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Research Article

Modeling the Effects of Safety Culture Affecting Safety Performance on Occupational Accidents with System Dynamics

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Abstract:

Despite the advancement of technology in the world, human safety and occupational health are still exposed to numerous hazards in working life. Due to the heavy material and moral burden that occupational accidents will create on the socio-economic structure due to the lack of safety culture, countries are constantly looking for alternative safety culture policies to prevent occupational accidents. In our study, the role of safety practices, pressures and other conditions to reduce occupational accidents and the relationships between them were examined. The aim of the study is to present a System Synnamics (SD) model that can show the frequency values, costs, level of system safety and risks associated with accidents, human resources and productivity performances of occupational accidents in a certain time period. For this purpose, the behaviors of the factors affecting safety management in order to reduce occupational accidents have been analyzed, and the complexity of the causal factors affecting safety performance and safety culture has been revealed. In the next step, basic variables were defined, causal diagrams and flow diagrams were drawn, and a model was prepared with Stella Archtect 3.3 software and the data was simulated. Four different scenarios were defined in order to evaluate the sensitivity of the model and to determine the leverage variables. As a result of our study, the effects of both the safety management scenario and the human resources management scenario that cause a significant decrease in the number of accidents were seen. Another important aspect of the model we prepared in the study is the expansion and development of the model by adding new modules to create different Safety models. As a result of the study, compared to other scenarios, the safety management scenario has reduced the number of unsafe situations and unsafe behaviors, the number of incidents, the number of risks, the effect of occupational accidents and the effect of accident costs; It has been found that with the focus on safety, it causes an increase in its effect on production efficiency and on the basis of its contribution to more efficient use of human resources.

1. Introduction

The workforce of any country, particularly developing countries, is considered a significant part of the national capital and forms the basis of economic and social development. The rapid increase in the world population has led to an increase in needs and an increase in insufficient production, and in the face of this situation, new employees were needed in the labor demand needed by the producers. Without a healthy workforce, it is not possible for the country's economy and industry to develop. Production and labor demand, occupational safety, sustainable use of production resources, efficiency and safety culture are of great importance. Due to the estimates of the heavy material and moral burden caused by occupational accidents due to the lack of safety culture, countries have constantly sought alternative safety culture policies for the prevention of occupational accidents. Occupational accidents are generally the result of unsafe behavior and unsafe situations, which are the cause of a series of in Safety. In order to prevent accidents, it is necessary to fully understand the mechanism of accident occurrence. However, in the past, human errors were seen as the main cause of all accidents, and different factors about accidents were prevented from occurring because they were considered as the starting point and often the end point of all investigations. There are many theories and models regarding the causes of occupational accidents in the literature. The "Domino Theory" is known as the first accident causality model developed by Heinrich [1]. This theory was updated by Bird and Adams in later years [2,3]. In researches on accident causality, from domino theory to behavioral approach, accident models can explain the reasons for the occurrence of accidents and play an important role in the investigation and analysis of accidents. Statistical analyses and different methods were used to reduce accidents and develop safety culture and to reveal the reflections of developments. However, traditional research methods in accident investigations ignore the interactions between various factors of the system because they follow a linear process of root-cause analysis [4,5,6]. Traditional statistical approaches have limitations in predicting the future and learning the main factors that cause occupational accidents in every sector. On the other hand, since SD has the unique advantage of analyzing multiple and complex feedback systems, it has the potential to examine the structural effects and possible effects of changes in dynamic system properties that cannot be achieved with traditional approaches, and the properties of complex systems from a holistic perspective. In contrast to the linear cause-and-effect paradigm, SD emphasizes the importance of feedback by systematically articulating problems [7,8]. While investigating the causality relationships between the cases, it shows that better results can be achieved by adopting a systematic perspective and evaluating the feedback obtained from the relevant variables. Research emphasizes that safety culture has a significant impact on reducing major disasters and accidents. In order to properly understand the system and make a precise OH&S performance assessment, all components of the organization and their interactions with each other must be evaluated together.

Management, commitment, safety objectives, safety investigation, safety policy, Safety implementation and regulation, safety prevention and control system, status of the safety committee, employee's attitude towards Safety, employee participation, perception of workplace safety, safety priority, accountability of work, employee's perception of safety, rules and procedures, risk assessment, safety training, management style, visibility of management, communication, production pressure, work satisfaction, cleanliness, work and workforce composition, risk management, commitment to safety, safety promotion and safety communication have also been identified as the main variables of safety culture. In addition, a trained workforce that is familiar with safety instructions has the opportunity to prevent a significant part of accidents. Having a systematic pl an and allocating a specific budget for the implementation of the plans can reduce the time and costs lost as a result of neglecting safety instructions [9].

Due to the nature and complexity of occupational accidents and safety culture, SD approach was used to analyze the effects of safety culture on occupational accidents in the model to be created. Studies show that adopting a systematic perspective and evaluating the feedback of relevant variables can lead to much better results when investigating the causal relationship between concepts. Using such an approach, and with the help of causal feedback loops analysis and inventory and flow structure, complex interactions within these systems can be identified and conceptualized. The method used in SD is usually categorized as problem, hypothesis, analysis, policy, and practice and focuses on solving the problem. In order to evaluate the sensitivity of the model to be designed and to determine the leverage variables, different scenarios can be defined and the results can be examined with sensitivity analysis.

This study aims to present an SD model that can show the frequency values, costs, level of system safety and risks associated with accidents, human resources and productivity performances of occupational accidents in a certain time period. In order to reduce occupational accidents for the achievement of the determined goal, the behaviors of the factors affecting safety management were analyzed and the complexity of the causal factors affecting safety performance and safety culture was revealed. This study describes the role of safety practices, pressures and safety conditions and the relationships between them in order to reduce accidents. It offers an SD model that can show the course and costs of accidents, safety level of the system and risks associated with accidents, human resources and productivity performances in a certain time period. The results of the study will make a positive contribution to the implementation of policies related to human resources management, safety culture and standardization in the development and implementation of safety within the organization, and the prevention or reduction of occupational accidents.

2. Literature

Safety culture is considered to have significant potential in reducing daily task related major disasters and accidents all over the world [10,11]. Gitinavard et al (2017) states in their study that one of the keys to successful Safety management is to develop a strong safety culture [12]. There are different metrics of safety that evolve with time and are considered evaluation tools for safety performance. These metrics can be indicators that can make two types of measurements, lagging or leading. While delayed indicators are related to the result of an accident; on the other hand, leading indicators are considered as measurements related to preventive actions.

Safety management systems have been studied by many researchers using analytical methods based on statistics and experimental analysis, focusing on the importance of taking Safety measures. Most of the studies on safety do not have causal interactions between variables. For this reason, a large part of researchers have not been interested in the causal interaction of factors because they have turned to direct factors on safety. Numerous studies have highlighted various safety culture variables as critical success factors in safety management programs [13,14,15,16]. For instance, Loushine et al. (2006) identified safety communication and management commitment as key elements in enhancing safety performance [15]. Additionally, factors such as employee participation, safety environment assessments, identification of unsafe actions and conditions, and hazard recognition have been found to significantly impact safety outcomes [17].

