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Article

Construction Safety Management System at Project Level using System Dynamic Model (SDM)

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Abstract. Construction industry is one of the sectors that contributed to a high number of accidents. Three elements (i.e., cost, time, and quality) that measure the successful of construction project have been the main key driver, but safety and health is deemed as taboo. Hence caused several setbacks especially on the daily workers facing hazards that could happen due to negligence towards safety aspect. So, identifying the root causes of accidents is vital to prevent it from happening. Therefore, this research was conducted to improve construction safety management system at project level by using System Dynamic Model (SDM) to achieve three objectives which are: (1) to identify the common factors that cause safety accidents on the construction sites, (2) to determine the theme for the factors identified, and (3) to investigate the interactions between the themes using SDM. For this research, semi structures interview and questionnaire survey to 54 respondents from 15 construction sites around Daerah Petaling were conducted. This research revealed 18 factors of accidents and classified them into four (4) themes which used to create a System Dynamic Model that identify four key factors for each theme. On top of that, the findings proved that there are relationship and interactions between the factors. It is expected that the findings from this research may contribute to identify the most effective corrective actions that can be exploited to decrease the number of construction accidents in Malaysia.

Keywords: Construction safety management, factors of accidents, System Dynamic Model.

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1. Introduction

One of the major concerns in construction industry in Malaysia is on the safety issue as it is known to be a very dangerous industry with high numbers of accidents happening on the construction sites and notes the highest number of fatal injuries among other industries in the country [1]. In a recent statistic updated in 2018, there are a total of 232 cases reported and 118 of the cases involved fatal accidents happened on the construction sites [2]. Generally, safety management system is defined as a series of processes that are well-defined and also organization-wide that can provide an effective risk-based decision making that relates to the business carried out [3].

As an industry with a complex relationship involving clients or the employers of the project, professionals, contractors, subcontractors, producers and suppliers, providers and installers and many other organizations which are relevant to the industrial built and design throughout, it is natural for problems to arise as the main concentration in this industry focuses on the cost, time and quality, and little to none in regards of safety [4].

Many researches done focused on the behavior of workers on the construction sites, which is one of the main factors contributing to the issue [5], [6].However, little to none has been done relating all the factors that contribute to the high number of accidents in the construction industry [7]. Therefore, it is important to learn and understand the complex system, and for that, System Dynamic Model is chosen where the interrelation within the system can be understand [8].

2. Background

Three elements that are being used to indicate the rate of successfulness of a construction project, which are cost, time and quality, have been the main key driven and any mention of safety and health is deemed as taboo in the industry [4]. Hence, the effect causes several setbacks especially on the workers facing many hazards daily that could happen due to the negligence towards the safety aspect. [9]stated that identifying the root causes of the accidents is needed in order to prevent such accidents.

Supporting the statement, several theories created by some of the theorists and researchers known as Accidents Causation Model (ACM) explained that every accident happened due to a cause. Heinrich (1959) in [10]comes out with the first phase of ACM with the "Domino Theory" which stated that there are five (5) sequential factors that affect any management, creating a domino effect starting with the ancestry or physical environment, followed by fault of a person (carefulness), unsafe act or mechanical or physical condition, which will then cause accidents and lastly, will result in injury. Updating the theory, [11] comes out with the "Swiss Cheese" model, and the latest update on ACM which is the Functional Resonance Accident Model or FRAM by Hollnagel in 2005 explained the several components causing accidents followed by the information have to be identified to prevent accidents in the future.

Corresponding with the theories, factors of accidents has been widely discussed in many researches, where [12] has conducted 880 case studies that studied the cause of accidents and 29.2% of the total case were caused by handling or carrying objects followed by 23.5% caused by falls to lower level. In a research done by [13], the author listed six factors which are lack of personal protective equipment, defective or poor or unsafe equipment, poor safety consciousness of workers or managers, unsafe behavior, excessive noise and also procurement and contract problem. Meanwhile, [4] listed 8 factors which are lack of personal protective equipment, defective or poor or unsafe equipment, lack of experienced project managers or skilled workers, unsafe condition of workplace, lack of concern to safety regulation, lack of concern for safety by management and lastly unsafe behavior.

A total of 18 factors of accidents can be seen shared by several authors that studied the cause of accidents that happened in the construction industry which are Lack of Personal Protective Equipment; Defective/Poor/Unsafe Equipment; Lack of Training; Poor Safety Consciousness of Workers/Managers; Unsafe Method of Handling Materials/Equipment/Operations; Lack of Experienced Project Managers/Skilled Workers; Fatigue by Workers Because of Overwork; Unsafe Condition of Workplace; Lack of Concern for Safety by Management; Lack of Compliance to Safety Regulation; Insufficient/Lack/Housekeeping Program; Unsafe Behavior; Poor Site Management; Poor Illumination; Excessive Noise; and Procurement & Contract Problem.

