AN INVESTIGATION OF PRODUCTIVITY LOSS
DUE TO OUTDOOR NOISE CONDITIONS

By

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ABSTRACT

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Most people in day to day life at one time or other get irritated or distracted by surrounding noises. The irritation might have resulted in minor aggravation or may have been dramatic enough to hinder their work. This leads us to think whether there are any losses in the efficiency of construction workers due to surrounding varying noise conditions, or if they naturally adjust to their acoustic environment. In an effort to answer this question, this study on productivity loss due to varying sound conditions was conducted. It was found that, the efficiency of labors was inversely proportional to the average intensity of the noise, irrespective of the level of difficulty of the task. Also, during this study, a survey was conducted to find the relationship between the surrounding noise conditions and construction accidents. Analysis of the survey showed that, intensity of noise and rate of accidents were directly proportional.

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CHAPTER 1

INTRODUCTION & BACKGROUND

This chapter presents a brief introduction to the importance of construction productivity, history of productivity studies, and possible loss in the productivity due to surrounding noise conditions.

1.1 Background

In the world of construction, there is a very thin line between profit and loss. Although there are many factors that contribute to the success of a construction project, one of the most important and hard to estimate accurately is productivity of labors. When a contractor bids for the project and is awarded a fixed priced contract, it is typically assumed that contractor can achieve a certain level of productivity, such that the contract will be financially viable. When losses are suffered, additional labor costs can be the largest element of those losses. Labor cost overruns can be attributed to numerous causes and factors. Noise could be one of the factors for loss of concentration, and increase levels of worker fatigue and irritation.

For this thesis, two case studies were carried out to investigate effects of noise on construction productivity and safety on construction projects. Appendices A, B, & C present all the data collected during the case studies. The two project sites studied were close to an active airport runway, and workers were subjected to varying sound conditions (50-100 dB[1] for 80% of time). The study was started when both project sites were equally completed; foundation and slab on grade (SOG) were completed for both the building sites. Same crews were used on both building sites for all the activities, with minor crew alterations, estimated at 20% of times. To analyze productivity, traditional methods were used, such as, method productivity delay model (MPDM), 5-minute rating, questionnaires, and interviews. These

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1 dB: The decibel (dB) is a logarithmic unit that indicates the ratio of a physical quantity (usually power or intensity) relative to a specified or implied reference level.

methods and their use in this research are described in Chapter 3.

1.2 History & Importance of Productivity Study

Labor productivity is defined as output per unit of labor-hour input (Drewin, 1982). It essentially measures the extent to which firms and industries take advantage of better education, training, management, equipment, supervision, and technology to increase the amount of production per worker. Labor productivity is commonly used as an indicator of a nation's comparative economic growth and prosperity.

During the Second World War, in the United States, a strategy of standardized mass production led to high levels of labor productivity and a concentration on the development of managerial capabilities, but the skills of the shop-floor labor force were neglected. In Britain and Germany, on the other hand, concentration on craft production led to greater emphasis on shop-floor skills. Thus, after the Second World War, the concepts of improving skills of shop-floor labors received the attention of all industries in USA and Britain, and construction industry was no exception (Broadberry & Wagner, 1994).

Since the World War II era, comparison of the productivity increases for various countries shows that the United States initially lagged behind other industrialized countries in productivity increases (Table 1-1) (U.S. Department of Labor, 2009). Average annual growth rate for manufacturing productivity for the period 1960 to 1970, shows that United States ranked 11th compared to the rest of the world in productivity, whereas in the 1997 to 2007 the United States was ranked 4th (Figure 1-1) (U.S. Department of Labor, 2009). The U.S. Bureau of Labor Statistics (USBLS) noted 2.1% of an average rise in productivity of manufacturing industry for the period 1960 to 2008 (Table 1-2). For the period of 1998 to 2008, USBLS also reported an annual average productivity increase of 2.5% in manufacturing industry (Figure 1-2). Thus, despite the recent advancement of new technology, the productivity increase remained constant. Part of this very slow productivity increase is caused by the mentality adopted in the construction business: "Do as it was done before you." Ideas that would lead to productivity increases in construction are faced with limited implementation and significant resistance from all levels of management. The divide between the construction worker and management has worsened this issue. This slow increase in productivity coupled with the limited implementation of new ideas results in cost inefficiencies in construction projects.

Table 1-1: Comparative Productivity Increase in the World Manufacturing Market (1960-1970)
Source: (U.S. Departmet of Labor, 2009)

Markets	Percent
Japan	10.5
Netherlands	7.5
Sweden	7.1
Belgium	6.5
Italy	6.4
France	6.0
West Germany	5.8
Switzerland	5.3
Canada	4.3
United Kingdom	4.0
United States	3.4

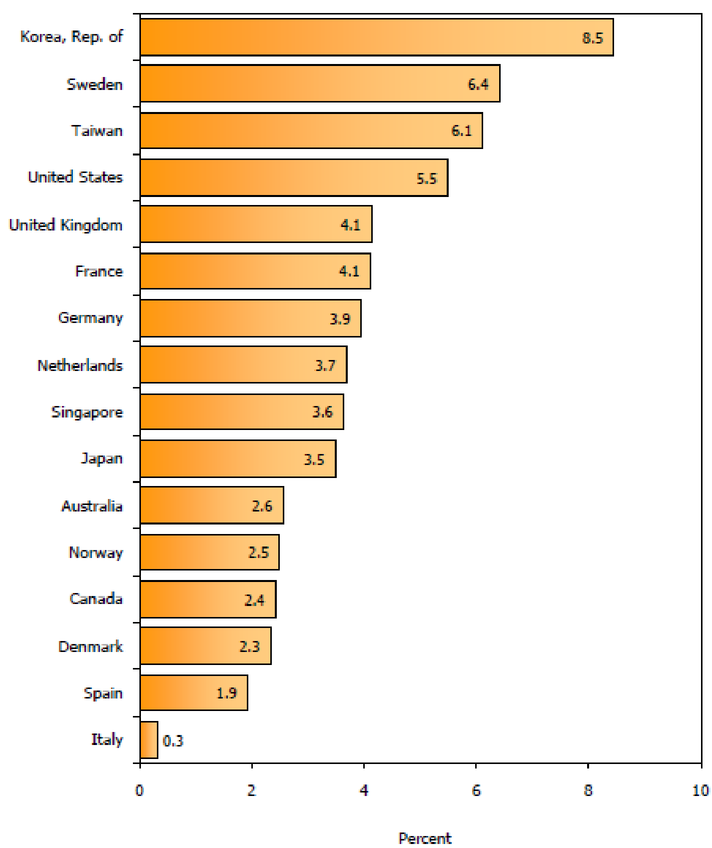

Figure 1-1: Average Annual Growth Rates for Manufacturing Productivity, 1997-2007
Note: Productivity is defined as output per hour worked.
Source: (U.S. Department of Labor, 2009)

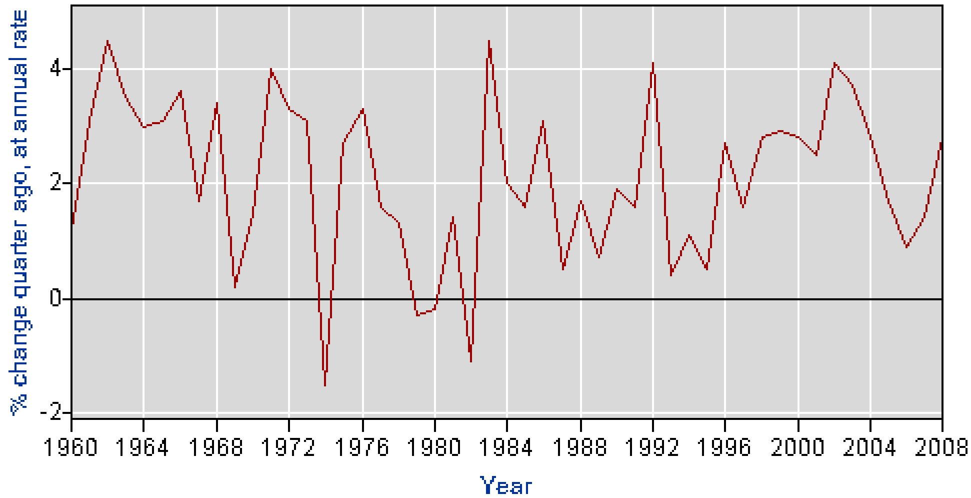

Figure 1-2: United States Major Sector Productivity and Cost Index 1960-2008
Source: (U.S. Department of Labor, 2009)

Table 1-2: United States Rise in the Productivity 1960-2009
Source: (U.S. Department of Labor, 2009)

Year	Annual	Year	Annual
1960 - 1961	1.2	1985 -1986	1.6
1961 - 1962	3.1	1986 - 1987	3.1
1962 - 1963	4.5	1987 - 1988	0.5
1963 - 1964	3.5	1988 - 1989	1.7
1964 - 1965	3	1989 - 1990	0.7
1965 - 1966	3.1	1990 - 1991	1.9
1966 - 1967	3.6	1991 - 1992	1.6
1967 - 1968	1.7	1992 - 1993	4.1
1968 - 1969	3.4	1993 - 1994	0.4
1969 - 1970	0.2	1994 - 1995	1.1
1970 - 1971	1.5	1995 - 1996	0.5
1971 - 1972	4	1996 - 1997	2.7
1972 - 1973	3.3	1997 - 1998	1.6
1973 - 1974	3.1	1998 - 1999	2.8
1974 - 1975	-1.5	1999 - 2000	2.9
1975 - 1976	2.7	2000 - 2001	2.8
1976 - 1977	3.3	2001 - 2002	2.5
1977 - 1978	1.6	2002 - 2003	4.1
1978 - 1979	1.3	2003 - 2004	3.7

Table 1.2 - continued

1979 – 1980	-0.3	2004 - 2005	2.8
1980 - 1981	-0.2	2005 - 2006	1.7
1981 - 1982	1.4	2006 - 2007	0.9
1982 - 1983	-1.1	2007 - 2008	1.4
1983 - 1984	4.5	2008 - 2009	2.8
1984 - 1985	2		

1.3 Need Statement

There are no doubts that, to improve productivity, losses in productivity due to different causes must be identified and reduced. This thesis addresses the following two issues:

1. Effects of surrounding noise intensity on the labor productivity, with productivity study under varying noise intensity conditions.

2. Effects of surrounding varying noise intensity on construction safety, which affects productivity.

1.4 Objective & Scope

The basic objectives of this thesis are:

1. Investigate the issue of loss in construction productivity due to surrounding outdoor noise conditions.
2. Compare the rate of drop in the construction productivity due to surrounding outdoor noise conditions.
3. Find the relationship between the surrounding varying noise conditions and rate of accidents.

1.5 Methodology

A literature search was conducted to identify and review past research. The sources searched included government documents and published reports, books, journal articles, conference papers, thesis and dissertations, and industry websites. To investigate the effects of sound on construction productivity and safety, a case study was conducted under varying noise conditions at a job site. A total of 8 subcontractor crews were surveyed and studied, working simultaneously on 2 building sites, performing similar work, but under varying sound conditions. These conditions were assumed to be appropriate to test the effects of varying sound levels on labor productivity.

The formal steps leading to the analysis of the loss in productivity, and aimed at improving productivity are gathering sufficient data, analyzing the data, and identifying the problems. As a contributive factor for productivity analysis, this thesis is focused on the work-face activities (work face activities are the activities performed by the crew and the foreman that will directly contribute to the production of the end production) only, and non work face activities (background work) were not considered. The methodology is explained in more detail in Section 3.2.3.

1.6 Expected Outcome

The expected outcome of this research is to:

- Find a relationship between the surrounding noise conditions with the labor productivity.
- Explore if there is any difference in the labor productivity loss due to surrounding noise conditions for processes which need cognitive thinking and for processes which are comparatively simpler.
- Find the relationship between the surrounding noise conditions at construction site and rate of accidents.

The results from this study are expected to create awareness on impact of noise on work environment, and improve the working conditions for the construction workers. This will also provide an incentive to the management to take into consideration the sound levels at the work site while bidding, scheduling, and estimating for future projects. It is expected that reducing noise and improving work environment by the management will improve the productivity of the construction workers.

