MAJOR THEORIES OF CONSTRUCTION ACCIDENT CAUSATION MODELS: A LITERATURE REVIEW

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ABSTRACT

Accidents in construction sites are unplanned occurrences involving movement of persons, objects or materials which may result in injuries, damages and losses to properties or people. The majority of accidents happen as result of unsafe acts and unsafe conditions. Since all hazards in construction workplaces are not always possible to be identified and eliminated therefore effective accident investigation programs are essential for collecting critical data. Construction accidents can be prevented just by identifying the root causes of accidents, which is possible by accident investigation techniques such as theories of accident causation theories and human errors; these theories provide explanations of why accidents happen. This paper is aimed at reviewing the most common accident causation theories which mainly focus on people variable, management aspects and physical characteristics of hazards. The intention of this paper is to enhance the overall understanding of the accident causation theories which signifies the identification of how hazards in the construction workplaces cause losses. On the contrary the weakness of these theories is that they do not offer extensive strategic guidelines for managers and supervisors for reducing risks at construction workplaces. Moreover, these theories imply the inappropriate perception that accidents in workplaces can be prevented if human errors are eliminated. Strategies need to be revised to manage the risk and workers need to be watchful of it. A great number of accidents can be prevented if the safety management system reflects both natural degradation and these intrinsic threats. The initial step in developing such system is preparing a model which shows the interaction between the accident likelihood and organizational tasks and activities in the presence of these hazards.

KEYWORDS: *Construction safety, Hazards, Construction accident, Accident causation theory/model, Accident prevention*

I. INTRODUCTION

Construction industry plays an important role in improvement of countries' economic growth. Despite the contributions to economical growth, construction industry has always been blamed for the high rates of accidents and fatalities; this issue has placed the construction industry among the industries with unreasonable rates of accidents, permanent and non permanent disabilities and even fatalities. There are many evidences in representing construction industry as a hazardous and inconsistent industry [1]. High rates of accidents and fatalities in this industry have placed it among hazardous industries. The costs of injuries, which are direct and indirect, Workers' compensation insurance, legal liability as well as legal prosecutions have pushed parties involved to seek ways of mitigating these hazards [2]. The world rates of occupational injuries, illnesses and fatalities are still alarming. Nationally, more than 55,000 people die from occupational hazards annually, 294,000 illnesses and 3.8 million are getting injured. The accidents' annual direct and indirect costs have been appraised to be from \$128 billion to \$155 billion. Construction accidents lead to delay in project completion, increase the expenses and ruin the reputation and reliability of constructors [3]. According to report by NSC (National Safety Council) in 1996, 1000 construction workers died at work and 350,000

suffered disabilities. Although Construction workers constitute only 5% of the United States' workforce, an out of proportion rate of 20% of all occupational fatalities and 9% of all disabling occupational injuries relate to construction industry [4].
Construction accidents can be prevented just by identifying the root causes of accidents, which is possible by accident investigation techniques such as theories of accident causation and human errors. Accident prevention has been defined by Heinrich as ‘An integrated program, a series of coordinated activities, directed to the control of unsafe personal performance and unsafe mechanical conditions, and based on certain knowledge, attitudes, and abilities’. Some other synonyms for accident prevention have been emerged later such as loss prevention, loss control, total loss control, safety management, incidence loss control [4]. This paper is aimed at reviewing the most common accident causation theories, which are focused on people variable, management aspects and physical characteristics of hazards. This paper tries to enhance the overall understanding of the accident causation theories, opportunities, weaknesses of them and effective strategies to overcome the deficiencies. The importance of understanding the accident causation theories is in recognizing how hazards in the construction workplaces cause losses.

II. THEORIES OF CONSTRUCTION ACCIDENTS CAUSATION

2.1 Heinrich Domino theory of accident causation

Heinrich was the pioneer in the Accident causation theories. He described the accidents causation theory, man and machine relationship, frequency and severity relation, unsafe acts reasons, management role in accident prevention, costs of accidents and the impact of safety on efficiency [5]. According to statistics on accident’s reports Heinrich deduced that 88 percent of accidents are due to unsafe act of workers, 10 percent due to unsafe conditions and 2 percent of all accidents are associated with act of God such as natural disasters. According to his analysis Heinrich defined accident as ‘an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof’ [4]. Heinrich (1959) described the accidents causation theory, man and machine relationship, frequency and severity relation, unsafe acts reasons, management role in accident prevention, costs of accidents and the impact of safety on efficiency (See Figure 1).

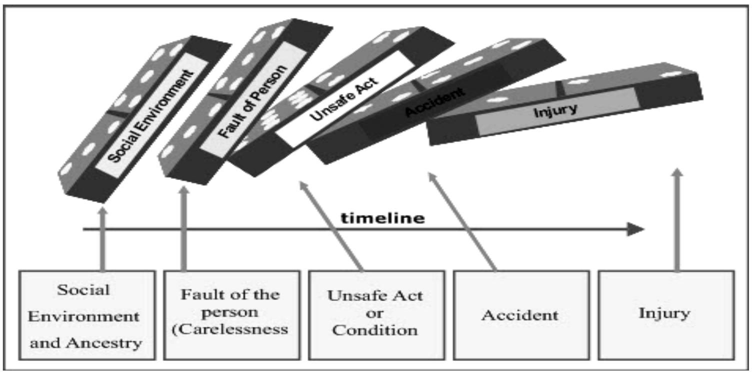

Figure 1: Domino theory of accident causation

Heinrich established the ‘Domino theory’ which is based on five sequential factors as following [6]:

i. Ancestry and social environment; Ancestry and social environment are the process of acquiring knowledge of customs and skills in the workplace. Lack of skills and knowledge of performing tasks, inappropriate social and environmental conditions will lead to fault of person.
ii. Fault of person (carelessness); Faults of person or carelessness are negative features of a person personality although these unwanted characteristics might be acquired. The result of carelessness is unsafe act/conditions.
iii. Unsafe act and/or mechanical or physical condition; Unsafe acts/conditions include the errors and technical failures which cause the accident.
iv. Accident; Accidents are caused by unsafe acts/conditions and subsequently lead to injuries
v. Injury; Injuries are the consequences of the accidents.

