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Analysis of Development Policies in Occupational Health and Safety Management System: A System Dynamics Approach

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Abstract

Despite Today's bold presence of machinery and the progress of technology in societies, human's safety, and occupational health are still under the shadow of numerous hazards. In order to ensure sustainability, in different sectors of industries, occupational health and safety must be observed diligently and businesses have every reason to be concerned. It is estimated that annually 120 million injuries, caused by work-related accidents, have led to 220 thousand death reports all over the world. Therefore, Precautious measures should be taken in order to protect labor force against unfortunate repercussions, stemmed from the hazards of the workplace. In an overall sense, injuries and occupational accidents, are the result of a set of unsafety (actions and conditions). Therefore, accidents can be decreased in rate by identification, prevention and elimination of this unsafety. The main purpose of this research is to propose a system dynamics model to analyze dynamisms of safety management systems, occupational health and accident management. Using such approach, and with the aid of causal feedback loops analysis and stock and flow structure, we can define and conceptualize complex interactions within these systems. In this approach we model the structure of their relationships; and lastly, simulate their dynamic behaviors. Results show that implementing policies related to human factor engineering and promote safety culture and standardization in the workplace, were the major appropriate and effective solutions which can have a positive effect on accidents management, they can help to develop the health and safety management system. Also, among these policies, both safety culture and human factor engineering have significant impacts on decreasing the number of accidents, but from a long-term viewpoint, safety culture is the most effective.

Keywords: *Occupational health and safety, accident, safety culture, human factor engineering, standardization of workplace, unsafe actions, unsafe conditions, system dynamic*

I. INTRODUCTION

In today's industrial units and due to exposure to harsh operation conditions, there's a high chance of an accident for businesses and their employees. In order to enumerate some of them we can mention: the explosion of NYPRO's nylon raw material factory in Felix Barro, Scotland, in 1974; the disastrous leak of MIC[1] in Union Carbide's pesticide factory in Bhopal, India, in 1985: the disaster of Chernobyl's nuclear power plant, Ukraine, in 1986; the catastrophe of piper Alpha oil platform in 1988 which had a high number of casualty; the explosion in Toulouse petrochemical plant in France in 2001; the explosion of the oil platform in Mexico Bay, in 2010; the collapse of a mine in San Jose, Chile, in 2010, which entrapped a number of workers for 69 days; and the fire outbreak and explosion of a pesticide factory in Texas, in mid-2013, which took killed and injured more than 160 people and destructed adjacent buildings, inflicting high financial repercussions. Such massive accidents can cause death, financial costs, and they have environmental consequences in inter-continental and global scales [1]. Reviewing such accidents, we can understand that, although chances of their occurrences and their consequences are not the same everywhere and they are not limited to specific countries, industries, and timelines, and do not occur in a uniform manner. This is confirmed by the fact that the aforementioned accidents have taken place in a number of countries and industries, and in different timelines. The variety of them is also high. The labor force of any country, especially developing ones, is deemed as an important part of the national capital, and is the foundation for economic and social development. There is no doubt that without healthy Labor force, economies and industries not only cannot flourish and will not thrive, but also they will lose their independence. Thus, it is important to protect the health of the Labor force and improve their workplace accordingly.

In 2014, International Organization of Work estimated that job hazards and Job-related accidents respectively has caused 350,000 accidents and roughly 2 million death cases, which adds up to 2.3 million death every year. In addition, in 2010, it was estimated that more than 313 non-fatal accidents have happened (as a result of four days of absenteeism). Unless labor forces and their families are hurt and international economic costs for businesses and societies ensue, these figures and estimations do not look big [2].

According to statistics of international Labor and global health organizations, job hazards are increasing and it does not have a logical trend. Safety risk management and occupational health help organizations identify, minimize or eliminate risks pertaining to health and safety. Since accidents can be very costly, it is necessary to care about safety and health of Labor forces, and in order to prevent accidents and job hazards, we need to develop health and safety systems, and conduct provisional measures. In this paper, we try to analyze different methodologies and policies to develop these safety systems.

II. BACKGROUND

So far most of the literature has focused on the importance of conducting safety measures within time boundaries. In a research by Leva, Vallerotonda [3] they try to help founders and health and safety professionals (job health and safety which has another common term: World Health and Safety) and delineate that safety measures are effective. Their survey is conducted among Italian workers, Job safety professionals, and academic modelers and it is to answer some of the conceptual models, stemmed from common beliefs. People still encounter job hazards. Job-related diseases and disorders are inevitable consequences of production [3]. Therefore, few companies are familiar with the Competitive edge and advantages of workers' safety. it is obvious that programs and policies regarding health and safety in the workplace can significantly reduce accidents' iterations, severity, and costs [4].

