Occupational Safety Dynamics in Onshore LNG Receiving Terminals

Abstract:

In onshore LNG receiving terminals (LNGRTs), any unsafe condition and/or act that may cause fire and explosion during LNG processes may lead to major occupational accidents endangering people, equipment and the environment. Hence, to prevent accidents, identifying unsafe condition and/or act is crucial. LNGRTs are complex systems, therefore; in this study, based on system dynamics approach, a dynamic simulation model is developed to unravel the dynamic feedback structures that operate over time and create unsafe conditions and/or acts. In order to penetrate the structure of the system, besides literature review, fieldwork is done in a major onshore LNGRT. The model structure comprises the activities of LNG processing, maintenance, repairing, and employee training. The management's time allocation decision under specific resource constraints drives the interactions among these system components. The model is run for 5 years and system behavior is analyzed with respect to several scenarios and policies. These analyses reveal that possibility of major occupational accidents increases with decreasing labor time for maintenance and training, which increases unsafe conditions and acts, respectively. The model can be used as an experimental platform to test the influence of several other factors on safety, such as; schedule pressure, overwork, equipment reliability, turnover rates.

PROBLEM STATEMENT

Depending on global energy demand, natural gas requirement has increased, therefore; new gas reserves that were thought to be too remote, technologically and economically not feasible for pipeline transportation have drawn attention. Then, natural gas transportation techniques, like liquefaction providing significant volume reduction, have been developed in recent years (Mokhatab et al., 2014). That is, after natural gas is obtained, it is liquefied for volume reduction which eases transportation and storage (Speight, 2018). After the liquefaction process, liquefied natural gas (LNG) is loaded on LNG trucks or LNG ships to be transported to remote areas. Then, arrived LNG to the LNG receiving terminals (LNGRTs) (on-shore or offshore) is unloaded, stored, and gasified. Finally, regained natural gas is sent to the pipeline system to reach end-users (Mokhatab et al., 2014). The process flow diagram for a typical onshore LNGRT and one of the onshore LNGRT top view are presented in Figure 1 and Figure 2, respectively.

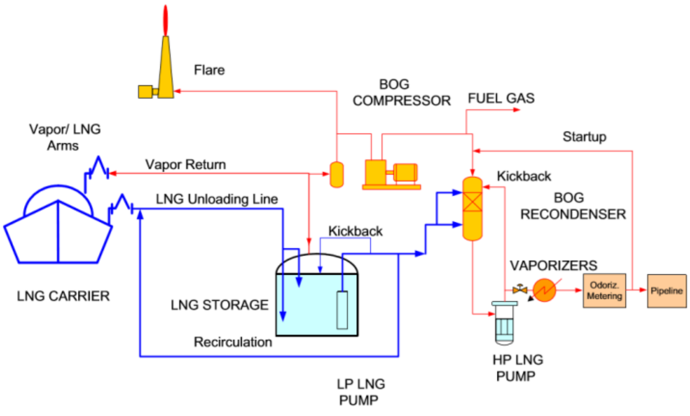


Figure 1. LNGRT basic process flow diagram (Mokhatab et al., 2014).

Figure 2. An example of the onshore LNGRT top view (BOTAŞ, 2019).

During such LNG processes, since LNG is a dangerous chemical in terms of fire and explosion, any unsafe condition and/or act may cause major occupational accidents that may endanger people, environment and equipment. The fire and explosion hazards are mostly emerged from the physical and chemical characteristics of LNG. Although LNG containments vary depending on the resource properties of natural gas, it contains mainly methane and includes smaller amounts of other hydrocarbons (Speight, 2018). It is not flammable in the liquid phase, however; LNG leaks and spills generate boil off gas and it is vaporized when it meets with surfaces. Then, it may form flammable vapor cloud that may cause fire and vapor cloud explosion if it meets with an ignition source (Mokhatab et al., 2014).

To eliminate or alleviate the major occupational accident risks, LNGRTs must be constructed and operated depending on safety rules in terms of site selection, design principles, procedures, equipment quality, maintenance, auditing, monitoring, employee qualification, prevention systems, and emergency response systems. To expand, reliable construction design; overpressure management; ventilation systems; temperature sensors; leak detectors; high/low level alarms; spill control systems; ignition source controls; emergency shutdown systems; periodic maintenance programs, regular site monitoring; work permit system; trained employees must be provided (Mokhatab et al., 2014; Woodward and Pitblado, 2010). It is obvious that there are many components related with the occupational safety system in the onshore LNGRTs and to provide safety, these components must be proper and be functional continuingly. Therefore, any unsafe condition or act that may ruin the convenience of these components must be identified and required measures must be taken. Depending on this, understanding of the components causing unsafe conditions or act is vital. Furthermore, these components interact with each other through feedback causalities. As it is seen, the onshore LNGRTs and so occupational safety are complex systems. Hence, understanding of the dynamic interactions of the components that leads to unsafe conditions and acts requires systemic conceptualization of the occupational safety system. That is, the system components and the interactions of these components with each other can be identified and analyzed by the system dynamics method based on dynamic and feedback structure analysis (Bouloiz et al, 2013; Garbolino et al, 2016; Leveson, 2004).

Accordingly, in this study, since it is aimed to determine causes of any unsafe condition and act that may lead to major occupational accident in the onshore LNGRTs, a dynamic simulation model based on system modeling approach is developed for occupational safety system. To gain insight into the system, besides literature review, fieldwork was done in one of the onshore LNGRTs. Depending on these, the model structure comprises of occupational safety related activities; LNG processing, maintenance and repairing, employee training, and incident learning where the management’s time allocation decision under specific resource constraints is the fundamental driver. Hence, the purpose of the study is to analyze labor time allocation among these activities as a policy for occupational safety. Since the dynamic simulation model also provides us with a tool to analyze how different scenarios and polices affect unsafe condition and unsafe act, and through these analyses it is also aimed to provide a method for implementing better policies without facing major occupational accidents.

LITERATURE REVIEW

Occupational safety problems are systemic problems and have dynamic complexity. Therefore, to gain insights to such complex systems, there have been studies based on the system dynamics approach in the field of occupational safety in the literature.

Cooke (2003) carries on one of the important ones, which analyzes the causes of Westray mine accident. It determines causative mechanisms of the accident with its variables and examines their interactions, feedback loops, time delays, and non-linear relationships to improve understanding of safety system complexity for the mine production industry. In the model, incident is defined as ‘an unplanned event that may or may not result in undesirable consequences’ and accident is defined as ‘an incident with actual negative consequences’. It is stated that incidents are caused by unsafe conditions, unsafe acts, and management tolerance to both of them. It is also observed in the study that when management commitment to production increases due to the growing backlog, management commitment to safety decreases, then employee commitment to safety decreases. This leads to an increase in incident rate. When incident rate reaches to ‘critical mass', accident becomes inevitable. Cooke concludes that the Westray mine accident occurred due to giving priority on production over safety. Moreover, it is stated that elimination or alleviation of accidents is possible if and only if the accidents are accepted as a result of the behavior of the whole system, not due to the individual components such as people, procedures or equipment.

Cooke (2003) also states that more production by skipping safety rules leads to incidents, and incidents cause disasters like a fatal explosion in the mine and eventually creates a ‘vicious cycle’ by resulting in production losses. Vicious cycle behavior is defined in ‘capability trap’ phenomenon by Repenning and Sterman (2001, 2002) in the system dynamic analysis of resource allocation problem in industries. When organizations have a performance gap, they often choose to work harder, which provides an immediate solution. And since the time is a scarce resource for organizations, it leads to a decline in time allocation for improvement issues, which also increases the capability of organizations and close the performance gap. Although working harder decreases the performance gap in a short period, spending time on improvement, which is working smarter, takes a longer time to close the gap. However, it is stated that the working harder provides better-before-worse situations while working smarter has worse-before-better dynamic since the allocation of less time for improvement leads to a gradual decrease in capability (Repenning and Sterman 2001, 2002). By working harder and harder, without fixing the actual problem and relying on shortcuts loop cause a vicious cycle in the reinvestment loop and generates capability trap (Repenning and Sterman 2001, 2002). To enlighten the work harder and work smarter concept, it is stated by Lyneis and Sterman, (2016) and Repenning and Sterman (2001) that work harder means; speeding up, overtime, shorter breaks, skipping steps, cutting testing, deferring maintenance, failing to follow safety procedures, setting aggressive targets for throughput, imposing penalties for missing those targets. Work smarter means; setting up improvement programs, encouraging people to experiment with new ideas, investing in training programs.

Another study is carried on by Salge and Milling (2006) who analyze Chernobyl accident causes in the system dynamic approach. They claim that the accident is caused due to the combination of human failures in the design of reactor and on-line operations. It emphasizes that perceived pressure on employees has important role in the accident.

Bouloiz et al (2013) built a system dynamic model for behavioral analysis of safety conditions in a chemical storage unit. The study focuses on the dynamics of technical, organizational and human factors in the system. It is analyzed that, increase in untrained employee leads to a significant decrease in safe behavior. Furthermore, the proper work environment has a positive effect on the safe behavior of employees. Repenning and Sterman (2001) contribute that putting overtime due to work harder is frequently extent overnights and weekends, and steal employee’s time from their family and community activities and that has long-run side effects like decrease in employee performance.

