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Engineering ethics within accident analysis models

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ABSTRACT

The purpose of this paper is to further investigate engineering ethics and its gap within accident analysis models. In this paper, at first, the role of human factors in the occurrence of accidents is presented. Then engineering ethics as an element of human factors is proposed. It is suggested that engineering ethics can provide engineers with the necessary guidelines to avoid possible accidents arising from their decisions and actions. In addition, the Challenger and Columbia space shuttle case studies that demonstrate the role of engineering ethics in the prevention and occurrence of accidents are discussed. Then sequential, epidemiological, and systemic accident analysis models are briefly investigated and negligence of engineering ethics as a gap in the accident analysis models is described. At the end, we suggest that by implementing engineering ethics as a controller within the system boundary in systemic accident models we may be able to identify and prevent the ethical causes of accidents.

1. Introduction

Engineering as a profession plays a vital and direct role in the life of humans. Thus, engineers are expected to observe the ethical responsibilities in the highest standards. "Accordingly, the services provided by engineers require honesty, impartiality, fairness, and equity, and must be dedicated to the protection of the public health, safety, and welfare" (NSPE, 2007). Implementing safety standards is an important ethical requirement in engineering activities (Hansson, 2006). Lack of safety measures and ethical responsibility by engineers can cause accidents. Accident causation models play an important role in analyzing accidents (Leveson et al., 2003). Accident models considerably have developed during the last 50–75 years from initial sequential models to contemporary systemic models. Along with this development, the role of human factors in accidents has also changed (Hollnagel, 2002). Human factors have a significant role in the occurrence of accidents (Wiegmann and Shappell, 2017; Baysari et al., 2008). Human Factors consist of human abilities, limitations, work ethics, environmental elements, and laws of human behavior (Shepherd et al., 1991). Thus analyzing engineering ethics as an element of human factors can provide further data for the study of engineering related accidents. Ethical shortcomings such as mismanagement, conflict of interest, and inattention to safety contribute to the occurrence of an accident (Fleddermann, 1999; Harris et al., 2013). For instance, the Challenger and Columbia space shuttle disasters are often referenced in engineering ethics literature. These two cases portray the impact of engineers and managers unethical decisions on the occurrence of accidents (Vaughan, 1997; Board, 2003; Murata, 2006). The accident analysis models we investigated did not address engineering ethics as an important factor, thus creating a gap. The purpose of this paper is to further investigate engineering ethics and its gap within accident analysis models. To achieve this purpose, we investigate six steps: first the role of human factors as a significant factor in arising accidents is explored. Then ethics and engineering ethics are explained. The Challenger and Columbia space shuttle incidents are presented as case studies. Moreover, several accident analysis models are briefly investigated. Then, we describe an important gap in the accident analysis models. Lastly, the study suggests applying engineering ethics as an ethical controller within the system boundaries.

The contributions of this paper are: 1) introducing engineering ethics as an effective factor in the area of human factors in the prevention and occurrence of accidents, 2) proposing “ignoring engineering ethics” as a gap in accident analysis models, 3) establishing a relationship between engineering ethics and systemic accident analysis models, 4) suggesting the new idea of using engineering ethics as a control criterion in the boundaries of system and subsystems in the systemic accident analysis models in order to prevent accidents, 5) implementing engineering ethics as a controller in three applied levels:

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i) comprehensive policymaking, ii) systematic decision-making, iii) individual employees performances.

2. The role of human factors in accidents

Meister (1989) defined human factors as: "the study of how humans accomplish work-related tasks in the context of human-machine system operation and how behavioral and non-behavior variables affect that accomplishment." The occurrence of accidents in recent years has revealed that human factors play a key role in the risk of system failure (Hollnagel, 2016). Feyer and Williamson (1998) note that behavioral factors cause more than 90% of major accidents. In technological systems, humans play a role in the initial design, maintenance, inspection, and adjustment of it (Hollnagel, 2002). According to Sanders and McCormick (1993), human factors apply information about "human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use."

