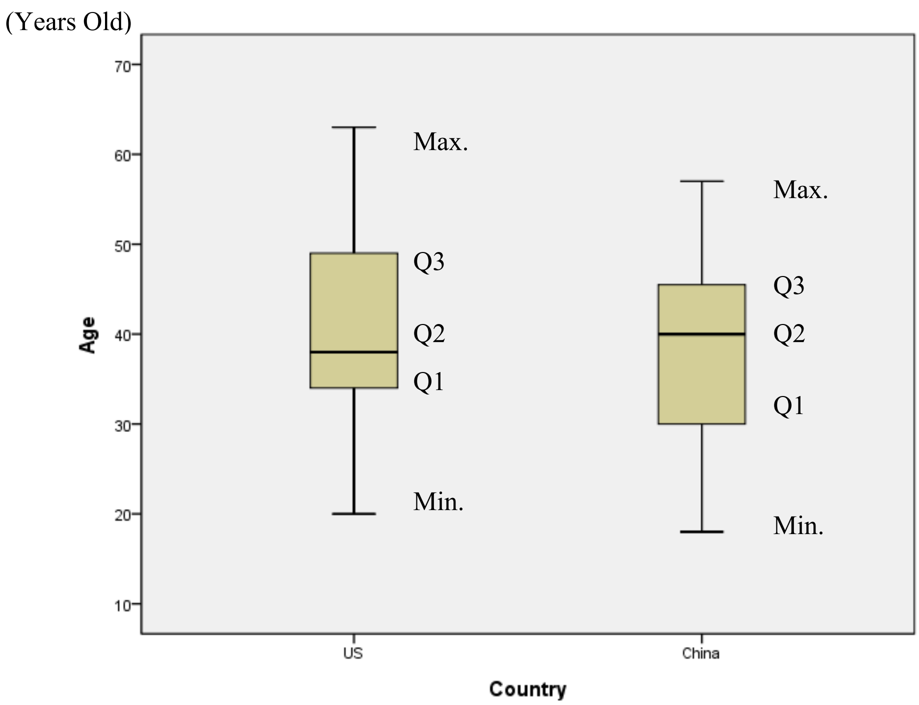


Figure 55. Box Plots on Workers' Age in the U.S. and China

Comparing workers' age in each work category, as shown in Table 22, the researcher made further inferences. A one-way ANOVA was conducted to evaluate the relationship between workers' age and work category in each country. The independent variable was the factor for country, which included the U.S. and China. The dependent variable was the workers' age in the U.S. and China. The result shows that the ANOVA was significant, $F(1, 886) = 23.43$, $p = <0.001$, for the fire protection sprinkler system workers. The result shows that Chinese workers working on fire protection sprinkler systems were significantly older (M = 34.40, SD = 9.82) than U.S. workers (M = 31.84, SD = 5.21) with the same responsibilities.

For HVAC system workers, the ANOVA found that Chinese workers were significantly younger (M = 36.24, SD = 7.08) than U.S. workers (M = 45.00, SD = 9.66), $F(1, 809) = 216.88$, $p = <0.001$. This result shows that there was a significant difference in the means between HVAC system workers' age and workers' age in the other two work categories.

For brickwork workers, the ANOVA found that Chinese workers were significantly older (M = 44.71, SD = 8.19) than U.S. workers (M = 42.43, SD = 9.15), $F(1, 1163) = 20.06$, $p = <0.001$. The 95 percent confidence intervals for the estimated marginal means, as well as the means and standard deviations for all three work categories, are reported in Table 22.

Table 22. Data Set Summary Statistics for Workers' Age in Each Work Category

		U.S.	China
Fire Protection Sprinkler System	No. of Observations	442	446
	Mean (Years)	31.84	34.40
	Standard Deviation	5.21	9.82
	95% Confidence Interval	31.11 32.58	33.67 35.13
	F test	23.43	
	p value	<0.001	
HVAC System	No. of Observations	407	404
	Mean (Years)	45.00	36.24
	Standard Deviation	9.66	7.08
	95% Confidence Interval	44.18 45.83	35.41 37.07
	F test	216.88	
	p value	<0.001	
Brickwork	No. of Observations	587	578
	Mean (Years)	42.43	44.71
	Standard Deviation	9.15	8.19
	95% Confidence Interval	41.73 43.14	44.00 45.42
	F test	20.06	
	p value	<0.001	

6.2 Workers' Experience

As shown Table 23, the summary statistics demonstrate the overall characteristics of workers' experience. The mean values for all workers' experience level were higher for U.S. workers (SD = 9.83) than Chinese workers (SD = 7.65). The variance and the standard deviation show the magnitude of data dispersion. As shown in Figure 56, the box plot provides a revealing summary of the data. Since half of the workers are between the hinges (between Q1 and Q3), it shows that half the U.S. workers had between 12 and 25 years of work experience whereas half the Chinese workers had between 3 and 16 years experience. Overall, it appears that U.S. workers had more years of work experience than Chinese workers had.

Table 23. Descriptive Statistics of Workers' Experience in the U.S. and China

	No. of Observation	Mean (Years)	Standard Deviation	Minimum	Maximum	Q1	Q2	Q3
U.S	1436	18.85	9.83	0	45	12	17	25
China	1428	10.53	7.65	0	26	3	9	16

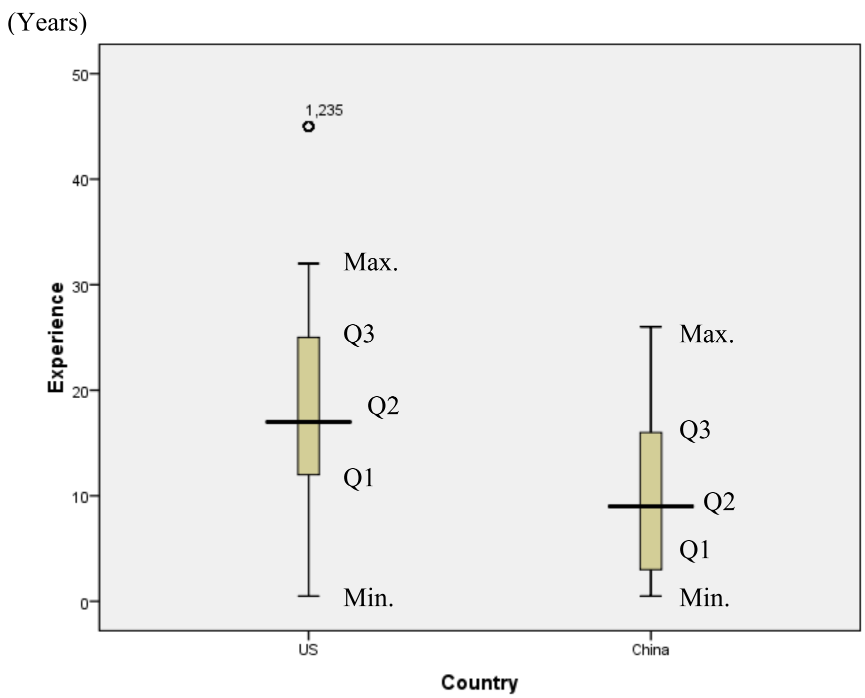


Figure 56. Box Plots on Workers' Experience in the U.S. and China

Comparing workers' experience in each work category, as shown in Table 24, the researcher made further inferences. A one-way ANOVA was conducted to evaluate the relationship between workers' experience and work category in each country. The independent variable was the factor for country, which included the U.S. and China. The dependent variable was the workers' experience in the U.S. and China. The result shows that the ANOVA was significant, $F(1, 886) = 271.57$, $p = <0.001$, for the fire protection sprinkler system workers. It shows Chinese workers working on fire protection sprinkler systems had significantly less experience (M = 5.89, SD = 5.29) than U.S. workers (M = 11.80, SD = 5.39) with the same responsibilities. For HVAC system workers, the ANOVA found that Chinese workers had significantly less experience (M = 9.55, SD = 6.54) than U.S. workers (M = 22.09, SD = 9.33), $F(1, 809) = 490.89$, $p = <0.001$.