Nasirzadeh, Afshar [5] state that inherent risks and uncertainties, which are a natural part of developing and undergoing projects, have an important role in undermining the performance of projects. Thus, it is vital to have an effective analytical approach to risk, with which effects of different hazards on project goals can be evaluated. In a strong analytical risk approach, it is possible to consider dynamic hazards in project life cycle and pay attention to feedback loops which can affect repercussions of risk. Azizi, Bastan [6] argue that having a systematic plan in place and allocating a

[1] Methyl isocyanate

specific amount of budget to it, we can reduce the time and cost lost as a result of neglecting safety instructions. Also, by training and using trained human forces who are familiar with safety instructions, we can prevent accidents significantly.

Han, Lee [7] states that one of the key factors of successful safety management is safety culture in companies. They claim that one of the keys to successful safety management is to develop a strong safety culture. Since employees' behavior is under the effect of the behavior of other employees, supervisors, and senior managers, it is highly beneficial to understand the dynamics between these behaviors to develop and reinforce safety culture in projects. Using models, managers can control and monitor safety culture (which is the result of interaction among workers, managers, and organizations) and improve safety within the organizations' visions. Cooper Ph. D [8] state that a safety culture is composed of three parts: individuals (environmental safety), behavior (safety behavior), and situation (safety management System), and their interactions. Cooper believes that psychology, behavior, and situation are the dimensions of safety culture.

There are several approaches which give us the opportunity to use human factor engineering (conduct human factor engineering measures). In operation approach, human factor engineering is implemented only after occurrences of a problem. in passive approach concepts of human factor engineering are used in the final stage of system development, and in Active approach issues of human factor engineering are dealt with before they change into problems [9]

III. METHOD

Research methodology followed by this paper is based on the general stages of system dynamics methodology. This method is an appropriate tool for analyzing and understanding the causes of dynamic behavior in complex systems in which the productive structure of problematic behavior is modeled using system thinking [10]. The model development process in system dynamics involves the following steps: 1) detailed problem statement and ambiguity expression; 2) reference Modes Analysis; 3) dynamic hypothesis; 4) system structure mapping; 5) mapping of the stock and flow structure; 6) mathematical formulation of the model; 7) model validation; 8) leverage points identification 9) scenario design; 10) simulation of scenarios implementation [11]. Applying system dynamics approach to solving healthcare problems are increasing. There is very cases of applying system dynamics approach in healthcare problems [6, 12-17]. Also, this approach applied with a combination of another approach such as neural network [18], and others [19-21]. In addition, it is an appropriate approach for modeling complex systems [22-29]. To develop a mathematical model for the research problem, a methodology similar to figure 1 is designed.