In their 2008 study, Aksorn and Hadikusumo categorized the top 16 success factors of safety programs in Thailand into four main groups: management commitment, safety regulation, worker engagement, and safety prevention and control systems. Furthermore, various researchers have recognized several other success factors in safety management, including workplace safety perception, safety practices, the status of safety committees, work accountability, employee participation, safety priority, safety investigations, safety policies, rules and procedures, risk assessments, employee attitudes toward safety, safety communication, safety training, safety compliance, and management commitment [13,18,19,20,21,22].

In addition, in recent years, various organizations have used accident rates and lost-time injuries to be used in evaluations instead of delayed indicators based entirely on retrospective data;

- Assessment of the Safety environment,
- Safety audits,
- Safety performance Safety planning,
- Management's safety culture commitment,
- Awards and recognitions for safe conduct and accident investigation,
- More persuasive and leading indicators, such as Safety trends and trainings, are included [23,9].

The SD tool presented by Forrester, (1961) makes it possible to accurately assess the current dynamics of Safety in terms of its active factors [24]. The high complexity of Safety management can lead to difficulties in identifying, analyzing, and resolving Safety issues, and can even cause multiple problems to merge into bigger problems. In such complex environments, administrators may not see the direct consequences of these policies because the effects of Safety measures taken to deal with issues will be delayed. In such cases, Safety administrators can better understand the Safety situation if they use SD models [25,5,26].

SD, compared to cause-and-effect analysis, concentrates more on the importance of feedback loops where dependent and independent variables are clearly defined [27,28]. The application of the SD approach in solving occupational accidents and safety problems is increasing. Within the system theoretical approach, many studies have been conducted based on system dynamics and developing new risk assessment methods [29,4,30,31]. To date, some researchers have used the SD tool and concepts to investigate the dynamics of Safety management, which is extremely important in a number of cases, which are discussed below. For example, both studies by Cooke and Goh in 2003 and studies by Goh et al. in 2010 and 2012 adopted the SD approach to better understand the cause of major accidents [4,5,27,32]. In their 2014 study, Han et al developed a causal loop diagram using SD to investigate the production pressure effects on safety performance [33]. SD has also been shown to be an effective tool for modeling the safety attitude and behavior dynamics, organizational learning [34,35,27,32]. As a systems approach, SD addresses the behavior patterns of the system over time by describing the feedback structure in a system and focuses on identifying the efficient/vicious cycles of the system [27]. In this regard, it is used as a tool in theory development.

The concept of systems thinking—understanding the relationships between individual elements to comprehend the behavior of the entire system—has been utilized to mirror the complexity of safety components within safety management systems for accident analysis and investigation [27,26,33,36]. Consequently, researchers have adopted the System Dynamics (SD) methodology to achieve a deeper understanding of the challenges and interconnections among safety culture components and safety performance indicators through a systems thinking approach. Table 1 provides an overview of the literature on System Dynamics, as well as other components relevant to our study, including occupational accidents, safety policies, and safety management.

Table 1. *Literature review on system dynamics approach*

Year	Auther(s)	Subject of the study
1959	Heinrich	He worked on the "Domino Theory", the first accident causality model.
1961	Forrester	It included issues for the effective assessment of the current Safety-related dynamics of the SD.
1974	Bird	The domino theory put forward by Heinrich has been updated and different studies have been carried out on accident models, causes of occurrence, investigation and analysis of accidents.
1976	Adams	
1980	Zohar	He has studied the factors identified for the success of Safety programs.
1986	Brown & Holmes	
1997	Diaz and Cabrera	
2000	Cooper	
2000	Guldenmund	Instead of delayed indicators (accident rates, lost-time injuries, etc.), he has worked on safety policies and practices.
2000	Sterman	It has included SD applications related to the solution of problems encountered in identifying, analyzing and solving Safety issues.
2003	Cooke	With the Westray Mine Disaster dimension, the interaction of three subsystems: human resources, mine capacity, production and safety is included using SD. It has been pointed out that the investigation of the accidents that occur and the results obtained can have an important role in reducing the accident rate.
2004	Wiegmann et al	He has conducted studies on the success factors of safety management programs.
2006	Cooke & Rohleder	It has established a Safety system and incident notification system, and has carried out studies to prevent possible future incidents by detecting events that have occurred in the past.
2006	Loushine et al	He has conducted studies on the success factors of safety management programs.
2006	Marshes et al	He laid out six causal loop diagrams that help to understand how and why the level of risk changes over time [37].
2006	Salge & Milling	He has worked to improve the understanding of the complex safety system resulting from the combination of design flaws and line operations in the Chernobyl power plant accident with SD [38].
2007	Choudhry et al	Emphasis is placed on the significant effects of safety culture in reducing major disasters and accidents.
2007	Morecroft	He has conducted research on the feedback of SD issues.
2007	Qureshi	He has studied other systemic factors that are ignored in traditional research methods.
2008	Adamides	He laid out six causal loop diagrams that help to understand how and why the level of risk changes over time [39].
2008	Aksorn & Hadikusumo	He has conducted studies on the success factors of safety management programs.
2009	Lyneis & Madnick	They have worked on new risk assessment methods based on system dynamics within the system theoretical approach.
2010	Goh et al	It has included SD applications related to the solution of problems encountered in identifying, analyzing and solving Safety issues.