However, [10] stated that accidents did not happened due to a single factor only but occur when the safety management failed as a system, and in an industry with a complex relation, the factors are often viewed as the cause of one another [14]. [10] classified the factors of accidents that happened on the sites into three elements which are technical, human and also organizational. In [15]research, another theme is used which grouped environmental factors that cause accidents happening in the construction industry. In order to decompose the complex relation within the safety system, System Dynamic (SD) Model is used. First introduced by Jay W. Forrester in 1958, it is used to map and explain industrial problem using the ideas from control theory [16]. By using the SD model as an analysis method, a complex problem can be understood, analyzed and modelled in a better view [17].

3. Methodology

There are many types of research design that may be used in order to conduct an appropriate research according to numerous types of research [18]. For this paper, both qualitative and quantitative method were used in order to collect the data properly to ensure sufficient data are collected in order to properly conclude this research. And as for the data analysis method, System

Dynamic (SD) modelling is chosen as the model to create the system as this type of modelling is quite popular to create a safety system in many other countries but it is rather new and rarely used in Malaysia.

3.1. Data Collection

In order for this research to obtain its first objective which is to identify the factors of accidents happened on the construction sites, a literature review is conducted to identify the common factors that has been identified by the previous researchers. After a list of common factors is reviewed, a qualitative method which is interviews, conducted to get confirmation from the personnel involved in Malaysian construction industry. A semi-structured interview was conducted with three safety and health officer involved in high-rise construction projects to achieve the first objective of this research.

Quantitative method chosen, which is questionnaire, is chosen to systematically compile questions for this research which is an important tool to gather widely scattered information [19]. Variables for the questionnaire were listed and compiled based on the first method conducted, which is the interviews with the personnel and distributed to selected high-rise projects in Klang Valley, Selangor. The result from the questionnaire will answer the second objective of this research which is to cluster the factors of accidents into different themes. With the result analyzed, the data will be used to generate a System Dynamic Model to study the interaction between the factors of accidents within its themes.

3.2. Data Analysis

The data obtained from semi-structured interview and questionnaire distributed and conducted beforehand is used to generate a System Dynamic Model (SDM). The questionnaire distributed was drafted into four sections which are demographic, presence of factors of accidents, categorizing the factors of accidents into four different themes and lastly the interactions of the factors according to the respondent. From 28 on-going construction projects involving high-rise building in Daerah Petaling awarded in 2015-2016, 53.57% response rate was obtained. A total of 54 participants contributed towards this research and the questionnaire data were analyzed using Statistical Package for the Social Science (SPSS).

The SDM has two elements which are stock and low diagram and also a causal loop diagram. The factors obtained through the literature review and interview are separated into two, whether it is identified as stock or as flow. The other element of SDM which is Causal Loop Diagram, also known as an influence diagram is the initial framework for any construction of a simulation diagram, which in this research paper is the SDM [20]. The factors of accidents identified are used as the components in this diagram and developed according to the identification whether the factor is to be in positive loop or the negative loop. The interaction between the loop will show the interaction between all the factors. The SDM and its components were generated using its software, which is Vensim PLE.

4. Findings

From the questionnaire, the factors of accidents were ranked according to its frequency of causing accidents on the construction sites by the respondents. A total of 31 respondents out of 54 chose unsafe behavior of workers as recurring factors of accidents. Similar to research conducted by [14], the top cause of accidents on construction sites is unsafe method of working by the workers. Unsafe behavior of workers is the most discussed factors of accidents where [21] study the factors that affect the workers' behavior and [5] linked the behavior of worker to the Heinrich's theory that unsafe acts will often leads to injuries over time. The following list is the result from the questionnaire, listed according to the rank of recurring factors of accidents picked by the respondent:

i. Unsafe behaviour
ii. Lack of personal protective equipment
iii. Unsafe method of handling materials/equipment/operations
iv. Poor safety consciousness of workers/managers
v. Unsafe condition of workplace
vi. Unforeseen circumstances
vii. Lack of training
viii. Poor site management
ix. Lack of experienced project managers/skilled workers
x. Insufficient/lack/housekeeping program
xi. Nature of the industry
xii. Lack of concern for safety by management
xiii. Lack of compliance to safety regulation
xiv. Procurement & contract problem
xv. Defective /poor/unsafe equipment
xvi. Fatigue by workers because of overwork
xvii. Poor illumination
xviii. Excessive noise

The four themes of the accidents identified are Human Factors, Management Factors, Technical Factors and lastly Environmental Factors. According to the classification of the factors of accidents by the respondents, lack of personal protective equipment, unsafe method of handling materials / equipment / operations, lack of compliance to safety regulation are categorized under human factor. This is supported by [15] where the research identify human related factors is the characteristics and load of human capabilities that contribute to the accidents and commit human error.

