DEVELOPMENT OF AN ACCIDENT MODEL
FOR CONSTRUCTION INDUSTRY

by

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ABSTRACT

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CONSTRUCTION INDUSTRY

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Safety has always been a persistent problem in the construction industry. Construction accidents are a major concern for the construction industry and the researchers. In spite of the role of many construction accident causation models in understanding the accident process, none adequately explain the underlying reasons for construction accidents because of their dynamic nature.

To overcome this restriction a new advancement in understanding construction accidents has been proposed by Howell et al (2002) based on the work of Rasmussen (1997). The model recognizes that organizational and individual forces push workers in to hazardous conditions. These forces overcome efforts to impose safe work rules particularly in a changing work environment such as in construction.

Therefore, this approach emphasizes the need to train workers to be conscious of hazardous work environments through better planning. The focus of this orientation is on construction workers, which in turn leads to the design of worker specific training.

To attain this objective a survey was developed based on OSHA standards for all types of construction accidents and from all cases reported by NIOSH. With the assistance of this survey the sensitivity and risk orientation of construction workers were determined using Signal Detection Theory (SDT). This research focused on evaluation of occupational safety and health competencies of construction workers.

The tools presented in this study will provide methods to determine the sensitivity and risk orientation of workers to unsafe conditions. The results of this analysis, enables the development of worker- specific planning to increase the sensitivity and decrease risky behavior in unsafe conditions.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Accidents in construction sites are identified as a major problem throughout the world. According to a report published by the Construction Industry Institute (CII), injuries and fatalities occur in the construction industry at a rate more than 50% higher than all other industries. Each work day, three or four construction workers die from injuries on the job in the U.S., totaling more than 900 deaths per year. Construction accounts for only 5% of the United States' workforce but take a disproportionate 20% of all occupational fatalities and 9% of all disabling occupational injuries (Huang & Hinze, 2003). According to Peraza and Travis (2009), from 1992 to 2006, there was an average of 42 workers deaths per year.

1.2 Problem Statement

Patel (2003) stated, that in 2001, 15% of the $145 billion spent on occupational injuries, was spent on construction cases. Although much progress has been made towards reducing the hazard prevention in construction occupations, construction is still a high-risk industry.

1.3 Objectives and Methodology

1.3.1 Objectives

The main goal of this research is to develop a methodology by which worker's sensitivity to unsafe conditions and risk orientation can be assessed prior to prescribing a training program. To achieve at this goal, the following objectives were proposed:

- Investigate the sensitivity and risk orientation of workers to unsafe conditions.
- Design and conduct a survey to determine the sensitivity and risk orientation of workers at risk for all type of construction accidents.

1.3.2 Methodology

The following describes research methodology:

- Signal detection theory (SDT), as described in Section 2.4 of this thesis, is used in this research to show that there is similarity between the answer of the construction worker in identifying defective and non-defective parts and the construction worker's answer in recognizing safe and unsafe conditions on site. Furthermore, SDT is the only technique that will help to determine both the sensitivity and risk orientation of the construction worker.
- A survey is developed by referring to case studies of some common types of construction accidents. The survey contains 21 questions involving conditions where some common types of construction accidents may exist. To keep the scope reasonable, the survey is given to 24 construction workers.

- For establishing whether the data achieved from the 24 construction workers pursues a normal distribution, normal quintile plots are considered using the Microsoft Excel software.
- Regression analysis is used to examine if age, years of experience or level of education are linearly correlated with the sensitivity (d`) and risk orientation (β current) of a construction worker.
- In this research, scatter plots are considered to examine the linear correlation between variables by using the Microsoft Excel software.
- Hypothesis testing is performed to assess the significance of the relation between the two variables under investigation.

1.4 Prior Research

This thesis follows the format previously conducted by Patel (2003) and von Bernuth (2006). According to Adam (2009) accident victims face enormous personal difficulties, and require large amounts of resources to deal with the consequences of an accident. Adam (2009) stated that in general there are three challenges to the maintenance of safe environments on construction sites.

- First, safety is difficult to measure, as obtaining a safe site depends on subjective judgment dependent on one's personal definition of safety.
- Second, human error is not controllable, and individuals can only be blamed for negligence and controllable circumstances within their oversight responsibilities. Construction projects are very complex and fragmented by

nature, since many parties work together to achieve desired outcomes; therefore matching responsibilities with control is extremely difficult.

- Third, projects are unique and temporary by nature; therefore adopting a standardized process that can be enhanced according to lessons learned from prior projects can result in failure to predict new sources of hazards, depending on the nature of the project.

On the other hand, von Bernuth (2006), placed "why" accidents occur, into three categories:

1. Accident Proneness Theories
2. Job Demand vs. Worker Capability Theories
3. Psychosocial Theories

In category one, accident proneness theories, "some people are more prone to have accidents than others because of a peculiar set of constitutional characteristics," meaning there is some permanent characteristic that certain people possess that makes them have more accidents than others, and more accidents than they could be expected to have according to pure chance.

In the second category, job demand vs. worker capability theories, the more demanding a job is, the more accidents can be expected. The adjustment to stress theory, also in this category, hypothesizes that accident rates will increase when the level of stress exceeds the worker's ability to cope with stress.

In category three, psychosocial theories, when workers are given more control over work goals and management is decentralized, accident occurrence is lower. This category also includes a subset of theories, called psychoanalytical theories, which view accidents as "self punitive acts caused by guilt and aggression."

1.4.1 Accident's Categories

In recent years, construction accident rates have declined as a result of substantial effort by many parties. According to Prichard (2002), the violations approach has contributed to the reduction of accident rates, but it also has limitations, as high levels of compliance are costly and compliance does not ensure safety. The following are some limitations of the violations approach.

1.4.1.1 Reactive Violations Approach

The violations approach is reactive. It manages the hazards with defenses and relies on increased safety effort to reduce accidents. A proactive approach avoids hazards reduces the safety risk of the production system and reduces accidents without increased safety effort (Prichard, 2002).

1.4.1.2 Conflict with Production

The safety effort does not add value to production (it only replaces one type of unacceptable loss) human suffering and financial consequences with a more acceptable cost. However, compliance requires significant safety effort and resources and in the short term, safety requirements are in conflict with production and cost goals. This often leads to noncompliance (Prichard, 2002).

1.4.1.3 Uncertainty Limits the Effectiveness of Defenses

Compared to the well structured, high risk technical systems, such as nuclear and process plants, airplanes, etc., construction is a less structured and loosely coupled system. The ill-structured, dynamic nature of the construction process and the large number of poorly defined situational hazards limit the effectiveness of such defenses, as they create many circumstances in which the needed defenses are absent or existing defenses are bypassed. Furthermore, safety defenses cannot address all types of hazards and in some cases cannot overcome the legacy of design and the need to work in dangerous circumstances (Prichard, 2002).

1.4.1.4 Limited View of Accident Causality

The violations perspective attributes accidents to the managers' or workers' lack of safety knowledge and/or motivation. This approach perceives safety as a problem of "right versus wrong" choice, and ignores the fact that the dynamic nature of work does not involve conscious decision making or risk assessment. What seems to be a rational act under a particular work situation may easily be judged as an unacceptable mistake on hindsight (Prichard, 2002).

1.4.1.5 Limited Learning

The focus on violations limits the ability to learn from accidents. Accident investigation focuses on violations and liability and does not increase understanding of the accident phenomenon; rather, it perpetuates the current structure by assigning blame (Prichard, 2002).

1.5 Thesis Overview

This research has utilized the constructs of Signal Detection Theory to assess not only workers' personality and their ability to identify a safe situation, but to also produce two measurable data sets that could then be compared to show a possible relationship between personality and safety awareness. This thesis is comprised of five chapters.

- Chapter one offers general introduction to the state of safety in construction as well as the motivation, goals, objectives, and limitations of the proposed research.
- Chapter two provides a background on different accident causation roots and models. In addition, the chapter gives background information on Signal Detection Theory (SDT), which will be used extensively in this research.
- Chapter three outlines the methods used extensively in this research to achieve the goals and objectives presented in chapter one.
- Chapter four discusses in detail the results achieved using the method developed and presents the results of the survey and a discussion of the analysis of the survey data.
- Chapter five offers the summary, conclusions drawn from the research as well as recommendation and suggestion for future research.

CHAPTER 2

BACKGROUND

2.1 Background

For many years, reducing injuries and accidents has been a prime focus of government organizations such as the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). Research efforts have focused on developing accident causation models to uncover root causes of occupational accidents. In this chapter, an overview of the different accident causation roots and different accident causation models and theories are provided.

2.2 Overview of Accident Root Causation

A review of the literature on construction safety reveals that much research effort has been directed at examining accident records to categorize the most common types of accidents that occur to a specific trade, and how these accidents happen.

- McClay (1989) identified three roots causation of accidents: hazards, human actions, and functional limitations.
- Toole (2002) identified eight root causes of accidents: 1) lack of proper training, 2) lack of safety equipment, 3) deficient enforcement of safety, 4) unsafe equipment, 5) unsafe method, 6) unsafe condition, 7) poor safety attitude, and 8) isolated deviation from prescribed behavior.

- Abdelhamid and Everett (2000) identified management deficiencies, training, and workers' attitude as the three general root causes.
- Hinze and Parker (1978) found that job pressures and crew competition as the general root causes.

2.3 Overview of Accident Causation Models

Accident causation models present factors and processes involved in accidents in order to develop strategies for accident prevention. The different models are based on perceptions of the accident process. Some of the most influential accident causation models and methodologies are:

- Domino Model
- Multiple Causation Model
- Behavior Model
- Ferrel Model
- Accident Root Causes Tracing Model (ARCTM)
- Rasmussen's Descriptive Model

2.3.1 Domino Model

Heinrich (1959) discussed several interrelated factors which include the interaction between man and machine, the reasons for unsafe acts, the management role in accident prevention, the costs of accidents, and the effects of safety on efficiency. The model graphically illustrated the sequential events which Heinrich believed to exist prior to and after the occurrence of accidents.

In addition, Heinrich developed the domino model of causation, in which an accident is presented as one of five factors in a sequence that results in an injury.

- Ancestry and social environment: According to Heinrich, factors like recklessness, stubbornness and avariciousness are inherent, and the environment in which one is brought up also may develop undesirable traits.
- Fault of person: Fault or errors of person are due to a violent temper, nervousness, and ignorance of safe practices, which are inherent factors. These could lead to unsafe acts or the existence of mechanical or physical hazards.
- Unsafe acts and/or mechanical or physical hazard: Heinrich believes unsafe acts performed by a worker or the existence of mechanical or physical hazard directly leads to accidents. These unsafe acts could be starting machinery without warning, removal of safeguard, etc.
- Accidents: According to Heinrich, an accident is an unplanned event that leads to an injury, which is due to an unsafe act.
- Injury: Fractures, laceration, etc. are injuries that result directly from accidents.

The five-domino model presented above states that through inherited or acquired undesirable traits, people may commit unsafe acts or cause the existence of mechanical or physical hazards, which in turn cause accidents.

2.3.2 Multiple Causation Model

Petersen (1971) believed that many contributing factors, causes, and sub causes are the main reason in an accident scenario and, hence, the model is named ‘‘multiple causation.” Under the concept of multiple causations, the factors combine together in random fashion, causing accidents.

Petersen viewed his concept to be different from the domino models in several ways. To explain his concept, Petersen provided an example of a common accident scenario, that of a man falling off a defective ladder. Petersen believed that by using present investigation forms, only one act (climbing a defective ladder) and/or one condition (a defective ladder) would be identified. The correction to the problem would be to get rid of the defective ladder. This would be the typical supervisor's solution if the domino theory was used. Petersen claimed that by using multiple causation questions, the surrounding factors to the incident would be revealed.

Applicable questions to the ladder accident would be: why the defective ladder was not found in normal inspections; why the supervisor allowed its use; whether the injured employee knew that he or she should not use the ladder; whether the employee was properly trained; whether the employee was reminded that the ladder was defective; whether the supervisor examined the job site and equipment first, and so on.

Petersen believed that the answers to these and other questions would lead to improved inspection procedures, improved training, better definition of responsibilities, and pre job planning by supervisors.

2.3.3 Behavior Model

According to Klumb (1995), there are permanent characteristics in people that make them more likely to have an accident. The model was supported by a simple fact that when considering accident statistics, the majority of people have no accidents, a relatively small percentage have one accident, and a very small percentage have multiple accidents.

2.3.4 Ferrel Model

According to Heimrich et al. (1980), the Ferrel model attributes accidents to a causal chain of which human error plays a significant role. According to the model, human errors are due to three situations:

- Overload, which is the mismatch of a human's capacity and the load to which he or she is subjected in a demanding state.
- Incorrect response by the person due to a basic incompatibility to which he or she is subjected.
- An improper activity performed either because he or she did not know any better or because he or she deliberately took a risk. The emphasis in this

model is on overload and incompatibility only, which are the central points in most human factor models.

2.3.5 Accident Root Causes Tracing Model (ARCTM)

According to Petersen (1982), the main purpose of ARCTM is to provide an investigator with a model to easily identify root causes of accidents. ARCTM directs attention of the investigator to the conditions that existed at the time of the accident and predecessor to human behavior. The main concept proposed in ARCTM is that an occupational accident will occur due to one or more of the following three root causes:

- Failing to identify an unsafe condition that existed before or that developed after an activity was started.
- Deciding to proceed with a work activity after the worker identifies an existing unsafe condition
- Deciding to act in unsafe manner regardless of initial conditions of the work environment.

2.3.6 Rasmussen's Descriptive Model

According to Rasmussen (1994), this model recognizes that organizational and individual pressures push people to work in hazardous situations. These pressures defeat efforts to enforce safe work rules, specifically in a changing work environment such as in construction. Therefore, this approach emphasizes the need to train workers to be conscious of hazardous work environments and engage in the work with be the original model as proposed by Rasmussen (1994) is shown in Figure 2.1.

As shown in Figure 2.1, Rasmussen divided the work environment in to three zones: 1) The Safe Zone which is surrounded by "Boundary of Unconditionally Safe Behavior," "Organizational Boundary to Economic Failure," and "Individual Boundary to Unacceptable Work Load," 2) The Hazard Zone which lies in the middle, and 3) The Loss of Control Zone which enclose by the "Irreversible Loss of Control Boundary."

Current safety regulations and management practice are directed at keeping the workers in the safe zone. Enlarging the safe zone through proper planning of operations will make the work safer. The zone encompassed by the "Boundary of Unconditionally Safe Behavior" and the "Irreversible Loss of Control Boundary" is Zone II or the hazard zone. Workers in the hazard zone are considered to be working on the edge (pushing their luck).

The third and final zone in Rasmussen`s model is the loss of control zone, in which accidents occur and workers lose their control, leading to injuries and/or fatalities. He proposed that workers should be educated on and trained in how to recover from situation in which control is lost.

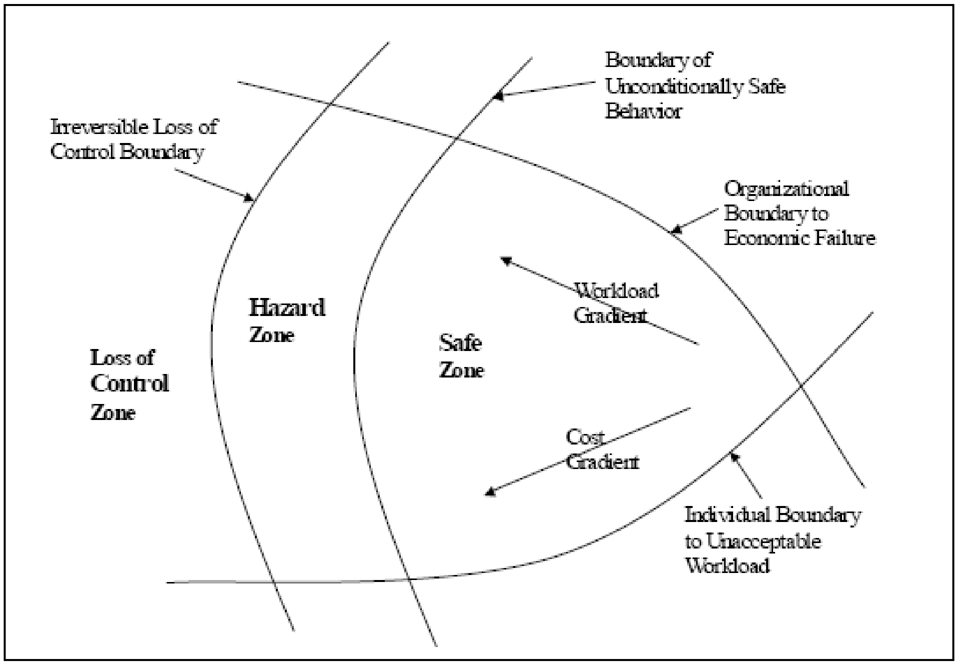


Figure 2.1 Rasmussen's Model Showing Three Zones of Risks (Howell et al. 2002)

The following section of this chapter will discuss Signal Detection Theory (STD), which had been applied mostly in the manufacturing industry to determine the performance of the operator.

2.4 Signal Detection Theory (SDT)

According to Wickens and Hollands (2000), Signal Detection Theory (SDT) is a method used to assess the decision-making strategy of a worker who must recognize and select a distinctly correct option. SDT has been used extensively in manufacturing to identify and remove defective products. SDT can be used in two areas of "noise" and "signal." In a manufacturing setting, if the state is "signal," and the product is defective, then the response of the worker would be either yes, the product is defective (HIT), or no, the product is not defective (MISS). Similarly, if the state is just a "noise," and the product is not defective, the response of the worker would either be yes, the product is defective (FALSE ALARM) or no, the product is not defective (CORRECT REJECTION).

The communication of "noise" and "signal" and the two response categories produces the 2 x 2 matrix shown in Table 2.1 generating four classes of joint events which are labeled hits, misses, false alarms, and correct rejections.

It is apparent that perfect performance is that no misses or false alarms occur. However, since the signals are not very important in the typical signal detection paradigm, misses and false alarms do occur, and so there are normally data in all four cells. In signal detection theory (SDT), these values are typically expressed as probabilities by dividing the number of occurrences in a cell by the total number of occurrence in column. Thus if there were 5 hits and 15 misses, we would write P (hit) = 5/20 = 0.25.

Table 2.1 The four outcomes of signal detection theory (Wickens and Hollands, 2000)

		Signal	Noise
Response	Yes	Hit = 80%	False Alarm = 1%
	No	Miss= 20%	Correct Rejection = 99%

Figure 2.2 illustrates another form of Table 2.1. As shown in Figure 2.2, X_c highlights the position at which a person decide to say "Yes" or "No." The most widely used

measure is called d` where the separation corresponds to the distance between the means of normal distributions.

