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# A hybrid FMEA-SD approach for behavioral analysis of factors affecting safety management and incidents in the pelletizing industry

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***Abstract*** *– This study aimed to analyze the behavior of effective factors on safety management to reduce incidents in the pelletizing industry using FMEA and the system dynamics approach. Risk assessment for the Sechahon pelletizing plant was performed using the FMEA method. A total of 625 risks were identified, of which 286 are high-risk RPNs and need to be scrutinized. These risks were categorized according to their nature into five categories of physical, exposure to dust, ergonomics, emergencies, and psychosocial risks. The results of our study show that decreasing the number of incidents in "risk reduction scenario" leads to the reduction of risk at the early durations of the study. Hence it is a high-priority policy in comparison with others. The technology improvement scenario shows an incremental growth trend, but the current situation scenario can decrease the number of incidents.*

***Keywords****– FMEA, Risk expenses, level of safety, pelletizing industry, system dynamics.*

## I. INTRODUCTION

Millions of work-related incidents occur every year. Some of these events cause death, and others cause temporary disability, which may last for months. Workers are often exposed to various hazards in industrial environments despite the types of machines and tools being used. With the advent of technology and the increased use of machinery in production, the risks and incidence rates of accidents increases in such environments. The incidents damage the device and equipment of raw materials, products, or work environment or associates immeasurable physical or mental harm (Hagimoradi & Zare Mehrjerdi, 2018, Mullen, 2004). Therefore, it is important to take precautionary measures and to pay attention to safety management in industrial projects to prevent or reduce occupational incidents. Researchers indicated that incidents and occupational diseases are important barriers to productivity and production (Griffin & Neal, 2005, Christian et al. 2009, Vinodkumar & Bhasi, 2010).

Among the factors of workplace incidence, the human error factor accounted for the largest share, i.e., 70 to 90% of the causes of the incident, according to studies (Akbari et al., 2006). Insecure behavior is beyond the standard and defined limits of the system and can affect the level of safety and health of the system (Sanaeinasab, 2008). Some of the high-risk behaviors in the workplace that endanger the health of the employees are poor physical condition at work (such as inappropriate sitting, lifting objects heavier than the standard set, kneeling for the long run), not using required respiratory, fatigue, and violence protection tools in the workplace (Mohamadfam and Zamanpour, 2002). Also, these behaviors include non-observance of work instructions, the inappropriate use of personal protective equipment,

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the use of non-essential tools for doing work, and dealing with non-duties (Souri et al., 2011). The statistics of work-related incidents indicate that industrial incidents are not in Iran isolated from most developing countries (Kiajordi, 2011).

Today, the diversity of the risks of workplace hazards is so high that it is impossible to compensate for the consequences in practice. For this reason, safety science has taken a completely preventive approach. One of the most prominent features of this science is its systematic functioning, which emphasizes the identification, evaluation, and control of all elements involved in all stages. The main elements of this system include humans, equipment, materials, and the environment (Hagimoradi & Zare Mehrjerdi, 2018). Among the elements mentioned above, human is the most critical factor, since this element, while dominating other elements, can influence three other elements by unsafe behaviors. The human factor in the immune system includes a wide range of people, from senior management to simple workers (Rauf et al., 2017). Safety at work is a complex phenomenon, and the issues of safety attitude and safety performance in industrial projects are even more complicated. In a capital-based society, it is a commonplace for industry stakeholders, especially those at the bottom of the supply chain, to focus exclusively on completing projects in order to achieve the required quality standards with minimal time and cost. The lack of incentives to strengthen the safety culture at both organizational and project levels generally results in historical safety weakness. Safety management improves performance indicators in workshops and industrial projects, so having an approach to safety management and safety management systems will enhance safety levels in industrial projects (Taghinejad, 2017).

Among the obvious capabilities of safety concepts, there is sufficient capacity to identify the cause-and-effect relationships and to design practical management and control approaches. These actions have come to the forefront in the form of practical methods of safety management since the beginning of the development. As a result, safety skills in all aspects of the industry have been rising over the years, and there has been an increasing change in the growing awareness and ability to meet the required tools and techniques for controlling risks. Evidence of this issue is seen in many related regulations, standards, and laws. This process may seem normal and conceivable; nevertheless, practical experiences and results remind us that incidents result in injuries and damage continues to occur despite the awareness of the causes and the existence of many proposed control tools (Taghinejad, 2017).

Rout and Sikdar (2017) conducted research on hazard identification, risk assessment, and control measures as a tool in the iron ore pelletizing industry. Singh et al. (2015) studied iron ore pelletizing technology and its environmental impact assessment in the eastern region of India. Failure mode and effect analysis (FMEA) has been used in many industries all around the world for various purposes. However, research that combines FMEA with a dynamic methodology for behavior trending of variables' performance is rare in the literature. Current research can help managements in Pelletizing as well as other industries to do promising researches and behavioral experimentations. This hybrid FMEA and system dynamics (S.D.) approach allows management to trace the behaviors of those variables that are costly to the system.

The main objective of this study is "the presentation of a system dynamics model that can depict the trend of accidents, costs of accidents, system safety level, and the risks associated with the accidents over some periods of time in such a way that the routine tasks at the working site continue without any significant factor changes. The rest of this paper is organized as below: Section II reviews the literature and research background. Research methodology is discussed in section III. Case study results are presented in section IV, while the conclusion and managerial implementation are given in section V.

## II. REVIEW OF LITERATURE AND RESEARCH BACKGROUND

In the past, the incidents included falling from a tree or a height, being hit and injured by domestic or wild animals, or poisoning with a plant, but today, given the remarkable advances in industrial affairs and the possibility of using modern means of travel, the use of electric power and machinery, contact with chemicals, and so, human beings are facing countless incidents.

**Incident:** An incident can be defined as an unplanned event or episode. The incident is unexpected and unpredictable. If we want to open this issue further, the incident is the result of an unwanted event. In addition to the general definitions for the various incidents referred to, the definition of the work-related incident can be found in article 60 of the Labor and Social Security Act (Dousti, 2014): Occupational incidents are events that occur during the task execution. The definition of an incident in the International Encyclopedia of Work is an unforeseen and unexpected event that causes injury and harm (Dousti, 2014). According to OHSAS 18001-2007 definition, an incident is an event that results in injury, illness, or death.

**The significance of work-related incidents:** every year, tens of millions of workers are the victims of their works, resulting in numerous deaths or disabilities.

**Humanly**: any work-related incident, even partly, causes the worker and his or her family to be distressed.

**Socially:** since the advancement of each social activity depends on the workforce community, the outcome of each worker at the job not only relates to his/her existence and family support but also to the capital and the backing of the economy from the society. As we know, nearly 50 to 60% of people in each social group are people of working age.

**Economically:** incidents, in any mode and degree, are economic losses for the worker, for the employer, and for the community. These losses are directly and indirectly impacting. Direct losses include losses resulting from work interruptions due to incidents, medical expenses, and eventually damages for the temporary, permanent incapacity or death. In calculating indirect losses, which are more than direct losses in all countries, losses caused by the interruptions in the work of other workers due to helping the injured person, discussing the cause of the incident, disrupting the work order after the transfer of the worker to the hospital until appointing the right person to do business, the damage to the machinery and, eventually, the damage resulting from the reduction of the work of the injured worker after returning to work (in the case of a disability) should be considered.

**Management of the process of incidents:** Management of the incident process means the investigation of the causes of incidents during work and preventive measures. Based on the proper management of incidents, it is possible to apply methods that minimize the economic costs of incidents. Managing the process of incidents involves examining the causes of incidents and taking preventive measures. The work-related incident is a fact that occurs during work, and there was no previous intention or planning for it.

