Application of Tripod Incident Analysis in Aviation

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Abstract: The purpose of this research was to investigate literature review to explore the history of Tripod Incident Analysis, components of the Tripod Incident Analysis method, accident analysis, and human error that includes a discussion on the Human Factors Analysis and Classification System (HFACS).

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1. INTRODUCTION

The purpose of this research was to investigate industry applications for tripod incident analysis. Literature was reviewed and exploratory research into Tripod Incident Analysis software was examined. The literature review consisted of the history of Tripod Incident Analysis, components of the Tripod Incident Analysis method, accident analysis, and human error that includes a discussion on the HFACS. The IncidentXP Software was explored in building Tripod diagrams to test the software capabilities in identifying the root cause of accidents (CGE Risk Management Solutions, n.d.). The Tripod Incident Analysis method has its foundations in the Swiss Cheese Model (Reason, 1990). The Swiss Cheese Model primarily focuses on risk management through focusing on barriers within an organization between the cause of harm or undesirable outcome and the outcome itself. In the Tripod methodology, the triggers for the sequence of occurrences leading up to an undesirable outcome are observed and documented. The analysis focuses on understanding, investigating and determining how the incident transpired, and which defenses or barriers failed to prevent the incident and why (Kianfar, Fam, & Faridan, 2010). While the prominent cause of aviation accidents has changed from mechanical factors to human factors, the method of investigating and analyzing aviation accidents has also evolved. Based on the different types of human error models, the Tripod methodology provides another option for researchers to use in the identification of root cause analysis of incidents and accidents internal and external to the aviation industry.

2. LITERATURE REVIEW

2.1. Incident Analysis History

Causal analysis or incident analysis involves applications of various methods and techniques to prevent or mitigate risks. This analysis also focuses on the reoccurrence of incidents through obtaining comprehensive knowledge and understanding of these occurrences. There are several known conceptual methods and techniques preeminent in incident and causal analysis such as Barrier Analysis, Change Analysis, Management Oversight and Risk Tree or Management Oversight and Risk Tree (MORT), and other causal analysis methods that leverage trees, checklists and charts (Pranger, 2014).

In the late 1980's and early 1990's, Shell International allocated funding for academic research aimed at understanding the contribution of human factors in incidents and conducting a more comprehensive root cause and immediate cause analysis of incidents. Universiteit Leiden and Victoria University, Manchester conducted this research. The by-product of this research was the Swiss Cheese Model and ultimately the Tripod Beta method, which builds upon the former (Reason, 1990; Energy Institute, 2015). Tripod Beta method is an advancement and extension of the Swiss Cheese Model, it is also appropriate to regard it as the culmination of other distinguished techniques such as the fault tree and barrier analysis (Pranger, 2014). The tripod methods not only facilitate the identification of human error that ultimately led the incident, but also explores the external factors and influences that induce these human errors (Energy Institute, 2015).

2.2. Components of Tripod Incident Analysis Method

The Tripod Beta incident analysis methodology focuses on the triggers for the sequence of occurrences leading up to an undesirable outcome. These triggers are observed and documented. The analysis focuses on understanding, investigating and determining how the incident transpired, which defenses or barriers failed to prevent the incident, and why (Kianfar, Fam, & Faridan, 2010). Being a synthesis of the fault tree and barrier analysis techniques, the Tripod Beta method utilizes a conceptual tree structure to be representative of the incident mechanism, events and their subsequent interrelations (Mansouri, Fam, & Nikoomaram, 2014).