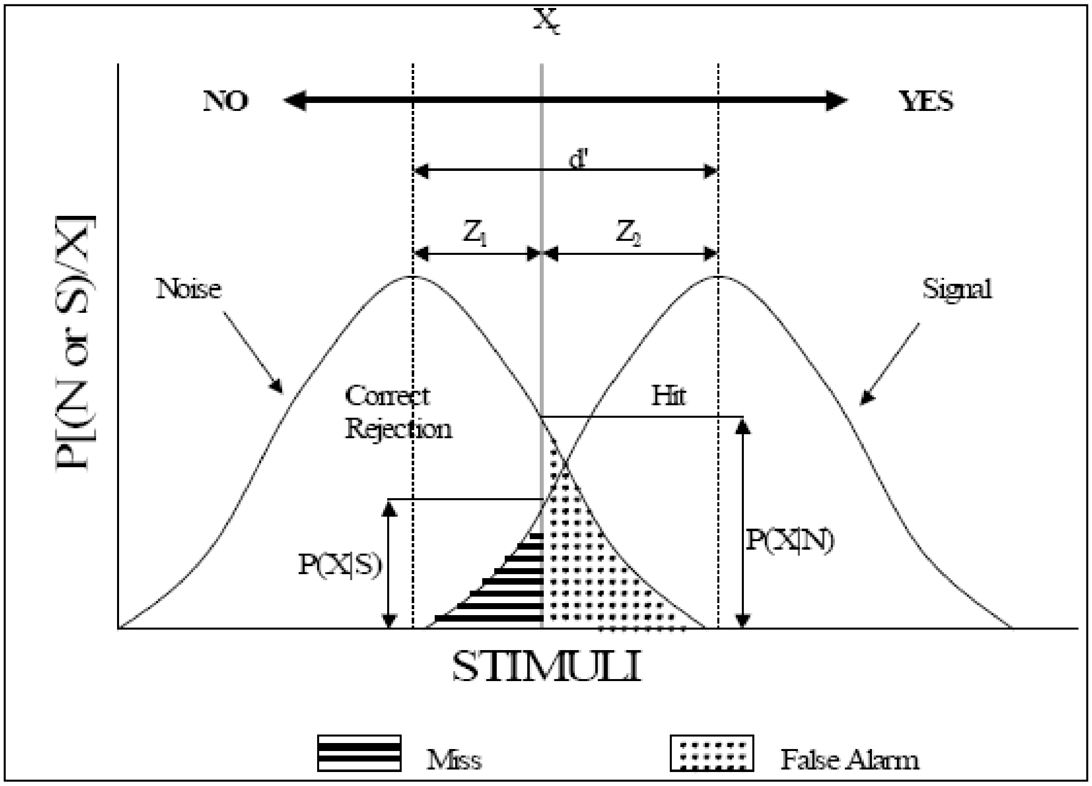


Figure 2.2 Distribution of Signal Detection Theory (Wickens and Hollands, 2000)

The measure of value X_c is limited by the vertical lines. All X values to the right ($X > X_c$) will cause the worker to respond “Yes.” All X values to the left ($X < X_c$) generates “No” responses. The shaded areas represent the occurrences of hits, misses, false alarms, and correct rejections.

2.4.1 Setting the Response Criterion: Optimality in SDT

According to Figure 2.2, worker`s conservative or risky behavior is determined by placing the decision criterion X. If X_c is placed to the right, then most responses will be “No” (risky responding). If it is placed to the left, then most responses will be “Yes” indicating that the strategy is conservative.

Mathematically, as shown in Figure 2.2, βcurrent is the ratio of the ordinates P (X|S) to P (X|N) for a given level of Xc. P (X|S) represents the conditional probability of X_c given signal and P (X|N) represents the conditional probability of X_c given noise. Equation 2.1 shows the calculation of βcurrent under the assumption that the variances of the noise distribution and the signal distribution are the same.

$$\beta current = P\ (X|S)/P\ (X|N) \qquad \text{Eq (2.1)}$$

A high value of βcurrent indicates a high number of misses, whereas a lower one will generate more false alarms. Because of inter-observer variability with respect to the choice of X_c, evaluating the results of multiple observers requires normalization of the values of βcurrent or comparison to an optimal value .The optimal value of β has been taken as the value corresponding to minimum number of errors, i.e. minimum misses and false alarms. Mathematically, this value is the ratio of the probability of noise, P (N), and the probability of a signal, P(S). Equation 2.3 gives this rationale.

$$\beta_{opt} = P\ (N)/P\ (S) \qquad \text{Eq (2.2)}$$

After defining the value of βcurrent and β_{opt}, the pair is compared to determine whether an observer is following a risky or conservative strategy. When βcurrent is greater than the value of β_{opt}, then Xc is positioned more to the right, resulting in fewer false alarms and more misses. Furthermore, when βcurrent is less than β_{opt}, then Xc is positioned more to the left, resulting in more false alarms and fewer misses. Based on SDT, this indicates that the observer needs less evidence to say "Yes" if a part is defective. Therefore, this strategy is considered conservative strategy.

2.4.2 Sensitivity

One of the most important contributions of signal detection theory is that it has made a conceptual and analytical distinction between the response bias parameters described above and the measure of the operator's sensitivity. As shown in Figure 2.2 d` is the worker's sensitivity or the separation between the mean of the signal and nose distributions respectively.

The value of d´ is calculated by adding Z_1 (the standard normal variable reflecting the possibility of a false alarm) and Z_2 (the standard normal variable reflecting the possibility of a hit. Both values of Z_1 and Z_2 can be found in standard statistical tables (refer to APPENDIX C). The ideal value of d` is +4.6 and the worst value of d` is -4.6. Figure 2.3 shows the range for low, moderate and high sensitivity.

$$d' = Z_1 + Z_2 \qquad \text{Eq (2.3)}$$

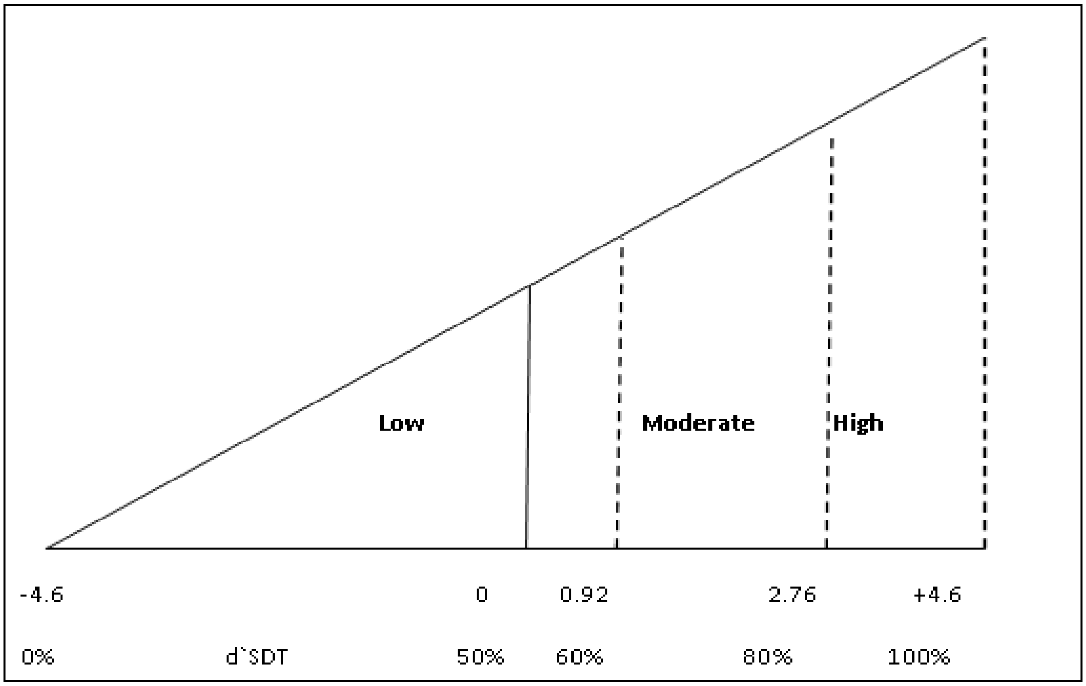


Figure 2.3 Sensitivity Ranges for d. (Patel, 2003)

2.5 ROC Curve

It should be apparent that all detection performance that has the same sensitivity is in some sense equivalent, no matter what its level of bias. A graphical method of presentation known as the Receiver Operating Characteristic (ROC) curve is used to portray this equivalence of sensitivity across changing levels of bias to understand the joint effects of sensitivity and response bias based on the data from a signal detection analysis experiment (Wickens and Hollands, 2000).

The ROC curve is plotted on a signal graph using the values of P (Hit) and P (FA) obtained from the STD analysis. When the same experiment is repeated several times and each time the response criterion is charged, a series of different points are produced. When these points are connected a ROC curve emerges as shown in Figure 2.4.

For more sensitive workers the ROC curve will be more curved as compared to other workers. This is a theoretical representation because it is hard to repeat the same experiment to get different points in real life.

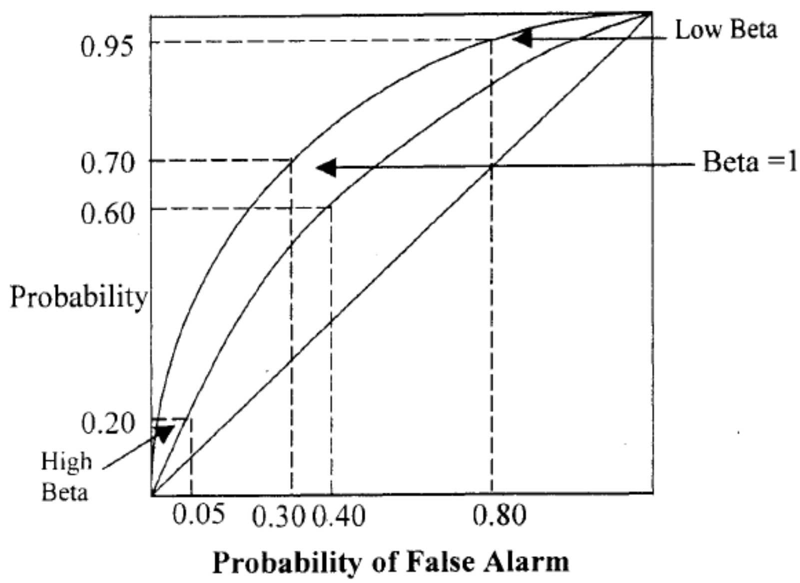


Figure 2.4 Theoretical Representation of the ROC Curve (Wickens and Hollands, 2000)

The alternative way of plotting the curves shown in Figure 2.4 is by plotting the curve on probability paper, as shown in Figure 2.5. This presentation has its advantage, as the bowed lines of the Figure 2.5 now become straight.

The value of P (Hit) and P (FA) could be replaced with Z scores standard value or scores from standard SDT table know as Z (Hit) and Z (FA) respectively. For any given points, d' (sensitivity) is equal to Z (H)-Z (FA).

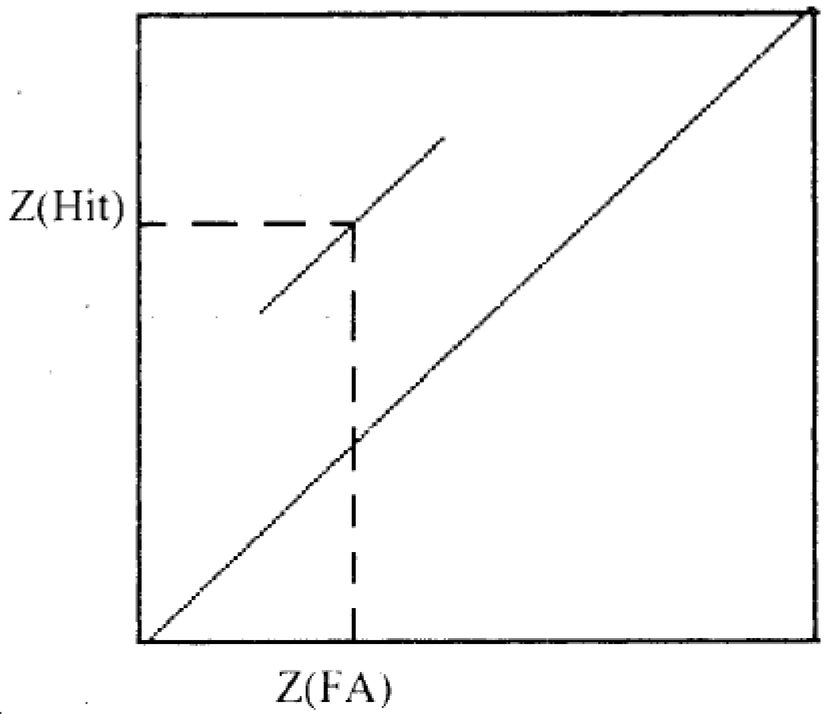


Figure 2.5 The ROC Curve on Probability Paper (Wickens and Hollands, 2000).

It is important to understand the difference between the theoretical representation of the ROC curved discussed above and actual empirical data collection in an SDT experiment. The representation shown in Figure 2.4 and 2.5 is continuous and smooth, while actual collection provides discrete points or due to some limitation it might not be possible to get more than one point. In such circumstances, a measure called P (A) representing the area under the ROC curve is an alternative which can be used to measure sensitivity as shown in Figure 2.5.

This area under the ROC curve represents the area to the right and below the line segments connecting the lower left and upper right corners of the curve as shown in Figure

2.4. The area represented by the formed triangle is Δ and P (A) represents the sensitivity (d`) of the respondent. The area P (A) is calculated using equation 2.4.

$$P(A) = \frac{P(HIT) + [1-P(FA)]}{2.0} \qquad \text{Eq (2.4)}$$

Equation 2.4 was used to determine the P (A) which represents the sensitivity (d') for the operator.

2.6 Summary

In this section Signal Detection Theory has utilized to establish the sensitivity and risk orientation of construction workers to unsafe conditions. In addition, the ROC curve also helped to establish the sensitivity of construction workers by considering the joint effects of answer bias and sensitivity (the joint effect of risk orientation and sensitivity).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The first chapter of this research presented a summary of construction fatalities and the contribution of most common types of construction accidents to these fatalities. In chapter 2, the background and improvement of accident roots causation, accident causation models and theories were discussed. In addition, an accident causation model, as proposed by Rasmussen, was presented. Furthermore, signal detection theory was also introduced which will be utilized in this research. In this chapter, methods to attain the objectives of the research will be discussed. The purpose of signal detection theory will also be established.

Developing a methodology by which workers' sensitivity to unsafe conditions and risk orientation (tendency of a worker to work in a condition knowing it is not safe) is the most important goals of this research. To achieve the research goals, the following two objectives are determined:

1) Investigating the sensitivity and risk orientation of workers to unsafe conditions.
2) Performing a survey to establish the sensitivity and risk orientation of construction workers at risk of common types of construction accidents.

3.2 SDT and Construction Condition (Unsafe and Safe)

SDT is used in this research because of the similarity between the answers of the construction worker in identifying defective and non-defective parts and the construction worker's answer in recognizing safe and unsafe conditions on site.

Furthermore, SDT is one of the techniques that will help to determine both the sensitivity and risk orientation of the construction worker. Once perfumed, this assessment could be used to give guidance to workers on how to improve their abilities to identify the limit beyond which work is no longer safe. In this section, application and tailoring of the theory will be presented.

On the other hand, a construction worker faced with a "Safe" condition and asked whether the condition is unsafe has one of two possible answer, namely 'Yes' the condition is "Unsafe" (False Alarm), or 'No' the condition is "Safe" (Correct Rejection).

Alternatively, a worker faced with an "Unsafe" condition and asked whether the condition is unsafe has one of two possible responses, namely 'Yes' the condition is "Unsafe (Hit), 'No' the condition is "Safe" (Miss). Table 3.1 shows the SDT matrix for these scenarios.

Table 3.1 The SDT Matrix for Detection of Unsafe Condition in Construction

		Signal	Noise
Response	Yes	Hit	False Alarm
	No	Miss	Correct Rejection

Signal detection theory allows the determination of the sensitivity of workers to unsafe conditions as well as their inclination (bias) to consider a situation as unsafe that is not. For construction workers, it is needed to minimize the number of misses (considering a condition safe while it is unsafe), at the cost of having more false alarms (considering a condition unsafe while it is safe). This is because a miss is more likely to result in injury of fatality.

As explained before, worker sensitivity to unsafe and safe condition as well as the inclination in regard to a condition as a safe or unsafe can be assessed using the SDT parameters d` and $\beta_{current}$:

- High values of d` indicate high sensitivity in separating between safe and unsafe condition.
- Low values of d` indicate that a construction worker needs more training to better differentiate between safe and unsafe conditions.
- If the value of $\beta_{current}$ is greater than that of βopt, then fewer false alarms and more misses will result. In the manufacturing industry, SDT application is considered risky. However, in construction, the cost of a miss could result in fatality or serious injury. Therefore, it is a more risky strategy to have fewer false alarms and more misses.
- If value of βcurrent is smaller than βopt, indicating that more false alarms and fewer misses result, these results are considered a risky strategy in SDT

normal field of use. For construction, this would be considered a conservative strategy.

Undertaking the assessment of worker sensitivity to unsafe and safe conditions as well as the inclination to relate to a condition with a safe response or unsafe requires the determination of SDT responses (Hit, Miss, False Alarm, and Correct Rejection) to number of safe and unsafe conditions.

3.3 Conducting Survey Using SDT

This survey was developed by referring to case studies of some common types of construction accidents recorded. A survey was developed using Signal Detection Theory, (SDT), to examine how a construction worker evaluates a theoretical situation that represents either an unsafe or safe condition. The developed survey portrays 21 scenarios is established an APPENDIX A.

There was no constraint on age, years of experience, level of education, race or any other standard for the construction workers who volunteered to join in this survey. In this research an attempt was made to evaluate at least 24 participants, as using 24 sample points allows the utilization of the normal distribution for results.

The questionnaire developed for the survey is shown in APPENDIX A. For each question, the worker is asked to choose from one of three responses:

- An Unsafe Condition
- Safe Condition

- I Don’t Know.

The construction worker’s answers determine how he or she encounters typical safe or unsafe condition as well as their risk orientation.

To demonstrate how an answer was found to a Hit, Miss, False Alarm, or a Correct Rejection, a sample question is revealed below which represents a safe condition. If the worker’s answer to this was “An Unsafe Condition” or “I Don’t Know,” then this indicates that the worker incorrectly considered the condition as unsafe or was not sure if it was a “False alarm.” The response “I Don’t Know” is considered a Miss if the condition portrayed by the question was unsafe.

3.3.1 Interview Questions

1) Electrical construction worker without personal protection equipment (PPE).

Is this situation ☐ Safe ☒ Unsafe ☐ I Don’t Know

To illustrate further the type of analysis that was performed based on the response of worker number one to a 21 question survey, with X safe condition scenario and X unsafe condition scenarios. Table 3.2 shows responses from one of the workers, who participated in the research.

Table 3.2 Sample Survey Analysis Result

		Signal	Noise
Response	Yes	Hit = 9	False Alarm = 3
	No	Miss= 3	Correct Rejection = 6

Note that:

P (Noise) = P (safe condition) = 9/21= 43%

P (Signal) = P (unsafe condition) = 12/21 = 57%

P (Hit) = 0.75 P (Miss) = 1-P (Hit) = 0.25

P (FA) = 0.33 P (CR) = 1- P (FA) = 0.67

Calculation of the sensitivity, the value of d`, involves the standard normal values Z_1 and Z_2. Using P (FA) and P (Miss), the values of Z_1 and Z_2 are:

$Z_1 = 0.44$ and $Z_2 = 0.674$

$d` = Z_1 + Z_2$

$d` = 0.44 + 0.674 = 1.114$

This indicated a moderate degree of separation between the signal and noise distributions, showing workers to have moderate sensitivity. In this situation, for a perfect score of "Hit" and "CR", the value of ideal $d`_{SDT} = +4.6$, and in the worst case scenario of no "Hit" or "CR", the value of $d`_{SDT} = -4.6$

Ordinate corresponding to $Z_2 = 0.32$

Ordinate corresponding to $Z_1 = 0.36$

$\beta current = 0.32/ 0.36 = 0.89$ Eq (2.1)

β_{opt} = P (Noise) / P (Signal) = 0.43/ 0.57 = 0.75

Obviously, $\beta current < \beta_{opt}$ which specifies a conservative strategy. Nevertheless with this strategy causing the worker to have more False Alarms, fewer misses will result.

