Systematic Review on Risk Management on maintenance

Naila Mendes Pena
nailamendes@estudante.ufscar.br

Jose Geraldo Vidal Vieira
jose-vidal@ufscar.br

Aline Patricia Mano
apmano@uesc.br

This paper provides a systematic literature review regarding risk management technological advances, including methods combined with proactive and predictive measures that are currently being used for mitigating risks in aviation sector. We have developed an iterative protocol that started with a preliminary review using authors recognized on human error and risk management fields. An initial string was created using the keywords from these references. Iterative searches found new articles that were selected by using two criteria. This protocol refers to a process of definition and refinement of the research scope. Once the scope was defined, the articles were chosen using three selection criteria. The findings from the systematic literature review indicate most current risk tools and models are reactive and not proactive. There is an opportunity to use advanced data analysis tool or artificial intelligence to mitigate risk in a more predictive way for the aviation sector. Then, this review may ensure improving safety and quality system on maintenance fields and on aviation.

Palavras-chave: Risk Management; Human Error; Data Analysis; Predictive; Artificial Intelligence

1. Introduction

There have been many measures implemented to reduce the number of aircraft accidents in Aviation since its conception. By the 1980's, the death rate reduced to one every 300 million passenger-miles (GRANT, 2007). Nowadays, flying became the safest form of travel in the world. The average death rate dropped even further to 9.87 billion passenger-miles (IATA, 2018 & ICAO, 2019). Many technologies advances, quality processes, and regulations, were implemented. However, one aspect it is still hard to control: human error. It is well known that human error is responsible for 80% of accidents causes (REASON, 2016). Managing errors is crucial to the aviation industry. Errors can waste time and resources, causing rework, negatively impact company's brand image, and reduce perceived value of a product or service.

Accidents are influenced by multiple contributing factors, caused by active conditions and latent conditions (REASON, 2006). The general approach is to use investigation techniques to identify gaps and inadequacies on the system. In general, this is a good approach. However, many latent conditions can stay unidentified in the system and can allow a sequence of errors to become a catastrophe (REASON, 2016). Organizational analysis is only performed after the fact (LOFQUIST, 2010). Specially, in high-risk environment or low risk but high impact, risks need to be constantly monitored to ensure that they will be properly mitigated. Organizations need an early recognition of latent risks and offer timely and targeted countermeasures. A lack of proactive safety theory (HALE, 1997) and a trial-and-error way of performing risk analysis (LOFQUIST, 2010) show a gap on risk management literature related to proactive and predictive countermeasure for eliminating threats or risks on high reliability organizations, specifically in aviation industry. This study is a comprehensive systematic review of risk management for proactive and predictive risk mitigation in maintenance aviation. Many new technologies can potentially help to uncovered risks in early stages of the process, such as artificial intelligence. Artificial intelligence employs human intelligence and how humans perceive the world to create algorithms and predictive models (WINSTON,1992). The combination of the study of human errors and artificial intelligence could help mitigate risks.

This study is divided in 4 sections. Section 2 presents how the literature review was conducted. Section 3 presents a summary of the research results on risk management, current common applications, methodologies and tools used on data analysis and artificial intelligence. Section 4 presents gaps and recommendations emerged from the literature review. Section 5 presents the conclusion and final remarks.

2. Research Methodology

A systematic review identifies key scientific contributions identifying gaps by consolidating the literature available (WEBSTER, 2002). The gap that this study would like to focus on risk management is the lack of proactive and informed decision-making to mitigate risk. Lofquist (2010) points out that there is a lack of holistic view of safety measurement for strategic leaders to use in a proactive decision-making. Its considered that proactive and reactive methods are important, but needs to be an interactive process, with more accurately real-time operations of a socio-technical system that gives organizational leaders timely information and understanding of system performance during changing conditions that allows them to take more informed proactive decisions before undesired events take place (LOFQUIST, 2010). The goal of this systematic review is to understand how errors and risks are measured, analysed and proactively mitigated identifying latent conditions, helping the decision-making process. This systematic review used a comprehensive and structured methodology to understand the status of risk management and mitigation used in aviation industry through the process described on this section. The protocol includes three phases: (1) planning phase composed of research questions, keywords and search databases; (2) conducting phase which encompasses selection criteria and quality assessment; (3) classification scheme to extract data from the selected studies (PETERSEN, 2015; TRANFIELD, 2003).