The tree structure is built up based on critical components such as the Object or Target, the Agent or Hazard, the Event, the Barriers, and extended branches. The tree represents the Causal Path if and when the barrier fails (Kianfar, Fam, & Faridan, 2010). The event is the subsequent result of an unwanted interaction between the agent and the object. The barriers or defenses employed by an organization or entity seek to prevent such interaction leading to an event. When the barriers do not hold or fail, the causal path helps investigators and analysts to determine how and why this is the case. When there is a failure of the barrier, the causation path works its way to unravel all the causes. By commencing the causal analysis at the active failure, the analyst works back through the control and defense failures and shallow failures. Then, the analyst determines the preconditions under which these failures occurred and traces back to the underlying or latent failures that helps to determine all the causes and occurrences that resulted in the failed barrier (Poursoleiman, Fam, & Derakhshanjazari, 2015). One example for the Tripod Beta Incident Analysis method using the tree is that the agent is a hot pipe work, the object is the operator and the event is the operator getting burnt as a result of failed controls, defenses, or the barrier. The organization and association then derive the causal paths that led to the agent-object interaction (Kianfar, Fam, & Faridan, 2010). Such in-depth analysis using the Tripod Beta tree is driven primarily by the Tripod theory. The hypothesis of the theory is engrained in the belief and assumption that the active failure of the defenses does not occur in isolation but instead there are multiple triggers and occurrences that cause it (Poursoleiman, Fam, & Derakhshanjazari, 2015). In this particular method, there is a strong presumption of the role of human error in triggering events and incidents, and the role of preventable external factors have on the cause of such errors (Kianfar, Fam, & Faridan, 2010). The tree is therefore structured in a way that provides a dynamic outlook of the incident to help prevent reoccurrence of similar incidents in the future.

In summary, the agent, object and event form the core of the Tripod Beta Tree, which further extends or branches out into identifying the failed barriers and their inherent causes. The incident investigation and analysis using the tripod beta technique outlined above is preceded by obtaining the initial findings and collecting evidences. It is succeeded by preparing a documented report with results, discussions, recommendations and suggestions to make this method useful in incident or accident prevention (Energy Institute, 2015).

2.3. Accident Analysis

Air transportation is a highly demanded form of transportation. The International Air Transport Association (IATA) expects that by the year 2036, approximately 7.8 billion passengers will travel through the use of flying (IATA, 2017). This constant increase in passengers solidifies the need for thorough and efficient safety programs in the airlines (Liou, Tzeng, & Chang, 2007). The challenge with the industry, that the Federal Aviation Administration or any other civil aviation organizations faces, is that aviation is already a very safe industry (Shappell et al., 2006). While it is considered a safe industry, accidents still occur resulting in the loss of life. A significant amount of accidents or incidents in aviation are attributed to human error. Shappell and Wiegmann (1996 as cited in Shappell et al., 2006) identified that about 60% to 80% of aviation accident are due to human error. According to Shappell et al. (2006), most studies have focused on pilot demographics or situational factors instead of deeper human error causes. In the earlier days of aviation, the focus of accidents was mechanical issues or a flight crew's physical skill deficiencies (Li & Harris, 2006). However, the focus has now expanded to organizational issues or human factors issues such as decision-making, supervisory factors, attitudes, and organizational culture.

