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# Exploratory study of construction safety culture through systems thinKing

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# EXPLORATORY STUDY OF CONSTRUCTION SAFETY CULTURE THROUGH SYSTEMS THINKING

by

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## ABSTRACT

**Exploratory Study of Construction Safety Culture Through Systems Thinking**

by

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Since its conception, in 1986 after the Chernobyl accident, the term "safety culture" has gained major popularity throughout many systems, especially the construction industry. Although this concept has gained much popularity over the course of two decades, it remains a heavily debated topic between advocates and skeptics for various reasons. Much of the skepticism is due to the failure of proponents of the concept to clearly define and provide an understanding of those factors that comprise what "safety culture" is, and how it can be achieved. A system (particularly a construction system) that possesses a safety culture is one in which safety is the first priority of all individuals involved from top-level management to those at the operational level including, but not limited to owners, architects, engineers, general contractors, subcontractors, vendors, workers, etc. Hence, construction safety culture is a top-down approach to achieving safety within systems.

System Dynamics, as defined by founder Jay Forrester, is the combination of theory, methods, and philosophy intended to analyze the behavior of systems in not only management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields. The objective of this thesis is to provide clarity to existing research and literature which defines construction safety culture, and explain how System Thinking/Dynamics is an effective tool for understanding and achieving a construction safety culture in a complex system. The program *Vensim* is used to construct a visual systems thinking model of causal loops that will ultimately provide a better understanding of construction safety culture. This model will illustrate the causal relationships between various safety-related variables as they pertain to the construction industry.

Keywords: Construction safety culture, systems thinking, safety

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To my mother, Paula Benford, thank you for giving me life, love, and the continuous motivation to seek what is above. And, Dr. David Shields for giving me the opportunity to take my career to the next level, and allowing me to "see the forest for the trees."

# CHAPTER 1

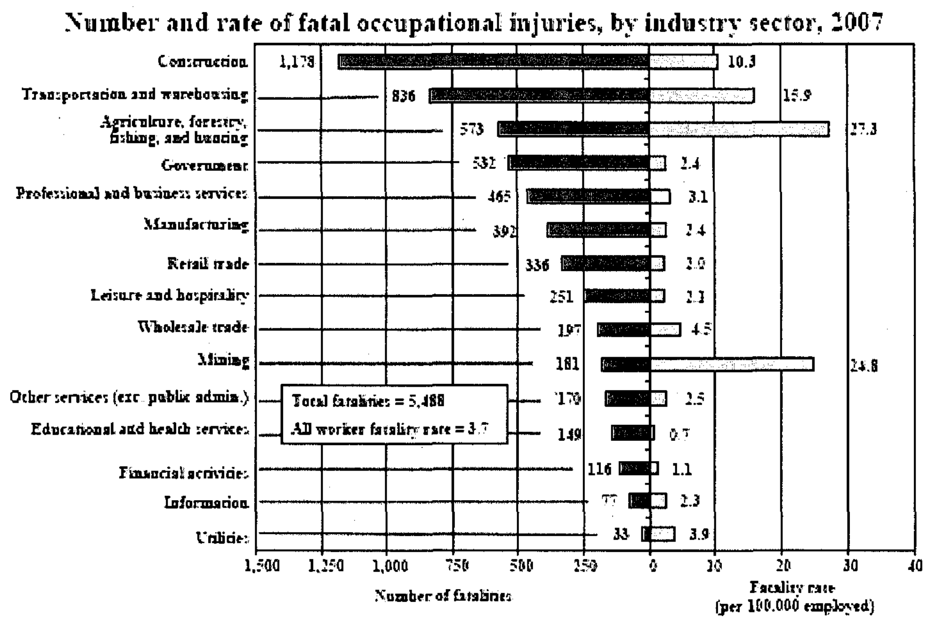
# INTRODUCTION

## 1.1 Background

It is difficult to comprehend that with all the technological advances that have been made in the industry, the number of accidents that occur in construction remains higher than those of any other industry. Accidents resulting in injury and fatality have always been a "black eye" for the construction industry. Of course, there has been some improvement in regards to safety in construction. There has been a slight decrease in the number of incidents reported over the past few years, but in comparison to other industries the numbers remain disturbing to researchers and safety professionals. Who is to blame for these safety mishaps? Much of the research that has been collected on construction safety concentrates on the number of accidents that have occurred in a certain time period, and then researchers, as well as policymakers, attempt to use these data to somehow achieve what "they" believe to be safety. At this point, the damage has been done. These data do provide valuable information; however, it is my belief that this approach does not achieve the ultimate goal, but only serves well as a numerical representation of a problem that has scarred this industry for much too long. Reactive measures are not the solution to achieving safety in complex systems. Safety cannot wait to be emphasized. It must be embedded and practiced at all times throughout the entire construction organization from the highest executive down to the operatives, and must be continuously observed, measured, and improved as required. "The only way of knowing if safety really exists is to measure it and as the saying goes—if you don't keep score you are only practicing" (Ahmad & Gibb, 2004). Construction safety must exist within an organization like a culture or a way of life. Culture generally refers to patterns of human activity and the symbolic structures that give such activities significance and importance. In a system, culture is the set of shared attitudes, values, goals, and practices that characterizes an institution or organization.

## 1.2 Why Study Construction Safety?

Construction is one of the largest industries in the United States. The U.S Bureau of Labor Statistics (2007) states that in 2006 there were 7.7 million wage and salary workers, and another 1.9 million self-employed individuals working in the construction industry. The number of workers in the construction industry continues to grow, but it is fair to say that safety awareness and zero-accident philosophy, unfortunately, has not experienced the same growth. Much of the industry's growth can be attributed to the financial gains that can be achieved in most sectors of construction. Despite the known dangers and health-related risks associated with construction work, individuals are attracted to the relatively high hourly earnings that can be attained in the field. In 2006, the average wage of a construction worker who did not hold a supervisory position was $20.02 an hour. You would think that an industry that has the ability to pay this type of money to its operatives would have the necessary finances to ensure a safe working environment, but it doesn't. The wage partly is a compensating differential for the danger; many insured contractors probably find self-insurance better than accident prevention. It is easy to blame the employers, but workers are just as much responsible for the accident rates that plague the industry. Safety seems to be no more of a priority of workers than it does employers. The problem is that the industry prioritizes production and profit, not safety. Historically, construction related fatalities have accounted for nearly 17-20% of all occupational related deaths (Hill, 2004). In 2006, the death rate for construction was 11.1 per 100,000 full-time workers, nearly three times the average rate of 4.2 per 100,000 full-time workers for all industries (CPWR, 2007). Figure 1 compares fatal occupational injuries for construction and other industries based on U.S Bureau of Labor Statistics data.




SOURCE: U.S. Bureau of Labor Statistics, U.S. Department of Labor, 2008

Figure 1. Number and rate of fatal occupational injuries by industry sector (CPWR, 2007).

This is the highest number reported by any other occupation. The Center for Construction Research and Training (formerly the Centers to Protect Workers' Rights), which is a non-profit organization created by the Building and Construction Trades Department of the AFL-CIO to perform research and training on construction safety, investigated the leading causes of death in the construction from 1992 through 2005 and their findings were as follows (in rank order): the highest ranking causes of work-related deaths were falls to a lower level, highway incidents (motor vehicle related crashes), being struck by falling objects, and contact with electric current (a subcategory of exposure to harmful substances or environments). The distribution of leading causes of death are shown in Figure 2.

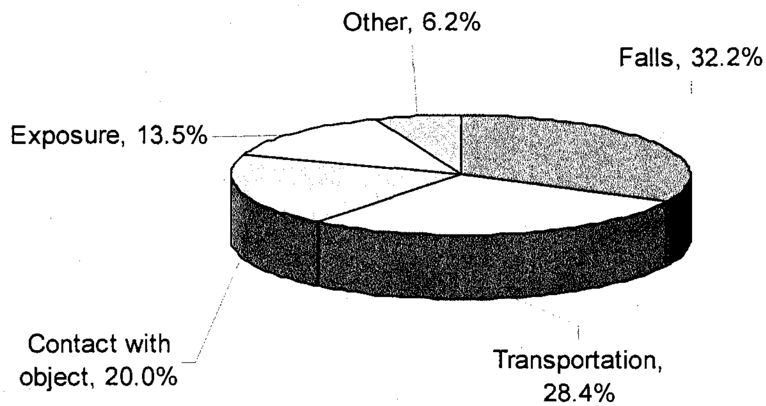



Figure 2. The distribution of leading causes of death from injuries in construction from 1992 to 2005 (CPWR, 2007).

The Center for Construction Research and Training (CPWR) (formerly the Center to Protect Workers' Rights), also provides a breakdown, by occupation, of work-related fatalities sustained in 2007. Figure 3 illustrates their findings.

| Occupation[1] | Fatalities | | Selected event or exposure[2] (percent of total for occupation) | | | |
|---|---|---|---|---|---|---|
| | Number | Percent | Highway[3] | Homicides | Falls | Struck by object |
| Total | 5,455 | 100 | 24 | 11 | 15 | 8 |
| **Management occupations** | 511 | 9 | 14 | 10 | 10 | 11 |
| Top executives | 29 | 1 | 14 | – | 10 | – |
| Operations specialties managers | 24 | (4) | 17 | 38 | – | – |
| Other management occupations | 445 | 8 | 12 | 5 | 10 | 12 |
| **Business and financial operations occupations** | 30 | 1 | 47 | 10 | – | – |
| **Computer and mathematical occupations** | 3 | (4) | – | – | – | – |
| **Architecture and engineering occupations** | 49 | 1 | 22 | 6 | 12 | – |
| Engineers | 28 | 1 | 25 | – | 11 | – |
| **Life, physical, and social science occupations** | 20 | (4) | 40 | – | 15 | 15 |
| **Community and social services occupations** | 28 | 1 | 54 | 25 | – | – |
| **Legal occupations** | 11 | (4) | – | 27 | – | – |
| **Education, training, and library occupations** | 21 | (4) | 19 | 33 | 19 | – |
| **Arts, design, entertainment, sports, and media occupations** | 51 | 1 | 22 | 16 | 14 | 10 |
| Entertainers and performers, sports and related workers | 29 | 1 | 21 | 10 | 10 | 17 |
| **Healthcare practitioners and technical occupations** | 65 | 1 | 34 | 5 | 9 | – |
| Health diagnosing and treating practitioners | 43 | 1 | 30 | – | 14 | – |
| Health technologists and technicians | 20 | (4) | 40 | – | – | – |
| **Healthcare support occupations** | 14 | (4) | 29 | 36 | – | – |
| **Protective service occupations** | 337 | 6 | 31 | 32 | 4 | 3 |
| Fire fighting and prevention workers | 50 | 1 | 36 | – | 6 | – |
| Law enforcement workers | 165 | 3 | 39 | 37 | 2 | 2 |
| Other protective service workers | 103 | 2 | 15 | 43 | 5 | 3 |
| **Food preparation and serving related occupations** | 81 | 1 | – | 79 | 7 | – |
| Supervisors, food preparation and serving workers | 24 | (4) | – | 83 | – | – |
| **Building and grounds cleaning and maintenance occupations** | 250 | 5 | 8 | 5 | 33 | 16 |
| Building cleaning and pest control workers | 62 | 1 | 10 | 16 | 52 | – |
| Grounds maintenance workers | 156 | 3 | 7 | – | 28 | 19 |
| **Personal care and service occupations** | 61 | 1 | 16 | 33 | 13 | 5 |
| **Sales and related occupations** | 311 | 6 | 17 | 54 | 9 | 2 |
| Supervisors, sales workers | 146 | 3 | 14 | 63 | 6 | 3 |
| Retail sales workers | 94 | 2 | 6 | 68 | 11 | – |
| Sales representatives, services | 14 | (4) | 64 | 29 | – | – |
| Sales representatives, wholesale and manufacturing | 26 | (4) | 58 | – | 12 | – |
| **Office and administrative support occupations** | 132 | 2 | 31 | 24 | 14 | 8 |
| Material recording, scheduling, dispatching, and distributing workers | 63 | 1 | 38 | 16 | 14 | 8 |
| **Farming, fishing, and forestry occupations** | 256 | 5 | 9 | 1 | 5 | 29 |
| Agricultural workers | 123 | 2 | 15 | 2 | 7 | 8 |
| Fishing and hunting workers | 39 | 1 | – | – | – | – |
| Forest, conservation, and logging workers | 78 | 1 | 4 | – | 4 | 78 |
| **Construction and extraction occupations** | 1,152 | 21 | 11 | 1 | 36 | 10 |
| Supervisors, construction and extraction workers | 115 | 2 | 15 | 6 | 29 | 6 |
| Construction trades workers | 877 | 16 | 8 | 1 | 40 | 9 |
| Extraction workers | 102 | 2 | 22 | – | 5 | 19 |
| **Installation, maintenance, and repair occupations** | 373 | 7 | 14 | 5 | 21 | 15 |
| Vehicle and mobile equipment mechanics, installers, and repairers | 118 | 2 | 9 | 6 | 9 | 29 |
| Other installation, maintenance, and repair occupations | 214 | 4 | 13 | 3 | 25 | 9 |
| **Production occupations** | 264 | 5 | 7 | 5 | 11 | 15 |
| Supervisors, production workers | 30 | 1 | – | 13 | 13 | – |
| Metal workers and plastic workers | 86 | 2 | – | 3 | 13 | 20 |
| **Transportation and material moving occupations** | 1,423 | 26 | 49 | 6 | 4 | 6 |
| Air transportation workers | 92 | 1 | – | – | – | – |
| Motor vehicle operators | 1,020 | 19 | 68 | 7 | 3 | 5 |
| Water transportation workers | 34 | 1 | – | – | – | 12 |
| Material moving workers | 255 | 5 | 10 | 2 | 13 | 15 |
| **Military occupations** | 62 | 1 | 11 | – | – | 6 |

[1] Based on the 2000 Standard Occupational Classification system.
[2] *The figure shown is the percent of the total fatalities for that occupation group.*
[3] 'Highway' includes deaths to vehicle occupants resulting from traffic incidents that occur on the public roadway, shoulder, or surrounding area. It excludes incidents occurring entirely off the roadway, such as in parking lots and on farms; incidents involving trains; and deaths to pedestrians or other non passengers.
[4] Less than or equal to 0.5 percent.

NOTE: Totals for 2007 are preliminary. Totals for major categories may include subcategories not shown separately. Percentages may not add to totals because of rounding. Dashes indicate no data reported or data that do not meet publication criteria.