2.1. Planning phase

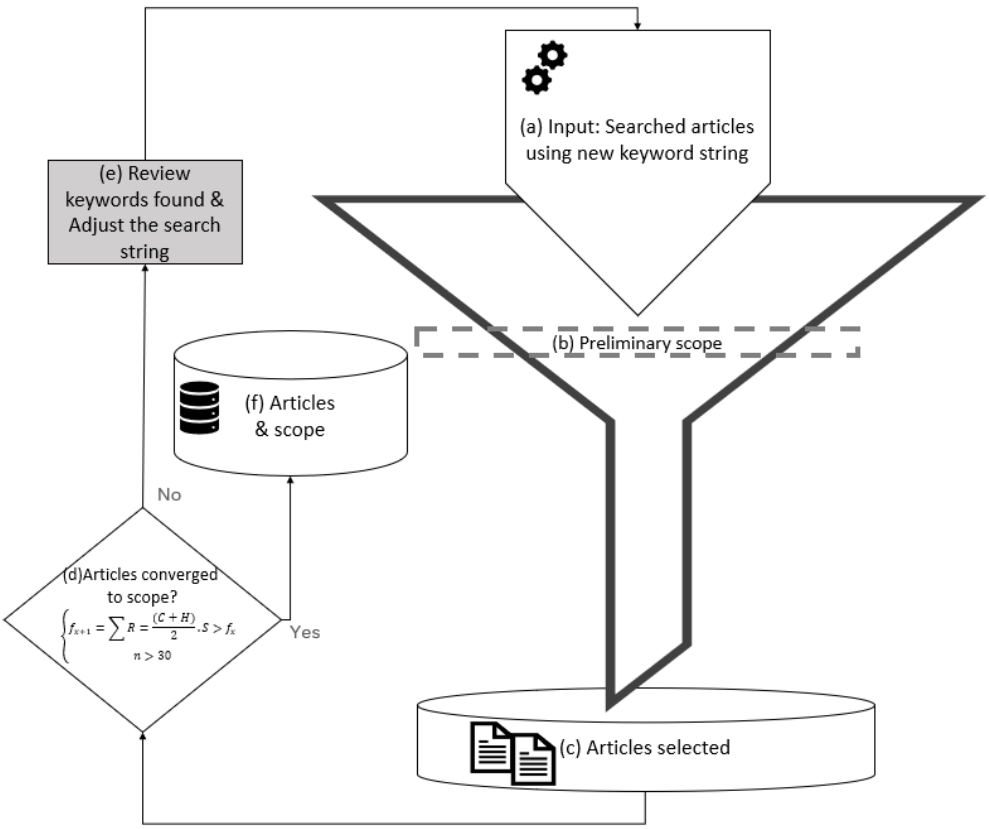
The initial phase is an iterative process to define and refine the scope of this research. A preliminary review searched for scoping studies assessing their relevance and impact. These scoping studies are important to be included to consider cross-disciplinary perspectives (TRANFIELD, 2003). This first phase searched for topics such as human errors and human factors (REASON 1995; REASON, 2016), and human reliability (SMITH, 2005). This preliminary review helped defining the research questions and the keywords string.

2.1.1 Protocol development for research

The initial stages of a systematic review are an iterative process of definition, and refinement of the scoping study (TRANFIELD, 2003). Figure 1 describes an iterative protocol process that was developed to meet these stages: (a) The protocol starts with a string composed by the keywords found on the preliminary review. (b) Then, the articles found on this search are evaluated for fitness to the preliminary scope. The preliminary scope was determined by 5 topics that the articles should discuss: Risk Management; Data analysis for risk or error management; Decision making used to problem solving, minimizing latent factors; Safety

system or quality system; Aviation or maintenance. (c) The articles were selected based on a score "S" greater or equal to four, considering if the article would cover the preliminary scope or not. (d)Two criteria were developed to find an optimized string of keywords. (f) This iteration stops when the search converges to the preliminary scope, (e) if it doesn't, a new string of keywords is adjusted based on the keywords from articles that scored between 4 and 5 in the last search (figure 1).