For brickwork workers, the ANOVA found that Chinese workers had significantly less experience (M = 14.80, SD = 7.58) than U.S. workers (M = 21.92, SD = 10.00, $F(1, 1163) = 187.02$, $p = <0.001$. The 95 percent confidence intervals for the estimated marginal means, as well as the means and standard deviations for all three work categories, are reported in Table 24. This result indicates that there was no significant difference in the mean values for workers' experience level in all three work categories.

Table 24. Data Set Summary Statistics for Workers' Work Experience in the U.S. and China

		U.S.	China
Fire Protection Sprinkler System	No. of Observations	442	446
	Mean (Years)	11.80	5.89
	Standard Deviation	5.39	5.29
	95% Confidence Interval	11.30	5.39
		12.30	6.39
	F test	271.57	
	p value	<0.001	
HVAC System	No. of Observations	407	404
	Mean (Years)	22.09	9.55
	Standard Deviation	9.33	6.54
	95% Confidence Interval	21.30	8.76
		22.87	10.33
	F test	490.89	
	p value	<0.001	
Brickwork	No. of Observations	587	578
	Mean (Years)	21.92	14.80
	Standard Deviation	10.00	7.58
	95% Confidence Interval	21.20	14.08
		22.64	15.53
	F test	187.02	
	p value	<0.001	

6.3 Labor Productivity

Comparing labor productivity in each work category, as shown in Table 25, a one-way ANOVA was conducted to evaluate the relationship between labor productivity and each work category. The independent variable was the factor for country, which included the U.S. and China. The dependent variable was the labor productivity in the U.S. and China. The result shows that the ANOVA was significant, $F(1, 886) = 9.08$, $p = 0.003$, for the fire protection sprinkler system workers. It shows Chinese workers working on fire protection sprinkler system were significantly lower in labor productivity (M = 3.67, SD = 9.24) than U.S. workers (M = 5.72, SD = 11.04) with the same responsibilities.

For HVAC system workers, the ANOVA found that Chinese workers were significantly higher in labor productivity (M = 4.92, SD = 9.31) than U.S. workers (M = 2.77, SD = 6.55), F(1, 809) = 14.43, p = <0.001. For brickwork workers, the ANOVA found that Chinese workers were significantly higher in labor productivity (M = 129.46, SD = 84.08) than U.S. workers (M = 60.96, SD = 71.34), F(1, 1163) = 225.04, p = <0.001. The 95 percent confidence intervals for the estimated marginal means, as well as the means and standard deviations for all three work categories, are reported in Table 25.

Table 25. Data Set Summary Statistics for Labor Productivity in the U.S. and China

		U.S.	**China**
Fire Protection Sprinkler System	No. of Observations	442	446
	Mean	5.72	3.67
	Standard Deviation	11.04	9.24
	95% Confidence Interval	4.77 6.67	2.72 4.61
	F test	9.08	
	p value	0.003	
HVAC System	No. of Observations	407	404
	Mean	2.77	4.92
	Standard Deviation	6.55	9.31
	95% Confidence Interval	1.99 3.55	4.13 5.70
	F test	14.43	
	p value	<0.001	
Brickwork	No. of Observations	587	578
	Mean	60.96	129.46
	Standard Deviation	71.34	84.08
	95% Confidence Interval	54.65 67.27	123.10 135.82
	F test	225.04	
	p-value	<0.001	

In Tables 26 and 27, frequency tabulations of the U.S. and Chinese labor productivity in fire protection sprinkler system, HVAC system, and brickwork are used to determine the distribution frequency of work activities' occurrence, such as, the number of work cycles without direct work/indirect work/non-working activities, the number of work cycles with only direct work/indirect work/non-working activities, and a number of work cycles with no physical output. For example, as shown in Table 26, there were a total of 126 times of 10-minute work cycles with no direct work activities. In other words, it shows that there were only indirect work and/or non-working activities during those 10-minute work cycles. The results in Tables 26 an 27 below show the frequencies and percentages for work activity status in each category. The output from the analysis allows for comparison between the two countries in each category.

Table 26. Work Cycle and Labor Productivity Frequencies in the U.S.

	Work Activity	No. of Work Cycles WITHOUT this Activity	No. of Work Cycles WITH ONLY this Activity	No. of Work Cycles WITHOUT Output	Total Number of Observations
Fire Protection Sprinkler System	Direct Work	126	26	257	442
	Indirect Work	45	66		
	Non-Working	276	9		
HVAC System	Direct Work	108	61	294	407
	Indirect Work	107	60		
	Non-Working	278	25		
Brickwork	Direct Work	60	131	181	587
	Indirect Work	197	28		
	Non-Working	409	19		

Table 27. Work Cycle and Labor Productivity Frequencies in China

	Work Activity	No. of Work Cycles ***WITHOUT*** this Activity	No. of Work Cycles ***WITH ONLY*** this Activity	No. of Work Cycles ***WITHOUT*** Output	Total Number of Observations
Fire Protection Sprinkler System	Direct Work	129	28	301	446
	Indirect Work	40	102		
	Non-Working	362	10		
HVAC System	Direct Work	117	15	251	404
	Indirect Work	27	86		
	Non-Working	326	7		
Brickwork	Direct Work	45	74	64	578
	Indirect Work	96	40		
	Non-Working	490	0		

Table 28 illustrates the percentages of work cycle for each work activity in each work category between the U.S. and China. In the fire protection sprinkler systems category, Chinese workers had more 10-minute work cycles with only direct work activities (6.3%) than U.S workers' had (5.9%); and had more work cycles without non-working activity (81.2%) than U.S. workers' had (62.4%). However, Chinese workers had more work cycles without physical output (67.5%), comparing to U.S. workers with 58.1 percent of work cycles without physical output. Overall, this table indicates that U.S. workers had higher productive work cycle rates than Chinese workers had from computing the frequencies; however, U.S. workers had lower work cycles rate without non-working activities than Chinese workers had.

Table 28. Work Cycle and Labor Productivity Percentage in the U.S. and China

	Work Activity	Work Cycles *WITHOUT* this Activity		Work Cycles *WITH ONLY* this Activity		Work Cycles *WITHOUT* Output	
		U.S.	China	U.S.	China	U.S.	China
Fire Protection Sprinkler System	Direct Work	28.5%	28.9%	5.9%	6.3%	58.1%	67.5%
	Indirect Work	10.2%	9.0%	14.9%	22.9%		
	Non-Working	62.4%	81.2%	2.0%	2.2%		
HVAC System	Direct Work	26.5%	29.0%	15.0%	3.7%	72.2%	62.1%
	Indirect Work	26.3%	6.7%	14.7%	21.3%		
	Non-Working	68.3%	80.7%	6.1%	1.7%		
Brickwork	Direct Work	10.2%	7.8%	22.3%	12.8%	30.8%	11.1%
	Indirect Work	33.6%	16.6%	4.8%	6.9%		
	Non-Working	69.7%	84.8%	3.2%	0.0%		

In the HVAC system category, Chinese workers had fewer work cycles with only direct work activities (3.7%) than U.S workers' had (15.0%); but they had more work cycles without non-working activity (80.7%) than U.S. workers' had (68.3%). However, Chinese workers had fewer work cycles without physical output (62.1%), comparing to U.S. workers with 72.2 percent of work cycles without physical output. Overall, this table indicates that U.S. workers had lower productive work cycle rates than Chinese workers had from computing the frequencies; and, U.S. workers also had lower work cycle rates without non-working activities than Chinese workers had.