2010	Han et al	It has been stated that occupational accidents can be prevented to a significant extent by training and using trained workforce who are familiar with safety instructions, that one of the key factors of successful safety management is the safety culture in companies, and that up-to-date data can be used instead of delayed data.
2012	Chen & Jin	He has studied the factors identified for the success of Safety programs.
2012b	Goh et al	It revealed the reasons why even if businesses have allocated a certain amount of resources to safety, the injury rate cannot be reduced.
2012a	Goh et al	It has been shown by using a group modeling approach that management's perception of risk can be distorted when there is a strong production focus.
2013	Bouloiz et al	By modeling the activity of the industrial system, he applied system dynamics for assessing the safety of the storage unit of chemical products.
2013	Cole et al	Emphasis is placed on the significant effects of safety culture in reducing major disasters and accidents.
2014	Han et al	By modeling feedback processes between management components and safety outcomes, he has used system dynamics to investigate the effects of production pressure on safety performance.
2014a	Jiang et al	Three important factors that affect the number of events were identified: management conditions, individual conditions and environmental conditions, and then the interactions between these factors were examined with SD.
2014b	Jiang et al	An SD model has been developed to understand the causes of unsafe behavior of construction workers. The dynamics involved in the causality mechanism are based on the effects of co-workers, the accumulation of fatigue, the effects of management on employees, hazard mitigation, and basic feedback loops such as limited management time and the completion of production at the planned time due to lost time.
2014	Shin et al	It has developed an SD model to investigate employees' safety attitudes and behaviors. With the model, it revealed the mental process of the employees consisting of risk perception, attitude, intention, behavior and results.
2015	Particle Mehrjeerdi & Fact	He developed a conceptual model based on the "Latin Hypercube" sampling to integrate occupational health and safety into the project risk assessment [40].
2016	Wang et al	They have worked on new risk assessment methods based on system dynamics within the system theoretical approach.
2017	Azizi el al	In a strong analytical risk approach, it has been revealed that allocating a certain budget by taking into account the dynamic hazards in the project lifecycle regarding feedback loops that may affect the repercussions of the risk and having a systematic plan can reduce the time and cost lost as a result of neglecting safety instructions.
2017	Gitinavard et al	He has worked on Safety management keys.
2017	Kim et al	He has conducted studies on the success factors of safety management programs.
2018	Bastan et al	It proposed an SD model to analyze safety management system dynamics, occupational health, and accident management [41].
2019	Ajayeoba et al	He has developed an SD model for effective Safety planning and management [42].
2019	Boukas & Kontogiannis	Emphasizing that an SD that examines organizational balances in more depth offers a Safety and production model, how the risk identified in the Safety model develops over time has been examined, in this context, the interactions between safety and production have been monitored by combining the safety culture with employee motivation and human reliability aspects, alternative work designs that can reduce the risk have been examined, and additional task management and human resources models have been developed [43].
2019	Mohammad and Takolan	The results of the feedback mechanism on the behavior change of the production pressure, safety performance and safety-related managerial components in the construction project were evaluated [44].
2019	Qayoom & Hadikusumo	Given the dynamic nature and complexity of the Safety management system, the effects of multi-level Safety culture on Safety performance over time were examined to improve the model [45].

2020	Di Nardo et al	Using the SD approach, a model for the safety management system was developed to examine behavior patterns in the face of incidental events [46].

2. Material

In our study, the behaviors of the factors affecting safety management in order to reduce occupational accidents were analyzed, the complexity of the causal factors affecting safety performance and safety culture was revealed, and the data were simulated by defining the basic variables, preparing causal diagrams and flow diagrams, and preparing a model with Stella Archtect 3.3 software.

3. Methods

In this study, SD methodology, which includes the steps of SD modeling, the iteration and feedback process of modeling, was used. Fig.1 provides information on the process proposed by Forrester (2009) and Sterman (2000) [25,47].

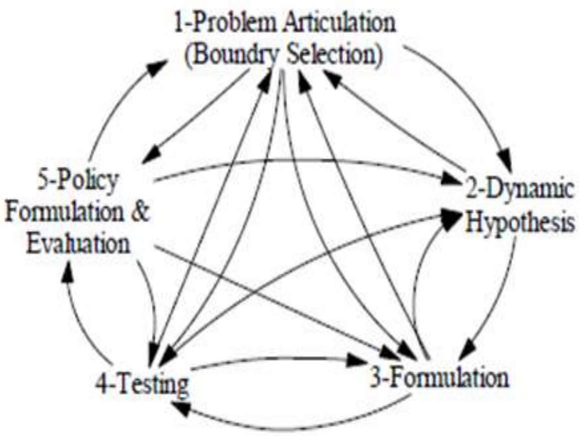

Figure 1. *The Iterative Process of Model Development (Sterman, 2000; Forrester (2009)*

Sterman (2000) describes System Dynamics (SD) as a modeling approach that centers on understanding the feedback structure and the resulting behavior of a system to grasp its complexity in a holistic manner [25]. Unlike traditional linear models, SD highlights the importance of feedback loops and intricate interactions among variables, where causes and effects can often be intertwined. SD is particularly effective for simulating complex systems, incorporating causal relationships to test various scenarios and generate appropriate recommendations.

- This method allows for the analysis of problems using both qualitative (causal analysis) and quantitative (stock and flow) approaches. To effectively solve a problem using SD, the following five steps must be followed.Identifying and defining the problem,
- Mapping cause and effect diagrams,
- Mathematical model development (stock and flow chart),
- Model simulation and validation,
- Create and evaluate scenarios, then select and implement the most appropriate solution.

For developing the mathematical model for the research problem, a methodology similar to the model in Fig.2 prepared by Salkın (2014) was designed [48].

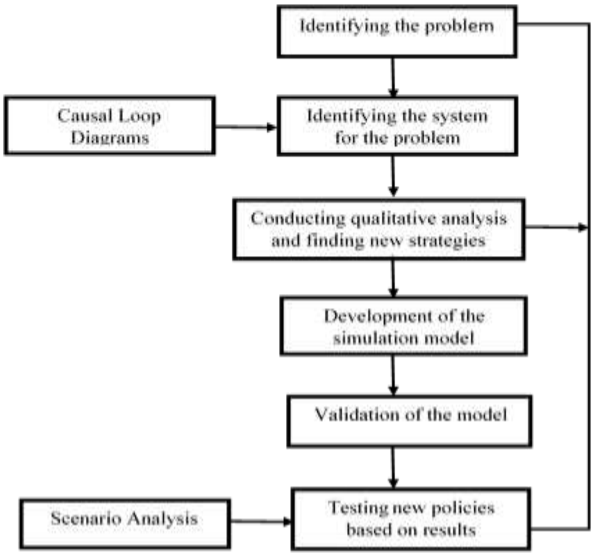

Figure 2. *Modelling Process of System Dynamics (Salkın, 2014)*

3.1. Definition of the Problem

A country's workforce is considered an important part of the national capital. The basis of economic and social development is labor. There is no doubt that without a healthy workforce, economic and industrial development cannot be achieved, and even countries can lose their independence. The need to avoid danger and seek safety has been an important part of human nature throughout history. Despite the rapid advancement of technology, human safety and occupational health are still exposed to numerous hazards in working life. Along with production and labor demand, occupational safety, sustainable use of production resources, efficiency and safety culture are of great importance. Due to the heavy material and moral burden estimates that occupational accidents will create on socio-economic structures caused by the lack of safety culture, countries are constantly in search of alternative safety culture policies to prevent accidents.

3.1. Dynamic Hypotheses

In general, injuries and occupational accidents occur as a result of a series of inSafety (unsafe behavior and unsafe situations). For this reason, occupational accidents can be reduced by detecting, preventing and eliminating this inSafety in order to protect the workforce and production against unfortunate consequences arising from workplace hazards and to improve and maintain sustainability. The OHS management system protects the safety of the workforce and the organization by reducing accidents. In order to create the dynamic model, we first had to define the variables and components related to accidents, safety culture and performance in our study. Therefore, the variables provided by the literature were used to accurately determine important parameters in our study. After adding and removing some variables in terms of suitability for the purpose of the model, the main variables of the study were defined.