There were 3 fatalities for which there was insufficient information to determine a specific occupation classification.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, in cooperation with State, New York City, District of Columbia, and Federal agencies, Census of Fatal Occupational Injuries.

Figure 3. Fatal occupational injuries by occupation and selected event of exposure, (CPWR, 2007)

It is important to note that these figures represent just the fatalities that have occurred in the construction industry. The numbers for injuries sustained in the construction field present an even more alarming representation of the safety concerns in the industry. Thus, one of the most important reasons for research in this area of study is that safety typically has an effect on every aspect or phase of any complex system or organization. In the construction industry, safety impacts design and planning, bidding, scheduling, construction, costs, overhead, etc. Safety impacts productivity, efficiency, and constructability. There is no operation or system that may exist without taking safety into consideration, and its due attention is critical to the functioning of all systems.

Safety is one of those topics that is frequently taken for granted. It is often assumed that some other individual has been given the responsibility of taking safety into consideration at any given point of a construction process. For example, it is often assumed that the architect has taken into consideration the possible hazards that may occur as a result of the complexity of his/her design. It is assumed that safety personnel are performing "walk-arounds" to recognize potential hazards. It is important for safety to exist not only as a priority in the construction industry, but as a culture just as the concepts of productivity and profitability exist in the industry. The objectives of this research thesis are: (1) define construction safety culture in its' entirety from conception to present day, (2) effectively explain the discipline of systems thinking and contributing factors such as modeling and simulation, and (3) explain how systems thinking is an effective tool for building a construction safety culture. Finally, this research will demonstrate that if organizations (including all levels) adopt and remain committed to the system thinking approach to construction safety culture the industry's ultimate goal of reducing injuries and fatalities at construction sites can and will be accomplished.

## 1.3 Costs of Accidents in the Construction Industry

Although their approaches to safety are reactive in nature, many organizations are finally emphasizing the prioritization of safety culture within their systems because of the extreme financial burdens of accidents and injuries. In fact, the cost of accidents is frequently cited by organizations as a major motivation for addressing health and safety (Hinze, 1996). This fact is unfortunate, but very true. It makes the assumption that if it would not be for the extremely high costs of construction accidents, then organizations would not place an emphasis on safety. There are two types of costs related to construction accidents: direct cost and indirect costs. Direct costs are those costs incurred directly as a result of medical costs and loss of wages from injuries. Indirect costs are all other costs incurred as a result of an accident such as: fines, lawsuits, damaged equipment, production delays, etc. In a study performed by Tang et al. (1997) many of the financial costs as a result of accidents were identified including:

- Loss due to the injured worker.
    - The compensation paid to the worker by the contractor is two-thirds of the wage of the injured person for each day of absence from work.
    - Disability compensation, which depends on the percentage of disability that the injured worker suffers.
- Loss due to the inefficiency of the worker who has just recovered from injury upon resuming work.

- When an injured person returns to work, he or she cannot initially work with 100% efficiency.

- Loss due to medical expenses.
  - Medical expenses of the injured worker, including the cost of transport to the hospital.
- Loss due to fines and legal expenses.
  - If the contractor faces prosecution, he may have to pay damages and fines imposed by the court.
- Loss of productivity of other employees.
  - The safety officer, site workers, project engineer, and foremen may be involved in assisting the injured and carrying out works related to the accident such as accident investigation and report writing.
  - Other workers may have to stop immediately after the occurrence of the Accident.
- Loss due to damaged equipment.
- Loss due to damaged material or finished work.
- Loss due to idle machinery or equipment.
  - After an accident has occurred, the workers may stop work temporarily and hence there will be idle machinery or equipment.

According to the CPWR, the total costs of fatal and nonfatal injures in the construction industry is estimated at nearly $13 billion annually (CPWR, 2007). Construction workers experienced 414,900 injury and illness cases in 2005, of which 157,100 cases were serious enough to require days away from work – lost workday cases

–about 628 per workday. Illnesses are less than 2.5% of the total in construction, so the numbers for construction essentially show injuries. Compared with other industries, the construction industry had the second highest rate of 239.5 per 10,000 full-time workers in 2005 (manufacturing industry has the highest rate), about 76% higher than the average rate of 135.7 per 10,000 full-time workers for all private industries. Overall, the rate of work-related deaths in construction declined gradually from 14.3 to 11.1 per 100,000 full-time workers from 1992 to 2005, while the rate of serious nonfatal injuries and illnesses dropped significantly by 55% from 529.5 to 239.5 per 10,000 full-time workers during this period. The rates of work-related deaths in construction are not as high as in agriculture and mining, but the rates of nonfatal injuries and illnesses in construction exceeded that for other goods-producing industries over time. Deaths are estimated to be 40% of the total, and nonfatal injuries and illnesses represent the other 60% of the total costs. Their research states that the death of a construction work on a project results in a valued loss of $4 million, while nonfatal injuries usually average about $42,000 per occurrence. These estimates include direct and indirect costs, and quality-of-life costs. Construction laborers and carpenters ranked the highest in cost for both nonfatal and fatal injuries, and the top five construction industries, which accounted for over half of the fatal and nonfatal injury costs included: miscellaneous specialty trade contractors; plumbing, heating, and air conditioning; electrical work; heavy construction except highway; and residential building construction (CPWR, 2007). Figures 4 through 6 represent their findings.

Fig.4 **Estimated costs of work-related injuries, by construction industry (Wage-and-salary employment)**

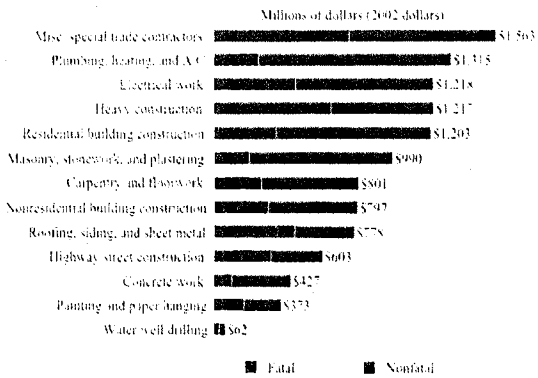



Fig.5 **Estimated costs of work-related injuries, selected construction occupations (All types of employment)**

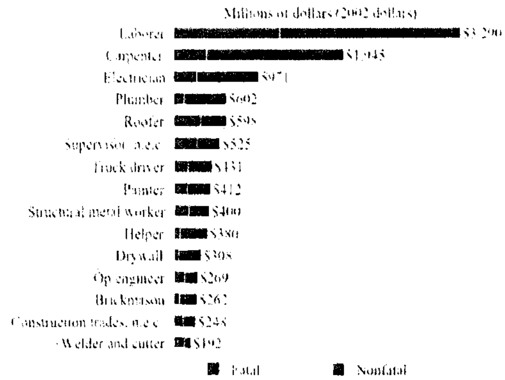
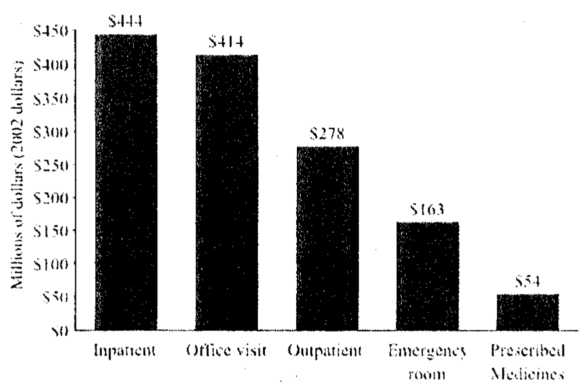



Fig.6 **Medical costs for work-related injuries in construction, by type of health services (All types of employment)**




Figures 4, 5, & 6. Estimated costs of work-related injuries by construction industry, by selected construction occupation, and by type of health service received (CPWR, 2007).

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Defining Construction Safety Culture

The term 'safety culture' first made its appearance in the 1987 Organization for Economic Co-operation and Development (OECD) Nuclear agency report on the 1986 Chernobyl disaster (Mohamed, 2003). On April 26, 1986 two explosions blew off the 1000 ton cap sealing the Chernobyl 4 reactor releasing molten core fragments into the vicinity. It was the worst accident in the history of commercial nuclear power generation costing more than 30 lives, contaminating over 400 square miles and increased the number of cancer related deaths in Western Europe (Reason, 1990). Since its birth the philosophy has gained much popularity throughout many systems, especially within the construction industry, that view safety as their first priority. The Chernobyl report stated that it was a "poor safety culture" that caused this catastrophe. There are many factors which contribute to a "good" construction safety culture. Since safety culture is such a broad concept it has been met with much criticism which generally stems from the various definitions that lack precision. Some critics of the safety culture paradigm consider it to be a fad (Woolfson, 1999), and others refer to it as a 'catch-all' for human factors issues and concept without substance (Cox and Flin, 1998). Also, the failure of researchers to establish means of quantifying the concept of construction safety culture has led negativist to bash its existence. System dynamics which will be addressed later will dispute the quantification issue. Admittedly, there are various definitions of construction safety culture that has led to skepticism, but it is a concept that can exist within organizations. Many critics negate safety culture because it is not a "one size fits all" approach to safety for all organizations. This does not mean that a safety culture cannot be created; however, it does indicate that safety culture can be achieved in various ways and the means of accomplishing is unique between systems. Hence, in regards to safety programs, what works for one organization may not work for others. Zhang et al. (2002) states that safety culture is comprised of the following factors:

- Safety culture is a concept defined at group level or higher, which refers to the *shared values* among all the group or organization members.
- Safety culture is concerned with formal safety issues in an organization, and closely related to, but not restricted to, the management and supervisory systems.
- Safety culture emphasizes the contribution from everyone at every level of an organization.
- The safety culture of an organization has an impact on its members' behavior at work.
- Safety culture is usually reflected in the contingency between reward system and safety performance.
- Safety culture is reflected in an organization's willingness to develop and learn from errors, incidents, and accidents.
- Safety culture is relatively enduring, stable and resistant to change.

The Advisory Committee on the Safety of Nuclear Installations (ACSNI, 1993) produced one of the most quoted definitions of safety culture to date. ACSNI defines safety culture as the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the proficiency of, an organization's health and safety management. What makes construction safety culture unique from all other approaches to reducing accidents is that it takes a top-down approach to achieving safety within systems. "The safety culture paradigm constitutes a holistic way of thinking about health and safety risk management to reveal underlying factors affecting safety performance in complex systems" (Peckitt et. al, 2004). This means that safety should not be the sole responsibility of individuals at the operational level; it should be the priority of all parties involved including the client, architects, designers, subcontractors, vendors, etc. (Baxendale and Jones, 2003). The top-down approach includes observable measures such as management commitment, participation and accountability, procedures and policies, communication, etc (Mohamed, 2004).

As expressed in this thesis, the factor of management's commitment to the construction safety culture is the most important factor necessary for its existence. There is much research that identifies management's lack of commitment to safety as one of the key factors contributing to construction accidents. Management is the key that allows safety performance improvements to occur in organizations (Freda et. al, 1999). Management must also establish and maintain a functional reporting and measurement systems. Without a reporting system, there is no way to measure and assess the state of the system's safety. The objective of the reporting system is to not only monitor accident rates, but to identify accident causes and risk exposures, monitor the effect of site safety initiatives, and to estimate the costs of accidents (Rowlinson, 2004). A safety reporting system is another activity that requires continuous, active participation of all members within an organization from top level management to the operational level. Ahmad and Gibb (2004) state that measurement will enable comparison, benchmark performance, and track progress over time. System dynamics will provide a means for all factors associated with construction safety culture to be measured over time to reveal valuable information about the status of an organization's safety program.

## 2.2 Systems Thinking and System Dynamics

Systems thinking can be as a concept or idea, as an approach or study, or as a tool to create a better understanding. The objective of systems thinking is very "cut and dry"--to provide a clear understanding to complex, real world problems and situations by examining systems holistically. Systems thinking, as defined by Sherwood (2002), is the study of the connectedness between those systems' component parts whether they be human beings, departments, or indeed businesses and organizations, as a whole. "Systems thinking is a powerful approach for understanding the nature of why situations are the way they are, and how to go about improving results" (Bellinger, 2004). Systems thinking is not an easy approach because it involves a significant amount of time, effort, and thought. Creating causal loop diagrams is the foundation upon which systems thinking is built. "Causal loop diagrams provide a language for articulating our understanding of the dynamic, interconnected nature of our world" (Kim, 1994). The causal loop diagrams provide researchers with a visual or mental model of factors that may be occurring in a complex system or organization. What makes systems thinking ideal is that it addresses problems events, etc. that occur in a system in a holistic approach. As humans, when solving problems it is part of our instinctual abilities to dissect problems into smaller subparts in an attempt to gain insight and understanding of that system. However, when we do this we often solve problems that are unassociated with the initial one that we wanted to solve or miss our goals altogether. There are many reasons for using the systems thinking approach to studying complex systems as described by Belinger (2004):

- Often previous fixes seem to overshoot the goal
- Previous fixes has created problems elsewhere
- After a fix is applied the problem returns in time
- The same fixes are usually repeated
- There is a tendency to allow an established standard to slip

Once the causal loop diagrams have been constructed into mental models of all that is occurring in the system the variable can be given mathematical computations to perform system dynamics modeling and simulation.

Jay Forrester, founder of system dynamics, defines it as the combination of theory, methods, and philosophy that is needed to analyze the behavior of systems in not only management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields. System dynamics takes the concepts from causal or feedback loops and organizes the information into computer simulated models. Examples of these feedback or causal loops are in the appendix of this paper. The first articles based on system dynamics appeared in the Harvard Business Review (Forrester, 1958). These computer simulations anticipate the behavior and actions of a system and provide researchers with valuable information of how certain situations would occur given the presence of certain behaviors, variables, stimuli, etc. Regardless of the type or format of the simulation, the overriding purpose for simulating systems remains: to provide a learning environment that supports the learner to develop mental models about the interrelationships of variables; to test the efficacy of these models in explaining or predicting events in a system; and to discover relationships among variables and/or confronting misconceptions (Milrad, 2002). The concept of system dynamics implies that individuals within a system do not make decisions or actions solely on their own; their decisions are motivated and driven by other factors within the system. In laymen's terms "every action causes a reaction." The discipline is known for its' representation of causal loops for the behavior. Forrester (1991) states that "we live in an on-going circular environment in which each action is based on current conditions, such actions affect conditions, and the changed condition becomes the basis for future action; there is no beginning or end to the process." As for construction which will be addressed later in the paper, system dynamics will not only examine individual causes of why a safety error occurred, but most importantly why the system failed. The system dynamics approach will illustrate how the actual error may have begun as far as the top level management within the system. For example, a single accident although it may be linked to human error may have ultimately been caused by the management's lack of commitment to safety or training. "System dynamics models organize, clarify, and unify knowledge that have previously caused confusion within a system and changes the way people think about that system by building on the reliable part of our understanding and compensating for the unreliable part" (Forrester, 1991).