Lack of training, poor safety consciousness of workers/managers, lack of experienced project managers/skilled workers, unsafe condition of workplace, lack of concern for safety by management, insufficient/lack/housekeeping program, poor site management and procurement & contract problem are the

factors selected by the respondents to be under the management factors. It is in line with a previous research where management factors are those that fall under the organization's policy or regulations that relate to the health and safety aspects both to the sites and to the workers [22]. Next, there are three (3) factors of accidents categorized under technical factors which are defective / poor / unsafe equipment, procurement and contract problem and lastly unforeseen circumstances. And lastly, poor illumination, excessive noise, nature of the industry and unsafe condition of the workplace are categorized under the environmental factors.

From the categorization of the factors of accidents into its themes, a subsystem model of SDM can be generated to get the overview of the whole model to ease the understanding and get the final picture of how SDM will turn out. Figure 1 below show the subsystem model of the whole dynamic model.

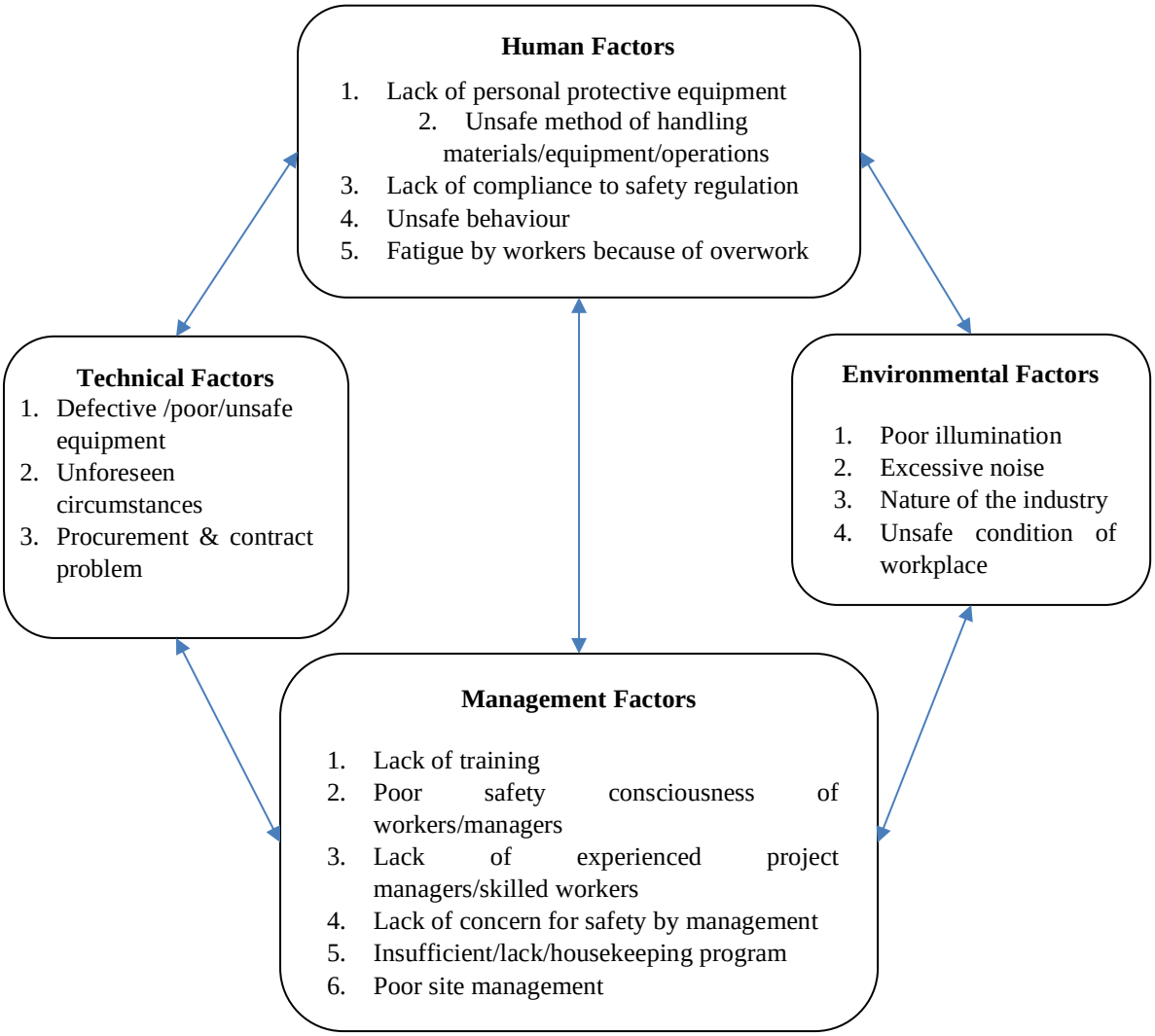

Fig. 1. Subsystems of model.