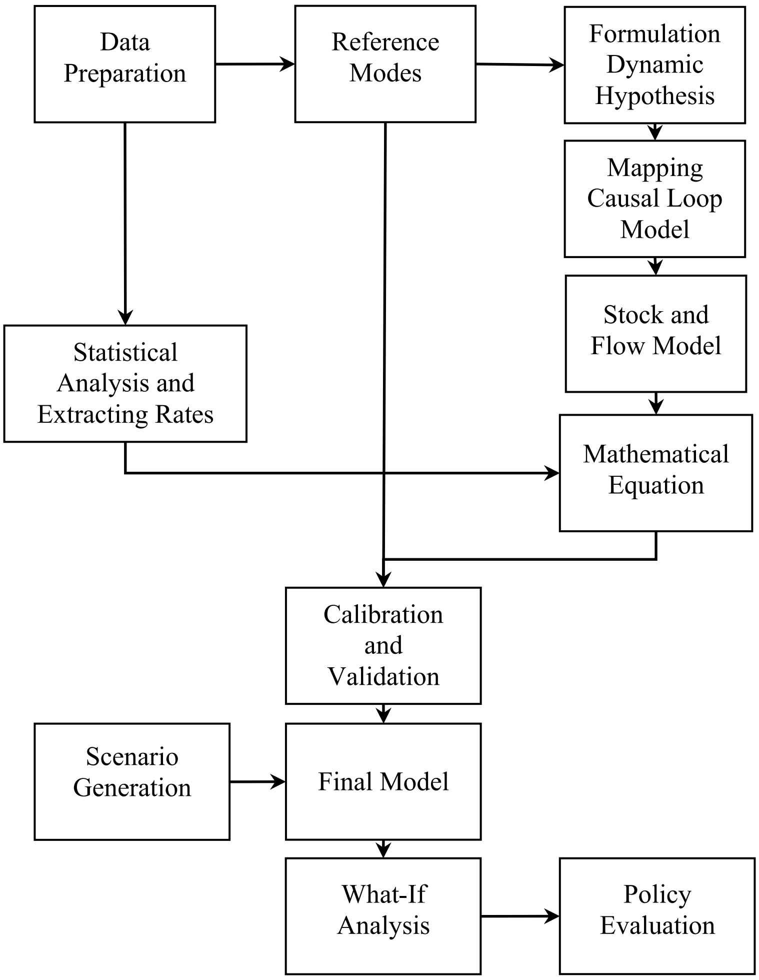

Figure 1. Process of the proposed approach

A. Problem Statement

Safety and occupational health management system protect Labor force's and organization's safety by reducing accidents. The need for avoiding danger and seeking safety has always been a cardinal part of human nature throughout history. But total safety can never be achieved because we can never get rid of all sources of dangers. There is no clear distinction between "dangerous" and "safe". many efforts have been made to improve conditions, reduce dangers, accidents, and hazards for men. Today, despite vast improvements in living conditions and huge technological advancements (new methods, materials, products, and equipment), catastrophes still happen in both industrial and non-industrial environments, and with the advent of the new changes and technological advancements, new dangers have emerged in industrial environments. In the past and based on traditional approaches, we would try to find answers to these questions: What has happened? Who is responsible? And when did it happen? However, in modern approaches, the past 50 years history of the event is reviewed with the emphasis on finding "why"s and "how"s, and safety shortcomings and hidden fundamentals reasons are revealed. Thus, instead of a particular action, somehow the safety culture of the organization is to be blamed.

B. Dynamic Hypothesis and Causal Structure

More than 15000 new laws are ratified annually, of which more than 10% is related to safety and health. Although injuries and number of death cases have decreased, most of the people are not completely satisfied by the safety measures provided by governments and industries. Fundamentals of safety in the workplace are lacking and there are no effective routine and periodical controls regarding occupational health and safety. Unsafe behavior is evident and copious. These are several reasons why, despite understanding the obvious role of occupational health and safety, accidents still happen in the workplace in such frequency and severity. In figure 2 the causal diagram of the model is depicted. this model helps us have a deeper understanding of the system and is the prerequisite for flow stock and model.

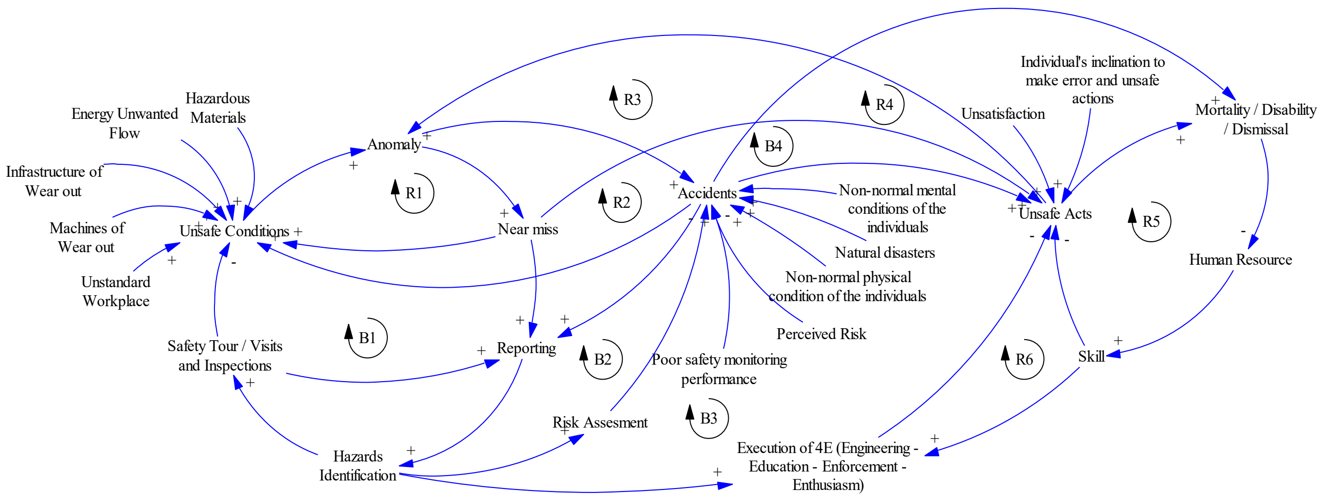

Figure 2. Causal Loop Diagram

In Table 1 you can find a brief explanation about the positive and negative loops in the causal loop diagram.