Figure 1 – Protocol routine



The two criteria developed were: the search should result in more than 30 articles that meet the preliminary scope with a score of 4 or 5; and the last search string should have a total Review factor higher than the prior searches. The score "S" will be a binary answer (1 or 0), if the article covers the topic or not. The articles were graded between 0 and 5. After the article is scored, the review factor is calculated. The Review factor "R" is the sum of the citations of the article "C" and the H index of the article's journal "H" divided by 2. The result times the preliminary scope score "S" will be the Review factor "R". See equation (1).

Eq. (1)
$$\begin{cases} f_{x+1} = \sum R = \frac{(C+H)}{2}.S > f_x \\ n > 30 \end{cases}$$

If the two criteria are met, the iteration stops, and the string of keyword is saved. This protocol ensure that the articles found are converging to the research scope.

2.1.2 Research questions

The following research questions were developed using CIMO (Context, Intervention, Mechanisms, and Outcome) logic (DENYER, 2009) to determine the scope of this study:

- Context & Intervention: R1: How risk management tools is being used on the decision-making process on safety or quality systems in aviation, maintenance in aviation, and/or other industries maintenance fields?
- Mechanisms & Outcome: R2: How safety or quality performance is measured and analyzed to improve proactive and predictive measures to help finding latent conditions and mitigating risks?

2.1.3 Search databases and keywords

The database used was Scopus, since it is a comprehensive database and allows to filter and extract articles. The preliminary review presented more than 80% of the articles indexed on Scopus database.

The iterative protocol described on this section defined a string of keywords. The first set of the string are the keywords related or equivalent to risk management. Human reliability is another term used in risk management and is related to the consistency of a design or a process involving humans, applying qualitative and quantitative methods. The second set of the string are important terms related to managing and understanding human factors on a safety system or quality system. Many authors don't use neither risk management, nor risk mitigation, nor risk assessment on their keywords. Therefore, the second set of the string is used with Boolean logic "OR" with the first set. By combining these two sets it allows this literature review to reach to deeper connections and influences, and find similarities between the different areas of study, but same essential focus: risk management. The third set are keywords related to the areas of interest of this study: aviation, safety systems, quality systems, and maintenance. Since risk management is present on a safety system and quality system and both can impact negatively the risk, both terms were included. The fourth and last set is related to goal of the study. Artificial intelligence and Knowledge base are fields that could potentially indicate studies on risk management that are using predictive measures to manage risks. All keywords and set of

strings were connected to Boolean logic "OR". A final string of keywords was set after 14 valid iterations, finding 715 articles that selected 135 articles with a Research Score of 27258.0 higher than the previous searches. The final keyword string was: ("risk management" OR "risk mitigation" OR "risk assessment" OR "human reliability" OR "error management") AND ("human factor" OR "human error" OR "team error" OR "maintenance error" OR "latent factor" OR "latent condition" OR "organizational factor") AND (aviation OR maintenance OR "safety system" OR "system safety" OR "safety management system" OR "quality system") AND (Analysis OR "decision making" OR predict* OR AI OR "Artificial Intelligence" OR "Knowledge base" OR KBS).