3.4 Analysis with ROC

This section discusses how the answers of the construction workers participating in the research would be analyzed using ROC. This will be illustrated with the help of the same example as is found in the previous section.

P (Hit) = 0.75   P (Miss) = 1- P (Hit) = 0.25

P (FA) = 0.33   P (CR) = 1- P (FA) = 0.67

From Equation 2.4: P (A) = 0.71

The ideal value of $d`_{ROC} = 1$ represents an ideal value, with the worst-case situation showing, the value of $d`_{ROC} = 0$. Thus a score of 0.71 is quite high with respect to the ideal. This will be further discussed in chapter four.

3.5 Summary

This section discussed how the answers of the construction workers participating in the research would be analyzed using SDT and ROC. Signal detection theory allowed examining how a construction worker evaluates a theoretical situation that represents either an unsafe or safe condition.

CHAPTER 4

SURVEY RESULTS AND ANALYSIS OF THE DATA

4.1 Introduction

In this chapter, survey data is analyzed and presented. The examination of the data utilizes SDT calculations to determine the sensitivity and risk orientation of construction workers. The data is analyzed following the steps discussed in Sections 3.3 and 3.4

4.2 Data Collection

As explained in chapter three, construction accidents are of high concern to the construction industry, since many lives are lost and businesses endures. However, even though several construction accident causation models have been developed, some common types of accidents still occur. Therefore, this research focuses on recognizing the risk orientation of construction workers to unsafe condition in order that worker exact training could be developed. The construction workers were selected because of their high risk of accident.

The participants were requested to choose one of three answers to each question on the questionnaire. The answers were then compared with the correct answers and then further evaluated using SDT to establish the sensitivity and risk orientation of each construction worker.

4.3 Risk Orientation and Sensitivity of the Construction Workers

The reaction of each construction worker (Hit, Miss, False Alarm or Correct Rejection) are provided in 4.1.Survey details in APPENDIX B (Table B.1)

The questionnaire had 21 questions with 12 unsafe and 9 safe situations. If the construction worker properly recognized an unsafe situation as “An Unsafe Condition” the answer was recorded a “HIT” and is represented by “H” in Table 4.1. If the construction worker incorrectly identified an unsafe condition as “A Safe Condition” or as “I Don`t Know” then it was considered a “Miss” and is represented by “M” in Table 4.1.

In the same way, a “Correct Rejection” represented by “CR” in Table 4.1 results when the construction worker properly recognized a safe condition as a “Safe Condition”. A “False Alarm” is represented as “FA” in Table 4.1 outcomes when the construction worker wrongly recognized a safe condition as “An Unsafe Condition” or as “I Don’t Know”.

Table 4.1 Results of the Survey of the Construction Worker

Question No.	Workers												
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13
Q1	H	H	H	H	H	H	M	M	H	H	H	H	H
Q2	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	CR	CR
Q3	FA	FA	FA	FA	FA	FA	FA	CR	FA	FA	FA	FA	FA
Q4	H	H	H	H	H	H	H	H	H	H	H	H	H
Q5	H	H	H	H	H	H	H	H	H	H	H	H	H
Q6	M	M	H	H	H	H	H	H	H	H	H	H	M
Q7	M	M	M	H	H	H	H	H	H	H	H	H	M
Q8	H	M	M	H	H	H	M	H	H	H	H	H	H
Q9	H	M	H	H	H	H	H	H	H	H	H	M	M
Q10	CR	CR	CR	FA	FA	FA	FA	CR	CR	CR	CR	CR	CR
Q11	CR	CR	CR	CR	CR	FA	FA	CR	CR	CR	CR	CR	CR
Q12	H	H	H	H	H	H	H	H	H	H	H	H	H
Q13	M	H	H	H	M	H	M	H	M	M	M	H	H
Q14	CR	FA	CR	FA	FA	CR	CR	CR	CR	CR	FA	CR	CR
Q15	H	H	M	H	M	H	H	H	H	H	M	M	H
Q16	CR	FA	FA	FA	FA	CR	FA	FA	CR	CR	FA	CR	CR
Q17	H	M	H	H	H	H	H	H	H	H	M	H	H
Q18	CR	CR	CR	FA	CR	CR	FA	CR	CR	CR	CR	CR	CR
Q19	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Q20	CR	FA	FA	CR	FA	FA	CR	CR	FA	CR	FA	CR	CR
Q21	H	H	H	M	M	H	M	H	H	H	H	H	H

Table 4.1 - Continued

Question No.	Workers										
	W14	**W15**	**W16**	**W17**	**W18**	**W19**	**W20**	**W21**	**W22**	**W23**	**W24**
Q1	H	H	M	H	H	H	M	M	H	H	H
Q2	FA	FA	CR	FA	FA	FA	FA	FA	FA	FA	FA
Q3	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
Q4	H	H	H	H	H	H	H	H	H	H	H
Q5	H	H	H	H	H	H	H	H	H	H	H
Q6	H	H	H	M	H	H	H	H	H	H	H
Q7	H	H	H	M	H	H	M	H	H	H	H
Q8	H	H	H	H	H	H	M	M	H	H	H
Q9	H	H	H	H	H	M	M	H	H	H	H
Q10	CR	CR	CR	CR	CR	CR	CR	FA	CR	CR	CR
Q11	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR
Q12	H	H	H	H	H	H	H	H	H	H	H
Q13	H	H	H	M	M	H	H	M	M	M	M
Q14	CR	CR	CR	CR	CR	CR	CR	FA	CR	CR	CR
Q15	M	H	M	H	M	H	H	H	H	H	H
Q16	CR	CR	CR	CR	FA	CR	CR	FA	FA	CR	CR
Q17	M	H	H	H	H	H	H	H	M	H	M
Q18	FA	CR	CR	CR	CR	CR	CR	CR	CR	CR	CR
Q19	FA	FA	FA	FA	FA	FA	FA	FA	CR	FA	FA
Q20	FA	CR	CR	CR	CR	CR	CR	FA	CR	CR	CR
Q21	H	H	H	H	H	H	M	H	H	H	H

Parallel estimates to those shown for worker "W1" in Chapter 3 was performed for all the construction workers. The results are summarized in Table 4.2 below. Details for each worker can be found in APPENDIX D.

Table 4.2 Outcomes of Examination of Survey by Standard SDT and ROC Curve

Worker	Age Score[1]	Education Score[2]	Experience Score[3]	d' SDT	d' ROC	βcurrent	β opt
1	1	3	1	1.11	0.71	0.89	0.75
2	3	2	2	-0.20	0.46	0.92	0.75
3	2	3	2	0.52	0.60	0.82	0.75
4	2	2	1	0.64	0.57	0.52	0.75
5	2	3	1	-0.13	0.49	1.10	0.75
6	2	1	3	3.10	0.67	0.00	0.75
7	2	2	1	-0.36	0.44	1.24	0.75
8	3	2	4	1.85	0.79	0.42	0.75
9	2	4	3	0.60	0.58	0.75	0.75
10	2	2	2	1.85	0.79	0.42	0.75
11	4	3	1	0.27	0.54	0.89	0.75
12	2	3	2	1.72	0.81	0.83	0.75
13	4	1	4	1.44	0.81	1.07	0.75
14	4	1	3	0.80	0.64	0.64	0.75
15	3	2	3	1.11	0.71	0.89	0.75
16	2	3	2	1.72	0.81	0.83	0.75
17	4	4	5	1.11	0.71	0.89	0.75
18	4	1	2	1.10	0.69	0.64	0.75
19	2	2	2	1.85	0.79	0.42	0.75
20	2	3	1	0.64	0.63	1.08	0.75
21	2	3	2	-0.10	0.49	1.10	0.75
22	2	2	3	1.39	0.75	0.69	0.75
23	3	2	3	1.84	0.79	0.42	0.75
24	5	1	2	1.39	0.75	0.69	0.75

[1,2,3] Refer to APPENDIX "A" on Page 69, for Age, Education, and Experience Scores.

Furthermore, Table 4.3 reviews the number of "Hits", "FA", "CR" and "Miss" for each question based on response of all 24 construction worker.

Table 4.3 Review of Answer to Each Question

Question No	Hit	Miss	FA	CR
1	19	5	0	0
2	0	0	21	3
3	0	0	23	1
4	24	0	0	0
5	24	0	0	0
6	20	4	0	0
7	18	6	0	0
8	19	5	0	0
9	19	5	0	0
10	0	0	5	19
11	0	0	2	22
12	24	0	0	0
13	12	12	0	0
14	0	0	5	19
15	17	7	0	0
16	0	0	10	14
17	19	5	0	0
18	0	0	3	21
19	0	0	23	1
20	0	0	8	16
21	20	4	0	0

Table 4.3 as reviewed before; summarizes the answer for each question. The first column of Table 4.3 indicates query numbers from the questionnaire, followed by column demonstrating the number of answers of each type (Hit, Miss, FA, and CR) for each question.

This table will assist in deciding how construction workers as a group understand each situation, meaning there might be a condition or state, which is unsafe according to OSHA standards, but that the group as a whole thinks it, is a safe condition. For example, on question number 13 (see APPENDIX A), 12 construction workers out of 24 think the situation represents a safe condition but OSHA disagrees. Similarly, in question number 19 (see APPENDIX A), 23 out of 24 construction workers considered that exacting situation is unsafe, contradicting OSHA standards. Based on this table, feedback can be given to OSHA on what the workers think about the exacting situations, and how such scenario can be addressed in training to change the approach of the construction workers.

4.3.1 Association between $d`_{SDT}$ and $d`_{ROC}$

This part illustrates the correlation between $d`_{SDT}$ and $d`_{ROC}$. As discussed in chapter 3, the ideal value of $d`_{SDT}$ is +4.6 and the perfect value of d'_{ROC} is +1.On the other hand in the worst case situation when there are no “Hit” or “ Correct Rejection” responses the worst values that d'_{SDT} and d'_{ROC} assume are -4.6 and 0, respectively.

Assuming that the connection between $d`_{SDT}$ and $d`_{ROC}$ is linear; a theoretical scheme is developed as exposed shown in Figure 4.1 To normalize values of d'_{SDT} a value of d'_{SDT} of -4.6 (worst case) is measured to be 0% and the value of d'_{SDT} of +4.6 (ideal case) is measured as 100%. It is assumed that $d`_{SDT}$ < 60% represents low sensitivity, 60 %< $d`_{SDT}$ < 80% represents moderate sensitivity, and that $d`_{SDT}$ > 80% represents high sensitivity (von Bernuth, 2006).

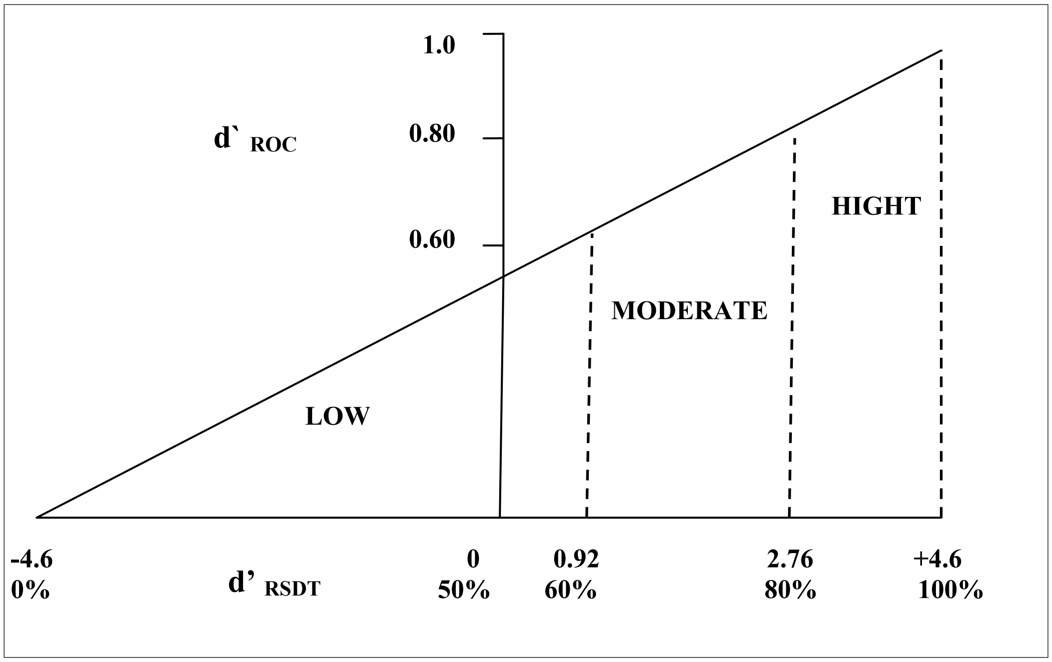


Figure 4.1 Sensitivity Ranges for d' (von Bernuth, 2006)

It is significant to note that the illustration of the relation between $d`_{SDT}$ and $d`_{ROC}$ in Figure 4.1 is only theoretical. To confirm whether this assumption is logical, the values of $d`_{SDT}$ and $d`_{ROC}$ listed in Table 4.2 were drawn as a scatter plot as shown in Figure 4.2.

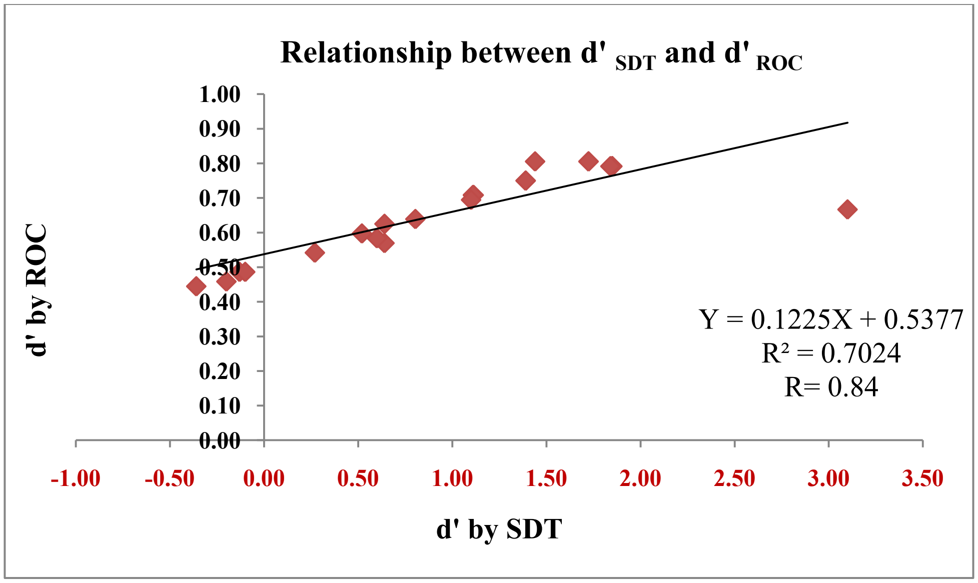


Figure 4.2 Scatter plot between d'_{SDT} and $d`_{ROC}$

The plot in Figure 4.2 signifies that the theoretical linear illustration is a logical approximation of the real relation. In actuality, the high value of the coefficients of correlation (R= 0.84) presents support that d'_{SDT} and d'_{ROC} are certainly linearly correlated.

4.4 Data Analysis

Sensitivity and response bias analysis of construction workers' results are summarized in Table 4.4. The Table provides the value of d` obtained for each construction worker using standard SDT and the ROC curves which helps to determine the sensitivity of each construction worker. Table 4.4 also shows the comparison between βcurrent and βopt which helps to determine the decision making strategy or risk orientation of each construction worker.

If the value of βcurrent is less than βopt, then such strategy is considered conservative strategy. If the value of βcurrent is greater than βopt, then such strategy is considered risky strategy.

4.4.1 Average Sensitivity and Risk Orientation

In this sector outcome from the inspection will be discussed in detail. The first item of discussion is the decision-making tactics of the construction workers. The last column of Table 4.4 shows the decision making strategy for participants. The average participant strategy was found to be risky. The risk orientation of each worker was determined by comparing βcurrent and βopt.

- If βcurrent < βopt then it is a conservative strategy
- If βcurrent > βopt then it is a risky strategy
- Normalized d` by standard SDT = [(d' by standard SDT + 4.6) /9.2]
- Normalized d` by ROC = (d' by ROC / Perfect d' by ROC)
- Coefficient of variation (COV) is defined as the ratio between standard deviation and average; and is provided to give a measure of the amount of variability relative to the value of the average.

Table 4.4 Summary of Outcomes from SDT and ROC

W	Age	Education	Experience	Normalized d'_{SDT}	Normalized d'_{ROC}	Sensitivity	β current	Decision Making
1	1	3	1	62.11	71	Moderate	0.89	R
2	3	2	2	47.83	46	Low	0.92	R
3	2	3	2	55.65	60	Low	0.82	R
4	2	2	1	56.96	57	Low	0.52	C
5	2	3	1	48.59	49	Low	1.10	R
6	2	1	3	83.70	67	High	0.00	C
7	2	2	1	46.09	44	Low	1.24	R
8	3	2	4	70.11	79	Moderate	0.42	C
9	2	4	3	56.52	58	Low	0.75	R
10	2	2	2	70.11	79	Moderate	0.42	C
11	4	3	1	52.93	54	Low	0.89	R
12	2	3	2	68.74	81	Moderate	0.83	R
13	4	1	4	65.65	81	Moderate	1.07	R
14	4	1	3	58.74	64	Low	0.64	C
15	3	2	3	62.07	71	Moderate	0.89	R
16	2	3	2	68.74	81	Moderate	0.83	R
17	4	4	5	62.07	71	Moderate	0.89	R
18	4	1	2	61.96	69	Moderate	0.64	C
19	2	2	2	70.11	79	Moderate	0.42	C
20	2	3	1	56.96	63	Low	1.08	R
21	2	3	2	48.91	49	Low	1.10	R
22	2	2	3	65.11	75	Moderate	0.69	C
23	3	2	3	70.00	79	Moderate	0.42	
24	5	1	2	65.11	75	Moderate	0.69	C
Ave	3	2	2	61.45	67	Moderate	0.76	R
STV	1.06	0.96	1.12	9.01	12.12	NA	0.00	NA
COV	0.40	0.42	0.49	0.15	0.18	NA	0.00	NA

As shown in Table 4.4:

- The average age score of the 24 construction workers was 3, which indicates an age group between 25 and 30 years old.
- The average education score for the 24 construction workers was 2, which indicates a middle school education as the norm.
- The average experience score for the 24 construction workers was 2, which indicates 2 to 4 years of experience.
- The average normalized d'_{SDT} and d'_{ROC} was close at around 60% indicating low sensitivity of construction workers.
- The average βcurrent shows a risky strategy for construction workers.
- As specified by the coefficient of variation (COV) values, there was more variation in βcurrent values which compares to sensitivity.