Another study is about the incident learning system. Cooke and Rohleder (2006) analyze the effect of incident learning system on accidents by using a system dynamics approach. In the study, it is stated that accidents are caused by passing over the warning signs of pioneer incidents or being unsuccessful to take lessons from the past. Therefore, the incident learning system is important to determine and examine incidents to correct deficiencies in the system. In the model, the incident learning system includes; identification, reporting, and investigation of incidents and then determining the causal structure of incidents, making recommendations and implementing corrective actions. Incident investigation is determined as an examination of the site, interviewing witnesses, gathering and evaluating all available data to establish the sequence of events and determine exactly what happened.

Lyneis and Madnick (2008) carry on a study about safety climate and organizational learning. Safety and social psychology, safety and organizational theory, organizational learning issues, and basic causal structures for Incident Rate are set in the study. In this structure, the effectiveness of safe behavior is positively related to adherence to rules and procedures and this being negatively related to incident rate. It is concluded that when industries give high priority to safety and learning, the incident rate becomes lower.

La Porte and Consolini (1991), Roberts and Bea (2001), and Weick and Sutcliffe (2001) as cited in Cooke and Rohleder (2006) argue that accidents can be prevented by organizational practices. Rudolph and Repenning (2002) state in their study providing to understand how disasters can be the results of novel events that for an understanding of disasters, novelties and the number of interruptions must be considered.

MODEL STRUCTURE

1. Model Overview:

In this study, a dynamic simulation model based on system dynamics approach is developed to understand occupational safety system structure and to determine causal mechanisms of major accidents in the onshore LNGRTs. The dynamic model also provides a platform to analyze the effects of different scenarios and management policies on the occupational safety system. The model is built on Stella software and its boundary is an onshore LNGRT. The model time unit is set as week and time horizon is selected as 5 years (250 weeks). The model is solved numerically by Euler's method and the computational step is selected as dt=0.125.

Depending on fieldwork in the onshore LNGRTs, it is found that labor time is a common scarce resource for all subsystems. In a general manner, it is allocated for production, maintenance, repairing, and employee training activities. Depending on this, labor time allocation is at the core of this model and for modeling purposes, the onshore LNGRT safety system is divided into five sectors; labor time allocation, production, maintenance and repairing, training, and incident learning. The overview of the model is represented in Figure 3.

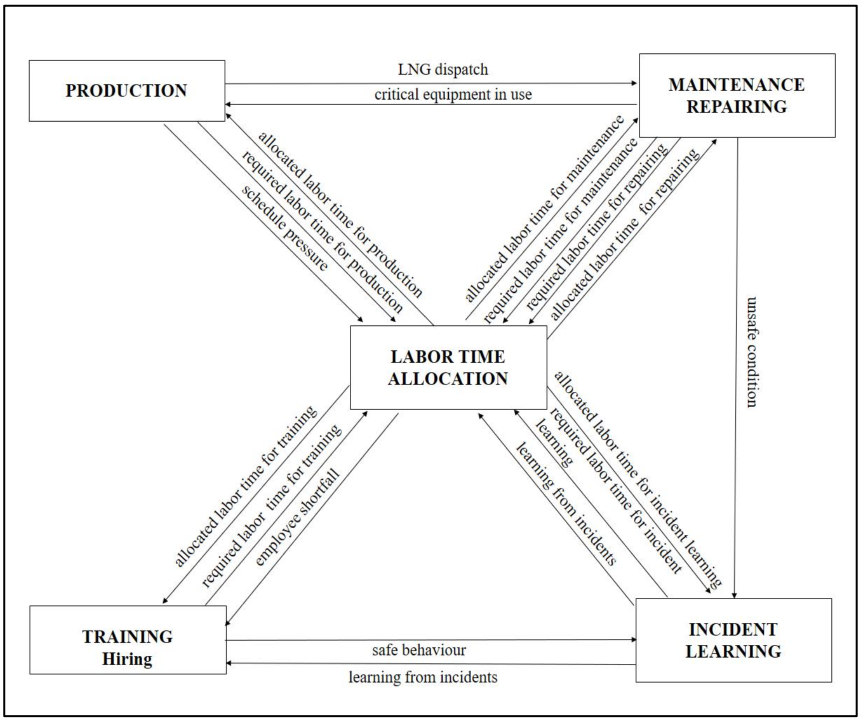


Figure 3. The overview of the model.

As seen from the Figure 3, each sector is in interaction with each other directly or indirectly and all sectors give information about their labor time requirement to labor time allocation sector. Then, total labor time is allocated among these sectors depending on their relative demands. In addition, when there is a labor time gap due to employee shortfall, the labor time allocation sector gives information to the training sector for hiring. The production sector gives information to the maintenance and repairing sector about LNG dispatch, since required labor time for maintenance depends on it. Also, the maintenance and repairing sector gives information about critical equipment in use to the production sector, since production depends on it. Furthermore, information about the schedule pressure generated by production activities are sent from production sector to labor time allocation sector. Unsafe condition and safe behavior affect the incident rate, therefore, maintenance and repairing sector and training sector are related to incident learning sector. Moreover, incident learning sector gives information about learning from incidents to labor time allocation sector.

To begin with, it is helpful to state safety terminology that is used in the model. Bird and Germain (1992) as cited in McKinnon (2000) state that unsafe acts are the ‘behavior or activity of a person that deviates from normal accepted safe procedure' and may cause an incident. Also, unsafe acts are exemplified as operating equipment without permission, misusage of equipment, making safety devices inactive, using improper equipment, unsuitable loading and placement, ignoring safety rules and cutting corners. Accordingly, in the model, unsafe acts are placed in the model as in its opposite definition: safe behavior. As cited in McKinnon (2000), Bird and Germain (1992) define the unsafe condition as ‘a hazard or the unsafe mechanical or physical environment’. Moreover, improper equipment, insufficient equipment, broken equipment, inadequate safety barriers, and protective equipment are stated as unsafe conditions. Accordingly, in the model, equipment suitability, quality, and well-functioning properties are related to unsafe conditions. For modeling purposes, only the critical equipment is considered. The critical equipment consists of safety equipment like temperature sensors, leakage/spill detectors, high/low-level alarms, emergency shutdown systems, relief valves, pumps, metering, vaporizers, compressors, etc. Furthermore, the incident is defined (HSE, 2004) as ‘an event that, while not causing harm, has the potential to cause injury or ill-health'. The accident is defined (HSE, 2004) as ‘an event that results in injury or ill-health'. Besides, major occupational accident is defined (Yıldırım, Ö., Gürpınar, Ö., Ercan, Ö., Öcal, A., Tiftik, A.P., Kumru, C., Baş, D, 2012-2014 Project Report) as ‘the accidents namely fire, explosion and dispersion including dangerous substances which lead a serious danger to health of large populations, result in high economic costs and causes contamination of natural environment for long term or permanently and requiring large scale emergency intervention’. It is added that major occupational accident risks may be ‘the fire emerged due to ignition of flammable substances by means of a flame or heat; the explosion arisen from flammable substance (air) mixture occurred with immediate gas release; release of toxic substances in the air, water or soil'. Accordingly, since the onshore LNGRTs include major accident risks due to LNG processes, to analyze major accident risks, the incident rate is modeled. The main causes of incidents are stated as unsafe conditions and unsafe acts (Bird and Germain, 1992 cited in McKinnon, 2000).

In addition, in the model, there are some assumptions, such as; one year is taken as 50 weeks, terminal is operated 7 days 24 hours in a week, terminal capacity is constant, incidents do not cause critical equipment loss or labor time loss, both Untrained Employee and Trained Employee work at the site, all employees are doing all works (production, maintenance, repairing) and each critical equipment has the same reference failure time.

In order to gain insight into the structure of the system, each sector is analyzed in detail.

2. Description of Sectors

2.1. Production Sector:

Production sector describes production processes, such as such as; LNG unloading, filling, storage, gasification, and gas send out in the onshore LNGRTs. The main causal loop diagram of the production sector and simplified stock-flow structure are presented in Figure 4 and Figure 5.

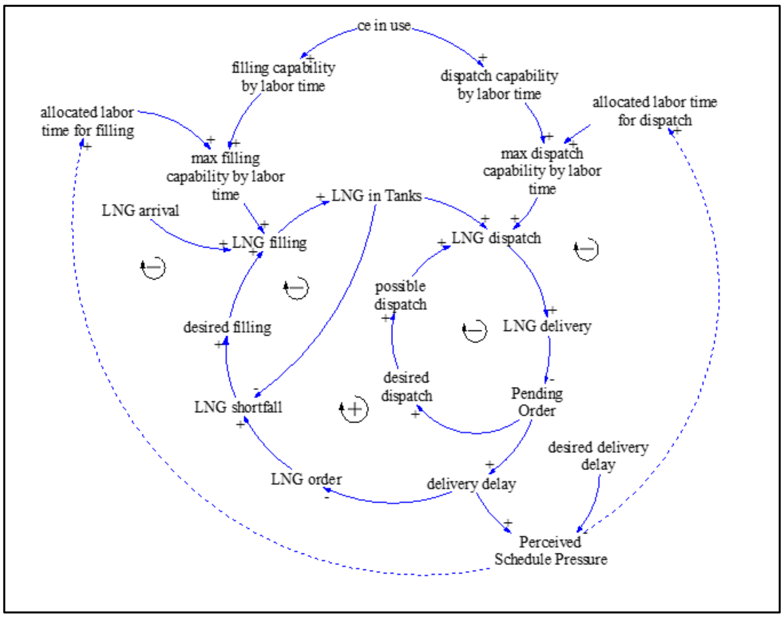


Figure 4. Causal loop diagram of production sector.