The dynamic hypothesis is description of a cause-and-effect diagram showing the relationships between key variables using feedback loops. This model's dynamic hypothesis increases unsafe situations, unsafe behaviors, and the risks of incident escalation. A coercion cycle occurs between risk and accident variables. While the accident causes the loss of working days and the decrease in human resources, this situation causes loss of productivity and accumulation of accident costs. As a result, Safety management begins and Safety culture rises. As a result of the increase in safety culture, the level of unsafe situations, unsafe behaviors, incidents, risks and accidents decreases. Fig.3 shows a representation of the dynamic hypothesis of the problem.

Figure 3: *Dynamic Hypothesis of the Model*

There is no unilateral action, as Senge (2006) claims [49]. Systematic thinking considers actions in terms of both cause and effect relationships. In this context, a positive sign (+) is used to indicate that variable A affects variable B in the same direction (either both increase or both decrease). Conversely, a negative sign (-) is applied when variable A affects variable B in the opposite direction (one increases while the other decreases). These principles were utilized in developing the cause-and-effect diagram shown in Figure 3. Figure 4 presents a causal diagram model illustrating the impact of safety culture on occupational accidents. This model not only enhances our understanding of the system but also serves as a foundational element for the stock-and-flow model.

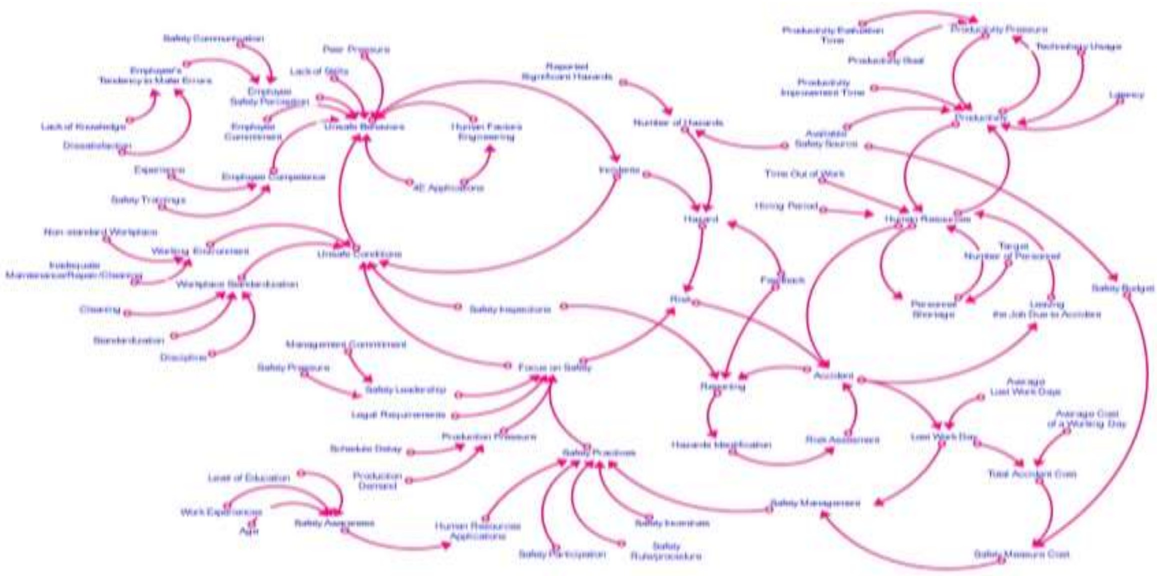

Figure 4: Casual Loop Diagram (CLD) of the Model.

- A balancing loop (B, or negative loop) is a structure that helps to align the actual state with the desired state through specific actions. It acts as a control mechanism, keeping a critical variable close to its target, typically after experiencing some fluctuations.
- A reinforcing loop (R, or positive loop) often leads to exponential changes in variables, amplifying existing growth or decline trends. It can be seen as a positive force that strengthens a positive trend, or as a negative force that generates side effects, eventually contributing to a balancing cycle. Table 2 outlines the feedback loops, highlighting the variables involved in forming positive and negative loops within the causal loop diagram.

Table 2. *Feedback Loop*

Loop	Stock/ Number of Varieties	Explanation
B1	7 / 19	Increase in Safety Focus → Focus on Safety → Unsafe Condition → Unsafe Conditions → Unsafe Behavior → Unsafe Behaviors → Incident Increase → Incidents → Hazard→ Risk Probability → Risk → Accident Occurrence → Accident → Lost Working Days → Cost Increase Rate → Total Accident Cost → Safety Precaution Cost → Safety Management → Safety Practices variables.
B2	1 / 5	Accident Prevention → Accident → Reporting → Hazard Identification → Risk Assesment
R1	6 / 16	Increase in Safety Focus → Focus on Safety → Unsafe Condition → Unsafe Conditions → Unsafe Behavior → Unsafe Behaviors → Incident Increase → Incidents → Hazard → Probability of Risk → Risk → Accident Occurrence → Accident → Lost Work Days → Safety Management → Safety Practices
B3	4 / 12	Increase in Safety Focus → Focus on Safety → Risk Probability → Risk → Accident Occurrence → Accident → Lost Working Days → Cost Increase Rate → Total Accident Cost → Safety Precaution Cost → Safety Management → Safety Practices
R2	3 / 6	Unsafe Behavior → Unsafe Behaviors → Incident Increase → Incidents → Unsafe Condition → Unsafe Conditions
B4	2 / 4	Accident Occurrence → Accident → Quitting Work → Human Resources
B5	1/3	Productivity Improvement → Productivity → Productivity Pressure
R3	3/9	Increase in Safety Focus → Focus on Safety → Risk Probability → Risk → Accident Occurrence → Accident → Lost Work Days → Safety Management → Safety Practices
B6	1/3	Recruitment → Human Resources → Pesonel Shortage
R4	1/2	Unsafe Condition → Unsafe Conditions
R5	1/2	Quitting Work → Human Resources
R6	2/5	Productivity Losses → Productivity → Recruitment → Human Resources → Quitting Work

The B1 cycle, shown in Fig.5; Increase in Safety Focus → Focus on Safety → Unsafe Condition → Unsafe Conditions → UnsafeBehavior → Insecure Behaviors → Incident Increase → Incidents → Danger → Risk Probability → Risk → Accident Occurrence → Accident → Lost Working Days → Cost Increase Ratio →Total Accident Cost → Safety Precaution Cost → Safety Management → Safety Practices variables.

The B1 cycle is a balancing cycle. Because by increasing the Safety in the system, unsafe situations, unsafe behaviors, incidents and risks in the system are reduced. Other variables, either by increasing or decreasing, affect each other in the same direction. Another loop is the R1 loop, shown in Fig.6 ; Increase in Safety Focus → Focus on Safety → Unsafe Condition → Unsafe Conditions→ Unsafe Behavior→ Unsafe Behaviors→ Incidents Increase → Incidents →

Hazard →Risk Probability → Risk → Accident Occurrence → Accident → Lost Working Days → Safety Management → Safety Practices.
The R1 cycle is a reinforcing cycle, where each variable has a positive effect on the other.

