JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **34** No. 1, pp: 130 - 157 (2025 A.D.)
DOI: 10.4197/Met. 34-1.7

Analysis of electrocution accidents in complex systems based on four models: HFACS, FTA, AcciMap, and STAMP

Mobasher A.Alasmari[(1)] Mansour Balkhyour[(1)] Radhouane Chakroun[(1)]

1 *Department of Environmental Sciences, Faculty of Environmental Science, King Abdulaziz University Jeddah 80208, Saudi Arabia.*
mmobasheralasmari@stu.kau.edu.sa

Abstract. this study aims to the examination of four accident causation models namely: human factors and classification system (HFACS), Fault tree analysis (FTA), AcciMAp, and the Systems-Theoretic Accident Model and Processes (STAMP) to study the causation of electrocution accidents and the advantages and drawbacks inherent in every model. Two objectives of the study are: to determine the most appropriate methods for investigating electrocution accidents within complex systems and to comprehend the features of four methodologies concerning their conceptualization of accident causation. The methodology of study was to investigate the causation of electrocution accidents. The study involves a systematic approach that includes a literature review, gathering relevant data, analyzing various factors such as electrical systems, equipment, human behavior, and environmental conditions, identifying hazards and risk factors, and determining the sequence of events leading to the accident. In conclusion, HFACS and AcciMap are found to be more effective as they both consider the failures and defects at different levels of organization. It is apparent that establishing clear communication channels among all levels of the organization is a critical aspect of implementing a holistic approach to safety management.
Keywords: Accident causation, Electrocution, Failure, Prevention, Model

Introduction

On a global scale, there is an approximate yearly fatality of 350,000 workers as a result of workplace accidents, thus signifying a significant loss of human life. Consequently, this translates to a staggering daily average of over 1000 fatalities, which is an alarming statistic that cannot be overlooked. The sheer scale of these tragic occurrences serves as a clear indication of the urgent need for improved safety measures and comprehensive regulations within the occupational sector. This necessitates efforts from governments, employers, and international organizations alike, to effectively address and mitigate the root causes of these fatal incidents according to Hämäläinen (2009). Accidents do not happen, they are caused. Accidents prevention is to reduce their chance to minimum according to Ridley (2016).

It is noticed that electrocution accidents are deadly due to the impact of electricity on human body organs, as per the National Safety Council (NSC), approximately 1000 fatalities occur each year because of electrocution accidents for both occupational and residential sectors, with more than half of these incidents happening while individuals are working on energized systems that operate at less than 600 volts. The amount of current needed to illuminate a 7.5-watt, 120-volt light bulb is sufficient to lead to a fatality if it were to pass through the chest area. Moreover, the most critical pathways for electrical current to traverse through the human body are the lungs, heart, and brain, which can result in severe damage and potentially fatal consequences. Furthermore, the cost of accidents in USA is four times the actual cost, this includes the damage of equipment, injury and loss of human being as per McKinnon (2000).

Gulati and Smith (2021) noticed that a significant proportion of accidents and failures often occur during the start and conclusion of operations. Nonetheless, inadequate maintenance can also contribute to asset failures. Unseen deviations are causes that may not be readily apparent. The crucial step towards preventing failures entirely is to identify and address these hidden abnormalities proactively before they result in actual failure. Human error, which is predominantly caused by individuals within an organization, leads to a higher number of asset failures compared to any other type of error. This type of error, originating from the actions or decisions of individuals, is the primary contributor to asset failures within organizational settings. There has been a lack of emphasis on offering proper guidance on conducting a thorough diagnosis to pinpoint the underlying causes of issues within organizations. Rather than addressing the root causes, organizations frequently opt to tackle the symptoms of problems. This approach often involves the implementation of what could be termed a quick fix or a "duct tape solution," with the hope that it will resolve the issue at hand. Consequently, the risks linked to recurring problems have notably escalated. Moreover, the assets and systems within organizations are becoming increasingly intricate. Despite a more stringent process for problem identification, the capacity to effectively resolve these issues has not necessarily kept pace with the advancements. The training provided to individuals tends to be overly theoretical and lacks a focus on practical, analytical problem-solving skills. Individuals are not equipped with the necessary tools for logical and deductive thinking. As a result, there is a deficiency in understanding which tools to utilize and how to apply them appropriately in various scenarios.

Generally, an accident is an unplanned activity that causes human injury or financial losses. To prevent accidents, it is essential to identify and address their root causes through investigation. The process of investigating incidents is crucial in determining the approach for learning from them to prevent their recurrence. This study examines four prevalent accident investigation methods and their attributes and utilization to find out the root causes of accidents. To achieve this aim, the study covers the implementation, advantages, and constraints of the most common accident investigation methods. The article has the following objectives.

1. To determine the most appropriate methods for investigating electrocution accidents within complex systems.
2. To comprehend the features of four methodologies about their conceptualization of accident causation.

The examination and contrasting of four models namely: Fault tree analysis FTA, human factors and classification system HFACS, AcciMap, and the Systems-Theoretic Accident Model and Processes (STAMP), the four models exhibited a multitude of viewpoints on the causation of accidents and the advantages and drawbacks inherent in them. Specifically, the literature review highlights the advantages of adopting a systemic methodology for analyzing accidents, which encompasses a broader comprehension of the intricacies and dynamics associated with accident causation. Moreover, implementing a systemic approach allows for a more holistic evaluation of the various contributing factors and interdependencies involved in accidents, thereby enabling more accurate identification of root causes and the development of more effective prevention strategies. Furthermore, this approach facilitates the identification of systemic vulnerabilities and potential systemic failures, which can inform the implementation of proactive measures to mitigate the likelihood of accidents occurring in the future. Thus, the adoption of a systemic approach to accident analysis offers numerous benefits that can significantly enhance accident prevention efforts.

To study causation and analysis of electrocution accidents, four accident models were utilized to analyze the accident, namely; FTA, HFACS, AcciMap, and STAMP models.

To begin with, Fault Tree Analysis (FTA) categorization of failure is based on two key relationships which are and or gates, FTA is a technique utilized for identifying the primary causes of accidents and failures. FTA as an analytical tool involves a systematic process that starts by pinpointing the ultimate failure or event under scrutiny and then accurately digging into each factor that played a role or leading up to the former factor as a root cause, thereby providing a comprehensive and in-depth analysis of the entire chain of events. The next Model of the study is the human factor-based model, according to the categorization of accident causes as per the HFACS model in the study of Sari et al. (2020), it is observed that 36% of accidents are attributable to unsafe acts. Following this, the second most significant factor leading to construction accidents is the existence of preconditions for hazardous actions, accounting for 31.3% of occurrences. Moreover, unsafe supervision is responsible for 20.1% of accidents, while organizational influences contribute to 11.4% of such incidents.

Additionally, external factors pertain to a mere 1.2% of the overall accidents. The researcher modified the HFACS model to consider external influences of regulations and societal and they claimed the modified model is validated by 4 parameters which are construct validity, internal validity, external validity, and reliability in addition to expert interviews, however, the study lacks to elaboration on how validation conducted and inclusion of verification results.

AcciMap is the third model to study accident causation, Wienen et al. (2017) as well as Waterson et al. (2017) defined AcciMAP as an approach to examine the causes of accidents in complex sociotechnical systems using a systems-based technique. The Model examines failures at six different levels within organizations, including government, regulators, company, management, staff, and work process and surroundings. It is worth mentioning that STAMP Model highlights failures occurring across the entirety of the control structure of the system and the back-and-forth relationship between these structures and the specific control failures that ultimately lead to the accident

Materials and methods

The methodology employed to investigate the causation of electrocution accidents involves the utilization of various accident models such as (FTA), (HFACS), (AcciMap), (STAMP) models.

These models are used to analyze different aspects of the accidents in order to understand the contributing factors and mechanisms involved in electrocution incidents comprehensively.

The methodology employed to investigate the causation of electrocution accidents involves a systematic approach that includes gathering relevant data, analyzing various factors such as electrical systems, equipment, human behavior, and environmental conditions, identifying potential hazards and risk factors, and determining the sequence of events leading to the accident. This process is essential for understanding the complex interactions and contributing factors involved in electrocution incidents, which can help in developing preventive measures and improving safety standards in electrical work environments. Furthermore, an extensive examination of academic literature pertaining to the factors contributing to accidents is conducted, specifically focusing on research published in reputable journals within the field of accident causation. This comprehensive review serves as a foundational element in the research process, providing a thorough understanding of existing knowledge and insights into the various aspects influencing accident occurrences. This particular literature review undertakes an examination and analysis of the prevailing and extensively employed conceptual frameworks that have been developed to explain the root causes and factors contributing to accidents. Following this, the study proceeds to study and explain the distinguishing features and applications of four methodologies employed in the investigation of electrocution accidents. The selection of a technique to utilize, to some extent, relies on various factors such as the objective of the investigation, the resources that are available, the investigators' level of knowledge and familiarity with different techniques, and an evaluation of the complexity and/or severity of an accident.