4.4.2 Negative d`

The sensitivity d' is determined by adding the two normal deviate values Z_1 and Z_2 , a negative d` results only when the overlap between the two curves, the signal and noise, is more than 50 %.

According to Patel (2003), the negative d' could happen in three cases:

- When P (Miss) is more than P (Hit) in which case Z_1 will have high negative value and d' will be negative.
- When P (FA) is more than P (CR), that mean Z_1 has high negative value.
- When both the above conditions are true, causing both Z_1 and Z_2 to be negative.

4.4.3 Distribution of d`and βcurrent

For establishing whether the data obtained from the 24 construction workers pursues a normal distribution, normal quintile plots were considered using the Microsoft Excel software. A quintile plot is plotted with standard normal (z) score on the X- axis and the data on the Y- axis.

It should be noted that, if the normal quintile plot forms a straight line, the plot indicates that the data is normally distributed. If there is any deviation from a straight line, then indicates an abnormal distribution.

Using Table 4.2, three quintile plots were constructed to establish the distribution of d'_{SDT}, d'_{ROC} and $\beta_{current}$. As shown in Figures 4.3, 4.4 and 4.5, all plots displayed a straight line verifying that the variables follow a normal distribution.

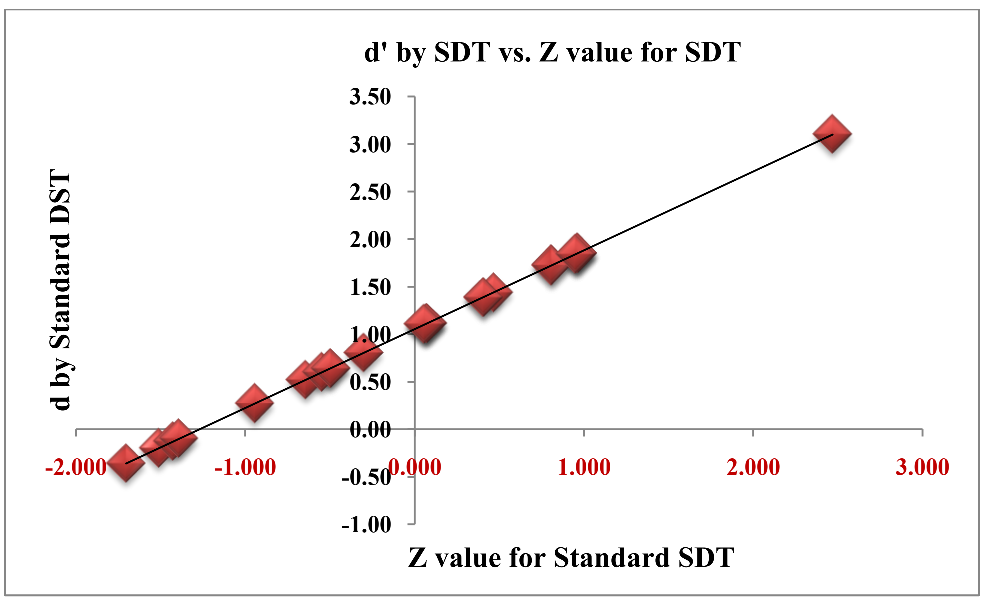


Figure 4.3 Distribution Plot for d` by SDT

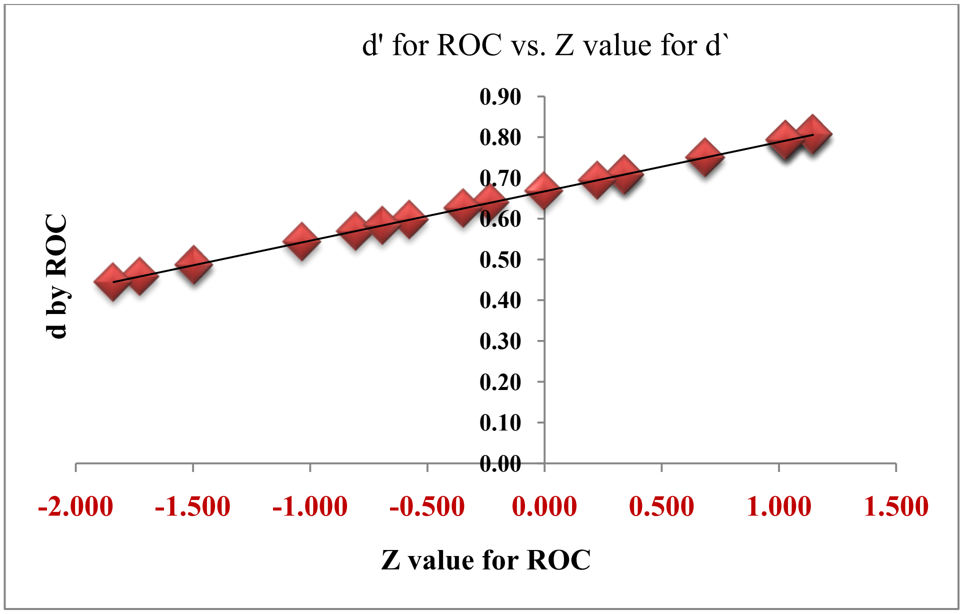


Figure 4.4 Distribution Plot for d` by ROC

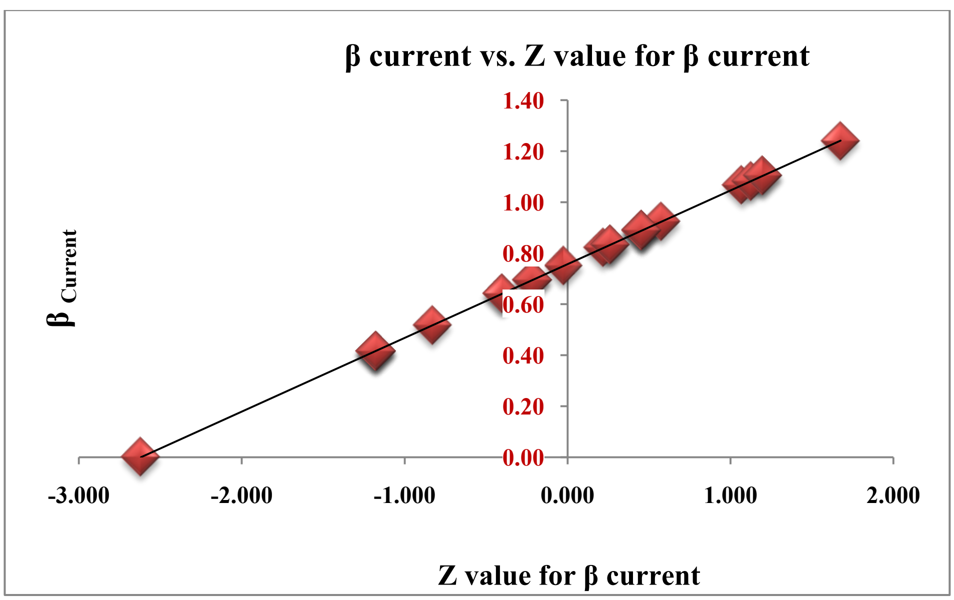


Figure 4.5 Distribution Plot for β current

4.5 Regression Analysis

In this part, regression analysis is used to examine if age, years of experience or level of education are linearly correlated with the sensitivity (d`) and risk orientation (β current) of a construction worker.

In regression analysis, the coefficient of correlation (represented by r) measures the linear relationship between the response variable and the predictor. The coefficient "r" is always a number between -1 and +1. A value of "r" near 0 indicates a very weak linear relationship. The strength of the relationship increases as "r" moves away from 0 towards either -1 or +1. The extreme values of r = -1 and r = +1 occur only when the points in a scatter plot lie exactly along a straight line.

4.5.1 Hypothesis Testing

After "r" is determined, hypothesis testing is typically performed to assess the significance of the relation between the two variables under investigation. The statement of null hypothesis is denoted as H_0: ρ= 0, and the statement that will be true if H_0 is not true, the alternative hypothesis is denoted as Ha: ρ ≠ 0 and is tested as follows:

- If $Z_{obs} > Z_{(\alpha/2)}$: H0 is rejected.
- If $Z_{obs} < Z_{(\alpha/2)}$: H0 cannot be rejected.

Z can be calculated using Equation 4.3

$$Zobs = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \qquad \text{Eq (4.3)}$$

For the purpose of this research, an α for 0.05 is used. Hence, $Z_{(\alpha/2)} = Z_{(0.05/2)} = 1.96$

4.6 Regression Analysis for Age Score

4.6.1 Age Score vs. d’ $_{SDT}$

The breakdown by age score with respect to sensitivity (d\`$_{SDT}$) is illustrated in Figure 4.8 and the regression plot of age score and sensitivity (d\`$_{SDT}$) is shown in Figure 4.7. The value of “r” for those relations was 0.014. This indicated that the relationship between the age of the construction workers and their sensitivity is quite low.

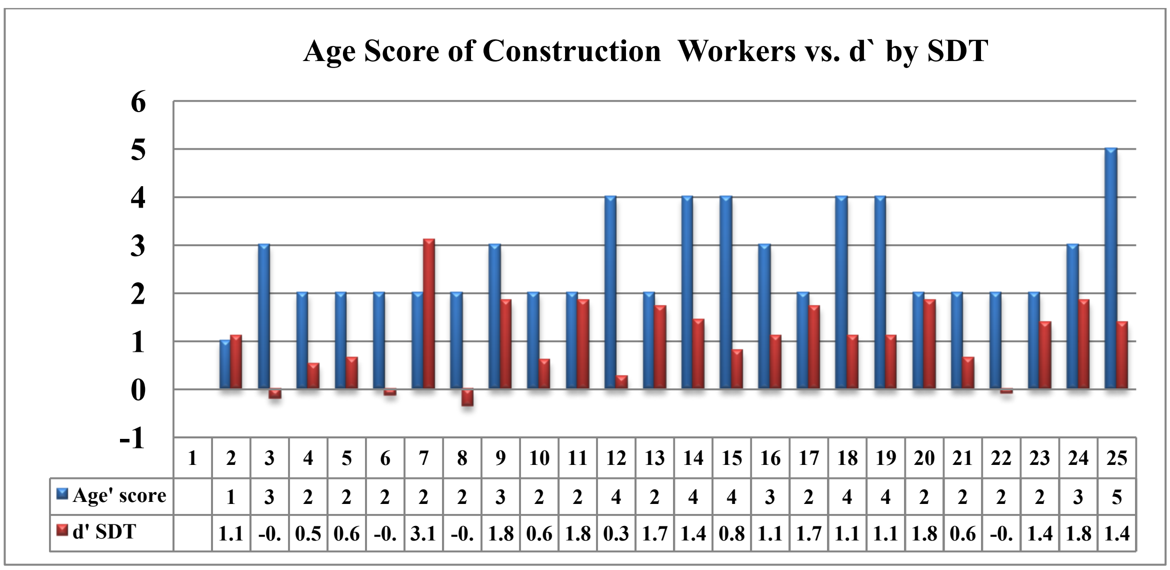


Figure 4.6 Age Score of Construction Worker vs. d’ by SDT

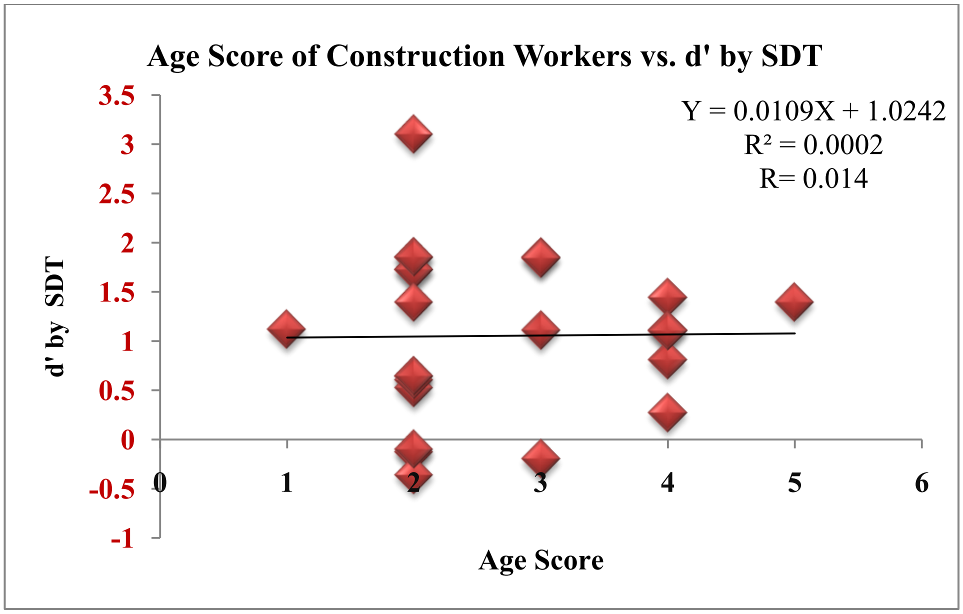


Figure 4.7 Age Score of Construction Worker vs. d' by SDT

Testing of the null hypothesis that age score and d`$_{SDT}$ are not related, H_0: ρ=0, and shown that they are conducted as follows using standard SDT:

Using Equation 4.3: $Z_{obs} = 0.066$ (Noted r = 0.014, $\rho_0 = 0$, and n= 24)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} < Z_{(\alpha/2)}$, hence H_0 cannot be rejected.

4.6.2 Age score vs. d'$_{ROC}$

The breakdown by age score with respect to sensitivity (d`$_{ROC}$) is illustrated in Figure 4.10 and the regression plot of age score and sensitivity (d`$_{ROC}$) is shown in Figure 4.9. The value of r = 0.144 which indicates a low correlation between age score and sensitivity.

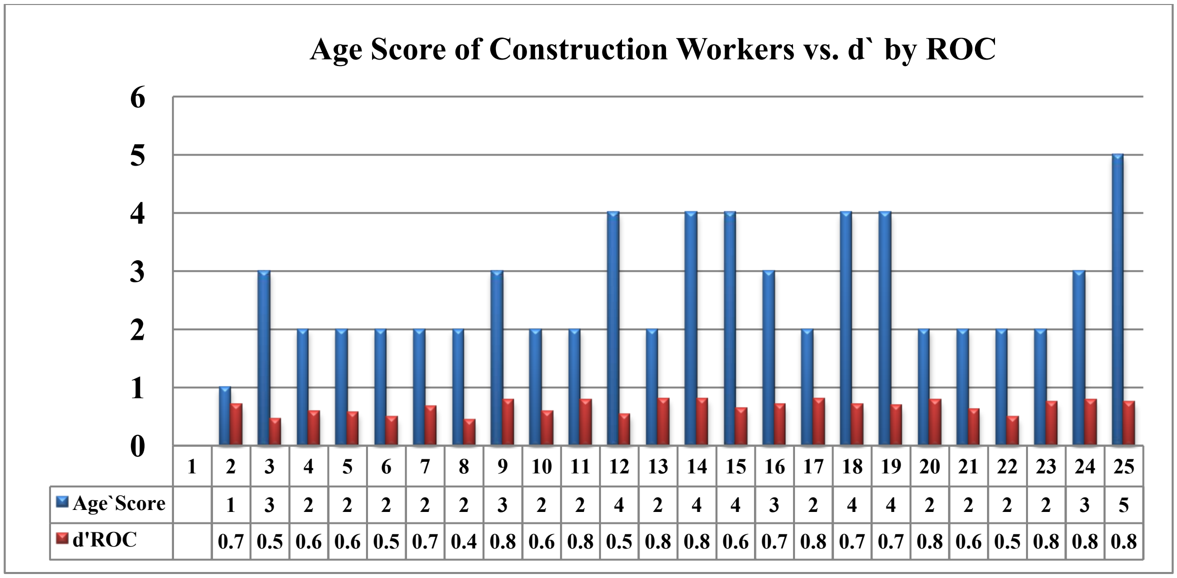


Figure 4.8 Age Score of Construction Worker vs. d' by ROC

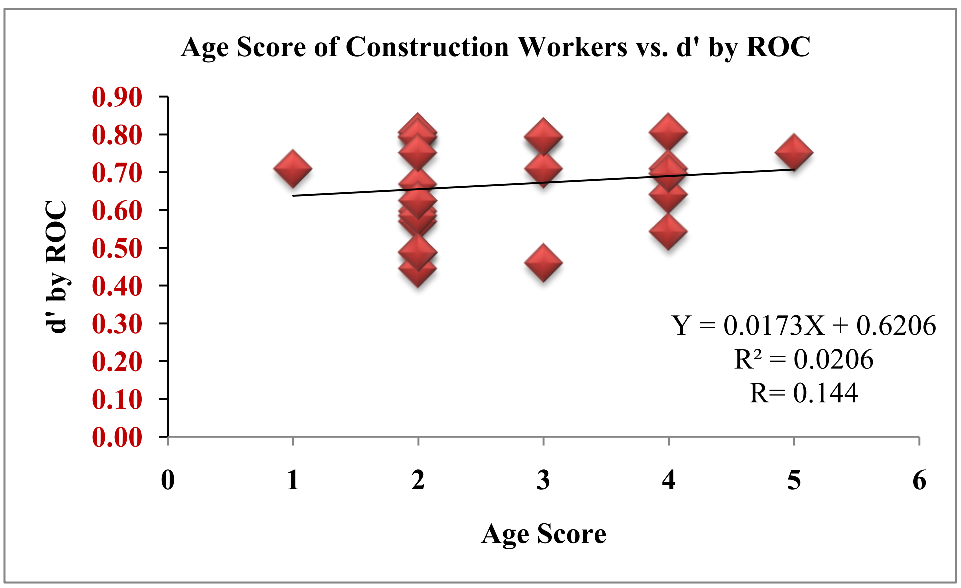


Figure 4.9 Age Score of Construction Worker vs. d' by ROC

Testing of the null hypothesis that age score and d'_{ROC} are not related, H_0: ρ=0, and shown that they are conducted as follows:

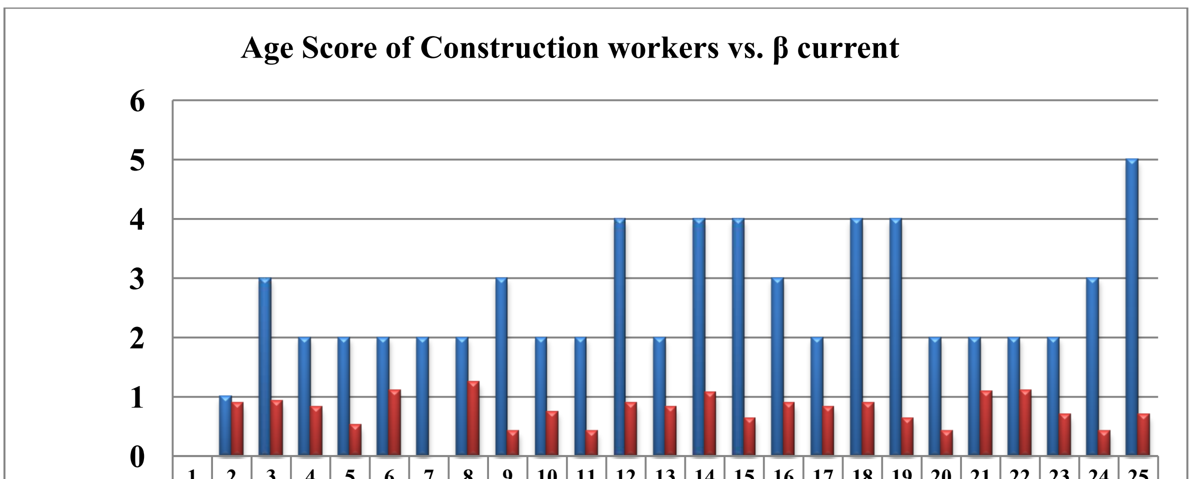
Using Equation 4.3: $Z_{obs} = 0.683$ (Noted $r = 0.144$, $\rho_0 = 0$, and $n = 24$)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} < Z_{(\alpha/2}$, hence H_0 cannot be rejected.