1.7 Chapter Summary

Noise has been evaluated in the past research as one of the factors for loss in productivity. This research will evaluate the effects of surrounding noise conditions at construction sites on construction productivity. This knowledge will provide a definitive relationship between the surrounding noise conditions and loss in efficiency, to be considered during the estimating phase of bidding for a project.

CHAPTER 2

LITERATURE SEARCH

2.1 Introduction

This chapter consists of a review of findings from a comprehensive literature search that was conducted as part of this research. As discussed in Chapter 1, literature search was used as one of the tools to understand more about existing research works on this topic and to get better knowledge of applicability of these methods. The subjects searched include (i) construction productivity measurement & improvement through work study, (ii) effects of noise on productivity, (iii) effects of noise on human nature, and behavior, and (iv) association of work related accidents with noise exposures in work places & noise induced hearing losses.

2.2 Varying Sound Conditions and Safety Hazards

Many groups and organizations have done exhaustive studies on noise. The U.S. Environmental Protection Agency (EPA) recognized noise as a problem to environment (Wikipedia, 2010). They undertook a major study of noise and have continued to update their findings. A Yale University study looked at the effects of noise stress on brain function in monkeys. Results indicated that stress impairs prefrontal cortex (PFC) cognitive function through its influence on dopamine, a key neurotransmitter that's involved in many brain disorders, including Attention Deficit Hyper Active Disorder (ADHD) and Parkinson's disease (Fi.edu, 2010).

In a previous research, it was proved that processes which require more cognitive thinking are most affected due to varying sound conditions (Landström, 2004). It was found that information overload tasks are harder under low frequency noise conditions, and that repetitive monotonous tasks may require longer exposures for there to be an effect (Landström, 2004). During the study, to determine how time length of exposure to background noise can affect the productivity, it was found that, exposure time did not have a significant effect on performance in the beginning, but later on subjects tended to rate signals as louder and hissy earlier in time. It was also found that perception of noise can impact performance (Errett, 2006).

OSHA has a regulation over the surrounding sound conditions to protect construction workers from hearing loss. OSHA hearing conservation program requires employers to monitor noise exposure levels in a way that accurately identifies employees exposed to noise at or above 85 decibels (dB) averaged over 8 working hours (OSHA, 2010). Research indicates that workplaces with proper hearing conservation programs have higher levels of worker productivity and lower incidence of absenteeism (OSHA, 2010).

There has been a sufficient amount of previous research work, on how high levels of noise affect productivity (Jones & Broadbent, 1998), but there is very little information available on typical reduction in the construction productivity due to background noise of varying levels. There have been several studies which focus on the effects of excessive low frequency energy in background noise (Kyriakides and Leventhall 1977, Landstrom et al 1991, Holmberg et al 1993, Persson et al 1997). Also, several studies are available which revealed the people working in the varying surrounding noise levels reported symptoms of fatigue, headaches, and irritation, all of which could lead to adverse effects on the job performance (Tokita 1980, Nagai et al 1989, Persson 2001). In particular, there is much debate as to how the length of time that a worker working under a single background noise condition can impact their performance and perception. Workers become increasingly aggravated by noise the longer they are exposed to it, while others contend that workers naturally habituate to their acoustic environment. There is additional debate over the types of tests that should be used in research examining the effects of background noise on occupants (Errett, 2006).

Occupational noise exposure and hearing loss contribute to the risk of industrial accident and for many occupational health and safety professionals this makes a compelling argument to reduce noise exposure in the workplace (Picard et al 2007). There is evidence that workers exposed to noise in the workplace (8hr ≥80 dB) have an increased risk of accident. Both the disruptive effect of noise and the degree of noise-induced hearing loss, when considered as independent variables seem to compromise safety in professional activities with the predictable outcome of increased risk of accidents and that of a compromised health status including stress-related disorders (dependent variables) (Picard et al, 2007). Continuously varying sound conditions in the surrounding may lead to the temporary or permanent hearing losses, which in turn may lead to compromise both the recognition of speech and of warning signals (Picard et al, 2007). This may reduce the quality and quantity of the communication with co-workers, may lead to irritation, excessive fatigue, loss of concentration which may lead to safety hazards. The circumstances of safety hazards due to varying sound conditions are important, because all the work related accidental cause for loss of capital and labor productivity. In Quebec, for instance, work-related accidents account for 90% of total compensation paid for industrial injuries and diseases (Picard et al, 2007). In 2007, a study was carried out to find the association of work related accidents with noise exposure in the work place. This study was carried on a sample of 52,982 male workers exposed to a minimum of 80 dB on a daily basis and whose hearing was examined at least once between 1983 and 1996 by public health authorities of Quebec. These participants evidenced bilateral average hearing threshold levels at 3, 4, and 6 kHz ranging from normal (≤15 dB) to hearing loss in excess of 50 dB as a result of chronic occupational noise exposure (subjects otherwise ontologically normal). The occupational accident count of these workers was derived from the individual histories registered with the Quebec workers compensation board (Canada) for the 1983–1998. Results showed an association between accident risk and worker's hearing sensitivity. For example, a hearing loss of 20 dB corresponds to a rise of accident risk equal to 1.14 when controlling for age and occupational noise exposure at the time of hearing tests. Overall, 12.2% of accidents considered in this study were attributable to a combination of noise exposure in the workplace (≥90 dB) and noise-induced hearing loss (Picard et al, 2007)

2.3 Chapter Summary

Various researches show that, human productivity is adversely impacted by the noise. This impact of noise on the human productivity depends on level of thinking involved in activity under influence of noise. Workers exposed to high level of noise may experience short term hearing losses, and long exposure to the noise may cause permanent hearing losses. Loss in the hearing capacity may induce potential safety hazards.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology adopted to obtain the results of this research. The overview of the methodology was presented in Chapter 1.

3.2 Productivity Loss Due to Surrounding Noise Conditions

One of the objectives of this research was to investigate the issue of loss in construction productivity due to surrounding outdoor noise conditions. The methodology behind the research for this thesis was the use of the tools of productivity analysis over actual working conditions. To study the effects of sound conditions on the productivity following tools were used:

1. MPDM
2. 5-Minute Rating

3.2.1 MPDM

The Method Productivity Delay Model (MPDM) is a model to measure, predict, and improve productivity. The model was developed by Dr. James Adrian and it is broken down into three elements: collection of data, model processing and structuring, and implementation (Adrian, 2004). Data is collected on three items – the production unit, the production cycle, & the time required for completion of production cycles as well as productivity delays (Adrian,2004). The production cycle time is documented by noting the time between completion of production units. The types of delays that are usually documented are environment, equipment, labor, material, & management. The processing of MPDM consists of the operations of measuring ideal productivity & overall productivity. Ideal productivity occurs when there are no productivity delays. The environmental, equipment, labor, material, & management factors in the productivity equation (Equation 7) relate the ideal productivity to the overall productivity (Adrian, 2004). Of the three elements of the MPDM process, the most improtant is the implementation of the model. The inspection of the MPDM sturcture can inform the contractor of the critical delays resulting in a high percentage of production delay times. The contractor can then focus on these critical delays while attempting to improve productivity.

The basic concept of MPDM is that simplified measures will make the method more accessible to relatively low-level field personnel (Halpin & Riggs, 1992). As MPDM is a simple method for calculating productivity factors, there are less chances of error, and results can be more trustworthy. On the other hand, the method is very limited and of questionable value when applied to extremely short-cycle or relatively long-cycle processes. This occurs because of value judgements that must be made by the data collector. These subjective judgments tend to undermine the objectivity of the data and impact the relability of the results obtained (Halpin & Riggs, 1992).

Table 3-1 shows the data collected and Table 3-2 illustrates calculations to refine the data. Mean Non-Delay cycle time is computed in Row A of 'MPDM Processing' Table 3-2. After this, Mean Non-Delay time is subtracted from each cycle time, this could be assumed as the nearest approximation to the delay attributed in delay cycle (Halpin, 1992). This delay occurred in each cycle is computed and written in the last column of the table "Cycle Delay Sampling." Last column of Row 'A' is calculated by adding all the values in the last column of 'Cycle Delay Sampling' table which is called as 'Minus mean non-delay time.' This value is used to find 'Ideal Cycle Variability' as showed in Equation 1.

$$\text{Ideal Cycle Variability} = \frac{\text{Minus mean non delay time}}{\text{Mean non delay cycle}} \quad \text{(Equation 1)}$$

It is difficult to set out a single set of acceptable variability because of widely-differing types of construction methods. A value greater than 1.0 for overall cycle of variability should usually be taken to mean that productivity prediction should be viewed with caution (Adrian, 2004).

Table 3-1: Data Collection: Roof Insulation Building A

Date	27-Sep-10		Work	Laying Insulation and screwing them to the roof.				
Location	NAS JRB Fort Worth		Weather Conditions	Cloudy				
Building	A		Temperature	92F				
Time whille readings were taken				10am				
Number of Labors Under Observation				5				
Average Sound Level				85.16 dB				
Wind Speed				15MPH				
Production Cycle Delay Sampling								
Page 1 of 1		Date:	27-Sep-10	Unit:	Seconds			
Method:	MPDM		Production Unit:		Insulation Panels laid per hour			
Production Cycle	Production Cycle Time (sec)	Environmental Delay (sec)	Equipment Delay (sec)	Labor Delay (sec)	Material Delay (sec)	Management Delay (sec)	Notes non-delay	Minus Mean Non-Delay Time
1	580			100%			90dB	115
2	420						68dB, Non-Delay	45
3	480						80dB, Non-Delay	15
4	800			100%			96dB	335
5	400		100%				84dB	65
6	650			100%			92dB	185
7	500						82dB, Non-Delay	35
8	743		100%				87dB	278
9	689				100%		64dB	224
10	490						80dB, Non-Delay	25
11	677		20%			80%	77dB	212
12	444						72dB, Non-Delay	21
13	591		50%		50%		96dB	126
14	612	70%		30%			91dB	147
15	602				90%	10%	90dB	137
16	768			10%		90%	95dB	303
17	488						76dB, Non-Delay	23
18	533	20%		80%			86dB	68
19	512	100%					90dB	47
20	902			100%			98dB	437
21	501			100%			86dB	36
22	453						79dB, Non-Delay	12
23	745	100%					100dB	280
24	703			100%			96dB	238
25	444						74dB, Non-Delay	21

In this case, $\text{Ideal Cycle Variability} = \frac{24.75}{465} = 0.053 < 1.0$

Row B: Calculations for Row B, are done similar to Row A, except they are done for all the cycles.

Row C: It counts for number of occurrences for each type of delay

Row D: It counts the total added time due to the specific type of occurrence of delay as showed in Equation 2.

$$Total\ Added\ Time = \sum_1^n \begin{matrix}(Production\ cycle\ time - Mean\ non\ delay\ cycle\ time) \\ \times\ percentage\ of\ delay\ caused\ by\ that\ type\ of\ delay\end{matrix} \quad \text{.................. (Equation 2)}$$

For example because of environmental delay:

$$Total\ Added\ Time = (612 - 465) \times 0.7 + (533 - 465) \times 0.2 + (512 - 465) \times 1.0 + (745 - 465) \times 0.1$$

$$= 443.5\ \text{Seconds}$$

Table 3-2: Calculation: Roof Insulation Building A

MPDM Processing					
Page 1 of 1	Date: 27-Sept-2010	Unit: Seconds			
Method	Roof Insulation	Production Unit: Panels			
Units	Total Production Time	Number of Cycles	Mean Cycle Time	Sum [1(cycle time)-(n.d. Cycle Time)1]/n	
A. Non-Delayed Production Cycles	3720	8	465	24.75	
B. Overall Production Cycles	14727	25	589.08	137.2	
Delay Information					
	Delays				
	Environmental	Equipment	Labor	Material	Management
C. Occurrence	4	4	8	3	3
D. Total Added time	443.5	318.4	1438.8	410.3	456
E. Probability of occurrence	0.16	0.16	0.32	0.12	0.12
F. Relative severity	0.18821722	0.13512596	0.305307	0.23217	0.25802947
G. Expect % delay time per period cycle	3.01%	2.16%	9.77%	2.79%	3.10%

Row E: It counts the 'Probability of Occurrence' of each type of delay as showed in Equation 3.

$$Probability\ of\ Occurance = \frac{\text{Number of occurences}}{\text{Number of total cycles}} \text{... (Equation 3)}$$

Row F: It counts for the relative severity of that type of delay as showed in Equation 4.

$$Relative\ Severity = \frac{\text{Total added time}}{\text{Number of occurance} \times \text{Overall production cycle mean time}}$$ .... (Equation 4)

Row G: It counts for Expect % delay time per period cycle as showed in Equation 5.

$$\text{Expect \% delay time per cycle} = RowE \times RowF$$ .... (Equation 5)

Based on these calculations from table, following calculations are made to reach final result.

$$\text{Ideal Productivity} = \frac{1}{\text{mean non delay cycle}}$$ .... (Equation 6)

$$\text{So, Ideal Productivity} = \frac{((60\text{min/hr}) \times (60\text{sec/min}))}{465}$$

= 7.74 Roof Insulation Panels/ Hr

Overall Method Productivity = (Ideal Productivity) (1 – Een – Eeq – Ela – Emt – Emm)......... (Equation 7)

= (7.74)*(1-0.0301-0.0216-0.0977-0.0279-0.031)

= 0.6118

Just to verify the result of Overall Productivity

$$\text{Overall method productivity} = \frac{1}{\text{mean overall cycle time}}$$ .... (Equation 8)

$$= \frac{60\frac{min}{hr} \times 60\frac{sec}{min}}{589.08}$$

= 6.11 Roof Insulation Panels/ Hr

$$\text{Ideal Cycle Variability} = \frac{\text{(Row A)}}{\text{mean non delay cycle time}}$$ .... (Equation 9)

$$= \frac{24.75}{465}$$

= 0.053 < 1 ……Ok

$$\text{Overall cycle variability} = \frac{\text{(Row B)}}{\text{mean overall cycle time}}$$ .... (Equation 10)

$$= \frac{137.2}{589.08}$$

= 0.233 < 1 ……Ok

Refer to Chapter 4 for relationships between the sound intensities and cycle times, as well as identification of factors causing delays in the construction process.