Human factors are often confused with human errors. Human factors consist of all of the things that should be controlled and managed to acquire reliable human performance. Human errors are a result of unreliable human performance and occur because of an incomplete interaction between the human and the situation (Fahlbruch, 2009). At a cognitive level slips, mistakes, and lapses are three main types of human errors (Reason, 1990; Norman, 1981; Hollnagel, 1993). Human factors examine human performance as the main element within a goal-directed system. In the design and utilization of a system, the human is regarded as a system component. Issues such as professional ethics, human abilities and limitations, and laws of human behavior are investigated within human factors (Shepherd et al., 1991). This paper examines the role of engineering ethics, which is regarded as a human factor, in the occurrence of an accident. The ethical problems often faced in the field of engineering are rather complex. Ethical issues "may involve bribery, fraud, environmental protection, fairness, honesty in research and testing, and conflicts of interest" (Fleddermann, 1999). For example, some road accidents have apparently proved the role of inattention to observing ethics in designing and production. Since the 1960s a number of the most popular and accredited Automobile manufacturing companies across the world have involved in legal disputes. Investigations and reviews of the media and legal authorities have proved that technical and safety problems due to ignoring ethical approaches in Automobile industries have caused many people to sustain injuries and die.

In 1965, Ralph Nader in his book "Unsafe at Any Speed" explained that how General Motors changed the Chevrolet Corvair to an unsafe car leading to many road accidents. General Motors did not want to spend more money on boosting swing-axle rear suspension system of the car. Nader also unveiled that this company has designed a steering wheel column with one piece in order to reduce the costs even by ignoring passengers' safety. The piece could possibly restrict the driver's performance in accidents. James Roche, the president of Automobile manufacturing center, was forced to give an official apology for this behavior in front of members of the parliamentary commission (Nader, 1965). In the 1970s, the Ford Pinto Company made over three million cars; a small and light car, which was supposed to be an economical product regarding the raise in energy price. After a while, Mother Jones Magazine showed that in accidents occurring on cars' back, Pinto is responsible for deadly fires. Ford's internal documents during the trial showed that the engineers of Ford knew about the hazards of the project (Dowie, 1977). However, since Pinto had to be supplied on the market soon and its price should be competitive compared to low-price cars produced formerly by other manufacturers, managers had restricted the engineers to use the design because the company's computations had proved that paying any probable fines for damages would be much cost-effective)Viscusi, 1999). In another case in 2009, a California Highway Patrol officer was driving his Lexus Sedan while the car got out of control and he and his family lost their lives due to the accident. Toyota called on 4.2 million vehicles and assured the customers that the company was working to find the root causes, namely, stuck car pedals (Andrews et al., 2011). However, later the company admitted that it had concealed the problem in pedals. Toyota confessed that it has misled the consumers by concealing and fraudulent statements. In 2014, Toyota paid a remarkable fine in $1.2 billion, the highest fine ever paid by an Automobile manufacturing company to that date (Whyte, 2016).

The ethical scandals in Automobile industries show that managers of these companies face an ethical dilemma: 1) No redesigning and jeopardizing the lives of people and finally paying a lower cost in the form of fines. 2) Modify and redesign, and incurring higher costs. Unfortunately, these companies prioritized their own interest and profit to the peoples' lives by choosing the first option.

For further clarification, the definitions of ethics and engineering ethics are provided.

3. What is ethics?

Ethics "is concerned about what is right, fair, just, or good; about what we ought to do, not just about what is the case or what is most acceptable or expedient" (Preston, 1996). Fleddermann defines ethics as "the moral choices that are made by each person in his or her relationship with other people" (Fleddermann, 1999). In addition, ethics means responsibility toward the rights of those with whom we communicate in a 360̊ environment of our ethical life (Gharamaleki, 2008). Ethics is an important factor in the individual and professional life of an engineer. Harris et al. (2013) divide ethics into three categories (Fig. 1). *Common ethics:* a series of ethical ideals, which are common for almost everyone. *Personal ethics*: a series of moral beliefs that a person holds. *Professional ethics:* "the set of standards adopted by professionals insofar as they view themselves acting as professionals." According to Gharamaleki (2008), professional ethics is the responsibility to rights of all who are infected from over actions in the job. Furthermore, professional ethics is evident within ethical codes of various professions. For example, the Declaration of Geneva is a code of medical ethics for physicians. The engineering profession also has a series of ethical codes such as NSPE. Our paper focuses on engineering ethics as a branch of professional ethics.