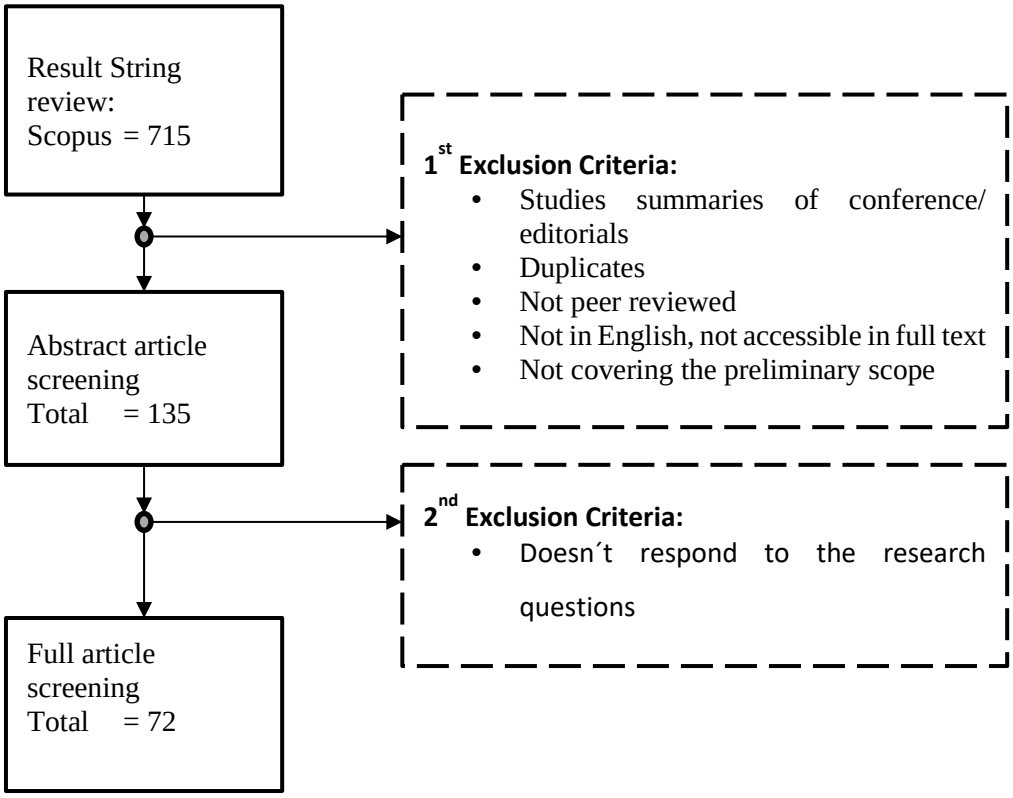
2.2 Conducting phase

The Conducting phase included selection criteria, and a classification scheme used to extract data from the selected studies.

2.2.1 Selection criteria

The keyword string found 715 articles that was evaluated by the exclusion criteria. These criteria were: articles not in English, not accessible full text, not reviewed by peers, duplicates, and not covering the preliminary scope (Fig.2). All articles that were found had their abstract evaluated on the first criteria. This exclusion criteria excluded 580 articles. After the first review the questions of the research was used to select the articles. A quality fitness was developed to evaluate if the studies selected could answer the research questions. A 3-point Likert scale was used to assess the quality: 0 for "No", 0.5 for "Not clear", and 1 for "Yes". The 135 articles selected scored between 0.5 and 2.0. An exclusion criterion was created to remove any study that scored below 1.5. From the initially selected studies, 72 pass the second exclusion criterion (Fig. 2).

Figure 2 - 1st and 2nd Exclusion Criteria



The second criterion of exclusion was also used as inclusion criterion. If an article found on previous searches scored above or equal to 1.5, and passed the first exclusion criteria, the article was included. This added 27 additional articles to this study that were previously selected on the preliminary review and on the first searches. The articles at this phase were fully reviewed, analyzing their introduction, results, discussion and conclusion. The type of methods was classified and organized. The classifications, results and applications are described on the next section.

3. Results and applications

After selecting the studies, a Quantitative Synthesis was developed using classification categories. The type of methods, tools, and observations from the study was classified and organized. The classifications found were presented on table 1.

Table 1 - Classifications

Classification	Description	Number of articles
Data Analysis	review of current or historic data	75
Risk tool	new or improved tool developed to help decision-making	71
Latent error/ factors	methods to identify latent errors or latent factors	32