4.6.3 Age Score vs. β current

In this case, the response variable is risk orientation (β current) and the predictor is the age 'score of the construction workers. The breakdown by age score with respect to risk orientation (β current) is illustrated in Figure 4.10 and the regression plot of age score and risk orientation (β current) is shown in Figure 4.11. In this case, a value of r = 0.709 was found, which again indicates a moderate correlation between age score and the risk orientation of the construction workers.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Age`Score		1	3	2	2	2	2	2	3	2	2	4	2	4	4	3	2	4	4	2	2	2	2	3	5
β current		0.9	0.9	0.8	0.5	1.1	0.0	1.2	0.4	0.8	0.4	0.9	0.8	1.1	0.6	0.9	0.8	0.9	0.6	0.4	1.1	1.1	0.7	0.4	0.7

Figure 4.10 Age Score of Construction Worker vs. β current

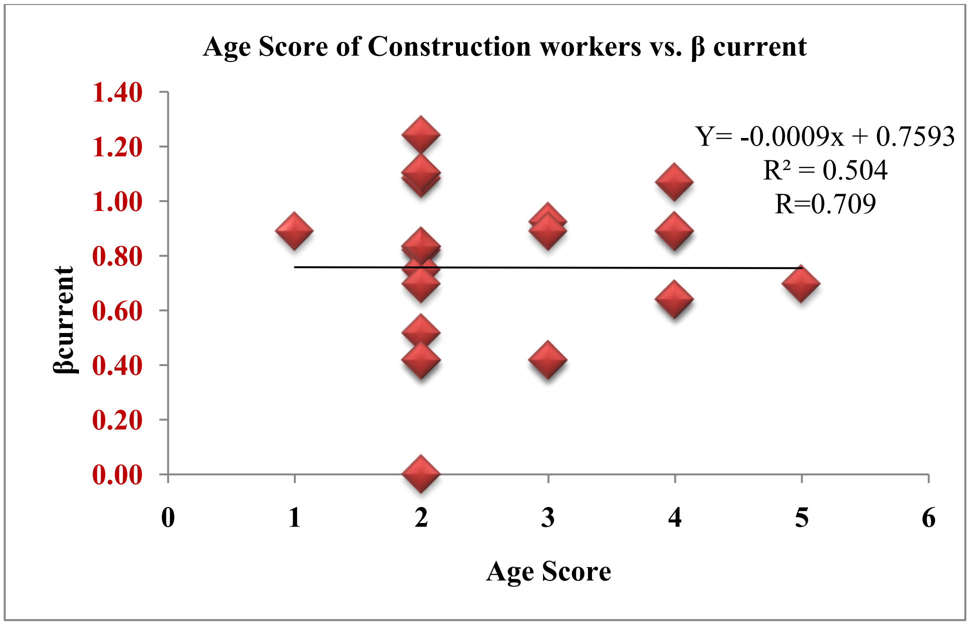


Figure 4.11 Age Score of Construction Worker vs. β current

Testing of the null hypothesis that age score and β current are not related, H_0: $\rho=0$, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 4.598$ (Noted $r = 0.709$, $\rho_0 = 0$, and $n= 24$)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} > Z_{(\alpha/2}$, hence H_0 can be rejected.

4.7 Regression Analysis for Experience Score

4.7.1 Experience Score vs. $d`_{SDT}$

The breakdown by experience score with respect to sensitivity ($d`_{SDT}$) is illustrated in Figure 4.12 and the regression plot of experience score and sensitivity ($d`_{SDT}$) is shown in Figure 4.13. The value of "r" for those relations was 0.446. This indicated that the relationship between the year of experience of the construction workers and their sensitivity is moderate.

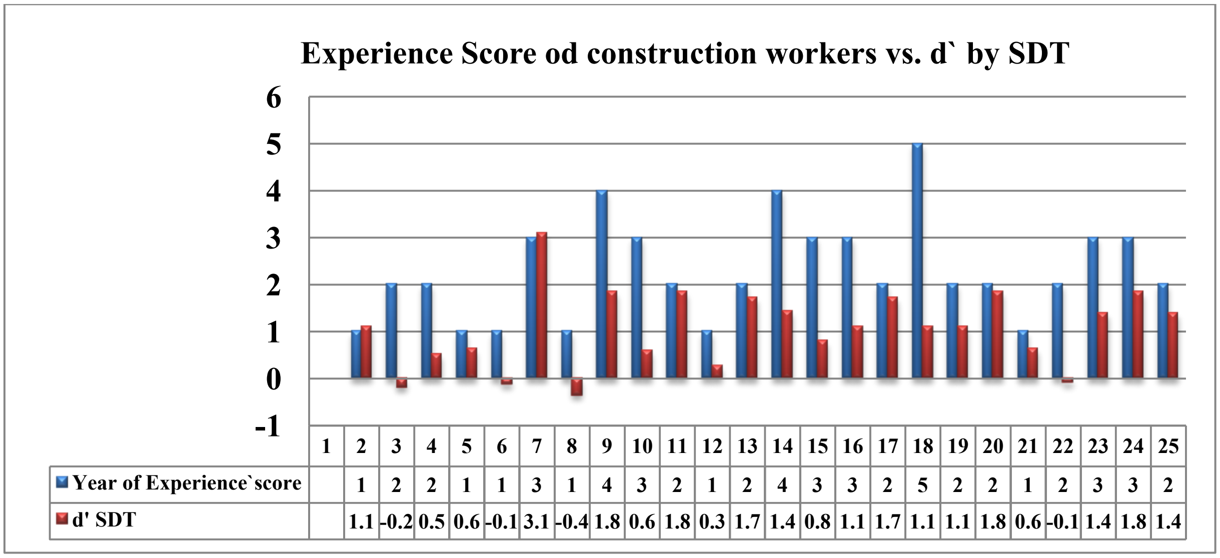


Figure 4.12 Experience Score of Construction Worker vs. d'_{SDT}

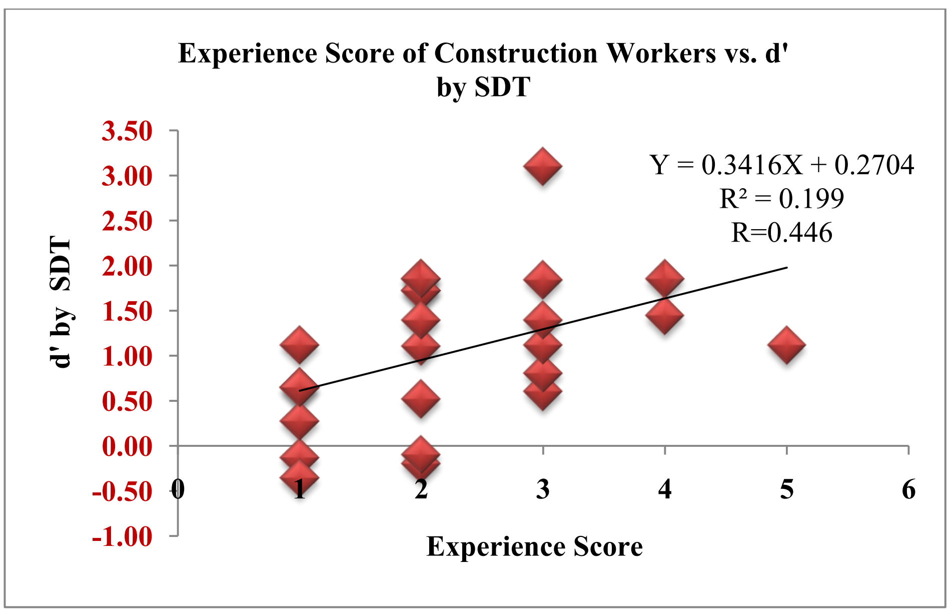


Figure 4.13 Experience Score of Construction Worker vs. d'_{SDT}

Testing of the null hypothesis that year of experience score and d' $_{SDT}$ are not related, H_0: ρ=0, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 2.337$ (Noted r = 0.446, $\rho_0 = 0$, and n= 24)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} > Z_{(\alpha/2)}$, hence H_0 can be rejected.

4.7.2 Experience Score vs. d'$_{ROC}$

The breakdown by experience score with respect to sensitivity (d`$_{ROC}$) is illustrated in Figure 4.14 and the regression plot of experience score and sensitivity (d`$_{ROC}$) is shown in Figure 4.15. The value of r = 0.470 indicates a moderate correlation between year of experience and sensitivity.

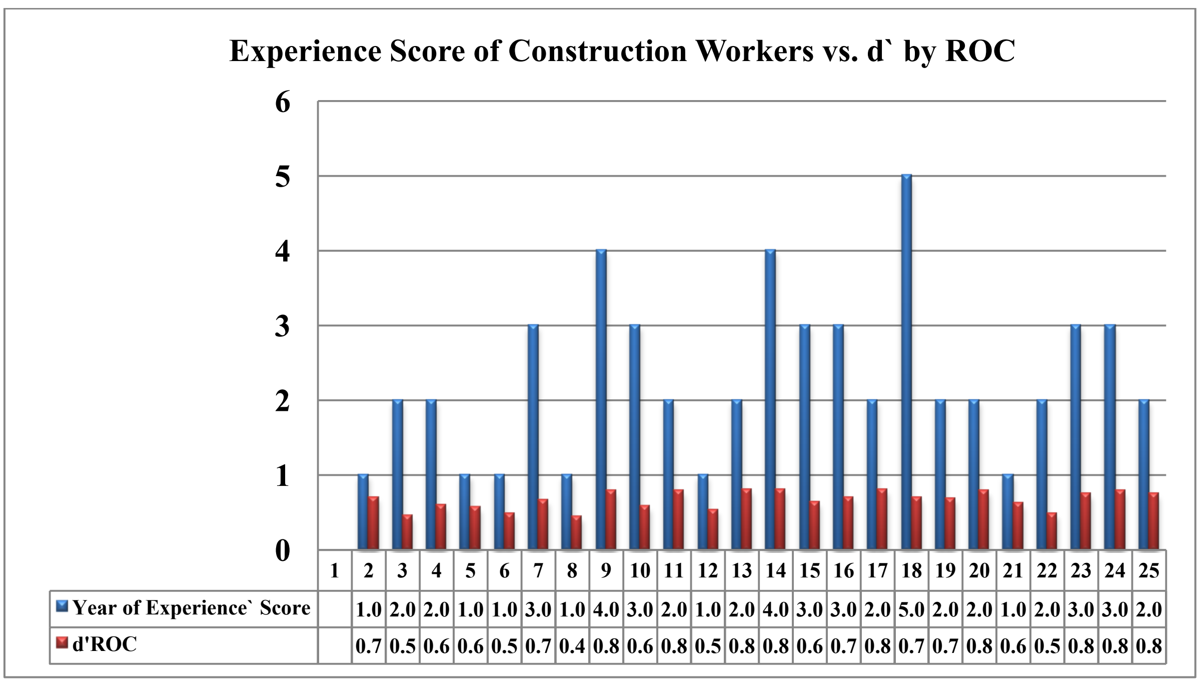


Figure 4.14 Experience Score of Construction Worker vs. d' ROC

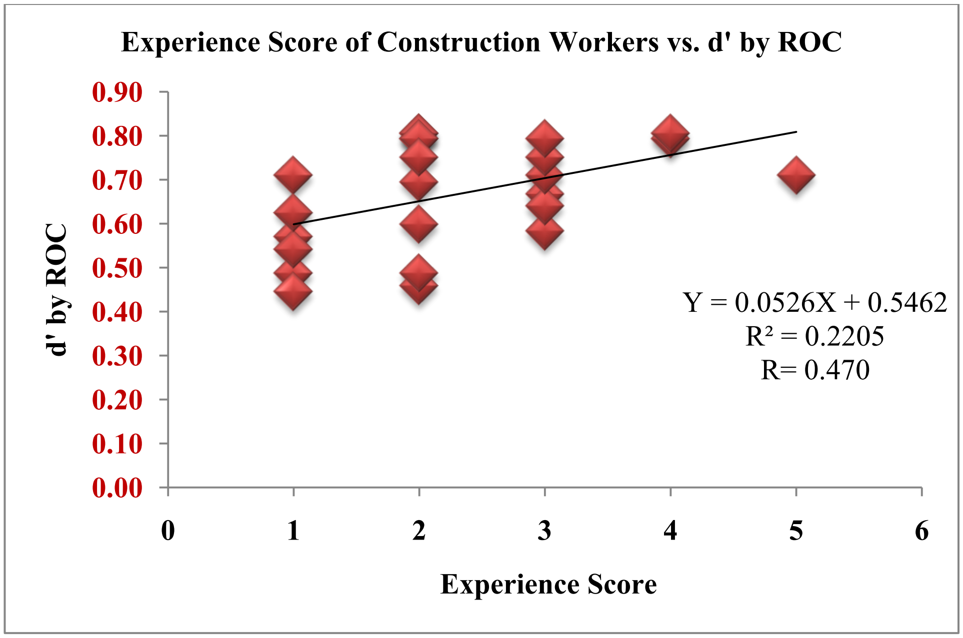


Figure 4.15 Experience Score of Construction Worker vs. d' ROC

Testing of the null hypothesis for the year of experience score and d'_{ROC} are not related, H_0: ρ=0, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 2.498$ (Noted r = 0.470, $\rho_0 = 0$, and n= 24)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} > Z_{(\alpha/2)}$, hence H_0 can be rejected.

4.7.3 Experience Score vs. β current

In this case, the response variable is risk orientation (β current) and the predictor is the experience score of the construction workers. The breakdown by experience score with respect to risk orientation (β current) is illustrated in Figure 4.16 and the regression plot of experience score and risk orientation (β current) is shown in Figure 4.17. In this case, a value of r = 0.278 was found, which again indicates a low correlation between year of experience and the risk orientation of the construction workers.

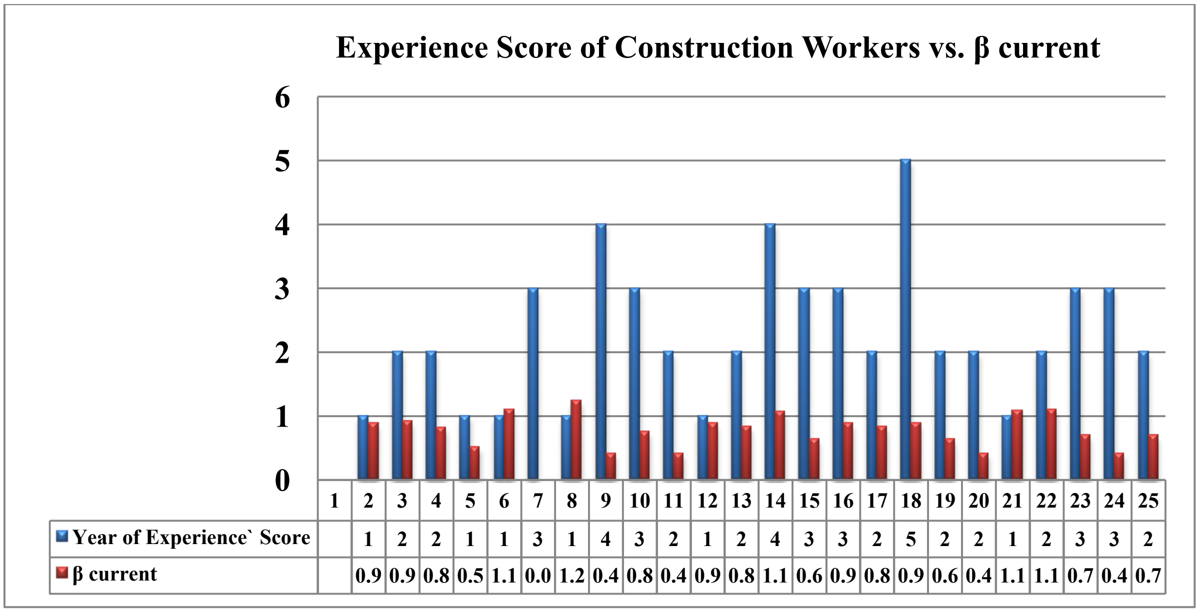


Figure 4.16 Experience Score of Construction Worker vs. β current

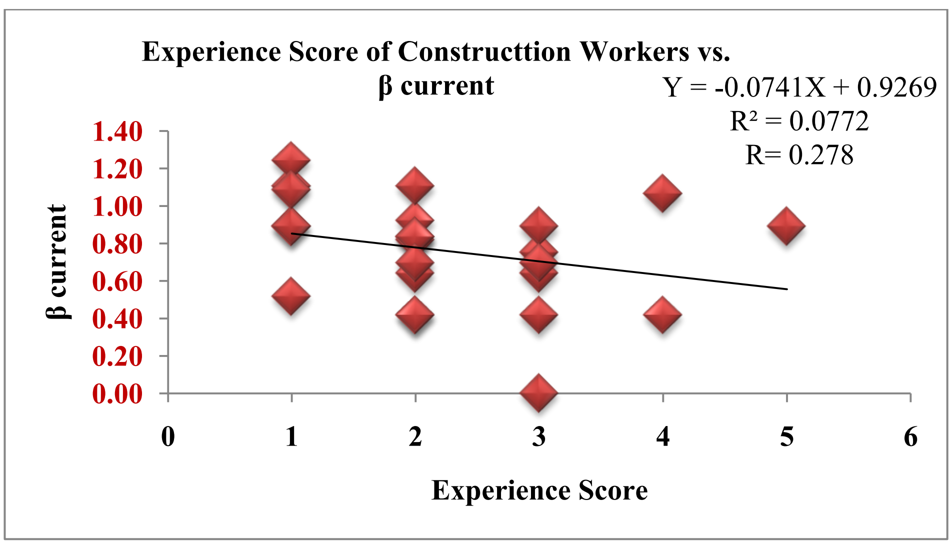


Figure 4.17 Experience Score of Construction Worker vs. β current

Testing of the null hypothesis that experience score and $d`_{ROC}$ are not related, H_0: $\rho=0$, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 1.357$ (Noted $r = 0.278$, $\rho_0 = 0$, and $n= 24$)

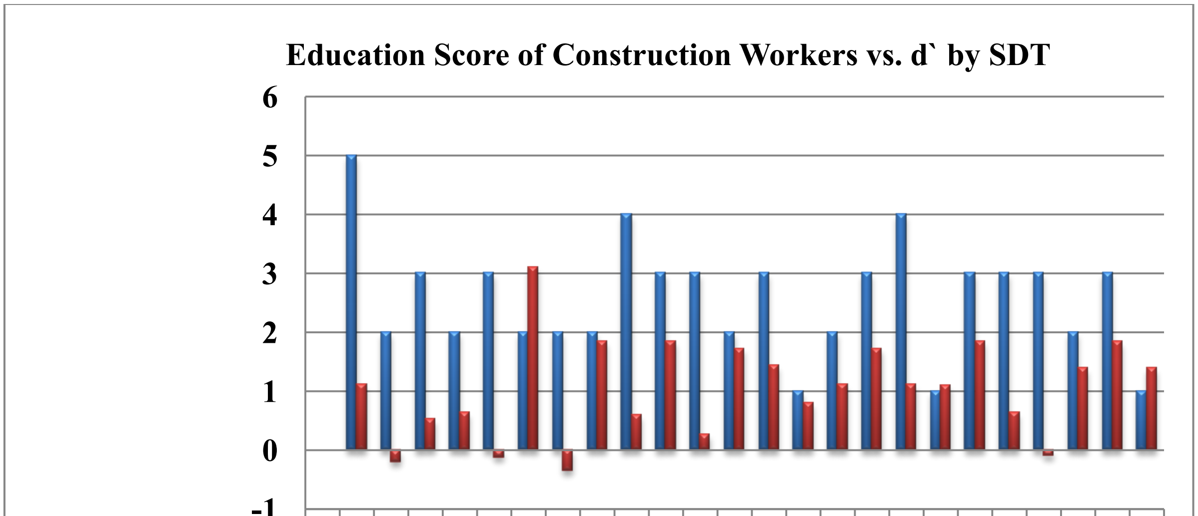
The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} < Z_{(\alpha/2)}$, hence H_0 cannot be rejected.