3.1. What is engineering ethics?

Engineering ethics is "a type of professional ethics" (Harris et al., 1996). The academic field of engineering ethics has developed in the last three decades due to analyzing ethical codes and accident cases.

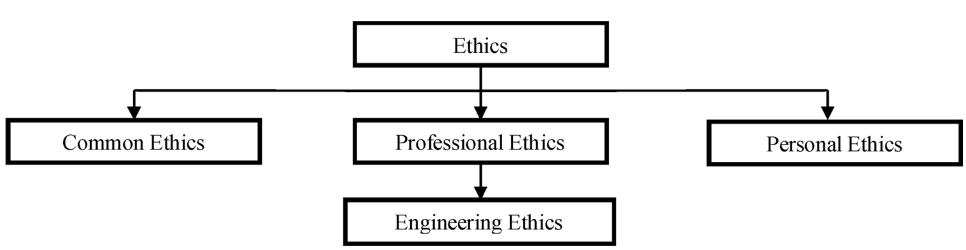

Fig. 1. Harris et al. categorization of ethics.

Engineering ethics can help prevent unethical decisions, unhealthy work environments, and accidents (Harris, 2008; Hollander, 2015). Engineering ethics is defined as "being concerned exclusively with the actions and decisions made by persons, individually or collectively, who belong to the profession of engineering" (Baum, 1980). Martin and Schinzinger (2005) define engineering ethics as "the study of the moral issues and decisions confronting individuals and organizations involved in engineering; and the study of related questions about moral conduct, character, policies, and relationships of people and corporations involved in technological activity" (Martin and Schinzinger, 2005). Ethical issues in engineering ethics generally appear as follows: ethical codes, the role of engineers versus managers, professional responsibility, honesty, merit, whistle-blowing, attention to safety, protecting commerce secrets, avoiding conflicts of interest and right to dissent (Davis, 1998; Lynch and Kline, 2000). Ultimately, since ethical problems are often complex, engineers and managers may struggle with finding solutions when problems arise. These ethical problems require some analysis using ethical theories (Fleddermann, 1999; Zandvoort et al., 2000). Any discussion of the concepts applied in engineering ethics such as harm or justice needs to reach a common understanding (Bouville, 2008). Ethical theories and codes of ethics help engineers and managers to achieve this common understanding.

3.2. Ethical theories and ethical codes

The application of ethical theories can help engineers and managers to identify ethical problems in order to set professional standards of conduct. There is a broad spectrum of "philosophical and legal" thinking in the study of engineering ethics (Fleddermann, 1999). Furthermore, ethical thinking and standards have expanded around the world. Many ethical theories such as *rights ethics, duty ethics, utilitarianism,* and *virtue ethics* are incorporated in addressing ethical problems in engineering (Fleddermann, 1999; Bouville, 2008; Harris et al., 2013). *Rights ethics* states that all humans have ethical rights and any actions which violate such rights is ethically incorrect (Fleddermann, 1999). *Duty ethics* states that actions that are duty-based are acceptable regardless of the good or bad outcomes (Kant, 1964). *Utilitarianism* considers the welfare of individuals as the ultimate value (Lyons, 2001). *Virtue ethics* focuses on the notion of virtue, in which good actions are ethical (virtues) and bad actions are unethical (vices) (Hursthouse, 1999). These ethical theories lay the foundation for ethical codes of conduct. Many engineering communities have ethical codes, such as the IEEE codes and the National Society of Professional Engineers (NSPE) codes. Ethical codes of conduct can be used as a framework for an engineer's decision-making in critical situations (Fleddermann, 1999). Furthermore, ethical codes of conduct can provide data when analyzing case studies.

3.3. Case studies

Harris et al. (1996) state that studying accident cases can be the best way to understand and implement engineering ethics. The Challenger and Columbia disasters are two case studies that will be discussed in the next section. These two accidents represent many of the issues related to engineering ethics (Fleddermann, 1999).

By analyzing case studies, engineers can further understand situations, procedures, and decisions that occur in accidents. This knowledge can help engineers to predict similar outcomes and understand the consequences of their actions (Lovrin and Vrcan, 2009; Abaté, 2011). Further analysis of case studies can help engineers develop higher-level cognitive skills when evaluating and solving ethical dilemmas (Abaté, 2011).