The Heinrich's domino theory is comprised of five standing dominos which will fall one after the other if the first domino (Ancestry and social environment) falls. The accident can be prevented only if the chain of sequence is disturbed, e.g. the unsafe act/condition can be eliminated in order to prevent the accidents and associated injuries. Heinrich efforts on accident causation theory can be summed up into two points, People (Human) who are the main reasons of accidents and Management which has the responsibility of preventing the accidents (having the power and authority) [7]. Heinrich's domino theory was blamed for the process of simplifying the human behavior control in accidents. Heinrich domino theory became the basis for many other studies on accident causation model with emphasis on management role in accident prevention; these studies are called Management Model or Domino's Updated Model. Management models believe that management system is responsible for occurrence of accidents [4].

2.2 Management-based theories

Heinrich's opinions were criticized for too much simplifying the control of human behavior in accident causation; however Heinrich's research and work was foundation for many other researchers. The domino theory of Heinrich has been modified and updated over the years with greater emphasis on management as an original cause of accidents. The results of this updating were named as management-based theories or updated domino models. The management-based theories define management as responsible for causing accidents and the theories attempt to recognize failures within the management system. Updated domino sequence (Bird 1974), the Adams updated sequence (Adams 1976) and the Weaver updated dominoes (Weaver 1971) are some examples of management-based theories. There are other management-basedtheories which are not domino-based such as Stair step model (Douglas and Crowe 1976) and the multiple causation model (Petersen 1971) [4].

2.2.1 Multiple causation model (Petersen, 1971; Non-Domino-based model)

The Heinrich domino theory is structured on theory that an accident is caused by a single cause. Petersen (1971) developed a model based on management system rather than individual (See Figure 2). Petersen believed that there are two major features of the events which leading to an accident, namely an unsafe act and an unsafe condition [6, 8]. However, there are more than single cause which contribute or lead to both unsafe act and unsafe condition and finally occurrence of an accident. Unlike simplified theory of domino, there are causes and sub-causes when an accident happens. Through identification of these multiple contributing causes of accident, the unsafe acts and unsafe conditions should be prevented from arising [9, 10].

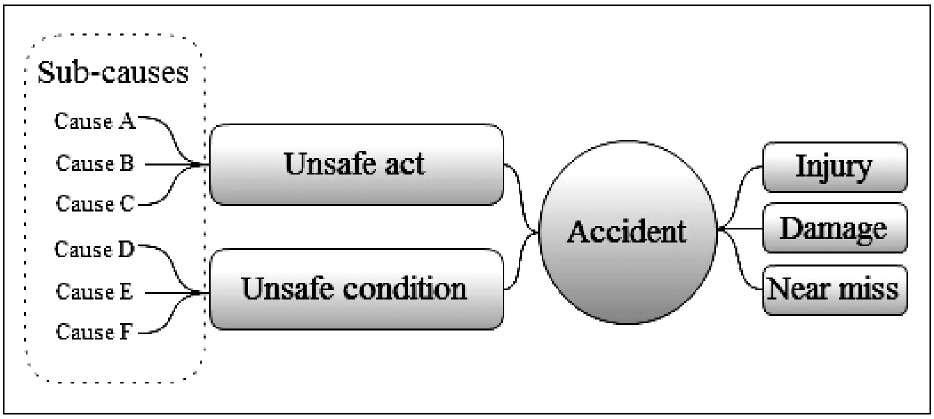

Figure 2: Multiple causation theory [11]

2.2.2 Weaver updated dominoes (Weaver, 1971; Domino-based model)

Weaver developed an accident theory based on Heinrich domino theory with emphasis on the role of management system. Weaver regarded the dominoes three, four and five of Heinrich dominoes as errors caused by operation. Weaver tried to reveal the role of operational errors by not only determining the cause of accident; but also identifying the reasons that the unsafe act was allowed to continue and determining whether the management had the safety knowledge to avoid the occurrence of accident. Weaver set questions in order to clarify the underlying causes of accident; if management had the knowledge of safety and relevant standards of the work, what was the reason that the worker was confused to continue the work in unsafe condition. The answers to the questions can manifest the underlying operational errors which caused the accident [4, 6].

2.2.3 Updated domino sequence (Bird, 1974; Domino-based model)

Bird and Loftus (1974) updated the "Domino theory" in order to reflect the role of management system in the sequence of accident causes defined by Heinrich (Domino-based model) (See Figure 3). The updated and modified sequence of events is [6, 12]:

i. Lack of control/management (inadequate program, inadequate program standard, inadequate compliance to standard)
ii. Basic causes/origins (basic causes: 1-personal factors, 2-job factors)
iii. Immediate causes/Symptoms (sub-standard act and condition)
iv. Incident (contact with energy and substance)
v. Loss (property, people, process)

The update domino sequence can be used and applied to all types of accidents and is fundamental in loss control management [9, 10].