As it can be seen, the factors of accidents that has been grouped in each of the themes has interactions with each other. The subsystem is connected to each other as it has been identified by the opinions from the respondents that has been analyzed in the correlation test, and has also been justified by the interviewee from the semi-structured interview. To further see the complex relation between all the factors, each factor as identified to be in a positive loop or negative loop and Causal Loop Diagram is generated. The whole diagram can be seen in Fig. 2 below:

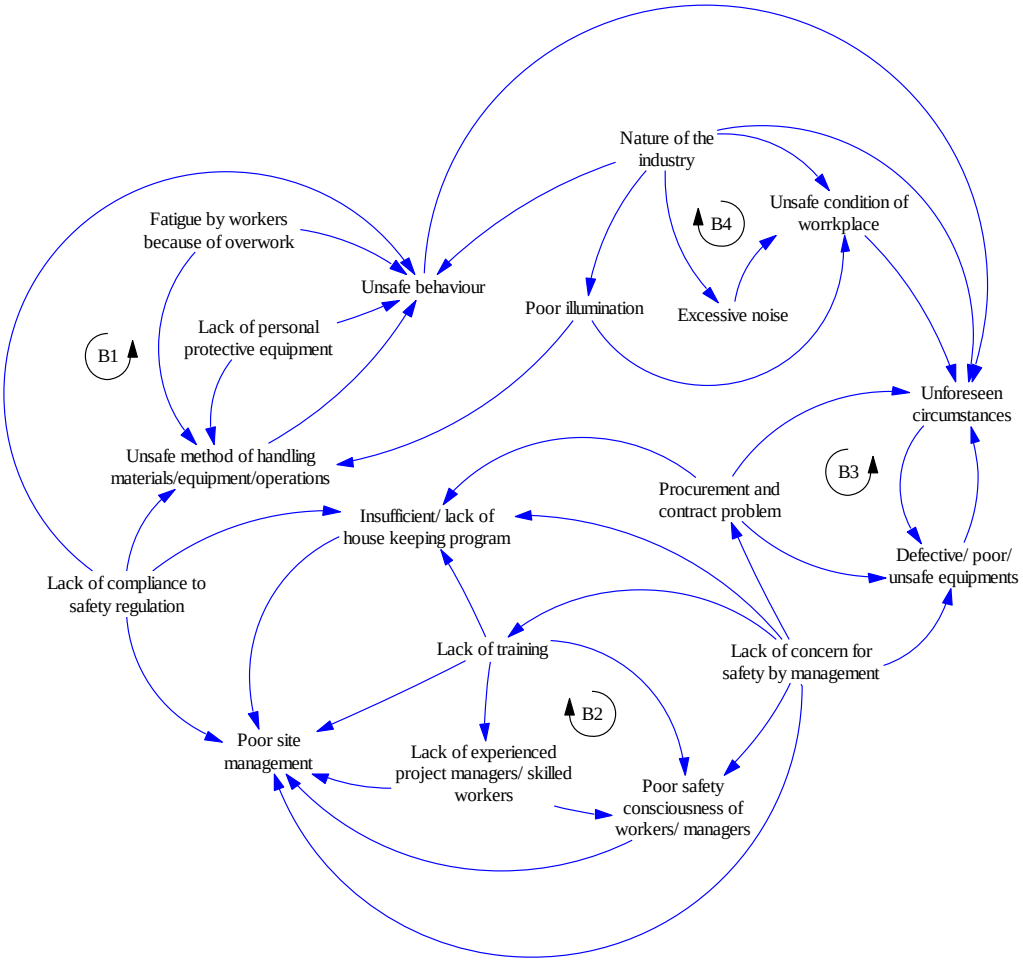

Fig. 2. Causal loop diagram.

As all the factors identified contribute to causing accidents on the construction sites, the arrows are not labelled with positive or negative polarity, which often used in causal loop diagram to show reinforced changes (positive) or to modify, oppose or balance the effect (negative) [23]. In balancing loop (B1), it is where the interactions of factors of accidents grouped into human factors. As it can be seen, fatigue by workers caused by overwork, lack of personal protective equipment and lack of compliance to safety regulation eventually caused the workers to use the unsafe method of handling the materials or equipment or the operations on the sites. All of these factors will lastly cause the worker to behave unsafely while doing their work.

Meanwhile, in balancing loop two (B2), it represents the management theme. From the loop, lack of concern of safety by management caused other factors to develop which are insufficient or lack of housekeeping program, lack of training, lack of experienced project managers or skilled workers and poor safety consciousness of workers or managers. Carrying on, balancing loop 3 (B3) shows the loop for the technical factors theme which only involve three factors. Starting from a problem in the procurement and contract, it will further cause the usage of defective or poor or unsafe equipment which then will develop unforeseen circumstances factor of accidents. This very same factor is also caused by the factor in management factors theme which is the lack of concern for safety by the management, and the loop continues. The unsafe behaviour factor from human factors theme also contribute to the development of unforeseen circumstances factor.

Finally, the last loop, which is the balancing loop 4 (B4) represent the last theme which is the environmental factors theme. The nature of the industry of construction cause excessive noise and also poor illumination in the workplace which then will create an unsafe condition of workplace. Unsafe condition of workplace and the nature of the industry will also contribute to unforeseen circumstances factor which also contribute to the unsafe method of handling of materials, equipment or operations from the human factors theme.