3.3.1. The challenger accident

On January 28, 1986, the NASA space shuttle Challenger exploded 73 (s) after take-off, leading to the death of seven astronauts. The investigation revealed that the explosion happened due to the failure of a seal in one of the solid rocket boosters. Ethicists, managers, and engineers analyze the Challenger case study because of its complexity, a great amount of data, and significance in understanding professional misconduct. NASA officials and Thiokol's engineers along with its supervisors all played a role in the occurrence of the accident (Werhane, 1991).

Roger Boisjoly as Senior Scientist and expert of rocket seal testified that "In fact, one of the most important aspects of the Challenger disaster - both in terms of the causal sequence that led to it and the lessons to be learned from it - is its ethical dimension. Ethical issues are woven throughout the tangled web of decisions, events, practices, and organizational structures that resulted in the loss of the Challenger and its seven astronauts" (Boisjoly et al., 1989). According to Bruce and Russell (1997): "NASA uses a low road, bureaucratic approach to what constitutes ethical behavior, with emphasis on financial conduct and risk management rather than upon morals and values."

On the night before the Challenger launch, a team of NASA managers and engineers met with Thiokol's engineers to discuss the safety of the launch, specifically regarding the low temperatures that were predicted for the launch day. Thiokol's engineers warned of previously noted issues with the shuttle's O-rings, especially during low temperature. They recommended that the launch should be delayed. Unfortunately, four NASA officials did not act upon the engineers' recommendations and voted for the launch. The decision-making processes were not in accordance with ethical standards. The Challenger accident was due to conflicts in the organization, the difference in priorities, and negligence of ethical responsibilities between Thiokol engineers, NASA officials and supervisors (Boisjoly et al., 1989; Werhane, 1991). Regrettably, seventeen years later another similar accident occurred: the Columbia disaster.

3.3.2. The Columbia accident

On February 1, 2003, NASA's Columbia space shuttle broke down during its return to earth, leading to the death of seven astronauts (Gehman et al., 2003). This disaster, which has many similarities with the Challenger disaster, demonstrates many of the issues surrounding ethics and responsibility in the engineering profession (Harris et al., 2013). According to Fleddermann (1999) "Many of the problems that existed within NASA that led to the Challenger accident 17 years earlier had not been fixed. Especially worrisome was the finding that schedule pressures had been allowed to supersede good engineering judgment. An accident such as the Challenger explosion should have led to a major change in the safety and ethics culture within NASA. But sadly for the crew of the Columbia, it had not".

The Columbia Accident Investigation Board (CAIB) identified "physical and organizational causes" in its report as the two main causes of the accident (Board, 2003). The accident occurred when a piece of foam fell from the external tank and breached the shuttle's wing in space. Although NASA was aware of previous problems with the shuttle's foam, it allowed the situation to continue for years resulting in the physical cause of the accident. The organizational causes of the Columbia accident were due to financial and scheduling pressures (Dimitroff et al., 2005). CAIB in their extensive 2003 accident analysis wrote: "NASA had conflicting goals of cost, schedule, and safety" (Board, 2003).

In summary, analysis of the Challenger and Columbia disasters highlights the significance of how procedures and ethical decisions can lead to accidents. The analysis demonstrated that both accidents were not solely due to the technical problems, but also management played a key role in these faults. For example, financial constraints and scheduling pressures were the main concerns instead of safety and ethical responsibilities during the Columbia disaster (Garrett, 2004; Haghighattalab et al., 2018). Furthermore, the managers in NASA and Thiokol did not follow ethical standards and simply jeopardized the life of astronauts with their decisions, causing organizations to incur huge expenses. Therefore, if the engineering ethics had been considered as a controller in such organizations and the managers' decisions had been verified as the system output in the highest level of ethics in decision making, the shuttles would not have been permitted to launch.

As explained in these case studies, engineering ethics as an element of human factors influences the occurrence of technical accidents. Hence, it is important to incorporate engineering ethics within accident analysis models.

For the purpose of this paper, we will review three types of accident analysis models: sequential, epidemiological and systemic models. In addition, we will further investigate whether engineering ethics is considered as an effective factor within accident analysis models.