3.2.2 5-Minute Rating

The 5-Minute Rating method has the advantage of quickly evaluating the crew activities although not as exactly as other methods of measuring worker's effectiveness. It was developed by Slim and Bernold (1994) and involves the collection of samples (Slim, 1994; Oglesby, 1989). This method is more useful for the study of short time spans. Since the observations are very small, they are not considered to be statistically significant (Slim, 1994; Oglesby, 1989).

All data collected during 5-minutes rating is tabulated in Appendix B. During this method of study, reading is taken after every specific period of time. It is noted at the time of every reading how many labors of the whole crew are involved in productive work (these labors are called as effective man units), and how many labors are idle or not involved in productive work (these labors are called as non-effective man units). After taking sufficient readings total effective labor hours are calculated by adding effective and non-effective labor hours. Effciency of the work process is calculated by Equation 11.

$$\text{Efficiency} = (\text{Effective Man hours})/(\text{Total Man Hours}) \qquad \text{(Equation 11)}$$

3.2.3 Construction Efficiency

Efficiency of the crew is calculated from the data collected by MPDM (appendix A) and five minute rating (appendix B). While calculating the efficiency total non-effective time is subtracted from the total observed time and then the answer is divided by total observed time (Equation 12).

$$Efficiency = \frac{(\text{Total Observed Time}) - (\text{Inefficient or unnecessary work time} + \text{Delays})}{\text{Total Observed Time}} \qquad \text{(Equation 12)}$$

Also, surrounding noise level was noted at the end of each cycle and average of sound levels of all the cycles was calculated to find out the average sound level for procedure. Then, on plotting efficiency against average sound level, the relationship between the efficiency and varying surround noise levels was established.

3.3 Safety

One of the objectives of this research was to apply data obtained from literature search, and surveys to find the relationship between the surrounding varying noise conditions and rate of accidents. The methodology behind the research for this thesis was personal interviews and questionnaires.

3.3.1 Survey

A survey was carried out in the form of personal interview and questionnaire, after every weekly safety meeting at the job site. Fifty Two labors from different subcontractors were surveyed randomly from various trades (varying from skilled to unskilled labors). The participants were given the full knowledge of this research work, at the beginning of the survey. Following questions were asked to each and every participant at the time of survey.

Table 3-3: Survey Questions & Responses

Questions	Answers and Remarks
1. Did you feel annoyance due to the sound conditions you were exposed to while working in building A and B?	44 out of 52 replied positive to this question, by saying; sound levels were quite annoying.
2. Were you ever experienced a hard time communicating with your co-worker, due to the surrounding noises?	46 out of 52 replied positive to this question, by saying; most of the times they have to shout while communicating with each other due to surrounding noise.
3. Did you ever felt loss of concentration, irritation, excessive fatigue due to the surrounding sound conditions?	48 out of 52 replied positive to this question, by saying; they always had to stop working for a moment at a time of airplanes takeoff and landing, because of very annoying loud noise.
4. Did you ever felt change in your hearing capacity due to working in noisy environment?	30 workers said they think that they are losing their hearing capacity. 5 workers said they feel permanent loss in their hearing capabilities due to the long exposure to the loud noises. These workers had more than 6 years experience in construction industry.
5. Did you ever felt any safety hazards due to the surrounding noise conditions?	Only one out of 52 replied positive to this question. This worker was a forklift operator. He said sometimes when he is carrying heavy load, he honks to the people to get out of the way, but they cannot hear him due to loud surrounding noise.

All the labors surveyed under this research were affiliated with labor unions. Affiliation of the labors with labor union, made it easier to obtain the information about the work history of the employee from employer. Head office of the respective individual was contacted after personal interview, to get the information about the years of construction industry experience of that person, number of accidents recorded against his name, and average sound levels under which he has to work 80% of time (Appendix C, Table C-1 entitled as ‘Rate of Accidents vs. Sound Conditions’).

3.3.2 Survey Responses

Following responses were obtained as a result of personal interview and surveys:

1. 84% of total population said the sound conditions were more annoying at building A (Figure 4-14). This shows the human nature of getting annoyed due to high frequency sound levels (Appendix C).
2. 88.46% of total population experienced problems in communication due to varying sound conditions (Figure 4-14).
3. 92.3% of total population experienced loss of concentration, irritation, and excessive fatigue due to surrounding sound conditions (Figure 4-14).
4. 57.7% of total population experienced temporary hearing loss, where as 9.61% of total population experienced permanent loss in hearing capabilities due to years of continuous exposure to varying sound conditions (Figure 4-14).
5. Only 1.95% of total population experienced the safety hazard due to surrounding noises (Figure 4.14). This tells us about the awareness among construction workers about the effect of surrounding noises on construction safety. One of the previous studies show that 22,566 of the 52,982 workers (42.6%) accumulated 43,250 accidents in the 5 years of the follow-up, averaging 1.9 accidents per injured worker, the actual number of accidents ranging between 1 and 25, per person (Picard et al, 2007).

Responses collected from the questions relating to the current job site noise conditions were used to reach a conclusion about the effects of varying surrounding noise conditions on construction safety. To find the relationship between the number of accidents on job site and noise, rate of accidents per year was calculated by dividing number of accidents witnessed so far, by number of years of experience. Then with the help of student’s t-distribution the pattern was found out, between the range of sound levels and rate of accidents (Appendix C: Table C-2 & C-3). To make the process easier and more efficient, sound conditions were categorized in three groups.

1. Above 90 dB: Very Noisy
2. Between 80 dB to 90 dB: Noisy

3. Below 80 dB: Ambient

The survey results are presented in Section 4.3.

3.4 Chapter Summary

MPDM and five minutes rating were used to find out the efficiency, and average sound levels. To find the relationship between average surrounding varying noise condition and labor efficiency, a graph was plotted in Section 4.2.7.

A survey was used to collect data about the rate of accidents and surrounding sound conditions of individual construction workers. To find out the pattern of distribution and rate of accidents over the noise level ranges, student's t-distribution test was performed (Appendix C: Table C-2 & C-3). Results & findings of this survey and related analysis are presented in Section 4.3.

CHAPTER 4

RESEARCH RESULTS

4.1Introduction

This chapter presents the results & findings of the research undertaken for this thesis as explained in Chapter 3. The results have been categorized into two areas, the results obtained from productivity analysis of effects of surrounding noise conditions on productivity and the survey conducted to find out the relationship between the rate of accidents and sound conditions.

4.2 Effects of Varying Sound Conditions on Construction Productivity

4.2.1 MPDM: Roof Insulation Building A

1. It was found that average sound level at the building A during this study was 85.16 dB. Highest sound level was 100 dB and lowest was 64 dB (Appendix A).
2. Distribution of the total delay over each cycle shows that, for every cycle 9.77% of time was wasted as a labor delay, 3.01% as environmental delay, 2.16% as equipment delay, 2.79% as material delay, and 3.1% as management delay (Table 3-2 in Chapter 3, entitled ‘Calculations: Roof Insulationsation Building A’).
3. Figure 4-1 shows the probability of occurrence of each type of delay. Labor delay has 32%, management delay has 12%, material delay has 12%, equipment delay has 16%, and environmental delay has 16% probability of occurrence (Table 3-1 in Chapter 3, entitled ‘Calculations: Roof Insulationsation Building A’).

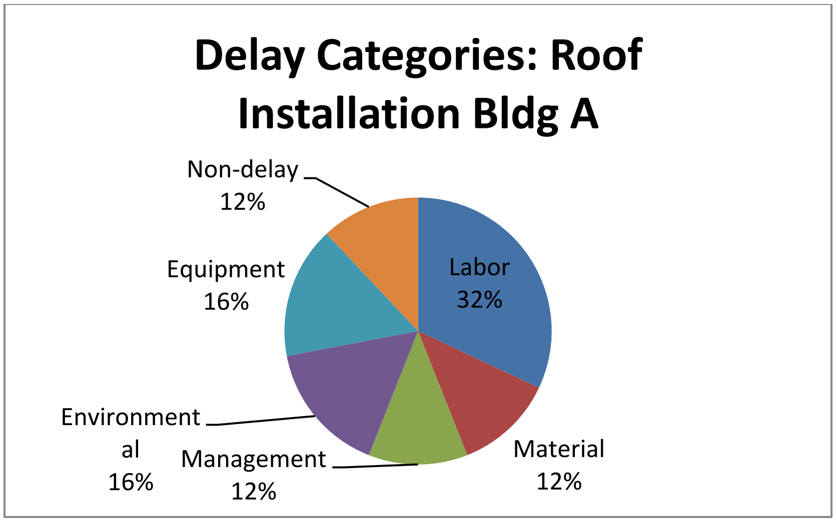

Figure 4-1: Delay Categories: Roof Installation Building A

4. Figure 4-2 shows the direct relationship between the sound conditions and cycle time. For plotting this graph only non delay cycles and cycles having labor delays are considered.

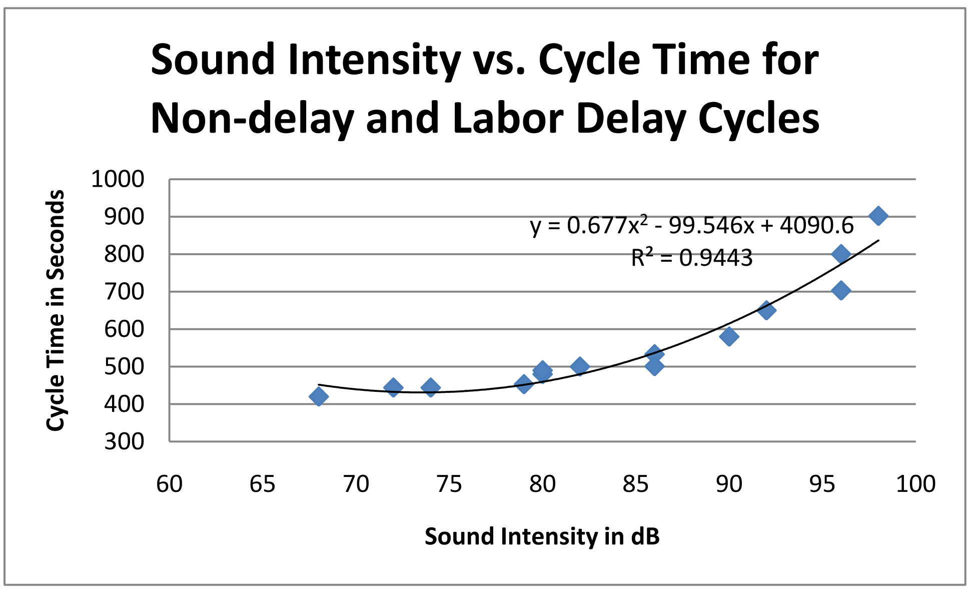

Figure 4-2: Relationship between Sound Intensity and Cycle Time for Non-delay and Labor Delay Cycles: Roof Installation Building A

Figure 4-2 shows that cycle time is directly proportional to the intensity of sound, and it follows the Equation 13.

