Analysis of Safety Decision-Making Data Using Event Tree Analysis

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Introduction

The analysis and prediction of employee decision-making patterns are important parts of managing worker safety. The identification and assessment of hazards workers face in daily workplace decision scenarios provides a valid starting point from which to begin a systematic approach to quantifying the role of humans in safe work environments (Targoutzidis, 2010; Ale et al., 2008; Khakzad, Khan, & Amyotte, 2011).

Historically, industrial researchers and practitioners have employed many techniques to identify and estimate hazards confronted by employees in daily work routines (Kingman & Field, 2005). Some of these include: cause and effect diagrams, fault tree analysis, decision tree, and event tree analysis (Baumont et al., 2000; Khakzad et al., 2011; Kingman & Field, 2005). Because of its bottom-up logic modeling approach and the usefulness in evaluating management decision options (Clemens & Simmons, 1998), event tree analysis (ETA) was chosen as the analysis tool in this case.

Construction of an ETA is a multi-step process. The end result is an examination of a safety system's response to an initiating event and the various paths of system successes and failures. However, the first step is identification of the initiating event. Once the initiating event is recognized, the next step is to isolate the safety countermeasures that are intended to respond to the event. The first two steps of construction form the basis of the event tree. Next, the sequences of events which occur following the initiating event are characterized and probabilities are assigned to each event in the sequence. Probabilities of individual event sequence are multiplied together along each path to calculate the probability of system success and system failure.

Traditionally, probabilities of the ETA are drawn from data that were established through prior analyses (such as equipment failure data) or human error predictions (Gertman & Blackman, 1994; Moriyama & Ohtani, 2009). However, none of these methods have adequately addressed the role human decisions play in risk in the workplace (Baumont et al., 2000). Human decision-making analysis offers a rich portrait of the process humans use to select their decision choice in a safety sensitive scenario (Mintz, 2004). The focus of this paper is to test whether the data generated from a decision-making scenario analysis can be used to develop a simple event tree and to calculate valid probability estimates of decision paths in both success and failure domains.

Using data from a previous decision-making simulation, an event tree is constructed. The initiating event, safety countermeasures, event sequences, and event probabilities are generated based on data from a hypothetical safety decision-making simulation. Once probabilities are calculated for each decision path, those paths with the highest probabilities of failure can be targeted for educational intervention. Implications for safety education and the potential uses and limitations of ETA in safety management are discussed.

Event Tree Analysis

Event tree analysis is based on binary logic, where an initiating event either occurs or does not occur (Institute of Engineering and Technology, 2010). Well-designed systems typically have a set of barriers called countermeasures that are intended to stop or reduce the effect of consequences which occur as the result of an initiating event. If the countermeasures do not function or do not function at the appropriate level, a failure of the safety system occurs. If the countermeasures function as designed, the safety system is successful (Rausand & Hoyland, 2004). Safety countermeasures may be technical, such as an alarm or an automatic battery back-up. Alternatively, safety countermeasures may be administrative, such as a supervisor's approval or permitting requirements (Rausand & Hoyland, 2004).

Event tree analysis functions in both the failure and success domain. This means that an ETA can explore each step of system failure by each component or can illustrate how a safety system works successfully to prevent a safety initiating event from causing damage or injury (Clemens & Simmons, 1998). The analysis has been successfully used in various scenarios, including in the evaluation of emergency response systems, assessment of new or improved operating procedures, and management decision options (Clemens & Simmons, 1998; Rausand & Hoyland, 2004).

There are several advantages to using the ETA methodology. The analysis provides a good way to graphically present the sequence of events which occur after the initial accident or event (Rausand & Hoyland, 2004). Additionally, ETA allows the evaluation of multiple or co-existing system failures and allows for the identification of ineffective countermeasures (Clemens & Simmons, 1998). Finally, detailed knowledge of the end event or outcome of each sequence of events is not needed to estimate risk of system failure (Clemens & Simmons, 1998).

The ETA methodology also has several limitations. The analysis does not recognize the initiating event that sets the safety system in motion – this must be pre-determined by the analyst. Therefore, new initiating events are not "discovered" when using ETA. Furthermore, only one initiating event or safety incident can be analyzed at one time. The advantage mentioned above concerning the evaluation of multiple system failures (safety countermeasures) can also be viewed as a disadvantage in that it is difficult to differentiate levels of loss within individual sequence pathways (Clemens & Simmons, 1998; Rausand & Hoyland, 2004).