2.4. Human Error

As aircraft have become more reliable in terms of mechanical or engineering failures, human error has been more common in aviation accidents. Wiegmann and Shappell (2001a) identify the multiple human error perspectives found in the aviation industry; cognitive, aeromedical, psychosocial, ergonomics and systems design, and organizational. Cognitive human error lies in the process of information progress through a series of mental operations or stages. Errors occur when information does not properly process in one of the stages such as "attention allocation, pattern recognition, and decision making" (Wiegmann & Shappell, 2001a, pg. 343). The aeromedical perspective suggests that human errors are due to the many different aeromedical factors that can impact a human such as "hypoxia, dehydration, fatigue, spatial disorientation" (Wiegmann & Shappell, 2001a, pg. 346). These factors are also often due to jet lag, alcohol, medication, smoking, and illness. Psychosocial factors include the social aspects of flight operations. Most commercial aircraft (i.e. Part 121 operations) are not single pilot operations but consist of an entire flight crew. While this is usually considered internal interaction, there is also a lot of external interaction of the flight crew with air traffic controllers, ground crew, company dispatch, and even flight attendants (Wiegmann & Shappell, 2001a). Due to the multiple different channels of communication and complexity of the aviation industry, the psychosocial perspective is a critical aspect to reference when investigating human error in aviation accidents. In ergonomics and systems design, technological aspects are viewed alongside the human element. The Software, Hardware, Environmental conditions, and Liveware (SHEL) model is a common tool used to describe the components that are necessary for any type of successful human-machine system design (Edwards, 1988, as cited in Wiegmann & Shappell, 2001a). The four basic components of SHEL are interacting factors that come together in the aviation industry and especially in the cockpit. The final piece of the perspective puzzle is the organizational factors that impact human error. Aircraft accidents are very complex in nature and are never only due to one factor. Bird's Domino Theory (1974, as cited in Wiegmann & Shappell, 2001a) prefaces that an accident occurs when the "dominoes" are correctly lined up in a sequence and each error "topples" over to the next. These dominoes start with the organizational factors, such as safety culture and if there is a problem at the higher level then it will affect the lower levels. This is in line with Reason's Swiss Cheese Model (1990) which is the primary foundation for HFACS established by Shappell and Wiegmann (2000). HFACS splits human error into four levels:

organizational influences, unsafe supervision, preconditions for unsafe acts, unsafe acts of operator. The first three groups can be considered more latent errors, whereas unsafe acts of the operator are where active failures of human error occur (Reason, 1990; Shappell & Wiegmann, 2000).

HFACS allows researchers to take vital information such as the probable cause issued by National Transportation Safety Board (NTSB) reports and apply this information to new safety systems, manufacturing procedures or practices, training, and more to help prevent future accidents. Shappell and Wiegmann (2003) specify that information such as gender, age, or flight hours do not help increase aviation safety. Wiegmann and Shappell are foundational leaders in human factors analysis and have completed many studies in the application of HFACS. Most studies that use HFACS as a way to analyze accidents, make use of the publicly available data provided by the NTSB and also investigation reports from the FAA's National Aviation Safety Data Analysis Center (NASDAC). By using the final report information on probable cause and contributing factors, "raters" can organize the different accidents based on HFACS categories. The highly technical data used for the HFACS analysis on these aviation accidents requires that "raters" have a very strong background in aviation and are familiar with its terms. Most likely due to the aeronautical aspect of these studies, pilots were used to categorize the data into the HFACS hierarchy. The downside to having pilot-raters as stated as a limitation by Shappell et al. (2006) is that pilots are not always current with or experts in human factors or psychology. Having pilots trained in HFACS is one step to help ameliorate the differences that could potentially occur between pilot-raters when compared with psychology based-raters.

Shappell and Wiegmann (2003) took a look at general aviation (GA) accidents that occurred between 1990 and 1998 and analyzed them using HFACS. Using "pilot-raters" who coded the data from 14,571 GA accident reports, it was determined that skill-based error, decision errors, and perceptual errors were the main contributing factors that led to GA accidents. In fatal accident cases, violations of regulation or rules were more common compared to the non-fatal GA accidents. Shappell and Wiegmann also determined that there was not a significant difference in the types of unsafe acts based on regional differences. While commercial aviation accidents can occur frequently, GA accidents "happen virtually every day" (Shappell & Wiegmann, 2003, pg. 1). Similar to previous analyses, Wiegmann et al. (2005), found when analyzing more than 14,000 GA accidents from 1990 to 2000, that skill-based errors, decision errors, and perceptual errors were factors in about 80%, 30%, and approximately 10% of accidents studied respectively. These numbers further build upon their previous studies of how important human factors are when it comes to accident analysis. Knecht and Lenz (2010) determined that while adverse weather still accounts for a high number of GA accidents, weather alone is not always the only contributing factor. By analyzing incidents, which are much more common than accidents, more salient causal factors were determined. Knecht and Lenz (2010) did not use HFACS to analyze incidents but instead used information directly from pilots who reported weather-related incidents. This is a potential area of focus for also using the HFACS Model.