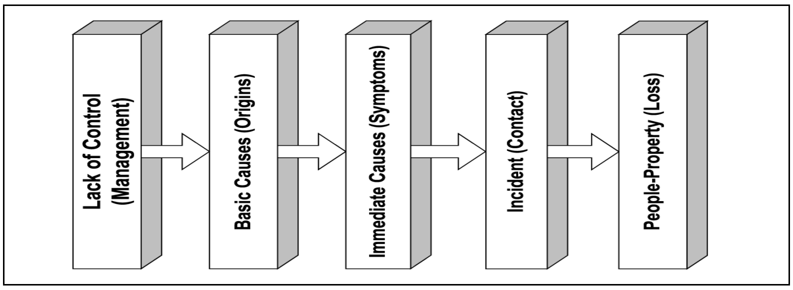

Figure 3: Updated Domino sequence of accident causation theory (Bird 1974)

2.3 Human errors Models

2.3.1 Behavior models

Behavior model blame humans for occurrence of accidents. Errors in this approach are likely to be done by humans in different environmental conditions. Humans are blamed just for their unsafe behavior [13]. Rigby (1970) defined human error as 'anyone set of human actions that exceed some limit of acceptability'. Behavior models are mostly based on the accident proneness theory indicating that some people have specific characteristics which make them more susceptible of having accidents. Many behavior models have developed by researchers in order to describe the reasons for accidents repeaters such as the 'Goals freedom alertness theory' (Kerr 1957) and the 'Motivation reward satisfaction model' (Petersen 1975) [4, 6].

2.3.1.1 Goals Freedom Alertness Theory (Kerr 1957)

Goals Freedom Alertness theory of accident reflects the idea that the psychologically satisfying and desirable work environment lead to the safe performance of tasks and activities. The theory expresses the idea that accidents are low-quality activities due to unpleasant psychological work environment. Alertness will be lowered as a result; the higher and the richer the climate is in terms of economic and non-economic opportunities, the more chance of alertness is created. The result of alertness is a higher quality performance and finally an accident-free work environment. A psychologically satisfying work environment is a place where the workers are encouraged for performing their best, taking part, arranging achievable goals and innovating methods of achieving those goals. Workers are free for participating in identifying and solving work problems; the management system permit their workers to define goals for themselves and also let them innovate methods of achieving their goals. Management can improve the environment of work for workers by managerial techniques, participative methods, setting defined goals for workers etc [4, 8].

2.3.2 Human factor models

Human factors model is based on the idea that the human errors are the major cause of accidents; however human unsafe behavior as well as poor design of workplace and environment which do not consider the human limitation, are considered as contributory factors. Ferrel theory (Ferrel 1977), the Human-error causation model (Petersen 1982), the McClay model (McClay 1989) and the Dejoy model (Dejoy 1990) are samples of human factor model [4, 6, 8].

2.3.2.1 Ferrel Theory

Doctor Russel Ferrel (1997) developed his theory of accidents based on a chain of human factors causes (See Figure 4). He believed that the human errors are the main causes of accidents occurrence and they are caused by the following factors [4, 6, 7, 8]:

i. Overload; the overload factor reflects the incompatibility between the load and the capability of the human. The result of this mismatch is anxiety, pressure, fatigue and emotions that can be intensified by physical environment such as dust, light, noise, fumes etc. where the person is working.
ii. Incorrect response; the incorrect response by the person is caused by the incompatible situation where he/she is working in.
iii. Improper activity; the person perform the activity improperly either due to lack of knowledge of appropriate way of performing the activity, or intentionally take the risk.

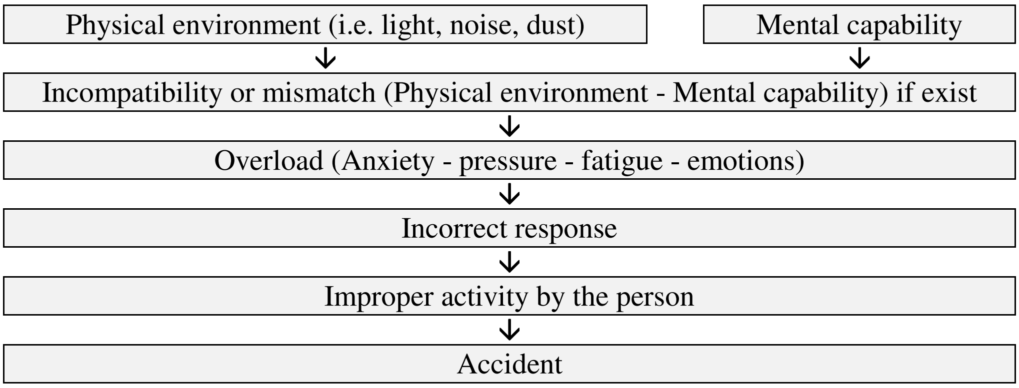

Figure 4: Ferrel's theory of accidents causation

2.4 The 'Swiss Cheese' Model

The 'Swiss Cheese' accident causation model was first developed by James Reason (1970-1977) as a linear accident causation model. The theory is currently widely used since it simply suggests that the organizations try to prevent accidents by defenses in order not to allow the risks and hazards become loss (See Figure 5). These organizational defenses are divided into two groups [16]:

i. Hard defenses which are automatic alarming systems, physical obstacles, engineered safety appliances and weak points included into the main system for protection such as fuses.
ii. Soft defenses which are dependent upon the personnel and procedures; regulations of required performance, investigation, checking, regular procedures of performance, education and training, supervision and working permission. Soft defenses also involve supervisors and operators as the pioneers. Losses to people, equipment, assets are the potential consequences of hazards in an organization.

Reason claims that a trade-off exists between the level of protection provided for the product and the production; the risks included in any product should be defended by the organization for the well being of customers but the level of safety and protection should be equivalent to the risks associated with the work [4]. If the level of protection is higher than required then the company will not be commercially profitable and if the protection level is less than the associated risks the occurrence of accident is susceptible and the organization will lose the business opportunities. The equilibrium between the protection and the production is essential for the durable commercial survival of the business; since the production process is visible the product can be managed and inspected for the desired output but the level of protection can be measured only after the inadequacy is determined [15, 16].