Human Factors in Workplace Safety

Human components have been found to play a significant role in models which attempt to explain why workers act in a safe manner. In this paper, the main human countermeasure is the action of the safe shutdown procedure rather than taking a safety shortcut. Several factors have been found to influence the employee's decision on whether to follow safety procedures. Simard and Marchand (1995) report that micro level factors such as work processes, hazards, and work group cohesiveness contribute to workers' willingness to follow and promote safety initiatives. In their work, they found that many micro level factors are influenced by macro-level factors such as managerial support and commitment. Numerous researchers have found supervisory and management commitment to be an important part of organizational and group safety outcomes (Clarke & Ward, 2006; Thompson et al., 1998; Zohar, 2000).

From an employee perspective, a supervisor's lack of priority given to safety could negatively impact their commitment to safety. Mosher (2011) and Keren et al. (2009) demonstrated that the worker's perception of their supervisor's commitment to safety, as measured by a safety climate assessment instrument, positively influences the worker's likelihood of making a safe decision choice. To test the probabilities of system success and failure paths in the safety decision-making process, probabilities were drawn from data from a safety decision-making simulation where the employee has the option of taking a safety shortcut (Keren et al., 2009; Mosher, 2011).

Collection of Decision-making Data

Limited research has explored the worker's safety decision-making process. Keren et al. (2009) established a framework for an examination of the relationship between safety climate and safety decision-making, where the decision making process reflects proximate behavior. Decision Mind™, a software platform using the decision process tracing method (Keren et al., 2009), was used to collect decision-making data. Decision process tracing is an approach used to capture cognitive processes by directly evaluating the information an individual uses to form a judgment and the sequence with which the information was examined (Ford et al., 1989).

A key advantage of process tracing is that it addresses the intervening steps between information acquisition and decision choice. Decision process tracing has several key advantages over self-reported questionnaires, which depend on recall ability and researcher observation of work behavior, which is cross-sectional at best and may have other serious biases (Guldenmund, 2007). Decision process tracing also has benefits not realized with structural modeling. The former focuses on the processes humans use to analyze and gather information in preparation to make a decision choice while the later emphasizes the outcome of the decision choice (Ford et al., 1989). Mintz (2004) adds an additional strength of the process tracing methodology – the ability to isolate decision rules and models used in the decision-making process as well as test the association of situational and personal factors with the decision process and the final decision choice. It is these data which will be tapped to establish the decision paths of the event tree.

In the ETA, the dilemma presented in the decision scenario (the cooling system failure and the resulting alarm) represents the initiating event. Personal and systemic factors (Mintz, 2004) form the basis of the event sequences and describe the outcome resulting from each decision choice. The probability of the decision is calculated based on how many participants chose to follow the safety procedure rather than take a shortcut.

Construction of the Event Tree

Construction of an event tree involves of six major steps (Clemens & Simmons, 1998). First, the initiating event is determined. This event is the action or occurrence which sets the safety system components in motion. In this scenario, the initiating event is the option for the employee to take a safety shortcut when completing the re-start of the cooling system. The second step begins by asking how the existing safety system is tested by the initiating event. Challenges to the initiating event are known as countermeasures (Clemons & Simmons, 1998). From there, alternate logic sequences are used – one a successful path where the safety system operates as designed and the second a failure path where countermeasures do not function as designed to stop undesirable outcomes from occurring. In the event tree demonstrated in the paper, the major decision affecting the safety of the system in question is the worker's decision to follow safety procedures when beginning the automatic shutdown of the cooling system. The data from the decision scenario that were used in the event tree are shown in Table 1 along with hypothetical probabilities assigned to the system countermeasures.

Table 1. Possible Decision and System Responses

Decision Choice or System Countermeasures	Frequency	Total Possible Frequency	Probability
Respond to the alarm	128	160	Failure = 0.2 Success = 0.8
Follow safety procedures to begin automatic shutdown	154	160	Failure = 0.04 Success = 0.96
System countermeasure fails	8	160	Failure = 0.05 Success = 0.95

The next four steps of the event tree construction involve the calculation of probabilities. Using a fault tree analysis or other analysis, the probability for the initiating event is determined. As is normally the case in a decision tree, the probability of the initiating event is assigned a probability of one (Clemens & Simmons, 1998). Next, the probabilities of the logic paths are calculated using standard event tree notation as shown in Table 2. Once the probability of each path is calculated, the probabilities of all failure paths and all success paths are figured by adding the probabilities together for each type of path (Clemens & Simmons, 1998).