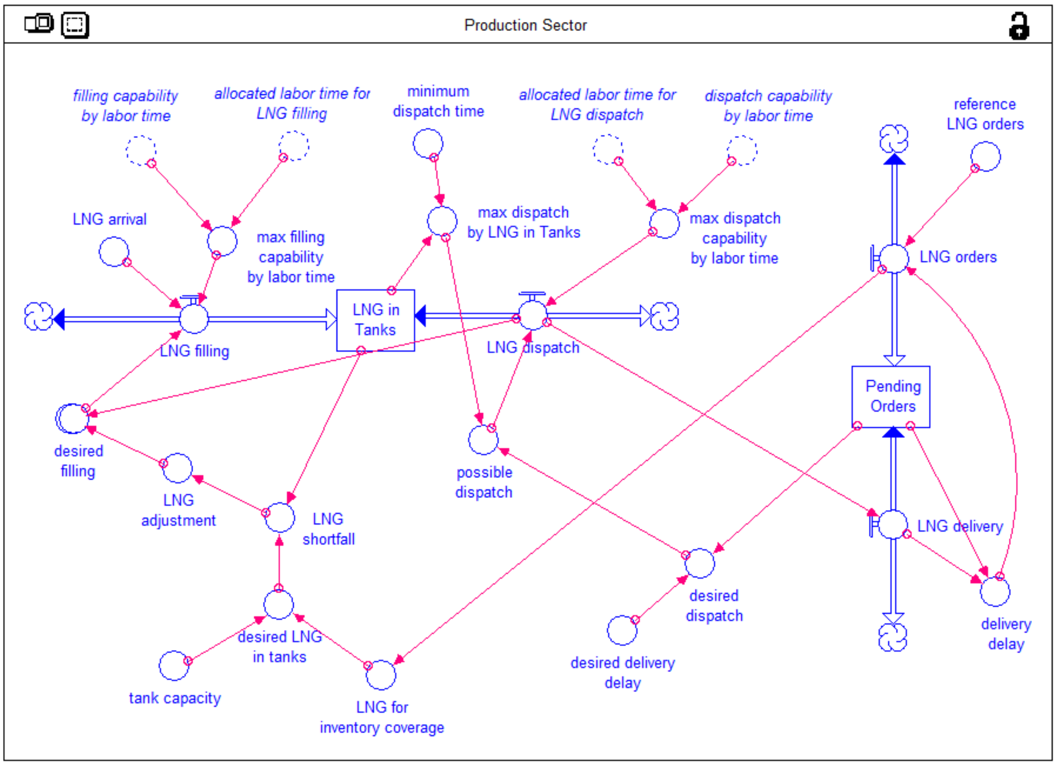


Figure 5. Simplified stock flow diagram of production sector.

When allocated labor time for production (filling and dispatch) increases, LNG filling, LNG in Tanks, and LNG dispatch increases. Then, LNG delivery increases, and so, Pending Orders and delivery delay decreases. Besides, when delivery delay increases, LNG order decreases and so LNG filling decreases. Furthermore, LNG filling depends on LNG arrival, filling capability by labor time and allocated labor time for filling, and desired filling. In the model, it is assumed that LNG arrival is exogenous and taken as constant. On the other hand, filling capability is affected by critical equipment in use. Furthermore, desired filling depends on LNG shortfall emerging from LNG orders and LNG in Tanks. Besides, LNG dispatch is determined by dispatch capability by labor time and allocated labor time for dispatch and by possible dispatch. Dispatch capability by labor time depends on critical equipment in use. Possible dispatch depends on maximum dispatch by LNG in Tanks and desired dispatch. On the other side, LNG orders is set as constant and changes with delivery delay being caused by Pending Orders and LNG delivery. When LNG dispatch decreases, LNG delivery decreases and so, Pending Orders increases. Then, delivery delay increases. An increase in delivery delay makes a decrease in LNG orders. When Perceived Delivery Delay passes to threshold, LNG orders are gradually cancelled. Increase in delivery delay also cause schedule pressure. When Perceived Schedule Pressure increases, it decreases the labor time allocation for maintenance, training and incident learning.

2.2. Training Sector:

Training sector describes how safe behavior of employee changes in the terminal. For this purpose, the mechanisms affecting safe behavior are examined. The main causal loop diagram of the training sector and simplified stock-flow structure are presented in Figure6 and Figure7, respectively.

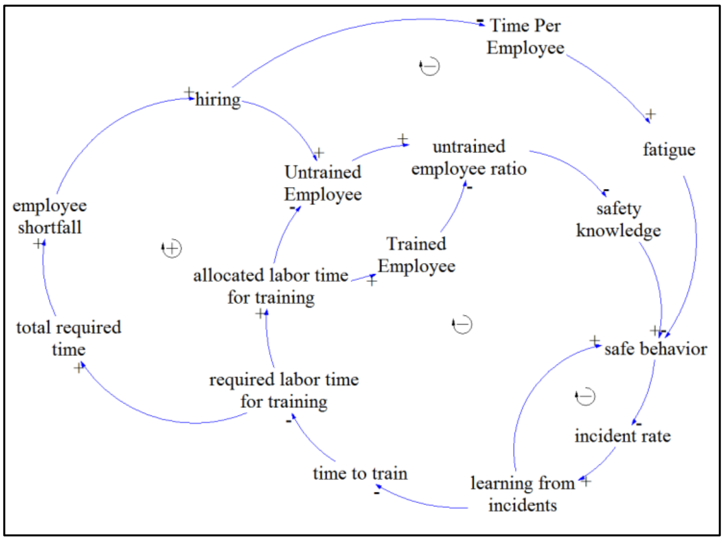


Figure 6. Causal loop diagram of training sector.

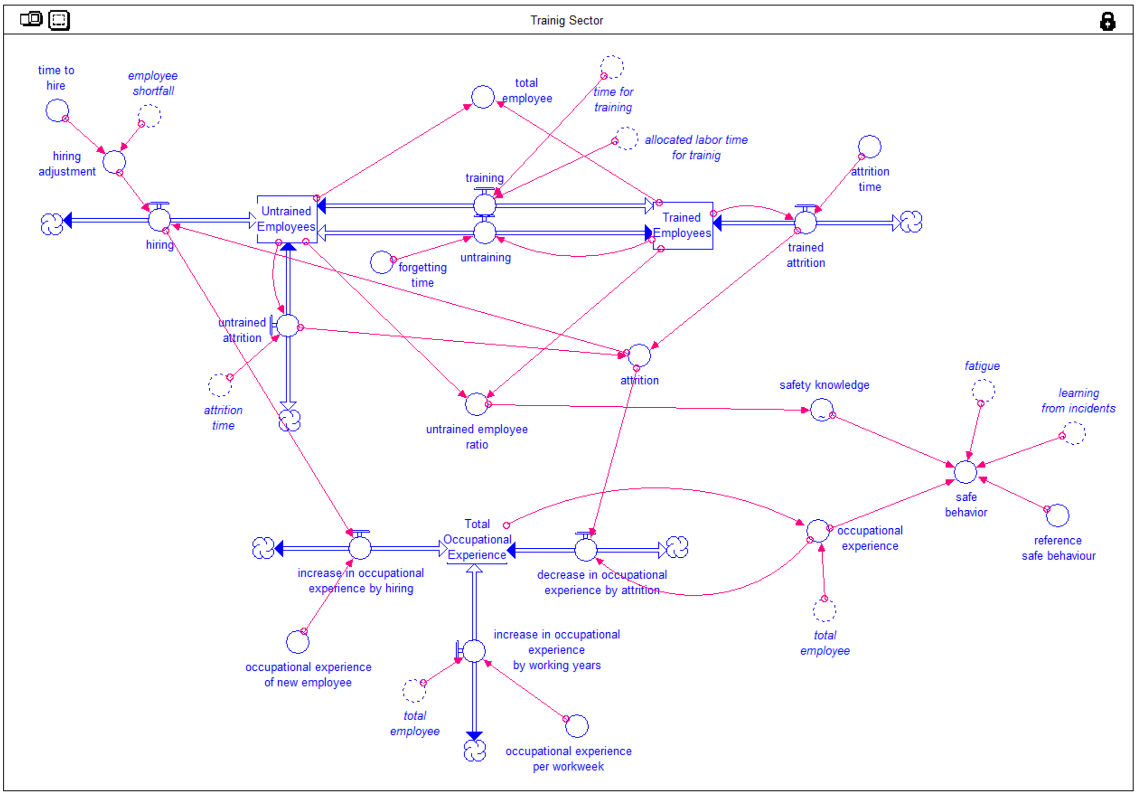


Figure 7. Simplified stock-flow structure of training sector.