4. Accident models

4.1. Sequential accident models

Sequential accident models describe accident causation as the result of a series of discrete events in a specific order (Heinrich et al., 1980). These models are used for investigating accidents caused by "physical components or human errors" within simple systems (Hollnagel, 2001). The domino theory is one of the first sequential models suggested by Heinrich (1931). The domino theory is based on five sequential factors: social environment, the fault of the person, unsafe acts or conditions, accident, and injury (Taylor et al., 2004). Since these factors are based on a sequential order, Heinrich believes that by removing a factor the occurrence of an accident may be prevented. Sequential models incorporate linear causality relationships. However it is difficult to analyze non-linear relationships, such as feedbacks within these models (Leveson, 2004). The sequential models act well for an accident caused by human errors or failure of physical components in a simple system, yet they cannot comprehensively describe accident causations in a complex socio-technical system (Abraha and Liyanage, 2015). Moreover, within these models complex multi-faceted view of human factors is not represented (Barnes et al., 2002). Thus, in sequential accident analysis models it is difficult to analyze consequences related to human factors, such as disregard for engineering ethics, resulting in a gap within sequential accident models.

4.2. Epidemiological accident models

Epidemiological accident models "regard events leading to accidents as analogous to the spreading of a disease, as the outcome of a combination of factors, some active and some latent" (Qureshi, 2007). The Swiss cheese model developed by Reason (1990) is a well-known epidemiological model. Reason used the Swiss cheese model to analyze accidents that occur when active failures and latent conditions are present within systems. The layers in the Swiss cheese model represent barriers set up in order to protect the system (e.g., defenses or safeguards). The developing holes in the Swiss cheese represent active failures and latent conditions. Active failures represent "unsafe acts" such as errors and procedural violations conducted by individuals within the system (e.g., operators or workers). Latent conditions represent organizational weaknesses and mismanagement within the system (e.g., decision-makers or management) (Reason, 1990; Rausand, 2013).

Epidemiological models can analyze complex accidents more efficiently than sequential accident models. However, epidemiological models have limitations when analyzing "complex interactions among different factors" (Hollnagel, 2002). Many organizational factors are identified as the "causal" factors that contribute to the possibility of an accident. However, in epidemiological models, it is difficult to describe and understand how multiple factors can come in line together to produce an accident (Abraha and Liyanage, 2015). Furthermore, epidemiological models are unable to specifically identify the origin of complex human factors that may lead to accidents. Similarly, analyzing consequences related to human factors, such as disregard for engineering ethics, is not investigated in epidemiological models hence resulting in a gap.

4.3. Systemic accident models

Systemic accident models are rooted in the theory of systems. They include the models, laws, and principles necessary to perceive complex interrelationships among components of a system. Systemic models consider accidents as a phenomenon, which arises because of complex interactions among system elements that can lead to system failures (Qureshi, 2007). Underwood and Waterson (2012) state that the two most cited systemic models, STAMP and FRAM, accounted for 52.0% and 19.9% of the references in 476 accident analysis documents.

Leveson (2004) proposed a systemic accident model, named the systems-theoretic accident model and processes (STAMP). STAMP examines the technical, organizational, and human factors in complex sociotechnical systems and focuses on the role of control systems in safety management. The principal concepts in STAMP are "constraints, process models, control loops, and levels of control" (Leveson, 2004). System failures, external problems, and flawed interactions within system components can be due to the lack of effective control within the system. Safety is regarded as a "control problem" and is managed by a control framework. Thus, in order to prevent future accidents, there needs to be a control framework that applies efficient constraints within a system (Hollnagel and Speziali, 2008).

Hollnagel (2004) developed the Functional Resonance Analysis Model (FRAM), which acts as an accident analysis and risk assessment tool. FRAM as a qualitative model examines the performance of system functions and their potential variability. FRAM identifies the main system functions and characterizes them "by six basic parameters (input, output, time, control, pre-conditions and, resources)." FRAM is able to provide data regarding accidents and "dependencies" within a system function. Furthermore, FRAM analyzes the variable barriers and can be used to account for non-linear interactions (Hollnagel and Goteman, 2004).