$y = 0.677x^2 - 99.546x + 4090.6$……………………………………………………… (Equation 13)

5. Figure 4-3 shows no relationship between the sound intensity and cycle time for Management, Material, Equipment, and Environmental delay cycles which shows that the surrounding sound conditions have no effect on these delay cycles

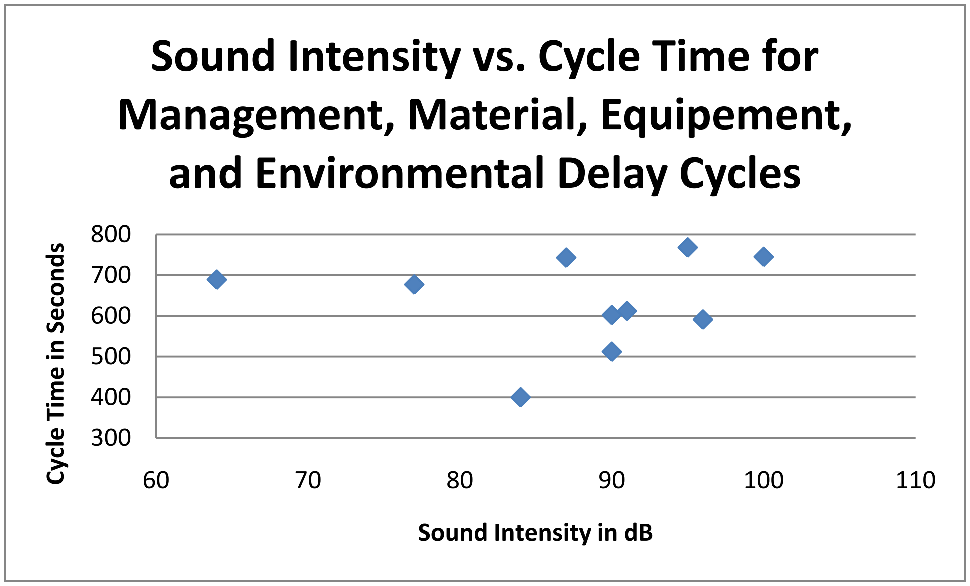

Figure 4-3: Relationship between Sound Intensity and Cycle Time for Management, Material, Equipment and Environmental Delay Cycles: Roof Installation Building A

6. Efficiency of the crew was found to be 79%.

Efficiency = 1- ((Ideal Cycle Time – Overall Cycle Time)/ (Ideal Cycle Time))

= 1- ((7.74-6.11)/ (7.74)

= 78.9%

4.2.2 MPDM: Roof Insulation Building B

1. It was found that average sound level at the building B during this study was 71.24 dB. Highest sound level was 82 dB and lowest was 59 dB (Appendix A).
2. Distribution of the total delay over each cycle shows that, for every cycle 5.83% of time was wasted as a labor delay, 2.19% as environmental delay, 0.43% as equipment delay, 2.93% as material delay, and 0.66% as management delay (Table A-4 in Appendix A, entitled ‘Calculations: Roof Insulationsation Building B’).

3. Figure 4-4 shows the probability of occurrence of each type of delay. Labor delay has 32%, management delay has 8%, material delay has 8%, equipment delay has 12%, and environmental delay has 2% probability of occurrence (Table A-4 in Appendix A, entitled 'Calculations: Roof Insulationsation Building B').

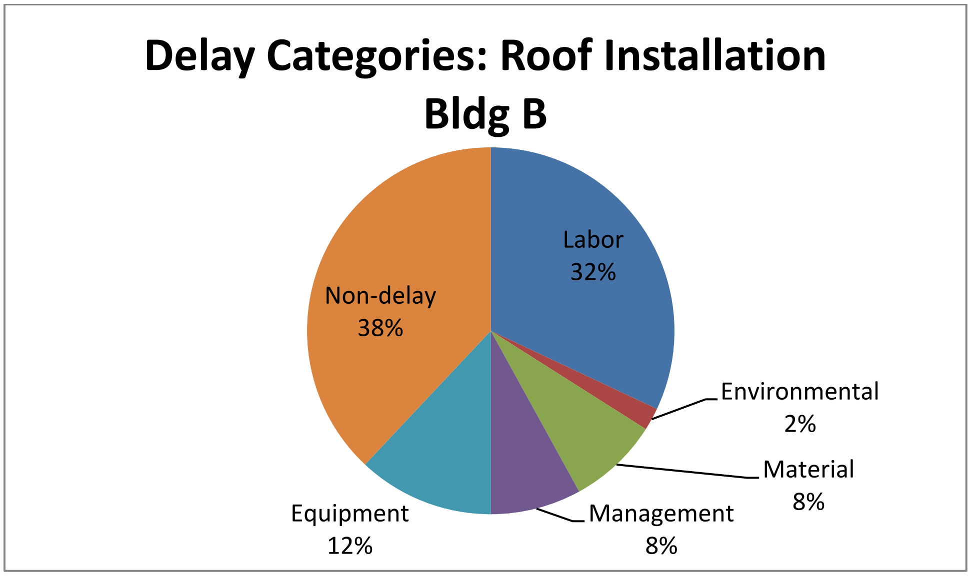

Figure 4-4: Delay Categories: Roof Installation Building B

4. Figure 4-5 shows the direct relationship between the sound conditions and cycle time. For plotting this graph only non delay cycles and cycles having labor delays are considered.

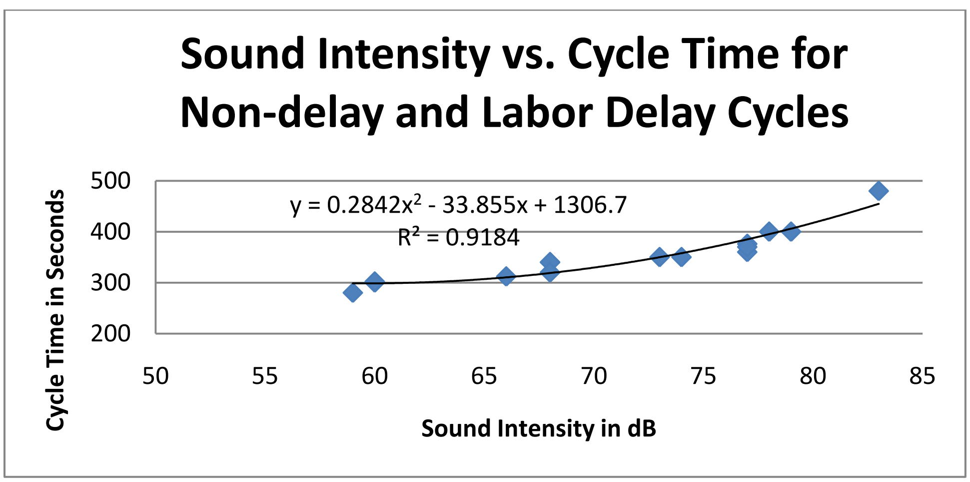

Figure 4-5: Relationship between Sound Intensity and Cycle Time for Non-delay and Labor Delay Cycles: Roof Installation Building B

Figure 4-5 shows that cycle time is directly proportional to the intensity of sound, and it follows the Equation 14.

$y = 0.2842x^2 - 33.855x + 1306.7$……………………………………………………… (Equation 14)

5. Figure 4-6 shows no relationship between the sound intensity and cycle time for Management, Material, Equipment, and Environmental delay cycles which shows that the surrounding sound conditions have no effect on these delay cycles.

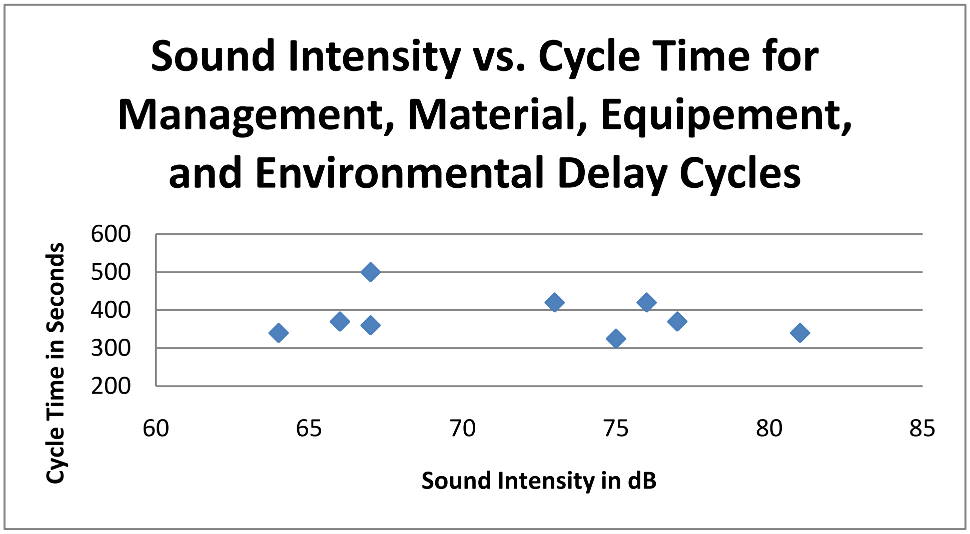

Figure 4-6: Relationship between Sound Intensity and Cycle Time for Management, Material, Equipment and Environmental Delay Cycles: Roof Installation Building B

6. Efficiency of the crew was found to be 88%.

4.2.3 MPDM: Dry Wall Installation Building A

1. It was found that average sound level at the building A during this study was 84.84dB. Highest sound level was 97dB and lowest was 70dB (Appendix A).
2. Distribution of the total delay over each cycle shows that, for every cycle 9.39% of time was wasted as a labor delay, 0% as environmental delay, 3.61% as equipment delay, 4.96% as material delay, and 3.66% as management delay (Table A-8 in Appendix A, entitled ‘Calculations: Dry Wall Building A’).
3. Figure 4-7 shows the probability of occurrence of each type of delay. Labor delay has 32%, management delay has 16%, material delay has 16%, equipment delay has 2%, and

environmental delay has 0% probability of occurrence (Table A-8 in Appendix A, entitled 'Calculations: Dry Wall Building A').

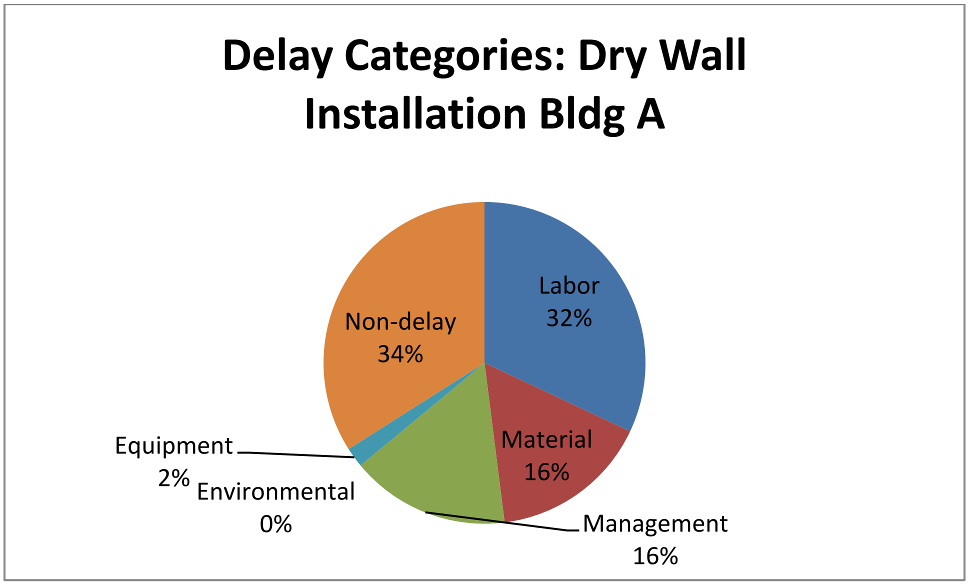

Figure 4-7: Delay Categories: Dry Wall Installation Building A

4. Figure 4-8 shows the direct relationship between the sound conditions and cycle time. For plotting this graph only non delay cycles and cycles having labor delays are considered.