Depending on the literature (McKinnon, 2000) and fieldwork, it is determined in the model that safe behavior is affected by safety knowledge, occupational experience, fatigue, and incident learning. Since safety knowledge is gained from training, the structure of the training system is built. When allocated labor time for training increases, Trained Employees increases and Untrained Employees decreases. Hence, untrained employee ratio decreases and safety knowledge increases that makes increase in safe behavior. On the other hand, it is stated that, when the occupational experience of a new employee is higher than the employed ones, hiring increases the occupational experience. When occupational experience increases, safe behavior is affected positively. Besides, in the fieldwork, it is stated by the managers that occupational experience increases safe behavior until approximately 16-17 years. Then, self-confidence, nonconformity to technology or new rules cause a decline in safe behavior. Furthermore, when hiring increases, Time per Employee decreases. Then, fatigue decreases which makes increase in safe behavior (Dembe et al., 2005; IPIECA, 2007; Repenning and Sterman, 2001). It is also observed that, decrease in safe behavior leads to increase in incident rate. When incident rate increases, learning from incidents increases. Then, allocated labor time for training and safe behavior increase.

2.3. Maintenance and Repairing Sector:

Maintenance and repairing sector gives information about causal mechanisms of unsafe conditions that may lead to an incident in the onshore LNGRTs. The main causal loop diagram of the sector and simplified stock-flow structure are presented below.

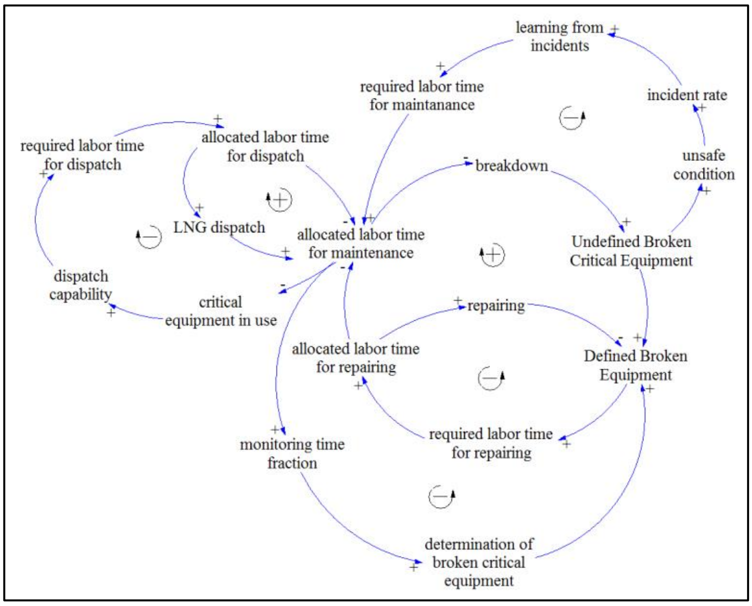


Figure 8. Causal loop diagram for maintenance and repairing sector.

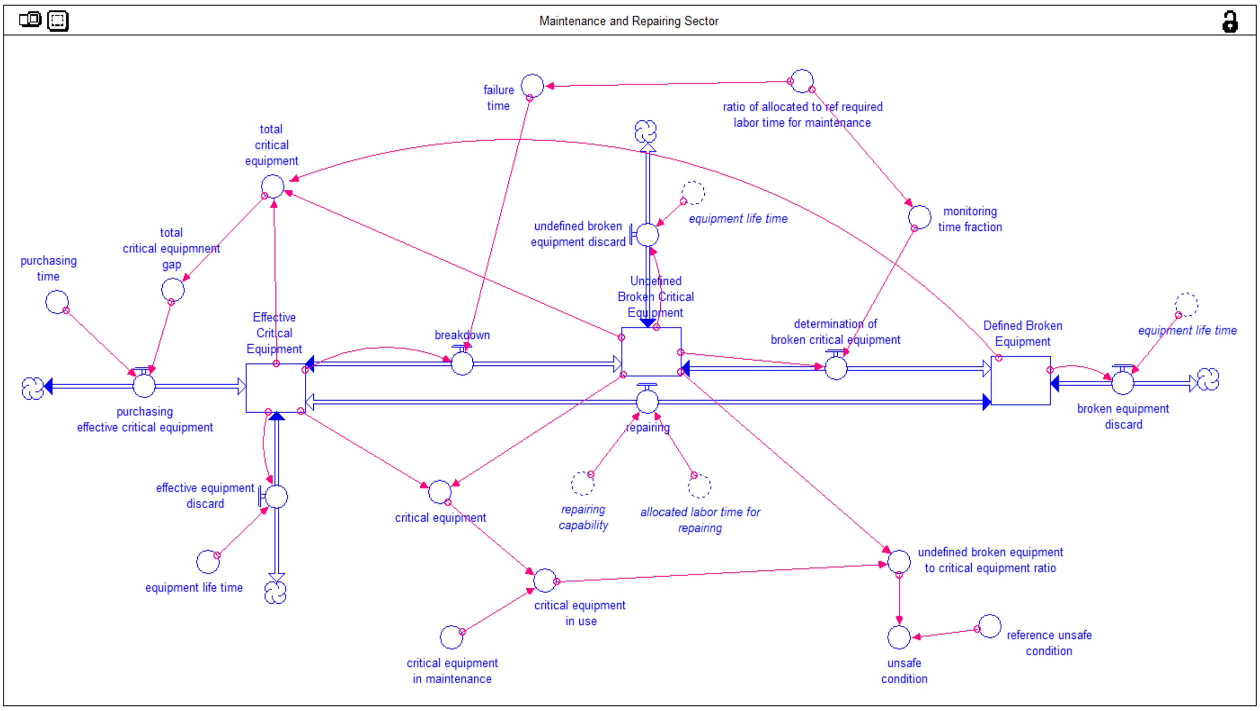


Figure 9. Simplified stock-flow structure for maintenance and repairing sector.

In the model, critical equipment is separated as Effective Critical Equipment, Undefined Broken Critical Equipment and Defined Broken Equipment by being inspired from the safety barrier division of Hoffman and Wilkinson (2011). Effective Critical Equipment corresponds to proper and functional equipment. Defined Broken Equipment equals to broken and improper equipment being determined and must be repaired to be used. Undefined Broken Critical Equipment corresponds to equipment that is improper or broken, however, not determined yet as Defined Broken Equipment, and be in use. When allocated labor time for maintenance increases, breakdown decreases and monitoring increases. Then, Undefined Broken Critical Equipment decreases. Hence, unsafe condition decreases. Accordingly, it is clear that unsafe condition arises from Undefined Broken Critical Equipment. When Undefined Broken Critical Equipment to critical equipment in use increases, unsafe condition increases. On the other hand, by allocated labor time for repairing, repairing increases and Defined Broken Equipment decreases. Besides, increase in unsafe condition leads to increase in incident rate and learning from incidents that makes increase in allocated labor time for maintenance. Furthermore, allocated labor time for maintenance decreases critical equipment in use, and then LNG dispatch.

Undefined Broken Critical Equipment increases depending on the breakdown of Effective Critical Equipment. Furthermore, breakdown depends on the failure time. When adequate maintenance, which means allocated labor time for maintenance corresponds to reference required labor time for maintenance, is provided failure time of equipment corresponds to reference failure time. However, when ratio of allocated to reference required labor time for maintenance decreases, failure time decreases, and breakdown increases. On the other hand, Defined Broken Equipment depends on monitoring ability of the system. Allocated maintenance time increases the monitoring time fraction, and it increases the determination of broken critical equipment. Depending on allocated labor time for maintenance, some of the critical equipment is in maintenance and this equipment cannot be used in production processes. This means, increase in allocated labor time for maintenance, increases the critical equipment in maintenance and decreases the critical equipment in use. Then, dispatch capability decreases, and allocated labor time for dispatch decreases and so it makes decrease in LNG dispatch. In addition, increase in unsafe condition leads to increase in incident rate. Hence, learning from incidents increases and so, required labor time for maintenance and allocated labor time for maintenance increase. This makes decrease in breakdown, and Undefined Broken Critical Equipment, and so unsafe condition.

2.4. Incident Learning Sector:

Incident learning sector aims to understand the structure of learning from incidents effect on occupational safety system in the onshore LNGRTs. The main causal loop diagram of the sector and simplified stock-flow structure are presented in Figure 10 and Figure 11.

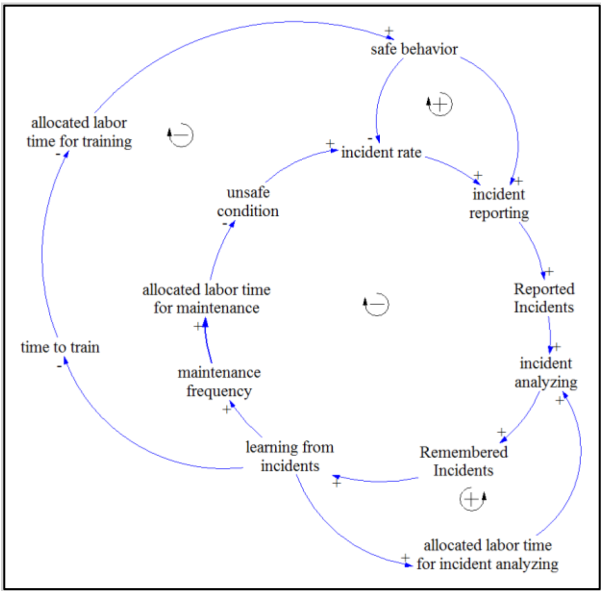


Figure 10. Causal loop diagram for incident learning sector.