Table 01 STAMP analysis - reference: adopted from Salmon et al. (2012)

Inadequate enforcement of constraints
• Hazards not identified • Control actions may be inappropriate, ineffective, or missing. • The control process fails to enforce constraints. • Process models may be inconsistent, incomplete, or incorrect. • Lack of coordination between controllers and decision-makers
Inadequate execution of control actions
• failures in communications • Insufficient actuator operations • Time delay
Feedback failures
• Not included feature in the system design • failures in communications • Time delay • Failure / improper sensor operation

Table-02 (Models features and related theories)

Model	*Model features*	*Approach*	*The theory used to generate the model*	*Reference*
HFACS	Human Factor and classification system. The model examines the role of human behavior in four areas, namely, unsafe actions, underlying factors for unsafe actions, inadequate supervision, and organizational influences.	The hierarchical chart is generated commencing from organizational influences positioned at the top, culminating with unsafe acts.	Swiss cheese model	Shappell and Wiegmann (2000)
FTA	FTA (Fault Tree Analysis) refers to the logical conjunction of technical factors and human actions that may result in an unfavorable top event.	The causal elements of an incident are documented via a logic tree to illustrate the coherent amalgamation of factors culminating in an incident or malfunction.	Sequential models/ logic tree	Gulati and Smith (2021) Vesley et al. (1981) Wienen et al. (2017)
Acci -MAP	The AcciMap approach is a method that examines the causes of accidents in complex sociotechnical systems using a systems-based technique. The Model examines failures at six different levels within organizations, including government, regulators, company, management, staff, and work process and surroundings.	AcciMap integrates the traditional cause-consequence chart with a hierarchical organizational risk management framework. The utilization of AcciMap entails developing a multi-tiered causal graph where the different factors leading to an accident are organized based on their degree of causal distance from the final outcome, which is represented at the lower part of the graph.	systematic models	Wienen et al. (2017) Waterson et al. (2017)
STAMP	Systems- Theoretic Accident Model and Process. The approach utilizes a systemic viewpoint to analyze the relationships among humans, technology, and the environment within a hierarchical structure of an organization. It considers the control measures implemented within the system to manage the connections between its components.	A hierarchical structure is employed for the purpose of depicting interactions among elements within socio-technical systems. Emphasis is placed on constraints, the breach of which results in accidents. Through the representation of hierarchical levels encompassing controls, constraints, and processes, the STAMP diagram explains the causes of the ineffectiveness of a control structure involving specific constraints in accident scenarios.	System theory Feedback control system	Leveson (2011) Wienen et al. (2017)

This study is designed to consider that components of technical elements, human factors, and organizational and managerial aspects are interacting interdependently in nowadays systems, and consequently to find the more suitable accident model, the four accident analysis techniques studied and necessary adjustments and customization were carried out to suit particular requirements in order to more effectively fulfill the distinct needs of professionals in various fields of expertise and at all levels of complex organization. The methodology of application of the four models is listed respectively as follows:

2.1-HFACS

According to Wiegmann and Shappell (2003), HFACS methodology encompasses four steps as following :

1. Identify organizational influence which includes the following tasks to find factors related to each one:

1.1. Identify resource management

1.2. Identify organizational climate

1.3. Organizational process

2. Identify unsafe supervision influence by finding factors related to each of the following:

2.1. Inadequate supervision

2.2. Planned inappropriate operations

2.3. Failure to correct the problem

2.4. Supervisory violation

3. Identify preconditions for unsafe acts via finding factors related to:

3.1. Personal factors which include: team resource management and personal readiness

3.2. Conditions of operators, which include three tasks; adverse mental state, adverse psychological state, and physical/mental limitations

3.3. Environmental Factors which include; the physical environment and technological environment

4. Identify unsafe acts of operators by finding errors and violations:

4.1. Errors include three types: Skill-based error, decision error, and perceptual errors

4.2. Violations which include: routine violations and exceptional violation

(HFACS) was developed with the specific purpose of outlining the latent and active failures linked to Reason's "Swiss cheese" model, thus facilitating its application as a means for investigating and analyzing accidents. To be more precise, HFACS identifies four tiers of failure, each corresponding to one of the four layers encompassed in Reason's model. These include Unsafe Acts, Conditions for Unsafe Acts, Unsafe Supervision, and Organizational Influences, according to Wiegmann and Shappell (2017). The approach to apply the HFCAS model, Figure-01, to analyze the accident reports is based on steps adapted from reference prepared by the developer of the model, Wiegmann and Shappell (2003) as outlined in the methodology section of this study. HFACS technique primarily examines human factors, but may not adequately address other contributing elements. Recognizing these strengths and limitations is essential to effectively utilize these techniques and ensure accurate accident investigations. (HFACS) is defined by Shappell and Wiegmann (2000) as a model to examine the role of human behavior in different areas, namely, unsafe actions, underlying factors for unsafe actions, inadequate supervision, and organizational influences. The HFACS hierarchical chart commences with the study of organizational influences situated at the highest level of the structure, gradually progressing downwards to culminate in the identification and analysis of unsafe acts occurring within the system. To illustrate more, according to Wiegmann and Shappell (2017), (HFACS) was specifically created to delineate the latent and active failures associated with Reason's "Swiss cheese" model, enabling its utilization as a tool for accident investigation and analysis. More precisely, HFACS delineates four levels of failure, each aligning with one of the layers encompassed within Reason's model. These include Unsafe Acts, Conditions for Unsafe Acts, Unsafe Supervision and Organizational Influences. Figure 02 describes in more detail every level of failure.

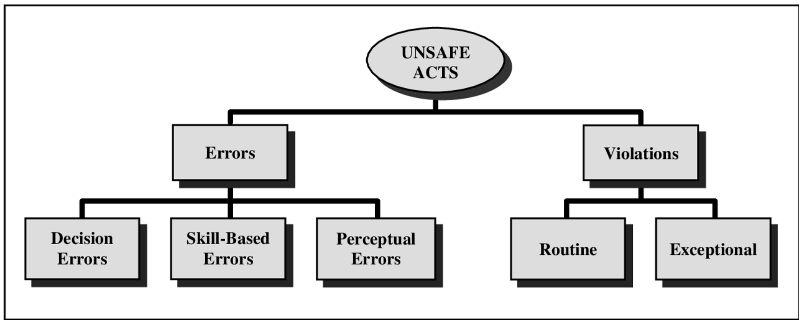


Fig.01- Shappell's Human Factors. Analysis and Classification System (HFACS)

The HFACS framework. Adapted from the HFACS model developed by Wiegmann and Shappell (2000). Retired from Figure 2 from The Human Factors Analysis and Classification System: HFACS: final report. | Semantic Scholar

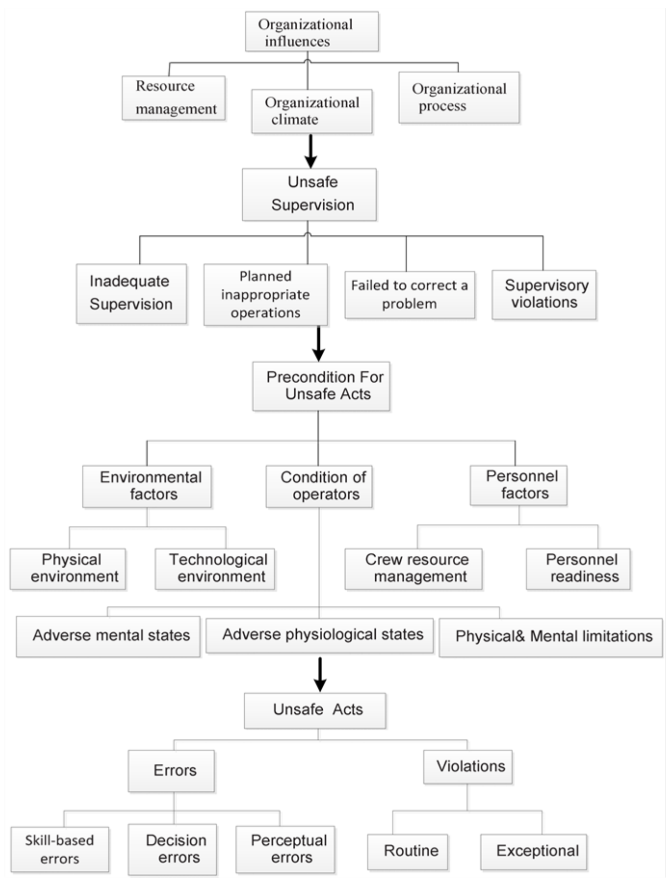


Fig.02. HFACS Model. Adapted from Wu, B., Kou, L., & Ma, Q. (2017). Research on HFACS based on accident causality diagram.

2.2-FTA

The methodology for Fault tree analysis (FTA) is adopted from CHAPTER IV - THE BASIC ELEMENTS OF A FAULT TREE, Reference: Vesely et al. (1981) and (software app.diagrams.net) Flowchart Maker & Online Diagram Software, n.d, outlined in the methodology section of this study. Based on Vesely et al. (1981), to conduct fault tree analysis, the system is analyzed in the context of its environment and operation to find all possible ways in which the undesired event can occur via 4 steps.

1. Identify the ultimate failure (or event) at the top of the tree diagram
2. Identify preceding event/s
3. gradually examining each factor that contributed to the preceding factor using and or gates (described below)
4. This process is repeated until it is impossible to trace the trail back any further

(FTA), Figure 03, is another method to identify root causes, FTA is an analytical tool developed by commencing with the ultimate failure (or event) and gradually examining each factor that contributed to the preceding factor. This process is repeated until it is impossible to trace the trail back any further. After the fault tree is finalized and verified for coherence, decisions are made regarding the necessary modifications to avert the repetition of the chain of causes (or events) with significant repercussions, the same concept of FTA is defined by Vesley et al. (1981) Wienen et al. (2017) too. Table no. 03 illustrate the legend of FTA model.