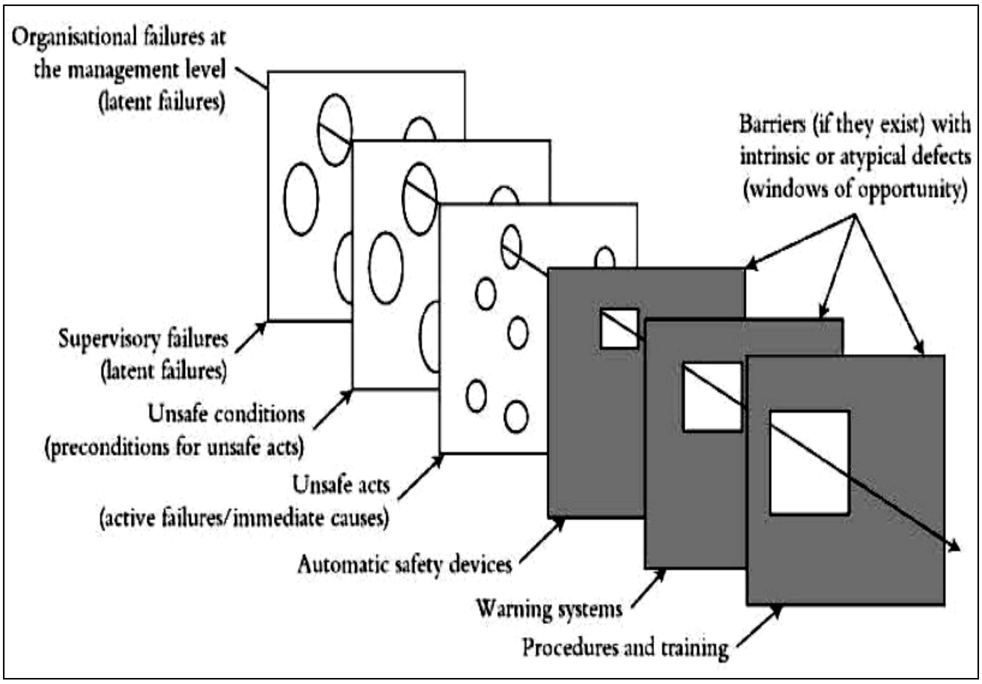

Figure 5: Swiss Cheese Accident Causation Model (James Reason, 1970-77)

Although organizational accident defenses are seen as obstacles which prevent the hazards from converting into losses, the obstacle and barriers have holes in them as slices of Swiss cheese; Reason called his model Swiss cheese because of theses defects in the organizational defenses [14, 15]. The foremen of an organization are in charge of the sharp-end procedures which represent the "unsafe acts" slice of cheese in the model. The holes in the unsafe act slice are the human errors or unsafe acts. Reason believed that accidents are caused by active failures and immediate causes which are the results of mistakes, slips and violations of standards. Accidents can be either caused by singular human error or a combination of them as immediate causes of accidents; the combination of violation and mistake is a very usual cause of accidents [4]. There have been a lot of improvements in technology and engineering which means the technical failures are tried to be eliminated; therefore most of the time human errors are blamed to be the major cause of accidents. On the contrast the more improvements have been achieved in technology and engineering, the more number of accidents caused by human errors are reported. Unsafe condition is represented by holes in the next slice of Reason Swiss cheese model; the unsafe condition and the psychological risk factors are the contributory factors to unsafe act of workers. Unlike active failures and immediate causes in previous slice, the holes in this slice are the hidden contributory factors of accident. The relationship between unsafe condition and unsafe act is a one-to-many interaction; unsafe condition can lead to many hazards and unsafe acts [14, 16].

2.5 Accident Root Causes Tracing Model (ARCTM)

Accident Root Causes Tracing Model (ARCTM) shows further advances of many of the previous accident models. Many important rules of the model have been derived from the effort of Heinrich (1959), Petersen (1971), Bird (1974), Ferrell ((as referenced in Heinrich et al. (1980)], and Petersen (1982). The main reason of this model is to provide an investigator with an easy model for identification of root causes of construction accidents, compared to sophisticated models of accident's investigation. ARCTM expresses the idea that accidents are caused by one or more of the following factors [8, 17]:

i. Not identifying the unsafe condition existed before or advanced after an activity starts (Unsafe condition)
ii. Performing the task despite the worker realizes the existence of unsafe condition (reaction of worker to unsafe condition)

iii. Performing unsafe act without consideration of task's environmental condition (Unsafe act of worker)

2.5.1 Unsafe condition

Unsafe condition is condition where workplace and its environment are not safe according to safety and health standards. Unsafe conditions include wrong scaffolding, openings, protruding reinforcement bar and etc. ARCTM defines two types of unsafe conditions in terms of when they occurred in task sequence and who made the unsafe condition to advance [4]:

i. Unsafe condition which exists before commencement of a task
ii. Unsafe condition which progresses after commencement of a task

The ARCTM suggests that the unsafe conditions are the result of one of the following factors [4, 8]:

i. Management acts or omissions; Management may, for instance, assign workers to do tasks beyond safety standards, not providing workers with protective equipment, not providing safeguards for equipments etc.
ii. Worker or coworker unsafe acts; Inexperienced workers or coworkers may perform unsafe acts
iii. Events not related to human act; Natural disasters such as earthquakes, storms, floods etc. may lead to unsafe conditions.
iv. Unsafe conditions which initially exist in construction workplaces; Examples of initial unsafe conditions include rough land situation, scattered materials, hidden holes etc.