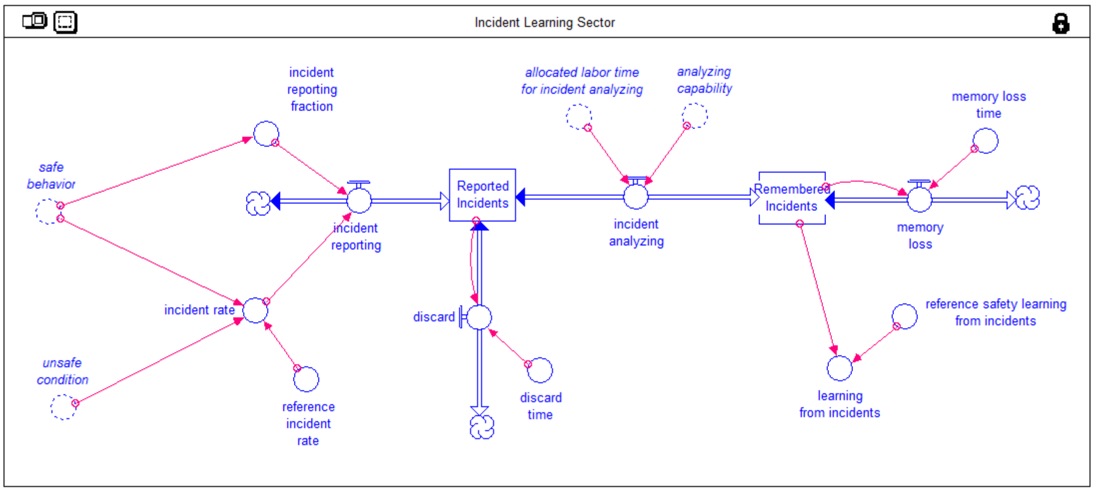


Figure 11. Simplified stock-flow structure of incident learning sector.

When unsafe condition increases and/or safe behavior decreases, incident rate increases. Furthermore, when safe behavior increases, incident reporting increasing, then Reported Incidents increases. Besides, if labor time allocated for incident analyzing, then incident analyzing and Remembered Incidents increase. This makes increase in learning from incidents. On the other hand, learning from incidents makes decrease in time to train and so increase in safe behavior. Also, it makes increase in maintenance frequency and finally decrease in unsafe condition. Reference incident rate is considered as maximum tolerable incident rate, which can be get under control without causing any accident. In the model, unsafe condition and safe behavior effects on incident rate do not dominate each other.

2.5. Labor Time Allocation Sector:

Labor time allocation sector is the core of the model. Since labor time is a common source for the onshore LNGRTs, it is allocated among subsystems that are stated as production, maintenance, repairing, training, and incident analyzing. Accordingly, labor time allocation sector aims to describe time allocation dynamics. The main causal loop diagram of the sector and simplified stock-flow structure are presented in Figure12 and Figure13, respectively.

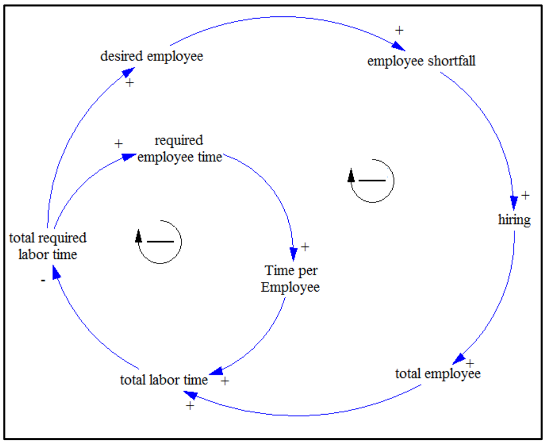


Figure 12. Causal loop diagram for labor time dynamics (hiring and overwork).

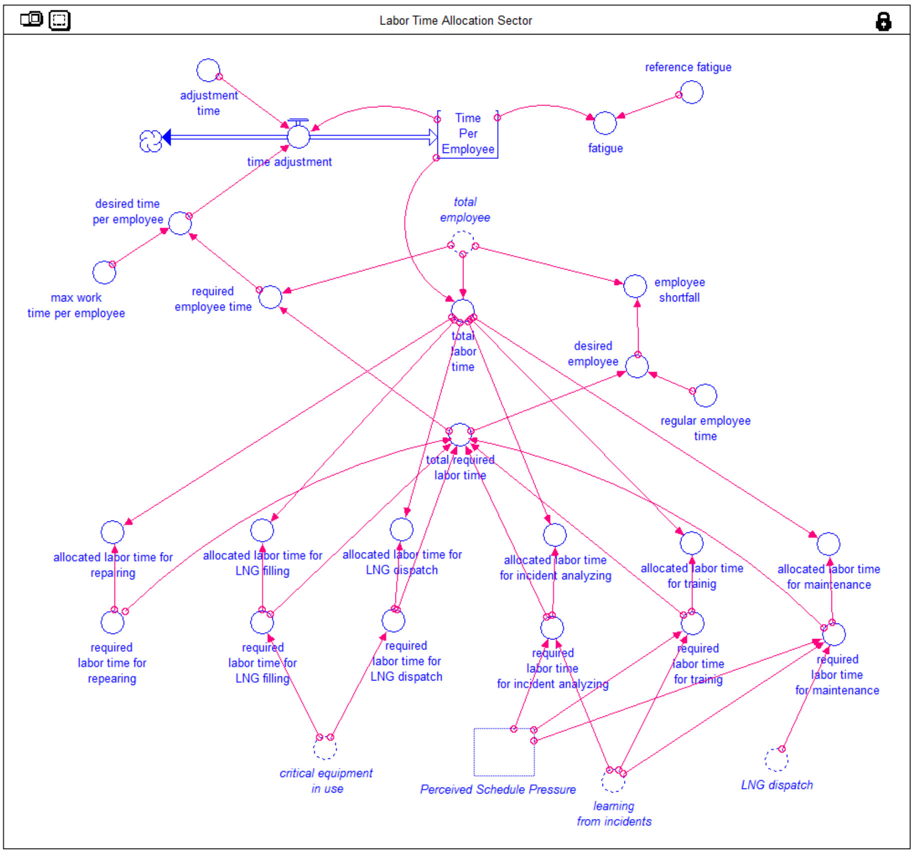
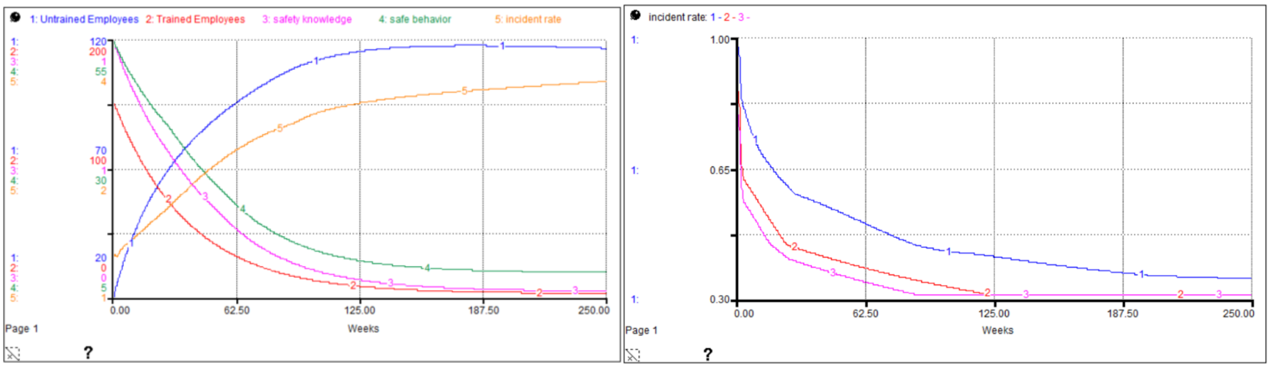


Figure 13. Simplified stock-flow structure of labor time allocation sector.

As seen from the causal loop diagram, each sector gives its required labor time information to the labor time allocation sector. The sum of them is regarded as the total required labor time. Besides, the system has also total labor time depending on employee quantity and regular employee time. When total required labor time is equal to or lower than total labor time, it is allocated to each subsystem depending on the required labor time fraction. However, if the total required labor time is higher than total labor time, there occurs time shortfall. At that time, for providing labor time to the system, time shortfall can be closed either by hiring or by increasing Time per Employee. On the other hand, Perceived Schedule Pressure and learning from incidents affect labor time requirement, and so allocated for training, maintenance and incident analyzing. When Perceived Schedule pressure increases, then required/allocated labor time for training, maintenance and incident analyzing decreases. When learning from incidents increases, then the time requirement/allocation for mentioned ones increases. Besides, decrease in critical equipment in use decreases time requirement, it means allocated time for production.