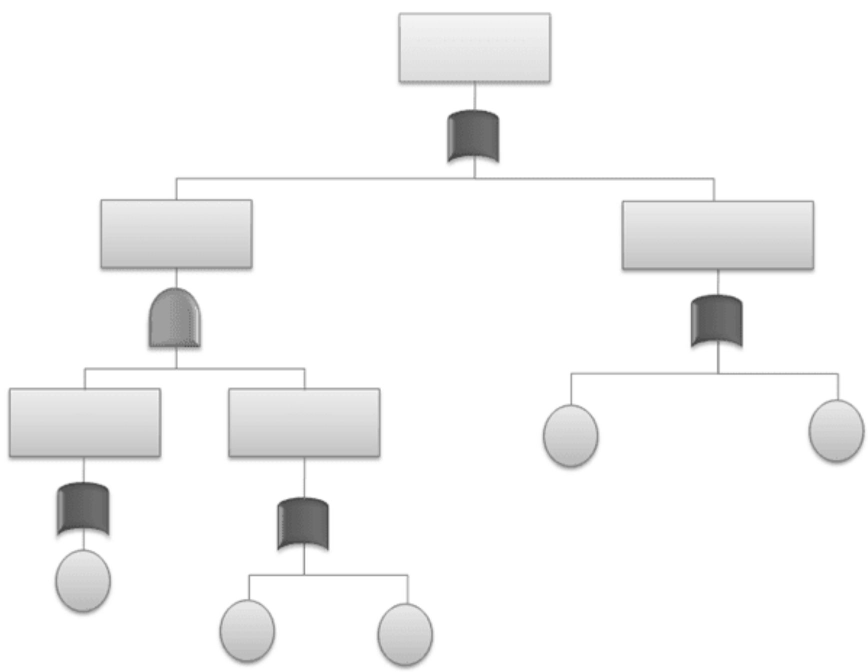
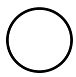
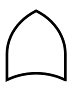
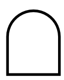
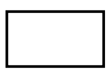


Fig. 03 -Fault Tree Analysis (FTA).
Fault Tree Analysis, adopted from (Hessing, 2024)

Table 03. LEGEND-Fault Tree Analysis (FTA)

	Symbol	Description
1		BASIC EVENT - A fundamental initiating fault that necessitates no additional detailing
2		Or Gate: An output fault arises when there is an occurrence of at least one of the input faults.
3		And Gate: The occurrence of an output fault is dependent on the occurrence of all input faults.
4		INTERMEDIATE EVENT - A fault event arises due to the influence of one or more antecedent causes that operate through logical gates.

2.3-AcciMap

Based on Delikhoon et al (2022), the AcciMap analysis is conducted in six steps as follows:

1. *Government Level* (Work laws), to find gaps or missing regulations items
2. *Regulators and associations Level* (General Regulations development), to identify gaps, specifically in energy industry regulations.
3. *Company Level* (Specific regulations, adjustment, and enouncement), to find the mismanagement at the executive level of the company
4. *Management Level* (Company policy, operation management, and setting goals)
5. *Staff Level* (plan and procedure) to find accidents caused at the middle and low management levels
6. *Work Level* (events, hazardous process, and actions), to expose causes related to unsafe actions and unsafe conditions at the lowest level of the company

In support of the same line of reasoning about the complexity of nowadays systems, Rasmussen (1997) proposed a hierarchical framework (namely AcciMap) for the conceptualization of a work system. This system encompasses various organizational levels, which include government, regulators, company, management, staff, and work process, in a top-down manner, figure 04. Each level within this hierarchy exhibits a greater degree of complexity compared to the level immediately below it and possesses emergent characteristics that are distinct from those of the lower levels. The fulfillment of safety within this framework is achieved through the identification of the boundaries of safe operation, ensuring that individuals are aware of these boundaries and are equipped with the necessary mechanisms to navigate them. To facilitate this process, each upper level within the system establishes constraints on the lower levels by defining control processes and actions. Concurrently, the upper levels also receive feedback from the lower levels regarding the safety status and effectiveness of the control actions. Consequently, Rasmussen perceives safety risk management as a control problem as opposed to a failure problem. Although Rasmussen's framework has served as the underpinning for the socio-technical system model that is AcciMap, certain researchers, including Katsakiori et al. (2009), pointed out that this approach is most suitable for organizations characterized by complexity and high technology due to its inherent sophistication. Likewise, Strauch (2015) agreed with the concept of complexity stating that accidents are complex events in which operators are faced with unfamiliar and unforeseen situations. Their responses may have appeared logical to them at the time, without a full understanding of the subsequent consequences they would face. As a result, investigators may find themselves puzzled when trying to comprehend these outcomes in hindsight. The objective of Strauch's (2015) paper was to elucidate various theories that have been proposed to interpret operator behavior in accident situations and to explain human performance in sociotechnical systems.

Tabibzadeh and Meshkati (2015) illustrated further the concept of an AcciMap, also known as an Accident Map, as a theoretical model that defines failures, decisions, and actions occurring at every tier within an organization by developing a causal diagram. By utilizing this method, the relationships among these levels are visually depicted, enhancing the understanding of organizational dynamics. The six hierarchical levels, starting from the highest to the lowest, encompass various aspects of an organization's structure and operations. These levels provide a comprehensive framework for analyzing incidents, errors, and responses within an organization, facilitating a systematic approach to risk management and safety enhancement. The AcciMap model serves as a valuable tool for identifying vulnerabilities and improving safety protocols across all levels of an organization, thereby fostering a culture of proactive risk mitigation and continuous improvement. Overall, the utilization of the AcciMap framework enables organizations to proactively address potential risks and enhance operational resilience by comprehensively evaluating and addressing factors contributing to failures and incidents at each organizational level. The six levels to implement AcciMap analysis are described in the methodology section of this study. Analysis of the AcciMap framework places a strong focus on evaluating not just the actions carried out by individuals at every tier but also on delving deeper into the examination of the connections between participants at these specified levels. This examination specifically pertains to the flow of decisions moving downwards and the flow of information moving upwards within the framework.

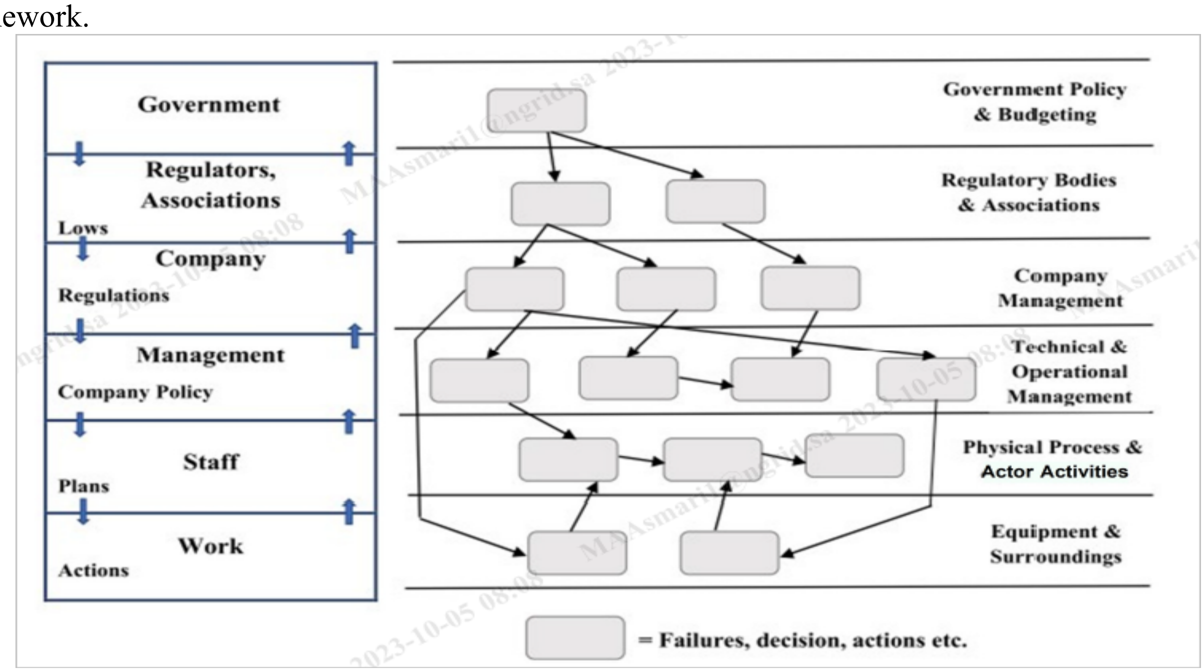


Fig. 04-Rasmussen's risk management framework (AcciMap)

Adopted from Delikhoon et al (2022), Rasmussen's Framework and AcciMap technique

2.4-STAMP

Systems Theoretic Accident Model and Processes (STAMP) -Methodology**.** Adopted from: https://www.ipa.go.jp/en/digital/complex_systems/stamp.html

There are five steps to performing an analysis of an accident using the STAMP model:

1. *Define the Purpose of the Analysis*
   Define target Accident (prevention target event) and hazards (potential situation to accident) and identify Safety Constraints to control Hazards on the system
2. *Model the Control Structure*
   Construct Components (subsystem, equipment, organization) and the Interactions (direction, feedback data). Analyze them in order to draw a Control Structure.
3. *Identification of Unsafe Control Action (UCA)*
   For every Control Action on the Control Structure, identify Unsafe Control Actions that may lead to Hazards by applying four guidelines. Control Action is defined as necessary interaction to implement Safety Constraints.
4. *Identification of Hazard Causal Factors (HCF)*
   For every UCA, construct a Control Loop Diagram and identify the Hazard Causal Factors (HCF) using guide words. Identify Loss Scenarios.
5. *Countermeasures*
   For every hazard causal factor, identify the control (countermeasures) as safety analysis results

Leveson (2004) presents the STAMP model which is based on constraints and examines the complex interactions among various components within a system and the control mechanisms that are deployed across the entire work system. In the paradigm of STAMP, systems are perceived as being comprised of hierarchical levels of controls and constraints as shown in table-01, where each level within this hierarchy exerts constraints on the level situated below it. Conversely, pertinent information regarding the appropriateness and state of the controls and constraints at the lower levels is conveyed upwards through the hierarchy to apprise the controls and constraints at the upper levels. Aligning with Rasmussen's theoretical framework, STAMP underscores the notion that complex systems are inherently dynamic in nature and tend to gravitate towards accidents as a result of a confluence of physical, social, and economic pressures, rather than experiencing an abrupt and complete loss of capacity for control. STAMP perceives accidents as the consequence of insufficient management of safety-related limitations, as described by Leveson (2004). According to Leveson (2009), incidents transpire when there is a lack of control over component malfunctions, external interferences, and/or inappropriate interfacing among different system elements. In her work, Leveson (2009) elaborates on a range of control mechanisms encompassing managerial, organizational, physical, operational, and manufacturing-oriented controls.