While the original HFACS tool was first applied to military aviation, Wiegmann and Shappell (2001) applied their HFACS model to human error in aircrew-related commercial aviation accident. By analyzing these accidents, that occurred during the years of 1990 and 1996, the findings suggest that the model is a useful tool to study and categorize human error in aviation accidents in the civilian industry. By using two investigation report sources (NASDAC and the NTSB), Shappell et al. (2006) suggest that the majority of the accident causal factors in commercial aviation, 14 CFR Part 121 air carrier and 14 CFR Part 135 commuter, were due to aircrew issues or the environment, whereas supervisory and organizational causes were not as frequent. Physical environment is a condition under preconditions of unsafe acts under HFACS and skill-based error and decision errors that fall under the unsafe acts of the operator under HFACS.

Figure 1 displays a sample Tripod Diagram using IncidentXP software that was explored to test the software capabilities in identifying the root cause of accidents (CGE Risk Management Solutions, n.d.). In Figure 1, the flawed component was the root cause of accidents. The precondition is the influencing factor for the root cause which is the inadequate inspection. The immediate cause is the substandard act, which in the case of Figure 1, is that previous inspection found issues. NTSB accident reports were used to test the software capabilities (NTSB, 2011). NTSB provides publicly available accident reports that include details about the accident or incident, analysis of the factual data, conclusions derived from the investigation experts, and then also states the probable cause and contributing factors of the accident. The Tripod Diagram provides researchers with a method to visually display what happened in regards to an accident, how did the accident occur and why did the accident occur.

