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ORIGINAL ARTICLE

Accident Investigation based on the Systems Theoretic Accident Model and Processes: A Car Industry Case Study

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ABSTRACT

In industry and developed societies, annual work accidents can bring about huge losses. By proper analysis of these events, the development of controlling measures can be the most important action to prevent similar events and enhance the health of the society. Hence, the current study was aimed at analyzing a case of occupational accidents leading to death in one of the car industries. This qualitative case study was conducted in spring, 2018. With the implementation of Systems Theoretic Accident Model and Processes (STAMP), the incident statement had been described accurately and, then, a safety control structure has been designed to determine inadequate effective safety control actions in the event of an accident. In the analysis of the incident, various factors were involved at different levels of incident hierarchy where the various components of socio-technical systems interact with each other; the inadequate control action of the safety unit was more prominent. Based on the STAMP technique, unlike traditional methods, does not consider the cause of the accident just a component of failure or malfunction of the system. Therefore, it provides a useful tool in incident analysis, especially in complicated and sensitive systems.

KEYWORDS: *Accident Analysis, Car Industry, STAMP*

BACKGROUND

The automotive industry has always been one of the most important hotspots regarding the incidence of work-related accidents. Some factors, such as the application of heavy machinery, variety of workplaces and governmental management policies, the number of automobiles produced per hour, significant workload, and scheduling of work cycles have made the automotive industry a high-risk context [1].

Despite all the benefits that the development of industry has bestowed on humankind, it has endangered different sources in human society. The worrying statistics of incidents in the automotive industry support this claim. About 250 million occupational incidents occur annually worldwide where 300,000 cases lead to occupational deaths [2]. Different conducted studies in Iran also revealed the large scale of physical and financial losses caused by accidents [3]. According to the General Directorate of Public Relations and International Affairs of the National Forensic Medicine Organization, the number of deaths resulting from occupational incidents in Iran has an ascending trend over recent years where 697 cases of these incidents have happened in 2004 and this has increased by 1,994 cases in 2013[3].

Therefore, investigating these incidents is an essential component in providing safety and controlling losses. A complete report of accident's losses and a comprehensive review of these losses actually help authorities and managers properly understand the scope or expanse of the circumstances which has led to a decline in the economic efficiency of organizations.

Besides the advancement of technology, systems and industries have become more complex and their components interact with each other in more complicated manners. Thus, the development of effective models is necessary to analyze accidents in complex systems. There are different systemic accident models that have been proposed in various researches [4]. Accident models able to explain the origin of accidents occurrence and, thereby, they play a fundamental role in investigating and analyzing accidents. Systemic accident models consider accidents as the emergent phenomena that arise from complicated interactions between system components; accordingly, this may lead to the degradation of system performance, or an accident [5]. The STAMP is a new qualitative and comprehensive accident causation model developed by Nancy Leveson to analyze accidents in the socio-technical systems [6]. System analysis is a useful method to assess complex accidents by means of software and the hierarchical management of the organization. The traditional accident causation models are unable to investigate such complex systems. The STAMP not only can be used to analyze the existent accidents but also can be utilized to provide a safer system during the system development stage and to prevent accidents [7].

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Based on the STAMP approach, accidents in complex systems do not simply occur due to independent component failures or malfunctions; rather, they occur when external disturbances or dysfunctional interactions among system components are not adequately handled by the control system. Accidents, therefore, are not caused by a series of events, but result from the inappropriate or inadequate control or enforcement of safety-related constraints on the development, design, and operation of the system.

The STAMP model basically focuses on constraints rather than an event. The cause of an accident, instead of being perceived in terms of a series of events, is viewed as a corollary of the constraints imposed on the system's design and operations [6].

It can be concluded that the STAMP considers the dynamic nature of systems, identifies the missing parts or inappropriate features (those which fail to fix the constraints). This method proceeds through the analysis of feedback and control operations which replaces the traditional chain-of-event model. On the contrary, the traditional accident analysis techniques rely on a chain-of-event paradigm of causation [5] and deal with systems and the environment as a static design and unchanging structure [7] such as Event Tree Analysis (ETA), Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Cause-Consequence Analysis (CCA). Thus, traditional accident analysis techniques are arguably inappropriate for the study of socio-technical systems, especially complex software-intensive systems, complex human-machine interactions, and systems-of-systems with distributed decision-making that encompass both physical and organizational aspects [8].

OBJECTIVES

The STAMP previously was used to analyze major accidents such as a public water supply contamination accident that happened in a small town

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of Walkerton, Ontario, Canada [9], and Friendly Fire Accident [9]. In the current study, the STAMP approach was used to evaluate one of the incidences leading to death in the car industry in Iran.