Table1 - Feedback Loops

Loop	Description
B1	shows the effects of unsafe condition on near misses Unsafe conditions influence anomaly factors which lead to near misses and, through reporting, danger identification and safety tours affect the unsafe condition.
R1	shows the effects of unsafe condition on near misses Unsafe conditions affect anomaly factor which leads to near miss and these near misses affect unsafe conditions and this creates a positive loop.
B2	Shows the effect of unsafe conditions on accidents Unsafe conditions affect anomaly factors which lead to accidents and it affects unsafe condition through reporting, identifying dangers and safety tours.
R2	shows the effects of unsafe condition on accidents unsafe conditions affect anomaly factor and this factor leads to an accident. Eventually, it affects the unsafe condition and a positive loop is generated.
B3	Shows the effect of the unsafe action on near misses Unsafe actions affect anomaly factor and this factor will lead to near miss. Through reporting, danger identification and quadruple actions, this factor affects unsafe actions.
R3	Shows the effect of the unsafe action on near misses Unsafe actions affect anomaly factor and this factor leads to near miss. Eventually, these near misses affect unsafe actions and a positive loop is generated.
B4	shows the effect of unsafe actions on accidents unsafe actions affect anomaly factor and this factor leads to accidents. Through reporting, danger identification and quadruple actions, this factor affects unsafe actions.
R4	Shows the effect of unsafe actions on accidents Unsafe actions affect anomaly factor and this factor leads to accidents. Eventually, these accidents affect unsafe actions and a positive loop is generated.
R5	Shows the effect of the skill of human factor on unsafe actions The more the skill, the fewer the unsafe actions. As the unsafe actions increase mortality and disabilities and dismissals rises. Human factor affects skill.
R6	Shows the effect of the skill of the human factor and the quadruple action on the unsafe action Skill affects quadruple action, and quadruple action decreases unsafe actions. As unsafe actions increase, mortality, disabilities and dismissals increase. Human factor affects skill.

C. Stock and Flow Model

In order to create a quantitative model and simulate results, the following stock and flow model is put forth.