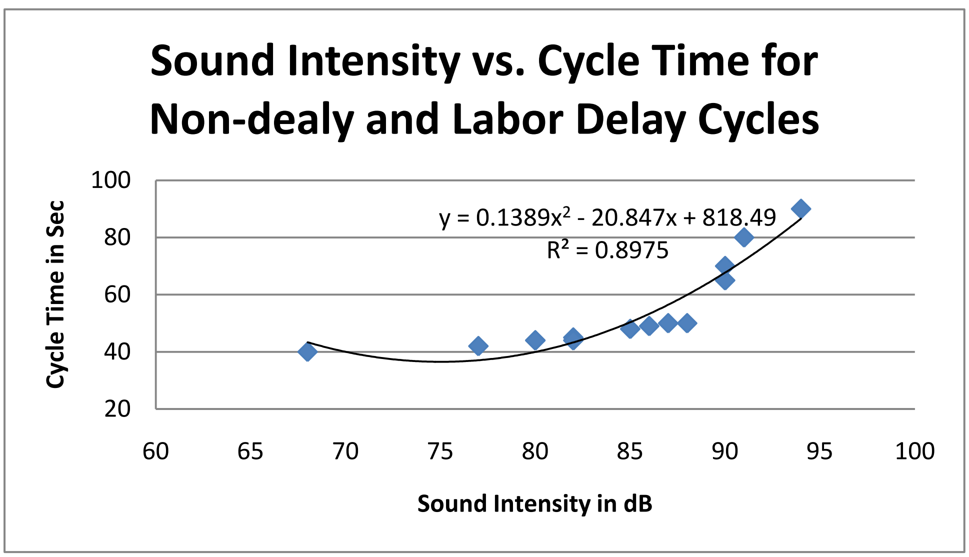

Figure 4-8: Relationship between Sound Intensity and Cycle Time for Non-delay and Labor Delay Cycles: Dry Wall Installation Building A

Figure 4-8 shows that cycle time is directly proportional to the intensity of sound, and it follows the Equation 15.

$y = 0.1389x^2 - 20.847x + 818.49$…………………………………………………… (Equation 15)

5. Figure 4-9 shows no relationship between the sound intensity and cycle time for Management, Material, Equipment, and Environmental delay cycles which shows that the surrounding sound conditions have no effect on these delays.

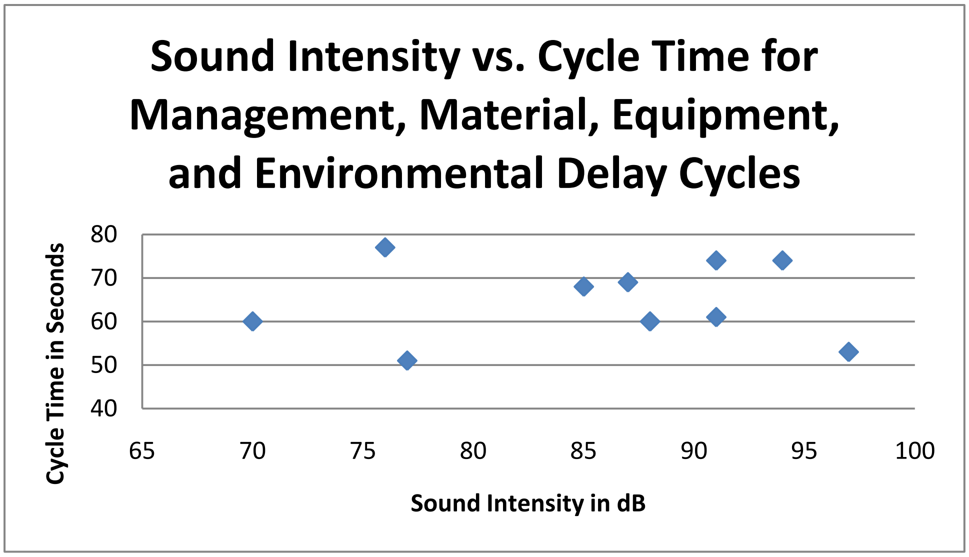

Figure 4-9: Relationship between Sound Intensity and Cycle Time for Management, Material, Equipment and Environmental Delay Cycles: Dry Wall Installation Building A

6. Efficiency of the crew was found to be 78%.

4.2.4 MPDM: Dry Wall Installation Building B

1. It was found that average sound level at the building B during this study was 89.32 dB. Highest sound level was 100 dB and lowest was 69 dB (Appendix A).

2. Distribution of the total delay over each cycle shows that, for every cycle 9.81% of time was wasted as a labor delay, 0% as environmental delay, 5.92% as equipment delay, 2.89% as material delay, and 2.36% as management delay (Table A-12 in Appendix A, entitled 'Calculations: Dry Wall Building B').

3. Figure 4-10 shows the probability of occurrence of each type of delay. Labor delay has 48%, management delay has 12%, material delay has 2%, equipment delay has 2%, and

environmental delay has 0% probability of occurrence (Table A-12 in Appendix A, entitled 'Calculations: Dry Wall Building B').

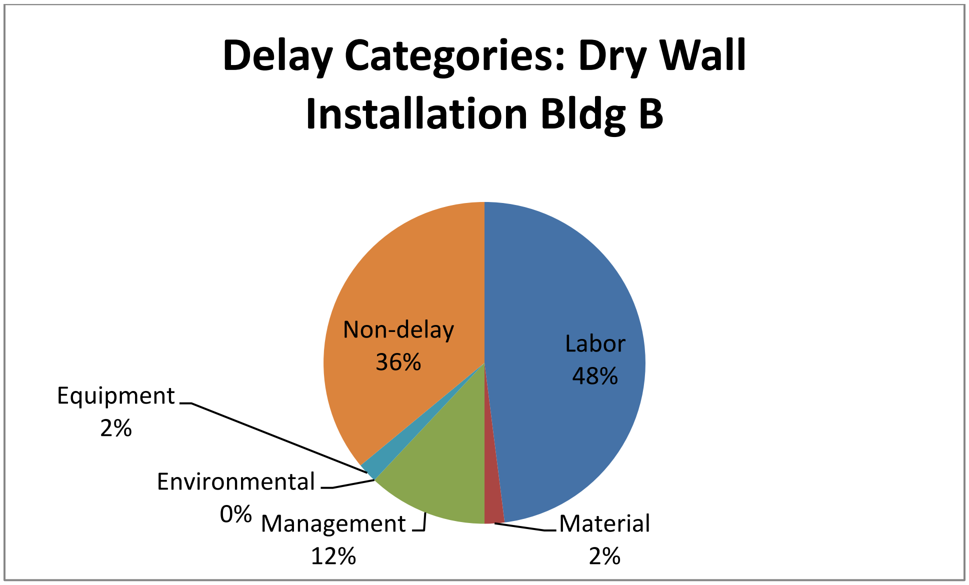

Figure 4-10: Delay Categories: Dry Wall Installation Building B

4. Figure 4-11 shows the direct relationship between the sound conditions and cycle time for only non delay cycles and cycles having labor delays are considered.

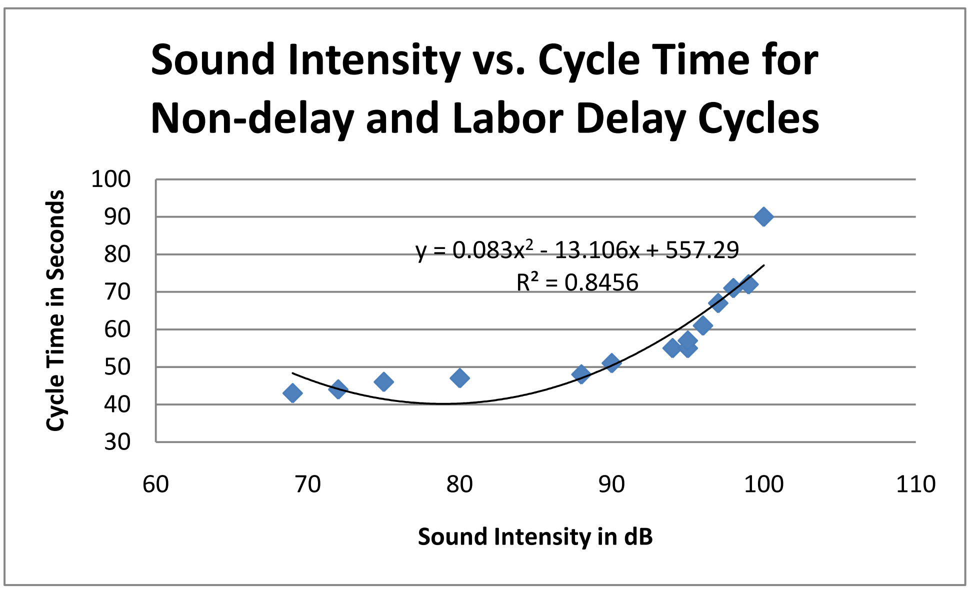

Figure 4-11: Relationship between Sound Intensity and Cycle Time for Non-delay and Labor Delay Cycles

Figure 4-11 shows that cycle time is directly proportional to the intensity of sound, and it follows the Equation 16.

$y = 0.083x^2 - 13.106x + 55729$……………………………………………………......... (Equation 16)

5. Figure 4-12 shows no relationship between the sound intensity and cycle time for Management, Material, Equipment, and Environmental delay cycles which shows that the surrounding sound conditions have no effect on these delays.

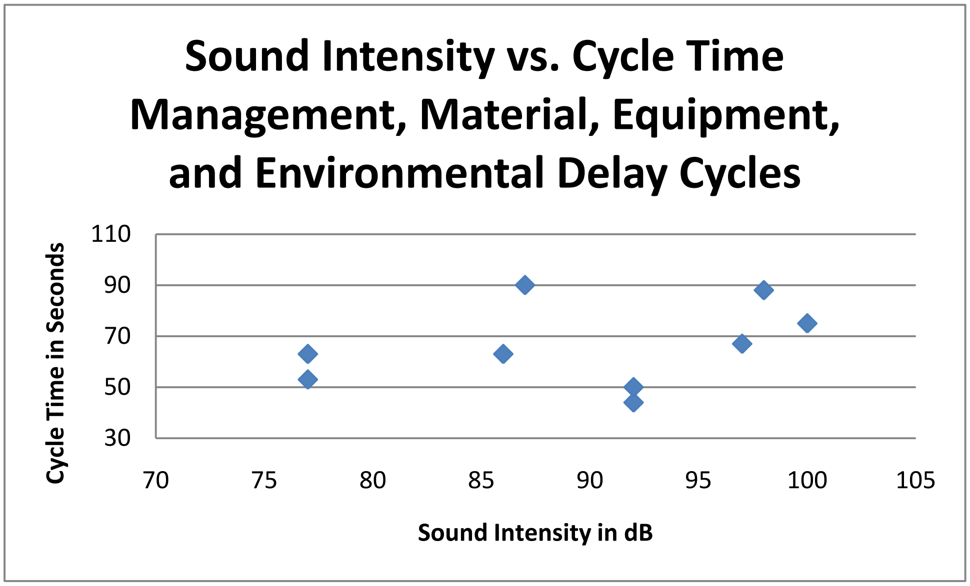

Figure 4-12: Relationship between Sound Intensity and Cycle Time for Management, Material, Equipment, and Environmental Delay Cycles: Dry Wall Installation Building B

6. Efficiency of the crew was found to be 77.61%.

4.2.5 Five Minutes Rating: Concreting Building B

1. Concreting was found to be an easier task than the two tasks studied earlier, of roof panel installation and dry wall installation since this involved only spreading of concrete dumped from concrete truck (Appendix B).
2. It was found that average sound level at the building B during this study was 78.44 dB. Highest sound level was 92 dB and lowest was 65 dB.
3. Efficiency of the crew was found to be 86.55%.

4.2.6 Five Minutes Rating: Concreting Building A

1. It was found that average sound level at the building A during this study was 87.49 dB. Highest sound level was 100 dB and lowest was 86 dB (Appendix B).
2. Efficiency of the crew was found to be 71.43%.

4.2.7 Relationship between Productivity loss and Relative Intensity of Noise

If we plot the graph of average sound levels during the work and percentage efficiency (Figure 4-13), it can be concluded that efficiency is inversely proportional to the intensity of noise.