When utilized for the purpose of accident analysis, (STAMP) generates a comprehensive depiction of the control structure within a system as shown in Figure 5. The more detailed description is then utilized to pinpoint failures within the control structure that directly contributed to the occurrence of the accident based on figure-06. In order to facilitate the identification of these control failures, Leveson (2004) introduces a taxonomy that encompasses various types of control failures. These include inadequacies in controlling actions, deficiencies in executing control actions, and instances of inadequate or missing feedback mechanisms. Moreover, subsequent analyses based on STAMP have expanded their scope to incorporate the concept of mental model errors. This addition aims to enhance the model's ability to account for the intricacies of human control structures within the system, particularly considering that the methodology's roots lie in the field of engineering (Leveson, 2002; Ouyang et al., 2010).

The analysis conducted through STAMP not only highlights failures occurring across the entirety of the control structure of the system but also delves into the interplay between these structures and the specific control failures that ultimately culminated in the accident. Figures 5& 6, which are adapted from Leveson (2004), presents the STAMP taxonomy alongside a generic sociotechnical system control structure. This visual representation aids in understanding the complexities of control structures and their failures in a more tangible manner.

STAMP application steps are outlined in the methodology section of this study.

The four models' theoretical framework, their attributes, and related theories and models are described in Table-02. The four models are rooted in widely applied theories namely Swiss cheese, sequential, and system-based theories.

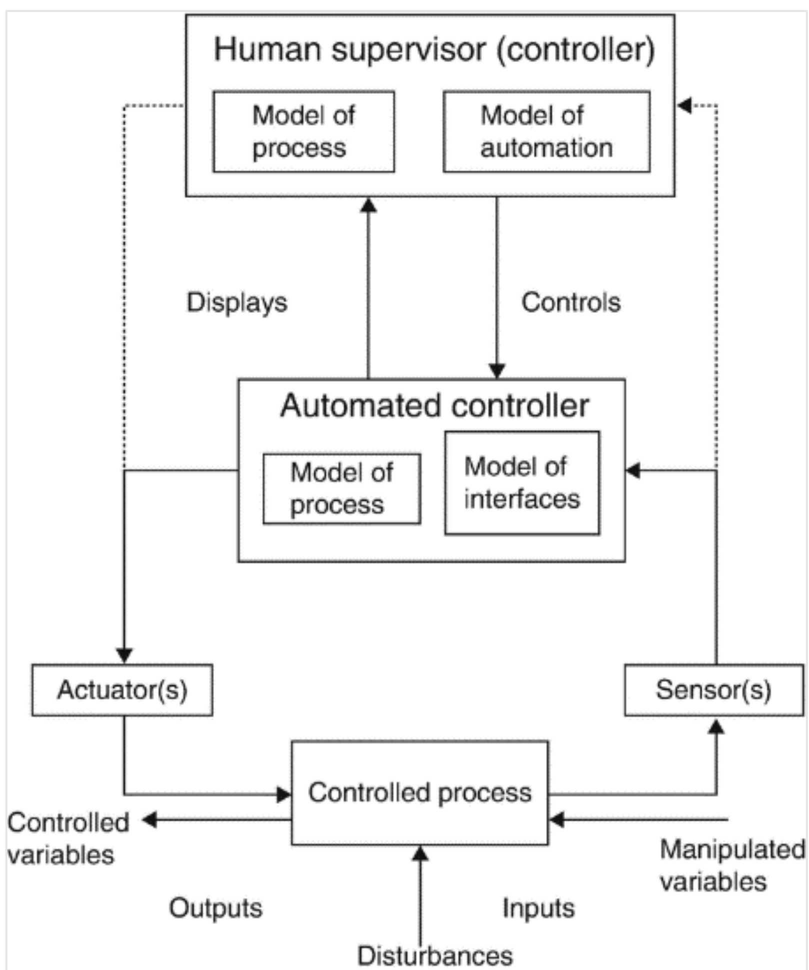


Fig. 05-STAMP. Adopted from (Leveson, 2004) General Form of System Model

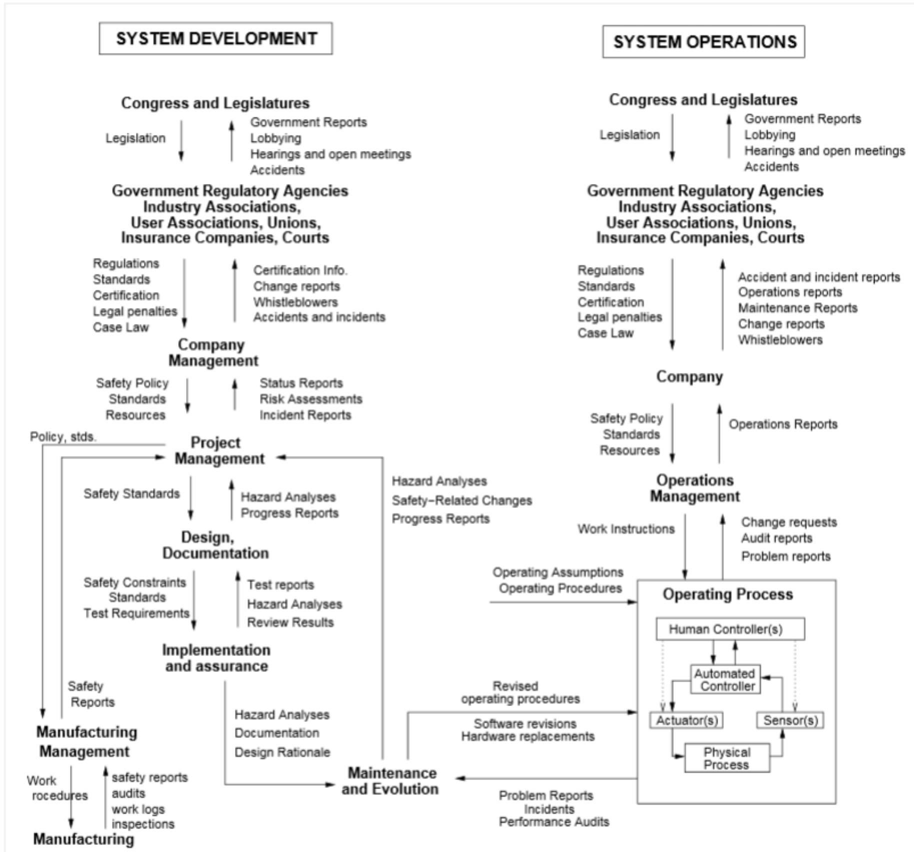


Fig. 06-STAMP. Adopted from (Leveson, 2004) General Form of System Model.

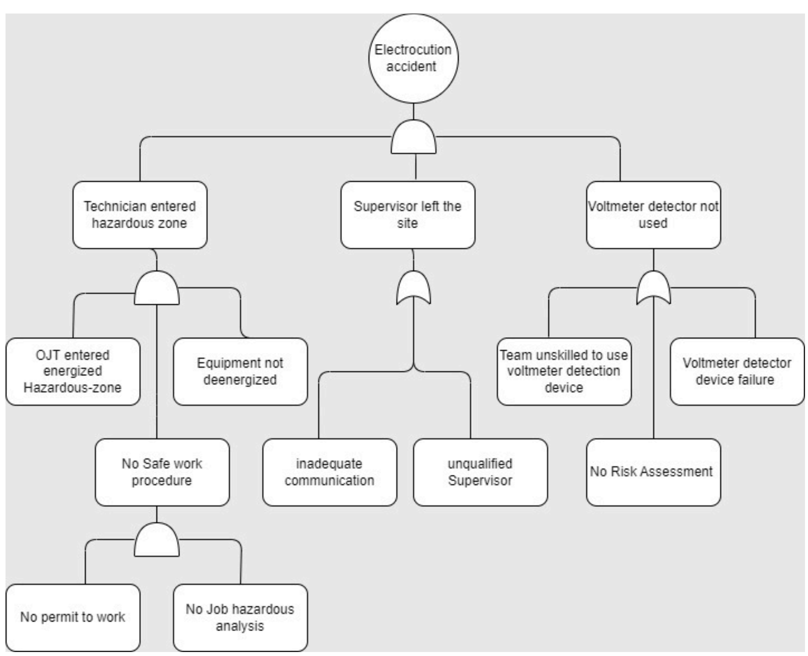


Fig.07 – Fault Tree Analysis of Electrocution Accident

Results

3.1-Accident description

One of the maintenance teams consisting of the team leader and a number of (2) on-job trainee (OJT), employees - under on job training, went to carry out the visual inspection of the equipment room of the 13.8 kV switch gear for one of the transformers in preparation for the inspection and cleaning works. The team opened the first back cover of the cell and examined the internal parts without cleaning, then opened the second back cover and examined the internal parts without cleaning as well, and this work was completed. Before closing, while the team leader was busy bringing some equipment from the car to lock the room, one of the employees (OJT - under job training) performed a visual examination of the internal components of the cell and thus entered the electrical field of the live parts of the cell (voltage 13.8 kV) and was electrocuted and led later to his death.

3.2-HFACS Model

At the level of organizational influence, the organization is clearly lacking in creating a safer work environment for all employees involved in electrical maintenance tasks. In a high-risk environment such as working with live electrical equipment, it is imperative that all necessary precautions are taken to prevent accidents and protect the well-being of employees. This includes proper isolation and grounding procedures, and strict adherence to work orders and permits.