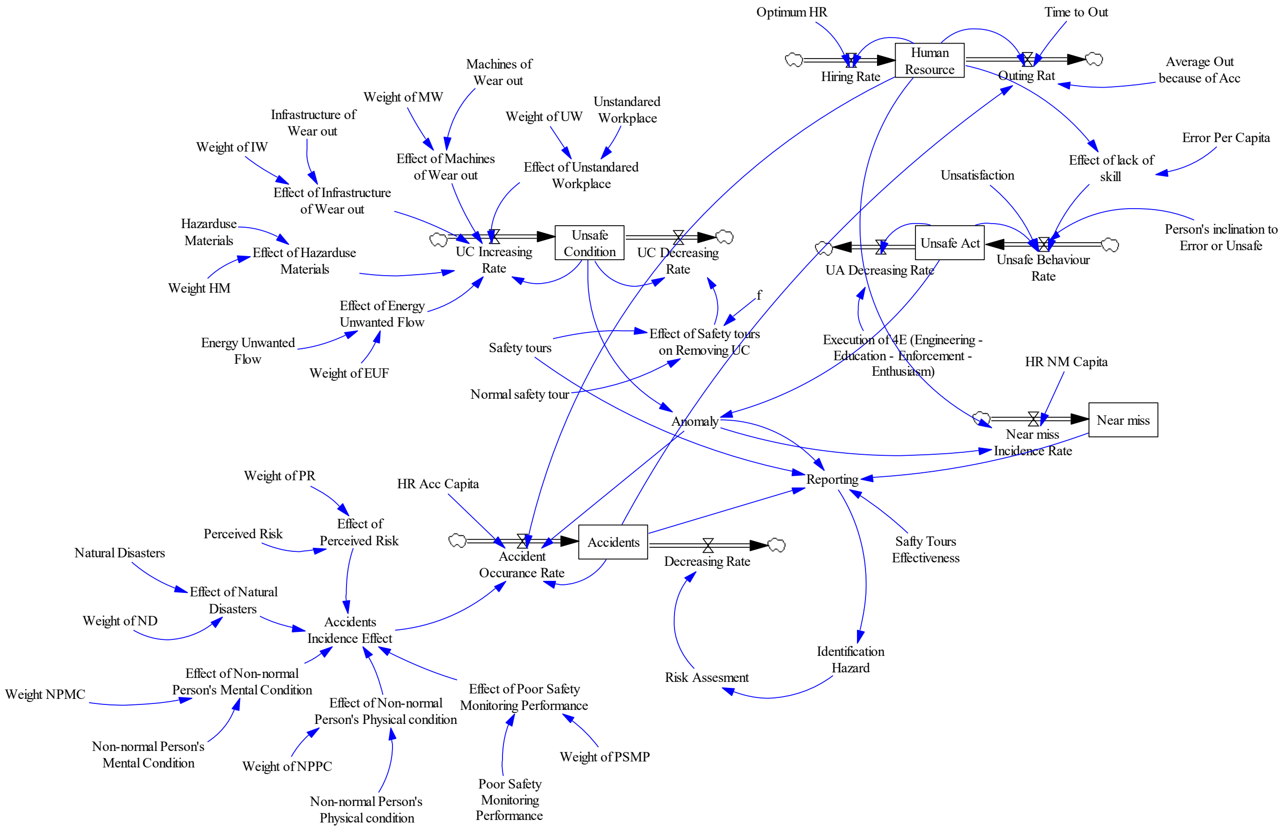

Figure 3. Stock and Flow Model

D. Model Validation

After developing the model and before creating scenarios and analyzing results, we need to ensure that the model is valid. Therefore we test the model and observe its behavior and specify its shortcomings and this way a deeper understanding is achieved. there are several tests and methodologies to validate a model including historical behavior reproduction test, extreme condition test, boundary adequacy for structure test, model equations logic test and dimensions consistency test has been performed, validation of the model is ensured.

E. Leverage Points Identification

Considering the structure of the problem and the modeling conducted in the field of occupational health and safety, leveraging points are identified: 1) Unsafe actions and 2) Unsafe conditions. Leverage points are those factors which affect occurrences of accidents and near misses.

F. Scenario Generation

1) Scenario 1: Continuing with of Current Situation :

in this scenario, no change is made to the values, parameters or the structure of the model. the purpose here is to describe the current situation and its outcomes, and behaviors of the key variables of accidents.

2) Scenario 2: developing human factor engineering by developing human factor engineering within occupational health and safety system, we can reduce the unsafe actions which stem from human error. As a result, it affects occurrence of accidents. According to this scenario, the stock and flow structure of this improving policy will be as figure 4.