## 2.3 Achieving a Safety Culture Using System Dynamics

The outrageous number of accidents in the construction industry has led many researchers to develop new measures to combat this problem. Researchers believed that prior methods of measuring accidents after they occurred and then implementing safety regulations and guidelines (a reactive approach) only achieved temporary success as far as safety was concerned. In response, researchers and construction safety culture advocates have begun using system dynamics, which involves modeling and simulation, to create safety management systems that will yield greater success. "The safety system label term encompasses all aspects of the organization's safety management system including safety policies, procedures, committees, etc. and provides a systematic process for planning, implementing, monitoring, and reviewing safety performance" (Choudhury et al., 2007). Figure 7 presents a representation of Choudhury et al. (2007) elements of the safety system model.

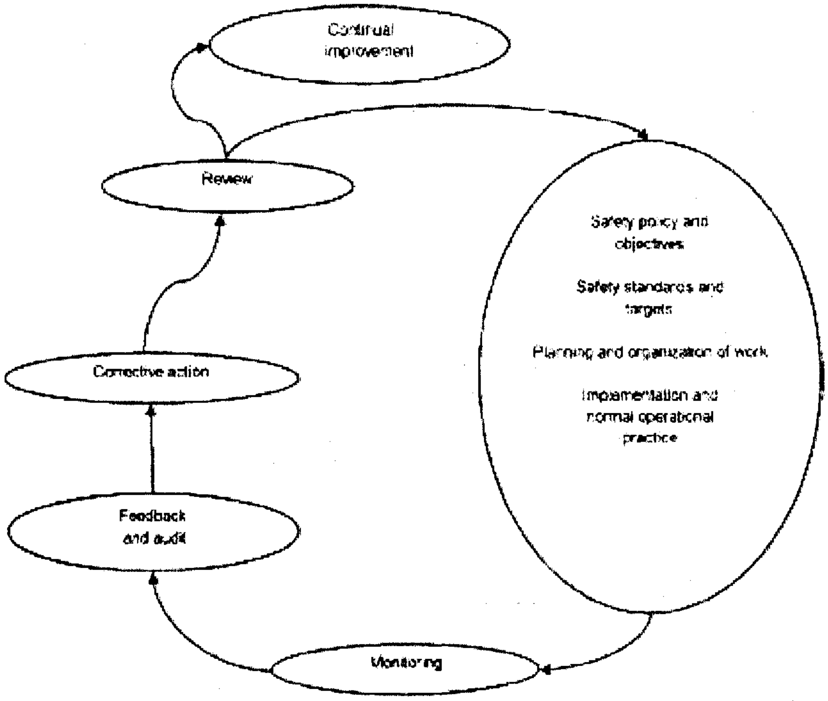



Figure 7. Basic elements of safety management system model (Choudhury et al., 2007)

Mohamed (2004) states that the fundamental principle on which safety management systems are based is that all project participants (clients, architects, designers, subcontractors, etc.) who contribute to safety on a project must be included in considering safety issues systematically, stage by stage, from the outset of the project. His research model emphasizes the top-down approach to addressing safety in organizations. Systems thinking/dynamics is compatible with safety culture for one main reason: the top-down approach of safety culture implies that all levels or aspects of a system will be incorporated into the problem solving technique and this holistic approach is shared with systems thinking and systems dynamics. Figure 8 presents this top-down approach to safety.

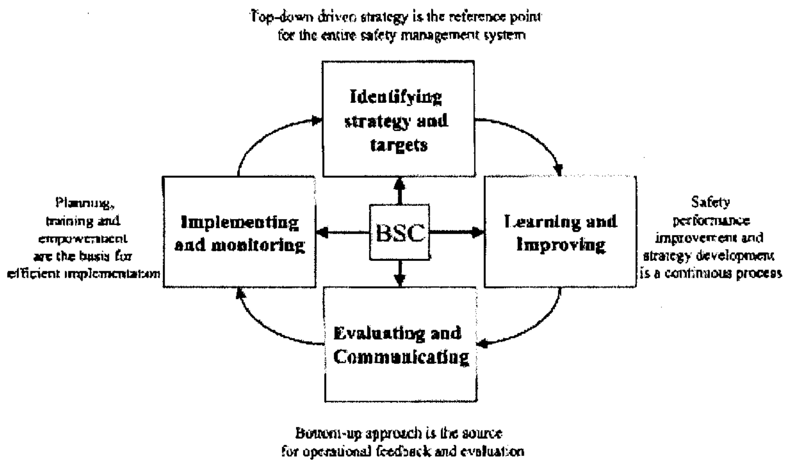



Figure 8. Safety management system for strategic and operational implementation (Mohamed, 2004)

System dynamics appears to be an appropriate methodology for demonstrating safety culture through mental modeling in the construction industry, as well as any occupation. For example, system dynamics was used to determine the cause of the Chernobyl accident that was mentioned in the introduction. In the study by Salge and Milling (2006), two stages of human failure were investigated by two separate system dynamics models including (1) the design of the reactor and (2) on-line operations. The system dynamics analyses indicate that the accident was caused by the combination of the specific reactor characteristics and infringements on safety rules which had previously not caused accidents, but led to more violations of safety rules and ultimately caused the Chernobyl accident (Salge and Miller, 2006). Reason (1990) suggests that "systems accidents have their primary origins in latent failures committed by designers and other high-level decision makers which typically become apparent due to certain unsafe acts committed by operators." Dulac et. al (2005) states that "while reduction in safety efforts and lower prioritization of safety concerns may lead to accidents, accidents usually do not occur for a considerable time period (years) so false confidence is created that the reductions are having no impact on safety and therefore pressures increase to reduce safety efforts and priority even further as the external performance pressures mount." An example of these latent failures in the construction industry may be the impact of productivity pressure by upper management on the workers of a project.

When pressure is placed on employees to achieve higher production rates, workers tend to neglect certain measures, generally safety, in an effort to cut time during certain activities. For example the fall of worker as a result of his/her failure to "tie-off," of course, at the individual level is viewed as human error, but system dynamics provides deeper understanding of how multiple variables such as management's lack of commitment to regulation enforcement may have contributed to the fall. Again, system dynamics uses a top-down approach to analyzing safety.

In developing system dynamics modeling for construction safety, literature covering research on the 1986 space shuttle Challenger incident was also examined. In one study, Cooke and Rohleder (2006) developed an organizational response system called incident learning in which normal precursor incidents are used in a learning process to combat complacency and avoid larger disasters such as the Challenger incident. Their system dynamics model, presented in Figure 9, provided valuable, latent information to the causes of the Challenger incident.

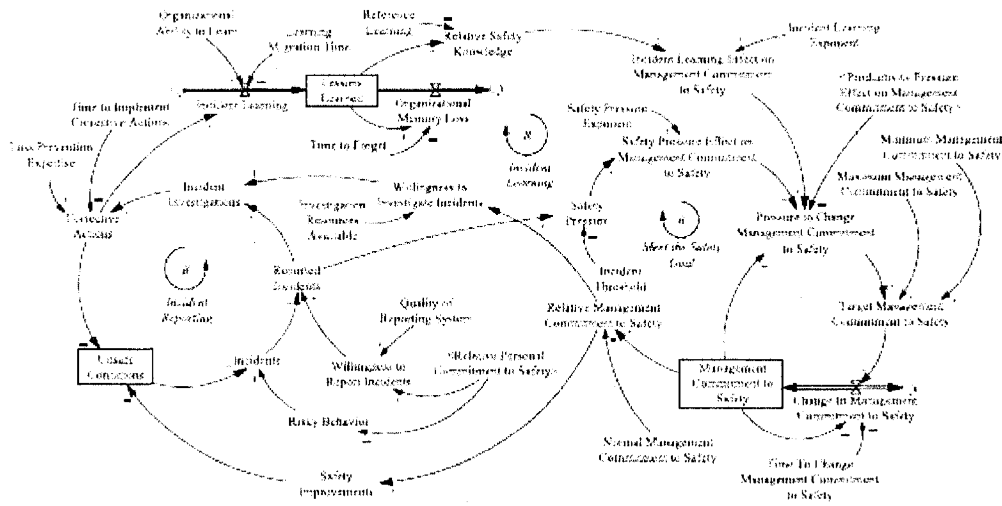


Figure 9. Systems thinking model of the incident learning system (Cooke and Rohleder, 2006)

The goal of their model was to motivate managers to implement learning systems that will achieve more reliable safety performance. Using system dynamics in the shuttle disaster cited the ultimate cause to be “the inability of the organization involved to effectively synthesize and share the information from separate precursor incidents with the relevant people across the organization so that appropriate action could be taken to reduce the risk of disaster” ( Cooke and Rohdeler, 2006). The incident learning system constructed by Cooke and Rohdeler allows for the reporting, recording, and communication of information involving minor incidents to improve safety performance over time which will, in turn, prevent major disasters. Similar research incorporating system dynamics to accident causation was used in the Westray mining disaster by Cooke (2003). In this model, such factors as management commitment to safety, worker training, and productivity revealed valuable information on what contributed to the disaster. This model is presented in Figure 10.

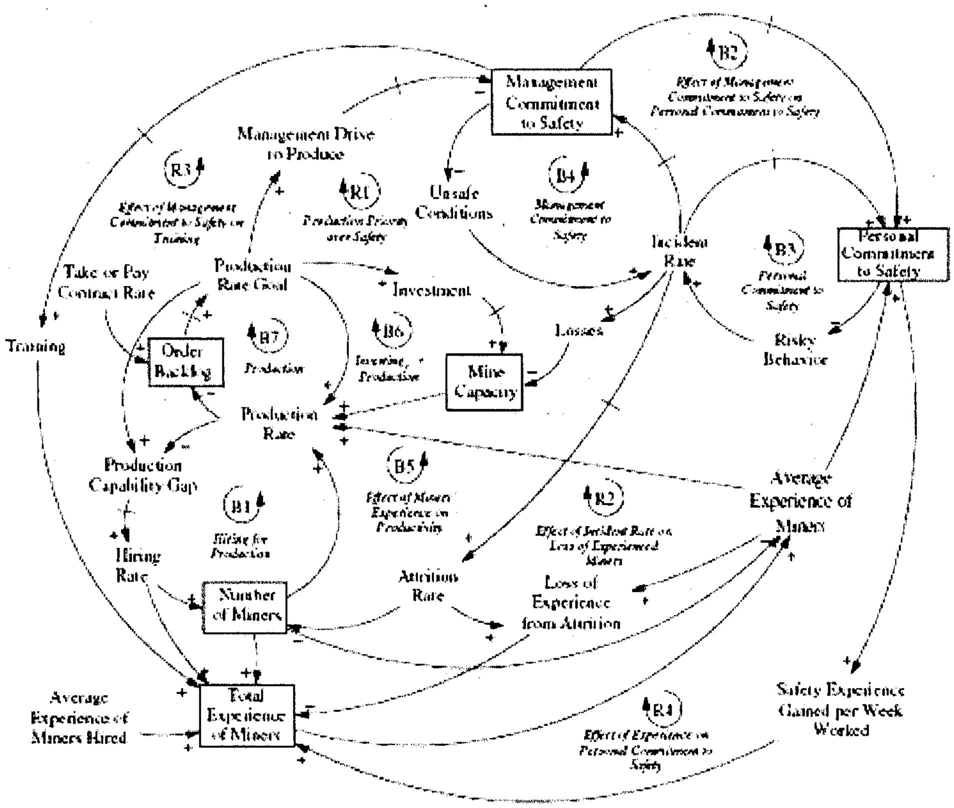



Figure 10. Systems thinking model of the Westray mine disaster (Cooke, 2003)

Other research which incorporates system dynamics with construction safety focuses on construction accident causation. This literature focuses on "how the characteristics of the production system generate hazardous situations and shape the work behaviors and analyzes the conditions that trigger the release of the hazards. The model identifies the need for two accident prevention strategies: (1) reliable production planning to reduce task unpredictability, and( 2) error management to increase worker's ability to avoid error" (Mitropoulos et al., 2005). There have been various models constructed on safety which have identified various factors and causes contributing to accidents. McClay (1989) presented his "universal framework" which identified hazards, human actions, and functional limitations to be the key elements of accidents. Hinze's distraction theory cited that the distraction of workers from hazards and potential accidents was due to production pressures (Hinze, 1996). Management deficiencies, training, and workers attitudes were identified as key elements in accidents in Abdelhamid and Everett (2000). There is research as early as Levitt (1975) which targets top management's attitude (or lack thereof) toward safety as an underlying factor in accident causation. Toole (2002) identified various root causes of accidents: lack of proper training, safety equipment not provided, deficient enforcement of safety, unsafe equipment, method, or condition, poor safety attitude, and isolated deviation from prescribed behavior. It is evident that there has been much research performed on modeling construction safety. One downfall of some, not all, systems approaches to construction safety is that they only focus on reducing the risks, but fail to increase the safety effort (Mitropoulus et al., 2005). "Safety efforts to control workers' behaviors reduce exposures to hazards" (Mitroupolus et al., 2005). This research thesis will construct a systems thinking model that will incorporate various factors required to achieve a safety culture in the construction industry.

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Variable Identification

As previously stated, the concept of construction safety culture has gained popularity over the course of two decades since the Chernobyl disaster. However, the concept remains at the center of debates because of the failure of many advocates to provide an explicit understanding of what it actually is and how this "culture" may be achieved. One tool that has shed light on this issue is the application of systems thinking to construction safety culture. Systems thinking investigates complex problems by determining causal relationships between a system's factors. It is the ultimate goal of this thesis to demonstrate the usefulness of systems thinking as a tool in hopes that organizations will use the systems thinking approach to establish or re-establish a safety culture within their system.

## 3.2 Management Commitment

The first step in the application of the systems thinking approach to construction safety culture is variable identification. This step involves indentifying and defining those variables or factors that are most valuable to the existence of a safety culture. Identifying all relevant factors is the prerequisite to construction of the system model. As mentioned before, construction safety culture is a top-down approach to achieving safety within the system. Therefore, our analysis must focus on what is believed to be the most important factor in safety culture—management's commitment to safety.