In the brickwork category, Chinese workers had fewer work cycles with only direct work activities (12.8%) than U.S workers' had (22.3%); but they had more work cycles without non-working activity (84.8%) than U.S. workers' had (69.7%). However, Chinese workers had fewer work cycles without physical output (11.1%), comparing to U.S. workers with 30.8% percent of work cycles without physical output. Overall, this table indicates that U.S. workers had lower productive work cycle rates than Chinese workers had from computing the frequencies; and, U.S.

workers also had lower work cycle rates without non-working activities than Chinese workers had.

As shown in Table 29, a Kruskal-Wallis test was conducted to evaluate differences between the U.S. and China on median labor productivity. The test for labor productivity on fire protection sprinkler systems, which was corrected for tied ranks, was significant, $\chi^2(1, 888) = 11.94$, $p = 0.001$. The test for labor productivity on HVAC systems, which was corrected for tied ranks, was significant, $\chi^2(1, 811) = 11.40$, $p = 0.001$. The test for labor productivity on brickwork, which was corrected for tied ranks, was significant, $\chi^2(1, 1165) = 206.46$, $p = <0.001$. The overall test results indicate that there was a fairly strong relationship between the distribution of labor productivity and in both the U.S. and China for all three work categories.

Table 29. Results of the Kruskal-Wallis Analysis for U.S and Chinese Labor Productivity

	Chi-Square (χ^2)	*p*-value
Fire Protection Sprinkler System	11.94	0.001
HVAC System	11.40	0.001
Brickwork	206.46	<0.001

Note: The result is significant when a *p*-value is less than 0.05.

As shown in Table 30, a Kruskal-Wallis test was conducted to evaluate differences between the U.S. and China on median direct work hours. The test for direct work hours on fire protection sprinkler systems, which was corrected for tied ranks, was not significant, $\chi^2(1, 888) = 0.22$, $p = 0.641$. The test for labor productivity on HVAC systems, which was corrected for tied ranks, was significant, $\chi^2(1, 811) = 23.15$, $p = <0.001$. The test for labor productivity on brickwork, which was corrected for tied ranks, was not significant, $\chi^2(1, 1165) = 0.035$, $p = 0.851$. The overall test results indicate that there was no relationship between the distribution of direct work hours in neither the U.S. nor China for fire protection sprinkler systems and brickwork. However, HVAC systems had a fairly strong relationship between the distribution of direct work hours in both the U.S. and China.

Table 30. Results of the Kruskal-Wallis Analysis for U.S. and Chinese Direct Work Hours

	Chi-Square (χ^2)	***p*-value**
Fire Protection Sprinkler System	0.22	0.641
HVAC System	23.15	<0.001
Brickwork	0.035	0.851

Note: The result is significant when a *p*-value is less than 0.05.

As shown in Table 31, a Kruskal-Wallis test was conducted to evaluate differences between the U.S. and China on median indirect work hours. The test for labor productivity on fire protection sprinkler systems, which was corrected for tied ranks, was significant, $\chi^2(1, 888) = 5.54$, $p = 0.019$. The test for labor productivity on HVAC systems, which was corrected for tied ranks, was significant, $\chi^2(1, 811) = 62.22$, $p = <0.001$. The test for labor productivity on brickwork, which was corrected for tied ranks, was significant, $\chi^2(1, 165) = 12.99$, $p = <0.001$. The overall test results indicate that there was a fairly strong relationship between the distribution of indirect work hours and in both the U.S. and China for all three work categories.

Table 31. Results of the Kruskal-Wallis Analysis for U.S. and Chinese Indirect Work Hours

	Chi-Square (χ^2)	***p*-value**
Fire Protection Sprinkler System	5.54	0.019
HVAC System	62.22	<0.001
Brickwork	12.99	<0.001

Note: The result is significant when a *p*-value is less than 0.05.

As shown in Table 32, a Kruskal-Wallis test was conducted to evaluate differences between the U.S. and China on median non-working hours. The test for labor productivity on fire protection sprinkler systems, which was corrected for tied ranks, was significant, $\chi^2(1, 888)$ = 33.46, p = <0.001. The test for labor productivity on HVAC systems, which was corrected for tied ranks, was significant, $\chi^2(1, 811)$ = 16.61, p = <0.001. The test for labor productivity on brickwork, which was corrected for tied ranks, was significant, $\chi^2(1, 1165)$ = 39.53, p = <0.001. The overall test results indicate that there was a fairly strong relationship between the distribution of non-working hours and in both the U.S. and China for all three work categories.

Table 32. Results of the Kruskal-Wallis Analysis for U.S. and Chinese Non-Working Hours

	Chi-Square (χ^2)	***p*-value**
Fire Protection Sprinkler System	33.46	<0.001
HVAC System	16.61	<0.001
Brickwork	39.53	<0.001

Note: The result is significant when a *p*-value is less than 0.05.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

This chapter describes the efforts of this research that focused on the measurement of construction productivity at task level and how such measurement uncovered additional areas of research that might be of value to U.S. construction firms concerned with the measurement and analysis of construction productivity in the U.S. and China. And the actual, project-specific, quantitative data obtained by work sampling ensured objective assessment of this research.

7.1 Conclusions

Construction is a labor intensive industry. The purpose of this research was to measure and assess the building construction process, and provide useful information about the labor work process and output. Although the construction industry is a major component of the U.S. and Chinese economy, the magnitude of the productivity problem in the construction industry is largely unknown due to the critical lack of measurement data.

Work sampling offers a method to gather information about the amount of labor productive and nonproductive work hours spent on building construction projects. In this research, random work sampling was used to determine the jobsite location and time that craftsmen spend at various activities throughout the day. The researcher and his research assistants walked the jobsite at random places to classify each worker who was being observed according to the activity in which he or she was engaged at the time of observation. The researcher used a preset, predefined number of activity classifications in each work item, generally divided into direct productive, indirect productive and nonproductive activities. The observations were generally made openly so that the workers and their representatives knew that observers were conducting a sample study. From the results of many such observations in the U.S. and China, a composite "snapshot" of the jobsite could be assembled and the percentage of workers engaged in each activity was calculated. Other collected data in relation to the workers and surroundings were also analyzed.

This research analyzed the data collected from jobsites in the U.S. and China to determine the labor productivity in three work categories and to compare the results between two countries. Since the data varies greatly and does not fit a normal distribution, nonparametric tests, which require less restrictive assumptions about the data, were used for the analysis of categorical data and comparison. In addition, descriptive statistics were used to develop the distribution plot that shows maximum, mean, median, and minimum values. Since sufficient data were available to produce box and whisker plots, the distribution plots were used to show central tendency and range of the metrics. The distribution plots illustrated the output which shows the relationships between variables and provided the potential outputs of future research.

As shown in Table 33, the data comparison of labor productivity shows that U.S. workers had higher labor productive rate (an average of 5.73 meter/hour of pipe installation) than Chinese workers (an average of 3.67 meter/hour of pipe installation) in the fire protection sprinkler system work category. However, U.S. workers had lower labor productive rate than Chinese workers in two other work categories, which include HVAC system (an average of 2.78 m/hr of duct installation in the U.S. versus an average of 4.92 m/hr of duct installation in China) and brickwork (an average of 61.08 bricks/hr in the U.S. versus an average of 129.72 bricks/hr in China).

Table 33. Comparison of Labor Productivity Results

	U.S.		China		RS Means	
Fire Protection Sprinkler System	5.73	m/hr	3.67	m/hr	N/A	
HVAC System	2.78	m/hr	4.92	m/hr	N/A	
Brickwork	61.08	bricks/hr	129.72	bricks/hr	64.69	bricks/hr
Brickwork (Based on Face Area)	0.677	m^2/hr	1.616	m^2/hr	0.717	m^2/hr

The results of this research can lead to a cooperative review of the fraction of working or nonworking time in each work category and the reasons for it can lead to actions by both labor and management to improve productivity by reducing the time spent on indirect and non-working activities. Furthermore, it could also help to enable cost management to affect productivity improvement on labor-intensive construction projects in the U.S. and China. This research also provided an example for systematic statistical observation on a project which can help monitor the work activity to obtain an overall picture of the utilization of the workforce. As part of its discipline, inferences can be made regarding constraints to the flow of work and resulting inefficiencies in the process.