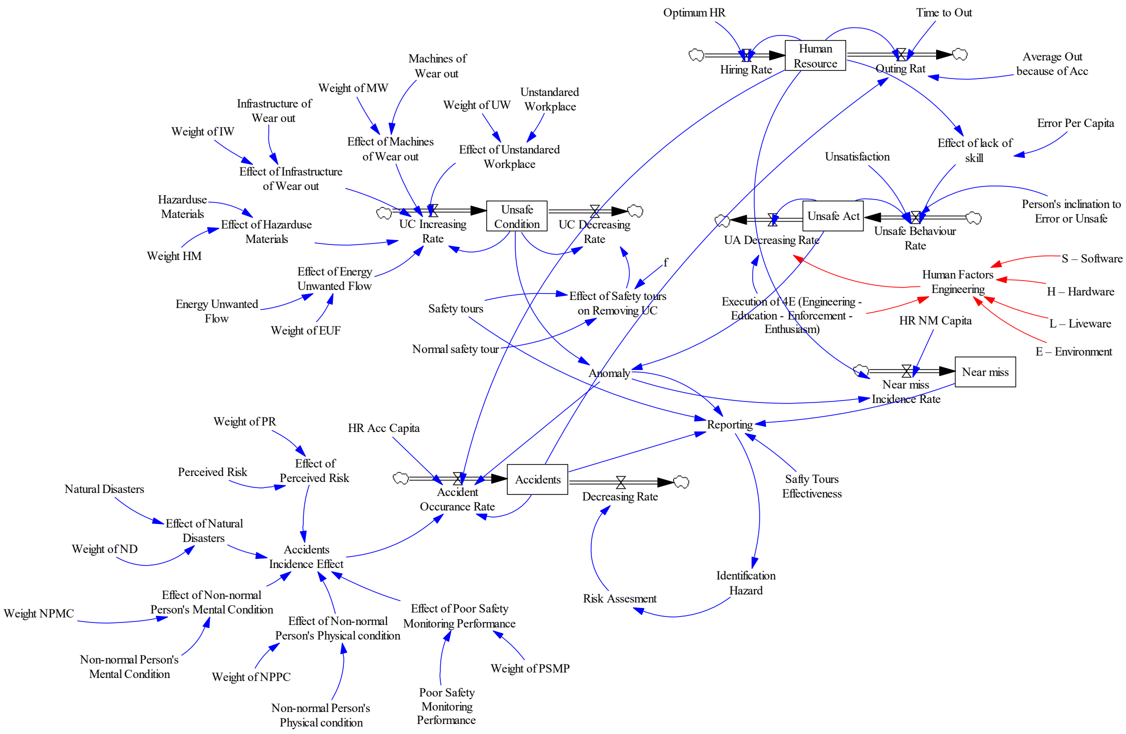

Figure 4. Stock and Flow structure for improving policy as scenario 2: developing human factor engineering

3) Scenario 3: developing safety culture

developing safety culture involves a reporting mechanism on near misses, errors, and a mechanism of encouragement (and not punishment) systems for the reporting system. Employees must be able to rest assured that these reports will not endanger their and their colleagues' job security. On the contrary, there should be a motivating system to encourage these reports. Having such reporting system in place, unsafe actions and conditions which are the main sources of accidents, decrease and the performance of the system of health and safety management will be positive. Developing safety culture has a positive effect on the sense of responsibility, understanding the hazards and environmental risks, and the cooperation among teams. Eventually, these factors have a significant effect on decreasing accidents.

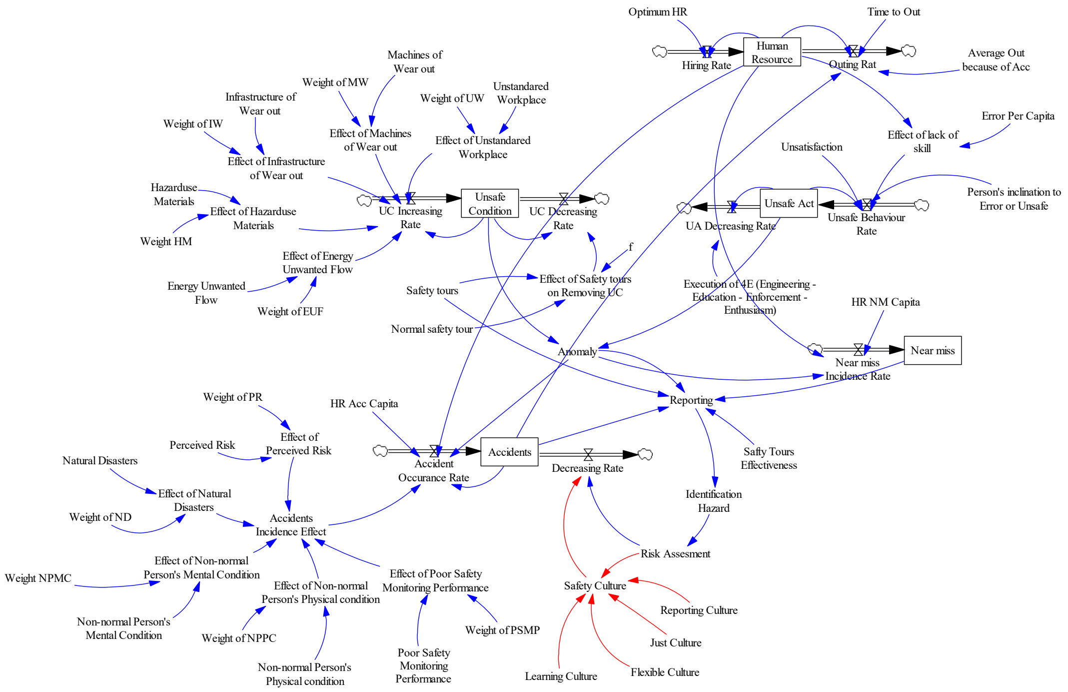

Figure 5. Stock and Flow structure for improving policy as scenario 3: developing safety culture

4) Scenario 4: standardization of workplace

standardization of workplace has an effect on unsafe conditions and it can reduce the number of unsafe conditions and decrease unsafe conditions results in fewer accidents. by comparing the trends of the aforementioned scenarios we can see that this variable (standardization of workplace) is positive and exogenous, and it leads to a reduction of unsafe conditions.