Each of the theme has identified factors that has been proven to cause accidents that most of the time resulted in injuries. Therefore, basic stock and flow diagram for each theme is developed by adding the theme as the inflow and accidents as the stock resulting in injuries as the outflow. In Fig. 3, it is shown the basic stock and flow diagram which has been used to demonstrate the flow for each theme. By using the basic stock and flow diagram, the flow for each theme can be seen in Fig. 3(a) until Fig. 3(d):

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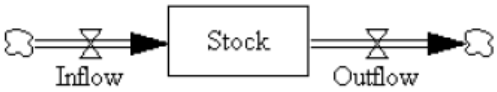

Fig. 3. Basic stock and flow diagram.

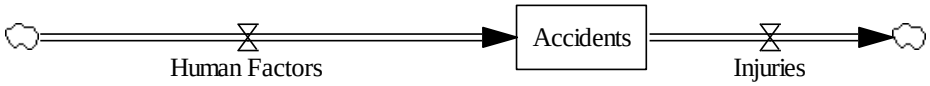

Fig 3(a). Stock and flow diagram for human factors theme.

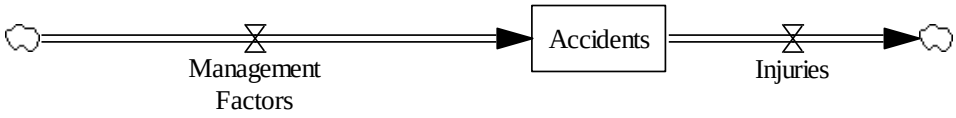

Fig 3(b). Stock and flow diagram for management factors theme.

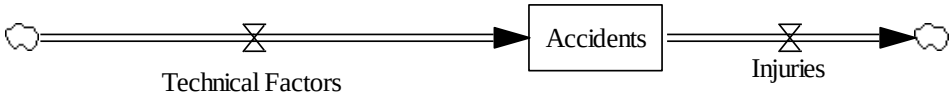

Fig 3(c). Stock and flow diagram for technical factors theme.

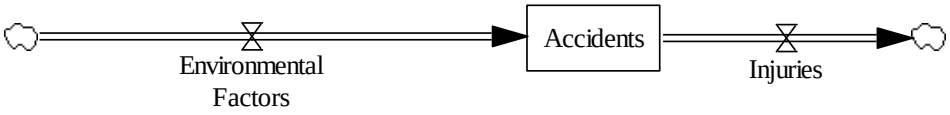

Fig 3(d). Stock and flow diagram for environmental factors theme.

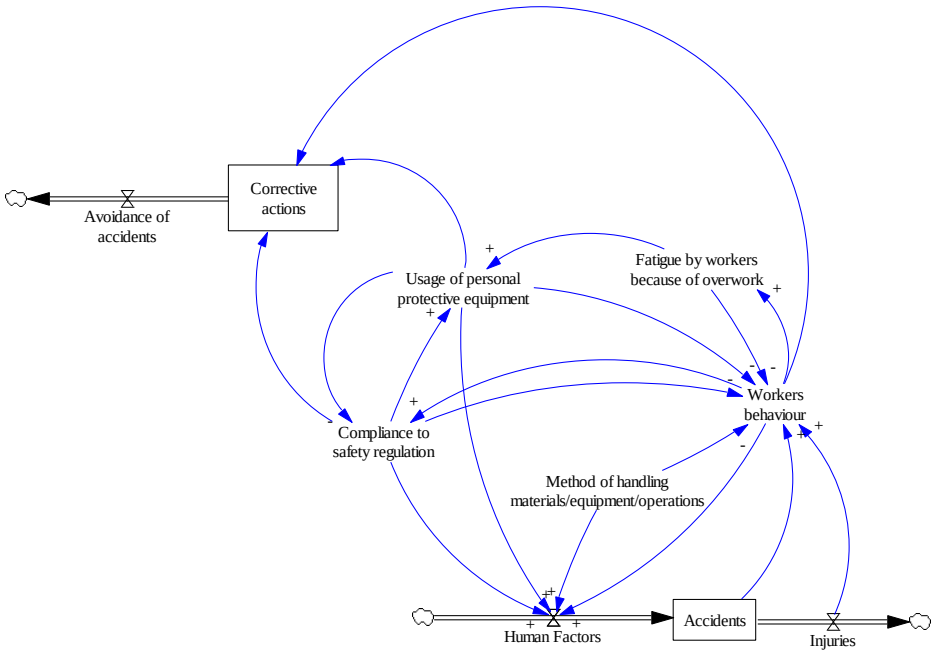

Fig. 4. Stock and flow structure of human factors theme.