This research provided U.S. construction firms the advancement of knowledge in the construction industry in the U.S. and China. The analysis of the data quantified direct work, indirect work, and non-working activities, and identified the causative factors in the U.S. and China. The results showed the areas in work scope where corrective actions can be taken for more efficient and safe completion of the work task. Therefore, fewer work hours will be expended than customary, which will help enhance U.S. construction firms' competitiveness in the Chinese and global markets and improve project management capabilities. The actual, project-specific, quantitative data obtained by work sampling also ensured objective assessment of this research. As such, the data support benchmarking and continuous improvement of efficiency and productivity. Properly applied, it is effective in getting more construction work done with fewer labor-hours and with greater worker safety and satisfaction in the U.S., China, or global construction markets.

7.2 Recommendations

The research effort was conducted without the benefit of similar research in developing countries and comparison between countries. This was further complicated by the lack of construction statistics on developing countries, such as China. However, the background work for this study uncovered many areas of that might be of value to the U.S. and/or Chinese private-sector organizations and government agencies concerned with the observation, measurement, analysis and understanding of construction productivity in other countries. Based on this research study, it shows that consistent application of sampling over a period of time can provide project managers ongoing information about the effectiveness of action taken to continuously improve the work process in the U.S. and China. This research analyzed the measurement challenges associated with the development of meaningful measures of construction productivity at task level and established a framework for future research. Specifically, this research identified the data needed to move forward in development of a standard practice for measuring task-level productivity. Once produced by other researchers in the future, these metrics, tools, and data will help U.S. construction firms make more cost-effective investment in productivity enhancing technologies and improved life-cycle construction processes in the U.S., China, or global construction markets.

Based on this on-site research, there are several research areas which are recommended for future studies: (1) there is a need to further investigate the data needed to move forward in development of a standard practice for measuring task-level productivity; (2) there is a need for additional on-site productivity measurements from building construction projects located in different cities for further investigation due to resource constraints in both countries; (3) there is a need to develop an algorithm for an observer to strictly follow with no reevaluation, hindsight, or second thoughts once the observation has been made to avoid a tendency to alter the data because of human physical limitations or biases for recording a large amount of data in a short time; (4) there is a need to validate and modify the procedures for collecting labor productivity using on-site productivity measurement methods in future research; (5) there is a need to determine factors affecting task-level labor productivity from the use of prefabrication, preassembly, modularization, and off-site fabrication techniques and processes in developing countries, such as China; (6) there is a need to quantify costs and benefits for the use of on-site productivity measurement methods; and (7) there is a need to develop a standard database system for direct work, indirect work, and non-working hours for future benchmark study.

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APPENDIX A: DATA COLLECTION FORM

Data Collection Form

Location:______________________ Observer:______________________

Date:____________ Time:__________ Work Activity:__________________

Weather Conditions:_______________ Temperature:__________________

Work Description:____

Crew/Experience/Age:____

Equipment/Tools Used:____

D = Direct-Work Time; I = Indirect-Work Time; N = Non-Working Time

	D	I	N	Remarks
1				
2				
3				
4				
5				
6				
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10				
11				
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25				

Initial: Date: Page 1

Figure A1. Data Collection Form Used in the Stopwatch Method

Table A1. Work Scope Coding Used for On-Site Data Collection

Direct Work (D):	Indirect Work (I):	Non-Working (N):
D1 – Measure space for exact position before installation D2 – Prepare materials for the activity (material measuring, cutting, lifting, taping, modifying, etc.) D3 – Hands-on activity (installing, sealing, finishing, etc.) D4 – Check and adjust position/alignment of new installation	I1 – Read blueprint drawing I2 – Prepare space for direct work (observing, initial measuring, cleaning, clearing, marking, cutting opening, etc.) I3 – Walk back/relocate with tools/materials (equipment, hand/power tools, accessories, etc.) I4 – Walk back/around empty handed (searching for tools/materials/accessories, etc.) I5 – Discuss with foremen/co-worker for direct work I6 – Receive tools/materials from other workers I7 – Assist co-worker I8 – Re-adjust previous installation I9 – Get electrical power for tools/equipment I10 – Seal outlet/opening of installment for temporary protection	N1 – Chat with others N2 – Personal reasons (phone calls, smoking, restroom, etc.) N3 – Break time N4 – Early Leave for Lunch

Table A2. Work Scope Coding Used for On-Site Data Collection (in Chinese)

直接工作 (D)：	间接工作 (I)：	非工作 (N)：
D1 – 安装之前，为找到正确的安装位置而进行的测量。 D2 –为安装而准备材料（材料的测量，切割，举起，修改等） D3 –实际安装活动（安装，密封，整理等） D4 –检查并调整刚安装工程的位置/路线	I1 – 读图 I2 –为直接工作而准备空间（观测，初步测量，清洁，清理，标识，打洞等） I3 – 拿来/拿走/搬动材料、工具（设备、手工工具、电动工具、配件等） I4 – 未拿回东西 I5 – 为直接工作而和工头和同事讨论 I6 – 等待工具、材料、帮助 I7 – 协助同事 I8 – 重新安装（返工） I9 – 为工具设备连接电源（插电） I10 –为临时保护而密封分部工作的插头、洞口	N1 – 与他人聊天（不是为工作） N2 – 个人原因（打电话、抽烟、上厕所等） N3 – 休息 N4 – 午餐

APPENDIX B: FIRE PROTECTION SPRINKLER SYSTEM INSTALLATION PROCEDURES

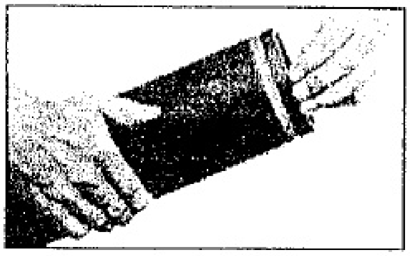


Figure 1. Check Pipe Ends

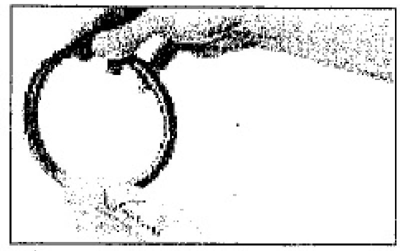


Figure 2. Check Gasket & Lubricant

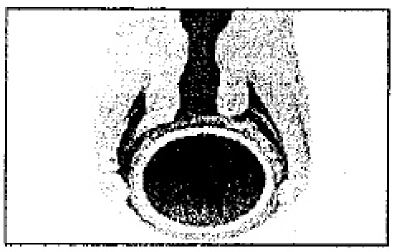


Figure 3. Install Gasket

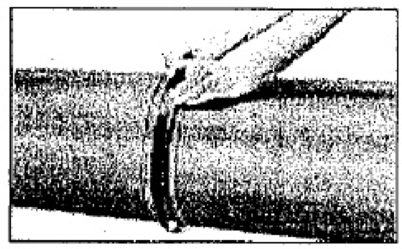


Figure 4. Join Pipe Ends

Figure 5. Assemble Segments

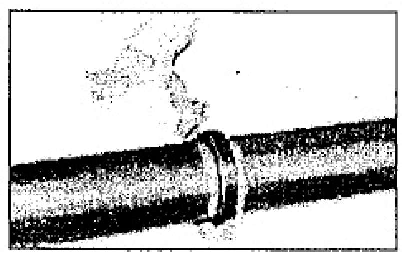


Figure 6. Apply Housing

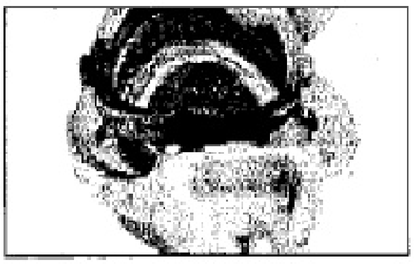
Figure 7. Insert Bolt

Figure 8. Tighten Nuts

Figure B1. Rigid Coupling Installation for Pipe Connection

Figure 1. Prepare To Assemble

Figure 2. Check Gasket and Lubricate



3. Position Gasket in Housing

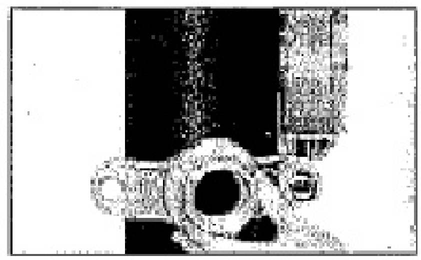


Figure 4A. Position Mechanical-T Outlet (S/920)