2.5.2 Reaction of worker to unsafe condition

Reaction of workers to unsafe conditions depends on the fact that whether the worker identifies the unsafe condition or not and can be summarized as follows [4, 17]:

i. The worker does not identify the unsafe condition; therefore there is no risk and hazard consideration by the worker. There is a fact that some unsafe conditions can not be identified such as not-human-related conditions or human factors violation. Human factors violation may lead to injuries namely cumulative trauma disorders, carpal tunnel syndrome, fatigue, overexertion etc.
ii. The worker identifies the unsafe condition and recognizes the related hazards; reaction might be safe act and quit the task until the unsafe condition is modified or disregard the unsafe condition and continue the task (unsafe act). The reasons of failure to identify unsafe condition and also the reasons that worker continue the task after identification of unsafe condition should be investigated by management.

2.5.3 Unsafe act of worker

A worker might perform unsafe acts regardless of the condition of the work (Safe or unsafe condition). In this situations worker might continue the work in unsafe condition or performing the task without safety standards consideration; working without protective equipments or working when lack enough sleep etc [4, 17].

2.5.4 Application of ARCTM in accident investigation

Following the occurrence of accident, the investigators use preliminary investigation and reporting tool for investigation of accident. The next step is to critically investigate the accident using the ARCTM which states that the accident is due to three root causes namely unsafe condition, reaction of worker to unsafe condition and unsafe act of worker. The ARCTM structured model try to help the investigator to identify how the root causes have advanced by series of questions and possible answers about the root causes (See Figure 6). The numbers shown in brackets represent specific issues that should be recognized and modified in order to avoid reoccurrence of accident. The numbers 1, 2 and 3 in brackets represent worker training problem, worker attitude problem and management procedure problem. Actually these problems are not the root causes of accidents and ARCTM insists on cooperation between workers and management to prevent the reoccurrence of accidents. ARCTM application in accident investigation includes the following steps [4, 17]:

i. The first step is to determine the existence of any unsafe condition either before or after commencement of an activity. If the worker was exposed to an unsafe condition, the existence and advancement of unsafe condition should be identified by the questions shown in table. ARCTM suggests that unsafe condition is caused by four factors as following:

- **a.** Management acts or omissions: The accident investigator should determine why the unsafe condition was not recognized by management and who is in charge of that. Number [3] shows that there is a problem with management system.
- **b.** Worker or coworker unsafe acts: The investigator should realize whether the cause of unsafe condition was social, peer or management pressure. Worker attitude problem lead to social and peer problem while management process problem lead to management pressure. Knowledge of (co)worker about the correct way of doing the task should be identified by the investigator. If the worker knew how to perform the task, then the worker has attitude problem but if the worker did not knew the correct way of performing task then the problem is due to training. The frequency of unsafe act by worker should be determined, if the worker occasionally/always perform unsafely then the problem is related to the management since there should be inspection programs which discourage the unsafe acts of worker. If the worker had committed the unsafe act for the first time then the previous question is to be answered.
- **c.** The investigator should identify whether the management or worker were able to recognize the unsafe condition or not. If they were capable of identifying the unsafe condition then the problem is related both to worker training and management process, but if identification of unsafe condition was impossible then the accident was inevitable.

ii. The investigator should determine that if an unsafe condition was existed either before or after the task, was the worker recognized it.

- a. If the worker did not recognize the unsafe condition then the investigator should find the reasons of this failure through the questions of ARCTM approach. If the worker assumption on condition was wrong then the reasons should be investigated whether it was due to the incapability to identify the unsafe condition of task because of lack of knowledge, or the task was new to the worker. Worker's training is the basic problem of accident in this situation. If the worker was informed that the condition was safe then the investigator should recognize the informant and the reasons that the informant considered the condition as safe. If a coworker considered the condition as safe and informed the worker then there is a problem related to worker training or attitude, but if the management informed the worker that the condition is safe then the management process is considered to have problem. Whether the worker followed the appropriate procedure of performing task should be identified by the investigator, if not so then the investigator should find out if the worker knew about the appropriate procedure. If the worker had the knowledge about the appropriate procedure the problem is related to his/her attitude, but if the worker did not have the knowledge then the problem is with the worker training. The frequency of performing the task in wrong way by worker should be determined by investigator. If the worker always or occasionally uses the wrong procedure of performing the task then the problem is related to the management since management should inspect and modify the wrong way of performing tasks, but if the worker performs the task wrongfully for the first time then the problem should be traced in the previous question.
- b. The reason behind the inappropriate decision made by the worker when he or she recognized the unsafe condition and continued the task should be determined by the investigator through the questions in ARCTM approach. Whether the worker regarded taking the task was essential or he/she was forced by social, peer or management should be investigated by the investigator. If management pressure resulted in decision then the problem is related to management process, but if the social or peer pressure resulted in decision to continue the task then the problem is with the attitude of the worker. Whether the worker did not consider all characteristics of the condition should be determined by the investigator; if so then the problem is related to the training of the worker. Whether the worker has though that he/she could continue performing the task safely should be determine by the investigator; if so there is a worker attitude problem. Whether the worker knew the appropriate way of doing the task

or not should be identified by the investigator; if the answer is positive the problem is related to attitude of the worker but if he/she did not knew the appropriate way then the problem is related to worker training. Whether the worker always/occasionally continued the task when he/she recognized the unsafe condition should be identified by the investigator; if the worker did so then it is a management-related problem because the management should inspect and modify the unsafe act of workers, but if the worker continued to perform the task despite he/she recognized the unsafe condition for the first time then the problem should be traced in the previous question.

iii. Whether the worker acted unsafely or not if there were no unsafe conditions confronted by worker involved in accident (before or after commencement of task) should be identified by the investigator. The investigator should review the step 1 for identifying unsafe conditions around the accident when the worker did not commit any unsafe acts; but if the worker acted unsafely then the investigator should follow the questions to identify the reasons of worker decision. Whether the unsafe act was caused by social, peer or management force should be determined by the investigator; if social or peer act resulted in unsafe act then the problem is related to the worker attitude, but if the management pressure resulted in unsafe act the problem is related to management process. Whether the worker knew the appropriate way of performing the task or not should be identified by the investigator; if the worker knew the problem is with his/her attitude, but if the worker did not knew the correct way of performing the task the problem is related to the worker training. The frequency of performing task in unsafe manner should be determined by the investigator; if the worker always/occasionally perform the task in unsafe manner the problem is with the management process because the management should inspect and modify worker's unsafe act, but if the worker perform the task unsafely for the first time then the problem should be traced in the previous question.