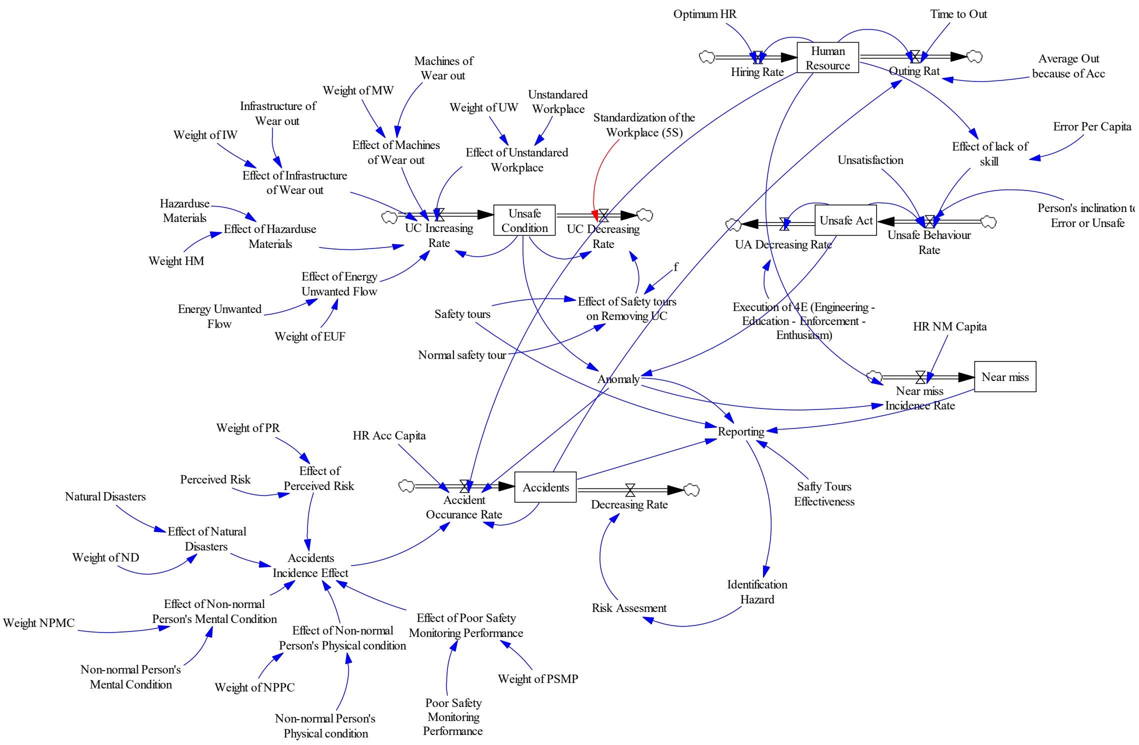

Figure 6. Stock and Flow structure for improving policy as scenario 4: standardization of workplace

IV. RESULTS

In the first scenario, the current situation continues and the key behavior of the model keeps its trend. That is, it is going to keep the ascending rate of accidents, due to unsafe actions and unsafe condition. In the second scenario by developing human factor engineering we can affect the unsafe actions and control them. Controlling this variable will result in fewer accidents. In the third scenario which is developing a safety culture, we can see that variable of accidents decreases. This scenario is the best-implemented scenario and the rate of reduction in accidents is more than when other scenarios are implemented. The fourth scenario is standardization of workplace and we can have an effect on unsafe condition and decrease it. Decreasing unsafe conditions leads to a reduction of accidents.