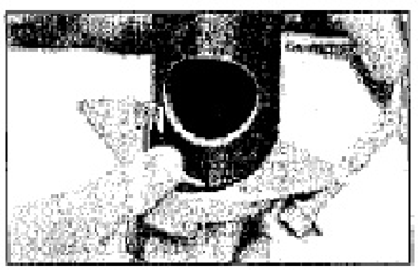


Figure 4B. Position Mechanical-T Outlet (S/921)

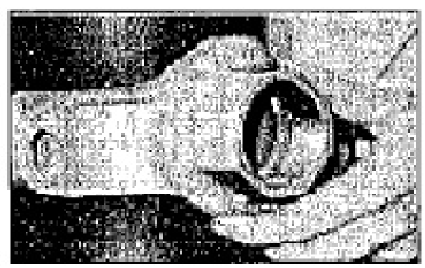


Figure 5. Check Locating Collar

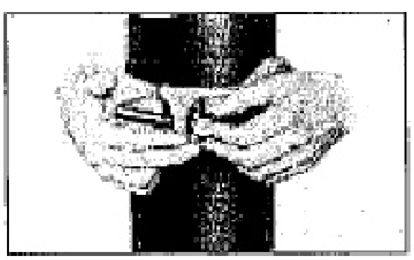


Figure 6. Insert Bolt

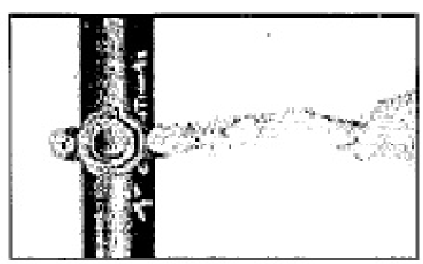


Figure 7.Tighten Nuts

Figure B2. Mechanical-T Installation for Branch Pipe Connection

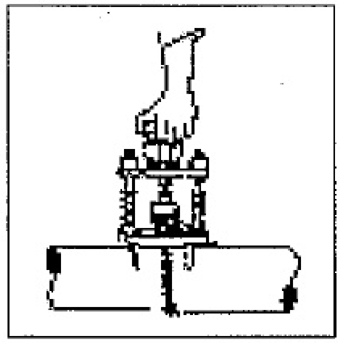


Figure 1 Drill a hole on pipe

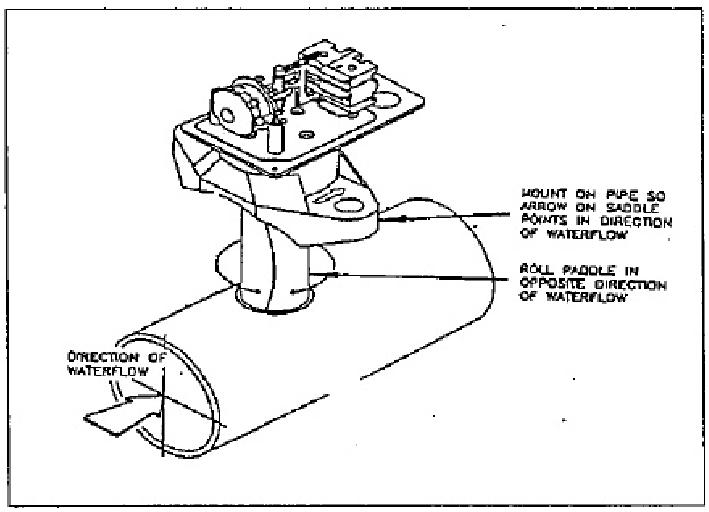


Figure 2 Insert vane

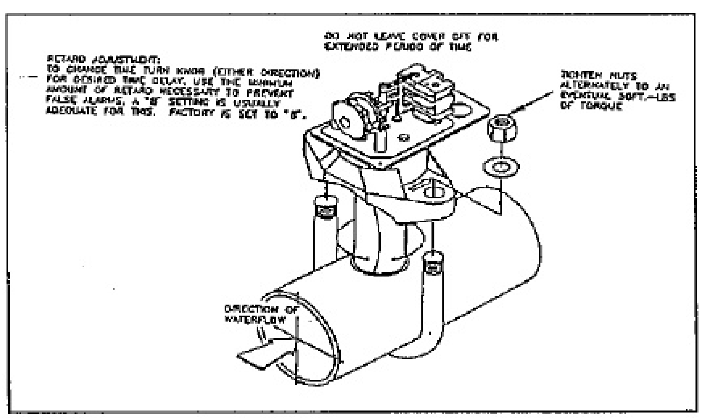


Figure 3 Tightening

Figure B3. Drilling Hole on a Steel Pipe

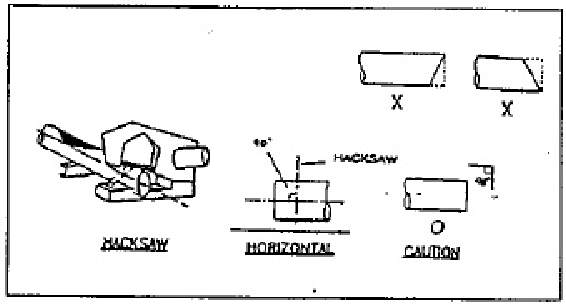


Figure 1 Marking and cutting

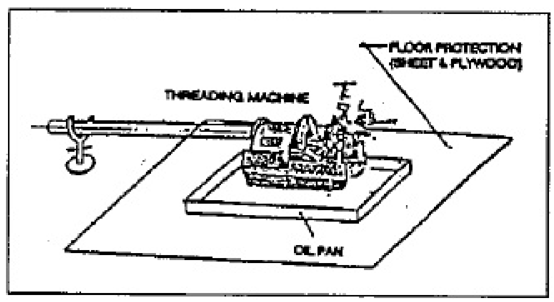


Figure 2 Threading

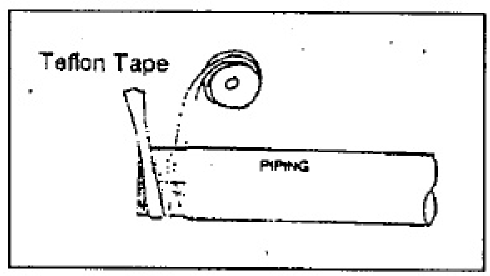


Figure 3 Wrap with Teflon Tape

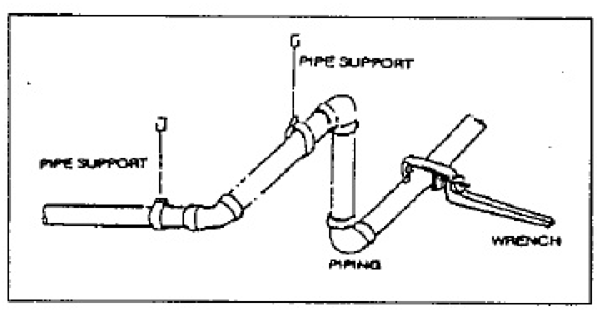
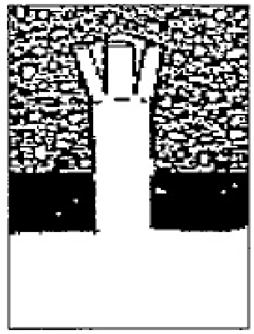