**Causes of work-related incidents:** Past studies indicate that work-related incident does not have a single cause, and the effect is due to technical and human causes. These causes depend on the type of work, environment, the conditions of the work, and the tools used. These causes can be divided into two categories of direct and indirect causes:

### *A. Direct causes*

The purpose of direct causes is the determination of the source of the main contributor to the occurrence of the incident. Given the work and industry, these can be summarized as follows: moving goods, working with machinery, falling objects, falling a worker from a height, improper use of tools, falling due to slipping, collision with a barrier, burn, or colliding with a vehicle in the workshop environment.

### *B. Indirect causes*

These causes do not directly impact the incident, but if there are direct causes, they can increase the chance of an incident. This group includes factors such as fatigue, discomfort, and labor dissatisfaction. The most important of these causes are improper light, excessive sound, poor ventilation, inappropriate working temperature, long working hours, over-speeding, family problems, financial difficulty, poor Relationships with co-workers and supervisors. It should also be noted that along with these two groups of causes, lack of experience and work skills and unfamiliarity with the principles of immunity at work are important in causing work-related incidents.

Amin Fathi Biranvand (2017) used a system dynamic approach to provide the most appropriate way to investigate the causes of incidents and incidents by using time management, cost, and quality method. In that research, required data were collected using field studies and statistical methods for data analysis. Then researcher has prepared a system dynamics model of the problem and simulated that model using Vesnim software. Next, an appropriate strategy for managing time, cost, and quality was suggested in the study of the causes of incidents and construction incidents. In the end, the issues that led to the reduction of incidents in the construction workshops were expressed.

Rauf et al. (2017), in a paper entitled, "Managing the safety of contractors in the control of incidents," discussed and evaluated the problems encountered by the contractors' safety and the reasons for the lack of attention of contractors to safety issues from the technical and economic viewpoints, the training and control of waste and analysis. In this study, 66 urban development and improvement projects in Asalouyeh have been considered as a case study. The results of this study indicate that the role of the employer in supervising the contractor, in various stages of that, until the end of the implementation, is undeniable. Also, the results of this research indicate that making employees familiar with safety culture is highly essential as a first step in preventing incidents. However, due to the lack of proper knowledge of safety precautions, some preventive events even occur with the most expensive protective equipment. In a study conducted by Chen Yang et al. (2018), a system dynamics model was proposed to simulate the chlorine process safety management system, which includes four modules for workers, management, rules (regulations), and equipment, as well as an integrated junction with the degree of corrosion that is comprehensively integrated. By introducing a series of scenarios with different inputs, it was determined that the proposed system dynamics model could obtain the penetration pattern in the degree of equipment corrosion. The results of this study showed that work skills have a positive impact on system safety, while work stress mainly affects system safety during the second half of the life cycle. Yeo et al. (2018) conducted a study where its results show that significant senior commitment in terms of human resources, cost allocation, and suitability of the security manager is a key to the implementation of the safety management system. Also, it was indicated that there are factors that have more impacts than incident and incident costs. These are improved organizational frameworks and increased ratings of security voting that were identified as the main benefits of implementing a safety management system. At the same time, factors such as adequate resources, close coordination, and high returns were the key challenges for implementing an effective safety management system in Hong Kong. Dabirian and Safar (2016) examined the structure of management safety management in construction workshops in research entitled "dynamic modeling of building safety management system based on correctional measures of the site," using system dynamics approach. The results of this study show that the severity and the number of incidents as well as the losses can considerably decrease by using factors such as learning from safety inspection, investigation of incidents, and corrective actions based on them. This study shows corrective actions as a useful policy to prevent incidents.

Mariani et al. (2015), in a paper entitled, "the dynamics of the system for modeling construction incidents," analyzed the occupational incidents in the construction project due to the probability of the variables affecting the events of construction projects using the system dynamics method. The model of this research covers the process of occupational incidents and direct and indirect costs. This model creates OSH cost components that need to be controlled. The results of the research show that the variables of work discipline and work hazards have the greatest impact on work incidents. Therefore, contractors in the construction project fully understand what works and which part of the construction supply chain should be improved. Additionally, it is shown that direct and indirect costs and occupational safety and health costs will impact the project budget controlling. Hence, the project's budget for occupational safety and health costs will not be more than it is planned.

A study conducted on healthcare cost control using a system dynamics approach was reported by Zare Mehrjerdi (2012). As far as applications of system dynamics to a variety of fields are a concern, Ghaderi et al. (2020) proposed a system dynamics approach to analyzing bioethanol and biodiesel supply chains: increasing bioethanol and biodiesel market shares in the USA. Di Nardo et al. (2019) developed a model for a safety management system using the System Dynamics approach to study the behavior of incidental events. With this regard, Zare Mehrjerdiet al. (2020)

developed a system dynamics approach for analyzing the impacts of health-related factors on economic growth. In addition to that, Eftekhari and Zare Mehrjerdi (2017) developed a system dynamics model to investigate the losses due to medicine consumption cycles.

Literature review indicates that in recent years some researches are conducted on the safety and risk management areas. Gitinavard et al. (2017) studied project safety evaluation by a new soft computing approach. The authors proposed a decision model based upon a new version of the complex proportional assessment method taking construction projects as a case study in their work. Zare Mehrjerdi and Haqiqat (2015) developed a conceptual model based on the Latin Hypercube sampling to integrate OHS into project risk evaluation. Ebrahimnejad et al. (2017) proposed a new extended analytical hierarchy process technique with incomplete interval-valued information for risk assessment in I.T. outsourcing. Haqiqat and Zare Mehrjerdi (2019) studied safety risks impacts analysis on construction project objectives using a fuzzy expert system hybrid model and Latin hypercube sampling. Golzar Ragheb et al. (2016) studied the hesitant fuzzy compromise group decision-making model by considering the weight of decision-makers to assess safety risks of production projects in the shipbuilding industry. Zare Mehrjerdi, Y. & M. Dehghanbaghi. (2013a) proposed a system dynamics modeling for risk analysis on the new product development process.

## III. THE PROBLEM STATEMENT, MOTIVES, AND NOVELTIES

Working as a consultant in the pelletizing industry has given researchers an opportunity to see a variety of accidents occur when related expenses accumulate. Close observations indicting that employees being injured, dis-benefited, removed from the task, and disabled. As a result of that great deal of working days was lost, activities were delayed and not being completed on time, so delay occurred. Such critical problems demand research be conducted. In this regard, the trend of accidents, costs of them, safety, and the associated risks over some periods in such a way that the routing work in the site continues without any working factors change was the objective of this study via the presentation of a system dynamics approach.

FMEA methodology allowing risky factors identification and prioritization using RPN numbers was selected as a tool to determine high-risk factors. On the other hand, system dynamics that allows studying the interrelationships among factors affecting safety, with feedback loops consideration, was selected for trending purposes. Integration of these managerial approaches is the new idea that can be considered as a new contribution of this article to the literature of risk and safety management.

### *A. Methodology*

Many researchers have employed FMEA as a tool for risk assessment. This research uses FMEA for risk identification, assessment, and reporting their impacts on the entire system of the Sechahon pelletizing plant for controlling purposes. Mutlu and Altuntas (2019) stated that "the accuracy and reliability of FMEA method have been fairly criticized by many researchers in the field. To deal with this deficiency of FMEA, they have integrated FMEA and fault tree analysis (FTA) method using fuzzy probability estimations of time. Oktarina & Muhardi, M. (2020) have also hinted to this fact that "FMEA is a time-consuming process and requires a multidisciplinary team which has a good understanding of the process being analyzed." Besides that, it needs to be recognized that "FMEA only helps in identifying the possibilities of a process to fail, it does not eliminate them."