Examining the second level as per the HFACS model, the unsafe supervision influence, there was no competent leadership within the maintenance team during the accident of electrocution. Furthermore, Regular field follow-up by supervisors and department heads was not carried out to monitor work progress and address any safety concerns promptly. Additionally, the maintenance task for the switchgear was poorly planned, and the trainee was not aware of the high voltage hazard of the tasks of inspection. The absence of technical expertise in the leader of the maintenance team had further exacerbated the already precarious situation. Without a competent leader guiding the team, the chances of errors and safety lapses increase substantially. Moreover, the failure of the supervisor and department head to provide adequate field supervision during work activities led to a lack of oversight and accountability.

At the level of preconditions to unsafe acts as per the HFACS model, the on-job trainees are not trained to carry out inspection of highly hazardous operations, they shouldn’t be part of high-risk activities. The conditions prior electrocution accident clearly encouraged the unsafe acts of entering the highly hazard area of the switchgear.

Finally, at the level of unsafe acts of operators via finding errors and violations, engaging in tasks involving live electrical equipment without the proper authorization in the form of a work order and work permit is a violation of safety regulations and puts the individual at great risk. The failure to execute a procedure to isolate and ground the unit from all interconnected sides which is a skill-based error can lead to serious safety hazards in the workplace. Such negligence resulted in exposing employees to potential electric shock or other electrical accidents. The non-trained employee committed a decision error by entering the electrical field of live equipment, such as the transformer breaker cell from the 13.8 kV side, without following the necessary procedures.

3.3-FTA Model

The results output of FTA Model is shown in figure-07.The analysis of the electrocution accident based on (FTA) revealed that the technician's failure to follow safe work procedures was a significant contributing factor to the incident. Additionally, the voltmeter device was either malfunctioned, poorly used, or not used at all. Furthermore, inadequate training on electrical safety and hazard identification contributed to the technician's actions. Moreover, the lack of proper PPE selection and use increased the severity of the technician's injuries. The root causes of the electrocution accident were:

1. Improper access to energized equipment: The technician conducted an inspection without safe work procedures for accessing energized equipment using a voltmeter detector device, entering the electrical field without proper authorization and precautions. Moreover, inadequate hazard identification and assessment as the team leader did not identify and assess the electrical hazards associated with working on the energized equipment, increasing the risk of electrocution.
2. Inadequate safety culture: The company's safety culture did not adequately emphasize the importance of electrical safety and safe work procedures for working on energized equipment. Failure to de-energize equipment as the team leader and technician failed to verify the de-energization of switchgear before commencing the inspection, leaving the components energized and posing a hazard hence it is clearly no work permits secured for hazardous job.
3. Insufficient training on electrical safety: The under-training technician did not receive complete training on electrical safety procedures and hazard identification, leading to a lack of awareness and understanding of the associated risks.
4. The team leader left the site: leaving the team members working without verbal instructions on energized electrical equipment, and hence leaving them vulnerable to the effects of electrocution.

3.4-AcciMAP model

According to the AcciMap analysis output in table-04. and figure-08. The root causes of the electrocution accident were studied at six levels, starting from the highest level as Ministry of Energy, descending to subsequent levels of regulatory bodies and all levels of management, and finally by the individuals. MOE has enabled all Saudi companies to improve their externals as well as their internal processes, however the internal processes still need improvement to mitigate the risk of industrial accidents. The findings included the inadequacy of training on isolation procedures as the under-training technician did not receive training on proper isolation techniques and procedures. Additionally, the team failed to follow safe work procedures as the group leader did not communicate proper isolation procedures and hence didn’t de-energize the equipment before commencing work. Furthermore, the PPE selection and use were not effective as no auditing was carried out prior to commencing the task to ensure team members were wearing the more suitable PPE. Although the PPE was provided but the group leader didn’t enforce using them and hence technician did not wear appropriate PPE for the task. Finally, no precautions to ensure the equipment was safe to work with as the device voltmeter measuring was not used.

Various contributing elements are situated within the equipment and its surrounding environment, playing a significant role in shaping the overall outcome or safety of a system. Factors of not isolating the system have the potential to influence the functionality and efficiency of the equipment through their interactions with the immediate surroundings, highlighting the importance of considering both internal and external variables in the design and operation of technological systems. These include a lack of risk controls on switch gear equipment and not following permit requirements for hazardous tasks. At the level of physical processes and on-site activities, apparent failures can be observed that are interconnected with the overall performance of the system and management of the team.

At the operational and technical management level, there are significant elements, as the instructor didn't communicate the hazards to team members, and no risk assessment was available to guide the team on how to mitigate the risk of working near energized equipment. A number of shortcomings in the management of the company contributed to the occurrence. The operations at the location were under considerable pressure to meet maintenance targets.

3.5-STAMP

STAMP analysis of electrocution accidents was conducted in three steps: first is the inadequate enforcement of constraints, second is the inadequate execution of control actions
, and finally; feedback failures. Results shown on table-05

3.5.1-The countermeasures as per STAMP analysis

The STAMP approach advocates for the analysis of the overall system as the fundamental unit. This strategy is highly regarded as it ensures the development of suitable systems reform and countermeasures. Recent research acknowledges the significant impact of failures at higher systemic levels on accidents within safety-critical domains, as highlighted by prominent authors such as Hollnagel (2004), Rasmussen (1997), and Reason (1997). Therefore, it is crucial to apply methodologies that can pinpoint these failures, as failure to do so may result in the implementation of inadequate remedial actions and countermeasures, as noted by Reason (1997).

At the procedural level, countermeasures to ensure the commitment of group members to acquiring a work permit are to adhere to the comprehensive procedures, regulations, and guidelines set forth by the relevant authorities, alongside the necessary training and qualifications required to successfully secure and be granted the work permit. This commitment underscores the importance of meeting all the necessary requirements and demonstrating the capability to comply with the legal and professional standards essential for obtaining and receiving authorization to work. Additionally, in the process of implementing safe work procedures for inspection tasks, it is essential to have these procedures carefully examined and sanctioned by the individual who holds responsibility within the organization. Furthermore, the maintenance team should be adequately trained on these procedures to ensure they are well-equipped to carry them out effectively. Regular reviews and feedback mechanisms should be put in place to assess the adequacy of the procedures, especially in cases where work conditions undergo changes.

Moreover, inspection and maintenance of the 13.8 KV circuit breaker, current, and voltage transformer units is imperative to ensure their proper functioning and reliability; it is crucial that all units undergo a thorough cleaning process in accordance with rigorous guidelines to guarantee optimal performance. This process should be carried out only once the insulation and grounding procedures of the 13.8 KV/132 KV units on both ends have been successfully completed, as per industry standards and safety protocols. The utilization of the voltage tag, a crucial tool in electrical safety control measures, is important to ensure the isolation of energized equipment prior to inspecting the ends and any visible parts of the internal components within the circuit breaker, figure-09. The practice of isolation of both ends of energized switchgear has to be controlled prior to any attempt to approach or make physical contact with electrical equipment components.

As final countermeasures based on STAMP, a key portion of the safety and occupational health system is developing a comprehensive and detailed schedule for training maintenance personnel is essential in ensuring that they acquire the necessary qualifications to effectively perform their tasks and execute them in a safe manner. This time plan should encompass various training on control and feedback systems, hazardous areas, risk control measures, practical exercises, and assessments to adequately prepare employees for the responsibilities associated with their roles, ultimately contributing to a safer and more proficient work environment. Additionally, all employees are to be trained in how to deal with electric shock via proper personnel protective equipment (PPE), and all site supervisors are to be requalified with necessary rescue skills for electrocution accidents.

Table-04 – AcciMap results description

	Results- AcciMAP analysis of Electrocution accident *AcciMap Analysis – 6 levels*
1	*Government Policy and Budgeting: Level 1* • The company operates in a regulated industry of energy
2	*Regulatory Bodies and Associations: Level 2* • The Occupational Safety and Health Administration (OSHA) has regulations that govern electrical safety in the workplace. • The Institute of Electrical and Electronics Engineers (IEEE) has standards for electrical safety.
3	*Local Health Economy Planning and Budgeting: Level 3* • The company has a safety management system in place that is designed to prevent accidents. • The company has a policy of investigating all accidents to identify root causes and implement corrective actions.
4	*Technical and Operational Management: Level 4* • The company had a gap in procedures for de-energizing equipment before working on it. • The maintenance team had no procedures for verifying de-energization using a voltage indicator. • The company had procedures for selecting and using PPE.
5	*Work Organization and Management: Level 5* • The technician was not properly trained on isolation procedures. • The technician did not follow proper isolation procedures. • The technician did not wear appropriate PPE.
6	*Individual Actions and Decisions: Level 6* • The group leader left the site temporarily without delegating his role to another employee • The under-training technician inspected the switchgear components without the attendance of the group leader. • The under-training technician entered the electrical field of the energized parts and got electrocuted causing his death.