METHODS

In the present case study, a qualitative approach was applied to analyze the causes of an Iranian car industry death.

Researchers prior to the study have visited the car industry to identify the factory process and, then, they conducted a survey of past events based on the STAMP. In the following section first, the steps of the STAMP technique were described and then, the incident and its analysis were described according to the STAMP technique process. STAMP methodology

The STAMP is designed to assess an accident based on the basic systems theory [8] and mainly focuses on inadequate control or the enforcement of safety-related constraints on the system design, development, and operation [8]. This method provides a systemic view of causality and examines non-linear, indirect, and feedback-based relationships among events [10]. The STAMP different steps are mentioned below (refer to Figure1).

Step 1: Identification and definition of incident hazards and Safety constraints associated with system safety levels

The first step according to the STAMP-based accident analysis process is to identify the system hazards and the system safety constraints. Leveson [8] defined a hazard as ‘‘a system state or set of conditions that together with a particular set of worst-case environmental conditions, will lead to an accident”. After the provision of a definition and identification of the system hazards, safety-related constraints should be identified by interpreting the risks in order to prevent the occurrence of accidents [8]. For instance, the loss of standard separation between aircraft in the designated airspace was recognized as the hazard in B738 and A319 occurrence analysis cases [11]. The related system safety constrain was the ATM system (airspace design, surveillance systems, data displays, etc.) and it must provide control instructions that ensure the existence of the minimum separation standards between aircraft in the designated airspace [11].

Step2: Determination of the safety control structure (organizational hierarchy)

The next step for the accident analysis is the construction of a control structure including control loops and feedback while considering the way it was built to work. Moreover, hazards and related constraints are defined and the control structure is a representation of the interactions among various components of the system. Control structures are hierarchical and consist of various control levels that influence the controlled process at the lowest level of the hierarchy.

Step3: Identification of inadequate control actions

After the definition of the safety control structure at the system level, the next step is to identify the inadequate control measures that may direct the system to a dangerous state. The hazardous state is a condition that violates the safety constraints that have been already defined for the system.

Step4: Safety assessment of the system

In this step, the whole information obtained from the previous steps is analyzed by the occupational health experts responsible for incidence analysis in order to identify the system weaknesses and provide pertinent control solutions.

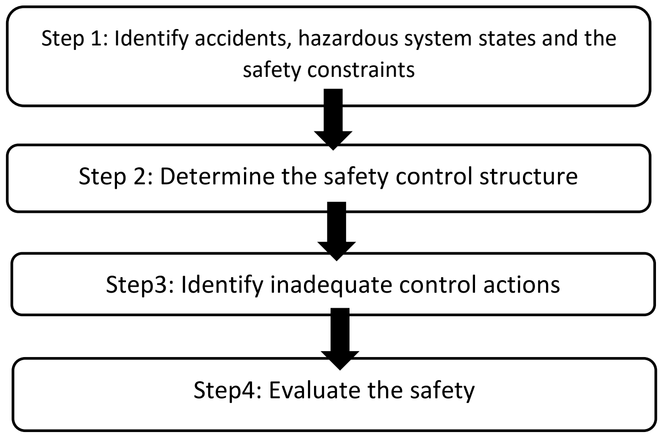

Fig 1. *Steps of STAMP for accident analyze*

RESULTS

1.1. The application of STAMP to an accident in the automotive industry:

The studied company has some advanced machinery for producing steel wheel rims and consists of 12 zones with 4 lines for rims and 7 assembly lines. In general, there are 400 employees working in this factory. An examination of the existing documents in the industry showed that there have been a total of 183 incidents and near misses between 2014 and 2018 where the number of four deaths has been recorded. The STAMP analysis was performed in two phases. The first output was the control structure as presented in Figure 1. The key personnel from the control structure including the field manager of industry, supervisor of the power plant, safety office, and factory electrical technician were then selected for further analysis. For this purpose, safety requirements and constraints, decision-making context, mental model flaws, inadequate enforcement of constraints, control actions, and inadequate or missing feedback were determined.