MODEL VALIDATION

The model is validated by structural validation tests (extreme condition tests and parameter sensitivity tests) and behavioral validation tests. First, during the modeling process, extreme condition tests are applied for each sector with different extreme parameters, such as; taking LNG arrival as zero, taking LNG orders as zero, minimizing allocated labor time for training and for maintenance, having maximum unsafe condition and minimum safe behavior, maximizing regular employee time, minimizing critical equipment to demonstrate their validity. After each extreme condition test, it is seen that the results comply with the expected model behavior. For example, when allocated labor time for training is minimized (time to train is multiplied by 1000, all sectors are run), it is expected that Trained Employee decreases, Untrained Employee increases, safety knowledge and safe behavior decrease, and incident rate increases. When the model is run, the results comply with expected behavior (see Figure14.a). Then, parameter sensitivity tests, such as; sensitivity analysis of learning from incidents to incident rate (see Figure 14.b), sensitivity analysis of occupational experience to incident rate, and sensitivity analysis of Perceived Schedule Pressure to safe behavior are done. It is also seen that the test results match up with the model theory.



a. b.

Figure 14. a. Extreme condition test results for minimizing allocated labor time for training b. Sensitivity analysis of learning from incidents to incident rate.

After structural validity of the model is sufficiently provided, the model is behaviorally validated. The model structure is a description of occupational safety dynamics, essentially based on the observations at a specific onshore LNGRT and the observed variables of LNG filling and LNG dispatch; Effective and Undefined Broken Critical Equipment, Defined Broken Equipment, Untrained Employees and Trained Employees are in steady state during normal operational condition. The model behavioral validity analyzing choses an arbitrary initial simulation time and when the model is run, it is observed that the model behavior matches with these steady state observations.

MODEL RESULTS

1. Reference Model Behavior

After validity of the model is sufficiently provided, reference model behavior is analyzed. In the base model, initial parameters are defined and taken by considering normal operational conditions. Then, when the model is run for an arbitrary initial simulation time, it is observed that the model behaviors correspond to the expected outcomes. That is, when allocated labor time corresponds the required labor time for each sector, after an instant transient behavior, LNG production becomes constant in its maximum value; Effective Critical Equipment, breakdown, Undefined Broken Critical Equipment, determination of broken critical equipment and Defined Broken Critical Equipment are balanced; while Untrained Employee decreases, Trained Employee increases, then safe behavior increases, unsafe conditions decreases and therefore, incident rate decreases (see Figure 15).

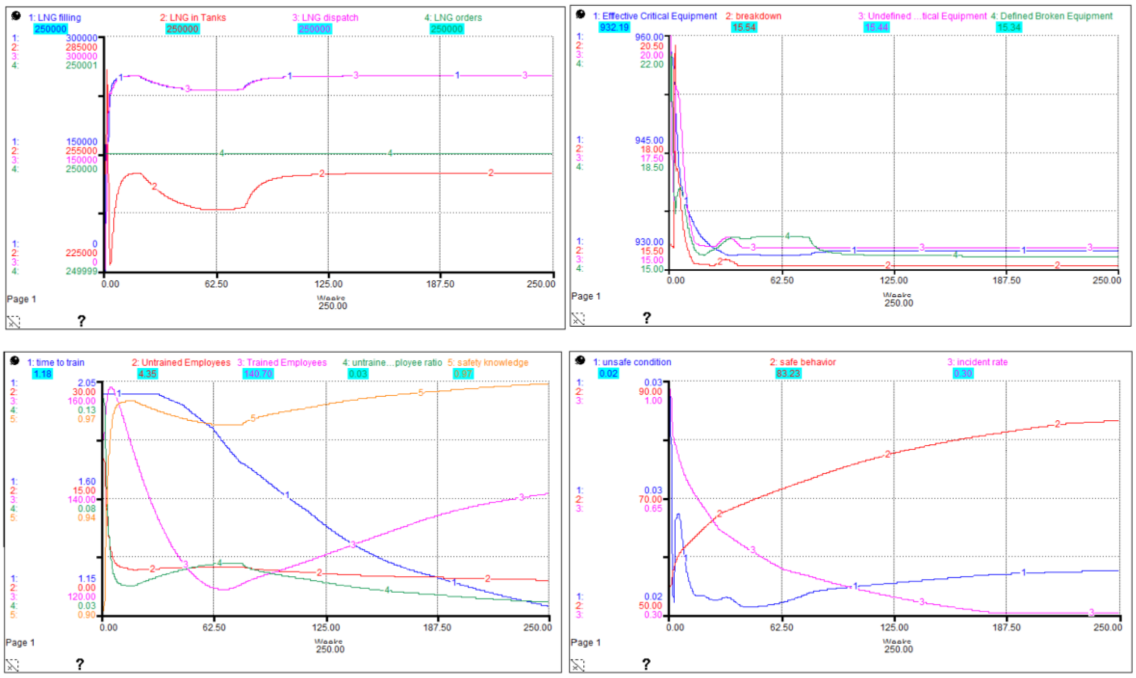


Figure 15. Reference behavior of the model.

2. Scenario Analysis

After analyzing reference model behavior, different scenarios and management policies are analyzed to understand the onshore LNGRT safety system dynamics.

2.1. Scenario Analysis Related to Seasonal Delivery Delay Tolerance

The first scenario is about the market and so, desired delivery delay tolerance depending on the season. In the fieldwork, it is stated that market and desired delivery delay tolerance is lower than the normal conditions in the winter. Depending on this, they are halved. When the model is run, it is observed that Perceived Schedule Pressure increases and passes tolerable limits for managers. Then, it makes decrease in maintenance frequency and increase in time to train and time to analyze in order to prevent any time loss because of the other activities. Since maintenance period decreases, allocated labor time for maintenance decreases. This means, allocated labor time for maintenance does not correspond to the reference required labor time. Accordingly, breakdown increases and Effective Critical Equipment decreases. This leads to increase in Undefined Broken Critical Equipment. Then, unsafe condition and incident rate increases (see Figure 16). It is worth to mention that, time to train and time to analyze are also affected by Perceived Schedule Pressure and learning from incidents. While they are increased by Perceived Schedule Pressure, at the same time, they are decreased by increase in learning from incidents. When the model is run, it is observed that increase in Perceived Schedule Pressure and learning from incidents finally cause decrease in time to train and time to analyze. Furthermore, since learning from incidents is higher than the reference model behavior, effect of learning from incidents on safe behavior is also higher. Hence, safe behavior is higher than the reference model behavior. However, although safe behavior is higher than the reference model behavior depending on learning from incidents effect, this scenario implies that, when schedule pressure increases, unsafe condition increases, and this leads to increase in incident rate.

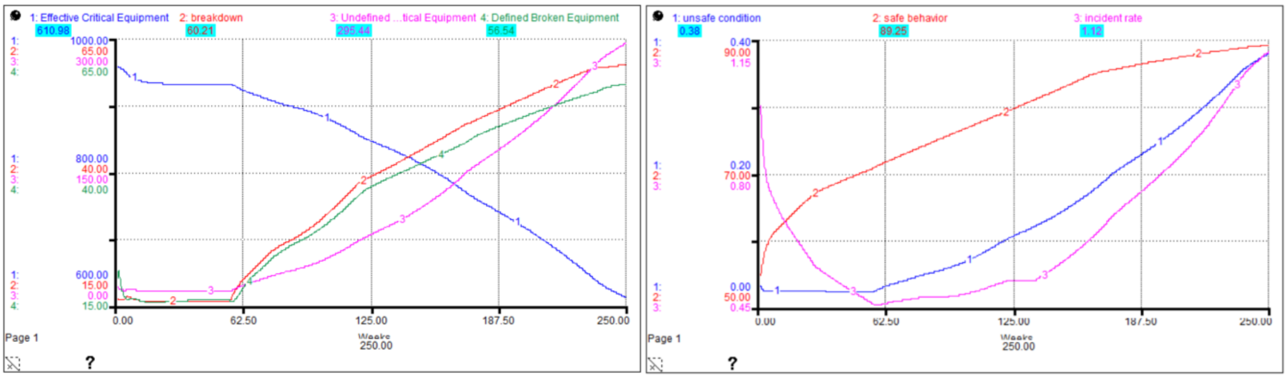


Figure 16. Change in Effective Critical Equipment, breakdown, Undefined Broken Critical Equipment, Defined Broken Equipment, unsafe condition, safe behavior and incident rate (desired and market delivery delay is halved).

2.2. Scenario Analysis Related to Increase in Turnover Rate Depending on Working Conditions

In the second scenario, turnover rate is assumed higher than the reference model due to heavy working conditions, low wage policies, stressful environment, negative relationships, lack of trust and others. In addition, preferring subcontracting rather than employing full-time employee also means having high turnover rate. Accordingly, when the model is run, it is observed that since attrition time decreases, initially Trained Employee decreases, and Untrained Employee increases more. Then, since untrained employee ratio increases, safety knowledge decreases. Furthermore, since occupational experience is lower than the reference model behavior, its effect on safe behavior decreases. Hence, though unsafe condition does not change significantly, incident rate increases. After a while, since time to train starts to decrease depending on effect of learning from incidents, which increases because of the incident rate, Trained Employees increases and Untrained Employees decreases. Then, safety knowledge increases. However, consequently, since safe behavior is lower than the reference run, it can be concluded that high turnover rate leads to increase in incident rate. In other words, having good working conditions or abandoning the subcontracting provides decrease in incident rate (see Figure 17).