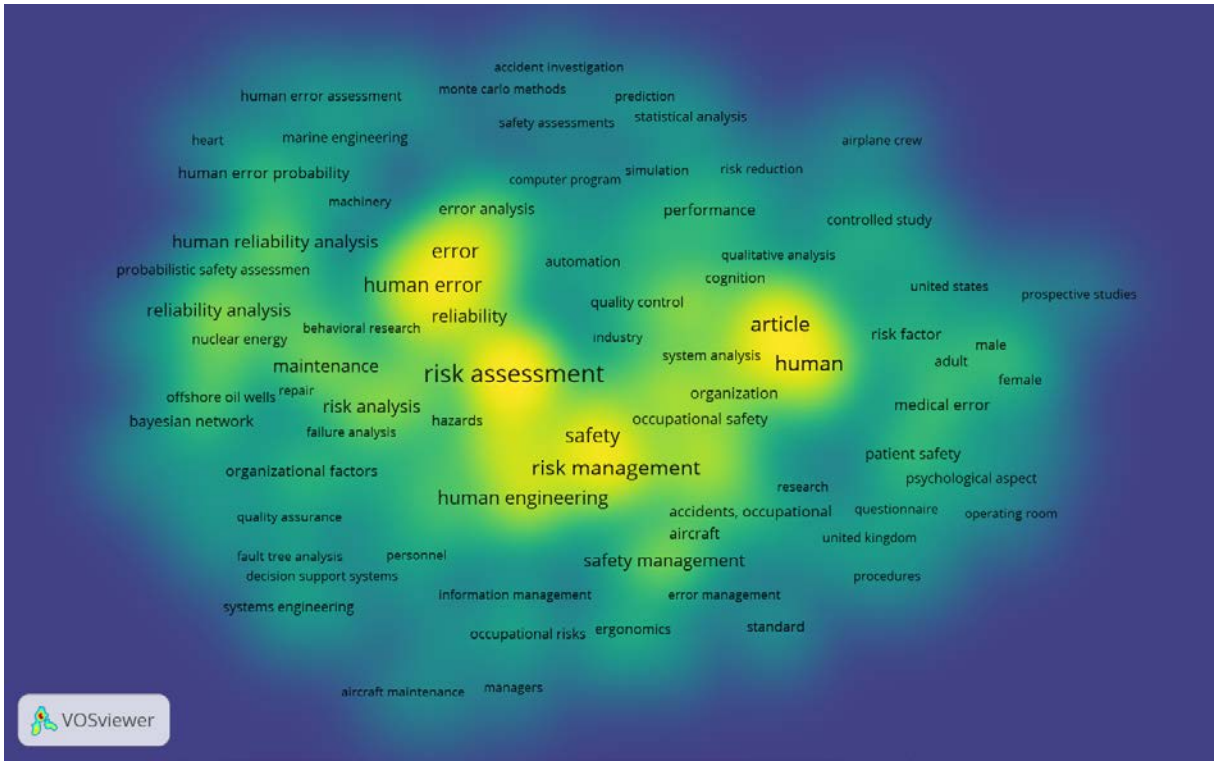
Proactive/on-time Measurement	on-time data collection /proactive risk mitigation	31
Predictive	use data collected to predict and prevent risks	12
Data collection	collection of data used to improve SMS/QMS	9
Post-morteum	failure analysis or accidents review used for improvement	8
Taxonomy	new taxonomy, or review of an old taxonomy	7
AI	AI applied to mitigate risk	7
Error tolerant system	benefits of error tolerant systems	5
Man-Machine	interaction between the interface of man and machine	5
Efficiency/Cost	relation between efficiency/cost and safety/quality	3
Lack of Knowledge or Awareness	impact of lack of knowledge or awareness	3

After reviewing the articles many important studies were found that presented important evolution of risk management. The articles were further classified and analyzed. This section presents a summary of the results.

3.1. Data analysis, synthesis and interpretation

The bibliographic analysis presents a strong relationship between risk management, risk assessment, human engineering and human error. Although, these areas of study were intensively explored in the past (REASON, 2016, RANKIN, 2000, RASMUSSEN, 1997), new areas have been developed and researched connecting these studies. Human reliability analysis and human error probability appears on the top left of figure 3. These are recent areas of study and have opened new paths of research exploring new risk tools and methodologies. Proactive data collection and analysis, and predictive risk mitigation are still relatively new fields and haven't been explored to their full potential. Prediction keyword appears on the top of figure 3. This shows that the density of the studies is low comparing to the other fields. Knowledge base and Artificial intelligence are also new fields of study and not many studies were found applied on safety and quality risk management in aviation maintenance.