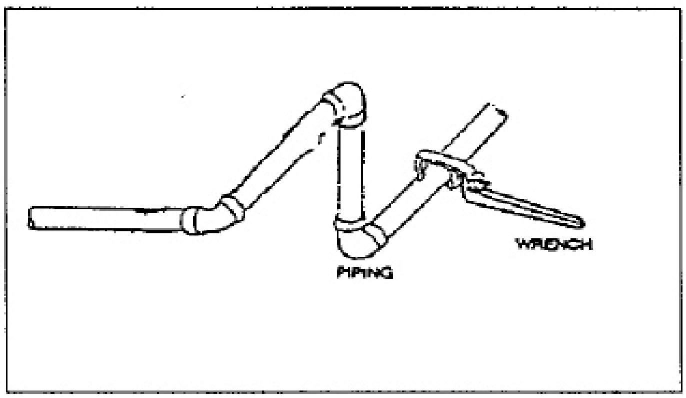
Figure 4 Installation

Figure B4. Screw Fitting Installation



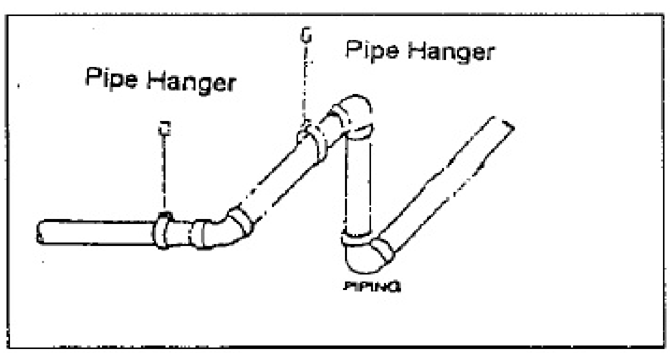
Figure

1. Install Drop in Anchor



Figure

2. Install Pipe



Figure

3. Install Hanger to Pipe

Figure B5. Pipe Hanger Installation

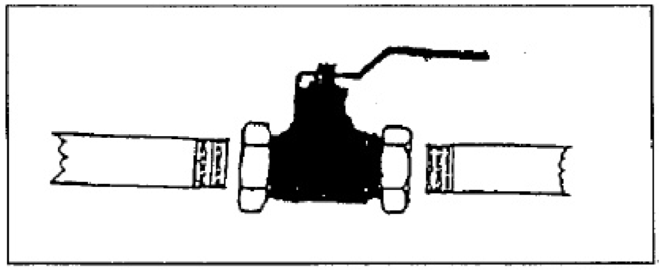


Figure
1. Positioning Valve

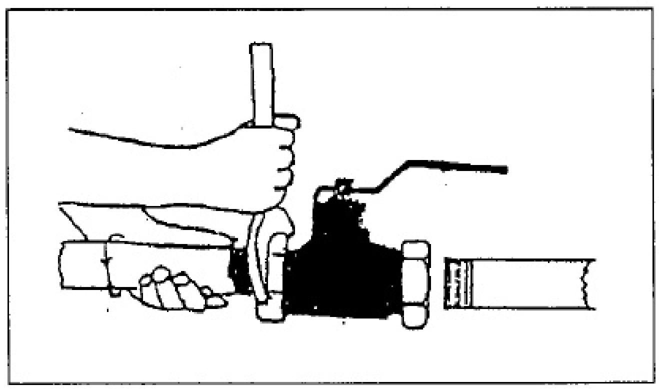


Figure
2. Jointing

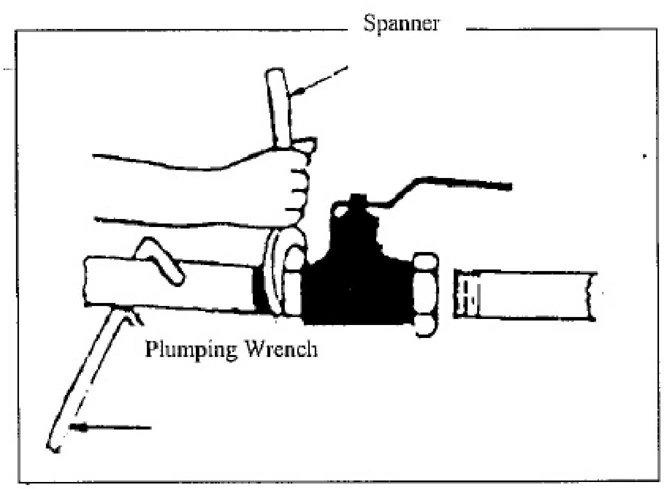
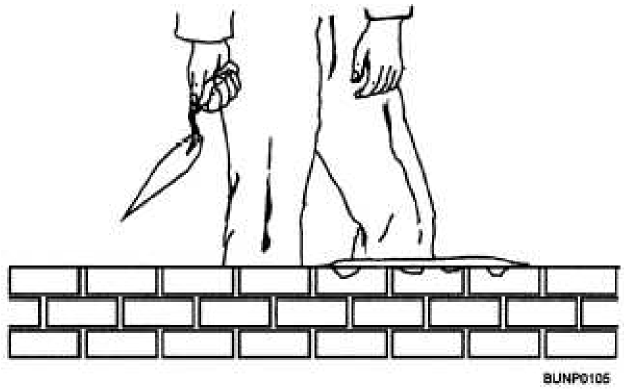