Table-05 (Results of STAMP Analysis)

	Results-Root Causes (STAMP Analysis)
1	*1-Inadequate enforcement of constraints* 1.1-Hazards not identified Hazards were not identified by the supervisor and hence posed a significant risk to the overall safety and health of employees including On Job Training in the workplace, the team leader clearly failed to recognize the potential threats that resulted in serious electrocution accident and death of the trainee employee in addition to a significant impact on productivity and efficiency of the work environment. 1.2-Control actions may be inappropriate, ineffective, or missing. Control actions within a 13.8 k.v switch gear system have the potential to be considered inappropriate, the control was not ineffective in achieving the desired protection of employees, on contrary the action of easy accessibility to energized hazardous parts of the equipment has caused critical unsafe actions to be committed by an under training employee, resulting in negative consequences. Furthermore, the control of energized parts of equipment is missing as no voltmeter to measure the level of voltage in the equipment parts 1.3-Control process fails to enforce constraints. The control process of 13.8 k.v of switch gear exhibited shortcomings in its ability to effectively implement and uphold the necessary constraints, leading to potential gaps in regulating and enforcing the established safe work procedure governing the system. These failures in enforcing constraints resulted in a breakdown of work order and adherence to guidelines, ultimately compromising the overall efficacy and reliability of the control mechanism in place figure-09. 1.4-Process models may be inconsistent, incomplete, or incorrect. Lack of process of conducting the task which is the safe work procedure of how tasks are carried out within an organization safely, had exhibited discrepancies such as inconsistencies, incompleteness, or inaccuracies, which impacted the efficiency and effectiveness of the organization's operations. It was crucial for organizations to address and rectify these issues in their process models to ensure smooth and reliable functioning. 1.5-Lack of coordination between controllers and decision-makers There was a notable absence of effective communication and collaboration between the individuals responsible for directing operations and maintenance groups and those in charge of making crucial decisions within the organization, which ultimately hindered the overall efficiency and effectiveness of the processes being carried out.
2	*2-Inadequate execution of control actions* 2.1-Poor control action Inadequate execution of control actions led to a variety of negative outcomes, such as increased risks of exposure to electrocution, and lower efficiency of already aged equipment which contributed to poor control actions. There were no safe procedural steps to monitor and evaluate the execution of control actions or identify any shortcomings or deviations in the switch gear equipment particularly the voltage transformer and current transformers Figure -09 and Table 01, and hence the team leader failed to take corrective measures to address the hazardous condition of electrocution to the team members in a timely manner in order to maintain safety of his team. 2.2-Failures in communication between team members This led to misunderstandings and disruptions in the flow of information, which caused inadequate communication channels resulted in errors in opening the cover of energized equipment for inspection, delays in acting to isolate the system, and ultimately endangered the team members. The supervisor has clearly failed to have effective communication to enhance collaboration, decision-making, and problem-solving within his group. Furthermore, the supervisor left the site without notification to his management nor delegating his role of leadership to control the team members and prevent any unsafe behaviors.
3	*3-Feedback failures* 3.1-The inadequacies in the feedback a loop within the switch gear and protection system led to feedback failures, which occur when the system doesn't properly receive or interpret feedback from disconnection switches and its users, in our case the maintenance and operation team failed to receive any alarm, resulting in a breakdown of the intended feedback mechanisms and hence inhibited the system's ability to make necessary adjustments

		or improvements to its operations, ultimately resulted in interaction with hazardous unsafe condition of electrocution. 3.2-Not included feature in the system design A Feedback feature is clearly disregarded in the design of a 13.8 k.v switchgear system. Failure to incorporate feedback mechanisms to ensure the effectiveness of the earthing switch caused the absence of valuable information on the system's performance hence preventing user satisfaction or continuous improvement. Furthermore, lack of feedback prevents optimization of the system's functionalities to protect against hazardous situations, in our case the electrocution risk. All types of feedback mechanisms are missing as usually the feedback encompasses various forms, including notification, alarm, and direct user comments, all of which can offer insights into areas of strength and weakness within the system, and consequently guiding designers in making informed decisions to improve the system's overall safety and reliability. Unfortunately, no integration of feedback features into the system design which resulted in a lack of improvement in the equipment safety requirements based on feedback by operation, and maintenance to the system designer. Feedback failure has led as expected to failure in communication among team members and leadership. Finally, the time delay in feedback to act to rescue the employee has contributed significantly to the deadly accident of electrocution.

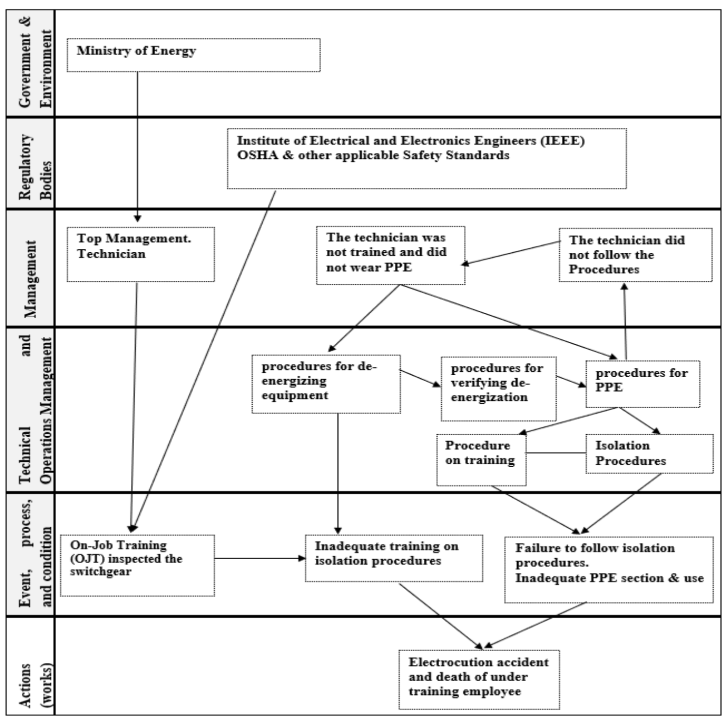


Fig.08-AcciMap (output Diagram)

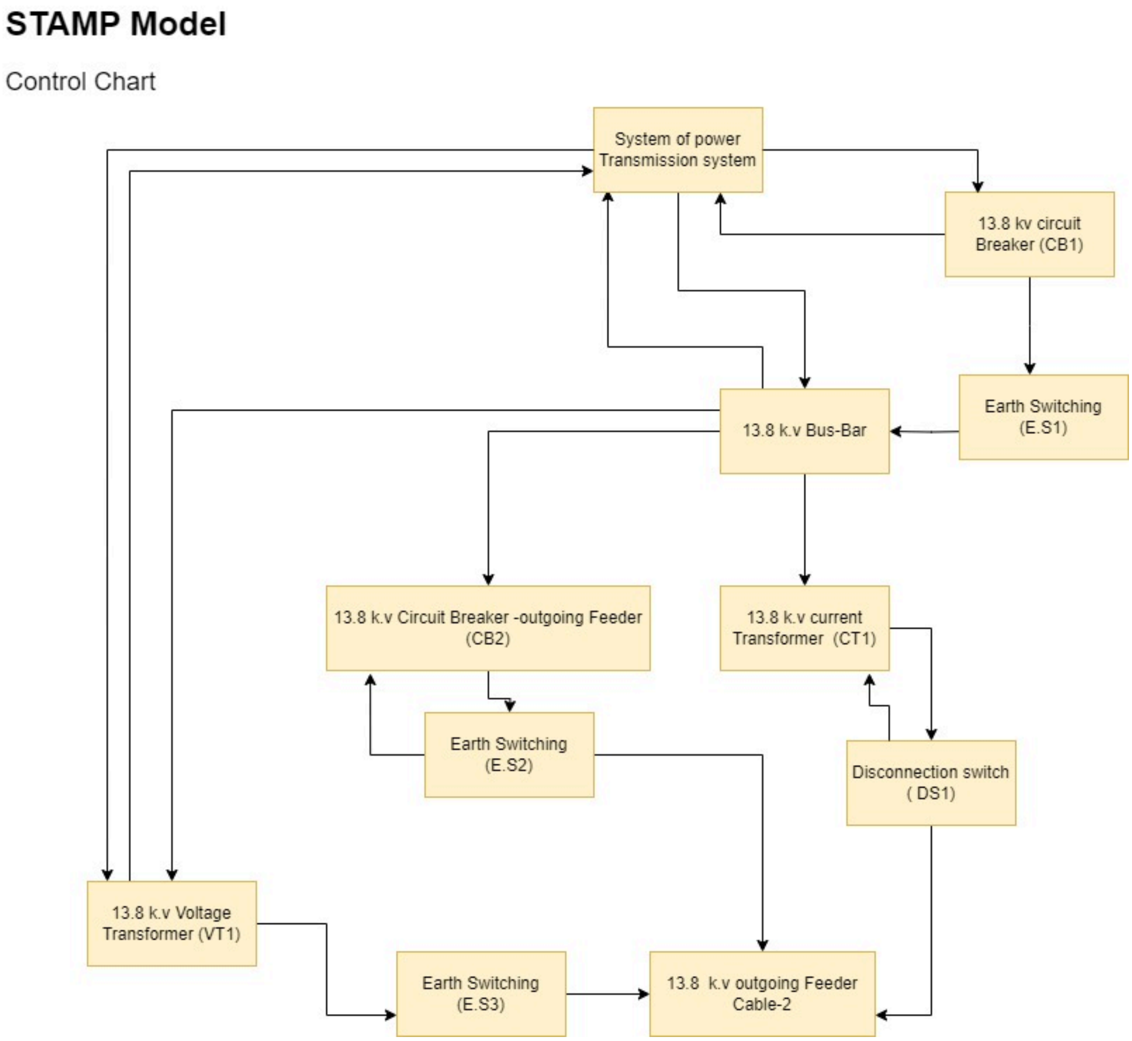


Fig.09 (Output of STAMP Control chart)

Discussion

It is essential to highlight that some tasks on specific parts of electric power generation and transmission as well as distribution network are at high risk of electrocution and arc-flash accidents, as they are of high vulnerability, such as switchgears, disconnecting switches and circuit breakers. Additionally, the collapse of structural components is extremely dangerous during startup , maintenance and operational setup.

Factors related to supervision have clearly caused the accident of electrocution. Firstly, the team leader had asked the two on-the-job trainee employees undergoing training to conduct a visual inspection of the equipment room housing the 13.8 kV switch gear for a transformer, the decision of the team leader was inadequate as the hazard of energized switch gear was not communicated to employees, nether safe work procedure and instructions provided to conduct the visual inspection.