Figure 3 - Keywords density VOSviewer



4. Discussion

Many studies were developed to understand the human aspects and how to overcome the fallibility of human condition. The interaction between man and machine became extremely important since new technologies are being developed and implemented, but still interfacing with humans. There is an extensive bibliography about taxonomy, classifications, to understand human factors and latent factors to prevent errors (SASOU,1999; RANKIN, 2000; KUCUK, 2019). Sasou (1999) explained the importance of understanding errors from each team member perspective, and categorized team errors. Maintenance error decision aid – MEDA, developed by Boeing, investigate maintenance errors. MEDA philosophy considers that a series of contributing factors are controlled by management and that maintenance technicians do no make error on purpose (RANKIN, 2000). A consistent process should be implemented to determine contributing factors that enable errors, preventing similar errors to reoccur (RANKIN, 2000). Kucuk developed a risk mapping model for human factors taking in consideration interrelations of risk factors. It presents an important point that not only human factors are important to understand, but also nontechnical skills such as management, situational awareness and decision making, having an important impact on risk management (KUCUK, 2019).

The Swiss Cheese Model (SCM), created by Reason (1990), is a heuristic accident model. Other models adopted same framework, for example The Human Factors Analysis and Classification System (HFACS). These models explain and communicate multiple conditions that can cause an accident. Analysis after an accident occurrence can help identifying latent conditions and increasing awareness. Many studies explore accidents investigation results, performing a complete review of multiple latent factors. Understanding latent factors from an organization can prevent risks (REASON 1995; BARON 1999; LATORELLA 2000; ROELEN, 2012). It's important to emphasize that when analyzing events, the SCM makes tempting to draw a line to the outcome linking latent conditions, which can invite hindsight bias (REASON, 2006). Humans overestimate what they would have known without outcome knowledge, leading to hindsight bias (FISCHHOFF, 1975). SCM fails to explain how different conditions influence each other and the overall effect on a complex system. The weight, and impact of latent factors and active failures are not clearly defined. The final effect, and sequence of each factor are also not explained.

New methods of risk analysis and human reliability analysis have been exploring weighted average to index factors to map risk using Multi-decision criteria such as AHP and ANP. (RASHID, 2014; WILKE, 2014; AKYUZ, 2016; PENG, 2019; ŞENOL, 2020). Peng (2019) collected safety data and analyzed the weight of each factor using a Fuzzy Analytic Hierarchy Process (FAHP) and machine learning. Combining Multi-decision criteria methods to define the impact of performance shaping factors (PSFs), can be a powerful tool to analyze data and even possibly predict errors. Artificial intelligence is also a new technology to be developed and implemented in maintenance aviation to mitigate risk. One of the goals of artificial intelligence is to solve real-world problems, and how to represent knowledge and explain various sorts of intelligence (WINSTON 1992). Although artificial intelligence is not a new technology applied on risk management, this research did not find available studies implemented on maintenance aviation. Two studies using AI on risk management are worth mentioning. Peng used machine learning to provide effective measures and suggestions to risk assessment applied on laboratory safety (PENG, 2019). And Knowledge-based reasoning was applied to nuclear plants' probabilistic risk assessment. This study provided some theoretical and empirical insights for human error prediction (LI, 2019).

The machine and human interface are becoming more critical as technology develops. Although is believed the automation can improve the efficiency and safety of the process, it comes with a cost. The interface between the machine and human becomes a weak point of the system, that

needs attention to prevent future errors. Both history and research show that this is a sensitive point and must be designed with caution (SASOU,1999). Automation can be used to mitigate human error (BAINBRIDGE, 1983). A machine could be used to counteract human error, on-line measurement and monitoring, but humans need to have adequate feedback (BAINBRIDGE, 1983). Increasing awareness, investing on training and feedback tools are important factors to reduce the numbers of errors on the system and prevent accidents (STOOP, 2012; NADERPOUR, 2014; BICEN, 2021).

Many different authors agree that is imperative to design a system that is error tolerant since human error is hard to prevent (RASMUSSEN, 1982; BAINBRIDGE, 1983; REASON, 1995, LATORELLA, 2000, KHAN ,2006). The timing of when the error is captured and identified makes all the difference. Continuous improvement relies on human trial and error characteristics. Efficiency and constant growth of expertise rely on human flexibility to try different ways (LATORELLA, 2000). The system needs to be designed to allow error, and the system design needs to reduce the probability of system induced human errors (LATORELLA, 2000).