The structure shown in Fig.6; It consists of 13 rings, six stabilizing and six reinforcing rings.

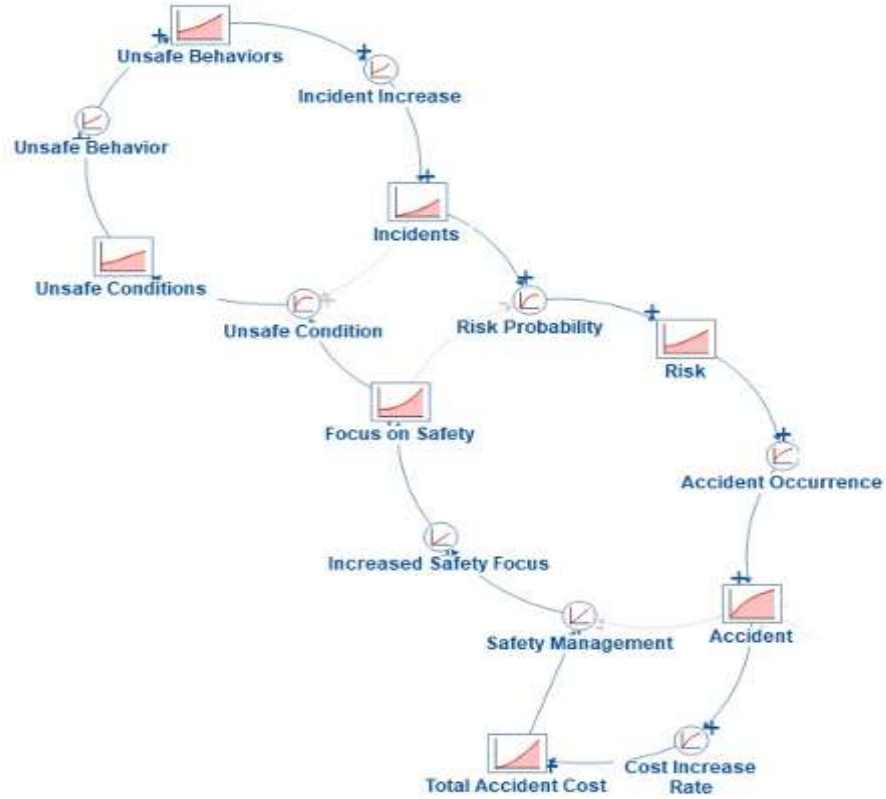

Figure 5. B1 Balancing Loop

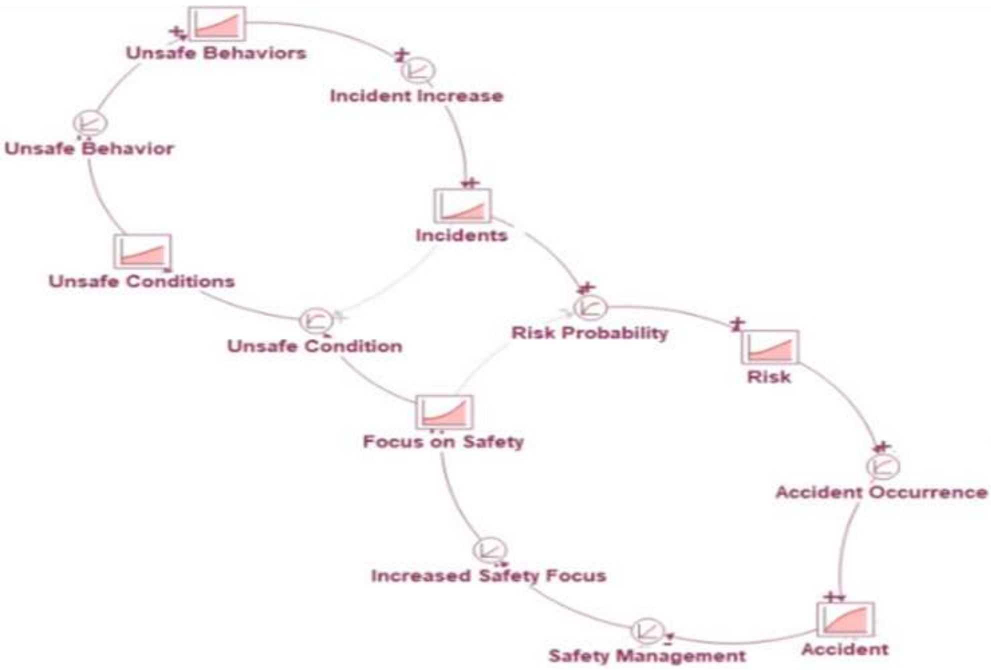

Figure 6. R1 Reinforcing Loop

3.2. Stock and Flow Model

The qualitative causal loop models were subsequently converted into quantitative stock and flow models, which are composed of stocks linked by flows. The amount of stock can be regulated through the flow. Every system is comprised of two types of variables: stocks and flows. In the following step, quantitative equations are developed to describe the relationships between stocks, flows, and auxiliary variables for simulation purposes. After validating the stock and flow model, it can be employed to evaluate the system's behavior and its response to changes in policy variables.

To create a quantitative model and simulate the outcomes, the stock and flow model depicted in Figure 7 was developed. This model was then simulated using the Stella Architect 3.3 software, a computer-based tool, and the results were analyzed.