Furthermore, upon arrival, the team proceeded to open the initial back cover of the cell and scrutinized the internal components without using a voltage measuring device and without any permit for hazardous works. It is true that there was a sequence of tasks successfully carried out by the team but the sequence was not documented nor approved. Additionally, there was no job hazard analysis prior to conducting the task, which necessarily showed that the risk assessment was not prepared. This failure to conduct a thorough risk assessment raises concerns about the overall safety and preparedness of the team in addressing potential hazards and ensuring a safe working environment.

Various contributory causes have led to the accident, to illustrate, the team leader was busy fetching additional equipment from the vehicle to secure the room before departure, this is a violation to leave the site without supervision, and this is a failure to delegate the task of leadership to another competent employee to lead the team and prevent any unsafe action. Unfortunately, the unsafe action of the team leader and the curiosity of job trainee employees led the OJT trainee to visually inspect the internal elements of the cell independently, inadvertently entering the electrified area of the live cell parts with a voltage of 13.8 kV, resulting in an electric shock incident that tragically led to the employee's death.

To prevent similar incidents of electrocution from reoccurring in the future based on the output of FTA highlighted in the results section of this study, the company's safety culture to include qualifying under-training employees for working on hazardous tasks. Furthermore, the trainees are to be qualified in electrical safety through regular training, reinforcement programs, and clear safety procedures. Additionally, hazard identification and risk assessment procedures are to be developed and shared with under-training technicians for implementation under supervision to ensure comprehensive hazard identification and risk assessment procedures specifically for electrical work to ensure that hazards are identified, evaluated, and controlled before work commencing. Besides that, the supervisor has to coordinate with safety engineers to develop effective PPE selection and use practices via detailed guidelines for selecting and using appropriate PPE for electrical work, consequently, the supervisor has to ensure that employees have access to and properly utilize the necessary PPE. By addressing the identified root causes and implementing the corrective actions, the company can enhance its safety culture, strengthen electrical safety procedures, improve hazard identification and risk assessment practices, and ensure that employees receive adequate training and supervision to work safely on energized electrical equipment. This will significantly reduce the risk of future electrical accidents and promote a safer work environment for all employees.

What is the best model that fits the analysis of electrocution accidents in a complex system?

To answer this question, the model is considered more suitable when covers the full view of analyzing systems components all together to find root causes of accidents at all levels of the organization, it is a must for all complex organizations to utilize an accident investigation model that consider proactively the factors of people, equipment and environment. This proactive approach to safety management is crucial as it enables organizations to anticipate and address potential issues before they escalate into accidents or incidents, thus preventing harm to people, property, and the environment. Furthermore, the best model is the one allows for the development and implementation of effective safety strategies and interventions that are tailored to the specific needs and characteristics of the system in question. Ultimately, adopting a systemic view and prioritizing proactive safety management can enhance the overall safety performance and resilience of the system, leading to improved outcomes and reduced risks in the long run. For example, accidents resulting from system failures can be better understood and addressed through the application of system's-based model. The systems approach, therefore, provides a framework for examining the intricacies of complex systems and unraveling their underlying dynamics, enabling researchers to gain valuable insights and make informed decisions. The integration of social and technical perspectives allows for a comprehensive understanding of the system, leading to more effective problem-solving and decision-making processes. Furthermore, this holistic approach considers the interdependencies within the system, recognizing that changes in one aspect can have ripple effects throughout the entire system. This comprehensive perspective enhances our understanding of complex systems and enables us to develop strategies to mitigate risks and enhance system performance. Additionally, the systems approach encourages a multidisciplinary approach, drawing insights from various disciplines to gain a more comprehensive understanding of the system. By considering both the social and technical aspects, researchers can identify potential challenges and opportunities and develop strategies to address them. In essence, the systems approach provides a framework that acknowledges the complex nature of systems and recognizes the need for a multidimensional perspective to fully comprehend and address system dynamics.

Leveson (2011), as cited in Delikhoon et al. (2022), introduced (STAMP), which is like Rasmussen’s technique. This groundbreaking theory revolutionizes the understanding of the investigation and analysis of accidents by offering a non-linear and system-based approach. STAMP, developed by Professor Nancy Leveson in 2011, provides a comprehensive framework for investigating accidents, enabling researchers and practitioners to delve into the underlying causes and complex interactions that contribute to accidents. By examining accidents as emergent properties of complex systems, STAMP shifts the focus from individual actions and human errors to the broader systemic factors that shape safety. This theoretical framework applies to a wide range of industries and domains, allowing for a more holistic understanding of accidents and their prevention. STAMP represents a significant advancement in accident theory and has the potential to greatly enhance safety practices and strategies across various sectors. Leveson stated that the present traditional approaches for acquiring knowledge from accidents are constrained by obsolete presumptions. Systems thinking and systems theory provide superior frameworks for comprehending and averting mishaps. Elaborate causality models grounded in systems thinking do not inevitably incur higher expenses and can yield greater effectiveness. Frequently, major mishaps have systemic origins that are not addressed by conventional methods of analysis. Investigative models that are based on systems theory are becoming increasingly critical in preventing accidents in complex systems.

(FTA) is another vital sequential and linear technique that has been widely utilized due to its relatively lower resource requirements and ease of application, as compared to systemic techniques. This technique has gained popularity in practical applications. However, research studies have indicated that the effectiveness of this method in capturing the complex interplay between human, management, and organizational elements in accidents is limited. FTA technique tends to prioritize the identification of easily identifiable causes while disregarding the less apparent organizational factors (latent factors) that contribute to accidents. However, the FTA model is applied in this article to explore the relationships between root causes leading to electrocution accidents. It is worth mentioning that Rasmussen (1997) Leveson (1995), and Hollnagel (2004), as cited in Qureshi (2007), pointed out that linear causal models such as (FTA) are effective in handling losses resulting from physical component failures or human errors in uncomplicated systems.

Yingyu et al. (2018) about the weaknesses and limitations of AcciMap, and STAMP; agreed that AcciMap is primarily suited for academic research, and may not be as applicable in practical settings as its graphic representation may oversimplify complex accident scenarios. For STAMP, it requires a deep understanding of system theory, which may limit its accessibility to non-experts. Also, the model may be time-consuming and resource-intensive to apply in practice. Similarly, the limitations of systems models discussed in the study by Karanikas, Soltani, de Boer & Roelen (2015), stated that the analysis of the accident causation model that was utilized in this study demonstrated that the root-cause model, which aims to identify the underlying factors that directly lead to accidents, was employed in approximately 48.1% of the accident reports. Moreover, a significant proportion of the reports, namely 50%, adopted an epidemiological model approach, which focuses on understanding the distribution and determinants of accidents within a population. Interestingly, it was found that only a single case, representing a mere 1.9% of the total reports, employed a systemic model approach, which emphasizes the interconnectedness and complexity of accident causation within a broader system.

Besides discussing the strengths and weaknesses of AcciMap, and STAMP, the characteristics of another systems-based model, which is the HFACS model are studied by Yingyu et al. (2018). The model has the strength of a taxonomic nature that allows for easy application in practical settings and provides a comprehensive classification system for human factors in accidents. However, the model is criticized for being limited to human factors, and may not capture all system-level factors as it relies on subjective judgment for classification of contributory factors. Additionally, Yoon et al. (2013) indicated that there are two disadvantages associated with HFACS. Firstly, they do not collectively consider an event and its causal factors. In other words, they identify events and their causal factors separately and subsequently establish connections between them. Although these connections are based on actual data pertaining to human errors and accidents, the acquisition and interpretation of the data rely on analysts' personal judgments. Consequently, the objectivity of the data employed in accident analysis can constantly pose a problem. Additionally, it is highly likely that analysts do not systematically consider diverse contextual information when linking an event to its causal factors. This is due to the presence of various cognitive biases, including hindsight bias, in their diagnostic reasoning from human error to its causal factors. To overcome this limitation, it is crucial to gather data on human errors and accidents and establish links between an event and its causal factors using a model that provides comprehensive contextual backgrounds explaining human activities. Secondly, most of the existing methods fail to adequately address why and how a set of causal factors is derived, as well as how these factors are interconnected. This is because they are identified without a theoretically robust model that offers coherent perspectives on a set of causal factors. Thus, to mitigate this limitation, it is necessary to present such a model when identifying and organizing the causal factors.

It is noteworthy to highlight that (HFACS) framework is derived from the accident causation model proposed by James Reason in 1990, commonly referred to as the "Swiss cheese" model. This model emphasizes the multiple layers of defenses within an organization that are meant to prevent accidents, where each layer has the potential for weaknesses that, when aligned, can lead to a breakdown in the system and result in an accident occurring According to Wiegmann and Shappell (2003).

Cristea and Constantinescu (2017) discussed the strengths and drawbacks of the fault tree analyses model, stating that this model is a deductive method that decomposes a general system state into chains of more basic events or components, the model describes the logical interrelationship of basic events and their dependencies, often visualized as a tree structure, providing a clear understanding of how failures propagate within a system**;** however FTA have weaknesses and limitations as the model is time-consuming, which can make them impractical to apply thoroughly in certain situations as FTA requires a clear understanding of the system and its components, which can be challenging if the system is complex or poorly documented, additionally the model assumes that the failure events are independent, which may not always be the case in complex systems, leading to potential inaccuracies in the analysis.

For all the above reasons, both models -AcciMap and HFACS – are found to be more appropriate to be used in complex systems for identifying root causes of accidents at all levels of the organization.