The steps listed below are necessary for dealing with safety problems in pelletizing industry using FMEA and the system dynamics approach. Figure 1 schematically shows how this research is done, from literature review to scenario development and analysis. Steps relating to FMEA and S.D. are discussed in the following sections with more details.

### B. steps of Failure Mode and Effect Analysis

According to Oktarina & Muhardi (2020) and Zare Mehrjerdi & Dehghanbaghi (2013a), the general steps of FMEA can be listed as below:

1. Inter-organizational working process flow study
2. Team creation for each section/process of the plant
3. Activities classification
4. Brainstorming using team of relating section/process
5. Accidents identification
6. Risks relating to accidents determination
7. RPN calculation
8. Identifying the root of the failure model's problem
9. Re-designing the process
10. Analyzing and testing the new process
11. Implementing and monitoring the re-designed process

In the current study, to deal with the shortcomings of FMEA, various teams were considered, one for each section of the plant. We asked team members to be honest and have frank discussions on the subject matter until an agreement reaches on each issue. Figure 1 depicts the steps to be followed to work with risk factors until RPN can be calculated. The value of RPN is calculated by multiplying the values of S (Severity), O (Occurrence), and D (Detection). According to the standard definition of FMEA literature, O, S, and D values ranges from 1 to 10 and hence the least value of RPN is one, and its highest value is 1000. Risks with the highest level of RPN are identified by ranking the entire list and then working with the highest RPN value risks. More details of that regarding the case study are given below. In the case study, a total of 625 risks were identified, of which 286 are high-risk RPNs and need to be scrutinized. These risks were categorized according to their nature into five categories of (1) physical, (2) exposure to dust, (3) ergonomics, (4) emergencies, and (5) psychosocial risks.

The rules used in this study are (Hagimoradi and Zare Mehrjerdi, 2018):

1. The maximum value of RPN cannot exceed 100.
2. A controlling measure is mandatory if the RPN is higher than 100 or one of the three indicators that determine the RPN has a value of seven while RPN is low.
3. If two indicators have values above seven and the related RPN is high, then a controlling measure is in order.

### C. Steps of System Dynamics

System dynamics steps are (1) key variables identification, (2) system boundary determination using endogenous and exogenous variables, (3) dynamic hypothesis clarification, (4) causal diagram construction, (5) flow chart building upon proposed causal diagram (6) mathematical modeling of the problem, (7) model simulation and validation, (8) sensitivity analysis, (9) policy-making and scenario presentation.

### D. System dynamics description

#### Steps 1 (exogenous and endogenous variables)

The key variables used in this study were gathered in the working theater of our pelletizing site development. Breaking down the entire system into three subsystems: (1) safety and accident management, (2) economy, and (3) human resources, the exogenous and endogenous variables were identified. The main variables used in this study are presented in Table I by subsystems and exogenous and endogenous categories. Then the final list was presented to the experts on the subject matter for finalization.

### *Step 2 (model boundary)*

The model boundary is summarized by listing endogenous, exogenous variables as it is customary in S.D. literature. For the problem under discussion, the model boundary is determined by the variables are given in Table I.

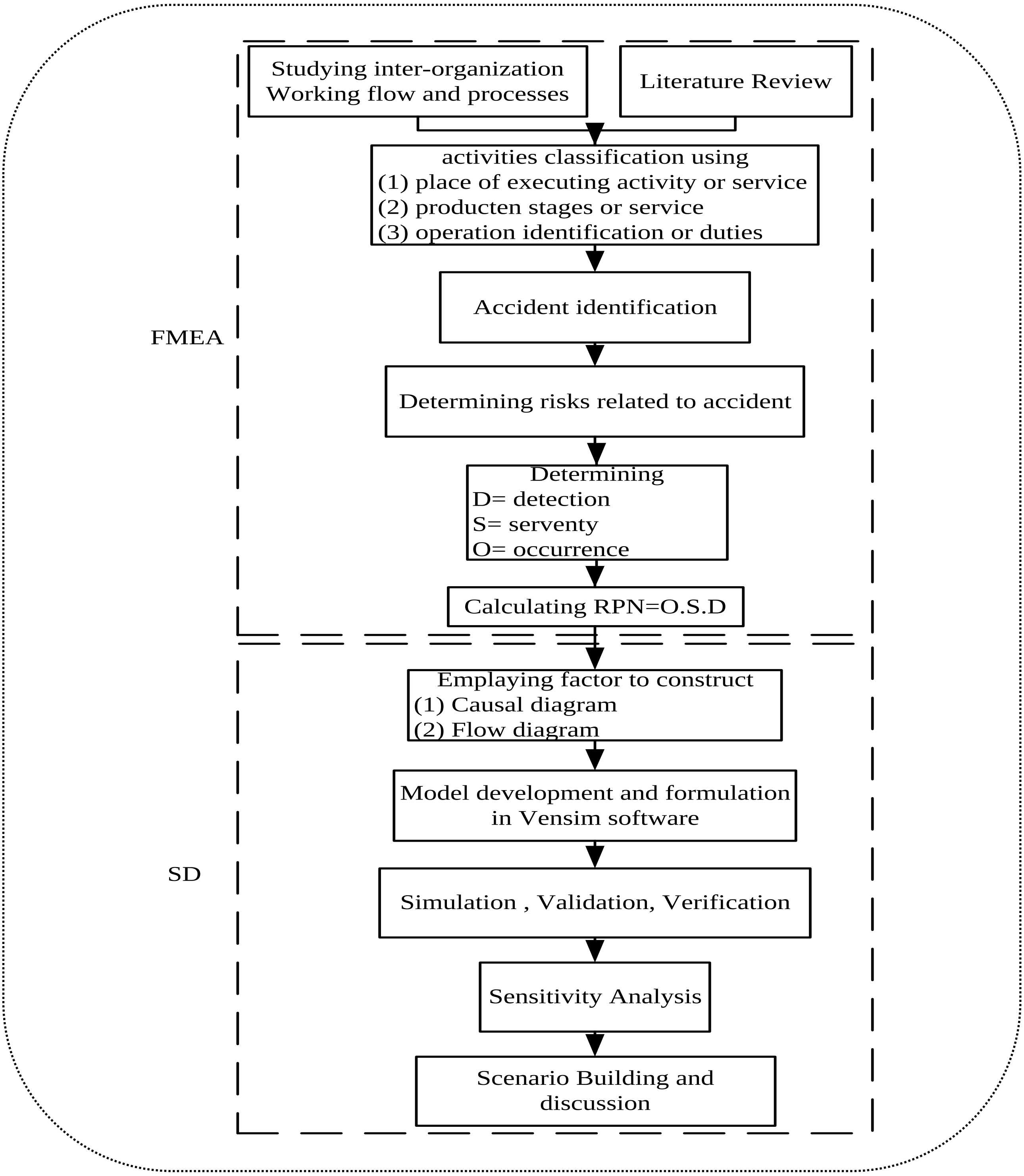


**Figure 1: Hybrid FMEA-SD approach to conduct research**

**Table I: key variables and model boundaries**

| Model subsystems | Endogenous variables | Exogenous variables |
|---|---|---|
| Safety and accident management subsystem | Safety<br>Safety rate<br>Total Risk<br>Risk rate(increasing)<br>Risk rate(decreasing)<br>Accident management<br>Risk contraction | Physical Risk<br>Dust, Chemical, toxic substances<br>Psychological Risk<br>Ergonomic Risk<br>Emergency Risk<br>environmental safety concern<br>Equipment safety concern<br>safety management |
| Economy subsystem | Safety measure cost<br>Safety budget<br>lost workdays<br>Cost rate(increasing) | Average lost workdays<br>total budget<br>the average cost of one working day |
| Human Resources subsystem | Safety awareness<br>Human resources Related action | Age<br>Level of education<br>Work experience |

### *Step 3 (Dynamic Hypothesis)*

The depiction of a cause and effect diagram demonstrating the interrelationships among key variables using feedback loops is known as the dynamic hypothesis. The dynamic hypothesis of this model shows that risk and accident variables generate an enforcing loop while accident causes working days being lost and expenses accumulate. As a result of that, accident management initiates, and the safety level increases. As a result that, the risk level decreases. Figure 2 is a representation of the dynamic hypothesis of the problem.