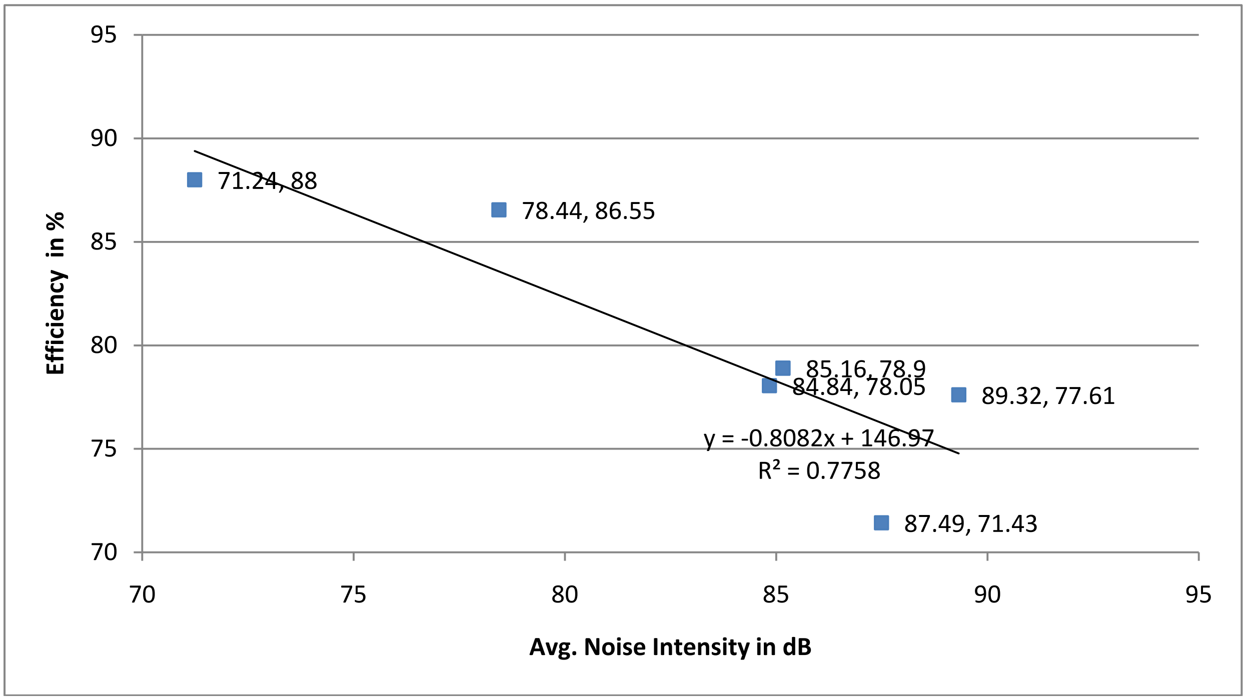

Figure 4-13: Decrease in the Efficiency with the Increase in the Average Intensity of Noise

This relationship can be better represented by Equations 17.

$y = -0.8082x + 146.97$……………………………….………………………………….. (Equation 17)

4.3 Effects of Varying Sound Conditions on Construction Safety

Graphical analysis of the personal interview and surveys (Figure 4-14) shows that majority of the population was in general agreement of sound as one of the cause for loss of concentration, irritation, excessive fatigue, & communication barrier at current job site. More than half of the population was experiencing temporary hearing losses.

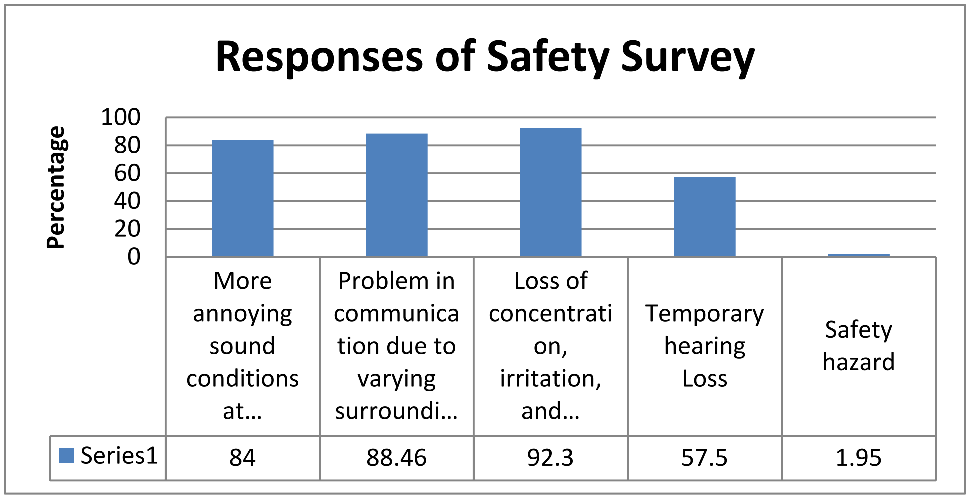

Figure 4-14: Results and Findings of Safety Survey

Statistical study of the survey showed that the rate of accidents witnessed by the individual per year is highest for sound levels above 90 dB with the average of 1.35 accidents per person per year, moderate for sound levels ranging between 80 dB to 90 dB with the average of 0.33 accident per person per year, and least for sound levels below 80 dB with the average of 0.26 accident per person per year.

4.4 Chapter Summary

To analyze the collected data, MPDM which is the best tool for productivity analysis was used. Though the method of five minutes rating was used, readings were taken for 34 minutes. Level of noise was measured at the end of every cycle and the average noise level for each procedure is calculated. Also, data was collected from variety of operations, which may or may not require cognitive thinking. All these factors make the results more reliable. The various productivity analyses showed that the efficiency is directly proportional to the average surrounding sound conditions.

The survey for this research was done in the form of interviews and questionnaire, to eliminate any misinterpretation of questions and responses. Labors from all categories (skilled/unskilled) and from different locations were surveyed to obtain a more reliable pool of data. Majority of the samples got distracted by sound. All the numerical data used for statistical analysis was obtained from reliable sources. Hypothesis of rate of accidents, verses the surrounding sound levels most of the times showed that rate of accidents is highest above 90 dB, moderate between (80 dB - 90 dB), and least under 80 dB.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Introduction

This chapter includes the conclusions drawn from the results and findings obtained in Chapter 4. It also includes the recommendations that can be incorporated into further study for the same subject.

5.2 Conclusions

1. There is direct relationship between the amount of time spent and surrounding sound intensity, for non delay and labor delay cycles. This proves the impact of surrounding sound intensity on labor productivity.
2. Efficiency of the workers was inversely proportional to the average intensity of the noise.
3. Loss of productivity due to varying surrounding noise conditions is directly proportional to the average intensity of noise.
4. Intensity of noise and rate of accidents witnessed per person per year were directly proportional to each other.

5.3 Recommendations for Future Research

1. This research can be further expanded to study the reasons for direct proportionality of loss in productivity and average intensity of varying surrounding sound conditions.
2. This research can be further expanded to study the effect of sound coming from different sources on labor productivity.
3. The research can be further expanded to include cost aspects of loss in productivity due to varying surrounding sound conditions

4. This research can be further expanded to include social cost of safety precautions need to be taken for corresponding surrounding sound conditions.
5. The survey for the analyzing the safety hazards due to the varying surrounding sound conditions can be conducted on a wider scale.
6. Further investigation can be done to minimize the surrounding sound at construction site.

APPENDIX A

MPDM

Table A-1: Non-delay & Major Labor Delays Cycle Time and Respective Sound Intensities for Roof Insulation Building A

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
1	90	580
2	68	420
3	80	480
4	96	800
6	92	650
7	82	500
10	80	490
12	72	444
18	86	533
20	98	902
21	86	501
22	79	453
24	96	703
25	74	444

Table A-2: Environmental, Equipment, Management, and Material Delays Cycle Time and Respective Sound Intensities for Roof Insulation Building A

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
5	84	400
8	87	743
9	64	689
11	77	677
13	96	591
14	91	612
15	90	602
16	95	768
19	90	512
23	100	745

Table A-3: Data Collection: Roof Insulation Building B

Date	20-Sep-10	Work		Laying Insulation and screwing them to the roof				
Location	NAS JRB Fort	Weather Conditions		Cloudy				
Project	B	Temperature		94F				
Time while readings were taken				10am				
Number of Labors Under Observation				2				
Average Sound Level				71.24 dB				
Wind Speed				17MPH				
Production Cycle Delay Sampling								
Page 1 of 1		Date:	20-Sep-10	Unit:	Seconds			
Method:	MPDM		Production Unit:		Panels laid per hour			
Production Cycle	Production Cycle Time (sec)	Environmental Delay (sec)	Equipment Delay (sec)	Labor Delay (sec)	Material Delay (sec)	Management Delay (sec)	Notes non-delay	Minus Mean Non-Delay Time
1	300						60dB, Non-Delay	18.22
2	350			100%			73dB	31.78
3	312						66dB, Non-Delay	6.22
4	376	20%		80%			77dB	57.78
5	325		100%				75dB	6.78
6	400			100%			79dB	81.78
7	302						60dBNon-Delay	16.22
8	340		100%				64dB	21.78
9	420				100%		73dB	101.78
10	280						59dB, Non-Delay	38.22
11	370		20%			80%	66dB	51.78
12	360	100%					67dB	41.78
13	480			100%			83dB	161.78
14	420	70%		30%			76dB	101.78
15	500				90%	10%	67dB	181.78
16	350						74dB, Non-Delay	31.78
17	320						68dB, Non-Delay	1.78
18	360			100%			77dB	41.78
19	340	100%					81dB	21.78
20	370			100%			77dB	51.78
21	340						68dB, Non-Delay	21.78
22	340						68dB, Non-Delay	21.78
23	370	100%					77dB	51.78
24	400			100%			78dB	81.78
25	320						68dB, Non-Delay	1.78

Table A-4: Calculations: Roof Insulation Building B

MPDM Processing					
Page 1 of 1	Date:	20-Sep-10	Unit:	Seconds	
Method	Roofing Insulation		Production Unit:	Panels	
Units	Total Production Time	Number of Cycles	Mean Cycle Time	Sum [1(cycle time)-(n.d. Cycle Time)1]/n	
A. Non-Delayed Production Cycles	2864	9	318.2222222	17.5308642	
B. Overall Production Cycles	9045	25	361.8	49.88888889	
Delay Information					
	Delays				
	Environmental	Equipment	Labor	Material	Management
C. Occurrence	5	3	8	2	2
D. Total Added time	198.1333333	38.91111111	527.4222222	265.3777778	59.6
E. Probability of occurrence	0.2	0.12	0.32	0.08	0.08
F. Relative severity	0.109526442	0.035849559	0.182221608	0.366746514	0.082365948
G. Expect % delay time per period cycle	0.021905288	0.004301947	0.058310915	0.029339721	0.006589276

$$\text{Ideal Productivity} = \frac{1}{\text{mean non} - \text{delay cycle}}$$

$$= \frac{((60\text{min/hr}) \times (60\text{sec/min}))}{318.22}$$ = 11.31 Roof Insulation Panels/ Hr

$$\text{Overall method productivity} = \frac{1}{\text{mean overall cycle time}}$$

$$= \frac{60\frac{min}{hr} x 60\frac{sec}{min}}{361.8}$$ = 9.95 Roof Insulation Panels/ Hr

$$\text{Ideal Cycle Variability} = \frac{(\text{Variation measure} - \text{Row A})}{\text{mean non} - \text{delay cycle time}}$$

$$= \frac{17.53}{318.22}$$ = 0.055 <1 ……Ok

$$\text{Overall cycle variability} = \frac{(\text{Variation measure} - \text{Row B})}{\text{mean overall cycle time}}$$

$$= \frac{49.88}{361.8}$$ = 0.137 <1 ……Ok

Table A-5: Non-delay & Major Labor Delay Cycle Time & Respective Sound Intensities for Roof Insulation Building B

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
1	60	300
2	73	350
3	66	312
4	77	376
6	78	400
7	60	302
10	59	280
13	83	480
16	74	350
17	68	320
18	77	360
20	77	370
21	68	340
22	68	340
24	79	400
25	68	320

Table A-6: Equipment, Environmental, Material, & Management Delay Cycle Time & Respective Sound Intensities for Roof Insulation Building B

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
5	75	325
8	64	340
9	73	420
11	66	370
12	67	360
14	76	420
15	67	500
19	81	340
23	77	370