4.8 Regression Analysis for Education Score

4.8.1 Education Score vs. d'_{SDT}

The breakdown by education score with respect to sensitivity ($d`_{SDT}$) is illustrated in Figure 4.18 and the regression plot of experience score and sensitivity ($d`_{SDT}$) is shown in Figure 4.19. This indicated that the relationship between the education of the construction workers and their sensitivity is low.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Level of Education`score		5	2	3	2	3	2	2	2	4	3	3	2	3	1	2	3	4	1	3	3	3	2	3	1
d' SDT		1.1	-0.2	0.5	0.6	-0.1	3.1	-0.4	1.8	0.6	1.8	0.3	1.7	1.4	0.8	1.1	1.7	1.1	1.1	1.8	0.6	-0.1	1.4	1.8	1.4

Figure 4.18 Education Score of Construction Worker vs. d’ SDT

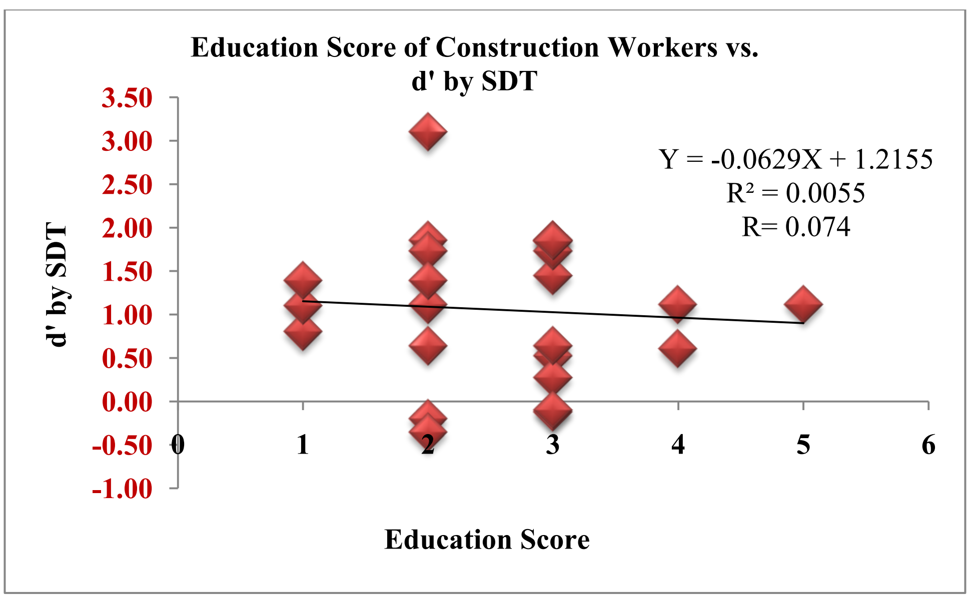


Figure 4.19 Education Score of Construction Worker vs. d'_{SDT}

Testing of the null hypothesis that education score and d'_{SDT} are not related, H_0: $\rho=0$, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 0.384$ (Noted $r = 0.074$, $\rho_0 = 0$, and $n= 24$)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} < Z_{(\alpha/2)}$, hence H_0 cannot be rejected.

4.8.2 Education Score vs. d'_{ROC}

The breakdown by education score with respect to sensitivity ($d`_{ROC}$) is illustrated in Figure 4.20 and the regression plot of experience score and sensitivity ($d`_{ROC}$) is shown in Figure 4.21. The value of $r = 0.94$ indicates a high correlation between education of construction workers and their sensitivity.

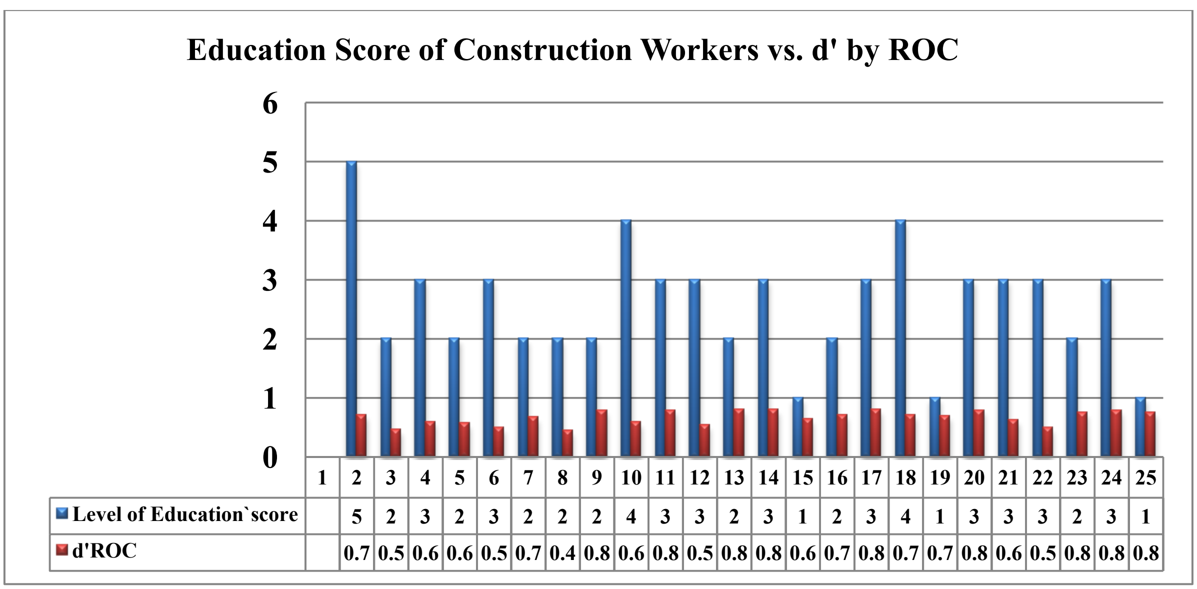


Figure 4.20 Education Score of Construction Workers vs. d'_{ROC}

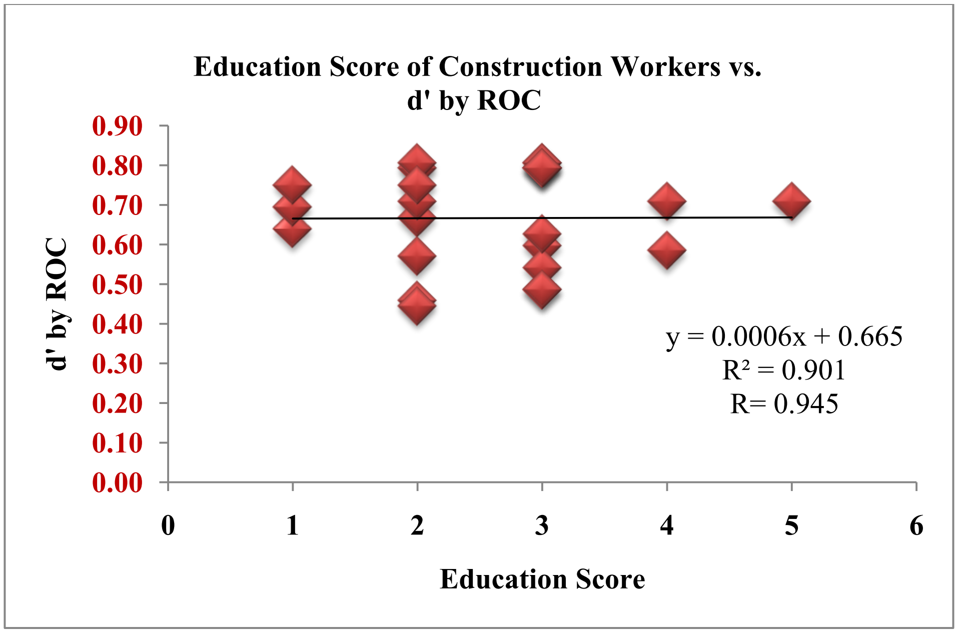


Figure 4.21 Education Score of Construction Workers vs. d' ROC

Testing of the null hypothesis that education score and d'_{SDT} are not related, H_0: $\rho=0$, and shown that they are conducted as follows:

Using Equation 4.3: $Z_{obs} = 9.684$ (Noted $r = 0.945$, $\rho_0 = 0$, and $n= 24$)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} > Z_{(\alpha/2)}$, hence H_0 can be rejected.

4.8.3 Education Score vs. β current

In this case, the response variable is risk orientation (β current) and the predictor is the education score of the construction workers. The breakdown by education score with respect to risk orientation (β current) is illustrated in Figure 4.22 and the regression plot of experience score and risk orientation (β current) is shown in Figure 4.23. In this case, a value of r = 0.235 was found, which again indicates a low correlation between education and the risk orientation of the construction workers.

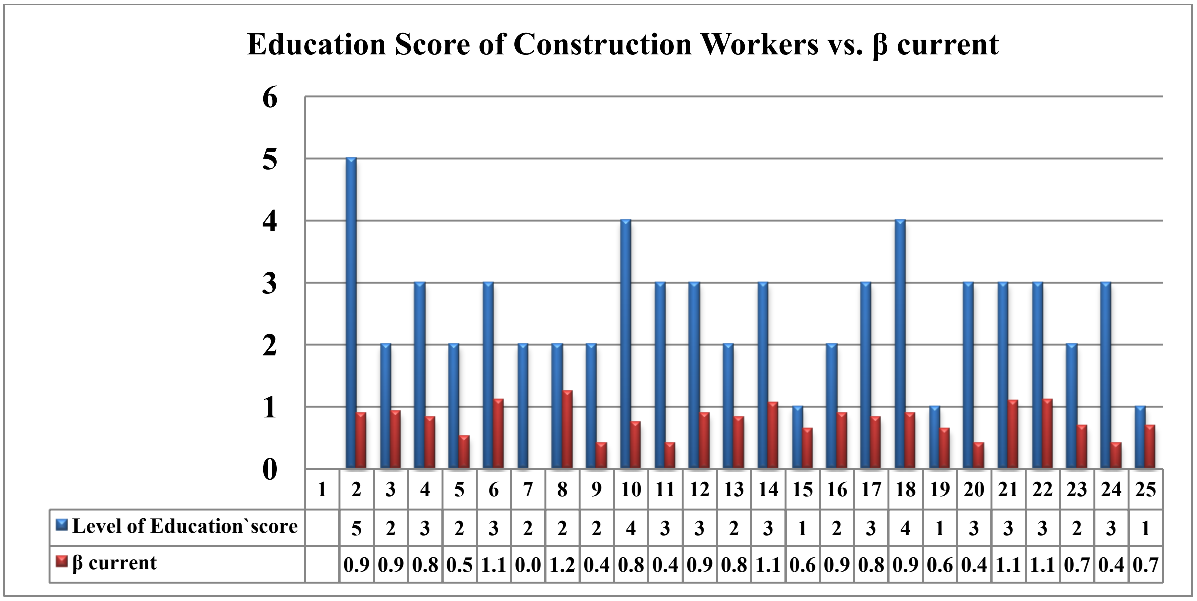


Figure 4.22 Education Score of Construction Workers vs. β current

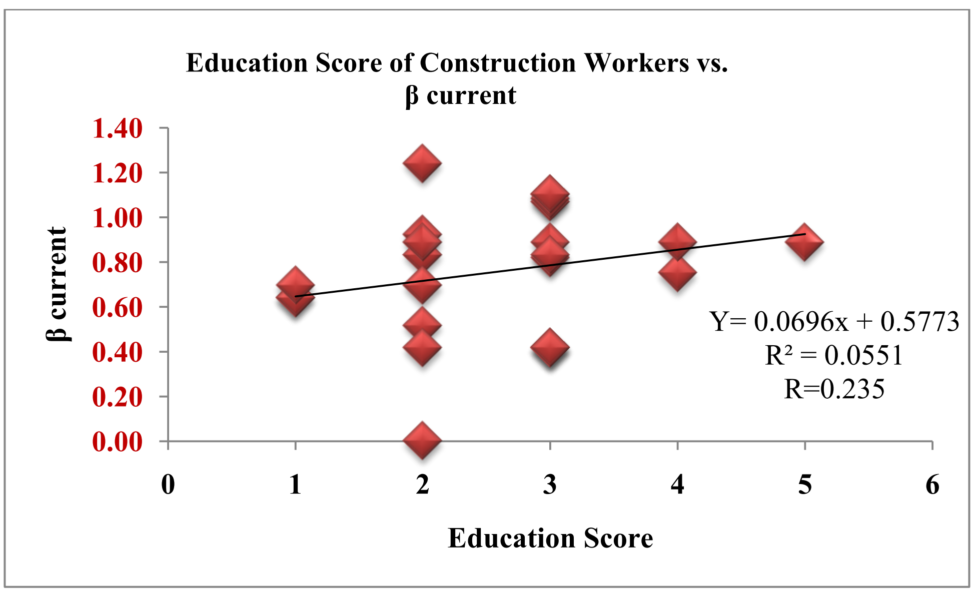


Figure 4.23 Education Score of Construction Workers vs. β current

Testing of the null hypothesis that education score and d'_{ROC} are not related, H_0: $\rho=0$, the assumption that they are related was conducted as follows:

Using Equation 4.3: $Z_{obs} = 1.134$ (Noted $r = 0.235$, $\rho_0 = 0$, and $n= 24$)

The rejection for H_0 is when $Z_{obs} > Z_{(\alpha/2)}$; $Z_{(\alpha/2)} = Z_{(0.005/2)} = 1.96$

$Z_{obs} < Z_{(\alpha/2)}$, hence H_0 cannot be rejected.

4.9 Results

In general, based on the analysis performed in this research, the following results are drawn:

1) Around 95% (out of 24) construction worker survey participants had "low" to "moderate" sensitivity toward unsafe condition which reveals that most workers lack proper safety and health knowledge and require additional training.

2) 85% of construction worker who participated in this research had risky strategy, which means they will have more misses than false alarms and they should be trained again to change their risky decision making strategy. These workers should be trained to change the decision – making strategy from risky to conservative.

3) The average sensitivity of the group is moderate when compared to ideal d'_{SDT}.

4) Regression analysis indicated that the relationship between the age of the construction workers and their sensitivity is quite low. The value of “r” for those relations was 0.014.

5) Regression analysis indicated a moderate correlation between the age of construction worker and their risk orientation. In this case, the value of r was 0.709.

6) Regression analysis indicated that the relationship between the years of experience and construction workers’ sensitivity is moderate. The value of r for those relations was 0.446.

7) Regression analysis indicated a low correlation between the year of experience of construction worker and their risk orientations. The value of r for those relations was 0.278.

8) Regression analysis indicated that the relationship between the level of education of the construction workers and their sensitivity is low. The value of “r” for those relations was 0.074.

9) Regression analysis indicated a low correlation between the level of education of construction worker and their risk orientation. The value of “r” for those relations was 0.235.

10) The sensitivity and response bias data for the construction workers follow a normal distribution.

11) Regression analysis indicated a high correlation between the sensitivity and risk orientation of construction workers. The value of "r" for those relations was 0.790.

12) The model proposed in this research could be used as a pre-test and post-test after training for assessing the effects of training.

13) Feedback can be given to OSHA on enforcing regulations; if for example a particular scenario is always missed or considered safe.

4.10 Summary

In this Chapter, survey data and results were analyzed, using:

- Signal Detection Theory to establish the sensitivity and risk orientation of construction workers to unsafe conditions.
- The ROC curve to establish the sensitivity of construction workers by considering the joint effects of answer bias and sensitivity (the joint effect of risk orientation and sensitivity).
- Regression analysis to determine whether the sensitivity or risk orientation of construction worker is related to their age, experience or education.

Furthermore, the objectives stated in Chapters 1 and 2 were achieved using the methods discussed in Chapters 3 and 4. Chapter 5 discusses the research contributions and concludes with the research limitations and areas of future research.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main goal of this research was to expand on an approach to measure a worker's ability to distinguish between a safe condition and an unsafe condition on a jobsite. It measured the worker's decision-making strategy.

In spite of the role of many construction accident causation models in understanding the accident process, none adequately have explained the underlying reasons of construction accidents because of its dynamic nature. To overcome this restriction, in this thesis, a model was used to consider organizational and individual forces that push workers to be in hazardous conditions. These forces overcome efforts to impose safe work rules particularly in a changing work environment such as in construction.

To attain this objective, a survey was developed. With the assistance of this survey and Signal Detection Theory (SDT) concept, the sensitivity and risk orientation of construction workers were determined.

5.2 Recommendations for Future Research

- It is recommended that a research be conducted with lower age group workers who may have more risky strategies towards unsafe conditions. These groups of workers need to be specifically trained and teaching materials can be developed to assist in this regard.

- A detailed database of all construction-related accidents and the results of investigations into the causes of accidents would help improve on-site safety practices and minimize future accidents. It is suggested that an accident database with investigation of accidents be made available to researchers and industry leaders in charge of safety concerns and training and that a single center responsible for construction project safety should be established.
- Future research should consider larger samples as well as other trades to determine the sensitivity and risk orientation of the workers. Based on the results of this thesis, SDT and ROC analyses can be performed in a similar fashion so that an in-depth investigation of how workers respond to safe and unsafe conditions is evaluated.
- Another important area of this research is that the needs for design of training workshops are highlighted.

APPENDIX A
CONSENT LETTER AND SURVEY QUESTIONNAIRE

Participant Consent Form

Project Overview

My name in Hoda Alavi, a graduate student at The University of Texas at Arlington (**UTA**) in the Department of Civil and Environmental Engineering. We have research program to assess the occupational safety knowledge and personality of construction workers. The research will help in improving the effectiveness of safety training programs. Therefore, we will appreciate your participation as a professional who has experience in this area, to answer to our short questionnaire.

As a participant in this research, you will be asked to complete 20 questions survey on occupational safety rules related to construction accident.