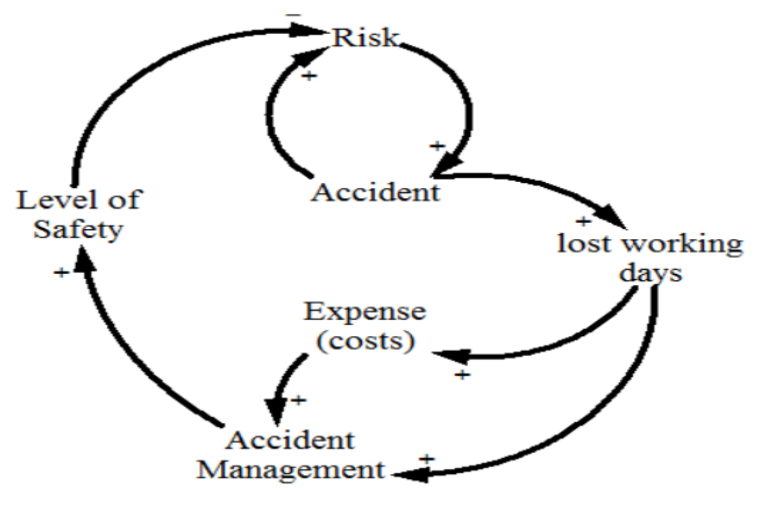


**Figure 2: The dynamic hypothesis of the problem**

### *Step 4 (Cause and effect diagram)*

As Senge (2016) claims, "there is no one-sided action." Systematic thinking considers actions with both cause and effect phenomena. By definition, when the impact of variable A on variable B is in the same direction (increasing both or decreasing both), then a positive sign

(+) is used. On the other hand, when the impact of variable A on variable B is in the opposite direction (one increasing and the other decreasing), then a negative sign (-) is used. These principles need to be followed to develop the cause and effect diagram presented in Figure 3.

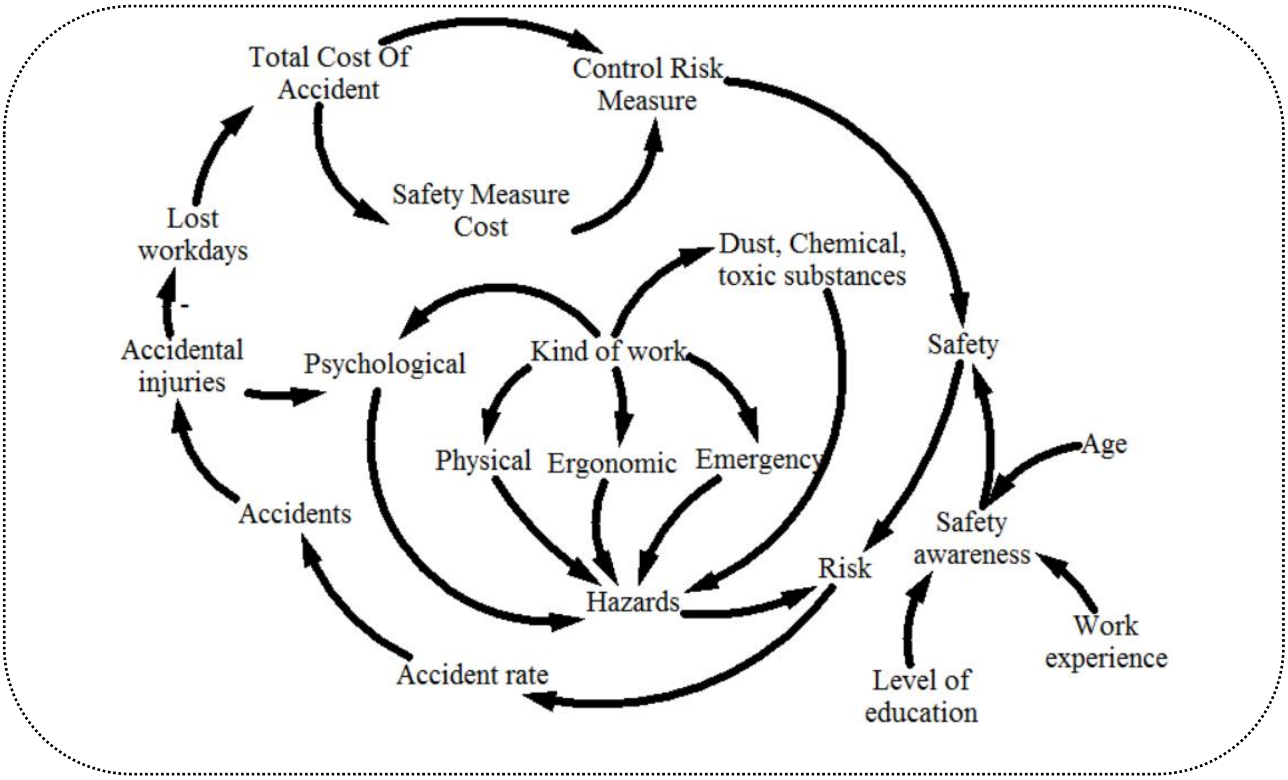


**Figure 3: Cause and effect diagram**

As it is shown in Figure 3, the main loop is comprised of variables of risk measure, safety, risk, accident rate, accidents, accidental injuries, lost working days, and total cost accident. This loop is a balancing loop because, by increasing safety in the system, the risk in the system decreases. Other variables impact each other in the same direction, by increases or decreases. Another loop starts from risk and continues through accident rate, accidents, accidental injuries, psychological hazards, and then risk. This is a reinforcing loop where each variable has a positive impact on the other. This structure is comprised of three loops, where two of them are balancing loops, and one is a reinforcing loop. The second balancing loop goes through safety measure costs after meeting the total cost of the accident.

## IV. CASE STUDY FEATURES

Sechahoon Bafgh Pelletizing Complex has been designed to produce 5 million tons of usable pellets in the iron and steel industry by direct reduction method to supply the required pellet in the steel industry. The site of the factory is located near Chaghart iron ore, 13 kilometers north of Bafgh city, from Yazd province (115 kilometers from Yazd) in the central part of Iran with a longitude of 55028 and latitude of 31042. Risk assessment for the Sechahoon pelletizing plant was performed using the FMEA method. A total of 625 risks were identified in this series, of which 286 are high-risk RPNs and need to be scrutinized. These risks were categorized according to their nature and consequences in five categories of physical, exposure to dust, ergonomics, emergencies, and psychosocial risks so that they can be reviewed in detail. Figure (4) shows the percentage of each sector's risks. As it turns out, the largest share is related to the physical risks as much as 95%. For this reason, physical risks were divided into various sectors of mechanical, electrical, vibration, radiation, sound, heating, and fire. The percentage of each of these risks in Figure 5 shows that the share of mechanical risks exceeds other risks, and then the electrical risks have a higher percentage of high-risk and high RPN risks that need to be addressed more often.