Finally, by combining the causal loop diagram and the stock and flow diagram, it will create a stock and flow structure, which is a complex and dependant diagram for each theme can be created. To simplify and for better understanding, the factors are neutralized, which means that the factors are neither positive nor negative. The arrow used to show the relationship are labelled positive (+) to show the positive effects and negative (-) to show the negative effects of the factors. In Fig. 4, factors of accidents under human factors theme engaged with each other where the workers behaviour engaged with all the other factors and have negative impact towards it which in return initiate positive and negative chain. Attitude referring to any person is where the reaction of the person on the evaluation or appraisal to be favourable or unfavourable towards the questionable behaviour [6].

For the negative relationship, failure to use personal protective equipment is the result of not complying with the safety regulation and also shows that the workers behave unsafely. Fatigue by workers because of overwork also contribute to the workers to not use the personal protective equipment due to laziness and also to quicken the process or working. The workers also behave unsafely by using the wrong method of handling the materials, equipment and also the operations. All of these factors contribute to the human factors theme which in the end will cause accidents that resulted in injuries.

When accidents and injuries happened, this will increase the workers to practice safe behaviour and this in return will get the workers to use personal protective equipment, comply to the safety regulation and use the correct method of handling the materials/ equipment/ operations. Apart from contributing to the factors that cause accidents, corrective actions can be put in between all of the factors in order for the accidents to be avoided.

For the management factors theme, the relationship between the six factors identified under this theme is investigated. The interactions can be seen in Fig. 5 below. In this loop, the concern for safety by management is very crucial as it holds the responsibility whether the loop can go positive or negative. If the concern for safety by the management is very low, there will be less training and less safety consciousness by the workers and the project managers. Safety training must be done routinely in order for the awareness and the knowledge of the workers towards safety can always be renewed [24]. With no continuous training, this will be resulted in no skilled workers and experienced project managers and poor housekeeping program installed at the site, where the management of the site will also be poor. The end of this loop will result in all of the factors causing accidents which will increase the number of injuries.

When there are accidents and injuries, the concern for safety by the management will increase, so there will be an increase in training and safety consciousness in workers and project managers. This is in line with the previous study done where positive feedback from the management through emphasis on safety will be the main reaction when any accidents happened [25], [26]. This in return will increase the number of experienced project managers and skilled workers and has a great housekeeping program. With competent workers and system, the site will be managed properly and corrective actions can be taken effectively, which in the end can lower the number of accidents and there will be less injuries at the construction sites.

The third structure is on the technical factors which only involved three factors of accidents which are the procurement and contract problem, condition of equipment and lastly unforeseen circumstances. The interactions between the factors can be seen in Fig. 6 below:

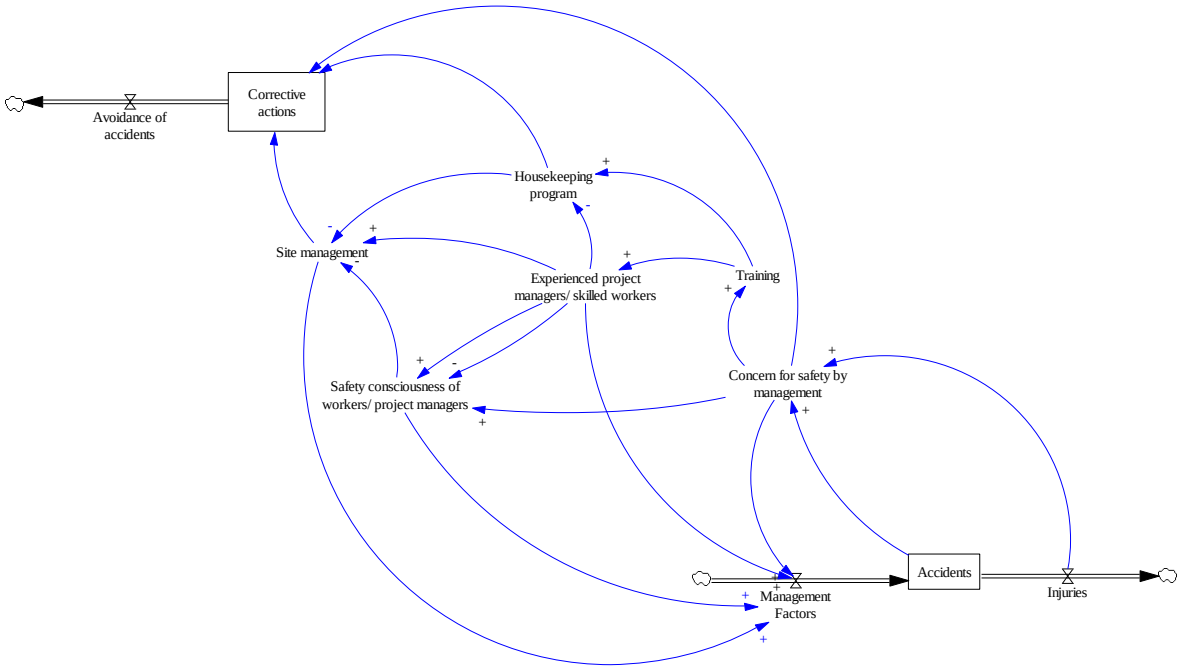

Fig. 5. Stock and flow structure of management factors theme.