Figure
3. Tightening

Figure B6. Valve with Screw Connection Installation

APPENDIX C: BRICKWORK PROCEDURES



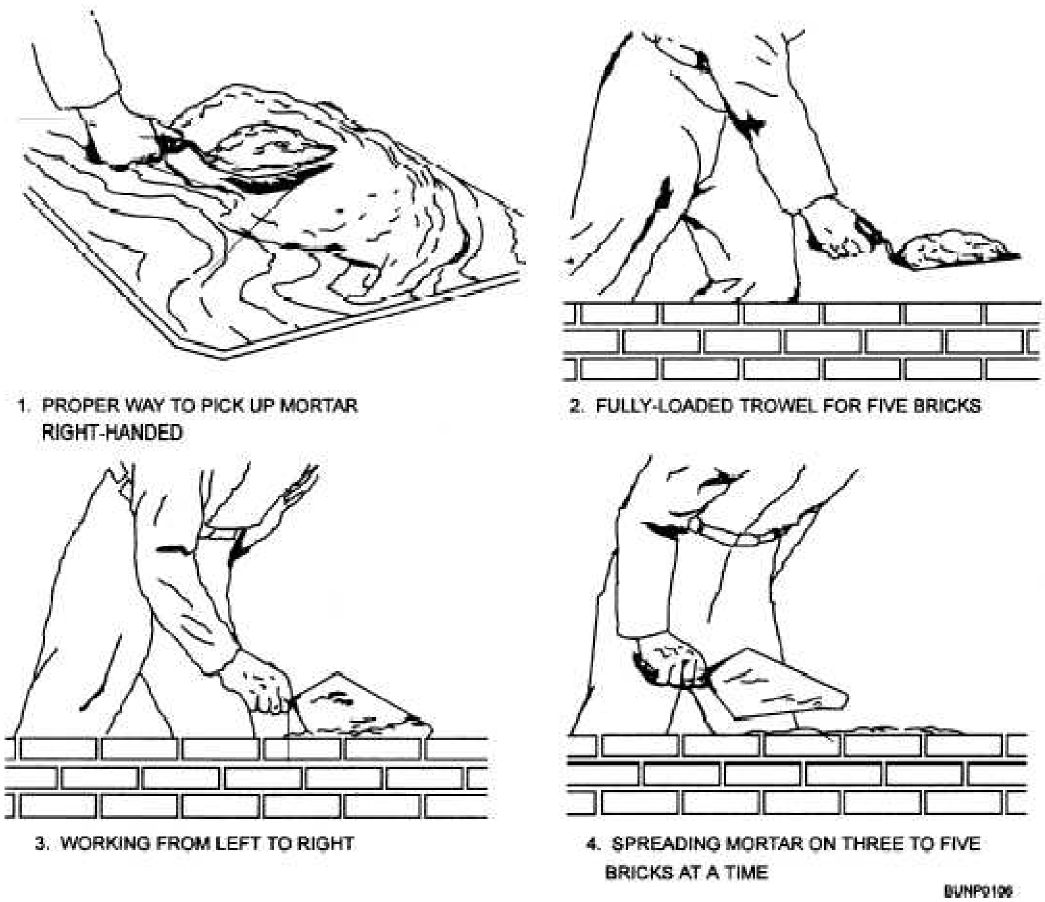


Figure C1. Picking Up and Spreading Mortar

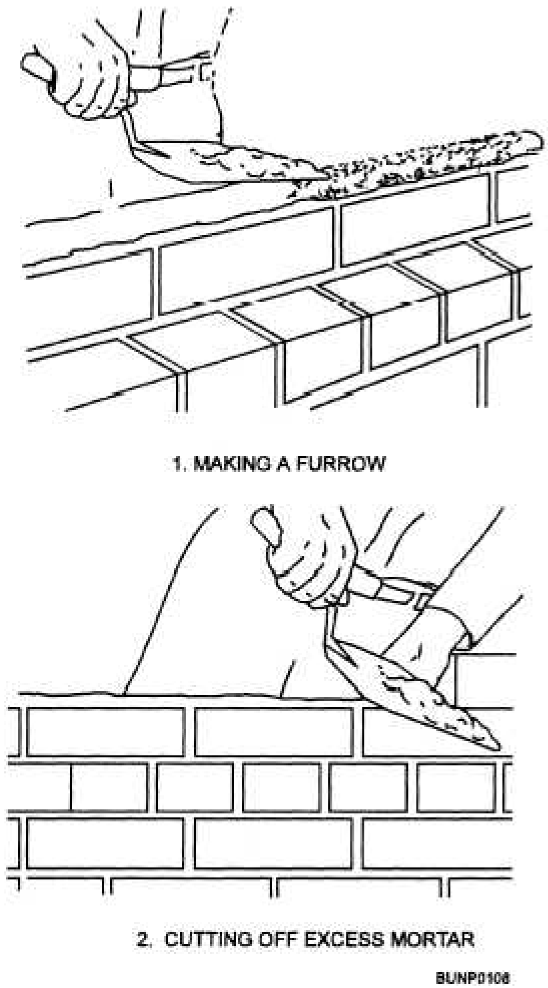


Figure C2. Making a Bed Joint in a Stretcher Course

Figure C3. Proper Way to Hold a Brick when Buttering the End

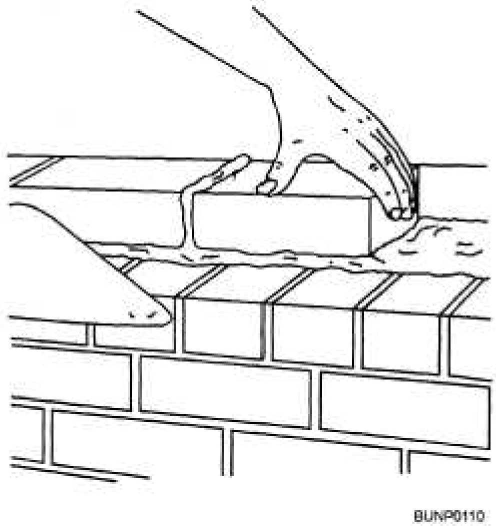


Figure C4. Making a Head Joint in Stretcher Course

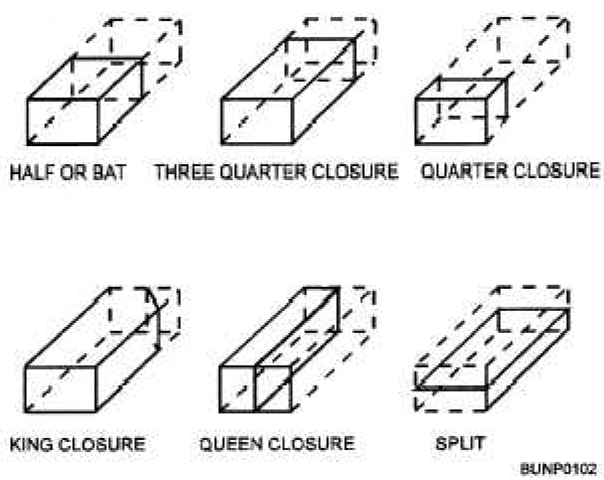


Figure C5. Common Cut Brick Shape

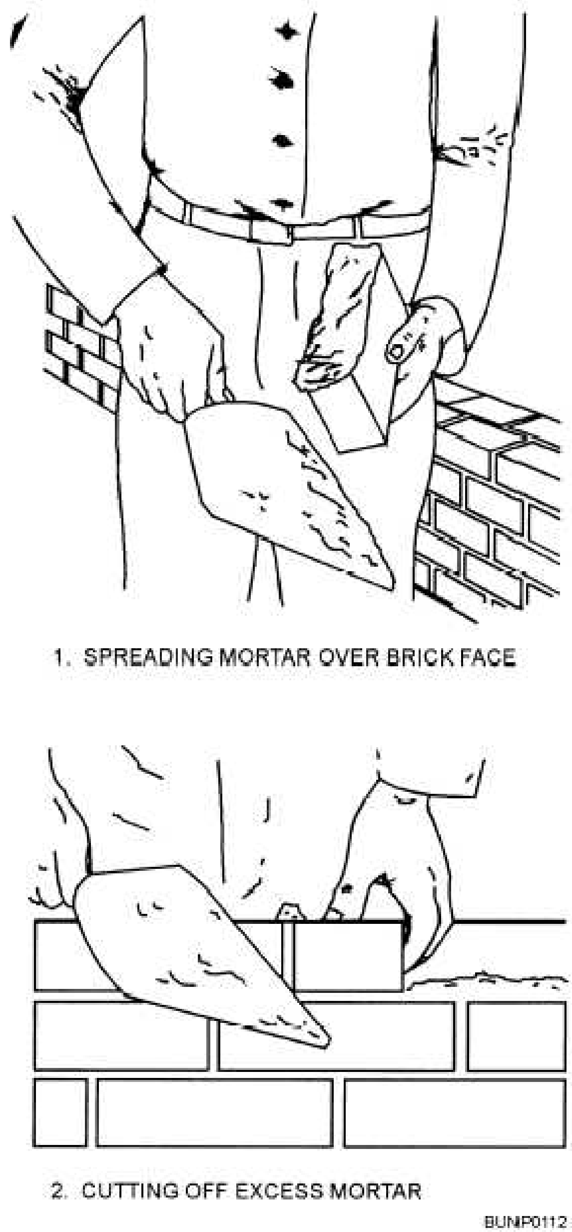


Figure C6. Inserting a Brick in a Wall Space

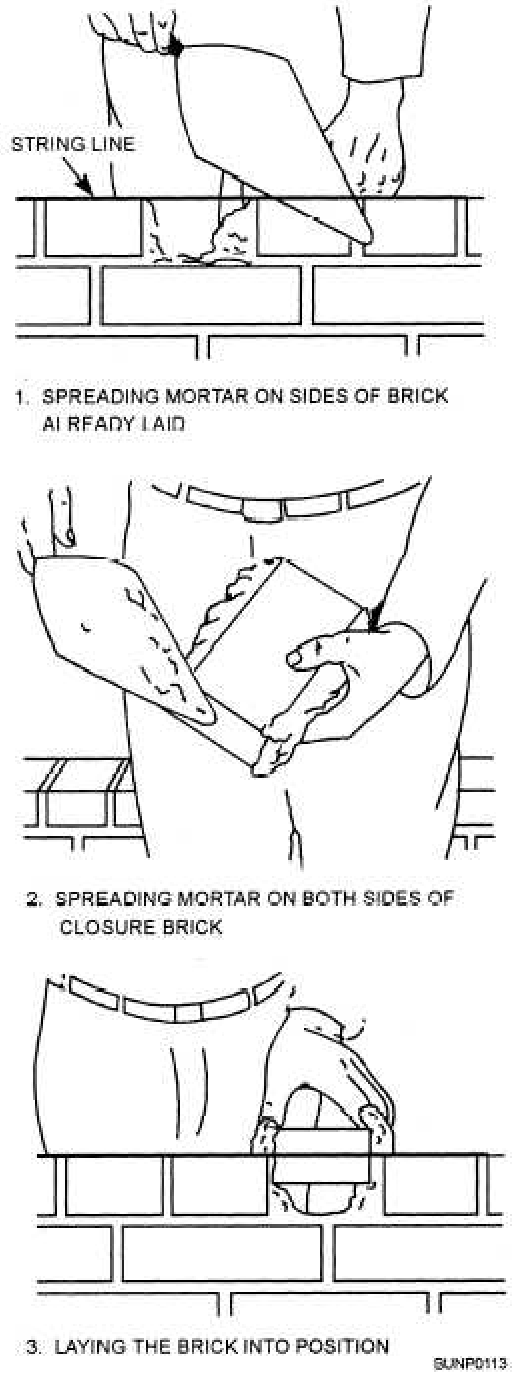


Figure C7. Making a Closure Joint in a Header Course

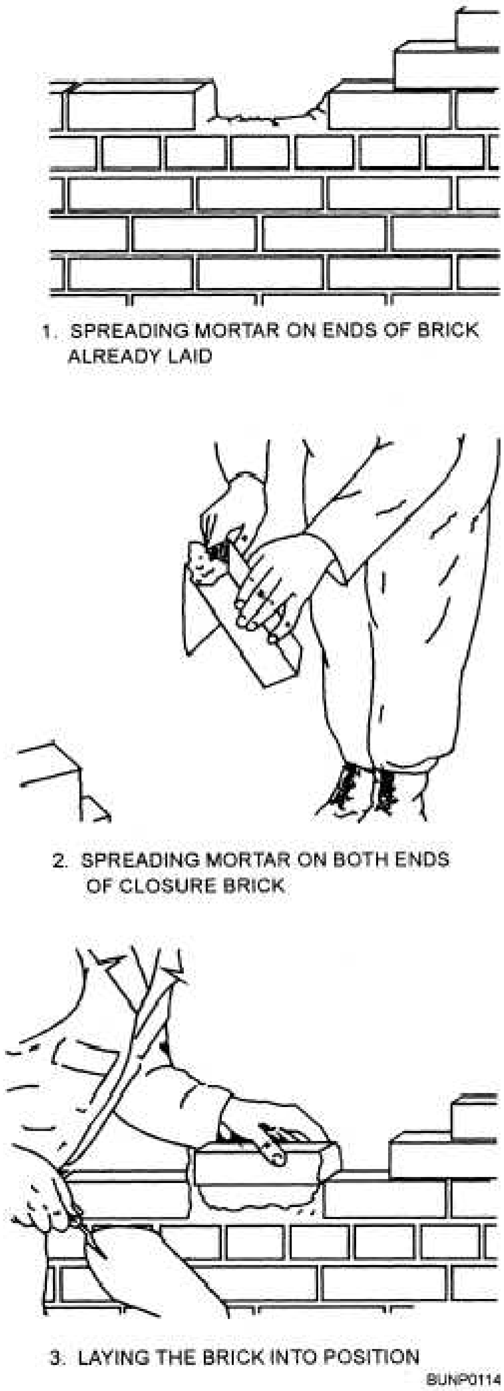
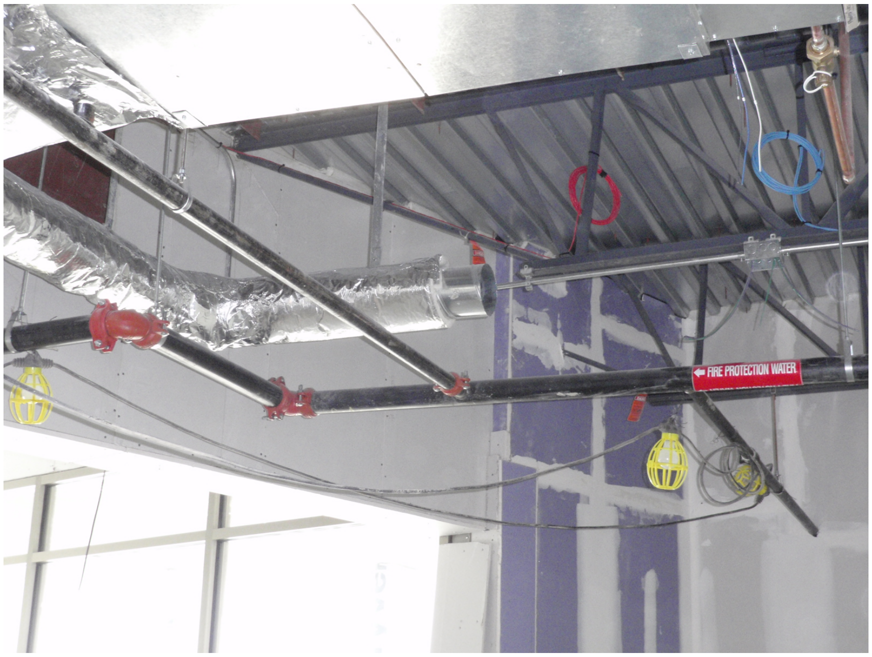


Figure C8. Making a Closure Joint in a Stretcher Course

APPENDIX D: PICTURES FROM THE FIRE PROTECTION SPRINKLER SYSTEM INSTALLATION IN THE U.S. AND CHINA

<u>In the U.S.</u>

Pipe Threading Machine at Jobsite



Installed Fire Protection Sprinkler Piping

Installed Fire Protection Sprinkler Piping

Rental Equipment Used by U.S. Workers for Pipe Installation at Jobsite

In China

Chinese Worker Using Pipe Threading Machine at Jobsite