Management's commitment to safety is the most important factor necessary to achieving a safety culture. Most research performed on safety has identified management's lack of commitment to safety as the root cause of accidents in various industries, specifically construction. In system dynamics modeling, management commitment can be measured as the level of commitment of management, as perceived by workers, to the safety program or safety culture of their organization. This information may be obtained by administering surveys, questionnaires, or interviews. The individuals being interviewed will be asked to rate using the Likert scale (1-5 with 5 being the highest) management's level of commitment to safety in the organization. It cannot be expected of individuals at the operative level to keep safety as their first priority if management has a lax commitment to it. Management is the key that allows safety performance improvements to occur in organizations (Freda et al., 1999). Safety is a social construct which means that the behaviors and attitudes that individuals develop towards it is learned and/or influenced by others in the environment. Therefore, "health and safety management is primarily dependent upon the occupational risk-related attitudes and behaviors of directors, managers, and workers who are part of the organization and wider society (Peckitt et al., 2004). Management's involvement in safety must go beyond constructing a set of rules and policies for individuals to follow at their own discretion. Management's commitment to construction safety culture cannot be overemphasized—the existence of this factor in the systems thinking application is crucial to the overall success of the model. Therefore, one can conclude that commitment is a prerequisite to creating and sustaining a positive safety culture in construction site environments (Mohamed, 2004). The systems thinking application to construction safety culture requires that all individuals that make up a system change the way they view safety in that environment. Change in any environment or situation is typically difficult to accomplish. For whatever reasons, people often resist change because they have grown accustomed to performing in a manner that is routine. Often, it is hilarious to see or hear construction organizations preach safety as their first priority, but begin toolbox meetings discussing increased productivity, cost control, etc. It may be difficult for an organization which has previously prioritized profit and production to make a shift to safety as the central focus. However, when upper management 'buys in' to these changes, it ensures success (Petersen, 1998). The degree to which upper level management becomes involved in the safety culture of the organization is directly proportional to the ultimate success. Diamond (1998) states that organizational change demands executive commitment and investment that is cognitive, emotional, and financial. The shift to a construction safety culture requires that managers and supervisors "set the tone" by leading by the examples they set forth. Freda et al. (1999) states, "major change is impossible unless the upper management of construction firms actively and demonstrably supports and understands the needs for the changes they introduce." The requisite changes to achieve a construction safety culture must not only include a commitment that is cognitive, emotional, and financial as suggested by Diamond (1998), but it must also include a commitment that is recognizable by all individuals within that system.

## 3.3 Training

Another main factor that is detrimental to the existence and maintenance of construction safety culture is a thorough safety training program. Rowlinson (2004) identifies three basic types of training required including: (1) induction training which focuses on the worker that is new to the construction site and introduces basic safety awareness; (2) refresher training which is aimed at those workers who have been in the construction business for a length of time and introduces them to the current and innovative methods and practices; and (3) ongoing training which addresses the need for continuous training and education on various safety procedures. In system dynamics modeling, training can be measured as the total amount of hours per year an organization requires training for their employees, including: induction training, refresher training, and ongoing training. Many construction accidents occur because workers lack adequate safety training—this means that they are either unknowledgeable or incompetent on the current safe practices and/or lack the ability to recognize potential hazards before they occur. "Formal safety training has proven to be the most effective and successful way to ensure that workers possess the knowledge required to perform tasks in a safe manner" (Fiori, 2004).

The Occupational Safety and Health Act was passed in 1970 to establish a universal, government regulated standard for safety for all industries in the United States with an ultimate objective of creating a safe working environment for all individuals. Out of this act, The Occupational Safety and Health Administration (OSHA) was established. One of the key components of OSHA is that it places the responsibility of safety on the employers and/or management of companies. Thus, reiterating the importance of management commitment to a safety culture within an organization. OSHA's section 1926.21 or 29 CFR is dedicated to the responsibility of employers and managers for providing safety training and education within the construction industry. The standards are as follows:

Regulaions (Standards – 29 CFR)
Safety training and education. – 1926.21
Part Number: 1926
Part Title: Safety and Health Regulations for Construction
Subpart: C

1926.21(a)

General requirements. The Secretary shall, pursuant to section 107(f) of the Act, establish and supervise programs for the education and training of employers and employees in the recognition, avoidance and prevention of unsafe conditions in employments covered by the act.

1926.21(b)

Employer responsibility.

1926.21(b)(1)

The employer should avail himself of the safety and health training programs the Secretary provides.

1926.21(b)(2)

The employer shall instruct each employee in the recognition and avoidance of unsafe conditions and the regulations applicable to his work environment to control or eliminate any hazards or other exposure to illness or injury.

1926.21(b)(3)

Employees required to handle or use poisons, caustics, and other harmful substances shall be instructed regarding the safe handling and use, and be made aware of the potential hazards, personal hygiene, and personal protective measures required.

1926.21(b)(4)

In job site areas where harmful plants or animals are present, employees who may be exposed shall be instructed regarding the potential hazards, and how to avoid injury, and the first aid procedures to be used in the event of injury.

1926.21(b)(5)

Employees required to handle or use flammable liquids, gases, or toxic materials shall be instructed in the safe handling and use of these materials and made aware of the specific requirements contained in Subparts D, F, and other applicable subparts of this part.

1926.21(b)(6)

1926.21(b)(6)(i)

All employees required to enter into confined or enclosed spaces shall be instructed as to the nature of the hazards involved, the necessary precautions to be taken, and in the use of protective and emergency equipment required. The employer shall comply with any specific regulations that apply to work in dangerous or potentially dangerous areas.

1926.21(b)(6)(ii)

For purposes of paragraph (b)(6)(i) of this section, "confined or enclosed space" means any space having a limited means of egress, which is subject to the accumulation of toxic or flammable contaminants or has an oxygen deficient atmosphere. Confined or enclosed spaces include, but are not limited to, storage tanks, process vessels, bins, boilers, ventilation or exhaust ducts, sewers, underground utility vaults, tunnels, pipelines, and open top spaces more than 4 feet in depth such as pits, tubs, vaults, and vessels.

OSHA has set the guidelines for safety on construction sites, as well as in other industries. However, it is the duty of employers to provide and ensure the training of the workers. Employers must establish criteria, goals, and a plan of implementation on how the training of its workforce will be executed. Each safety training program shall be unique to the needs of that specific organization or operation to guarantee success. First, employers must establish who is in need of training. The answer is everyone needs formal training. All individuals that are involved in the organization must be educated on general jobsite training from those at top level management positions down to the individuals at the operational level. General safety training shall provide an in-depth understanding of all potential hazards that may occur while working on construction projects. Also, the training must provide individuals the competency on recognizing potential hazards and unsafe work practices. Training must also involve training that is specific to that particular project. Organizations must perform a job hazard analysis to pinpoint those existing or potential hazards that may occur. For example, if a crane is required during construction the organization is responsible for making sure all individuals are competent on crane safety and best practices.

No safety training program is effective without an established implementation effort by the organization. Fiori (2004) recognizes several methods that should be utilized to help in the implementation phase including: checklists, policy enforcement, and routine safety meetings. Checklists are a simple, inexpensive method of implementing safety on a project. The checklists allow workers, as well as managers, to routinely review rules, regulations, and procedures that are specific to the operations to be performed. Policy enforcement is a major component of safety training program that re-emphasizes the importance of management commitment to safety. No training program will be effective without the committed enforcement of those who regulate it. After training, employers must require workers to sign a contract acknowledging that they have received training and fully understand the expectations of the organization in regards to safety. At this point, policy enforcement is required by the organization to guarantee that individuals are performing safe practice during their routine operations. Finally, routine safety meetings must be conducted to "further enforce and bolster the safety commitment and culture on a job site" (Fiori, 2004). Meetings should be scheduled at the start of the work week. This reiterates the notion that safety is the first priority of the organization; this suggests that safety should be considered before any other job task or activity.

## 3.4 Employee/Worker Involvement

As previously mentioned, the success of a construction safety culture relies on the commitment of management to establish and maintain safety within a system. However, the achievement of a construction safety culture requires the active participation of all individuals within an organization, especially those at the operational level. In system dynamics modeling, worker involvement can be measured as the level of commitment or participation of workers to the safety culture of their organization. This can be determined by survey, interview, or questionnaires. Workers may be asked to rate, using a 1-5 Likert scale, their commitment and the perceived commitment of their peers to the construction safety culture of the organization.

Safety is the responsibility of every person. One must not assume that someone else has taken their safety into consideration when they walk onto a construction project, so workers must become actively involved for their own benefit, as well as their colleagues. "Management must be willing to devolve some decision-making power to the workforce by allowing them to become actively involved in developing safety interventions and safety policy, rather than simply playing the more passive role of recipient" (Williamson et al., 1997). Providing the opportunities for worker involvement in decision making regarding safety also develops a trust relationship between management and operatives which will result in compliance with safety rules. Garner (2004) suggests that employees who become actively involved in the safety program of their organization become stakeholders—they develop a sense of ownership for the success of the venture and support it. OSHA (2006) provides examples of active and meaningful participation that workers must perform to help establish the construction safety culture in their organization including:

- Participating in ad-hoc safety problem-solving programs
- Participating in accident and incident investigations
- Developing or participating in employee-involved suggestion programs
- Training other employees in safety
- Analyzing the job and/or processing hazards
- Acting as safety observers
- Serving on safety committees

Management commitment is at the helm of construction safety culture; however, if operatives do not "buy into" the safety program of the organization there will be devastating consequences. Failure of workers to actively participate in the program will lead to increased injuries and/or fatalities on any construction project.

### 3.5 Safety-Focused Planning and Design

It may be difficult to accept but, in regards to safety, some construction projects may be doomed from the very beginning. Why? Many owners, architects, designers, engineers, schedulers and all others involved in the planning and preconstruction phases of construction seldom take safety into account. Often the only concern with these individuals is cost, feasibility, and profit. Through technological advances including computer software such as AutoCad 3D and Revit, the designs of buildings and other structures continue to increase in complexity. Architects and engineers are designing buildings that are taller, and of varying geometrical shapes. Should we assume that when designing structure such as Las Vegas' City Center or Dubai's Burj Dubai that the design staff accounts for the safety of the individuals that will ultimately construct it? It is highly likely that safety was either considered very, very little or not at all. This is extremely troubling. To achieve a safety culture within a construction organization safety must be incorporated from the commencement of pre-project planning. As mentioned previously, a system that possesses a safety culture is one in which safety is the first priority of all individuals involved from top-level management to those at the operational level including, but not limited to owners, architects, engineers, general contractors, subcontractors, vendors, workers, etc. Whittington et al. (1992) illustrated how failures in project planning can eventually lead to accidents on construction sites in their model of construction industry accident causation. Effective planning and design for safety is essential if projects are to be delivered on time, without cost overrun, and most importantly without accidents (Cameron and Duff, 1999).

How do we incorporate safety into the design and planning phases of construction? Many designers and planners lack knowledge and experience to predict how their designs affect those individuals and the duties they perform on the project site. The International Labour Office (ILO) (1992) specifically states that designers should: receive training in health and safety; integrate the health and safety of construction workers into the design and planning process; not include anything in the design which would necessitate the use of dangerous structural or other procedures or hazardous materials which could be avoided by the design modifications or by the substitute materials, and take into account the health and safety of workers during subsequent maintenance. Admittedly, this approach may seem rather far-fetched, but it is possible and will, in fact, result in decreases in accidents and fatalities on the job site. Safety-oriented design and planning only requires a change or shift in focus from the design personnel. Architects and engineers must adopt new approaches in the design phase, which prioritizes safety before constructability, feasibility, production, etc.

The importance of effective planning and design which incorporates safety as its' first priority cannot be overemphasized. "The more significant the project design and management teams involvement is in the safety planning effort, the greater the likelihood of positive outcomes for the project's risk-control program" (Broderick, 2004). It is also important for design and planning team to incorporate safety which is unique and ideal to that particular project in which they are working because every project design is different in some form. Incorporating safety into the design phase will eliminate those potentially risky hazards that workers may encounter before the onset of construction. In the construction industry it is a known fact that the earlier problems, hazards, etc. are recognized and addressed in the construction process (entire) the more options the organizations have when exploring solutions. These options also tend to be much cheaper than they would during the construction phase. Therefore, design personnel including architects, engineers and managers should perform constructability reviews during the design phase to identify potential safety threats early on. The Construction Industry Institute (CII) based in Austin, Texas defines constructability as the optimum use of construction knowledge and experience in planning, engineering, procurement, and field operations to achieve ultimate objectives (Jergeas and Van der Put, 2001). Constructability reviews will result in improved safety during the construction phase.

Toole (2005) supports the increase of designers' role in construction safety. In his study, Toole recognizes five tasks that civil design engineers may perform differently than the traditional duties of design professionals to contribute to construction safety. These tasks include: reviewing their designs, creating design documents, assisting the owner in procuring construction, reviewing submittals, and inspecting work in progress. Toole (2005) also list those barriers that prevent design engineers from adopting an increased involvement in safety including: lack of safety expertise, lack of understanding of the construction process, typical contract terms, and professional fees. It will be beneficial to the construction industry, as a whole, to educate design professionals on safety and construction processes just as construction managers may receive education and training on business management.

Gamabatese et. al (1997) addressed the much required need for incorporating safety into the design phase. Their research cited the lack of designers' involvement in worker safety as being attributed to minimal education and experience in addressing safety on the construction site, and their attempt to minimize their liability exposure. In 1993 and 1994, surveys were conducted on owners of projects who responded on the role of designers' consideration to safety in the design of the owners' projects. Their responses supported data that unfortunately design professionals give much less consideration to safety than necessary to make a positive impact on construction safety. And, since OSHA places the responsibility of safety on employers and not on design professionals they are even less motivated to prioritize safety. Figure 11 presents the breakdown of the results of the survey. In fact, 45% of the interviewed owners admitted that worker safety was not taken into account during the design of their projects. Another 29% stated that safety was occasionally addressed in their designs depending on specific activities.