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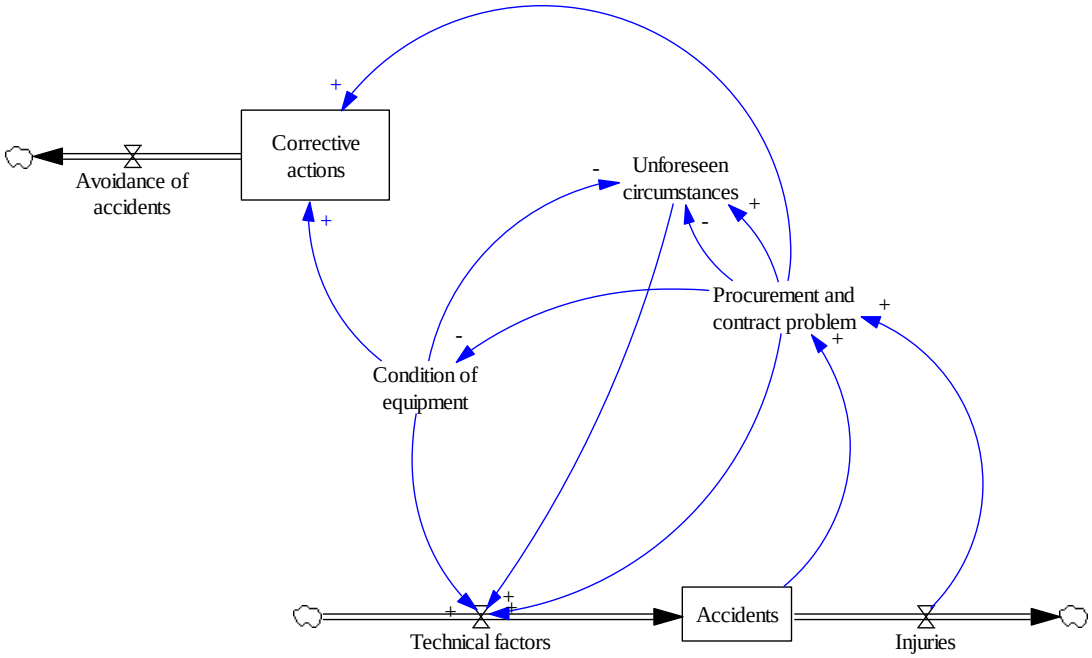

Fig. 6. Stock and flow structure of technical factors theme.

Procurement and contract problem are actually a very serious problem, and in this loop, it holds a very important place. Though in the industry, the workers are not really aware of its importance, the problem will often lead to less and low quality of equipment for the workers. With the equipment that the workers used and handled be in a bad condition, or there is not enough safety equipment provided due to less enforcement of the contract, this will create unforeseen circumstances where accident can happen at times that cannot be predicted. In the end injuries will happened towards the workers. With the occurrence of accidents, the involved parties will pay more attention towards the contract and procurement which in return will increase the condition of the equipment used and create less situation that may lead to unforeseen circumstances that may cause accidents. Through a research done by [27], when the equipment, materials, and facilities are in adequate manners, the workers' perceived behaviour can be directly controlled. With less risky situation, corrective actions can be placed properly in the loop which can prevent further accidents to happen.

Finally, the last loop represents the stock and flow structure for the environmental factors theme which involve four of the factors which are the condition of the workplace, nature of the industry, illumination and also noise. The interaction may be seen in Fig. 7 below:

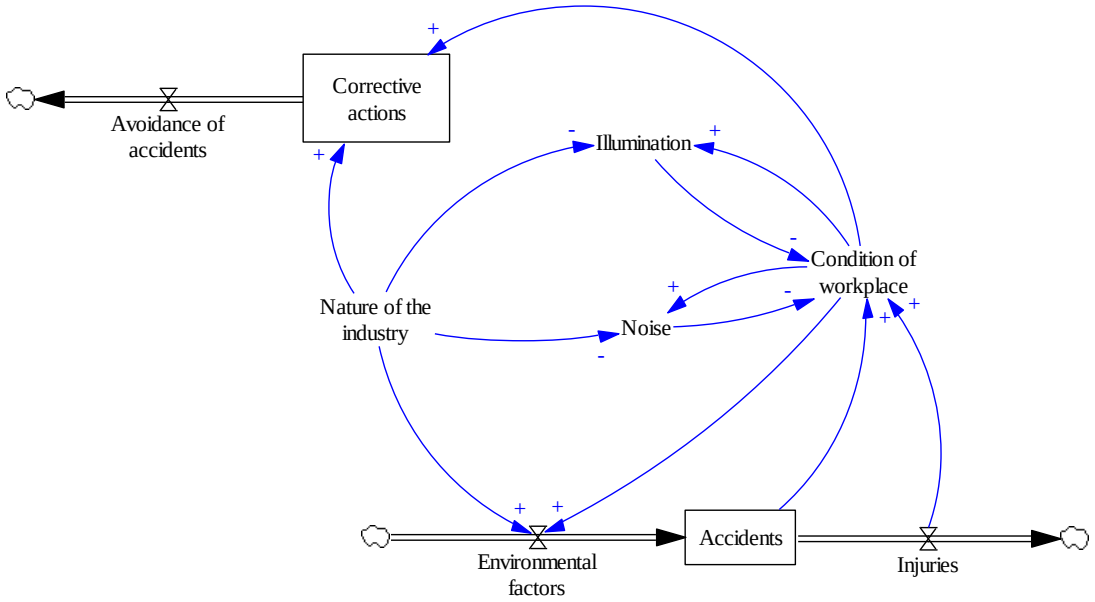

Fig. 7. Causal loop diagram.

For the environmental factors theme, the crucial factor is the condition of the workplace, however, this factor is very much dependant on the nature of the industry. Nature of the industry that includes huge sites with different types of machinery and equipment and kept on changing during the duration of the project provides a very dangerous condition of workplace for the workers. According to [28], working in an environment which is hazardous to the workers will exceed the physical capability of the workers to detect hazards in the surroundings. With all the machinery, condition with excessive noises may be faced by the workers and working in incomplete building often offer limited illumination hence the negative interaction caused by the nature of the industry. This will directly lead to low quality for the condition of the workplace which will cause accidents and injuries. After accidents and injuries happened, the reaction will be in ensuring the condition of the workplace to be better and this can be done by lowering the noise and increase the illumination in dangerous places. This will lead to better condition and corrective action may be placed where the workers may experience even lower possibility of accidents occurrence.

5. Conclusion

The finding of the research is made based on the three objectives defined in the beginning of the process which are to identify the common factors that cause safety accidents on the construction sites, to determine the theme for the factors identified and lastly to investigate the interactions between the themes using System Dynamic Model. For the first objective of this research which is to identify the common factors that cause safety accidents on the construction sites, it has been identified that according to its frequency, they are lack of personal protective equipment, unsafe method of handling materials/equipment/operations, poor safety consciousness of workers/managers, unsafe condition of workplace, unforeseen circumstances, lack of training, poor site management, lack of experienced project managers/skilled workers, insufficient/lack/housekeeping program, nature of the industry, lack of concern for safety by management, lack of compliance to safety regulation, procurement & contract problem, defective /poor/unsafe equipment, fatigue by workers because of overwork, fatigue by workers because of overwork and lastly excessive noise.

For the second objective which is to determine the themes for the factor of accidents, there are four themes which are human factors, management factors, technical factors and lastly environmental factors. For the human factors theme, there are a total of five factors classified which are the lack of personal protective equipment, unsafe method of handling materials/equipment/operations, lack of compliance to safety regulation, unsafe behavior and lastly fatigue by workers because of overwork. Continuing on, the management factors theme includes the factors lack of training, poor safety consciousness of workers/managers, lack of experienced project managers/skilled workers, lack of concern for safety by management, insufficient/lack/housekeeping program and lastly poor site management. The third theme which is the technical factors theme classified the following factors to be under it which are procurement and contract problem, defective/ poor/ unsafe equipment and lastly unforeseen circumstances. Finally, the last theme which is the environmental factors theme has four factors of accidents which are unsafe condition of the workplace, nature of the industry, poor illumination and also excessive noise.

Under the process of creating the System Dynamic modelling, there are a total of three steps which are creating the causal loop diagram, the basic stock and flow diagram and combining those two to create stock and flow structure. All of these steps are what makes the diagram of the System Dynamic Model. From this research, the five factors that caused safety accidents grouped under human factors theme are studied and the interactions are identified. From the structure, the most crucial factor under this theme is known to be the workers behavior which in return will lead to the other factors as well. Meanwhile, under the management factors theme, the factor that hold the crucial part in the concern for safety by the management. The most important factor in technical factor theme is the factor procurement and contract problem and lastly in the environmental factors theme is the condition of the workplace.

5.1. Limitations

There were several limitations faced while conducting this research. Limited time and fund to conduct the research caused limited sample to be obtained from the construction sites involving high-rise projects in the industry which lead to limited data to be analyzed making it hard to generalize the finding for this research.

5.2. Recommendation for Future Research

Every construction project involves a very complex relationship between the parties and working condition. There are many other aspects that can be studied to add to the finding of this research such as the effective corrective actions to be proposed and also the relationship between the parties involved in a construction project. As this research was carried out within the limitation, further research can be made to further solidify and justify the findings and add more views and opinion from the industry people on this issue. More comprehensive usage of the System Dynamic Modelling on the data finding can also be further carried out to find out the placement of the corrective methods in order to decrease the number of accidents that are happening in the construction industry in Malaysia.

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