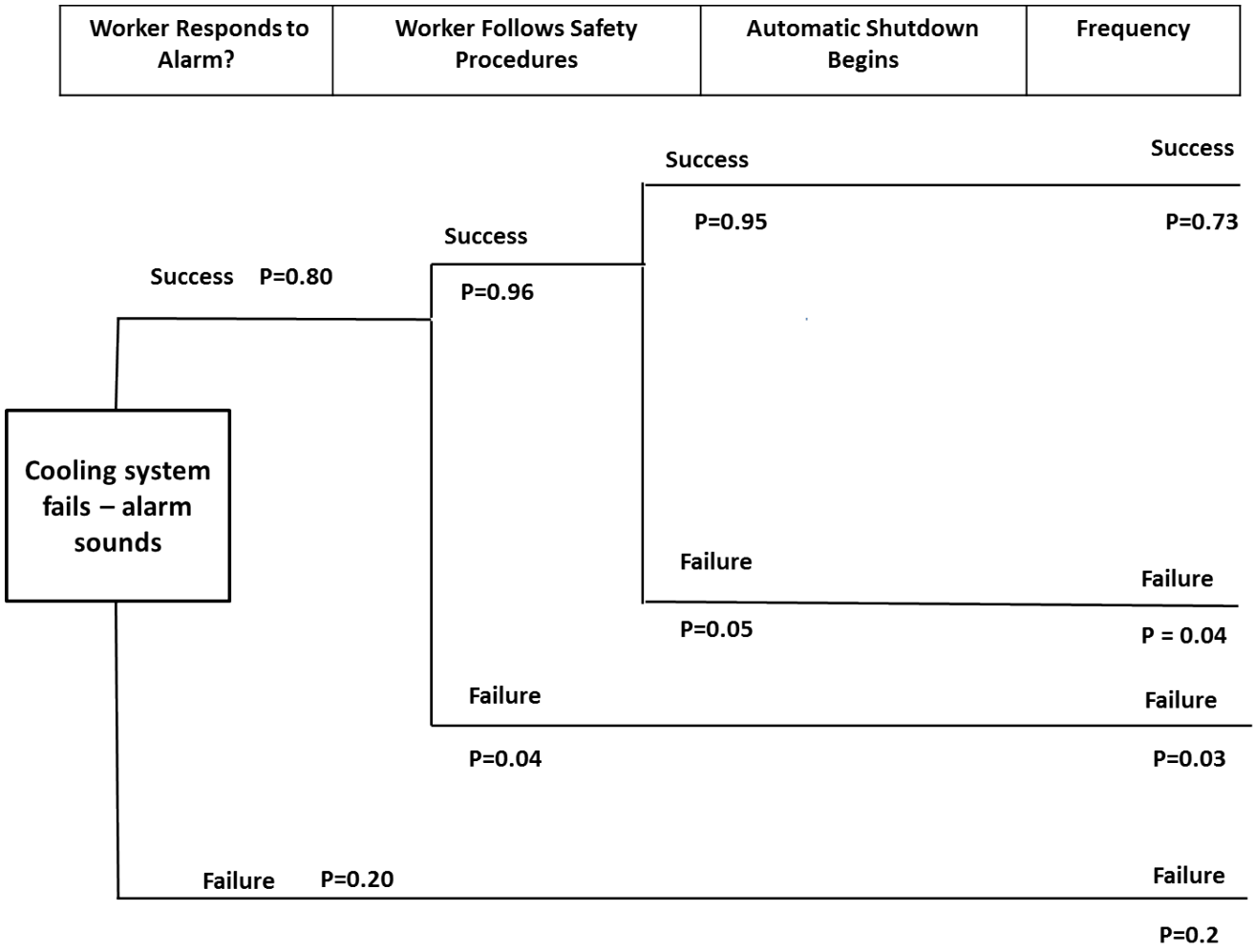
Table 2. Logic path probability formulas