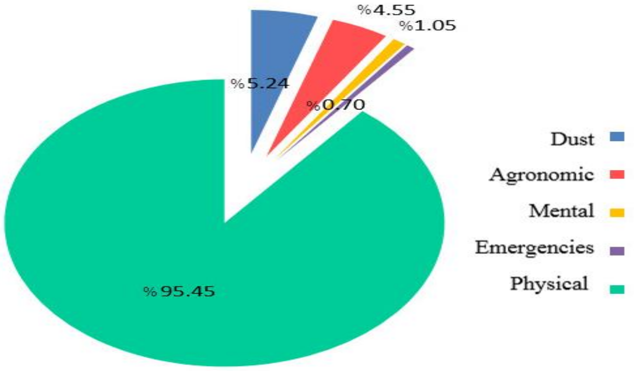


**Figure 4: The extent of identified hazards by different sections**

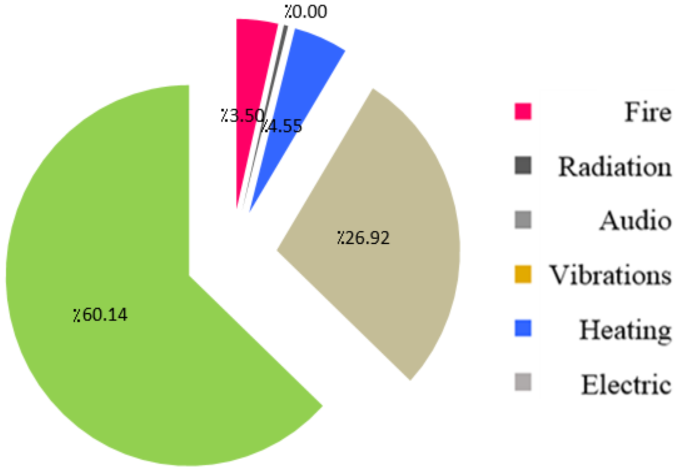


**Figure 5: Physical hazards in different sections**

## V. RESULTS

### *A. The system dynamics model (referral data)*

The number of incidents as well as the number of lost days due to unwanted events should be examined to enhance the safety of existing processes and the factors affecting them. Figures 6 and 7 show the number of incidents and lost days, respectively. For this purpose, a system dynamics model was created with data about different months of the year 2018, and then its status was examined for the year 2019.

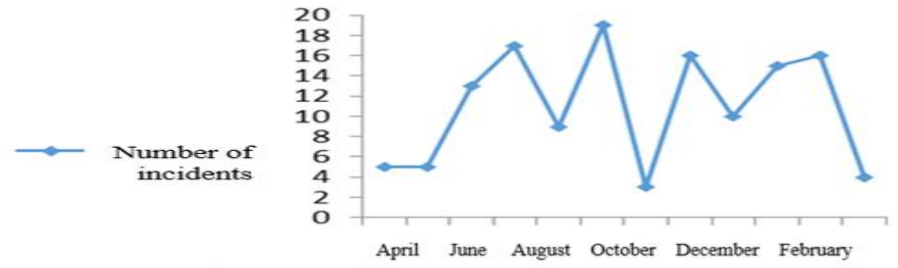


**Figure 6: Number of the incident in the pelletizing plant in 2018 in different months**

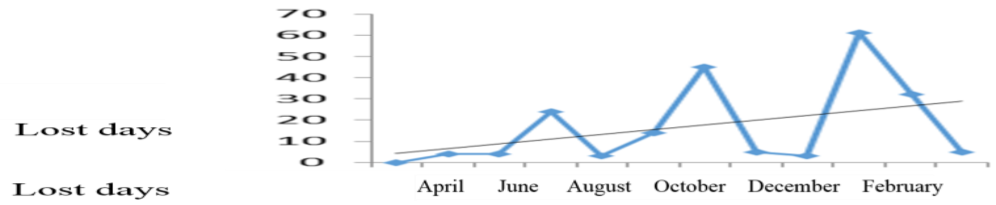


**Figure 7: Number of lost days due to incident in 2018 by month**

## *B. Validation of the model*

After creating the flow diagram based upon the cause and effect diagram of the system under

study and examining the results of many simulations run, up to management satisfaction, then it is time to validate the proposed simulation model with its relational formulation. There are many validation tests discussed in the book of system dynamics written by Sushil (2012). In this research, the validity of the proposed model was investigated by most common tests as are listed below:

1. Border adequacy test
2. Structural Assessment Test
3. Re-behavior test
4. Boundary conditions test

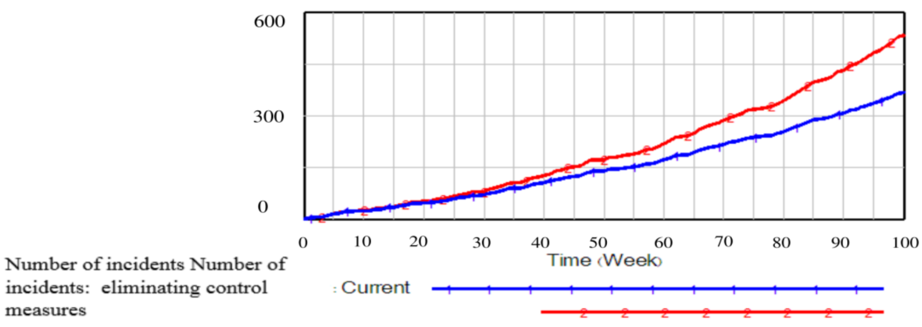


**Figure 8. Border adequacy test**

### *C. Border adequacy test*

For the proposed model, key variables are investigated by reviewing the literature and by live observations of working theater for a period of time. In addition to that, the necessity and important variables mentioned by experts in the field and academics have also been considered. In response to the question of whether model behavior, after the removal of border assumptions, does change significantly, the results of the proposed model were analyzed after removing parts of the model and changing the boundary of that. Figure 8 shows the effect of eliminating the "risk control measures" variable. Deleting this factor will reduce the safety level and increase the level of incidents. This graph compares the number of incidents related to the state of the safety control measures when these measures are eliminated. The number of events will be increased if these measures are removed. For other variables, in a similar way, this test can be performed.

### *D. Structural Assessment Test*

The purpose of the structure test is to determine that the model's structure matches the descriptive knowledge associated with the system. In addition to that, the examination of the logic of the decision rules in shaping the behavior of the variables and the correctness of the structure of the model equations is a must. Since the model equations have been written in the software environment, the correctness of the structure of the model equations was verified by the software (Figure 9).