In conclusion, HFACS and AcciMap are found to be more effective as they both consider the failures and defects at different levels of the organization. A key finding is that effective supervision is crucial in ensuring that safety procedures are followed, and that work is carried out in compliance with established standards. Using the systems approach as the conceptual model for accident investigation in a complex work environment surpasses the mere examination of failure events and unsafe actions. These innovative models strive to comprehend a system as an integrated and holistic entity, elucidating the intricate processes and non-linear components interactions that shape the behavior of the system and propel it towards states of heightened risk. This valuable information can be utilized retrospectively to gain insights into the causes and mechanisms underlying accidents. Additionally, it holds great potential for prospective utilization, facilitating the detection and prevention of escalating risks through the implementation of appropriate controls, the delicate balancing of competing objectives and control requirements, or the refinement of the system design, all enacted prior to any unfortunate loss or mishap taking place.

Goetsch, (2009) found that the accidents of short circuits are the highest potential among electrical hazards, the risk to humans resulted from current flow. However, the electrical grounding system is the primary approach to mitigate the risk. And hence the electrocution incident highlighted the critical importance of implementing and enforcing effective electrical safety measures. By addressing the identified root causes, implementing the recommended corrective actions, and fostering a strong safety culture, the company can significantly reduce the risk of future electrical accidents and promote a safer work environment for all employees.

Based on HFACS and AcciMap, it is apparent that establishing clear communication channels among all levels of the organization is also a critical aspect of implementing a holistic approach to safety management. Ensuring that all individuals involved in the system have the means to report safety concerns, share information, and participate in safety-related decision-making processes is essential for creating a unified and proactive safety culture. This can be achieved through regular safety meetings, transparent reporting systems, and the use of technology to facilitate communication and collaboration. Ultimately, the active involvement of all stakeholders in the safety management process is fundamental to effectively addressing the multifaceted nature of contemporary socio-technical systems.

References

Cristea, G., & Constantinescu, D. M. (2017, October). A comparative critical study between FMEA and FTA risk analysis methods. In IOP Conference Series: Materials Science and Engineering (Vol. 252, No. 1, p. 012046). IOP Publishing.

Delikhoon, M., Zarei, E., Banda, O. V., Faridan, M., & Habibi, E. (2022). Systems thinking accident analysis models: A systematic review for sustainable safety management. Sustainability, 14(10), 5869.

Flowchart Maker & Online Diagram Software. (n.d.). App.diagrams.net. https://app.diagrams.net

Goetsch, D. L. (2009). *The Basics of Occupational Safety*. https://www.amazon.com/Basics-Occupational-Safety-Trades-Technology/dp/0134678710

Gulati, R., and Smith, R. (2021). Maintenance and reliability best practices. Industrial Press Inc..

Hämäläinen, P. (2009). The effect of globalization on occupational accidents. Safety Science, 47(6), 733-742.

Hessing, T. (2024, 5 30). six sigma study guide. Retrieved from Fault Tree Analysis: https://sixsigmastudyguide.com/fault-tree-analysis/

Hollnagel, E. (2004). Barriers and accident prevention. Ashgate, Aldershot, UK.

Karanikas, N., Soltani, P., de Boer, R., & Roelen, A. (2015). Evaluating advancements in accident investigations using a novel framework. In Proceedings of the 5th Air Transport and Operations Symposium (pp. 1-10). Delft University of Technology.

Katsakiori, P., Sakellaropoulos, G., & Manatakis, E. (2009). Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. Safety Science, 47(7), 1007-1015.

Leveson, N. (2004). A new accident model for engineering safer systems. Safety Science, 42(4), 237-270.

Leveson, N. G. (2002). System safety engineering: Back to the future. Massachusetts Institute of Technology.

Leveson, N. G. (2009). The need for new paradigms in safety engineering. Safety-Critical Systems: Problems, Process and Practice (2009): 3-20. Proceedings of the Seventeenth Safety-Critical Systems Symposium, Brighton, UK, 3–5 February 2009

Leveson, N. G. (2011). Applying systems thinking to analyze and learn from events. Safety Science, 49(1), 55-64.

McKinnon, R. C. (2000). *Cause, Effect, and Control of Accidental Loss with Accident Investigation Kit*. https://www.taylorfrancis.com/books/mono/10.1201/9780429092787/cause-effect-control-accidental-loss-accident-investigation-kit-ron-mckinnon

National Fire Protection Association-NATIONAL ELECTRICAL CODE COMMITTEE. (2015). NFPA 70E Standard for Electrical Safety in the Workplace. Batterymarch Park, Quincy.

Ouyang, M., Hong, L., Yu, M. H., & Fei, Qi. (2010). STAMP-based analysis on the railway accident and accident spreading: taking the China-Jiaoji railway accident for example. Safety Science, 48:5, pp. 544-555.

Qureshi, Z, H. 2007. A review of accident modeling approaches for complex socio-technical systems. In Proceedings of the twelfth Australian workshop on Safety critical systems and software and safety-related programmable systems - Volume 86 (SCS '07). Australian Computer Society, Inc., AUS, 47–59.

Rasmussen, J. (1997). Risk management in a dynamic society: a modeling problem. Safety Science, 27(2-3), 183-213.

Reason, J. (1997). Managing the risks of organizational accidents. Routledge.

Salmon, P. M., Cornelissen, M., & Trotter, M. J. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. Safety Science, 50(4), 1158-1170.

Ridley, J. (2016). *Health and Safety in Brief* (T. Francis, Ed.; 4th ed.). Routledge

Sari, S., Zaman, A. N., Waluyo, M. R., & Nurfajriah, N. (2020). HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS) MODEL IN ANALYZING CONSTRUCTION ACCIDENTS. Spektrum Industri, 18(2), 113.

Shappell, S. A., & Wiegmann, D. A. (2000). The human factors analysis and classification system--HFACS.

Shappell, S., & Wiegmann, D.A. (2000). The Human Factors Analysis and Classification System: HFACS: final report.

Strauch, B. (2015, September). The use of investigation models to explain accident causation and operator performance. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 59, No. 1, pp. 961-965). Sage CA: Los Angeles, CA: SAGE Publications.

Tabibzadeh, M., & Meshkati, N. (2015, April). Applying the AcciMap methodology to investigate a major accident in offshore drilling: A systematic risk management framework for oil and gas industry. In SPE Western Regional Meeting (pp. SPE-174020). SPE.

Vesely, W. E., Goldberg, F. F., Roberts, N. H., & Haasl, D. F. (1981). Fault tree handbook (p. 0216). Washington, DC: Systems and Reliability Research, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission.

Waterson, P., Jenkins, D. P., Salmon, P. M., & Underwood, P. (2017). 'Remixing Rasmussen': the evolution of Accimaps within systemic accident analysis. Applied ergonomics, 59, 483-503.

Wiegmann, D. A., & Shappell, S. A. (2003). A human error approach to aviation accident analysis: The human factors analysis and classification system. Routledge.

Wiegmann, D. A., & Shappell, S. A. (2017). A human error approach to aviation accident analysis: The human factors analysis and classification system. Routledge.

Wienen, H. C., Bukhsh, F. A., Vriezekolk, E., & Wieringa, R. J. (2017). Accident analysis methods and models-a systematic literature review. Centre Telematics Information Technology.

Wu, B., Kou, L., & Ma, Q. (2017). Research on HFACS based on accident causality diagram. Open journal of safety science and technology, 7(2), 77-85.

Yingyu, Zhang., Linlin, Jing., Chang, Sun. (2018). Systems-Based Analysis of China-Tianjin Port Fire and Explosion: A Comparison of HFACS, AcciMap, and STAMP. Journal of Failure Analysis and Prevention, doi: 10.1007/S11668-018-0534-1

Yoon, Y. S., Ham, D. H., & Yoon, W. C. (2013). Applying Activity System Model to Human-Related Accident Analysis. IFAC Proceedings Volumes, 46(15), 310-316.

تحليل حوادث الصعق الكهربائي في الأنظمة المعقدة استنادًا إلى أربعة نماذج:

HFACS، وFTA، وAcciMap، وSTAMP

مبشر الأسمري ، منصور بالخيور ، رضوان شقرون

قسم العلوم البيئية، كلية العلوم البيئية

جامعة الملك عبد العزيز، المملكة العربية السعودية.

mmobasheralasmari@stu.kau.edu.sa

مستخلص. تهدف هذه الدراسة إلى فحص أربعة نماذج لتفسير الحوادث وهي: العوامل البشرية ونظام التصنيف (HFACS)، وتحليل شجرة الخطأ (FTA)، ونموذج AcciMAp، ونموذج الحوادث والعمليات النظرية للأنظمة (STAMP) لدراسة تفسير حوادث الصعق الكهربائي والمزايا والعيوب الكامنة في كل نموذج. وتهدف الدراسة الى هدفين: تحديد أكثر النماذج ملاءمة للتحقيق في حوادث الصعق الكهربائي داخل الأنظمة المعقدة وفهم ميزات أربع منهجيات تتعلق بتصورها لتفسير الحوادث. منهجية الدراسة تتضمن مراجعة الأدبيات وجمع البيانات ذات الصلة وتحليل عوامل مختلفة مثل الأنظمة الكهربائية والمعدات والسلوك البشري والظروف البيئية وتحديد المخاطر وعوامل الخطر وتحديد تسلسل الأحداث المؤدية إلى الحادث. تبين أن HFACS وAcciMap أكثر فعالية حيث إنهما يأخذان في الاعتبار الأعطال والعيوب على مستويات مختلفة من المنظمة. ومن الواضح أن إنشاء قنوات اتصال واضحة بين جميع مستويات المنظمة يشكل جانبًا بالغ الأهمية لتنفيذ نهج شامل لإدارة السلامة.

الكلمات المفتاحية: أسباب الحوادث، الصعق الكهربائي، العُطل، الوقاية، النموذج

JKAU: Met., Env. & Arid Land Agric. Sci., Vol. **34** No. 1, pp: 130 - 157 (2025 A.D.)
DOI: 10.4197/Met. 34-1.7