The ARCTM approach can be summed up into three main principles; Workers who are new and do not have enough knowledge and training on performing their tasks should not be hoped for recognizing all unsafe conditions or even preventing accidents from happening. Workers who have enough knowledge and training about how to perform their tasks will not be free of accidents if they do not change their behavior in terms of safety; and finally management process has to be planned as to inspect and eliminate the unsafe conditions faced by workers proactively; management should continuously mention and reinforce the significance of safety among workers [8, 17].

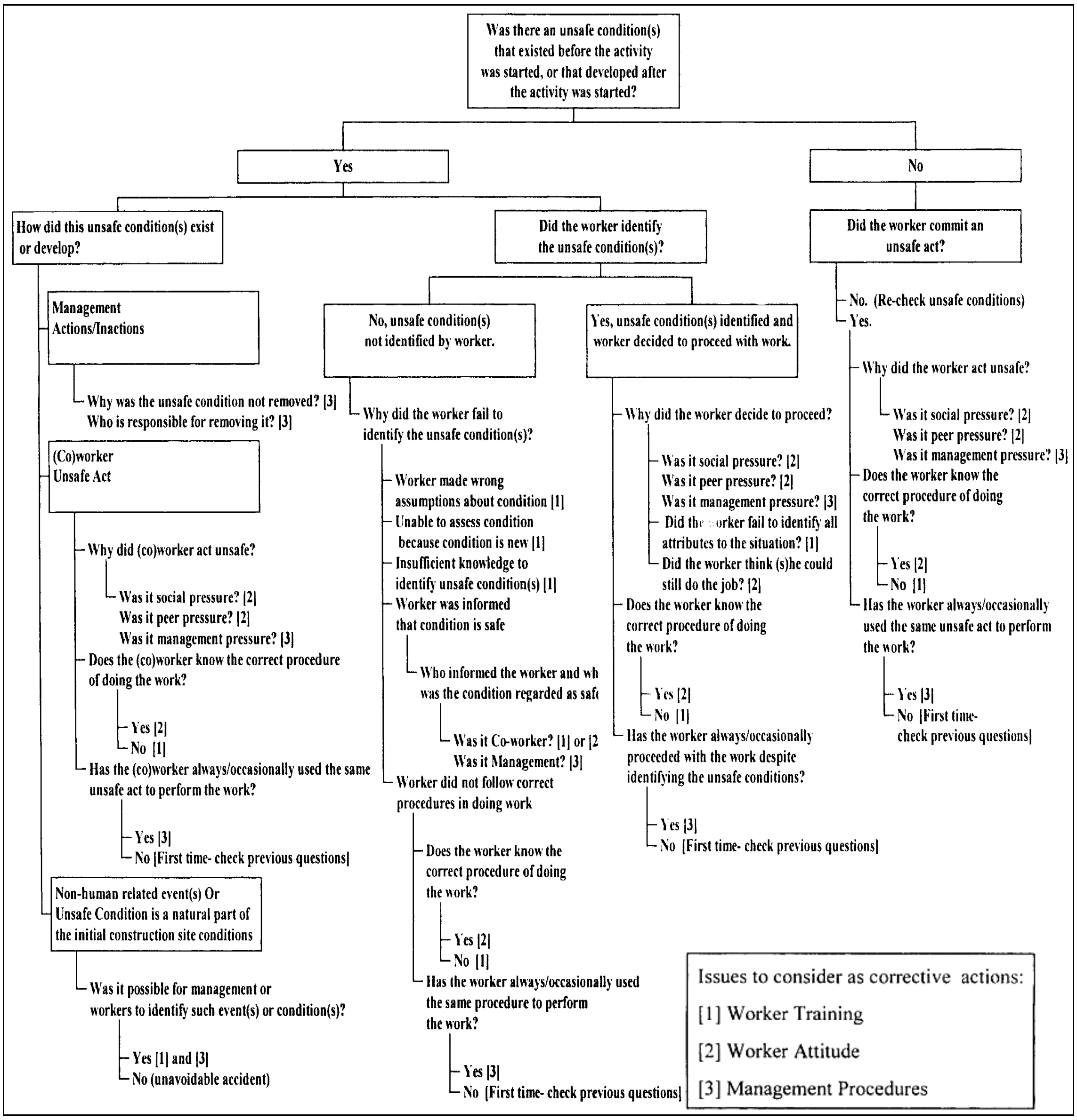

Figure 6: Accident Root Causes Tracing Model (ARCTM) [4, 17]

2.6 Hierarchy of causal influences

The approach in the model of 'Hierarchy Of Casual Influences' is close to opinions of Kletz (2001) and Svedung and Rasmussen (2002) and others who believe that there is a lack of suitable and versatile accident causation model in handling high versatile socio-technical procedures like those exist in construction industry. The model proposes that the lack of adequate communication between work team, workplace, equipment and materials can lead to creation of 'immediate accident circumstances'. The performance of worker, site, equipment and material agents which could ultimately lead to or prevent an accident, relying on proximal effects in turn; such factors are named 'Shaping factors' in this model. Shaping factors are dependent on other effects away from the center of model named 'Originating influences' (See Figure 7) [9, 18].