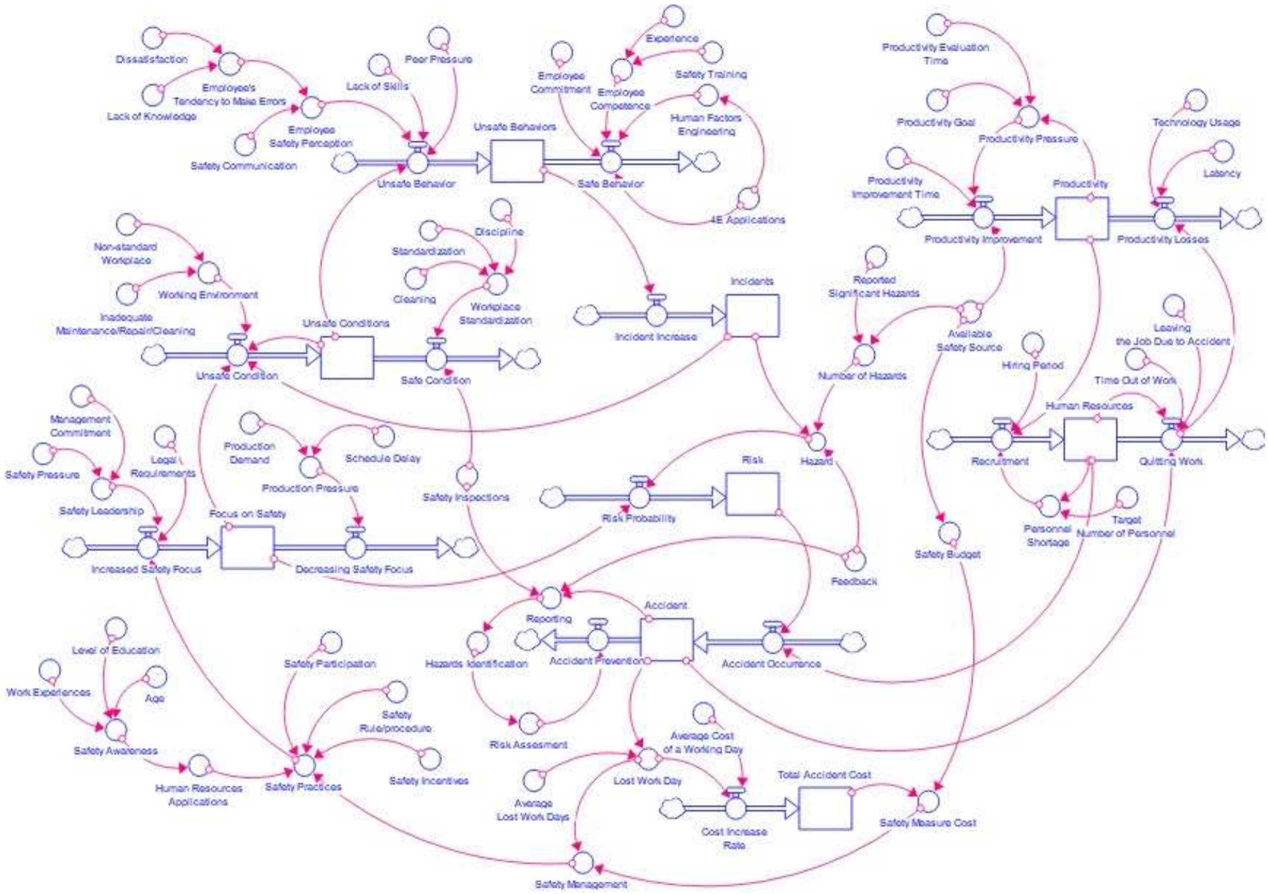

Figure 7: *Stock & Flow Model*

3.3. Model Validation

Sterman (2000) emphasizes that model validation is essential to ensure that the model accurately replicates historical behavior, aligns with real-world logic, maintains dimensional consistency across all equations, and possesses sufficient sensitivity for evaluating policy recommendations [25]. It's crucial to confirm the validity of the model. After developing the flow diagram based on the system's cause-effect diagram, the proposed simulation model must be verified with its relational formulation before scenario creation and result analysis. Forrester (2007) notes that there is no single test for validating an SD model [50]. Sushil's book "System Dynamics" (1994) discusses numerous validation tests [51]. Various methods and tests are available for model validation, including historical behavior reproduction tests, extreme condition tests, boundary adequacy tests, logic consistency of model equations, and dimensional consistency tests. These tests collectively validate the model. The model undergoes sequential testing, with its behavior observed and deficiencies identified, ultimately refining the model through a thorough process.

In our study, we conducted boundary adequacy tests, structure evaluation tests, extreme case tests, behavior verification, and sensitivity analysis to validate the developed model.

3.3.1. Sensitivity Analysis and Scenario Generation

The sentiment analysis purpose is to investigate whether changes in parameters, boundaries, and time intervals in general lead to important changes in their numerical values, behaviors, and observed policies. After simulating and monitoring the behaviors of all components of the model in the desired time interval, it investigates the changes in the variables of the model and the impact analysis on their main variables. Several policy options can be tested in SD. One of them is the base situation, which represents traditional operations, often referred to as the "current situation". In our study, we defined four different scenarios in order to reveal the variables that significantly affect safety culture and performance, and the effect of both variables on reducing accidents and the negative consequences they affect. Our aim is to find out the course of accidents in a certain period of time, accident costs, system safety level and risks associated with accidents, the effect of safety practices determined to reduce accidents on human resources and productivity performance, and to observe the behavior structure of the system over time. At first, all of the policy variables were kept at average values, and the model prepared to obtain stock values in traditional transactions was simulated using the Stella Archtect 3.3 program. Subsequently, different combinations of policies are designed to achieve the appropriate value level of the output variables. After the results of the variables and their effects on the main variables of the problem were analyzed, the safety focus of the key indices and their effectiveness on accidents were determined. Unsafe situation, unsafe behavior, incident, risk, accident, accident costs, efficiency and human resources were examined separately with the following four scenarios.

- Maintain the Status Quo Scenario: In this scenario, no changes are made to the values, parameters, or structure of the model. The aim here is to define the current situation and its consequences and the behavior of the basic variables of the created model.
- Workplace Standardization Scenario: In this scenario, the usage of more advanced technological equipment and accordingly better fault detection, machine protection and machine maintenance/repair, tidy cleaning work can partially prevent accidents. Workplace standardization has an impact on unsafe conditions and can reduce the number of unsafe conditions, we can see that workplace standardization is positive and extrinsic, leading to a reduction of unsafe conditions. Fewer accidents occur in the burum.
- Human Resources Management Scenario: Human resources do not have the potential to completely meet work Safety. However, it may require a significant amount of attention in Safety practices when necessary. By improving human resources management within the occupational health and safety system, we can reduce unsafe behaviors caused by human error. As a result, this situation affects the occurrence of accidents. This scenario aims to increase the safety of human resources so that the accident numbers and other related factors within the model does not increase. In general, the use of human resources is considered to be related to education level, age and more work experience. In addition to these, employee participation, safety communication, Safety trainings and the employee's commitment to safety and perception of Safety are leading indicators that will have a positive impact on the system.
- Safety Management Scenario: This scenario shows that the number of accidents can be decreased by monitoring and auditing safety measures, increasing safety incentives and increasing safety communication, employee and management commitment, establishing rules and procedures for activities and establishing a reporting system and developing safe work areas. Having this type of reporting system will reduce unsafe behaviour and conditions, which are the main source of accidents, and the performance of the health and safety management system will be positive. These factors have a significant impact on reducing accidents.

4. Results and Discussions

The findings obtained in the study are included in items on the basis of each scenario.

- In the first scenario, under production pressure, the current situation continues and maintains the behavioral trend of the model. Increased incidents and risks due to unsafe situations and unsafe behaviors will continue to increase the accident rate. Loss of working days and accident costs as a result of increasing accidents will show an upward trend. This situation will adversely affect many situations, including the safety budget, and will cause more accident costs and low efficiency, while it will also have a negative impact on the safety focus. In the model specified in this scenario, human resources are designed as a search for a target in order to protect the workforce despite the losses to be experienced, so the human resource strives to maintain its initial value.