Table A-7: Data Collection: Dry Wall Building A

Date	1-Oct-10	Work		Laying Roofing Insulation and screwing them to the roof				
Location	NAS JRB Fort Worth	Weather Conditions		Not applicable as indoor job				
Project	A	Temperature		83F				
Time while readings were taken				10am				
Number of Labors Under Observation				5				
Average Sound Level				84.84dB				
Wind Speed				Not applicable as indoor job				
Production Cycle Delay Sampling								
Page 1 of 1		Date:	1-Oct-10	Unit:	Second			
Method:	MPDM		Production Unit:		Gypsum board panels			
Production Cycle	Production Cycle Time (sec)	Enrvironmental Delay (sec)	Equipment Delay (sec)	Labor Delay (sec)	Material Delay (sec)	Management Delay (sec)	Notes non-delay	Minus Mean Non-Delay Time
1	44						80dB, Non-Delay	1.5
2	42						77dB, Non-Delay	3.5
3	48						85dB, Non-Delay	2.5
4	80			100%			91dB	34.5
5	40						68dB, Non-Delay	5.5
6	65			100%			90dB	19.5
7	50						87dB, Non-Delay	4.5
8	74		100%				91dB	28.5
9	69				100%		87dB	23.5
10	49			10%			85dB	3.5
11	68		20%			80%	85dB	22.5
12	44						80dB, Non-Delay	1.5
13	60		50%		50%		88dB	14.5
14	61		70%	30%			91dB	15.5
15	60				90%	10%	70dB	14.5
16	77			10%		90%	76dB	31.5
17	49						86dB, Non-Delay	3.5
18	53		20%	80%			97dB	7.5
19	51					100%	77dB	5.5
20	90			100%			94dB	44.5
21	50						88dB, Non-Delay	4.5
22	45						82dB, Non-Delay	0.5
23	74				100%		94dB	28.5
24	70			100%			90dB	24.5
25	44						82dB, Non-Delay	1.5

Table A-8: Calculations: Dry Wall Building A

MPDM Processing					
Page 1 of 1	Date: Oct-1-2010		Unit: Seconds		
Method:	Dry wall		Production Unit: Gypsum board panels		
Units	Total Production Time	Number of Cycles	Mean Cycle Time	Sum [1(cycle time)-(n.d. Cycle Time)1]/n	
A. Non-Delayed Production Cycles	455	10	45.5	2.8	
B. Overall Production Cycles	1457	25	58.28	13.9	
Delay Information					
	Delays				
	Environmental	Equipment	Labor	Material	Management
C. Occurrence	0	5	8	4	4
D. Total Added time	0	52.6	136.8	72.3	53.3
E. Probability of occurrence	0	0.2	0.32	0.16	0.16
F. Relative severity	0	0.180507893	0.293411119	0.3101407	0.228637612
G. Expect % delay time per period cycle	0.00%	3.61%	9.39%	4.96%	3.66%

$$\text{Ideal Productivity} = \frac{1}{\text{mean non} - \text{delay cycle}}$$

$$= \frac{((60\text{min/hr}) \times (60\text{sec/min}))}{45.5} \qquad = 79.12 \text{ Panels/ Hr}$$

$$\text{Overall method productivity} = \frac{1}{\text{mean overall cycle time}}$$

$$= \frac{60\frac{min}{hr}x60\frac{sec}{min}}{58.29} \qquad = 61.76 \text{ Panels/ Hr}$$

$$\text{Ideal Cycle Variability} = \frac{(\text{Variation measure} - \text{Row A})}{\text{mean non} - \text{delay cycle time}}$$

$$= \frac{2.8}{45.5} \qquad = 0.061 \quad <1 \text{ ......Ok}$$

$$\text{Overall cycle variability} = \frac{(\text{Variation measure} - \text{Row B})}{\text{mean overall cycle time}}$$

$$= \frac{13.9}{58.29} \qquad = 0.24 \quad <1 \text{ ......Ok}$$

Table A-9: Non-delay & Major Labor Delays & Respective Sound Intensities for Dry Wall Installation of Building A

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
1	80	44
2	77	42
3	85	48
4	91	80
5	68	40
6	90	65
7	87	50
12	80	44
17	86	49
20	94	90
21	88	50
22	82	45
24	90	70
25	82	44

Table A-10: Environmental, Equipment, Material, & Management Delay Cycle Time & Respective Sound Intensities for Dry Wall Installation of Building A

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
8	91	74
9	87	69
11	85	68
13	88	60
14	91	61
15	70	60
16	76	77
18	97	53
19	77	51
23	94	74

Table A-11: Data Collection: Dry Wall Building B

Date	30-Sep-10	Work	Dry wall (Putting gypsum board panels)
Location	NAS JRB Fort Worth	Weather Conditions	Not applicable as indoor job
Project	B	Temperature	70F
Time while readings were taken			10am
Number of Labors Under Observation			2
Average Sound Level			89.32 dB
Wind Speed			Not applicable as indoor job
Production Cycle Delay Sampling			

Page 1 of 1		Date:	30-Sep-10	Unit:	Second			
Method:	MPDM		Production Unit:		Gypsum board panels			
Production Cycle	Production Cycle Time (sec)	Enrvironmental Delay (sec)	Equipment Delay (sec)	Labor Delay (sec)	Material Delay (sec)	Management Delay (sec)	Notes non-delay	Minus Mean Non-Delay Time
1	90		20%	80%			100dB	43.8
2	61			100%			96dB	14.8
3	44			50%	25%	25%	92dB	2.2
4	72			80%			99dB	25.8
5	75		100%				100dB	28.8
6	55			100%			94dB	8.8
7	50				100%		92db	3.8
8	88		100%				98db	41.8
9	63				100%		77db	16.8
10	44						72dB, Non-Delay	2.2
11	90		20%			80%	87dB	43.8
12	39						87dB	7.2
13	48			100%			88dB	1.8
14	50			30%			98dB	3.8
15	53				90%	10%	77dB	6.8
16	51						90dB, Non-Delay	4.8
17	47						80dB, Non-Delay	0.8
18	55			100%			95dB	8.8
19	46						75dB, Non-Delay	0.2
20	57			100%			95dB	10.8
21	43						69dB, Non-Delay	3.2
22	67		30%	70%			97dB	20.8
23	63				100%		86dB	16.8
24	71			100%			98dB	24.8
25	66			30%			91dB	19.8

Table A-12: Calculations: Dry Wall Building B

MPDM Processing					
Page 1 of 1	Date:	14-Aug-10	Unit:	Seconds	
Method:	Dry wall (gypsum board panels)		Production Unit:	gypsum board panels	
Units	Total Production Time	Number of Cycles	Mean Cycle Time	Sum [1(cycle time)-(n.d. Cycle Time)1]/n	
A. Non-Delayed Production Cycles	231	5	46.2	2.24	
B. Overall Production Cycles	1488	25	59.52	14.52	
Delay Information					
	Delays				
	Environmental	Equipment	Labor	Material	Management
C. Occurrence	0	5	12	5	3
D. Total Added time	0	88.12	146.02	42.97	35.17
E. Probability of occurrence	0	0.2	0.48	0.2	0.12
F. Relative severity	0	0.296102151	0.204441084	0.144388441	0.196964606
G. Expect % delay time per period cycle	0.00%	5.92%	9.81%	2.89%	2.36%

$$\text{Ideal Productivity} = \frac{1}{\text{mean non} - \text{delay cycle}}$$

$$= \frac{((60\text{min/hr}) \times (60\text{sec/min}))}{46.2}$$ = 77.92 Panels/ Hr

$$\text{Overall method productivity} = \frac{1}{\text{mean overall cycle time}}$$

$$= \frac{60\frac{min}{hr}x60\frac{sec}{min}}{59.52}$$ = 60.48 Panels/ Hr

$$\text{Ideal Cycle Variability} = \frac{(\text{Variation measure} - \text{Row A})}{\text{mean non} - \text{delay cycle time}}$$

$$=\frac{2.24}{46.2}$$ = 0.048 <1 ……Ok

$$\text{Overall cycle variability} = \frac{(\text{Variation measure} - \text{Row B})}{\text{mean overall cycle time}}$$

$$=\frac{14.52}{59.52}$$ = 0.24 <1 ……Ok

Table A-13: Non-delay & Major Labor Delay Cycle Time & Respective Sound Intensities for Dry Wall Installation Building B

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
1	100	90
2	96	61
4	99	72
6	94	55
10	72	44
13	88	48
16	90	51
17	80	47
18	95	55
19	75	46
20	95	57
21	69	43
22	97	67
24	98	71

Table A-14: Environmental, Equipment, Material, & Management Delay Cycles & Respective Sound Intensities for Dry Wall Installation Building B

Cycle Number	Sound Intensity (dB)	Cycle Time (Seconds)
3	92	44
5	100	75
7	92	50
8	98	88
9	77	63
11	87	90
15	77	53
22	97	67
23	86	63

APPENDIX B

FIVE MINUTES RATING

Table B-1: Five Minutes Rating: Concreting Building A

Date:	29-Apr-10	Type of Work	Spreading Concrete Dumped by
Location:	NAS JRB Fort Worth	Weather	Sunny & Cloudy
Building	A	Temperature	87 F
Time While Starting			8:27 AM
Number of Labor Observed			7
Average Sound level			87.94 dB
Wind Speed			12 MPH

Sr. No.	Time	Crew							
		Vibrator	Spreader 1	Spreader 2	Spotter 1	Spotter 2	Supervisor	Spreader 3	Sound Levels
1	8:27	-	X	X	X	X	-	X	92dB
2	8:28	-	X	-	X	-	X	X	93dB
3	8:29	X	X	X	-	-	X	X	88dB
4	8:30	X	-	-	-	-	-	-	98dB
5	8:31	X	X	X	-	-	-	-	95dB
6	8:32	-	X	X		X	X	-	88dB
7	8:33	X	X	X	-	X	X	-	86dB
8	8:34	X	X	-	X	X	X	X	80dB
9	8:35	X	X	X	-	-	X	X	80dB
10	8:36	X	X	X	-	-	X	X	79dB
11	8:37	-	-	-	X	X	X	X	88dB
12	8:38	-	X	X	-	X	X	X	90dB
13	8:39	X	-	-	-	-	-	-	98dB
14	8:40	-	X	-	-	X	X	X	99dB
15	8:41	X	X	X	X	X	X	X	88dB
16	8:42	X	X	X	X	X	X	X	92dB
17	8:43	X	X	X	X	-	-	-	100dB
18	8:44	X	X	X	X	X	X	X	94dB
19	8:45	X	X	X	X	-	X	X	86dB
20	8:46	X	X	X	-	-	X	X	84dB
21	8:47	X	X	-	X	X	X	X	88dB
22	8:48	X	-	X	-	-	X	X	69dB
23	8:49	X	X	X	-	-	-	-	94dB
24	8:50	X	X	X	X	X	X	X	87dB
25	8:51	X	X	X	X	X	X	X	85dB
26	8:52	-	-	-	-	-	-	-	90dB
27	8:53	X	X	X	X	X	X	X	84dB
28	8:54	X	X	X	X	X	X	X	88dB
29	8:55	X	X	X	X	X	X	-	85dB
30	8:56	X	X	X	X	X	X	-	82dB
31	8:57	X	X	X	-	-	X	X	87dB
32	8:58	X	X	X	X	-	X	X	88dB
33	8:59	X	X	-	X	X	X	X	85dB
34	9:00	X	X	X	X	X	X	X	80dB

Effective Man Units	= 27+29+25+19+19+25+26	= 170 units
Total Man Units	= 34*7	= 238 units
Effectiveness	= 170/238*100	= 71.43%