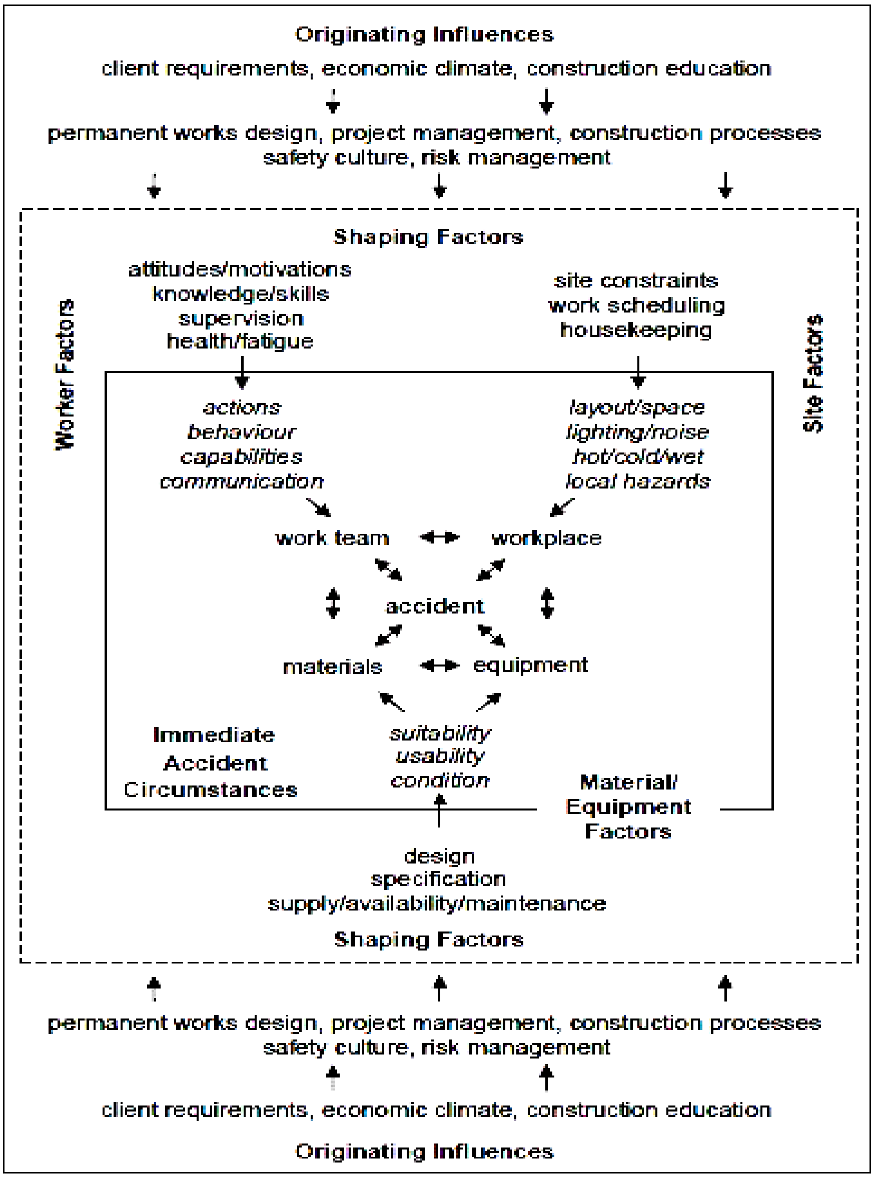

Figure 7: Hierarchy of casual influences in construction accidents [9, 18]

2.7 Behavior-based safety (BBS)

Behavior-based safety (BBS) is the main area to consider when discussing safety issues in construction. BBS are safety techniques which have the capacity to enhance safety and health issues if it is implemented in a safety supportive environment [19]. With regard to Furnham's (1994) Sequential Accident Model, Lingard and Rowlinson expressed that BBS techniques will not succeed if workers fail to recognize and understand the health hazards at construction sites. The integration of safety and health of construction workers into the early stages of planning and design is the ultimate aim of BBS systems [20, 21]. The integration of safety and health of construction workers into the early stages of planning and design is the ultimate aim of BBS systems. The systems of integration of safety into planning and design can identify general health and safety hazards which are related to different construction activities prior to commencement of activities in planning and design phase [22].

2.8 Modified Statistical Triangle of Accident Causation

Based on the Modified statistical triangle of accident causation (See Figure 8) when a hazard happens, the base of the triangle is the location where the hazard will be placed; this is called 'hazardous event'. The severity of the hazard will determine the movement of the hazard up the triangle. 'Near miss' is the term used for the lower base of the triangle which means that a hazardous event with no physical injury for instance zero severity. The intermediate part of the triangle represents the area of severity greater than zero and it means that the hazardous event causes an accident with physical injuries. The highest point of the triangle represents the most hazardous event which means that the accident occurs and the result is fatality and loss of human life. [22].

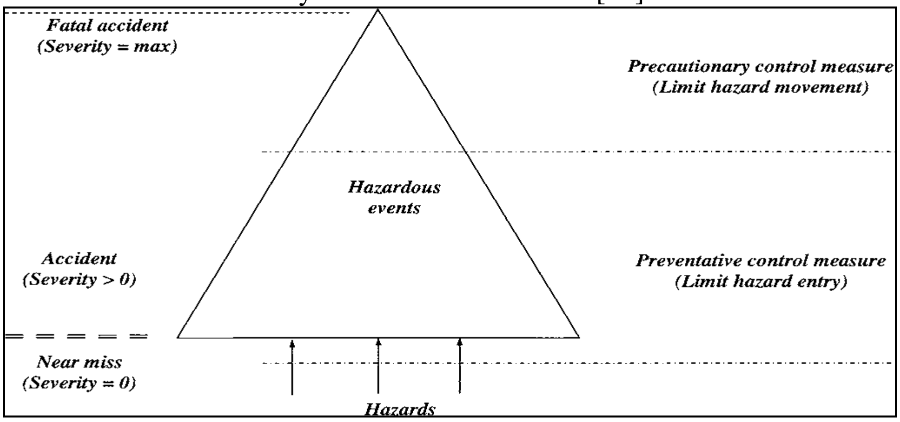

Figure 8: Modified Statistical Triangle of Accident Causation [22]

There are two main aspects in control and management of hazards in construction; avoidance of occurring of hazardous event and restricting the severity potential of hazards if the hazard happens. Based on Fig. 8 the first step is preventive control measures which include practices to restrict the entrance of hazardous event into the triangle by lessening the probability of happening of the hazard. Precautionary control measures are at the second step which is designed to restrict the movement of hazardous event through the upper part of the triangle; this step lessens the risk via lessening the severity of the hazard if it happens. [22].