Event	Domain	Equation
Failure of cooling system causes alarm – initiating event	NA	$P_{SystemFail} = 1$
Employee fails to respond to alarm	Failure	P_{alarm}
Employee responds to alarm	Success	$(1-P_{alarm})$
Employee fails to follow safety procedures	Failure	$(P_{safe} - (P_{alarm} P_{safe}))$
Employee follows safety procedures	Success	$(1-P_{alarm} - P_{safe} (P_{alarm} P_{safe}))$
Automatic shutdown fails	Failure	$((P_{shutdown} P_{safe}) - (P_{shutdown} P_{safe} P_{alarm}))$
Automatic shutdown commences	Success	$P_{safe} - (P_{safe} P_{alarm}) - (P_{shutdown} P_{safe}) + (P_{shutdown} P_{safe} P_{alarm})$
System failure probability	Failure	$P_{alarm} + (P_{shutdown} + P_{safe}) - (P_{shutdown} P_{safe} P_{alarm})$
System success probability	Success	$P_{alarm} - (P_{shutdown} P_{safe}) + (P_{shutdown} P_{safe} P_{alarm})$

Estimation of Probabilities

The probability of the initiating event was assigned as one incident per month. Failure decision paths were calculated by taking the number of people who did not chose the safe decision option and dividing it by the total number in the sample. The probability for success paths were calculated by subtracting the opposite failure paths from one. To determine the probability of each path, the probabilities calculated at each decision choice are multiplied together. Finally, to estimate the probability of system success and failure, the probabilities of all paths in each domain are added together. The event tree with the calculated events and failure and success paths is shown in Figure 1.

Figure 1. Event Tree for Cooling System Failure



Based on the estimates from Figure 1, the probability of system success was calculated to be 0.73 and the probability of system failure was 0.27. Based on these probability estimates, the ETA suggests that human decisions play a major role in safety outcomes in the work environment. In the absence of safety-minded employees, the probability for success in terms of safety outcomes decreases markedly. When the systemic failure of the cooling system alarm is taken out of the probability estimate in the failure domain, a failure probability of 0.07 still remains, with approximately half (0.03) of the failure directly attributed to the worker's choice to take a safety shortcut by not following the safety procedure. The interpretation, calculated over a month time period (as noted with the probability of the initial event), indicates that in every month a failure probability of approximately 0.03 can be directly linked to the unsafe decision choice made by employees.

Limitations and Implications

Although the use of decision-making data resulted in a completed event tree and valid calculations of probabilities, several limitations exist for using this type of data. First, although decision-making scenarios are narrowly defined, the outcomes from such a scenario can be difficult to illustrate graphically in an event tree. Part of the reason for this is the multiple possible outcomes, which are impossible to trace on one event tree.

Second, the decision-making scenario data are specific to the individuals who completed the scenario. In addition, the use of decision-making data in ETA examines a system based on human actions but does not adequately account for interactions between systemic countermeasures and human responses that would occur in an actual scenario. Although the data from a decision-making simulation is used as a basis for the probability human actions, probabilities for the system responses were based on hypothetical human error calculations. The ideal system analysis would include actual data from both human and

system components, but such a system is difficult to construct from a hypothetical perspective. Including all components from both system and human limitations would be large and cumbersome to calculate without the use of advanced software. Finally, the lack of a sequential chain of events in decision-making situations makes decision-making scenarios difficult to illustrate in the linear and binary logic constraints of the ETA methodology.

However, this does not mean that there is no role for ETA in examining safety systems involving humans. The event tree allows practitioners and researchers to easily see where the largest probabilities for system failure exist. In the case of this event tree, outside of systemic failures, the largest probability for failure occurred when the employee failed to follow safe procedures when initiating the automatic shutdown. In addition, the event tree allows practitioners to better target educational intervention toward system components with the largest probability for failure.

Event tree analysis cannot serve as the only component of system safety, but it can play an important role in identifying system failures and successes. The use of ETA to examine decision-making systems has great potential in terms of targeting high risks to worker safety. For optimum use, decision scenarios should be fairly structured and have limited decision choice options. Narrowly defined decision-making scenario data can be used to spot unacceptably high probabilities for failure as well as reward and encourage high probabilities of success.

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