Table B-2: Five Minutes Rating: Concreting Building B

Date:	2-Jun-10			Type of Work			Spreading Concrete Dumped by Concrete Pump		
Location:	NAS JRB Fort Worth			Weather			Sunny & Cloudy		
Building	B			Temperature			87 F		
Time While Starting							8:27 AM		
Number of Labor Observed							7		
Average Sound level							86.55db		
Wind Speed							17 MPH		
Sr. No.	Time	Crew							
		Vibrator	Spreader 1	Spreader 2	Spotter 1	Spotter 2	Supervisor	Spreader 3	Sound Levels
1	8:27	X	X	X	X	X	-	X	80dB
2	8:28	-	X	X	X	-	X	X	76dB
3	8:29	X	X	X	-	-	X	X	85dB
4	8:30	X	-	-	-	-	-	-	92dB (Yelling at each other)
5	8:31	X	X	X	-	-	-	-	88dB
6	8:32	-	X	X	-	X	X	-	79dB
7	8:33	X	X	X	X	X	X	-	65dB
8	8:34	X	X	X	X	X	X	X	70dB
9	8:35	X	X	X	X	X	X	X	87dB
10	8:36	X	X	X	X	X	X	X	80dB
11	8:37	-	-	-	X	X	X	X	83dB
12	8:38	-	X	X	-	X	X	X	70dB
13	8:39	X	X	X	-	-	X	X	72dB
14	8:40	-	X	-	-	X	X	X	88dB
15	8:41	X	X	X	X	X	X	X	79dB
16	8:42	X	X	X	X	X	X	X	65dB
17	8:43	X	X	X	X	-	X	X	70dB
18	8:44	X	X	X	X	X	X	X	87dB
19	8:45	X	X	X	X	-	X	X	78dB
20	8:46	X	X	X	X	X	X	X	84dB
21	8:47	X	X	X	X	X	X	X	77dB
22	8:48	X	-	X	X	X	X	X	73dB
23	8:49	X	X	X	X	X	X	X	77dB
24	8:50	X	X	X	X	X	X	X	88dB
25	8:51	X	X	X	X	X	X	X	79dB
26	8:52	X	X	X	X	X	X	X	65dB
27	8:53	X	X	X	X	X	X	X	70dB
28	8:54	X	X	X	X	X	X	X	87dB
29	8:55	X	X	X	X	X	X	X	80dB
30	8:56	X	X	X	X	X	X	X	83dB
31	8:57	X	X	X	X	X	X	X	70dB
32	8:58	X	X	X	X	X	X	X	72dB
33	8:59	X	X	X	X	X	X	X	88dB
34	9:00	X	X	X	X	X	X	X	80dB

Effective Man Units	= 29+31+31+27+28+30+30	= 206 units
Total Man Units	= 34*7	= 238 units
Effectiveness	= 206/238*100	= 86.55%

APPENDIX C

SURVEY: YEARS OF EXPERIENCE AND ACCIDENTS WITNESSED

Table C-1: Rate of Accidents Vs Sound Conditions

No.	Experience	Number of accidents witnessed so far	General sound conditions more than 80% of time (v = very noisy; n = noisy; a = ambient)	# accidents/year/person
1	2	6	v	3
2	3	2	v	0.67
3	10	3	n	0.3
4	20	12	n	0.6
5	5	1	a	0.2
6	6	2	a	0.33
7	7	3	n	0.43
8	4	4	n	1
9	9	3	n	0.33
10	2	3	n	1.5
11	7	3	n	0.43
12	5	2	n	0.4
13	9	1	n	0.11
14	11	7	n	0.64
15	13	3	a	0.23
16	16	20	v	1.25
17	3	5	v	1.67
18	4	2	n	0.5
19	11	2	a	0.18
20	3	1	n	0.33
21	33	2	a	0.06
22	4	5	v	1.25
23	8	3	n	0.38
24	3	3	v	1
25	8	2	a	0.25
26	5	1	a	0.2
27	4	1	n	0.25
28	1	0	a	0
29	4	2	n	0.5
30	5	6	v	1.2
31	9	1	a	0.11
32	7	3	n	0.43
33	5	7	v	1.4
34	6	2	n	0.33
35	9	3	n	0.33
36	21	7	n	0.33
37	4	6	v	1.5
38	6	3	n	0.5
39	8	3	a	0.38
40	9	5	n	0.56
41	6	2	n	0.33
42	6	1	n	0.17
43	6	5	n	0.83
44	7	4	v	0.57
45	3	2	a	0.67
46	5	3	n	0.6
47	2	1	n	0.5
48	4	4	a	1
49	2	3	n	1.5
50	7	4	n	0.57
51	8	3	n	0.38
52	9	2	a	0.22

Table C-2: Hypothesis 1: Comparison of Accidents In Very Noisy & Noisy Conditions

Very Noisy			Noisy		
# person	und Condit	Rate	# person	und Condit	Rate
1	v	3	1	n	0.3
2	v	0.67	2	n	0.6
3	v	1.25	3	n	0.43
4	v	1.67	4	n	1
5	v	1.25	5	n	0.33
6	v	1	6	n	1.5
7	v	1.2	7	n	0.43
8	v	1.4	8	n	0.4
9	v	1.5	9	n	0.11
10	v	0.57	10	n	0.64
Average		1.350476	11	n	0.5
Standard Deviation		0.673786	12	n	0.33
			13	n	0.38
			14	n	0.25
			15	n	0.5
			16	n	0.43
			17	n	0.33
			18	n	0.33
			19	n	0.33
			20	n	0.5
			21	n	0.56
			22	n	0.33

Student's t-distribution test ………………………………………………………… at 95% level of confidence

μ_1: Accidents in very noisy conditions (90dB and above)

N_1 = 10, $\bar{X}$1 = 1.35, SD_1 = 0.6737

μ_2: Accidents in noisy conditions (80dB – 90dB)

N_2 = 29, $\bar{X}$2 = 0.52, SD_2 = 0.3265

μ_3: Accidents in Ambient Conditions (Below 80dB)

N_3 = 13, $\bar{X}$2 = 0.29, SD_3 = 0.2678

H_0: $\mu_1 \leq \mu_2$ (Null Hypothesis)

H1: $\mu_1 \geq \mu_2$ (Alternate Hypothesis)

We will check for Null Hypothesis.

$S_p^2 = \frac{(9x0.674^2+28x0.32^2)}{37} = 0.188$

$S_p = 0.433$

$T = \frac{1.35-0.52}{0.433\sqrt{(\frac{1}{10}+\frac{1}{29})}} = 5.22$

From Table of Student's T-Distribution

$T_{0.05,\ 37} = 1.68$

So, this disproves the null hypothesis, and it is proved that probability of accidents is more in very noisy conditions than noisy conditions.

Table C-3: Hypothesis 2: Comparison of Accidents in Noisy & Ambient Conditions

Noisy			Ambient		
# person	Sound Condition	Rate	# person	Sound Condition	Rate
1	n	0.3	1	a	0.2
2	n	0.6	2	a	0.33
3	n	0.43	3	a	0.23
4	n	1	4	a	0.18
5	n	0.33	5	a	0.06
6	n	1.5	6	a	0.25
7	n	0.43	7	a	0.2
8	n	0.4	8	a	0
9	n	0.11	9	a	0.11
10	n	0.64	10	a	0.38
11	n	0.5	11	a	0.67
12	n	0.33	12	a	1
13	n	0.38	13	a	0.22
14	n	0.25	Average		0.29
15	n	0.5	Standard Deviation		0.26788
16	n	0.43			
17	n	0.33			
18	n	0.33			
19	n	0.33			
20	n	0.5			
21	n	0.56			
22	n	0.33			
23	n	0.17			
24	n	0.83			
25	n	0.6			
26	n	0.5			
27	n	1.5			
28	n	0.57			
29	n	0.38			
Average		0.52			
Standard Deviation		0.326515			

H_0: $\mu_2 \leq \mu_3$ (Null Hypothesis)

H1: $\mu_2 \geq \mu_3$ (Alternate Hypothesis)

We will check for Null Hypothesis.

$S_p^2 = \frac{(28x0.32^2+12x0.27\hat{}2)}{40} = 0.09355$

$S_p = 0.306$

$T = \frac{0.52-0.29}{0.306\sqrt{(\frac{1}{29}+\frac{1}{13})}} = 2.5$

From Table of Student's T-Distribution

$T_{0.05,\,40} = 1.684$

So, this disproves the null hypothesis, and it is proved that probability of accidents is more in noisy conditions than ambient conditions.

REFERENCES

Adrian, J. J. (2004). *Construction Productivity Improvement.* New York: Elsevier.

Broadberry, S. N., & Wagner, K. (1994). Human Capital and Productivity in Manufacturing during the Twentieth Century: Britain, Germany and the United States. *C.E.P.R. Discussion Papers.*

Drewin, F. J. (1982). *Construciton Productivity, Measurement and Improvement through Work Study.* New York: Elsevier Science Publishing Co., Inc.

Errett, E. E. (2006). Effects of noise on productivity: does performance decrease over time? *ASCE* , 185(2), 217-224.

Fi.edu. (2010). Retrieved November 15, 2010, from http://www.fi.edu/learn/brain/stress.html

Halpin, D. W., & Riggs, L. S. (1992). *Planning & Analysis of Construction Operations.*

Jones, D., & Broadbent, D. (1998). Human Performance and Noise. In *Handbook of Acoustical Measurements and Noise Control* (pp. Chap. 24, pp. 24.1 – 24.24). Melville, NY: Acoustical Society of America.

Laborer's, U. D. (2009, March). *A Chartbook of International Labors*. Retrieved April 25, 2009, from http://www.bls.gov/fls/chartbook2009.pdf

Landström, U. (2004). Ventilation noise and its effects on annoyance and performance. *J. Acoust. Soc. Am.* , 115(5), 2370(A).

Nagai, N., Matsumoto, M., Yamasumi, Y., Shiraishi, T., Nishimura, K., Matsumoto, K., et al. (1989). Process and Emergence on the Effects of Infrasonic and Low Frequency Noise on Inhabitants. *J. Low Freq. Noise Vib.* , 8, 87-99.

OSHA. (2010). *www.osha.gov*. Retrieved November 15, 2010, from http://www.osha.gov/Publications/OSHA3074/osha3074.html

Persson, W. K. (2001). The Prevalence of Annoyance and Effects After Long Term Exposure to Low Frequency Noise. *J. Sound Vib.* , 240, 483-497.

Persson, W. K., Rylander, R., Benton, S., & Leventhall, H. G. (1997). Effects on Performance and Work Quality due to Low Fequency Ventillation Noise. *J. Sound Vib.* , 205, 467-474.

Picard, M., Serge, A. G., Larocque, R., & Simard, M. (2007). Association of work related accidents with noise exposure in work place and noise induced hearing loss based on experience of 240,000 person-years of obervation. *Accident analysis and prevention*.

Poulson, T. (1991). Influence of session length on judged annoyance. *J. Sound Vib.* , 145(2), 217-224.

Thomas, H. R. (1987). The manual of construction productivity measurement and performance evaluation. *Construction Industry Institute, Austin, Tex*.

Thomas, H. R., & Oloufa, A. A. (1995). Labor Productivity, Disruptions, and the Ripple Effect. *Cost Engrg* , 37(12), 49-54.

Thomas, H. R., Sanders, S. R., & Bilal, S. (1989). Comparison of labor productivity.

Thomas, R. H., Riley, D. R., & Sanvido, V. E. (1999). Loss of Labor Productivity due to Delivery Methods and Weather. *ASCE.*

Tokita, Y. (1980). Low frequency noise pollution problems in Japan. *Low Frequency Noise and Hearing, .* Aalborg, Denmark.

Wikipedia. (2010, December). *Paul Lazarsfeld*. Retrieved December 12, 2010, from www.wikipedia.com: http://en.wikipedia.org/wiki/Paul_Lazarsfeld.

Wikipedia. (2010, November). *Student's t-test*. Retrieved November 1 15, 2010, from www.wikipedia.com: http://en.wikipedia.org/wiki/Student's_t-test

BIOGRAPHICAL INFORMATION

At the time of presentation of this paper, Shripad D. Maldikar has a Bachelors Degree in Civil Engineering from the University of Mumbai. He has continued to maintain a strong academic standing while pursuing a Masters in the area of Construction Management and Engineering at the University of Texas at Arlington. Mr. Maldikar has been under employment of the University of Texas at Arlington as a Graduate Student Worker from August 08 to August 09, and Graduate Teaching Assistant from August 09 to December 09. He has been employed as a Scheduler/Superintendent Intern by SMR Construction Inc. from February 10 to August 10. Mr. Maldikar has been the recipient of the CUIRE Scholarship of Fall 09, Spring 09 and Summer 09 and ASCE Scholarship Fall 10. During his career so far Mr. Maldikar has earned many certifications, awards, and prizes. Some of the most important certifications and prizes are Associate Constructor (AC) from ‘American Institute of Constructors’ and 1st Prize winner of All over India Inter-Collegiate Paper Presentation Competition (January, 2007), Mumbai, India.