III. RESULTS AND DISCUSSION

Theories and models of construction accidents causation are developed on the basis of describing how construction accidents happen. These theories and models illustrate how threats are translated into an injury or loss. Heinrich's domino theory, as an example, developed in 1931, proposes that one event leads to another, then to another and so forth, ending in an accident. The domino theory defined that 88 per cent of construction accidents are caused by unsafe acts of persons, 10 per cent by unsafe conditions and finally 2 per cent by 'acts of God'. It is interesting to notice that 'acts of God' concept in domino theory implies the fact that there might be a level of risk which is not controllable [4]. The domino theory represented a simple model based on a singular concept of risk. Subsequent theories and models of accident causation represented a higher level of sophistication and extensiveness. These subsequent theories defined immediate and contributing causes of accidents. Immediate causes constitute of unsafe acts and unsafe conditions while contributing causes include safety management performance and the mental and physical condition of the worker. The later theories of accident causation express the significance of the management of the systems, such as regulations for the use of safety equipment and interventions for hazards correction. This idea is, however, overshadowed by an intense emphasis on the worker as the initial inciter of accidents with the worker acting unsafely or being in an unsuitable mental or physical state [5]. There are some other accident causation theories, such as biased liability theory, state that once a construction worker has experienced an accident, the opportunities that the same worker experience further safety and health violations may either decrease or increase compared to other workers. According to these former theories of accident causation there is always a group of workers who are more likely to experience accidents. These models ignore the safety responsibility of management and put the whole responsibility on the shoulder of workers. Training of workers in order to reduce risks tolerance is recommended in these types of accident causation theories. Human behavior is the basis and foundation of risk in these models [23].

Further accident causation models, such as Goals freedom alertness theory' (Kerr 1957) or Motivation reward satisfaction model' (Petersen 1975), focused on the concept of 'human errors'. It is not defined that whether these human errors were the signs of underlying systematic problems, such as training deficiencies or situation of the working. According to these models, it is not easy to change the view to underlying problems rather than symptoms since the emphasis of the accident investigation is on 'unsafe acts' and 'unsafe conditions' [8]. It should be taken into account that many accidents happen not because they are not preventable, but because the organization did not learn from previous accidents. Therefore in preventing the reoccurrence of accidents in construction workplaces, the human dimension of accidents causation should be taken into consideration at a macro or organizational level, rather than simply considering the individual worker level [23].

The human error concept of accident causation was extended later by the development of the human factors in accident theories and models such as Ferrel theory (Ferrel 1977), the Human-error causation model (Petersen 1982) and the McClay model (McClay 1989). The interactions between the worker and the work environment, tools and equipments and other contributing factors results in adverse effect in work systems which began a sequence of events leading to accident [6, 8]. These theories of accident causation define that for instance, worker errors may result in mistakes and deficiencies in design of equipments. In addition, poor maintenance practices may intensifies the design defects; therefore the combination of these causes with poor operating routines may create violations from safety [13].

There are theories of accident causation such as that developed by reason in 1990's, which states that, the accumulation of human errors result in active and latent failures. The active failures can be notices immediately most of the time, while the latent failures are noticeable just when they are combined with supplement causes to violate the systems' defensive actions. The Reason's theory of accident causation challenges the inappropriate belief of managers which assume that systems are safe and to search for underlying variables [23]

IV. CONCLUSION

Accidents and incidents in construction workplaces are unplanned and unwanted occurrences involving movement of persons, objects or materials which may result in injury, damage or loss to property or people. The majority of accidents happen when employees disregard safety rules (Unsafe acts) and management ignore the presence of unsafe conditions. Therefore unsafe acts and unsafe conditions are the immediate (direct) causes of accidents. On the other hand, physical and mental condition of the person as well as environmental forces and supervisory safety performance are the contributory (indirect) causes of accidents.

Accidents are determined to follow a pattern; accidents causation theories and models provide explanations of why accidents and incidents happen. All the construction accident causation theories and models developed have considerably increased the understanding of accidents and how they happen. They have stimulated a strong and powerful emphasis on the role of human error which has resulted into a reasonable place for training and education of workers in order to develop competencies and safety awareness. However there is a fundamental dilemma which is the different interpretations of risk, safety and the extent of risk which needs to be reduced to be acceptable. People are likely to believe that once an action is executed in response to a hazard, the situation is safe or safe enough. The weakness of the accident causation theories is that they do not offer extensive strategic guidelines for managers and supervisors for reducing risks at construction workplaces. Moreover, these theories have implied the inappropriate perception that accidents in workplaces can be prevented in case human errors are eliminated. Since risk is beyond the human intervention, not all accidents are preventable. Strategies require to be revised in a manner to manage the risk and workers need to be watchful of it. A great number of accidents can be prevented if the safety management system reflects both natural degradation and these intrinsic threats. The initial step in developing such system is preparing a model which shows the interaction between the accident likelihood and organizational tasks and activities in the presence of these hazards.

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