Your privacy will be protected to the maximum level permissible by law. The estimated time for the survey is 25-30 minutes. As a participant, you may request a copy of this consent letter for your records.

Thank you in advance for taking the time to read this email and complete the survey. If you have any questions about this project, you may contact me at: hoda.alavi@mavs.uta.edu or my professor at Najafi@uta.edu or phone: (817)272-0507.

Education Level	Elementary	Middle school	High school	College	Bachelor degree	Master Degree
Score	1	2	3	4	5	6
Age	15-20	20-25	25-30	30-35	35-40	40-45
Score	1	2	3	4	5	6
Year of Experience	0-2	2-4	4-6	6-8	8-10	More than 10Years
Score	1	2	3	4	5	6

SAFETY QUESTIONS

Please read the following questions and select your answer from the choices: "**Safe**"," **Unsafe**" or "**I am not sure**." Please circle only one answer per question.

1. The point of operation is with some distance from the crane's operator station.
Is this situation
A. Safe
B. Unsafe
C. I Don't Know

2. Each crane operator is needed to have adequate training and experience.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

3. Equipment and materials located 15 feet from an electrical power lines.
Is this situation (the distance between the equipment and materials and the power line)
A. Safe
B. Unsafe
C. I Don't know

4. A crawler crane lifting steel columns located 25 feet from a 550 kV power line.

Source: von Bernuth (2006)
Is this situation (the distance between the crane and the power line?)
A. Safe
B. Unsafe
C. I Don't know

5. A situation of a crane with heavy loads that surpass the crane's structural limitations and stability ratings.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

6. Crane came with unsecured Load.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

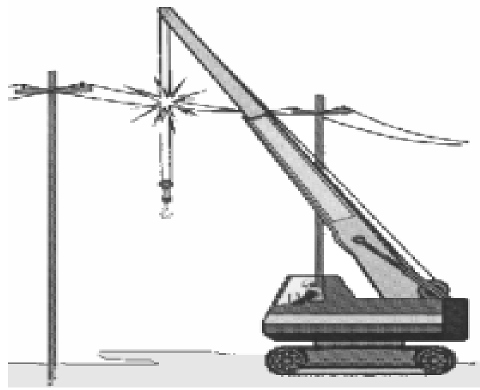
7. Crane with the lack of preventative maintenance and required inspections.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

8. Electrical construction worker without personal protection equipment.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

9. When a crane came into contact with overhead electric lines.



Is this situation
A. Safe
B. Unsafe
C. I Don't Know

10. Welding with personal protective equipment (PPE) and by someone who has had the training necessary to master the skill.

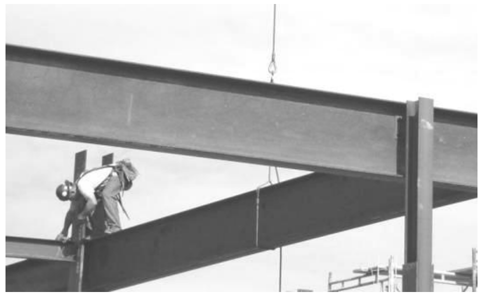
Is this situation
A. Safe
B. Unsafe
C. I Don't Know

11. Working on a 3.500-sq.ft.decking which has an unsecured condition.

Source: von Bernuth (2006)

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

12. Ironworker climbs on the steel beam, when it is held by the crane (tied with a choker), to bolt it in place.



Source: von Bernuth (2006)

Is this situation
A. Safe
B. Unsafe
C. I Don’t Know

13. A 50-inch square opening was created while working on renovation of a floor roof

Is this situation
A. Safe
B. Unsafe
C. I Don’t Know

14. Handling hazardous chemicals by reviewing the manufacturer's Material Safety Data Sheet information

Is this situation
A. Safe
B. Unsafe
C. I Don’t Know

15. When climbing a portable ladder to access an upper landing surface, the side rail extends 3.5 feet above the upper landing surface.

Is this situation (the height that the ladder's side rail extends above the landing surface)
A. Safe
B. Unsafe
C. I Don't Know

16. There is a requirement for all trucks and equipment near overhead utility wires to have spotter.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

17. There is soil shifting due to rain, insufficient preparation or maintenance of the trench

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

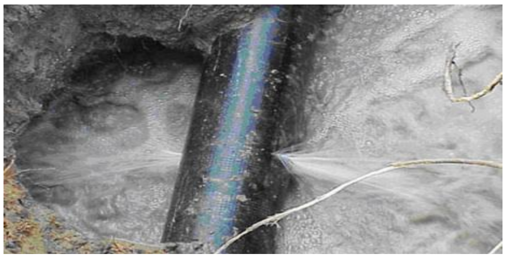
18. Operating a forklift on the 4th floor when all perimeter cabling is in place and precast concrete panels are being placed.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

19. Trucks could dump when they are not parked side by side with another vehicle.

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

20. Pipe begins to leak toxic chemical or gases.



Is this situation
A. Safe
B. Unsafe
C. I Don't Know

21. There is soil shifting due to rain, insufficient preparation or maintenance of the trench

Is this situation
A. Safe
B. Unsafe
C. I Don't Know

APPENDIX B
RESULTS OF ANSWER OF CONSTRUCTION WORKERS

QUES	Worker 1				QUES	Worker 2			
	Age= 19					**Age=29**			
	Exp= 2					**Exp=2.5**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6		x			Q6		x		
Q7		x			Q7		x		
Q8	x				Q8		x		
Q9	x				Q9		x		
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13	x			
Q14				x	Q14			x	
Q15	x				Q15	x			
Q16				x	Q16			x	
Q17	x				Q17		x		
Q18				x	Q18				x
Q19			x		Q19			x	
Q20				x	Q20			x	
Q21	x				Q21	x			
TOTAL	9	3	3	6	TOTAL	7	5	6	3
PRO	0.75	0.25	0.33	0.67	PRO	0.58	0.42	0.67	0.33

QUES	**Worker 3**				QUES	**Worker 4**			
	Age=24					**Age=21**			
	Exp=2.5					**Exp=2**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7		x			Q7	x			
Q8		x			Q8	x			
Q9	x				Q9	x			
Q10				x	Q10			x	
Q11				x	Q11				x
Q12	x				Q12	x			
Q13	x				Q13	x			
Q14				x	Q14			x	
Q15		x			Q15	x			
Q16			x		Q16			x	
Q17	x				Q17	x			
Q18				x	Q18			x	
Q19			x		Q19			x	
Q20			x		Q20				x
Q21	x				Q21		x		
TOTAL	9	3	5	4	TOTAL	11	1	7	2
PRO	0.75	0.25	0.56	0.44	PRO	0.92	0.08	0.778	0.22

QUES	Worker5				QUES	Worker 6			
	Age= 24					Age=25			
	Exp= 1					Exp=6			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8	x				Q8	x			
Q9	x				Q9	x			
Q10			x		Q10			x	
Q11				x	Q11			x	
Q12	x				Q12	x			
Q13		x			Q13	x			
Q14			x		Q14				x
Q15		x			Q15	x			
Q16			x		Q16				x
Q17	x				Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20			x		Q20			x	
Q21		x			Q21	x			
TOTAL	9	3	7	2	TOTAL	12	0	6	3
PRO	0.75	0.25	0.78	0.22	PRO	1	-3	0.67	0.33

QUES	Worker 7 Age=21 Exp=1				QUES	Worker 8 Age=27 Exp=6.5			
	H	M	FA	CR		H	M	FA	CR
Q1		x			Q1		x		
Q2			x		Q2			x	
Q3			x		Q3				x
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8		x			Q8	x			
Q9	x				Q9	x			
Q10			x		Q10				x
Q11			x		Q11				x
Q12	x				Q12	x			
Q13		x			Q13	x			
Q14				x	Q14				x
Q15	x				Q15	x			
Q16			x		Q16			x	
Q17	x				Q17	x			
Q18			x		Q18				x
Q19			x		Q19			x	
Q20				x	Q20				x
Q21		x			Q21	x			
TOTAL	8	4	7	2	TOTAL	11	1	3	6
PRO	0.67	0.33	0.78	0.22	PRO	0.92	0.083	0.33	0.67

QUES	**Worker 9 Age= 24 Exp= 4.5**				QUES	**Worker 10 Age=25 Exp=3**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8	x				Q8	x			
Q9	x				Q9	x			
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13		x		
Q14				x	Q14				x
Q15	x				Q15	x			
Q16				x	Q16				x
Q17	x				Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20			x		Q20				x
Q21	x				Q21	x			
TOTAL	10	2	6	3	TOTAL	11	1	3	6
PRO	0.883	0.2	0.7	0.33	PRO	0.92	0.08	0.33	0.67

QUES	Worker 11				QUES	Worker 12			
	Age=31					Age=23			
	Exp=1.5					Exp=3.5			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2				x
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8	x				Q8	x			
Q9	x				Q9		x		
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13	x			
Q14			x		Q14				x
Q15		x			Q15		x		
Q16			x		Q16				x
Q17		x			Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20			x		Q20				x
Q21	x				Q21	x			
TOTAL	9	3	6	3	TOTAL	10	2	2	7
PRO	0.75	0.25	0.67	0.33	PRO	0.83	0.17	0.22	0.78

QUES	Worker 13				QUES	Worker 14			
	Age= 32					Age=32			
	Exp= 7					Exp=5			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2				x	Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6		x			Q6	x			
Q7		x			Q7	x			
Q8	x				Q8	x			
Q9		x			Q9	x			
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13	x				Q13	x			
Q14				x	Q14				x
Q15	x				Q15		x		
Q16				x	Q16				x
Q17	x				Q17		x		
Q18				x	Q18			x	
Q19			x		Q19			x	
Q20				x	Q20			x	
Q21	x				Q21	x			
TOTAL	10	2	2	7	TOTAL	10	2	5	4
PRO	0.833333	0.17	0.22	0.78	PRO	0.83	0.17	0.56	0.44

QUES	Worker 15				QUES	Worker 16			
	Age=30					Age=22			
	Exp=4.5					Exp=3			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1		x		
Q2			x		Q2				x
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8	x				Q8	x			
Q9	x				Q9	x			
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13	x				Q13	x			
Q14				x	Q14				x
Q15	x				Q15		x		
Q16				x	Q16				x
Q17	x				Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20				x	Q20				x
Q21	x				Q21	x			
TOTAL	9	3	3	6	TOTAL	10	2	2	7
PRO	0.75	0.25	0.33	0.67	PRO	0.83	0.167	0.22	0.78

QUES	**Worker17**				QUES	**Worker 18**			
	Age= 24					**Age=35**			
	Exp= 9					**Exp=2.5**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6		x			Q6	x			
Q7		x			Q7	x			
Q8	x				Q8	x			
Q9	x				Q9	x			
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13		x		
Q14				x	Q14				x
Q15	x				Q15		x		
Q16				x	Q16			x	
Q17	x				Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20				x	Q20				x
Q21	x				Q21	x			
TOTAL	9	3	3	6	TOTAL	10	2	4	5
PRO	0.75	0.25	0.44	0.56	PRO	0.83	0.17	0.44	0.56

QUES	Worker 19				QUES	Worker 20			
	Age=24					**Age=21**			
	Exp=4					**Exp=1**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1		x		
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7		x		
Q8	x				Q8		x		
Q9		x			Q9		x		
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13	x				Q13	x			
Q14				x	Q14				x
Q15	x				Q15	x			
Q16				x	Q16				x
Q17	x				Q17	x			
Q18				x	Q18				x
Q19			x		Q19			x	
Q20				x	Q20				x
Q21	x				Q21		x		
TOTAL	11	1	3	6	TOTAL	7	5	3	6
PRO	0.92	0.08	0.33	0.67	PRO	0.58	0.42	0.33	0.67

QUES	Worker21				QUES	Worker 22			
	Age= 25					**Age=24**			
	Exp= 3					**Exp=4.5**			
	H	M	FA	CR		H	M	FA	CR
Q1		x			Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8		x			Q8	x			
Q9	x				Q9	x			
Q10			x		Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13		x		
Q14			x		Q14				x
Q15	x				Q15	x			
Q16			x		Q16			x	
Q17	x				Q17		x		
Q18				x	Q18				x
Q19			x		Q19				x
Q20			x		Q20				x
Q21	x				Q21	x			
TOTAL	9	3	7	2	TOTAL	10	2	3	6
PRO	0.75	0.25	0.778	0.22	PRO	0.83	0.17	0.33	0.67

QUES	Worker 23				QUES	Worker 24			
	Age=25					**Age=30**			
	Exp=5					**Exp=3**			
	H	M	FA	CR		H	M	FA	CR
Q1	x				Q1	x			
Q2			x		Q2			x	
Q3			x		Q3			x	
Q4	x				Q4	x			
Q5	x				Q5	x			
Q6	x				Q6	x			
Q7	x				Q7	x			
Q8	x				Q8	x			
Q9	x				Q9	x			
Q10				x	Q10				x
Q11				x	Q11				x
Q12	x				Q12	x			
Q13		x			Q13		x		
Q14				x	Q14				x
Q15	x				Q15	x			
Q16				x	Q16				x
Q17	x				Q17		x		
Q18				x	Q18				x
Q19			x		Q19			x	
Q20				x	Q20				x
Q21	x				Q21	x			
TOTAL	11	1	3	6	TOTAL	10	2	3	6
PRO	0.92	0.083	0.33	0.67	PRO	0.83	0.17	0.33	0.67

APPENDIX C

NORMALIZED STD TABLE

Table C.1 Normal Deviates and Ordinates for Calculating d′ and β
(Adapted from Bernuth, 2006)

p	Normal Deviate Z	Ordinates
0.01	2.326	0.027
0.02	2.054	0.048
0.03	1.881	0.068
0.04	1.751	0.086
0.05	1.645	0.103
0.06	1.555	0.119
0.07	1.476	0.134
0.08	1.405	0.149
0.09	1.341	0.162
0.1	1.282	0.176
0.11	1.227	0.188
0.12	1.175	0.2
0.13	1.126	0.212
0.14	1.08	0.223
0.15	1.036	0.233
0.16	0.994	0.243
0.17	0.954	0.253
0.18	0.915	0.263
0.19	0.878	0.272
0.2	0.842	0.28
0.21	0.806	0.288
0.22	0.772	0.296
0.23	0.739	0.304
0.24	0.706	0.311
0.25	0.674	0.318

p	Normal Deviate Z	Ordinates
0.26	0.643	0.325
0.27	0.613	0.331
0.28	0.583	0.337
0.29	0.553	0.342
0.3	0.524	0.348
0.31	0.496	0.353
0.32	0.468	0.358
0.33	0.44	0.362
0.34	0.412	0.367
0.35	0.385	0.371
0.36	0.358	0.374
0.37	0.332	0.378
0.38	0.305	0.381
0.39	0.279	0.384
0.4	0.253	0.386
0.41	0.228	0.389
0.42	0.202	0.391
0.43	0.176	0.393
0.44	0.151	0.394
0.45	0.126	0.396
0.46	0.1	0.397
0.47	0.075	0.398
0.48	0.05	0.398
0.49	0.025	0.399
0.5	0	0.399

APPENDIX D

RESDULTS OF THE ANALYSIS OF THE DATA

Table D.1 Summary of Response of each Construction Worker

Worker	Age`s Score	Level of Education` Score	Year of Experience` Score	d'_{SDT}	d'_{roc}	$\beta_{Current}$	β_{opt}
1	1	3	1	1.11	0.71	0.89	0.75
2	3	2	2	-0.20	0.46	0.92	0.75
3	2	3	2	0.52	0.60	0.82	0.75
4	2	2	1	0.64	0.57	0.52	0.75
5	2	3	1	-0.13	0.49	1.10	0.75
6	2	1	3	3.10	0.67	0.00	0.75
7	2	2	1	-0.36	0.44	1.24	0.75
8	3	2	4	1.85	0.79	0.42	0.75
9	2	4	3	0.60	0.58	0.75	0.75
10	2	2	2	1.85	0.79	0.42	0.75
11	4	3	1	0.27	0.54	0.89	0.75
12	2	3	2	1.72	0.81	0.83	0.75
13	4	1	4	1.44	0.81	1.07	0.75
14	4	1	3	0.80	0.64	0.64	0.75
15	3	2	3	1.11	0.71	0.89	0.75
16	2	3	2	1.72	0.81	0.83	0.75
17	4	4	5	1.11	0.71	0.89	0.75
18	4	1	2	1.10	0.69	0.64	0.75
19	2	2	2	1.85	0.79	0.42	0.75
20	2	3	1	0.64	0.63	1.08	0.75
21	2	3	2	-0.10	0.49	1.10	0.75
22	2	2	3	1.39	0.75	0.69	0.75
23	3	2	3	1.84	0.79	0.42	0.75
24	5	1	2	1.39	0.75	0.69	0.75

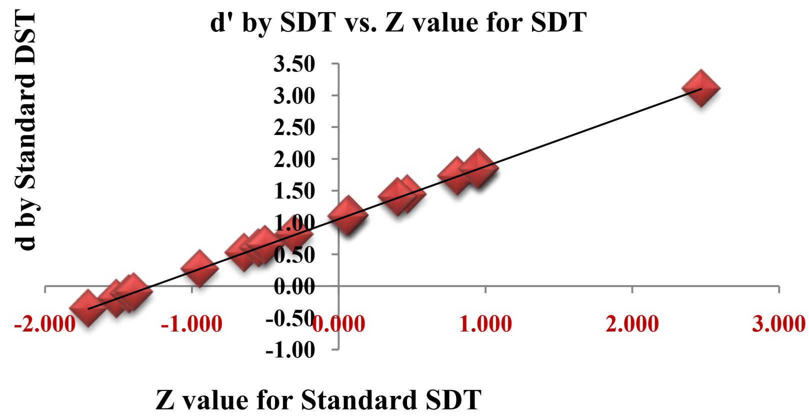
Table D.2 Summary of Response of Each Construction Worker