- The second scenario is the standardization of the workplace. Here, the Kaizen (5S) method can be effective in improving workplace standardization. 5S; It is a simple and applicable method used to ensure order, order, cleanlins and discipline in the workplace. With this method, and we can influence and reduce the insecure situation. In the model, it is seen that it provides improvement in unsafe conditions with parameters such as maintenance/repair, tidy order and cleaning to improve the standardization of the workplace. While the impact of a reduction in unsafe situations will lead to a decrease in accidents and their negative effects, the positive effects will be on safety, efficiency and accident costs.
- In the third scenario, by improving human resources management; The employee's education level, age, and greater work experience can influence and control unsafe actions. Controlling this variable will result in fewer accidents. With the development of the scenario, there will be a decrease in accident costs while causing an increase in safety focus and efficiency. In addition to these, employee participation, safety communication, Safety trainings and the employee's commitment to safety and perception of Safety are leading indicators that will have a positive impact on the system.
- Finally, the fourth scenario, in which a safety culture was developed, was carried out under the Safety commitment and Safety pressure of the management. In this case, we see that the variables of unsafe situations, unsafe behaviors, number of incidents, risks and accidents and accident costs that cause accidents decrease. This scenario is the best-implemented scenario in terms of its results, and the rate of reduction in accidents is higher than the implementation of other scenarios.

With the implementation of this scenario, the Safety focus in system internal access has positive effects on efficiency and human resources.

Both management of human resource and Safety management scenarios are advised as effective models.

Fig.8, 9, 10, 11, 12, 13, 14, 15, 16 show the behavioral trends of the components of the created model against the applied scenarios. It was determined that the results obtained were in line with and parallel with former research studies on the improvement of safety programs and safety performance carried out by Gao et al (2016) [22,13,52,53, 54,55].

4. Conclusions

There is a limited number of studies in the literature with the SD methodology method for the behavioral

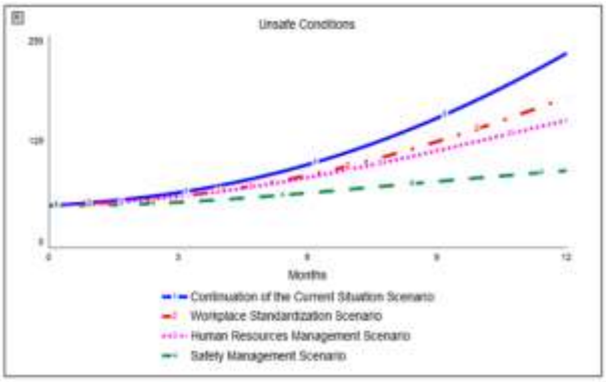

Figure 8. *Comparison of the Effect of Application Results of Different Scenarios on **Unsafe Conditions***

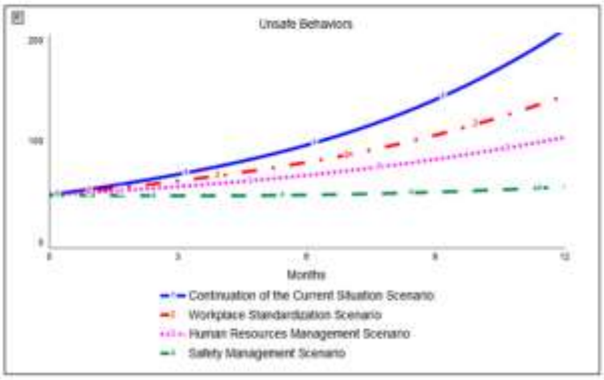

Figure 9. *Comparison of the Effects of Application Results of Different Scenarios on **Unsafe Behaviors***

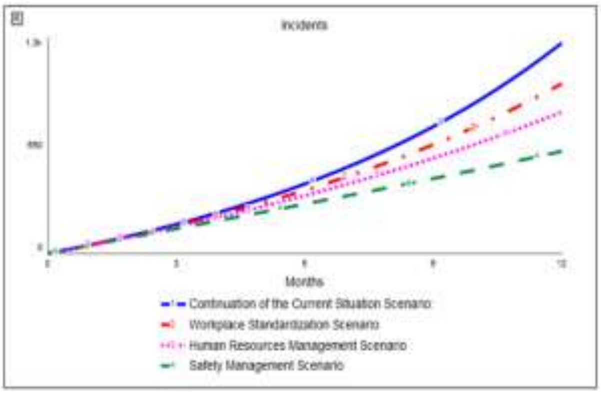

Figure 10. *Comparison of the Impact of Application Results of Different Scenarios on **Incidents***

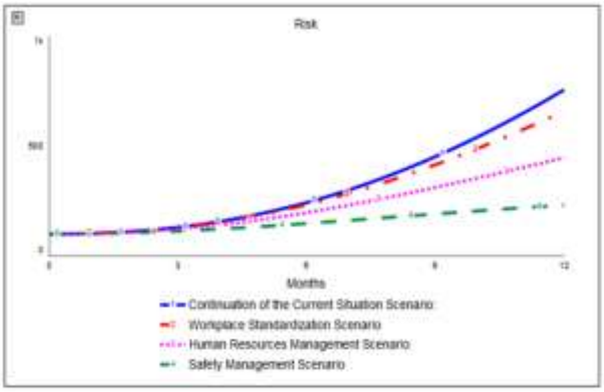

Figure 11. *Comparison of the Impact of Implementation Results of Different Scenarios on **Risks***

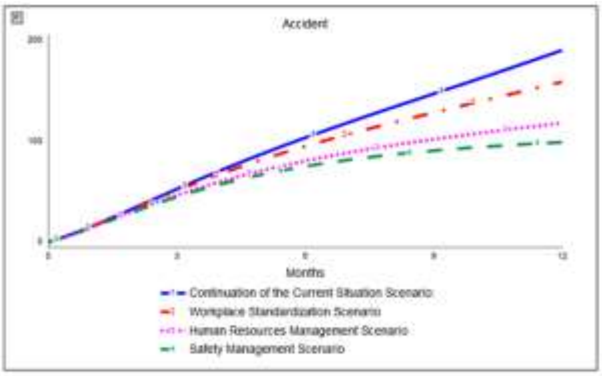

Figure 12. *Comparison of the Effect of Application Results of Different Scenarios on* ***Accidents***

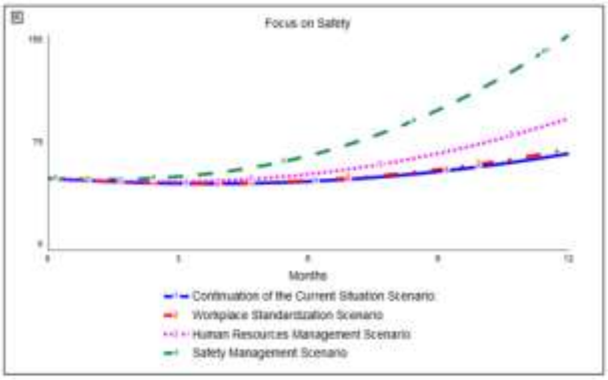

Figure 13. *Comparison of the Impact of Application Results on* ***Safety*** *for Different Scenarios*