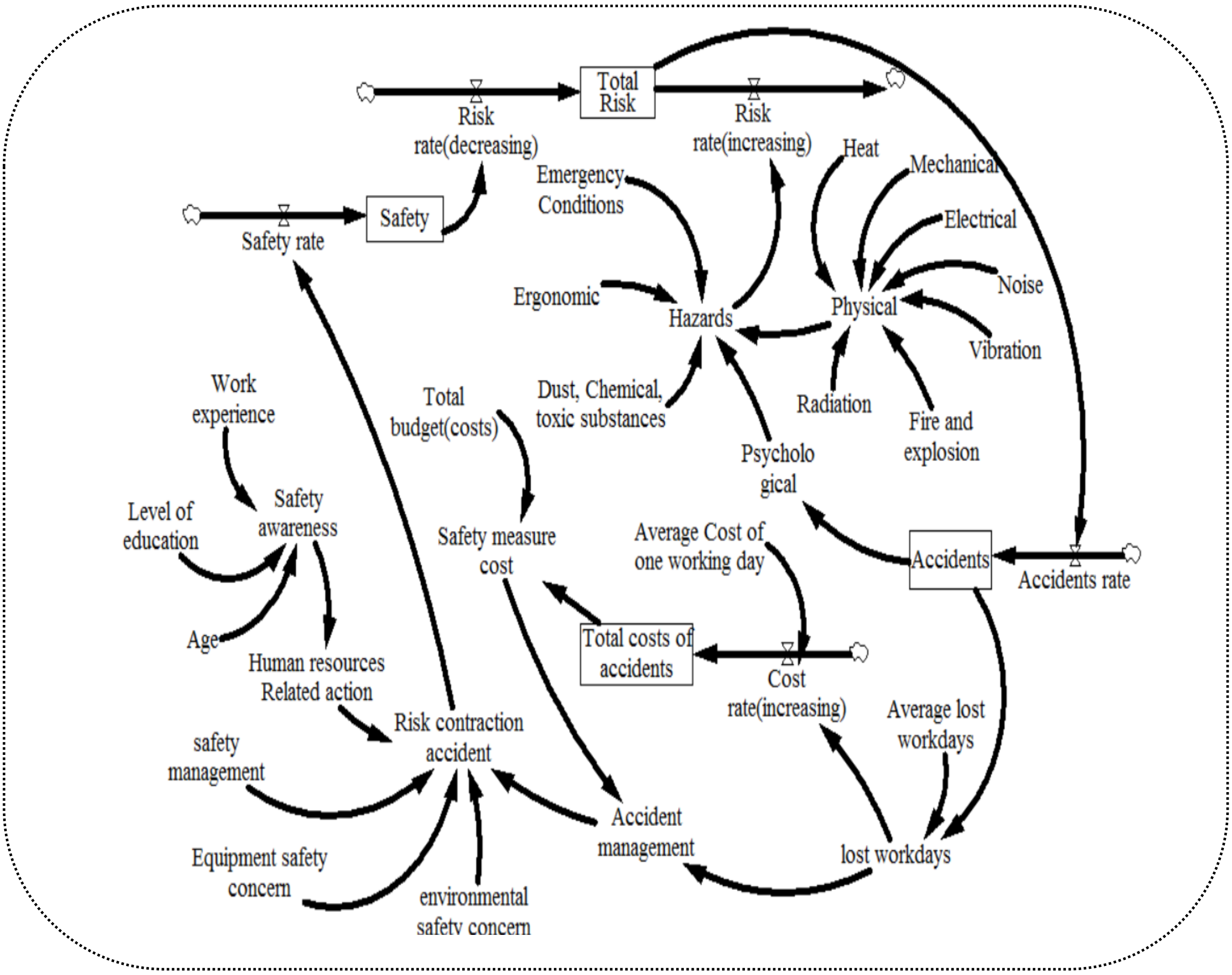


**Figure 9: Structural assessment test**

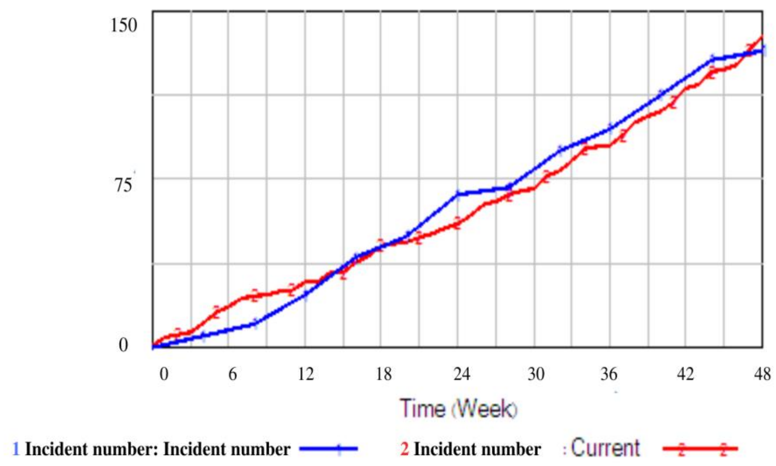


**Figure 10. Re-behavior test**

### *E. Re-behavior test*

One of the most important tests available to analysts for model validation is the reproduction of the behavior of goal variables. Such results are usually compared with the historical data of relating goal variables. With this test, it is determined which model variables can rebuild the amounts of historical data. Figure 10 compares the outputs of the model with the actual data

obtained from the past. When such a match occurs the modeling results can ensure that validity for future predictions may be warranted (Sushil, 1993).

### *F. Boundary conditions test*

This test examines whether the model behaves appropriately when its inputs are in extreme conditions such as zero or infinity. In other words, in this test, the stability of the model is measured in extreme conditions. Zagonel & Corbet (2006) stated in their research that extreme conditions tests guide us to find a response to the question of "does the model respond plausibly when subjected to extreme policies, shocks, and parameters?" In this model, the shock is when the number of lost working days approaches infinity (a large number). However, to examine this test, the variables "risk control measures," "safety," and "risk" were placed in their boundary condition, the results of which are shown in Figure 11.

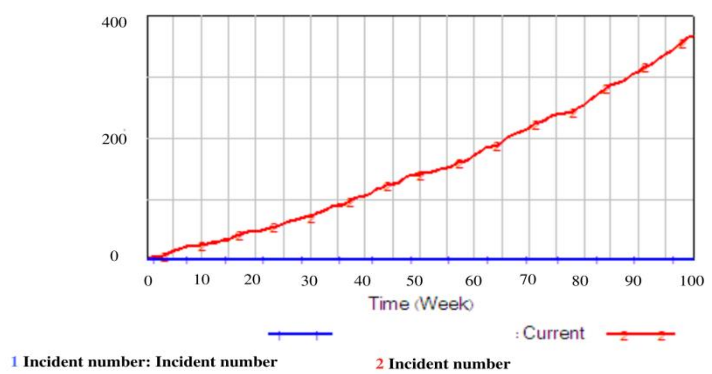


**Figure 11. Boundary conditions test**

## G. Sensitivity analysis

In general, the purpose of the sensitivity analysis is to investigate whether changes in the parameters, boundaries and time intervals result in significant changes in the numerical values, behavior, and policies observed or not. After simulating and observing the behavior of all components of the model in the desired time period, the changes in the variables of the model and their impact analysis on the main variables are investigated. Table II shows the results of sensitivity analysis for various variables.