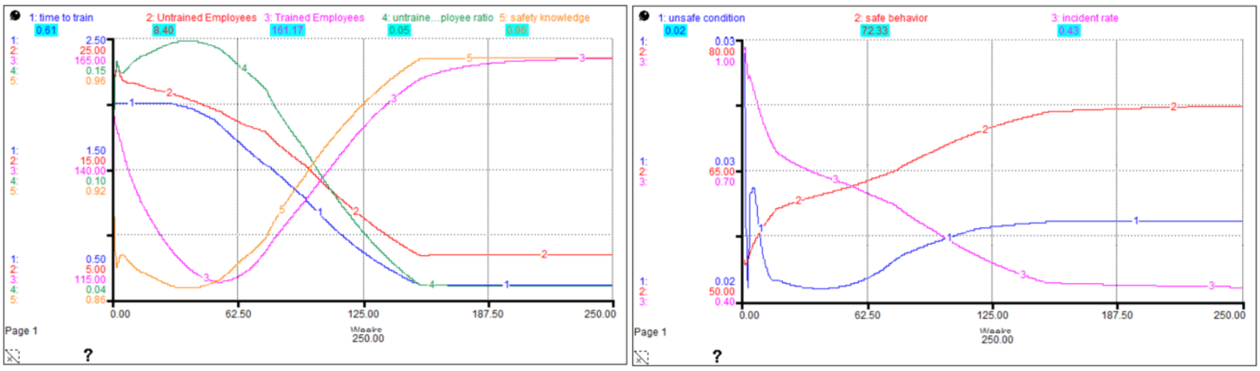


Figure 17. Change in time to train, Untrained and Trained Employees, untrained employee ratio, safety knowledge, unsafe condition, safe behavior and incident rate (attrition time is decreased by 10 times).

2.3. Scenario Analysis Related to Reliable Critical Equipment

In industries, less reliable critical equipment may be used since it is economic or its supply is easier although they have less failure time and break downs more. Therefore, in the third scenario, it is aimed to analyze how using less reliable critical equipment affects the safety system. For this purpose, reference failure time is halved. When the model is run, it is seen that since breakdown increases, Undefined Broken Critical Equipment increases. Therefore, unsafe condition and incident rate increase and are higher than the reference model behavior (see Figure 18).

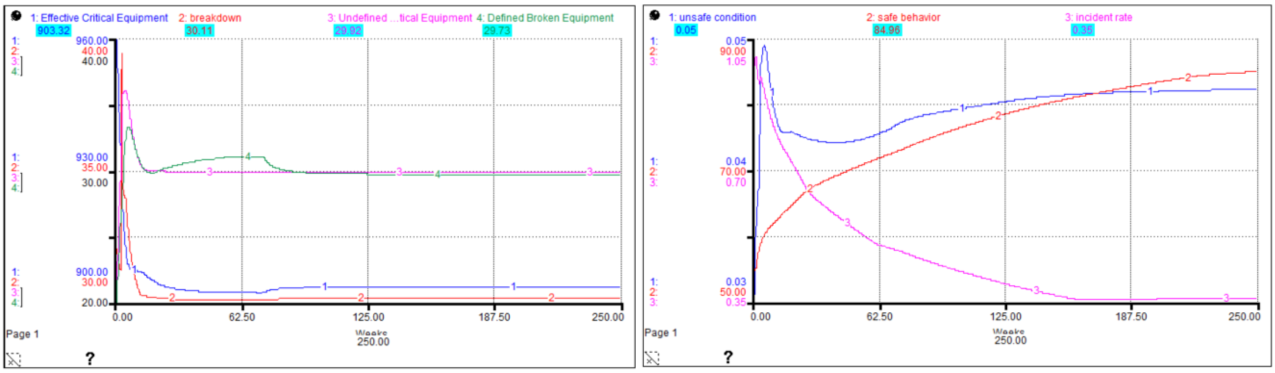


Figure 18. Change in Effective, Undefined Broken Critical Equipment, Defined Broken Equipment, breakdown, unsafe condition, safe behavior and incident rate (reference failure time is halved).

On the other hand, how using more reliable critical equipment affects to safety system is also analyzed by doubling reference failure time. Then, it is seen that breakdown is lower, Undefined Broken Critical Equipment decreases. Hence, unsafe condition and incident rate decreases below the reference model behavior (see Figure 19). The results imply that using less reliable critical equipment makes increase in incident rate, and possibility of major accidents.

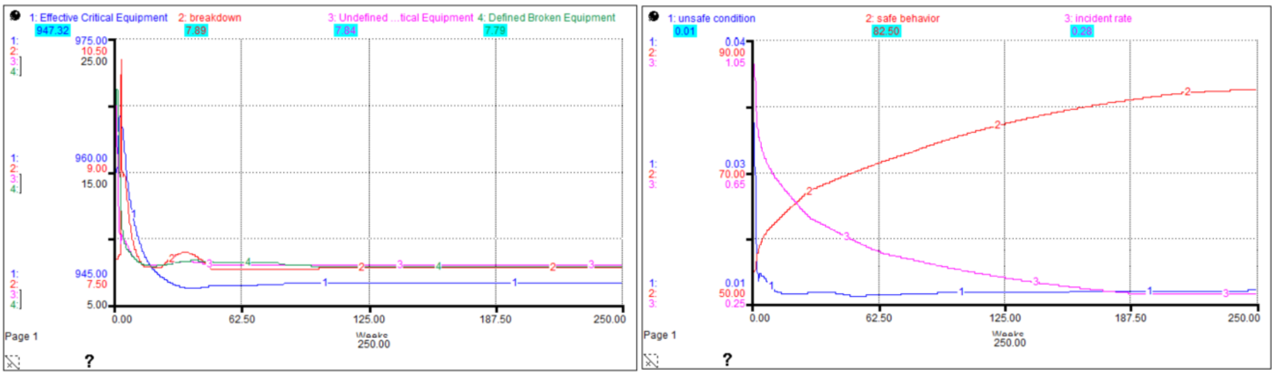


Figure 19. Change in Effective, Undefined Broken Critical Equipment, Defined Broken Equipment, breakdown, unsafe condition, safe behavior and incident rate (reference failure time is doubled).

3. Policy Analysis

Besides these scenarios, to demonstrate effect of different management policies on safety system, several policy analyzes are performed.

3.1. Policy Analysis Related to Time to Train

It is aimed to understand how training policies affect the safety system. Therefore, time to train is multiplied by 25. When the model is run, it is observed that increase in time to train makes decrease in required and so allocated labor time for training. Hence, untrained employee ratio increases and safety knowledge decreases. Decrease in safety knowledge causes decrease in safe behavior and increase in incident rate (see Figure 20).

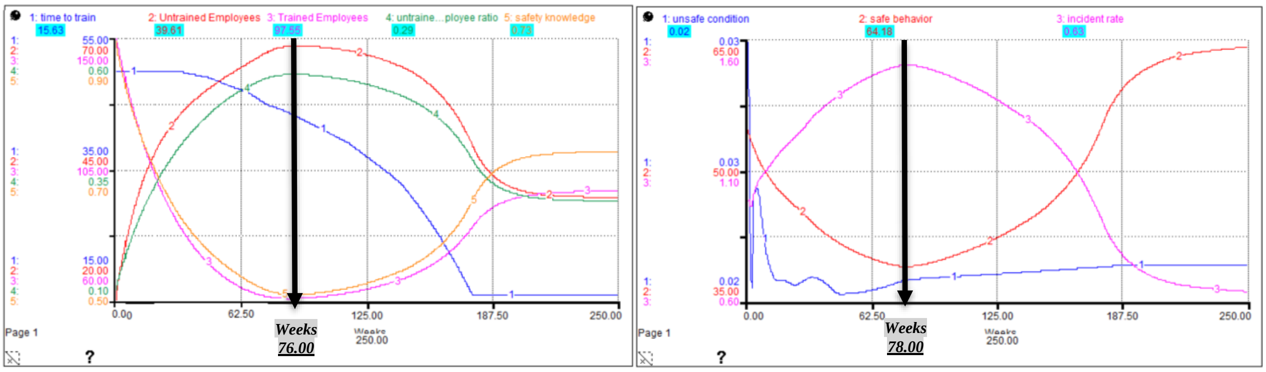


Figure 20. Change in training sector variables and unsafe condition, safe behavior and incident rate (time to train is multiplied by 25).

3.2. Policy Analysis Related to Time to Analyze

In addition it is also seen that, incident learning system prevents more decrease in safe behavior, and do more increase in incident rate. To gain insight into the incident learning system effect on safety system, in the second policy, time to analyze policy is analyzed. For this purpose, in addition to time to train policy, time to analyze is taken as 250 weeks that means the system does not allocate any time for incident learning. When the model is run and model behavior is compared to the reference and time to train policy, it is observed that safe behavior decreases much more and unsafe condition increases. Hence, incident rate increases more (see Figure 21). This policy implies that when there is not incident learning and then taking corrective action system in the onshore LNGRTs, incident rate increases more since safe behavior decreases and unsafe condition increases more.