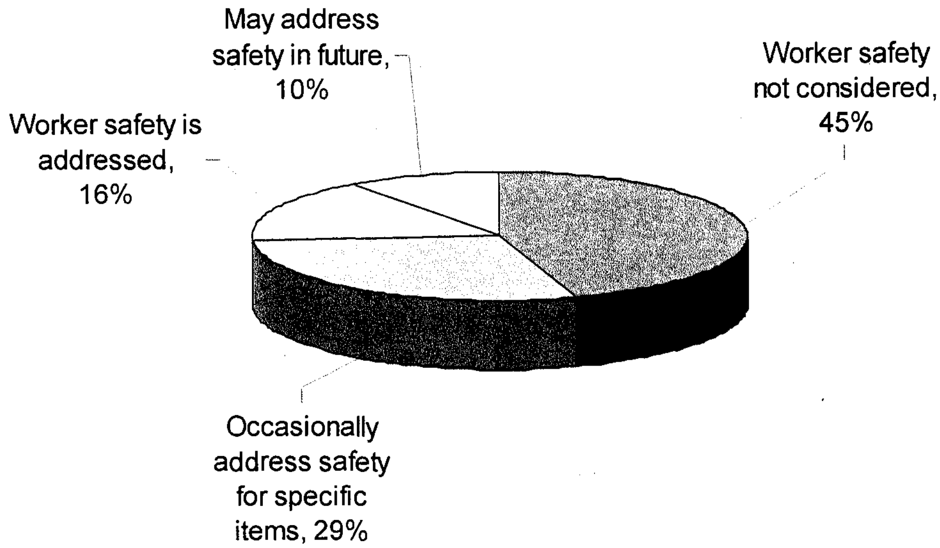



Figure 11. Owners response regarding worker safety in design (Gambatese et al., 1997)

To provide a reactive solution to this severe problem, Gambatese et. al (1997) developed software called the "Design for Construction Safety Toolbox" that aids designers in recognizing potential threats and hazards. Interviews were conducted from various professionals in the construction industry—owners, designers, project managers, workers, etc. They were asked to provide suggestions for designers to take into consideration when designing projects. These suggestions, in addition to information collected from best practice manuals and literature, were compiled into a computer database that the design professionals can reference during their work. Since the start of this research in 1994, Gamabatese and his colleagues have input over 400 suggestions into the safety design tool database. The tables 1 through 5 present the number of suggestions that were provided (via interview) categorized by design discipline, and the percentage of those suggestions that were incorporated into the "Design for Construction Safety Toolbox."

Table 1 Design Suggestion Sources (Gambatese et al., 1997)

| Number | Source | Number of Suggestions | % of Recorded Suggestions |
|---|---|---|---|
| 1 | Safety Design Manuals and Checklists | 140 | 32.6 |
| 2 | Authors and Safety Taskforce Members | 123 | 28.6 |
| 3 | Interview (Telephone, in Person) | 81 | 18.8 |
| | Constructors and Designers | {50} | |
| | Academics | {17} | |
| | Local/state/federal public agency personnel | {7} | |
| | Owners | {5} | |
| | Designers | {2} | |
| 4 | OSHA (CFR, publications, data) | 34 | 7.9 |
| 5 | Journal articles | 19 | 4.4 |
| 6 | Periodicals | 14 | 3.3 |
| 7 | Public safety courses | 8 | 1.9 |
| 8 | Other ( NIOSH, HBR Constructability Plan) | 11 | 2.6 |
| | Total | 430 | 100 |

Table 2 Number of Suggestions Recorded by Discipline (Gambatese et al., 1997)

| Number | Design Disciplines | Number of Times Addressed | % of Recorded Suggestions |
|---|---|---|---|
| 1 | Structural | 141 | 32.8 |
| 2 | Architectural | 127 | 29.5 |
| 3 | Piping/plumbing | 84 | 19.5 |
| 4 | Electrical/instrumentation | 69 | 16 |
| 5 | Mechanical/HVAC | 69 | 16 |
| 6 | Construction management | 62 | 14.4 |
| 7 | Civil | 48 | 11.2 |
| 8 | Tanks/vessels | 17 | 4 |
| 9 | Traffic/transportation | 16 | 3.7 |
| 10 | Geotechnical | 5 | 1.2 |
| 11 | Coating/insulation | 3 | 0.7 |
| | Total | 641 | |

*Since suggestions may address more than one design discipline, the sum of these numbers (expressed as % of 430 recorded suggestions) exceeds 100

Table 3 Project Components Addressed by Design Suggestions (Gambates et al., 1997)

| Number | Project Component | Number of Times Addressed | % of Recorded Suggestions |
|---|---|---|---|
| 1 | Piping | 77 | 17.9 |
| 2 | Electrical/Instrumentation | 58 | 13.5 |
| 3 | Mechanical/HVAC | 55 | 12.8 |
| 4 | Structural framing | 52 | 12.1 |
| 5 | Stairs, ladder, ramp | 43 | 10 |
| 6 | Work schedule/sequence | 41 | 9.5 |
| 7 | Slab on grade, floor, roof | 35 | 8.1 |
| 8 | Roads, paving, flatwork | 32 | 7.4 |
| 9 | General conditions/special provisions | 31 | 7.2 |
| 10 | Earthwork, sewer, etc. | 24 | 5.6 |
| 11 | Furnishings, finishes | 20 | 4.7 |
| 12 | Structural plan/elevation | 20 | 4.7 |
| 13 | Door, window | 19 | 4.4 |
| 14 | Foundation | 18 | 4.2 |
| 15 | Project layout | 16 | 3.7 |
| 16 | Tank, vessel | 16 | 3.7 |
| 17 | Technical specifications | 13 | 3 |
| 18 | Walkway, platform | 11 | 2.6 |
| 19 | Contract drawings | 10 | 2.3 |
| 20 | Handrail, guardrail | 10 | 2.3 |
| | Total | 601 | |

Table 4 Construction Site Hazards Addressed by Design Suggestions (Gambatese et al., 1997)

| Number | Construction Site Hazard | Number of Times Addressed | % of Recorded Suggestions |
|---|---|---|---|
| 1 | Falls | 141 | 32.8 |
| 2 | Electric shock | 60 | 14 |
| 3 | Explosions | 57 | 13.3 |
| 4 | Cave-in | 56 | 13 |
| 5 | Fire | 42 | 9.8 |
| 6 | Toxic Substances | 38 | 8.8 |
| 7 | Work area | 34 | 7.9 |
| 8 | Environmental/climate | 31 | 7.2 |
| 9 | Struck by objects | 25 | 5.8 |
| 10 | Vehicular traffic | 25 | 5.8 |
| 11 | Work issues | 21 | 4.9 |
| 12 | On-line equipment | 20 | 4.7 |
| 13 | Obstructions | 18 | 4.2 |
| 14 | Heavy equipment | 13 | 3 |
| 15 | Confined space | 10 | 2.3 |
| 16 | Caught in between | 6 | 1.4 |
| 17 | Lighting | 5 | 1.2 |
| | Total | 602 | |

*Since suggestions may address more than one construction site hazard, the sum of these numbers (expressed as % of the 430 recorded suggestions) exceeds 100.

Table 5 Project Systems Addressed by Design Suggestions (Gambatese et al.,1997)

| Division | Project System | Number of Times Addressed | % of Recorded Suggestions |
|---|---|---|---|
| 15 | Mechanical | 118 | 27.4 |
| 2 | Sitework | 69 | 16 |
| 10 | Specialties | 68 | 15.8 |
| 16 | Electrical | 58 | 13.5 |
| 1 | General Conditions | 51 | 11.9 |
| 5 | Metal | 30 | 7 |
| 3 | Concrete | 26 | 6 |
| 8 | Doors and windows | 19 | 4.4 |
| 11 | Equipment | 19 | 4.4 |
| 13 | Special construction | 16 | 3.7 |
| 6 | Wood and plastics | 12 | 2.8 |
| 9 | Finishes | 8 | 1.9 |
| 7 | Thermal and moisture protection | 6 | 1.4 |
| 4 | Masonry | 4 | 0.9 |
| 14 | Conveying systems | 3 | 0.7 |
| 12 | Furnishings | 2 | 0.5 |
| | Total | 509 | |

*Since suggestions may address more than one project system, the sum of these numbers (expressed as % of the 430 recorded suggestions) exceeds 100.

If used effectively by design professionals, the tool by Gambatese et. al (1997) can have a tremendous positive impact on the safety culture of the organizations which utilize it. In system dynamics modeling the factor, safety-oriented designs can be measured by the number of hours spent by architects, designers, and engineers reviewing their designs and incorporating the use of CII/Gambatese model "Design for Construction Safety Toolbox." Now that the lack of training and education has been addressed with this tool, we must now aim to alter the mentalities of designers in which they, themselves, take more responsibility and liability of their designs on the individuals that have to construct them.

Scheduling is another aspect of construction that occurs in the planning phases in which safety should be incorporated to target and account for those activities that may pose potential threats to workers when construction has begun. In system dynamics modeling the factor safety-oriented planning and scheduling can be measured as amount of additional hours allocated to those construction activities that pose increased threats of accidents during the construction process. In addition to designers and engineers, schedulers should also receive training on safety and construction processes to learn which activities have increased hazards or risks. Yi and Langford (2006) presented a theory of safety planning method which estimates the risk distribution of a project and helps the safety manager to both estimate situations of concentrated risk and then reschedule activities when necessary. This method requires coordination between the scheduler and the safety manager to eliminate the occurrence of activities before the construction phase. Experience and knowledge of past projects is also a prerequisite for safety-focused scheduling. If various activities caused hazardous situations on past projects, then these activities should be identified, evaluated, and incorporated into the scheduling of future projects.

There has been significant research that has identified the benefits of incorporating safety into the planning, design, and scheduling phases of construction. Kartam (1997) discussed the introduction of safety measures into construction plans using critical path method (CPM) techniques. Tam et al. (2001) devised a method of allocating resources according to their order of priority after comparing safety improvement measures developed in the construction industry, Saurin et al. (2004) developed a safety planning and control model which integrated safety management with production planning and control. Incorporating scheduling and safety is a requirement for achieving a construction safety culture.

Many accidents in the construction industry are attributed to human error. Production pressures often lead individuals to "cut corners" or engage in hazardous behaviors (failure to tie-off, working without PPE, operating without clearance, etc.) to make up for time. In due time, these hazardous behaviors eventually result in injuries and/or fatalities. If workers, as well as organizations, compare the time lost while taking necessary safety precautions to the time lost during the occurrence of an accident the workers may think twice before "cutting corners" and the organizations will be more strict on allowing these hazardous behaviors. If hazards can be identified early on and the adequate time and resources are allocated to the activities in the scheduling phase then delays caused by accidents will be, more than likely, eliminated.

The importance of safety focused scheduling must not be underestimated. Accidents resulting in injury and fatalities can have uncontrollable and often irreversible impacts on a project's schedule. When accidents occur, especially those serious in nature, projects tend to come to halt. Accidents result in lost time and productivity. The situation will affect the morale of the organization which will cause workers to either slow down or stop work altogether. That particular area of the job site may be temporarily closed down for investigation. All in all, the project's efficient production is severely affected and typically results in the project being behind schedule. Once a schedule is behind it is often difficult to get back on track. Therefore, taking the necessary steps to incorporate safety into the scheduling process is beneficial for the entire system.

### 3.6 Accident Reporting and Investigation System

Accident reporting and investigation systems are an integral part of any safety management program, and this system must exist to establish a safety culture within an organization. In system dynamics modeling, accident reporting and investigation system can be measured by the number of times the accident reporting and investigation system was used during a construction project or a specified time period. It is the responsibility of management to establish and maintain a functional reporting and measurement systems. Without a reporting system, there is no way to measure and assess the state of the systems safety.

The objective of the reporting system is to not only monitor accident rates, but to identify accident causes and risk exposures, monitor the effect of site safety initiatives, and to estimate the costs of accidents (Rowlinson, 2004). A safety reporting system is another activity that requires continuous, active participation of all members within an organization from top level management to the operational level. Many times construction accidents go unreported for various reasons. Workers may not report accidents because they may feel that their position may be jeopardized; they may feel that the lack of severity did not require the reporting of an accident; they sometimes feel that the company will require them to take time off, etc. Construction companies may fail to report an accident for fear of insurance increases. Whatever the case, no excuse is valid for failure to report any accident that occurs on the project site. Cooke and Rohleder

(2006) states that the fraction of incidents reported is dependent on the personal commitment to safety of the workers who observe or are involved in the incidents.

Reporting systems reveal valuable information on the status of an organizations safety culture, and allows progress within the organization to be tracked over time. Rowlinson (2004) states that the role of the reporting system in an organization is to reduce the occurrence of accidents by analyzing and reporting on accident causation and highlighting areas where action is needed. Highlighting these areas where action is needed requires thorough investigations on the part of management. Again, the notion of management's commitment to safety comes into play. If management is committed to the construction safety culture of their organization they will be willing to perform thorough investigations to identify errors in their safety program for future prevention. The goal of investigations is to collect as much information about the accidents as possible. These investigations must not only investigate those unsafe acts or behaviors that caused the accident, but most importantly, those root causes that provided the opportunity for those unsafe acts to exist. The information may collected by performing a site examination, performing interviews with witnesses, etc. Organizations must learn from the information collected from reporting and investigation system to maintain and enhance the safety culture within their environments.

## 3.7 Safety Investment

When thinking of safety investment, what comes to mind is the slogan, "if you do not put anything into the bank, then you will not get anything out." In system dynamics modeling, safety investment can be measured as the amount of dollars a construction organization spends annually on safety resources including: safety personnel (safety managers, officers, etc), safety equipment, and safety training and promotions. There is no secret to success when it pertains to safety. The fact is that those organizations which possess a construction safety culture and have stellar records when it comes to safety have invested a substantial amount of resources (both time and money) into their safety programs. Tang et al. (1997) identifies the three components of safety investment as:

(a) Safety administration personnel

- Site staff and head office staff; safety officers and safety supervisors on site to monitor safety-related matters.
- Some large contractors will employ safety manager/senior safety officers to direct and coordinate safety staff.
- The salary of these personnel and their supporting staff are part of the investment.

(b) Safety equipment

- Purchasing of safety boots, goggles, safety fences, first-aid facilities, etc. which are related to safety on the site.

(c) Safety training and promotion

- Safety training courses are organized by contractors for their employees
- Safety promotion includes the printing of pamphlets and posters, the production of safety advertising banners and boards, organization of safety campaign and monetary rewarding of individual workers who achieve a god safety standard of work, etc.

An organization's safety investment should be directly proportional to its safety performance, and vice versa. The underlying theme of construction safety culture is management's commitment. The routine presence of safety personnel on a construction site emphasizes that level of commitment that an organization places on safety. It is unfortunate that companies must invest hundreds of thousands or possibly millions of dollars to achieve safety culture within their organizations; however, it is reality. As unfortunate as it may appear, many operatives do not prioritize their own safety when working in the field. They tend to overestimate their skills and abilities in performing their trade, and they underestimate potential hazards and dangers that they face when they enter construction sites. It is also unfortunate that the occupations of safety officers, safety managers, etc. exist predominantly to pose as constant reminders to workers that their safety is first priority. In the absence of safety personnel, many individuals only prioritize production. Therefore, organizations must invest in people to monitor and ensure that workers are complying with safety regulations.