**Table II: Sensitivity analysis results**

| *Analytical results* | *Intervals* | *Variable* |
|---|---|---|
| The number of incidents is susceptible, and sensitivity increases with time. Safety is a high sensitivity, and sensitivity increases with time. | 60 -15 | Age |
| The number of incidents is susceptible, and sensitivity increases with time. Safety is a high sensitivity, and sensitivity increases with time. | 30-0 | Work experience |
| The number of incidents is susceptible, and sensitivity increases with time. Safety is a high sensitivity, and sensitivity increases with time. | 1-0 | Education level |
| The number of incidents has low sensitivity, and sensitivity does not increase with time. Safety is sensitive and increases with time. | 1-0 | Measures related to human resources |
| The number of incidents and safety is susceptible, and sensitivity increases with time. | 1-0 | Safety management measures |
| The number of incidents has low sensitivity, and sensitivity does not increase with time. | 1-0 | Safety measures related to machinery |
| The number of incidents has a low sensitivity and sensitivity does not increase with time. Safety is sensitive and increases with time. | 1-0 | Safety measures related to the environment |
| The number of incidents has low sensitivity, and sensitivity does not increase with time. Safety is sensitive and increases with time. | 5000000000- 0 | Safety measures budgeting |
| The number of incidents is not sensitive. Safety has a low sensitivity and increases with time. | 1000000 -0 | Cost of one working day |
| The number of incidents is sensitive and increases with time. Safety is not sensitive. | 1-0 | Heating risks |
| The number of incidents has high sensitivity, and sensitivity increases with time. Safety is not sensitive. | 1-0 | Mechanical risks |
| The number of incidents has high sensitivity, and sensitivity increases with time. Safety is not sensitive. | 1-0 | Electrical risks |
| The number of incidents and safety is not sensitive | 1-0 | Audio risks |
| The number of incidents and safety is not sensitive | 1-0 | Vibration risks |
| The number of incidents has a low sensitivity and increases with time. Safety is not sensitive. | 1-0 | Fire and explosion risks |
| The number of incidents and safety is not sensitive | 1-0 | Radiation risks |
| The number of incidents has a low sensitivity and increases with time. Safety is not sensitive. | 1-0 | Dangers of exposure to dust and toxic and chemical substances |
| The number of incidents has a low sensitivity and increases with time. Safety is not sensitive. | 1-0 | Ergonomic risks |
| The number of incidents and safety is not sensitive | 1-0 | Emergency risks |
| The number of incidents has a low sensitivity and increases with time. Safety is not sensitive. | 1-0 | Mental risks |

After analyzing the results of variables and their impacts on the key variables of the problem, the effectiveness of key indices on safety management and incidents were determined. The number of incidents was examined under the following scenarios:

- The scenario of maintaining the current situation
- The scenario of human resources management
- The scenario of technological improvement
- The scenario of safety management
- The scenario of risk reduction

### *H. Scenarios*

**The scenario of maintaining the current situation:** According to this scenario, the process of safety management is assumed to be in line with the past and with no changes in current policy or adoption of a new policy. All variables are the same as those defined previously. The actual values of some parameters are as described below:

(1) Concerning safety rate, management measure is 0.5 (on a scale of 0 to 1),
(2) About equipment safety, management measure is 0.6 (scale 0 to 1),
(3) Concerning environmental safety, the management measure is 0.6 (0 to 1 scale).

If such a process continues, the number of incidents will end at the 100th week to 365 incidents. Figure 12 shows the trend of the number of events in this scenario.

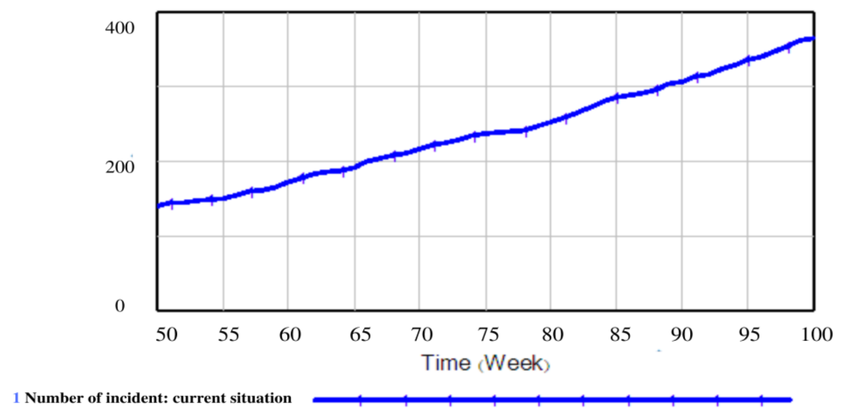


**Figure 12: Scenario of maintaining the current situation**

**The scenario of Human Resources Management:** The purpose of this scenario is to increase the safety of the human resource so that with its development, the number of incidents does not increase. The human resource does not have the necessary potential to fully cover occupational safety. But, it can take a considerable amount of attention when needed.

Generally, the increase in human-resource risk control measures in this scenario began after about two months from the starting point, and the use of human resources is considered to be with higher education and more work experience. The number of incidents in this scenario was compared with the values for the scenario of maintaining the current state Figure 13.

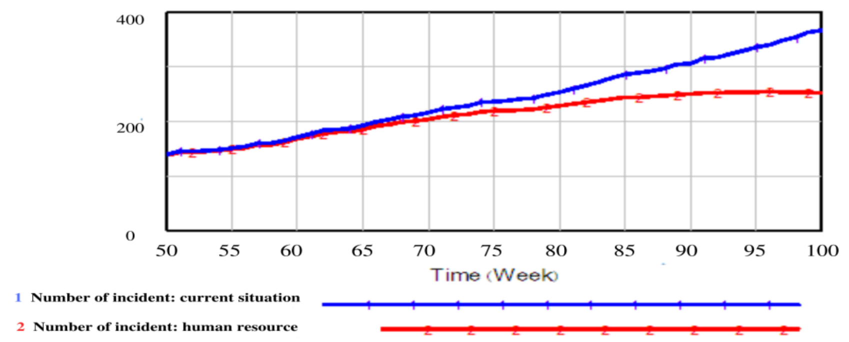


**Figure 13: Comparison of two scenarios for maintaining the current status and human resource management**

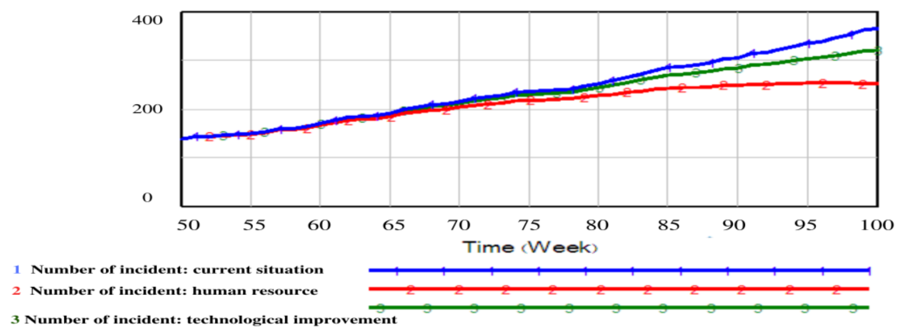


**Figure 14. The scenario of Technological improvement**

**The scenario of Technological improvement:** In this scenario, the use of more advanced equipment and subsequently better failure detection and machine repairing, machine protection and operation can be partly prevented from the incidents.

**The scenario of Safety Management:** This scenario shows that the number of incidents can be reduced by monitoring the performance of safety measures, monitoring the performance of safety measures, enforcing rules, creating guidelines for activities, and establishing a monitoring system, and developing safe spaces. The results of using this scenario are shown in Figure 15. As this figure shows, the number of events increased initially with the implementation of this scenario and then decreased.

**The scenario of Risk reduction:** General speaking, safety management scenarios are conceptually wide and diverse. However, the development of this scenario focuses on reducing the likelihood of incidents and increasing safety. The number of incidents will be reduced by creating changes that have been recently made to the model and reducing those more severe risks referred to in the previous section. Figure 16 shows the results of this scenario in comparison with the previous scenarios. According to this figure, the greatest reduction in the number of incidents occurs with this scenario, and then it will increase.