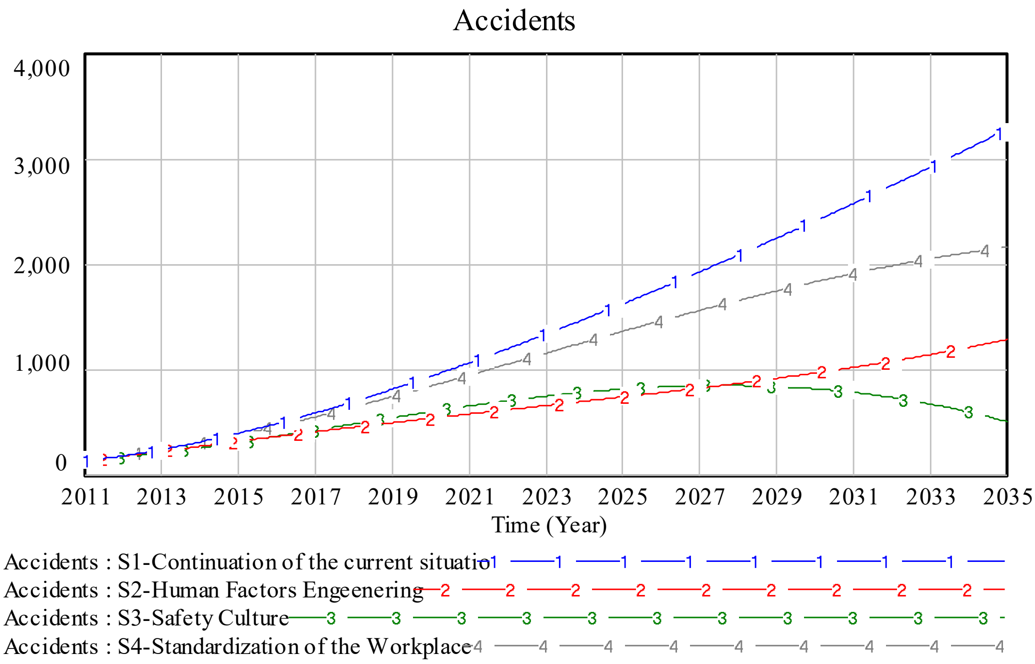

Figure 4. The impact of implementing different scenarios on accidnets

V. CONCLUSION

In this research, in order to develop occupational health and safety, we designed the structure and behavior of a system and analyzed the influential factors which affect increase or reduction of accidents. The structure of the system is used to identify its behavior, and its stock-flow model was proposed to describe its performance.

Afterward, four scenarios involving the proposed policies and methodologies were used to solve the problem and gather the results. The four scenarios are the First scenario: continuation of the current scenario, second scenario: developing human factor engineering, third scenario: developing a safety culture, and fourth scenario: standardization of workplace. In the following, results of implementing these scenarios are shown in Table 2.

Results of this research proved that if long-term results are of a priority then the order of the scenarios should be as follows: the first priority should be given to the third scenario (developing safety culture) and this can lead to a decrease in accidents with a descending trend. After that second scenario (human factor engineering) is the second effective scenario. In this scenario, accidents decrease but they still have a mild ascending trend. The last priority should be given to the fourth scenario (standardization of the workplace) which has less effect on decreasing accidents in comparison to the other two scenarios.

Table 2-Summary of Scenario Results

Scenario		Description	Results
S1	**Continuation of the Current Situation**	In this scenario, accidents are increasing and although the decreasing loops were in place, they were weaker than increasing loops.	Despite the fact that in many organizations (in different industries) several health and safety culture systems are employed, the best way to select and implement a precocious approach is to integrate necessities of human factor engineering into the present occupational health and safety management systems. Investments in this area can reduce the accidents but without a plan, the total number of accidents cannot be reduced.
S2	**Human Factor Engineering**	The number of unsafe actions was decreased significantly but it still has an ascending trend.	In this model, the moment this policy is implemented, its results can be perceived and these preliminary results can affect the number of unsafe actions. In the long term, this effect will get stronger. Considering human factor engineering within safety systems can protect the system from potentially harmful conditions, and this will eventually reduce accidents.
S3	**Safety Culture**	The number of accidents had a higher decrease in comparison to the other scenarios. It also has a descending trend.	This scenario is the best scenario in the long term because the number of accidents prevented is more than other scenarios. It also has a descending trend. Strong safety culture in the organization can be a determining factor in decreasing accidents for the human factor in any company. Managerial factors and the position of safety department within the structure of organizations have a significant role in implementing safety culture. This can lead to a fewer number of accidents for the personnel. However, having a traditional approach to safety, which is mainly based on passiveness, still reigns in organizations and unless an accident happens, no action is made to remedy it. Taking safety culture into account can help us solve the problem in question.
S4	**Standardization of Workplace**	This scenario significantly decreases the number of unsafe conditions but in comparison to the other two scenarios, it has a weaker effect on decreasing accidents.	This scenario targets unsafe condition and by decreasing this variable, accidents are decreased. Adding this scenario to the other two scenarios does not make noticeable changes.

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