A substantial amount of an organization's investment on their safety program must be allocated to proper, updated safety equipment for workers. This not only includes personal protective equipment (PPE)—safety goggles, hard hats, gloves, etc., but also state-of-the art machinery and tools designed and guaranteed to decrease the risk of worker injuries and fatalities on construction sites. One way of addressing safety issues on site is to provide innovative technological solutions to problems. Outdated and poor-quality equipment has been the direct cause of many construction accidents, historically. Construction organizations must be willing to take advantage of the modern, technological advancements in construction equipment.

The major reasons companies lack much of the proper tools and equipment is cost. Management's commitment to safety culture is once again revisited. As mentioned time after time, most organizations prioritize profit and productivity over safety. The goal of companies is to get the greatest possible return on investment. The profit margin in the construction industry is typically very low with most organizations making an average of 1% to 3% profit on any given project. So, some companies take unnecessary risks by providing their employees with the "bare minimum," sub-standard and outdated equipment that will get the job done.

Modern construction equipment, in fact, is very expensive; however, investing in innovative equipment or even renting it is a win-win situation for construction companies. Not only will companies get increased safety performance but increased productivity performance as well. And, when comparing the cost of equipment purchase or rental to the phenomenal cost that injuries and fatalities have on organizations resource investment on safety is, without a doubt, the most logical decision to make. The fact is that the majority of construction companies are not those large "powerhouse" corporations that are featured in the Engineering News Record Magazine (ENR). Most construction organizations are relatively small and their net worth is typically not that high. The point is--the average company, although insured, cannot withstand the impact of a serious accident on a construction project. An unfortunate fatality, with a valued cost of $4 million according to the CPWR (2007), will likely force the average construction company out of business. Therefore, resource investment in safety culture is critical for survival in the construction industry. Technological advancements in construction equipment addresses the number one concern of most organizations worldwide—how to get more production without jeopardizing the safety of the workforce. Resource investment is the key.

By now, it is evident that safety culture at the surface level is very basic and simple to achieve. As mentioned before, it is unfortunate that much of the effort exerted on achieving construction safety culture revolves around "babysitting," for a lack of better words. This opinion may be rather extreme; however, it is reality. Construction safety culture entails posing a constant reminder to all individuals within a system that safety is the first priority. One form of reiterating safety to workers on a construction site is through safety training and promotions. Training has been addressed earlier in this thesis. Promoting safety through banners, posters, pamphlets, etc. is an inexpensive method of advertising an organization's stance on the safety culture. It also gives the workers a constant reminder of the rules and regulations that they have agreed upon before beginning work on the project. Organizations must take any and every measure possible to promote the safety culture within their organizations. The impact of promotions material will have many positive impacts on the construction safety culture of an organization.

### 3.8 Contractor/ Sub-Contractor Selection

To achieve construction safety culture within a system every company and individual must be on board with safety as their main objective while completing the project. Therefore, owners and general contractors must be stricter in selecting contractors and sub-contractors to perform work on their projects. Besides, owners and general contractors do have an economic stake in the safety performance of subcontractors due to required insurance coverage for workers during the construction process, i.e. owner-controlled insurance programs or contractor controlled insurance programs. Recall that culture is defined as shared values, goals, and beliefs within a group or system. The key word is shared. It is highly unlikely if not impossible to achieve a construction safety culture within a system if the sub-contractors do not share the values or beliefs in safety as the owner of the project or the general contractor. All parties involved must have the same vision or philosophy in regards to safety. To ensure that specialty contractors and sub-contractors share the same vision of construction safety culture, both owners (clients) and general contractors must implement a selective prequalification or screening process. This is accomplished by reviewing the contractor's past safety history or experience modification rate. Emmons (2006) states that the following information should be reviewed from the past three years of the company: OSHA recordable rates (now referred to as incident rate), lost work day rate, and obtain references from most recent clients.

The experience modification rate (EMR) is a system designed to determine a company's premiums for worker' compensation insurance. The rating takes into account the compensation losses for an organization's type of work and amount of payroll, and predicts the cost of expected losses to be paid by that employer within a three-year rating period. The EMR is calculated according to the following formula

$$EMR = \frac{PL_A + BV + ((IL - PL_A)\times WV) + (1 - WV)\times EL}{PL_E + BV + ((EL - PL_E)\times WV) + (1 - WV)\times (EL - PL_E)}$$

where $BV$ is the ballast value, $EL$ expected losses, $IL$ actual incurred losses, $PL_A$ is the actual primary losses, $PL_E$ is the expected primary losses, and $WV$ is the weighting value. The rating is then compared to other companies who perform the same type of work to develop an experience rating. Lower rates are equivalent to fewer accidents occurring in the three year rating period.

The Occupational Safety and Health Act (1970) requires employers to record and report accident information on an Occupational Injuries and Illnesses Annual Survey Form known as the OSHA 300 log which must be retained for a minimum of five years (Beaujon and Everett, 2004). The information on the contractor's log includes: number of fatalities, number of injuries and illnesses involving lost work days, number of injuries and illnesses involving restricted work days, number of days away from work, number of day of restricted work activity, number of injuries and illnesses without lost work days. To obtain the OSHA-recordable incident rate calculate the total number of fatalities, injuries, illnesses involving lost and restricted work days, and injuries and illnesses without lost work days. Incidents are simply defined as individual occurrences or events. This number (No. of incidents) is then multiplied by 200,000 hours, and then divided by the total number of employee hours worked during that year:

$$Incident\ Rate = \frac{Number\ of\ incidents \times 200{,}000\ hours}{Number\ of\ hours\ worked}$$

The 200,000 hours represents the standard base for incident rates which is equal to 100 employees working 40 hours per week for 50 weeks out of the year. Reviewing a company's OSHA recordable incident rates provide owners and general contractors with a very accurate representation of how safely workers from that sub-contractor will perform, as well as comply with safety regulations on future projects. It also serves as a model for management's level of commitment to safety within that organization. If an organization has high incidence rate, it is safe to assume that a construction safety culture is non-existent and the prioritization of safety is very minimum.

Owners and general contractors must establish higher standards for the companies that they choose to perform work for them. The reason that the construction industry has such high injury and fatality rates is because of mixed priorities. The only factor that management generally takes into consideration is cost. Companies want the most for less—the majority of contracts in this business are awarded to the lowest bidder. It is standard industry practice to select the lowest, competent bidder; however, the competency of the specialty or subcontractor is usually overlooked or not emphasized because of prioritization on the low bid that they may have submitted. A popular phrase that pertains to this discussion of contractor selection is "you get what you pay for!"

Owners and general contractors responsible for selecting specialty or subcontractors have two alternatives: they can either pay more in the earlier phases of the construction process by selecting a bidder who shares the same value and commitment to safety as they do, or pay more later in workers' compensation, lawsuits, etc. as a result of selecting the lowest bidder who places no importance on the construction safety culture of their organization. "As a contractor's safety focus and execution decreases, the owner's costs increase. If an owner chooses to work with select, safer contractors, then the owners' costs will be significantly less. Owners who pay attention to contractor safety records experience fewer third-party lawsuits and get more efficient execution of their work" (Beaujon and Smith, 2004). All decisions made early on during the pre-construction phases of a project will significantly impact cost once construction has begun.

CHAPTER 4

# MODEL DEVELOPMENT AND ANALYSIS

## 4.1 Systems Thinking

Systems thinking can be viewed in many fashions—as a concept or idea, as an approach or study, or as a tool to create a better understanding. Whichever way it is viewed, the objective of system thinking is very "cut and dry"--to provide a clear understanding to complex, real world problems and situations by examining systems holistically. Everything around us makes up some kind of system which means that all things in an environment have some kind of connection between them. As human beings, it is in our nature to solve problems by dissecting them into smaller pieces and analyzing various aspects individually. This approach may work for very simple problems, but when we destroy the connection between system components by breaking them down into smaller parts we run the risk of losing valuable, or possibly latent, information about that system that may have provided a better understanding or solution. Systems thinking, as defined by Sherwood (2002), is the study of the connectedness between those systems' component parts whether they be human beings, departments, or indeed businesses and organizations, as a whole. To gain the understanding of complex systems it is imperative that we maintain the connectedness of system components, and study the system in its entirety. There are two tools used in systems thinking that provides a better understanding: (1) causal loop diagrams, which describe complex systems in terms of cause-and effect relationships, and (2) system dynamics modeling which allows the behavior of system components to be evaluated over time in computer simulations. Sherwood (2002) presents the many benefits of using system thinking as a tool for understanding including:

- Systems thinking can help you tame the complexity of real-world problems by providing a structured way of balancing a broad, complete view with the selection of the right of detail.
- Causal loop diagrams--a visual method of capturing this now-tamed complexity—are a powerful means of communication, and their use can ensure that as wide a community as you wish has a genuinely, and deeply, shared view. This is enormously valuable in building high-performing teams.
- Causal loop diagrams can also help you identify the wisest way of influencing the system of interest. As a result, you can avoid taking poor decisions, for example decisions that look like fixes but are likely to backfire.
- System dynamics modeling is a computer modeling technique that allows you to simulate how a complex system, as expressed as a causal loop diagram, is likely to evolve over time. This provides you with a "laboratory of the future," so that you can test likely consequences of actions, decisions, or policies before you are obliged to commit.
- Overall, systems thinking can help you take decisions that pass the most stringent test there is—the test of time.

As mentioned throughout this thesis, many critics believe that safety culture is just a "catch-all" fad that cannot realistically be achieved on projects in the construction industry. Much of the skepticism on this topic may be contributed to pass researchers' failure to precisely define those steps that organizations must take to establish safety culture on a construction project or any other system. Past research has attempted to explain safety (or lack of) by dissecting and examining the various factors or variables. This is our instinctual behavior as humans. It is assumed that when things are broken down into component parts it is easier to gather the information or insight that we are seeking about what it is that we are studying. "Taking a complex, dynamic, and circular world and linearizing it into a set of snapshots may make things seem simpler, but we may totally misread the very reality we were seeking to understand" (Kim, 1994). Systems thinking suggest that all the answers we are in search of are best revealed by studying systems in their entirety. Creating a system thinking model will provide an objective analysis of the connectedness or cause-and-effect relationships between all factors required to achieve a construction safety culture.

## 4.2 Cause-and-Effect Relationships

In system thinking, cause-and-effect relationships are presented in the form of a diagram known as the causal loop diagram. The diagram consists of all factors or variables that make up the system in which we are studying. The relationships between variables are represented by arrows and may be given the designation of positive (+) or negative (-) depending on the type of relationship. Positive relationships are those in which the factors are going the in same direction. Figure 12 represents a positive causal relationship between corporate-level and project-level management's commitment.

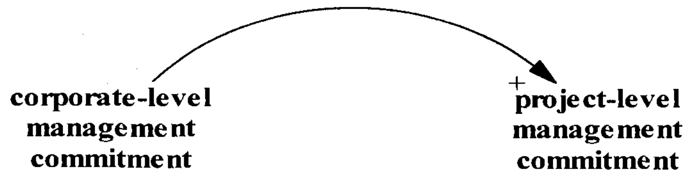



Figure 12. Positive causal relationship between corporate level and project level management's commitment

Negative relationships are going in the opposite direction. For example, as management's commitment to safety increases, injuries decrease. The arrow representing the relationship between management commitment and accidents will be denoted with a "-" sign. Figure 13 represents a negative causal relationship between management commitment to safety and number of injuries.

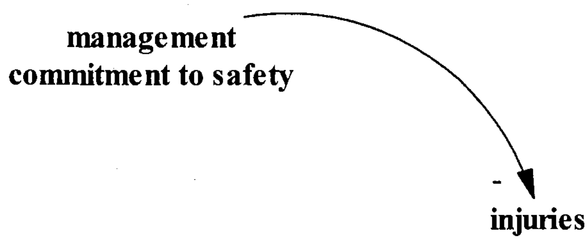



Figure 13. Negative causal relationship between management commitment and number of injuries.

All causal loop diagrams have one central feature in common which is known as the feedback loop. Feedback loops imply that all factors or variables in the diagram are connected in some way. "Feedback manifests itself in causal loop diagrams by the presence of one or more continuous, closed loops: loops representing chains of causality that link back on themselves, loops with no beginning and no end, and loops in which everything is ultimately connected to everything else" (Sherwood, 2002). Henceforth, construction safety culture is a feedback loop. Feedback loops can be divided into two distinct chains of causality known as reinforcing and balancing loops. A feedback loop is known as reinforcing if the number of negatives (-) in that complete loop are even, and classified as balancing loops if the number of negatives (-) in the loop is an odd number. In reinforcing loops, feedback increases the impact of change and in balancing loops the causal relationship between variables keeps the system in equilibrium.

For this exploratory study Vensim, a modeling program, is used to create a qualitative mental model of how safety culture can be achieved in a construction system. "Vensim, the Ventana Simulation environment, is an integrated framework for conceptualizing, building, simulating, analyzing, optimizing, and deploying models of dynamic systems" (www.ventanasystemsinc.com). Using modeling software to understand safety related topics is not a new approach. Howell and Obren (2005) used *Powersim* to investigate the validity of their approach to develop an understanding of the interaction of safety policies with the school bus environment in New Zealand. Milrad (2002) suggests using *STELLA*, *Powersim*, *StarLogo*, and *Agentsheets* as ideal modeling tools and programs which enable users to develop better intuitions about the mechanisms that govern dynamic interactions. In their study of the space shuttles Columbia and Challenger accidents, Dulac et al. (2005) performed a 200-run Monte Carlo sensitivity simulation to investigate the effects of their model, the Independent Technical Authority structure, on NASA. *DYNAMO* was the modeling tool of choice in Nuthmann's (1994) research of the use of human judgment in system dynamics models of social systems. *DYNAMO* was the first system dynamics modeling software and was developed by Jay

Forester at the, then newly founded, Sloan School of Management at the Massachutsett Institute of Technology. Details of *DYNAMO* may be found in Richardson and Pugh (1981). *DYNAMO* is no longer used due to the advent of advanced, micro-computer based programs such as *STELLA, Vensim, Powersim, Berkely Madonna*, *Mystrategy, AnyLogic*, etc. For the purposes of this exploratory study, *Vensim* was chosen various reasons: (1) it is easy to use for first-time and experienced modelers, (2) it provides a practical way of communicating how complex systems function, (3) allows the simulation of systems over time, bridges the gap between theory and real world, demonstrates changes and predicts outcomes within a system, (4) the program has built-in functions which automatically produce mathematical, statistical, and logical data, and (5) provides sensitivity analysis which reveal which sectors of the construction safety system may potentially be in jeopardy, and (6) it was cost efficient—*Vensim* allows a free downloadable version to be used for educational purpose in comparisons to other programs that cost anywhere from two hundred to thousands of dollars.