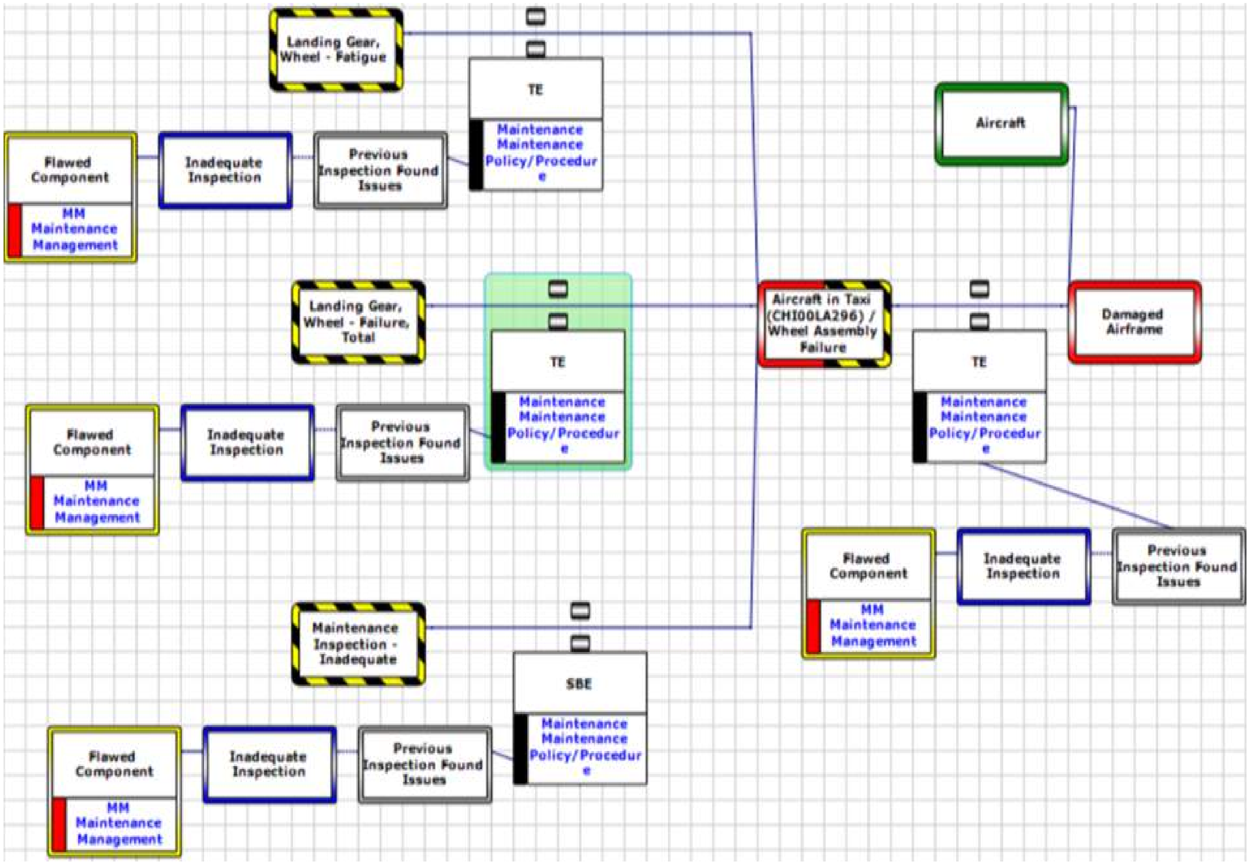

Figure 1. Tripod Diagram

Yan and Histon (2014) used HFACS to categorize airline accident and incident reports from the NTSB and the Transportation Safety Board of Canada. These reports were from 2006 until 2010. The research suggests that approximately 61% of the 267 reports were related to human error. Similar to previous results (Shappell et al. 2006), the results suggest that Unsafe Acts and Preconditions of Unsafe Acts were the most prominent human factors risks when it came to accidents and incidents of airlines in North America. A trend analysis was also completed that indicated that the number of accidents or incidents due to violations was on the rise. Furthermore, the findings suggest that Crew Resource Management (CRM) is a prominent causal factor as well as a lack of training (Yan & Histon, 2014). Kharoufah, Murray, Baxter, and Wild (2018) found that the most significant human factor that affected commercial air transport accident and incidents was situational awareness followed by non-adherence to procedures. The research suggests that accidents such as Air Asia 8501 and Air France 447 were the result of human factors. Daramola (2013) suggests that after applying HFACS categories to 45 accidents, that occurred in Nigeria during the years of 1985 until 2010, skill-based errors were one of the most occurring categories. Following skill-based errors, physical environment (i.e. weather conditions) followed by inadequate supervision. Daramola classifies many inadequate supervisions categorized accidents as due to when a commander (usually an aircraft crew captain) gives instructions or makes decision that led to an accident. While some accidents were due to flight crew captains making inadequate decisions, some were also due to maintenance oversights. One cited example includes a Concorde Airlines accident that occurred in 1990 where a supervisor did not cross-check maintenance records which led partly to the crash. Li, Harris, and Yu (2008) used HFACS to analyze 41 civil aviation accidents that involved aircraft registered to the Republic of China. The research suggests that the HFACS categories of precondition for unsafe acts, unsafe supervision, and organizational influences each had statistically significant relationships. These accidents that were studied between 1999 and 2006 led to a discovery of the "routes to failure" which is the primary reason that HFACS is a great tool to help prevent future accidents in the aviation industry.

3. CONCLUSION

While the cause of aviation accidents has changed from mechanical factors to more human based factors, the way of investigating and analyzing aviation accidents has evolved. Based on the different types of human error perspectives and other models of human error such as the Domino Theory and the Swiss Cheese Model, the HFACS is a tool used by researchers internal and external to the aviation industry. The use of HFACS can be helpful to safety organizations to re-evaluate current regulations, industry standards, or even organizational procedures. By analyzing accidents or incidents, the aviation industry can move from reactive types of analysis or change to a proactive analysis where aviation safety is continuously monitored and adjusted as necessary. Software, such as IncidentXP software, is also a useful tool for researchers to visually display information on accidents such as what happened, how did it happen, and why did it happen (CGE Risk Management Solutions, n.d.).

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