1.1.1. Accident process:

Mr. A.B. was the factory electrical technician working on the night shift on April 28, 2008. On the morning of April 29, 2008, he continued working overtime in the same job. He was working on the day shift with his co-workers and was involved in repairing burnt bulbs in the painting line at 8:40. Mr. A.B was lifted up by the overhead crane (at a height of 9 meters from the ground), was settled there, and started working. It is noteworthy that lifting was done manually. On that day, the atmospheric weather was sultry without any wind blowing. Suddenly, the person became ill while repairing the bulbs and fell off the top of the overhead crane. Electricity co-workers who had been working with him at the bottom of the lifts had witnessed the event; then, they brought him down and immediately rang the ambulance. During the incident, an ambulance was not present in the company. Lowering the person from the top of the overhead crane was done with delay due to the heavy weight of the person and the inadequacy of the lift efficiency. On the other hand, the ambulance reached the painting line after 20 minutes. The rules set by the management before the accident had closed painting line doors because of security issues. Finally, the person passed away because of a heart attack after being sent to hospital. The technician, from the time of recruitment (2001) to the incident (2008), had refused to undergo annual medical examinations, and no documentation of his occupational health was available.

Investigations from co-workers and families of the decedent person indicated that he had a high body mass index (weight of 100 kilos and height of 175 cm) and he had smoked cigarette.

1.1.2. Causal analysis:

An occupational incidence leading to death is described using the STAMP technique in accordance with the following steps.

Step 1: Identification of accidents, hazardous system states, and safety constraints:

The hazardous system states leading to the aforementioned losses pertain to the main processes in the safety chain, including: 1) Exposing a person to a dangerous work station without meeting the necessary requirements: The person did not enjoy the ability and sufficient skills to perform the job as he was just a technician without the required experiences and also the worker's supervisor had not chosen an eligible person for the job, as the technician's heavy weight had made him unsuitable for working in the height.

2) Constraint: This refers to the employment of an appropriate workforce with the necessary capabilities for any operation. The workforce must have the required abilities and skills to do the job and should also physically fit for a job assignment.

Step 2: Determination of the safety control structure

The control structure schema for this incident is shown in Figure 1. A control structure is a representation of the interactions among different components of the system. Control structures were hierarchically designed and consist of various levels of controlled process at the lowest level of the hierarchy.

Step 3: Identification of possible inadequate control actions

The STAMP model assumes that hazardous states result from the inadequate control. In this step, the insufficient control measures that can lead the system to a hazardous state have been identified. A hazardous state (one that violates safety constraints) is the one that occasions some impairment in safety constraints due to ineffective control.