Chinese Workers Preparing Piping at Jobsite

Chinese Workers Drilling Hole on a Pipe at Jobsite

Chinese Workers Installing Rigid Coupling for Pipe Connection at Jobsite

APPENDIX E: PICTURES FROM THE HVAC SYSTEM INSTALLATION IN THE U.S. AND CHINA

<u>In the U.S.</u>

Prefabricated Duct Storage at Jobsite

Preparing Ductwork for Installation at Jobsite

U.S. Workers Installing Ductwork at Jobsite

U.S. Workers Installing Ductwork at Jobsite

U.S. Workers Installing Ductwork at Jobsite

<u>**In China**</u>

Chinese Workers Fabricating Ductwork at Jobsite

Chinese Workers Installing Ductwork at Jobsite

Chinese Workers Installing Ductwork at Jobsite

Chinese Workers Installing Ductwork at Jobsite

APPRENDIX F: PICTURES FROM THE BRICKWORK IN THE U.S. AND CHINA

<u>In the U.S.</u>

U.S. Worker Transporting Bricks at Jobsite

U.S. Worker Transporting Bricks at Jobsite

Brick Storage at Jobsite

A Package of Bricks from Manufacturer

U.S. Bricklayters Working on Platform

In China

Brick Storage at Jobsite

Chinese Worker Transporting Bricks at Jobsite

Chinese Worker Transporting Bricks at Jobsite

Chinese Bricklayer Setting Up Work Platform at Jobsite

Chinese Bricklayters Laying Bricks