Systemic accident models, such as STAMP and FRAM, explain the efficiency of a system as a whole rather than focus on a particular cause-effect mechanism or epidemiological factor (Hollnagel, 2004). Furthermore, within systemic accident models, human factors are considered as variables. Therefore, it is essential to analyze various human factors in order to improve systems safety and performance (Hollnagel, 2002). However, systemic models do not explicitly mention the role of engineering ethics as a human factor in the occurrence of accidents hence resulting in a gap. Summary comparison of the three types of accident models is shown in Table 1.

5. A gap in the accident analysis models: engineering ethics

Analyzing consequences related to human factors, such as disregard for engineering ethics, was not analyzed within the accident analysis models hence resulting in a gap. Regarding accident analysis models Rasmussen states there should be a focus "on the mechanisms and factors that shape human behavior" which influence their performance and decisions (Rasmussen, 1997; Leveson, 2004). Accidents can have a series of complex interconnected elements with many contributing organizational, technical, and human factors as shown in the Challenger and Columbia accident cases (Leveson and Turner, 1993). Literature in engineering ethics indicates that unethical behavior of engineers and managers such as dishonesty, conflict of interest, dissent, irresponsibility, selfishness, and inefficiency may lead to the occurrence of many accidents (Harris et al., 2013; Fleddermann, 1999; Michelfelder et al., 2014). For example, the Hyatt Regency Walkway disaster (1981), Bhopal disaster (1984), Chernobyl nuclear disaster (1986), Hydrolevel Corporation (1971), and Deepwater horizon (2010) are accident cases

Table 1
Summary of the three types of accident analysis models.

Models	Scope	Advantages	Shortcomings	Gap	Example
Sequential models	Describe accident causation as the result of a series of discrete events in a specific order.	Proper for a fatality caused by human errors or failure of physical components in a simple system.	The cause-effect relationship between humans, management, and organizational factors in a system is insufficiently described. Cannot analyze accident causation in a socio-technical system	Do not assess engineering ethics as a human factor.	Domino theory by Heinrich (1931)
Epidemiological models	Explain an accident as the result of a combination of factors, some active and latent, which occur to be together in space and time. (disease analogy)	More valuable than sequential models because they can be used as a basis for complex accidents. Can overcome the constraints of sequential models.	Are unable to directly describe how origins of human factors cause accidents. Cannot address complex interactions between the various factors.	The role of engineering ethics as a preventive factor in the occurrence of accidents is not investigated in these models.	SCM (Swiss Cheese model) by Reason (1990)
Systemic models	Consider accidents as a phenomenon, which arises because of the complex interactions among system elements that can lead to a system performance failure.	Explain the characteristic efficiency of a system as a whole rather than having cause-effect mechanisms or epidemiological factors.	Future research is needed to examine the applicability of the new systemic models beyond a wider class of sociotechnical systems, especially in parts such as transportation, patient safety, maritime, and aerospace.	Do not explicitly mention the role of engineering ethics as an effective human factor in the occurrence of accidents.	STAMP by Leveson (2004) FRAM by Hollnagel (2004)

with instances of unethical decisions in engineering[1] . These accident cases demonstrate that there are also non-technical factors, such as ethical factors, that should be considered in the analysis of accident models. By not incorporating human factors, such as engineering ethics, in accident analysis models a gap is evident.