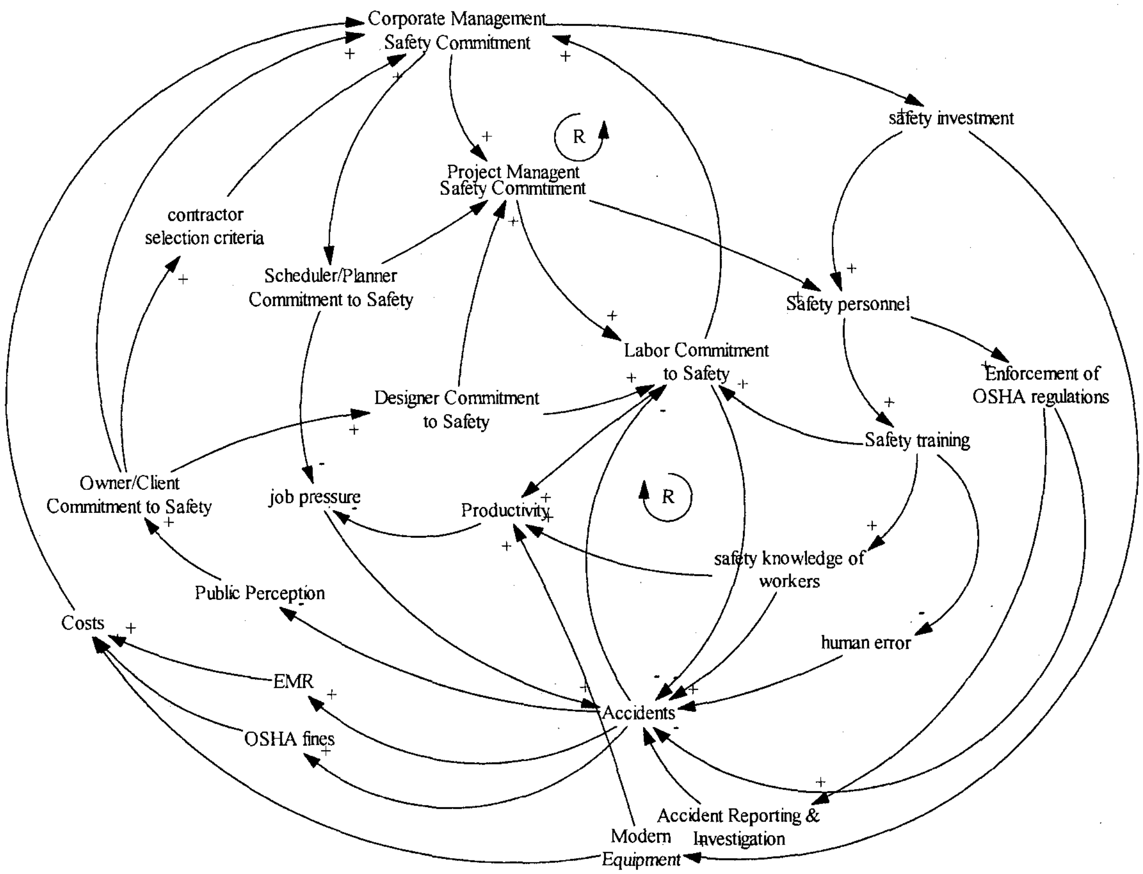



Figure 14. Systems thinking model of construction safety culture.

Figure 14 represents the systems thinking model of construction safety culture developed by this research. This model provides a visual or mental representation of those factors requisite to achieving a construction safety culture in addition to other factors that are either directly or indirectly related to the safety in complex systems. The model was constructed in group model building sessions that involved Dr. David Shields, Prof. Neil Opfer, and myself. In our group model building sessions, “group think” style brainstorming was used to come to a consensus on which factors were most relevant to achieving a construction safety culture and the causal relationships or interconnectedness that exist among them. It is important to remember that systems thinking models are closed systems that have no definite starting point and no ending point. There are many factors within this model that share more than one relationship. This is typical of system dynamics modeling—to gain the insight or answers to the hidden problems, we must study and exhaust all possibilities for relatedness between variables. It is the objective of this thesis that this model will add clarity to the concept of construction safety culture and express how it can be achieved.

As mentioned earlier, construction safety culture is a top-down approach to achieving safety in construction organizations. By top-down approach it is not meant that a commitment must come from only those individuals that are directly involved in the day-to-day construction activities, but also those individuals such as the owner/client possess the ultimate power to make impacts on a construction project. Having this ultimate power means that the owner possesses the initial capability of making safety first priority and establishing it as a culture on his/her project to be constructed. Although management commitment is the foundation of construction safety culture, the top-down approach suggests that the initial commitment should come from the owner or client. Historically, this has been the first obstacle to achieving safety on construction projects. Why? The answer is cost.

Cost has always been the driving force in the construction industry. Owners/clients want the most for their money. They want the most elaborate buildings that can be built and they want them for the lowest price that they can obtain. So, often they award contracts to the bidder with the lowest prices and seldom take any other criteria or qualifications into account i.e. EMR, OSHA-recordable incidents, etc. This lowest cost mentality is particularly prevalent in public works projects. Awarding contracts to the lowest bidder frequently does not result in being the less expensive route for owners or contractors. However, this method is persistent even though its' weaknesses and disadvantages are well known and recognized. Through owner-controlled insurance programs, accidents on jobsites, and workmen's compensation claims, owners in some way or another, always have a financial stake in the safety of their projects. It is to their best interest to pre-qualify potential bidders and have a set of established criteria, especially safety-related criteria, that organizations must meet to perform work for that owner/client.

The first causal relationships that exist in this system thinking model is the between "owner/client commitment to safety, contractor/sub-contractor selection criteria, and corporate level management commitment to safety." The system thinking model states that there is a positive causal relationship between the owner/client commitment to safety and the contractor/sub-contractor selection criteria. The model states that as owners/clients commitment to safety increases the number of pre-qualifying criteria involved in selecting the appropriate contractor increases. Owners have the ability to positively or negatively influence the safety of their projects during the selection of their contractors. Bids are generally awarded to the lowest, competent bidder. However, as safety data and research suggests that many contractors lack competency in recognizing the importance of safety in the construction process. Owners/clients neglect safety for the same reasons that contractors performing the work do—it is because they view safety as an overhead expense rather than an investment and eventually a cost saving benefit. To owners, as well as the organizations that construct their projects, safety is believed to be an expense that does not directly yield profits—hence, overhead. Many are ignorant of the direct positive impacts that safety has on productivity. Productivity is an important factor in the profitability of constructing a project. Safety programs are similar to having automobile insurance—everyone dreads paying into it them until an accident occurs, then we are fortunate that we made the investment. It has been noted that a major shift in priorities must occur to achieve a zero-accident philosophy that the industry has longed for. Owners, too, must place safety at the front of their projects. As owners establish the commitment to construction safety culture, corporate level management of construction firms will then be forced to establish this same commitment if they want to obtain the contracts.

Another causal relationship that is critical to the success of a safety culture on construction projects is between the owner/client commitment to safety culture and design professionals commitment to safety culture. As previously mentioned, the owner/client has the ultimate power to positively or negatively impact the safety culture on their prospective project. Owners have the ability to select architects and engineers that emphasize the importance of safety in their designs—i.e. those design professionals that consult the CII "Design for Safety Toolbox." Addressing safety at this level is believed to have the potential for a positive impact on the safety culture of the system because this is the first opportunity that is provided to control potential safety hazards that may occur once construction as commenced. Historically, architects and engineers have been reluctant to become entangled in construction safety aspects when designing projects. Their main reason for avoiding involvement in the safety aspect of a construction project is it exposes them to unnecessary liability.

The entire project delivery system will need to be completely changed if risk sharing for safety among all parties is to be obtained. Without this paradigm shift, architects and engineers will continue to avoid liability associated with construction safety, and rightfully so. The goal is to create a construction safety culture, and not just make safety a priority but a shared value. Cultures fail when individuals do not accept the responsibilities that have been collectively established by the group. The systems thinking model illustrates a positive causal relationship—as the owner/client's commitment to safety increases, industry design professionals' commitment to safety should also increase. If owners make a commitment to safety-oriented designs, and financially accept the cost of increased liability for architects and engineers, architects and engineers will more likely participate in the construction safety culture. This commitment will, in turn, reinforce management's commitment to safety.

Management commitment to safety is the foundation to which construction safety is based upon. No safety program, or any other program for that matter, will be successful without the full support and commitment of both corporate management and project-level management. "A well designed management system can help to reduce incidents along with the associated hidden costs; increase efficiency; improve productivity, morale, and quality of products; and reduce the potential for regulatory citations" (Roughton & Mercurio, 2002). Although the appropriate starting point for this systems thinking model is the owner/client's commitment to safety, the commitment of management to safety is the driving force of the culture. Skeptics of safety culture question whether or not management commitment has that much of an impact on the success of a safety program.

It is management's duty to, not only develop the safety culture which is ideal for its organization, but to develop one in which implementation comes from active participation. Active participation of management provides the motivation for those at the operational level to participate in the safety program. In my systems thinking model, there is a positive relationship between the commitment of corporate and project-level management. As the commitment of corporate level management to construction safety culture of their organization increase, the commitment of the project-level management will also increase. There are many ways that both corporate and project-level management can demonstrate their commitment visibly to other members of their system. Roughton & Mercurio (2002) states some methods that management can utilize to display their commitment:

- Getting out where you can be seen, informally or through formal inspections
- Being accessible
- Being an example, by knowing and following the rules that employees are expected to follow
- Being involved by participating on the workplace safety and health committee
- Conducting frequent inspections with selected employees

When it comes to safety, management must lead by example. As mentioned before, management cannot expect its workforce to comply with jobsite safety regulations if they do not, themselves, display a commitment to those regulations. We often see top level management walking around construction sites without their PPE. This makes a statement to the entire organization suggesting that safety is not a priority. For a safety culture to exist, the beliefs and values have to be shared among all individuals within that system. Safety is the responsibility of everyone in the organization.

There is also a positive causal relationship that exists between corporate-level management's commitment to safety culture and the project scheduler's commitment to safety culture. As management's commitment to construction safety culture increases, project scheduler's commitment to safety should also increase. One of the most important aspects of any construction project is effective planning and scheduling. Scheduling impacts all areas of construction including: safety, costs, productivity, profitability, etc. Most activities involved in construction pose some kind of risk of illness and/or injury to workers, but some activities greater than others. Certain activities that pose increased threats to workers require additional time to perform those activities safely and efficiently. If safety is taken into consideration during the scheduling phase of a project and additional time is provided for various activities that are more dangerous, then workers will be able to work efficiently and cautiously when working. When projects get behind schedule for various reasons, workers tend to work faster and cut corners in regards to safe working practices. Effective safety-oriented scheduling is the solution. Safety is as just as much the responsibility of project schedulers as it is any other member of the construction project.

Corporate-level management may also express its commitment to safety culture by providing the necessary resources to achieve the goals and objectives of the safety program. In the systems thinking model there is a positive causal relationship between corporate management's commitment to safety culture and their investment on safety programs. As corporate level management's commitment to safety increases, the amount of resources that they invest in their safety program will also increase. Resource investment in safety programs may come in many forms. Management may invest financial resources in their training programs for both workers and project level management. Financial investment may be allocated to the hiring of various safety professionals i.e. safety managers, safety officers, and administrative support. Also, safety investment results in the purchase or rental of modern advanced construction equipment that has state-of-the-art safety features.

The systems thinking model indicates a positive causal relationship between safety investment and various safety resources. As investment in safety increases, the number of safety professionals hired into the organization increases, in addition to the increase in the number of modern, technologically advanced pieces of construction equipment a company uses—either owned or rented. It is important to mention that all of these factors have begun via management's commitment to safety. If you have a sufficient number of safety professionals assigned to a job site this will also increase enforcement of OSHA regulations on the jobsite. The systems thinking model illustrates that there is a positive relationship that exists between the number of safety professionals assigned to a construction project and enforcement of OSHA regulations.

To enforce and comply with OSHA regulations, safety professionals will increase its use of accident reporting and investigation systems. It is the responsibility of safety personnel to establish and maintain a functional reporting and measurement system. Organizations are required, legally, to report on all accidents that occur during work performance. However, organizations have a greater need for accident reporting and investigation systems. "This need is based on the reporting of accidents for insurance premium calculation purposes and also as part of the safety management system to reduce the occurrence of accidents by analyzing and reporting on accident causation and highlighting areas where action is needed" (Rowlinson, 2004). As mentioned before, the objective of the reporting system is to not only monitor accident rates, but to identify accident causes and risk exposures, monitor the effect of site safety initiatives, and to estimate the costs of accidents. Reporting and investigation systems are another means of checking the safety status of the organization. Ultimately, as the use of accident reporting and investigation systems increase, the system should experience a decrease in the number of accidents on the construction project. This negative causal relationship is illustrated in the systems thinking model. Safety investment is another way that management's commitment to construction safety culture is visibly demonstrated.

There is probably no better way to provide the knowledge of safe working practices and hazard recognition than through effective training programs. Training programs should be provided for both management and labor. Training programs will vary throughout various organizations according to their needs and objectives. However, workers should be provided, at a minimum, an OSHA 10-hour training course in safety and jobsite hazard recognition or equivalent. Many construction companies require that their management level employees receive the 30-hour OSHA safety training or equivalent. As mentioned earlier in the text, there are three common types of training: induction training, refresher training, and ongoing training. Management can demonstrate their commitment to safety culture by paying for the various types of training as hours worked. This will emphasize to workers that safety is the main objective and the organization is willingly to make a financial investment in insuring the safety of its workforce.