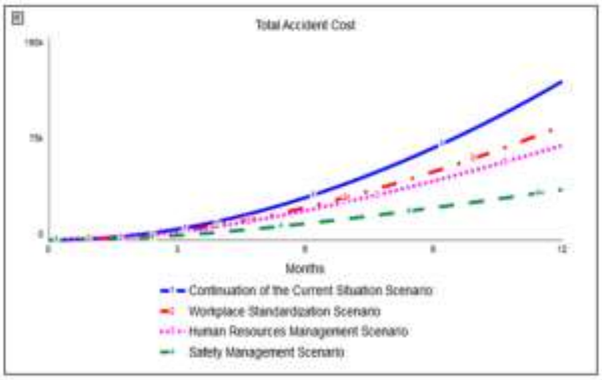

Figure 14. *Comparison of the Impact of Application Results on* ***Total Accident Costs*** *for Different Scenarios*

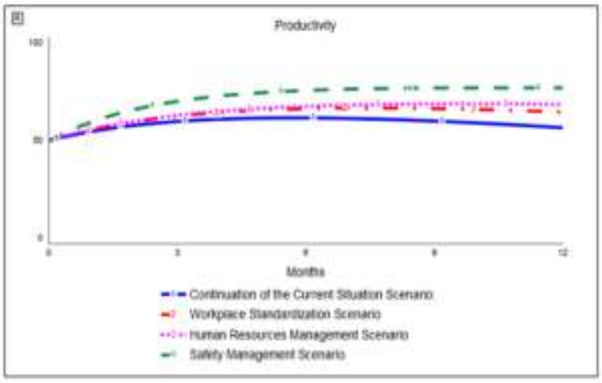

Figure 15. *Comparison of the Impact of Application Results on* ***Productivity*** *for Different Scenarios*

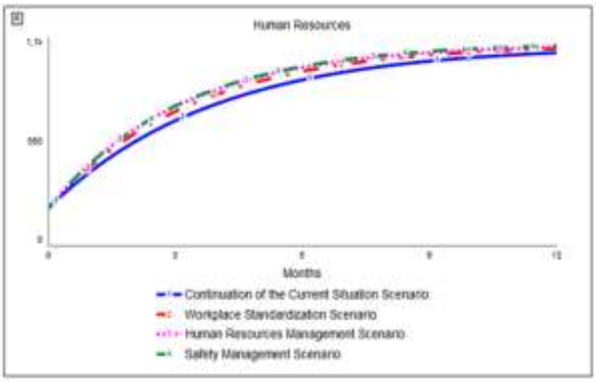

Figure 16. *Comparison of the Impact of Implementation Results on* ***Human Resources*** *for Different Scenarios*

tendency of safety culture and safety performance. This research defines the role and relationships between safety practices, pressures and safety conditions to reduce accidents.

It offers an SD model that can show the course of accidents, costs of accidents, level of system safety and risks associated with accidents, human resources and productivity performance in a certain time period. The model was simulated with Stella Archtect 3.3, a computer-based software. In order to evaluate the interaction of variables, the existing literature was used together with expert opinions to determine the causal relationships between the parameters, and then these parameters and their relationships were quantified.

A stock-flow model is proposed to determine the structure and behavior of the system and to analyze its performance. In our study, four scenarios including proposed policies and methodologies were used to obtain data on the solution of the problems and their outcomes. When the scenarios applied in the model used are examined;

- In the current situation scenario, accidents are increasing, other components of the system are adversely affected as a result of the accident, and the increase in the number of lost days has increased the cost of accidents and caused a decrease in efficiency and safety focus.
- Although the workplace standardization scenario aims to reduce unsafe situations and reduce accidents, it is the scenario with the weakest effect in terms of results compared to the other two scenarios. In order to improve safety performance, maintenance/repair and cleaning, which are among the basic variables of safety culture, should not be ignored and should be developed within the system in order to develop a safety culture, while the benefits for businesses and production are obvious.
- In the model where the human resource management scenario is applied, the results can be

seen quickly as soon as this policy is implemented, and the increase in Safety focus ensures that unsafe behaviors are reduced. Depending on the corporate culture, this effect will become stronger in the long run.

Considering human resources management within Safety systems will be able to protect the system from potentially unsafe situations, as a result of this situation, it will reduce occupational accidents and reduce accident costs, and it will have positive reflections on productivity performance.

- In the safety culture scenario, safety training, safety audits, rules and procedures, safety communication, employee participation, safety incentives and senior management's commitment to safety can lead to a decrease in accidents and accident costs. This scenario has been identified as the best scenario among the implemented scenarios. Because the number of accidents prevented is higher than in other scenarios, there is a decreasing trend in the number of accidents. With this scenario, efficiency increases, while accident costs tend to decrease.

Many organizations use a variety of health and safety systems. The best way to implement an advanced safety system is to integrate the requirements of human factor engineering, which ensures a safe harmony between human and other system elements, with existing occupational health and safety management systems, by taking into account the human factor within the system.

Managerial factors, corporate culture and the place of Safety in the organizational structure and how it is perceived by employees have an important role in the implementation of safety culture. Despite legal obligations, having a passive safety approach persists in organizations, and unless there is an accident, the activities carried out to correct it are insufficient or no action is taken.

Among the basic variables of safety culture to improve safety performance, management's commitment, employee commitment, safety training, Safety awareness and employee competence, employee's education level and experience, employee participation, safety communication, safety incentive program, safety rules, safety priority, Safety audits, incident reporting system and maintenance/repair organization and cleaning concepts have a significant impact.

Taking into account the safety culture will help us solve the problem in question. A strong safety culture is a decisive factor in reducing accidents in any organization. Investments in a safety culture can reduce accidents, but it is not possible to reduce the total number of accidents and the negative socio-economic effects of the accident without planning and reaching an active level of safety culture.

The main advantages of the proposed model and approach are;

- The proposed model could help to build on existing research, as well as similar research and behavioral experiments on the effects of safety culture in their industry on accidents and the negative effects of accidents on human resources, accident cost and productivity.
- Using SD as a tool will help decision-makers to be aware of task-related accidents and their incidence and will encourage managers to better understand the problem.
- It will help businesses to look holistically at the long-term behavior of the system and develop policies.
- At the same time, different modules are added to the proposed model, allowing the new model to be expanded. In this way, the SD approach will allow management to monitor behavior of variables that are costly to the system.

As stated by Cooke (2003) and Sterman (2000) in the context of the limitations of our study and future studies, all models are limited and simplified representatives of the real world [34,25]. It is recommended that the effects of other effective factors that are not included in our study on the problem should be evaluated by academicians and researchers in new studies.

In terms of the development of the model put forward by this study, our study can also be used as a basis for the preparation of different scenarios to prevent occupational accidents, to correct the causal factors affecting safety performance and safety culture, and to discover the best solution. By redesigning the causative structure, new leverage points and critical management strategies can be identified. Future research may improve the model by using different inventory and flow models to create other Safety models. If the data from our study is used and adapted to their own organizational structure, organizations can create their own Safety management models and use them as tools for additional improvement.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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