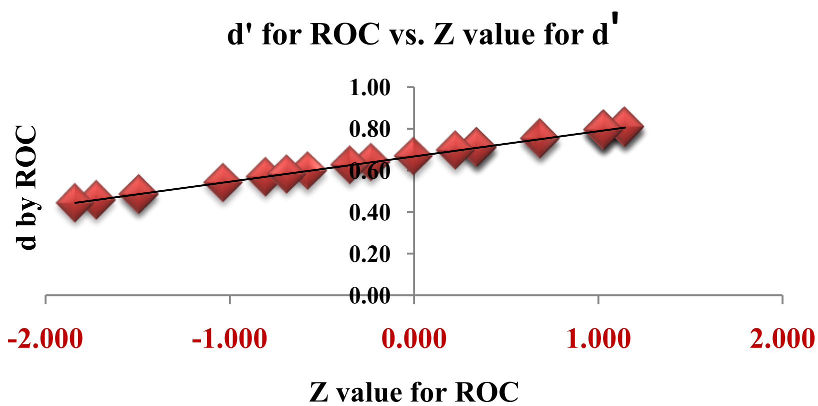
W	Probability				Z value		Coordinates		d'_{SDT}	$d`_{ROC}$
	P(HIT)	**P(Miss)**	**P(FA)**	**P(CR)**	**Z1**	**Z2**	**z1**	**z2**		
1	0.75	0.25	0.33	0.67	0.44	0.674	0.36	0.32	1.11	0.71
2	0.58	0.42	0.67	0.33	-0.4	0.2	0.39	0.36	-0.20	0.46
3	0.75	0.25	0.56	0.44	-0.15	0.67	0.39	0.32	0.52	0.60
4	0.92	0.08	0.78	0.22	-0.77	1.41	0.29	0.15	0.64	0.57
5	0.75	0.25	0.78	0.22	-0.8	0.67	0.29	0.32	-0.13	0.49
6	1.00	0.00	0.67	0.33	-0.4	3.5	0.36	0	3.10	0.67
7	0.67	0.33	0.78	0.22	-0.8	0.44	0.29	0.36	-0.36	0.44
8	0.92	0.08	0.33	0.67	0.44	1.41	0.36	0.15	1.85	0.79
9	0.83	0.17	0.67	0.33	-0.4	1	0.4	0.3	0.60	0.58
10	0.92	0.08	0.33	0.67	0.44	1.41	0.36	0.15	1.85	0.79
11	0.75	0.25	0.67	0.33	-0.4	0.67	0.36	0.32	0.27	0.54
12	0.83	0.17	0.22	0.78	0.77	0.954	0.3	0.25	1.72	0.81
13	0.83	0.17	0.22	0.78	0.77	0.67	0.3	0.32	1.44	0.81
14	0.83	0.17	0.56	0.44	-0.15	0.954	0.39	0.25	0.80	0.64
15	0.75	0.25	0.33	0.67	0.44	0.67	0.36	0.32	1.11	0.71
16	0.83	0.17	0.22	0.78	0.77	0.954	0.3	0.25	1.72	0.81
17	0.75	0.25	0.33	0.67	0.44	0.67	0.36	0.32	1.11	0.71
18	0.83	0.17	0.44	0.56	0.15	0.95	0.39	0.25	1.10	0.69
19	0.92	0.08	0.33	0.67	0.44	1.41	0.36	0.15	1.85	0.79
20	0.58	0.42	0.33	0.67	0.44	0.2	0.36	0.39	0.64	0.63
21	0.75	0.25	0.78	0.22	-0.77	0.67	0.29	0.32	-0.10	0.49
22	0.83	0.17	0.33	0.67	0.44	0.95	0.36	0.25	1.39	0.75
23	0.92	0.08	0.33	0.67	0.44	1.4	0.36	0.15	1.84	0.79
24	0.83	0.17	0.33	0.67	0.44	0.95	0.36	0.25	1.39	0.75

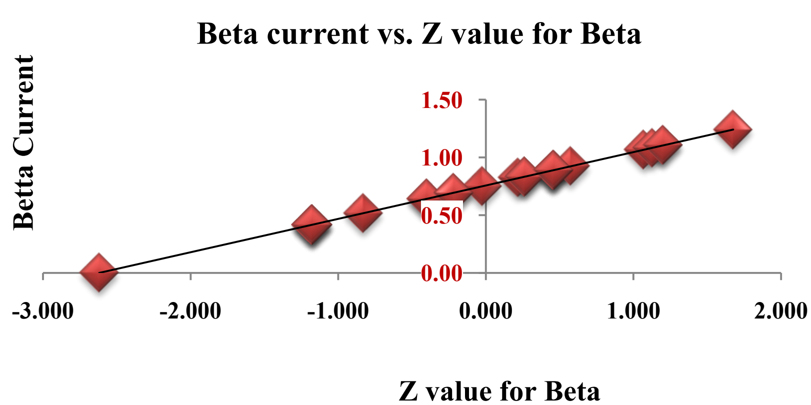
Table D.3 Summary of Outcomes form SDT and ROC

W	Age	Education	Experience	Normalized d'_{SDT}	Normalized d'_{ROC}	Sensitivity	β current	Decision Making
1	1	3	1	62.11	71	Moderate	0.89	R
2	3	2	2	47.83	46	Low	0.92	R
3	2	3	2	55.65	60	Low	0.82	R
4	2	2	1	56.96	57	Low	0.52	C
5	2	3	1	48.59	49	Low	1.10	R
6	2	1	3	83.70	67	High	0.00	C
7	2	2	1	46.09	44	Low	1.24	R
8	3	2	4	70.11	79	Moderate	0.42	C
9	2	4	3	56.52	58	Low	0.75	R
10	2	2	2	70.11	79	Moderate	0.42	C
11	4	3	1	52.93	54	Low	0.89	R
12	2	3	2	68.74	81	Moderate	0.83	R
13	4	1	4	65.65	81	Moderate	1.07	R
14	4	1	3	58.74	64	Low	0.64	C
15	3	2	3	62.07	71	Moderate	0.89	R
16	2	3	2	68.74	81	Moderate	0.83	R
17	4	4	5	62.07	71	Moderate	0.89	R
18	4	1	2	61.96	69	Moderate	0.64	C
19	2	2	2	70.11	79	Moderate	0.42	C
20	2	3	1	56.96	63	Low	1.08	R
21	2	3	2	48.91	49	Low	1.10	R
22	2	2	3	65.11	75	Moderate	0.69	C
23	3	2	3	70.00	79	Moderate	0.42	C
24	5	1	2	65.11	75	Moderate	0.69	C
Ave	3	2	2	61.45	67	Moderate	0.76	R
STV	1.06	0.96	1.12	9.01	12.12	NA	0.00	NA
COV	0.40	0.42	0.49	0.15	0.18	NA	0.00	NA

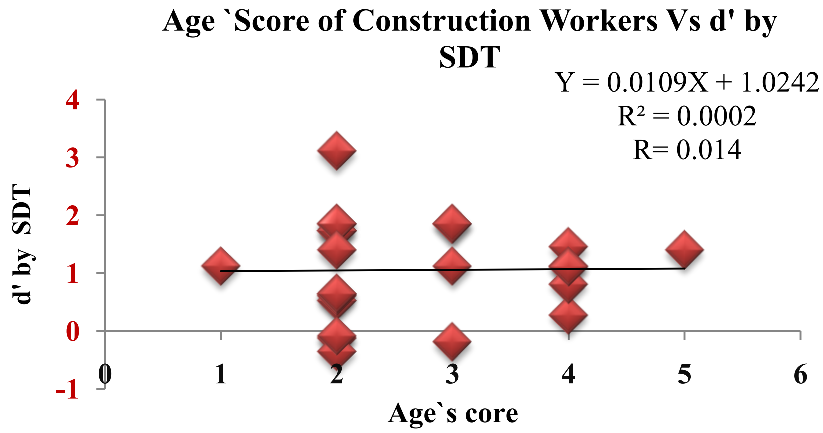
APPENDIX E
DISTRIBUTION OF d` AND βcurrent

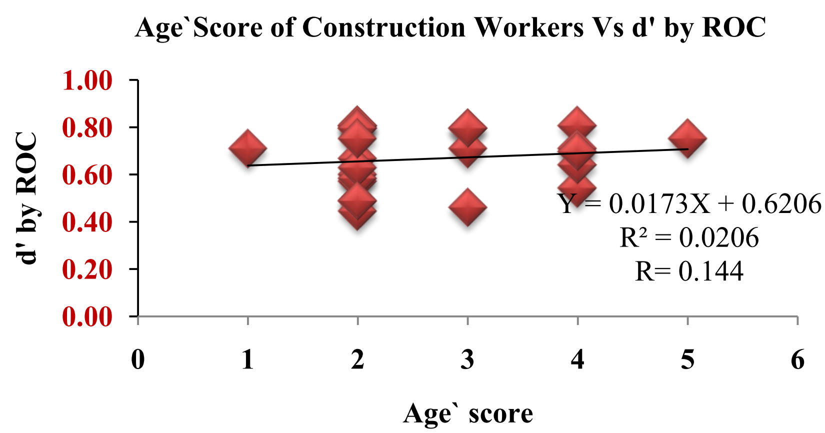

d' by SDT vs. Z value for SDT
d by Standard DST
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-2.000
-1.000
0.000
1.000
2.000
3.000
Z value for Standard SDT

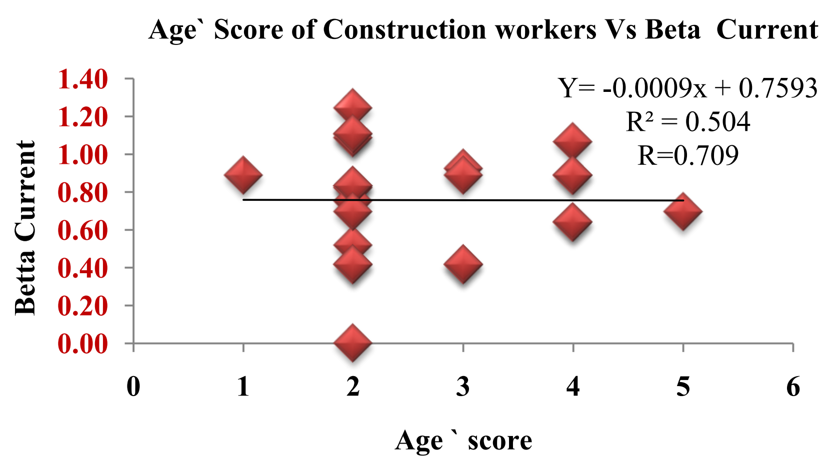

d' for ROC vs. Z value for d'
d by ROC
1.00
0.80
0.60
0.40
0.20
0.00
-2.000
-1.000
0.000
1.000
2.000
Z value for ROC

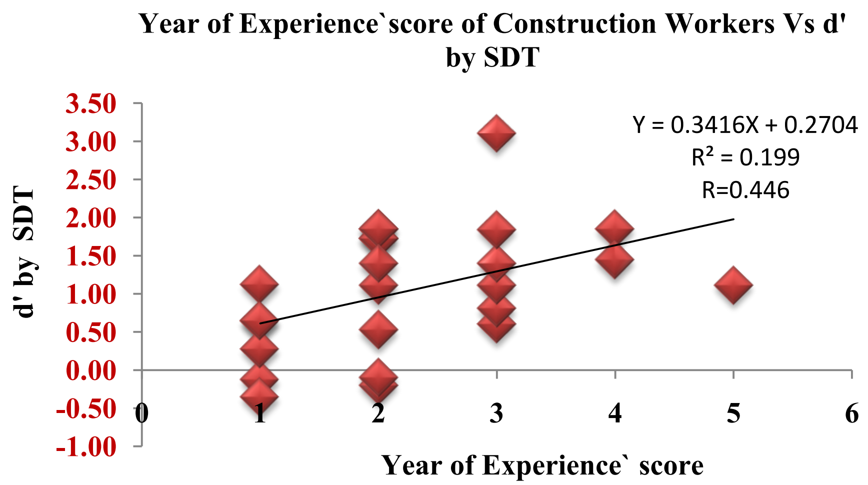

Beta current vs. Z value for Beta
Betta Current
1.50
1.00
0.50
0.00
-3.000
-2.000
-1.000
0.000
1.000
2.000
Z value for Beta

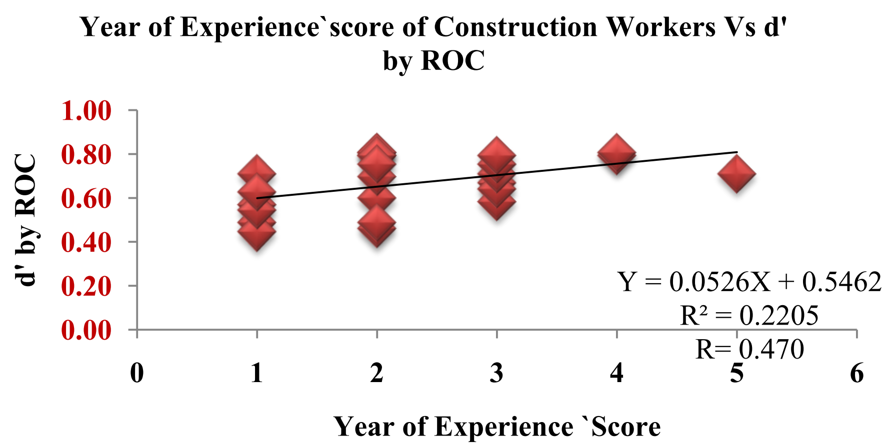
APPENDIX F
RESULTS OF REGRESSION ANALYSIS

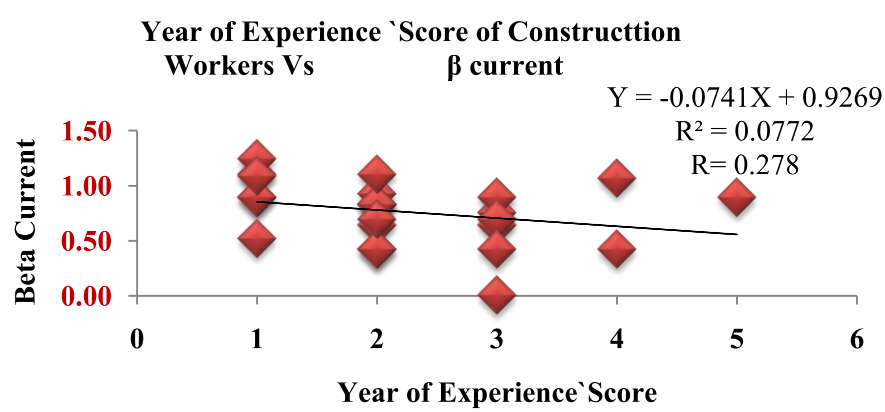

Age `Score of Construction Workers Vs d' by SDT
Y = 0.0109X + 1.0242
R² = 0.0002
R= 0.014
d' by SDT
4
3
2
1
0
-1
0
1
2
3
4
5
6
Age`s core

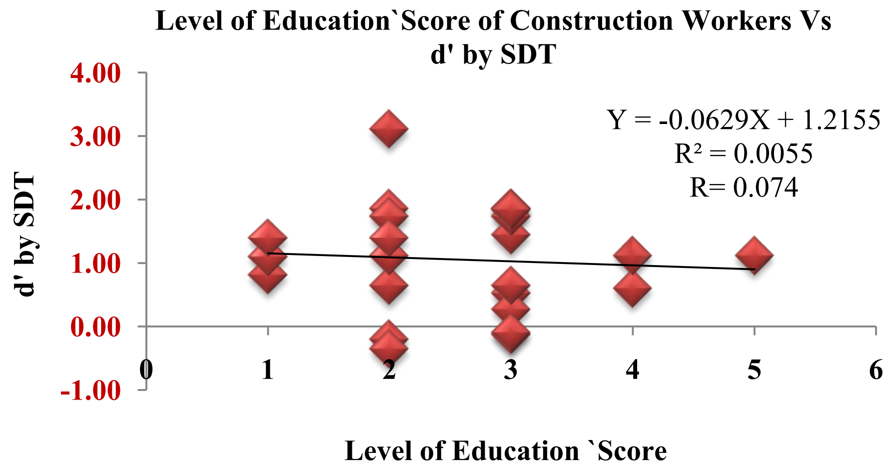

Age`Score of Construction Workers Vs d' by ROC
1.00
0.80
0.60
0.40
0.20
0.00
d' by ROC
Y = 0.0173X + 0.6206
R² = 0.0206
R= 0.144
0
1
2
3
4
5
6
Age` score

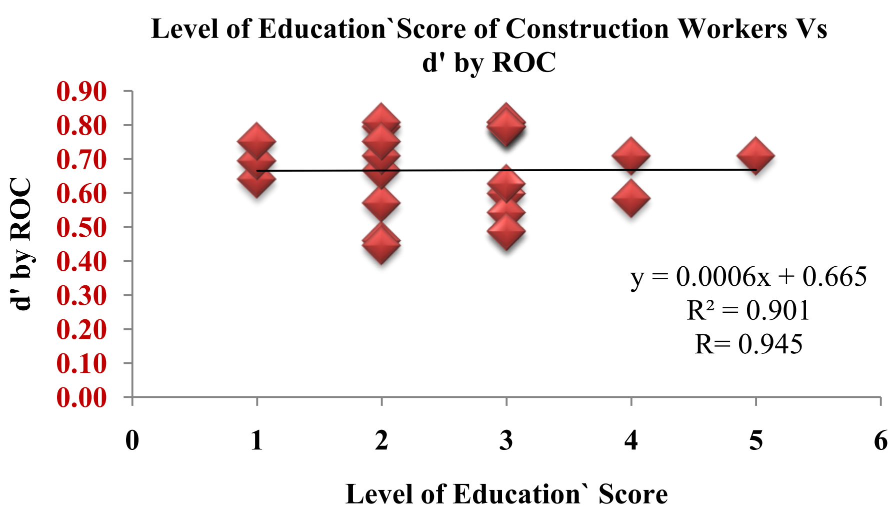

Age` Score of Construction workers Vs Beta Current
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Betta Current
Y= -0.0009x + 0.7593
R² = 0.504
R=0.709
0
1
2
3
4
5
6
Age ` score

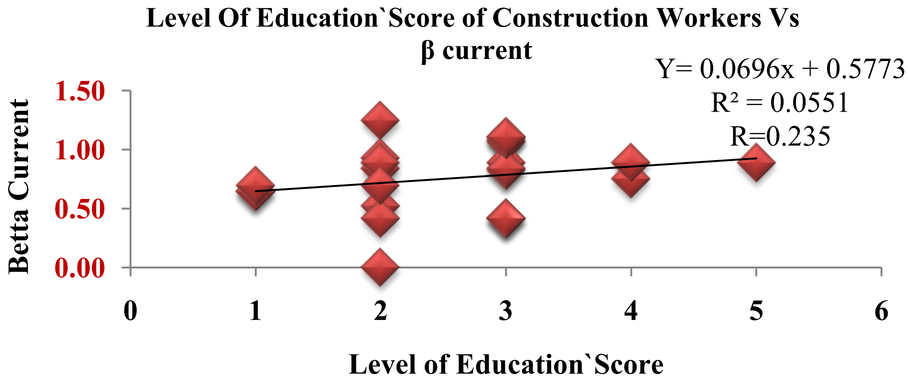

Year of Experience`score of Construction Workers Vs d' by SDT
Y = 0.3416X + 0.2704
R² = 0.199
R=0.446
d' by SDT
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
0
1
2
3
4
5
6
Year of Experience` score


Year of Experience`score of Construction Workers Vs d' by ROC
d' by ROC
1.00
0.80
0.60
0.40
0.20
0.00
Y = 0.0526X + 0.5462
R² = 0.2205
R= 0.470
0
1
2
3
4
5
6
Year of Experience `Score


Year of Experience `Score of Constructtion Workers Vs β current
Y = -0.0741X + 0.9269
R² = 0.0772
R= 0.278
Beta Current
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
Year of Experience`Score


Level of Education`Score of Construction Workers Vs
d' by SDT
d' by SDT
Y = -0.0629X + 1.2155
R² = 0.0055
R= 0.074
4.00
3.00
2.00
1.00
0.00
-1.00
0
1
2
3
4
5
6
Level of Education `Score


Level of Education`Score of Construction Workers Vs
d' by ROC
d' by ROC
y = 0.0006x + 0.665
R² = 0.901
R= 0.945
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
4
5
6
Level of Education` Score


Level Of Education`Score of Construction Workers Vs β current
Y= 0.0696x + 0.5773
R² = 0.0551
R=0.235
Betta Current
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
Level of Education`Score

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Hoda Alavi received her B.S. degree in Architecture from Shiraz University, Iran in 2006. In 2008, she came to the U.S.A for continuing her studies in Construction Engineering and Management area of Civil Engineering.

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