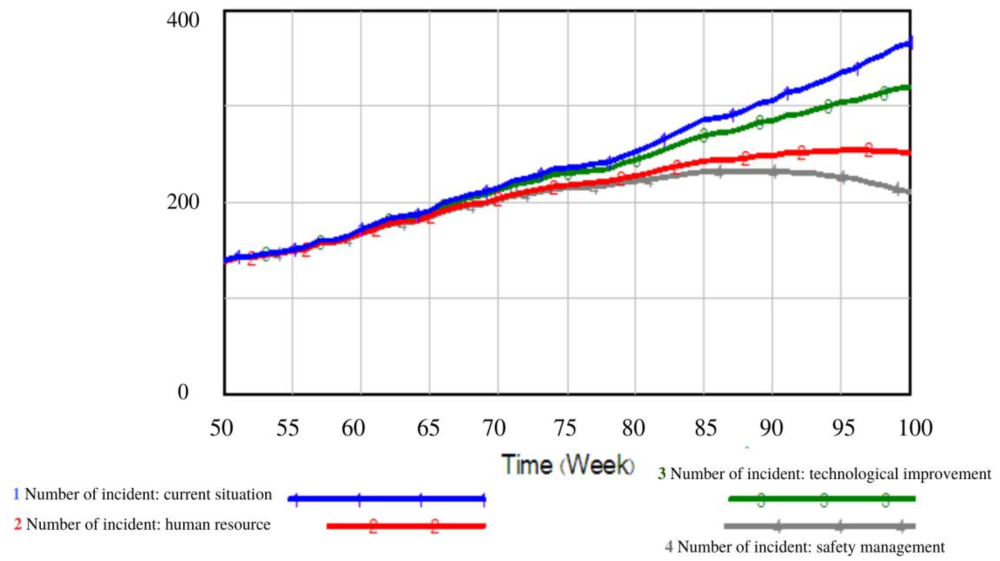


**Figure 15: Scenario of safety management**

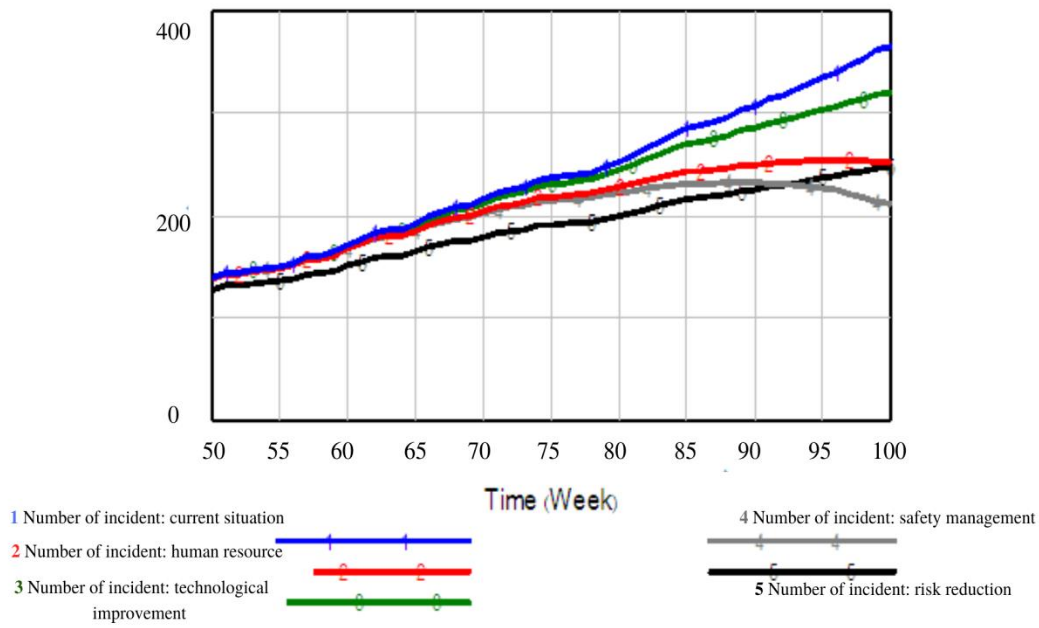


**Figure 16. Risk reduction scenario**

## *I. Scenario analysis*

The number of incidents in different scenarios is shown in Figure 13. In the risk reduction scenario, the reduction of incidents occurs in earlier periods where it was initially at a higher value; however, it increased again with the passage of time. This scenario can be effective in the short run. The scenario of technology improvement represents a slight upward trend; however, it is better than maintaining the current situation and reducing the number of incidents in the long run. Both of the human resource management and safety management scenarios are recommended as effective long-term models. In either the short term or long term, two scenarios of risk reduction and safety management, as two successive scenarios, can be considered the best scenarios in which it can reduce incidents. In the short term, the risk reduction scenario and in the long run, the safety management scenario will have the best results in the number of incidents reduction.

## VI. MANAGERIAL IMPLICATIONS AND CONCLUSION

Research combining FMEA approach with a dynamic methodology for behavior trending of variable performance is rare in the literature. Current research can help managements in Pelletizing industry as well as iron and steel industries to conduct similar researches and behavioral experimentations. In addition to that, construction sites, road building, bridge construction, ship industry, and high-rise buildings are also accident prunes and hence good cases for model implementation. This hybrid FMEA-SD approach allows management to trace the behaviors of those variables that are costly to the system. The main advantages of this hybrid approach are listed below:

1. The use of FMEA as a tool always helps engineers and managers be aware of task-related accidents and their incidence rate.
2. Emphasis on the fact that "many researchers in the field criticize the accuracy and reliability of FMEA method." So, it requires careful implication of the results. To deal with the FMEA shortcomings, some guidelines must be stated in advance by the team leader, to be followed by all members, all through the study.
3. Encourages managers to better understand the problem before starting the modeling of the problem due to the risks and accident components that need to be identified in advance.
4. Non-systemic risks and their associated costs give managers a feeling of what will happen to the system both accidentally and financially. Hence more attention would be given to the working theater and production floor to closely watching unwanted accidents occur.

There are many situations that management needs to deal with to better identify likely job-related accidents and the level of safety that the system is carrying on. The case under study presents a sample problem from the pool of situations that are in need of elaboration both analytically and managerially. The results of the simulation indicate that reducing the number of incidents in the risk reduction scenario is not so very difficult, and hence it can be treated as a priority policy. The scenario of risk reduction is the best scenario in the short term. The scenario of technology improvement shows an incremental growth trend, but the scenario of maintaining the current situation can better reduce the number of incidents. The scenario of human resource management and safety management scenario will initially be on an upward trend and will continue to decline. The scenario of human resource management and safety management is a good way to reduce disasters in the long run. The safety management scenario is better than the scenario of human resources management. The best method to reduce the number of incidents is to successive use of two risk reduction and safety management scenarios. In the short term, the risk reduction scenario and in the long run, the safety management scenario will have the best results in reducing the number of incidents.

With regard to the findings and limitations, it is recommended to evaluate the impacts of other effective factors on the problem. The cost of running any of the scenarios can be an important issue for managers; hence such calculations are helpful for making decisions. Considering that electrical and mechanical risks have the highest stake in increasing the probability of occurrence of accidents, the risk reduction scenario can present the number of incidents and may be used as an optimal scenario in the short run. It is good to pay attention to electrical and mechanical risks and watch them closely. The methods used to reform the risks will be effective when they can reduce the number of incidents. Additionally, new research can be conducted to get hands-on values for factors such as weather conditions, temperatures, and sound pollution. Fire accident is another problem in the working theater, however. Employees who fall from very tall steel structures and high-rise buildings also need such research attention.

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