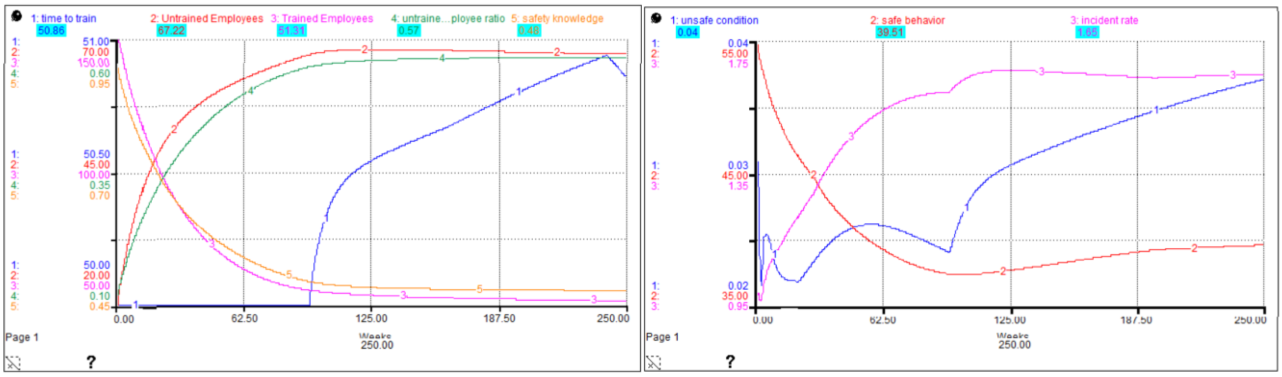


Figure 21. Change in in training sector variables and unsafe condition, safe behavior and incident rate (time to train is multiplied by 25 and time to analyze is taken as 250 weeks).

3.3. Policy Analysis Related to Maintenance Period

To understand how maintenance activities affect safety system, maintenance period policies are analyzed. Hence, maintenance frequency is halved. When the model is run and the model behavior is compared to the reference model behavior it is observed that, decrease in maintenance frequency leads to breakdowns and decrease in determination of broken equipment. Then, Undefined Broken Critical Equipment increases which causes increase in unsafe conditions. Then, incident rate increases (see Figure 22).

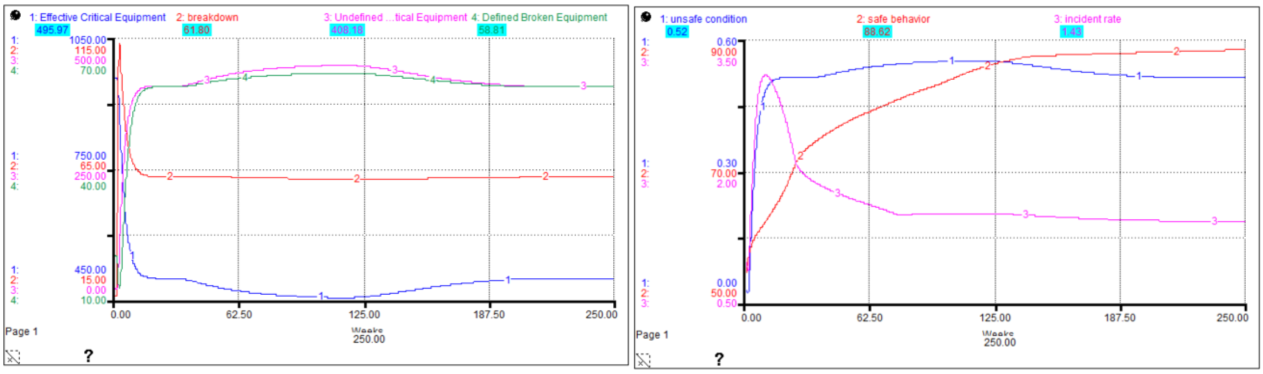


Figure 22. Change in Effective, Undefined Broken Critical Equipment, Defined Broken Equipment, unsafe condition, safe behavior, and incident rate (maintenance frequency is halved).

3.4. Policy Analyzes Related to Hiring

To analyze hiring policy, hiring is quartered. Then, it is observed that employee shortfall increases, and the labor time gap is tried to be closed by increase in Time per Employee. Hence, fatigue increases and so safe behavior decreases. On the other hand, since hiring is decreased and there is much more delay to adjust labor time than the reference model, Perceived Schedule Pressure increases, maintenance period decreases. Then unsafe condition also decreases. Consequently, incident rate increases (see Figure 23).

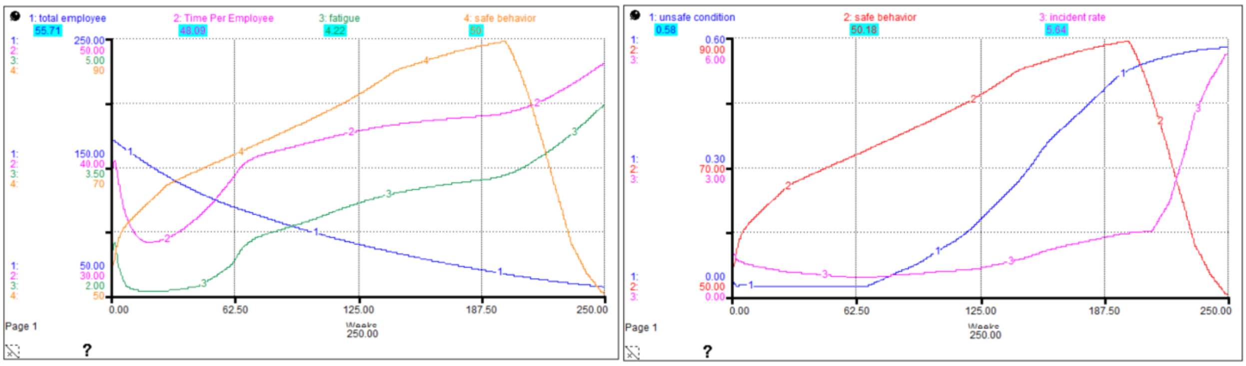


Figure 23. Change in total employee, Time per Employee, fatigue, safe behavior, unsafe condition, and incident rate (hiring is quartered).

It is also worth to mention that, when the model is run, there occurs transient behaviors in the beginning since the initial values can not be assigned to variables proper. Therefore, while analyzing the model behaviors, such transient behaviors are ignored.

DISCUSSION and CONCLUSION

In this research, the causal mechanisms of major occupational accidents in the onshore LNGRTs that may endanger people, equipment and the environment are analyzed by using dynamic simulation model based on system dynamic methodology. The model structure comprises of occupational safety related activities; LNG processing, equipment maintenance and repairing, employee training, and incident learning where the management's time allocation decision under specific resource constraints is the fundamental driver. Hence, the purpose of the study is to analyze labor time allocation among these activities as a policy for occupational safety. Since the dynamic simulation model also provides us with a tool to analyze how different scenarios and polices affect unsafe condition and unsafe act, and through these analyses it is also aimed to provide a method for implementing better policies without facing major occupational accidents.

The model is built depending on literature reviews, fieldworks and interviews done in one of the major onshore LNGRT. Then, the confidence of the model is provided through the validation procedures taking place in the scope of the system dynamic methodology.

The dynamic model is simulated by choosing an arbitrary initial time. Since the parameters are taken considering normal operational conditions, the reference model behavior implies that production, maintenance, repairing, training and incident learning activities are well operated, therefore; unsafe condition and safe behavior, which cause increase in incident rate, are close to the tolerable and reference levels.

To gain insight to the safety system dynamics, different scenario and policies are analyzed. Though these analyzes, it is seen that decrease in allocated labor time for maintenance leads to increase in unsafe condition. Furthermore, decrease in allocated labor time for training makes decrease in safe behavior. And when unsafe condition increases and/or safe behavior decreases, incident rate increases that mean possibility of facing major occupational accidents increases. Besides, analyses demonstrate that increase in schedule pressure makes decrease in allocated labor time for maintenance and training. However, incident learning system and according to taking corrective actions prevent more increase in unsafe condition and more decrease in safe behavior. That is, learning from incidents to take corrective actions has important effect on safety system to prevent increase in possibility of future incidents. On the other hand, it is also understood that, using less reliable critical equipment increases unsafe condition while using more reliable ones decreases unsafe conditions and incident rate. In addition, the model implies that high turnover rate because of the heavy working conditions, low wage policies, stressful environment, negative relationships, lack of trust and/or preferring subcontracting policy lead to high turnover rate that makes decrease in safe behavior, therefore; increase in incident rate. Besides, it is observed that preferring overwork rather than hiring policy makes increase in fatigue that leads to decrease safe behavior and increase incident rate.

Consequently, though this research, many causal mechanisms and feedback structures of the components that lead to unsafe condition and unsafe act are identified under favor of system dynamics methodology. This enables a better understanding of the occupational safety dynamics in the onshore LNGRTs. Moreover, a dynamic simulation model also provides a platform to analyze effects of different scenarios and policies on safety system. Hence, it is a useful tool for the managers to prevent incidents. On the other hand, the model built in this study aims to make contribution to occupational safety system dynamics literature.

In the model, total labor time is allocated among the activities in the onshore LNGRTs depending on their relative demands. As future work this labor time allocation structure could be made more realistic. Besides, collecting field data regarding time for training, reference maintenance frequency, reference incident rate, and the effects of components on each other etc. from different onshore LNGRTs, and analyzing them would make the model more sound.

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