Although safety is the responsibility of all within the system, safety should still be reiterated with the presence of safety personnel. The investment in safety personnel including safety managers, officers, and administration demonstrates that an organization is willing to increase efforts to insure the success of their safety program. Implementing any program and especially developing a safety culture is a difficult task to achieve. It is a job that should be given special attention by individuals who have been trained or educated in safety. "Training is more complicated than telling or showing someone how to perform a task. Training is the transfer of specific knowledge to trainees in such a way that the trainees accept and use the knowledge in the performance of their jobs." (Roughton and Mercurio, 2002). In the system thinking model, as the number of safety personnel increases, the amount of training including induction, refresher, and ongoing training will also increase. There is a positive causal relationship between the number of safety personnel that management has invested in with the amount of training that the workforce receives from its employer.

Training of our workforce cannot be emphasized enough. It is much less expensive to provide workers the necessary training they need to perform tasks safely and efficiently than to pay medical bills as a result of injuries caused by lack of training and experience. Lack of training has been attributed to the cause of many accidents that have been cited as "human error," in which an individual's negligent actions were the primary cause of the accident. Refresher training is one method of improving human error in the construction industry. Refresher training reinforces and reiterates the safe practices and precautions that will increase workers' safety and well-being on construction sites.

In the systems thinking model, human error has a positive causal relationship with accidents. As human error action on the job site increases, the number of accidents will also increase. The same positive relationship also exists with a decrease in human error—as human error decrease, the number of accidents caused will likely experience a decrease. In the systems thinking model training has positive causal relationships with both safety knowledge of workers and their commitment to the safety culture of their organization. There is no question that employee training significantly enhances the level of safety knowledge of workers. In the model, as training of the workforce increases, the average safety knowledge of the workforce and their commitment to the safety culture also increase. As a result of both corporate and project management level's visible commitment to safety, those individuals at the operational level will develop an inherent commitment to safety. When management "sets the tone" by visibly demonstrating their commitment, workers will be motivated to follow or practice the same culture of the organization.

The next major causal relationships that exist within this systems thinking model of construction safety culture revolves around the factor 'productivity.' Acquiring the proper, modern equipment for employees to perform tasks efficiently and safely is another major demonstration of management's commitment to the safety of their employees. As management's commitment to safety increase, so does the amount of resources it invests in modern, technologically advanced equipment. Equipment has a tremendous impact on the safety status of an organization. The safety of the most competent, safety-focused individuals can be compromised with the use of out-dated tools and equipment.

Over the years, the manufacturers of construction equipment and tools have shifted its focus not only on increased productivity, but also increased safety of the individuals who use them. For example, cranes are being designed with hi-definition monitoring systems which increase visibility of workers and activities that are occurring below. In addition to monitoring systems, anti-two block systems have become standard safety equipment on cranes. Cranes are just one example of the many, major advancements that equipment manufacturers have made to increase safety efforts in the construction industry. The American National Standards Institute (ANSI), the governing voice of standards for consumer goods in the United States has also increased its' standards for participating organizations to ensure the health and safety of workers that utilize the products. In addition to safety, a major advantage of technologically-advanced equipment is that it can increase productivity on the job site. There is also a positive causal relationship between the number of pieces of modern equipment a company uses (owns or rents) and the amount of productivity that is achieved on the construction project. In addition to safety, modern tools and equipment are designed for increased productivity. It is important to point out, that the increase in new state-of-the art equipment will also require workers to receive training on safe, effective operations of the newly, acquired equipment. Productivity plays a major part in other causal relationships in this systems thinking model

In most cases safety has never been the overall, driving principle (priority) of the construction industry. Typically, management overemphasizes production, cost, and even quality over safety (McSween, 2003). As previously stated, the reason that safety is not the overall priority of the construction industry is because safety is considered to be an overhead cost. It is an activity that does not directly yield profits. Most construction employers fail to realize the impact that safety can have on productivity. Workers commitment to safety is the result of training, experience level, and overall commitment of management itself. When workers embrace the safety culture of an organization they will not only become committed to achieving safety-related goals and objectives, but all organizational goals including productivity. When workers are confident about their safety and well-being in their work environment it is believed that they will work more efficiently to accomplish tasks.

The goal of any organization is to get the greatest performance from its workforce as possible. Often, workers are pressured by management to achieve high and sometimes unrealistic goals and milestones. The pressure to perform faster and produce more often causes workers to "cut corners" during activities to make up time. Because workers generally perform the same tasks daily they get complacent in regards to safety. They focus more on productivity, but neglect safety because they feel overconfident that their actions (cutting corners) will not lead to injury. The systems thinking model illustrates the negative causal relationship that exists between productivity and job pressure. As productivity increase, job pressure from upper level management to produce more decreases, and vice versa. As a result, another causal relationship exists—there is a positive causal relationship that exists between job pressure and accidents. The systems thinking model illustrates that as job pressure on workers by upper management increases, accidents occurring on job site will also increase, and vice versa. Of course, the goal is to achieve that latter—job pressure decrease and accidents decrease. There is a major difference between working fast and working efficient. When workers experience pressure from management they tend to work faster. Failure to tie-off and working without necessary personal protective equipment are two common examples of "cutting corners" that workers fail to perform to make up time on the jobsite.

The final relationship that exists in this loop of the system thinking diagram is between accidents and labor commitment to safety. The relationship that exists between these two factors is negative. The systems thinking model illustrates that as the number of accidents on a construction site decreases, labor/worker commitment to the safety culture of the organization increases. A decrease in accidents or zero-accident job site reinforces the notion that the organizational commitment to construction safety culture has paid off.

Throughout this thesis I have made references on how to achieve a construction safety culture. A zero-accident job site is a likely indication that a safety culture exists within that organization. Decreased accidents means that everyone in the organization, specifically the workers, have performed their tasks safely and in a manner which has prevented injury to themselves and others in the work environment.

The variable 'accidents' is also related to other important variables in the systems thinking model. There is a positive causal relationship that exists between accidents and an organization's experience modification rate. The other positive causal relationship exists between accidents and OSHA fines. Finally, a negative causal relationship exists between accidents and public perception.

An organization's EMR is directly impacted by the number of accidents that occurs in that company in a certain time period. As mentioned previously, the EMR of an organization is a comparison of that organization's workers compensation claim to other organization of the similar size. Many accidents on the jobsite result in workers compensation claims. According to the number of accidents an organization has experienced, an experience modification rating is assigned. The experience modification rate determines the annual insurance premium that companies must pay to insure their operations. The systems thinking model illustrates that as the number of accidents an organization experiences increases, the company's experience modification rate also increase. As managers, we strive to reduce our organizations experience modification rate to reduce costs of operation. The average experience modification rate is 1.0. Falling under this number for example, an EMR of .80, means that the organization has an above average rating in regards to safety. Anything above 1.0 indicates that an organization is above its industry counterparts in regards to safety. The latter indicates a need for an effective safety program. If the EMR increases, the overall costs of operating the construction business will also increase. This positive causal relationship is illustrated in the systems thinking diagram.

Accidents that result in injury and/or death typically involve penalties issued by OSHA. The systems thinking model illustrates the positive relationship between accidents and OSHA fines. The Occupational Safety and Health Act of 1970 placed the responsibility of providing a safe and healthy working environment on employers. Failure to comply with OSHA regulations results in fines. The following table provides a good representation of the severity of the safety problem for the construction industry.

The Table 6 presents the total amount of violations and the amount of money collected in fines in 2002.

Table 6. OSHA Violations and Penalties in 2002 (OSHA, 2002)

| **OSHA's Federal Inspections by Type of Violation (Fiscal Year 2002)** | | | |
|---|---|---|---|
| **No. of Violations** | **Percent** | **Type** | **Current Penalties ($)** |
| 54,842 | 70% | Serious | 48,312,043 |
| 20,749 | 26% | Other-than-Serious | 2,145,151 |
| 1,969 | 2.50% | Repeat | 7,710,736 |
| 416 | 0.50% | Willful | 11,799,539 |
| 231 | 0.30% | Failure to Abate | 597,301 |
| 226 | 0.30% | State Inspections | 2,268,508 |
| 78,433 | 100% | Total | 72,827,278 |

In 2002 alone, OSHA issued citations for 78, 433 violation totaling $72,827,278 in fines. Whether employers spend the money on an effective safety program or spend money in fines resulting from accidents, the fact is that safety will impact the overall costs an organization, one way or another.

Public perception plays a rather unique and important role in this entire systems thinking model. In the systems thinking model, there is a negative causal relationship between accidents and public perception of the construction organization or system. The model illustrates that as the number of accidents increase, there is a decrease in the public's perception of that construction system including the client/owner and the general contractor. Image is everything. No matter how spectacular a project or structure may be, the poor safety culture of the system could destroy the public's perception of the project and all parties involved including the owner/client and the contractors.

Public's perception of an owner/client and contractors may be a driving force for making a commitment to construction safety culture. No organization wants to be the target of bad press. Public perception can play a role in the financial interests of organizations. For example, if it is publicly known that a contractor has subpar performance with respect to safety it may be difficult to pre-qualify for various projects. The average owner will not carry a company with a poor safety history on the owner-controlled insurance program (OCIP) because these companies are a liability to the owner. Implications of poor safety culture exist for the owner as well. Also, if owners/clients have a poor safety history on their projects this will affect the cost of insurance premiums. Public's perception of the owner may also affect the success of the business once it has been constructed and open for operation. Therefore, in response to public perception, both owners and corporate level management must make a full commitment to the construction safety culture of the system. The systems thinking model illustrates a positive causal relationship between public perception and the owner/client commitment to construction safety culture. It is important to point at that the relationship between these two variables may also exist as a negative causal relationship. As public perception of an owner/client or project goes down, the owner's commitment to construction safety culture may increase.

Whether the relationship between public perception and owner commitment to safety exist as negative or positive, the relationship results in the owner/client increasing its standards and criteria for prequalifying contractors to construct their projects. The systems thinking model illustrates the positive relationship between the owner/client commitment to construction safety culture and contractor selection criteria. As the owner's commitment to construction safety culture increases there is an increase in the number of contractor selection criteria that the owner uses to screen or pre-qualify potential contractors. The vision of safety must be shared by all parties involved in the construction project. Adversarial relationships often exist between the owner/client and contractors during the construction process. These relationships tend to improve sometimes only after the owner and contractor have multiple business ventures. To achieve a safety culture, these differences between owners and contractors must be set aside immediately to accomplish a more important goal of a zero-accident construction project. Safety is a team process; owners and contractors cannot exist as separate entities. In every team each individual is assigned responsibilities that are critical to the overall success of the team. Owners and contractors must share the same vision for success of safety culture. Owners must have a stringent prequalification/screening process in which they are able to determine if the shared vision of safety culture exists in prospective contractors. This same process must be repeated when general contractors select potential sub-contractors.

In the model, there is no definite ending point. When systems thinking models are converted into system dynamics models it is important to run the model long enough to see the dynamics of the problem or issue play out.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

This systems thinking model provides an understanding for the interconnectedness of the many factors requisite in achieving a construction safety culture. The ultimate goal of construction safety culture is to reduce and/or eliminate the number of accidents in the industry, improve the productivity of our workforces, build more positive business images, reduce cost associated with accidents, produce highly trained, competent workers, and select more safety-conscious subcontractors, vendors, and design personnel. This study has revealed that the major underlying cause of failure of safety culture in the construction industry results from management's (both corporate and project level) lack of commitment to safety and the enforcement of its safety program. Of course, construction safety culture may not be limited to just these variables that have been presented in this thesis. Admittedly, this model may not result in a "one-size fits all" solution to achieving construction safety culture. Creating systems thinking models entails that we are predicting the behavior of a system over time. This systems thinking model of construction safety culture provides a vivid image of those factors that are critical to the establishment and maintenance of construction safety; however, no model will ever be 100% accurate. Kim (1992) states that "drawing out future behavior means taking a risk—the risk of being wrong. The fact is, any projection of the future will be wrong, but by making it explicit, we can test our assumptions and uncover inconsistencies that may otherwise never get surfaced." When making predictions, especially on the behavior of complex systems we run the risk of having some inaccuracies; however the systems thinking approach does provide one guaranteed benefit—assessment.

An assessment tool is critical to the success and maintenance of any program. The goal of a safety program assessment is to ensure that the goals and objectives of the program are being met, and to determine which criteria, procedures, and/or practices may be lacking and in need of improvement. All-in-all, an assessment tool serves as a "reality check" of our beliefs and speculations about the status of our organization's safety program. McSween (2003) provides several objectives of safety assessments including: (1) identifying existing efforts and develop a plan that builds on these efforts, (2) incorporate input from key personnel, (3) identifying high risk areas, (4) identifying training needs, and (5) build management support for implementation. To assess the status of a safety culture within a system, an organization must determine the collective attitudes of all employees (both management and operational levels) about the various factors that make up that system. This is best achieved by performing confidential questionnaires (perception survey), interviews, focus group meetings, and visits to assess workplace conditions and possible causes to incidents. Because safety is such a problem for the construction industry, it is best to have a system which allows the system to be continually assessed; not only after an incident has occurred, but also when we feel that the program is performing at it best. Historically, organizations have taken the reactive approach to safety implementation. Only after accidents have occurred do they attempt to figure out what aspect of their safety program has failed. Data supports the notion that the reactive approach to construction safety has been unsuccessful.

It is recommended that this system thinking model of construction safety culture be converted to a system dynamics model to serve as an assessment tool. The benefit of the systems thinking/system dynamics approach to construction safety culture is that it identifies system errors and allows problems to be addressed before accidents occur. Hence, system dynamics is a proactive approach to solving problems. In order to convert the mental model that has been created in this thesis into a system dynamics model, we must take the information from the causal relationships and apply parameter values to them that have been taken from various sources, i.e. statistical analysis of time series data. The numerical data may then be fed into modeling and simulation programs, such as Vensim, to simulate the behavior of the various factors within the system. The benefits that system dynamics may have on safety and the construction industry, as a whole, may be endless. The ultimate benefit is that if we, as managers, have a tool that provides information on potential failures within our safety programs we can direct our attention to that source that requires improvement or change all together. Corrective action to prevent further injuries and/or fatalities may be initiated before they become reality. Systems thinking and system dynamics are appropriate tools for understanding the interconnectedness of those factors that must exist to create and maintain a safety culture in complex, construction systems. Past research has studied safety in various ways that have seemed less successful in determining why this problem has plagued the industry for far too long. Systems thinking illustrates that all aspects of construction safety culture have failed because management has failed to make and demonstrate a full commitment. Making safety the so-called "1$^{st}$ Priority" has proved only to be a catchy slogan on company banners. To reduce injuries and fatalities in the construction industry, we must make a shift from safety being our "1$^{st}$ Priority" to our way of life—our culture.

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