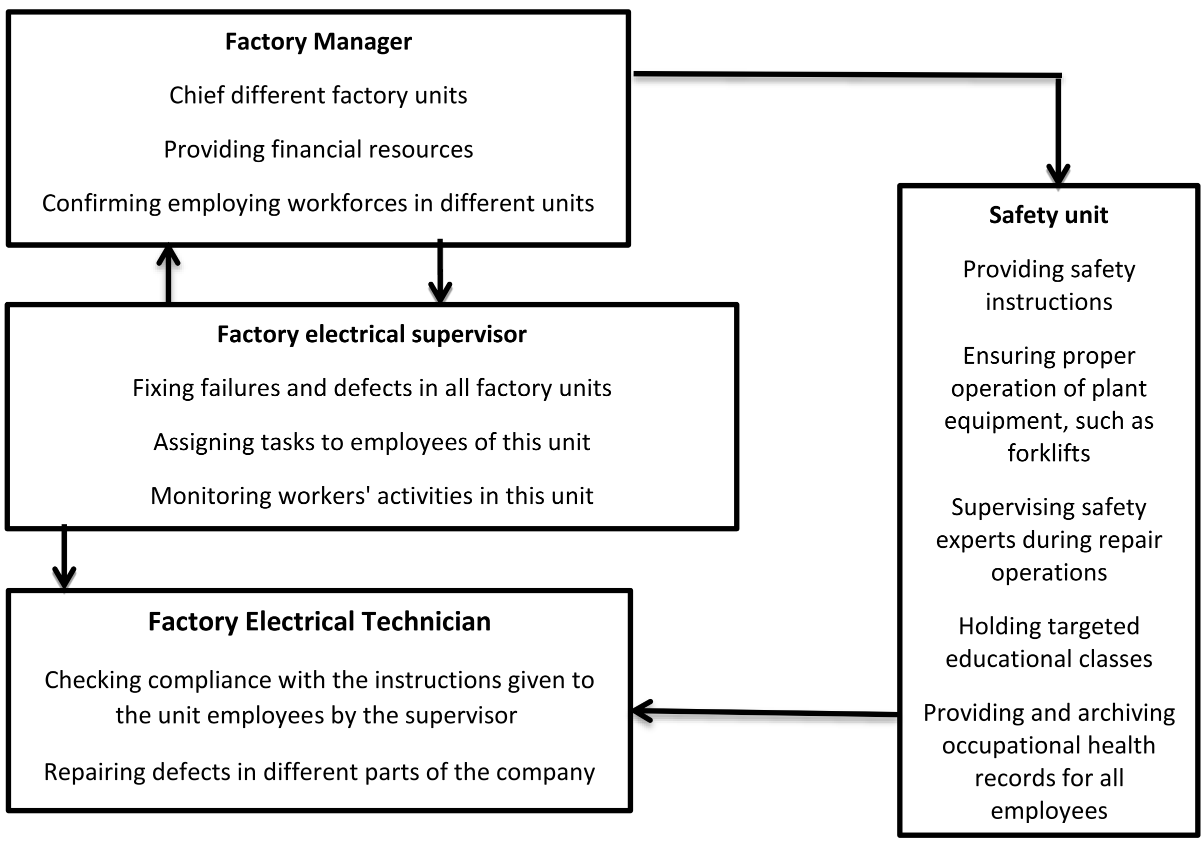

Fig 2. Electrical technician accident: basic control structure diagram

Table 3. The role of the manager in the accident

Factory management
Safety constraints Hiring and accepting personnel for different sectors Evaluating different units' performance Verifying the program implementation specified by the supervisor Providing the required financial resources to carry out occupational examinations and receiving reports on the performance of occupational safety and health unit
Context Running the blocking plan for the sub-entries leading to the ring line in order to improve the working space
Inadequate decision and control action Not considering possible emergencies in relation to the blocking of sub-entries Lacking an in-depth examination of the safety unit performance Lacking a penalty system for the subject units who have not executed the specified instructions Not providing an ambulance for responding to emergencies
Mental Model Flaws It is assumed that the safety unit personnel are present at the repair time. It is assumed that the electrical supervisor chooses the right person for this task. It is assumed that the plant equipment, including lifts, is healthy and has an appropriate performance.

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Table 4. The role of safety unit in accident occurrence

Safety unit
Safety constraints
Attendance in the repair process of different units
Presentation of the attendance report for annual occupational health examinations
Identification of the risks and assessing the company's high risk areas
Identification of vulnerable and susceptible people
Context
Safety experts' absence during repairs
Inadequate decision and control action
Safety experts' absence during repairs
Not presenting a report on the ambulance's delayed arrival to the management and different sectors of the plant, if the sub-entries are closed in the emergency conditions
Not filling out the lift truck inspection checklist
Not presenting a report on defective equipment to the repair department
Not all employees to take annual occupational examinations
Mental Model Flaws
It is assumed that the person enjoys occupational health for attending different job positions.
The fast and punctual arrival of ambulances in all sectors in emergency conditions

Table 5. The role of factory supervisor in accident occurrence

Factory electrical supervisor
Safety constraints
Selecting individuals with proper abilities for related job responsibilities
Providing a performance report for the management based on the completion of assigned tasks pertaining to electrical maintenance
Informing the safety unit before starting repairs
Assessing work environment conditions and then starting electrical repairs (such as measuring weather conditions)
Context
Implementing blocking the sub-entries leading to the ring line in order to enhance the work environment safety
Inadequate decision and control action
Not informing the safety unit at the time of operation
Not assigning job to a person in accordance with his/her physical ability
Not considering the weather conditions on the day of the incident
Mental Model Flaws
It is assumed that the forklifts are in good conditions.
It is assumed that the qualified electrical technician has the ability to perform the assigned duty.
It is assumed that during an incident, an ambulance is present in the ring line with the minimum time delay.

Table 6. The role of electrical technician in accident occurrence

Electrical Technician
Safety constraints
Assigning job duties in line with electric unit supervisor's decisions
Doing an assigned duty accordingly
Following the rule of taking annual occupational examinations
Context
Not understanding the risk of performing the task in those weather conditions
Inadequate decision and control action
Neglecting to perform an annual occupational examination and knowing self- health
Mental Model Flaws
The forklift is assumed to be in good conditions.
It is assumed that s/he had the ability to do work at that height and that weather condition.

Step 4: Safety assessment of the system:

The executive manager has confirmed the blocking of sub-entries without considering the emergency situation that may occur in the workplace. In this context, emergency response management should be established in the company. The absence of proper safety instrument such as ambulance was clear. On the other hand, the manager of the safety office performance was not constantly investigated; therefore, the absence of the safety officer during repairs is related to two reasons, i.e. the poor performance of the safety office and inadequate performance checking of this office by safety manager. The safety office should determine obligatory annual occupational examinations for all personnel; and who has refused to perform occupational examinations should be introduced to the management. In this accident, the safety office did not introduce the electrical technician to the management because of they did not perform annual occupational examinations. The supervisor should choose the qualified person in accordance with job task and physical ability. The content of this incident showed that all major units of this company (manager, safety office, electrician supervisor, and electrician) have been involved in different ways. Therefore, it can be concluded that in the interpretation of occupational incidents based on the systems theory-based technique, a set of components in that system are involved in the incidents affecting mutual impact on each other.