6. Engineering ethics as a controller within system boundary

A system is an entity that is defined by the boundary between itself and its environment (Morin, 2001; Ng et al., 2009). The boundary of a system specifies the inputs from and outputs to the environment of the system. A system boundary is considered as a place where the control is regulated (Wilson, 1984). All elements of the environment, society, and economy are linked together in a dynamic relationship between systems and their sub-systems. System-thinking suggests the best opportunity for recognizing contributory factors is by exploring both predictable and unpredictable interactions. Unpredictable interactions such as unethical behavior can lead to system failure, instability and disturbance (Bennett, 2016). In physical, biological, and mechanical systems, the boundaries tend to arise naturally and are readily identifiable. However, in some systems such as social organizations, the boundaries are not apparent and are often variable in different situations and demands. A social organization's system boundary can be specified by its management's decisions (Lucey, 2005). Furthermore, financial and systemic pressures can influence the management's ethical decisions. In some cases, such decisions, especially in the long run may cause accidents within a system boundary (Cassano-Piche et al., 2009). As stated by Dulac and Leveson (2004) "accidents are most likely in boundary areas or in overlapping areas of control." Rasmussen (1997) also states that accidents mostly occur because of systematic movement of organizational behavior to the boundaries (Fig. 2). Thus, accounting all control factors such as ethical factors and accurately defining boundaries by management plays an important role in accident prevention. In order to regulate such accidents from occurring this paper suggests incorporating ethics as a controller within the boundaries of system and subsystems in order to address the gap, engineering ethics, in the systemic accident analysis models. In fact, when engineering ethics is regarded as a controller in system boundary, all system inputs and outputs should be assessed based on ethical standards whether in terms of human factors or technical elements. After this assessment, they can enter or exit the system.

Being inspired by the idea of Gharamaleki (2018) who believes that ethical control is based on ethical considerations of policy makers, decision makers, and performances, we propose that when engineering ethics is considered as a control criterion in the boundaries of system and subsystems, it can be implemented in three levels: comprehensive policymaking, systematic decision-making, and individual employee performances (Fig. 3).

At the highest level of a system, ethical consideration can be assessed within comprehensive policymaking. An ethics expert can evaluate policy in order to assess if ethics was taken into consideration. For example, can the policy endanger the safety of the environment or society? At the next level in a system, ethical consideration can be assessed within systematic decision-making. In order to implement policies, decisions are made throughout a system such as by the board of directors or others. These decisions can be assessed to see if ethics was taken into consideration. For example, can the decision negatively affect systems processing, operations, and results? At a lower level in a system, an individual employees' performance can be ethically assessed. An employees' performance can be evaluated to see if they took ethics into consideration. For example, how do individual employees' ethical work-related decisions affect their overall performance within

[1] See: Ladd (1985); Fleddermann (1999); Harris et al. (2013); Van den Hoven (2018).

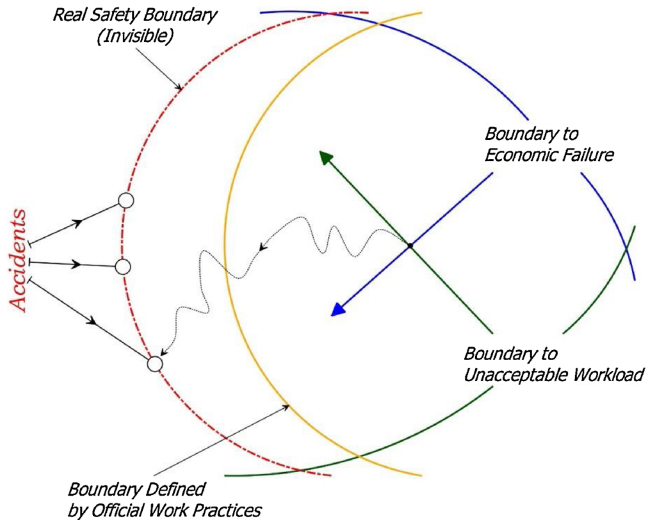

Fig. 2. "Brownian motion model showing how financial and psychological forces can create behavior gradients that cause work practices to migrate systematically toward the boundary of safety" (Woo and Vicente, 2003). Adapted from Rasmussen (1997).