DISCUSSION

The purpose of this study was to analyze a work-related death using the STAMP technique. Whenever this technique applied in real situation, it should be noted that there is enough accessibility to additional data about the incident in order to draw up a safety control structure and come to a deep understanding of the system including factors of government policies and laws pertaining to that industry, plant processes, training programs, and company rules and regulations. Pereira et al. showed that the accident after analysis by this technique is recognized as the largest accident in the oil industry and shows the usefulness of this technique to improve the evaluation of the whole system [16]. Also Leveson et al. pointed out that the use of a systemic accident model like STAMP may not be satisfying to those focused on attributing blame, as it does not lead to the identification of single causal factor or variable. However, they offer a different perspective to chain of events models such as Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA), by providing information about the changes needed at a system level to prevent, or minimize the impact of accidents in the future [17].

Nematolahi et al. in their study showed that the failure to use a system-based theory for analyzing the causes of accidents in an automotive industry leads to an increase in the incidence rate and the imposition of direct and hidden costs on the organization [12]. In the same way, the results of Rolf-Arne Haugen study aimed at analyzing the largest oilfield incident indicated that the STAMP technique proved to be useful in improving the overall system assessment [13]. Hickey also pointed out that this technique reveals the causal factors involved in an incident [14]. In this incident, four sections (factory manager, electrical technician, safety office, and electrician supervisor) have been interactively involved in the incident. Regarding this incident, the factory manager has contributed to the incident due to control deficiencies such as the lack of budget assignment for the purchase of ambulances; and the high number of employees in this industry and agreement to block sub-entries for increasing security (in this condition ambulances cannot enter the production lines). In this incident, the management had not received a performance report from the safety office. On the other hand, the lack of safety features and actions, such as lack of performance reports and occupational health examination, forklift inadequate inspection, and safety supervisor absence at the time of repair are obvious and these factors have contributed to the interaction of control deficiencies related to the manager and personnel.

This company had no regular HSE program which consequently results in such incidents. In the study of Touri, an effective establishment of management systems in the field of safety, health, and system-based measures in the field of safety, health and environment can reduce the number of accidents and improve related indicators which were consistent with the results of this study [15]. It is recommended that employees who are unable to work in the production line due to heavy physical activity were transferred to the units required less physical activity, such as the safety office, with the permission of the manager. It is not possible to dismiss these labor forces and the management will usually take this decision according to the circumstances. Therefore, due to the lack of specialized knowledge, the safety office performance is weak and completely superficial and, as a result, it is considered as one of the main factors of the incident in interaction with other factors. In fact, training classes, the analysis of occupational examination results, equipment inspection, engineering control, and about 70% of safety and health issues were not carried out according to these conditions. The manager did not pay enough attention to safety; rather, the main focus had been placed on production. In addition, the catastrophe arises when we become aware that no safety culture has been defined in the least in this industry and among the employees. In this industry safety has been sacrificed for the sake of production, so far and, as a consequence, it has been the cause of such incidents.
The electrician's supervisor also does not consider the physical condition to perform this task. Finally, the electrical technician is required to conduct an annual occupational examination. It is likely that the person will not be certified to work at his/her work station or in conditions, such as working at heights even if s/he has completed the occupational examination annually. In general, in the incident analysis, every unit in the control structure was interactively involved with the incident due to control defects.
Lessons learned from the incident:

- Components of various sectors in the industry were involved in the incident. It was not just a blame for the incident.
- Various factors' role should be considered in the occurrence of such accidents.

The most important limitations of this study were limited access to incident data, time consuming technique, and sensitivity of industries to provide access to their accident reports.

CONCLUSIONS

The STAMP hazard analysis method was used for the first time in Iran to analyze incidents. According to the results obtained from this method, the STAMP provides a comprehensive analysis of all factors affecting the incident. In this technique, most of the components and their interaction are also taken into consideration. For this reason, the STAMP method is also called a systematic analysis method. This approach evaluates not only components but also the interactions among all components, or between the operator and components [6]. The STAMP technique is a new method of incident analysis based on the theory of the system and the development of such tools can be useful for safety experts of sensitive systems. In addition, as demonstrated in the current research, this technique has been able to provide more comprehensive analysis of the incident compared to other methods.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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