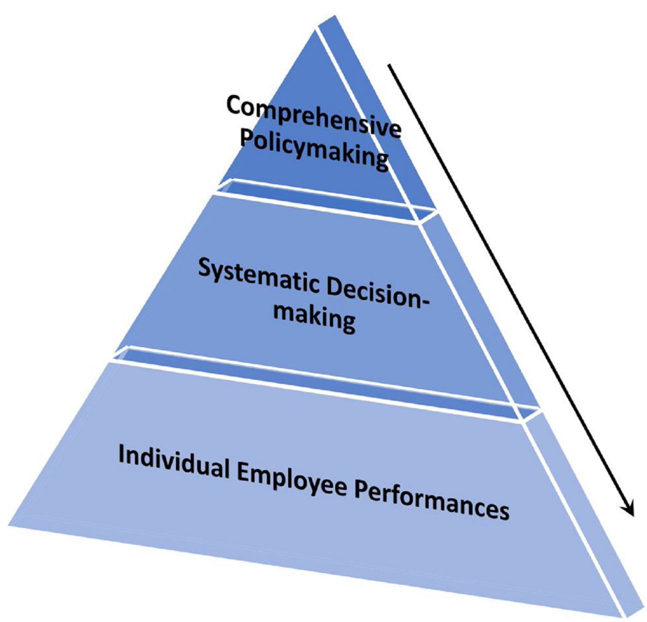

Fig. 3. Assessing for ethical consideration within comprehensive policymaking, systematic decision-making, and regarding individual employees performances can play an important role as a control indicator within the boundaries of system and subsystems.

the system? According to the definition of ethics by Gharamaleki in section 3, the criterion of these assessments is the rights of people who are influenced by an environment 360° of each policy making, decision making and performance. In fact, ethical control evaluates whether or not the rights of individuals in a 360° environment are observed (Haghighattalab et al., 2019).

Here, a question may be raised whether engineering ethics act as a goal or as a constraint? To answer this question, at first, we should ask: What is our imagination of ethics? If we imagine that ethics is simply several pieces of advice, we will have a cold, elusive and heartless look at engineering ethics. However, if we know that ethics is a program for prevention, improvement, treatment and development, we will take it more seriously (Gharamaleki, 2009). In fact, If ethics is defined as an ethical life (ethical development in all aspects) in a system, ethics will be applicable in all aspects of the system such as goals, aspirations, processes, and professional procedures. According to this definition of ethics: 1) the aim of engineering ethics is ethical development anywhere in the system (i.e. inputs, processes, and outputs) 2) considering engineering ethics as a constraint is a reductionism in ethics. The reductionism is an obstacle to the promotion of ethics. Thus, engineering ethics is neither a goal nor a constraint. Instead, engineering ethics is an ethical life where we will have ethical development in the system. In this ethical development we have to create some constraints in order to eliminate obstacles in ethical development. The ethical development in all objectives, aspirations, inputs, processes and outputs of the system is a continuous move and effort. Moreover, ethics has different degrees. Ethical development of the system leads to a transition from lower hierarchies of effective ethical factors in inputs, processes, and outputs of the system to its upper hierarchies. For example, ethical attributes such as loyalty, honesty, and trust have different degrees. These ethical attributes will evolve in the process of ethical development of the system.

The theoretical foundation of different systemic accident models considers accidents as a consequence of uncontrolled interactions within the system. In order to analyze accidents accurately, systemic analysis models should consider every possible cause of failure, especially all aspects of control such as ethical control. However, accident analysis models do not address ethics as a factor of the control structure. It is important to expand the concept of control in systemic accident models adequately so that ethical control is considered as a component of the control structure within these models. This paper suggests that if engineering ethics is considered as a control criterion in the boundaries of system and subsystems in systemic accident models, it may be able to surround all system components in order to identify and prevent ethical causes of the accidents.

7. Conclusion

This paper further explored engineering ethics and its gap within systemic accident analysis models. At first, the key role human factors play in the occurrence of accidents was discussed. Engineering ethics as an element of human factors was reviewed. In addition, the role of engineering ethics in the prevention and occurrence of accidents was examined in two different case studies. The Challenger and Columbia space shuttle instances were provided as case studies in which the role of engineering ethics was evident. Then, we further investigated whether engineering ethics can be considered as an effective factor within accident analysis models. This paper discovered that sequential, epidemiological, systemic accident analysis models did not adequately address engineering ethics role in the occurrence of accidents. By not adequately addressing human factors, such as engineering ethics, in accident analysis models a gap was evident. Lastly, this paper suggested that when engineering ethics is considered as a control criterion in the system boundary, it can be implemented in three levels: comprehensive policymaking, systematic decision-making, and individual employee performances. By considering engineering ethics as a controller within the system boundary in systemic accident models, we may be able to identify and prevent ethical causes of accidents. Additional research and case studies are needed in order to further explore the role of engineering ethics in the occurrence of accidents, investigate alternative approaches in accident analysis models, and assess engineering ethics as a controller within the system boundary in systemic accident models.

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