5. Conclusion

Errors can have major safety consequences and can potentially result in the loss of human lives. There are different methods and strategies for risk management. Reactive methods are the most common applied throughout the industry. The real challenge is to apply proactive methods, that could prevent incidents from happening. There were studies found that have a potential to predict errors and help on the decision-making process. Combining methods such as Multi-criteria decision analysis with Artificial intelligence showed great potential. A method that can predict human error is yet to be seen.

Humans are brilliant and creative but cannot work flawlessly like machines. It is possible to use machines to prevent errors by monitoring and giving timely feedback (BAINBRIDGE, 1983). Also, humans have limitation on how many variables they can process and understand. The human analyzing limit is 4 variables (HALFORD, 2005). This leads to a proposed solution using what is best from the two worlds, man and machine. A model could be created by integrating both, using man creativity capacity and the ability to implement abstracts ideas and the machine, using the data analysis processing capacity helping humans on the decision-making process, mitigating risk and preventing errors.

REFERENCES

AKYUZ, Emre; CELIK, Metin; CEBI, Selcuk. **A phase of comprehensive research to determine marine-specific EPC values in human error assessment and reduction technique**. Safety Science, 2016. Vol. 87 pp.63-75.

BAINBRIDGE, Lisanne. **Ironies of automation.** Automatica, 1983. Vol. 19 pp.775-779.

BICEN, Samet; KANDEMIR, Cagatay; CELIK Metin. **A Human Reliability Analysis to Crankshaft Overhauling in Dry-Docking of a General Cargo Ship.** Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, 2021. Vol. 235 pp.93-109.

DENYER, David; TRANFIELD, David. **"Producing a systematic review"**, in Buchanan, D. and Bryman, A. (Eds), The Sage Handbook of Organizational Research Methods, Sage Publications, London, 2009. pp. 671-89.

EDKINS, G.D. **The INDICATE safety program: Evaluation of a method to proactively improve airline safety performance.** Safety Science, 1998. Vol. 30 pp.275-295.

FISCHHOFF, Baruch. **Hindsight is not equal to foresight: The effect of outcome knowledge on judgment under uncertainty.** Journal of Experimental Psychology: Human Perception and Performance, 1975. Vol. 1 pp.288-299.

GRANT, R.G. **Flight (Reprint) The Complete History**, Dorling Kindersley, 2007. 452 Pages.

HALE, Andrew Richard; HEMING, B.H.J; CARTHEY, J; KIRWAN, Barry. **Modelling of safety management systems**. Safety science, 1997. Vol.26(1), pp.121-140.

HALFORD, Graeme S.; BAKER, Rosemary; MCCREDDEN, Julie E.; BAIN, John D. **How Many Variables Can Humans Process?** PSYCHOLOGICAL SCIENCE, 2005. Vol. 16, Number 1, 70-76.

IATA. **Airline Safety Performance**, 2018. Disponível em: <https://www.iata.org/en/pressroom/pr/2019-02-21-01/> Acesso em: 13 mar 2021.

ICAO. **Annual Report**, 2019. Disponível em: <https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.> Acesso em: 13 mar 2021.

KUCUK, Yilmaz A. **Strategic approach to managing human factors risk in aircraft maintenance organization: risk mapping. Aircraft Engineering and Aerospace Technology**, 2019. Vol. 91 pp.654-668.

LI, Yuandan; MOSLEH Ali. **Dynamic simulation of knowledge-based reasoning of nuclear power plant operator in accident conditions: Modeling and simulation foundations.** Safety Science, 2019. Vol. 119 pp.315-329.

LOFQUIST, Eric A. **The art of measuring nothing: The paradox of measuring safety in a changing civil aviation industry using traditional safety metrics.** Safety Science, 2010. Vol. 48 pp.1520-1529.

NADERPOUR, Mohsen; LU, Jie; ZHANG, Guangquan. **A situation risk awareness approach for process systems safety.** Safety Science, 2014. Vol. 64 pp.173-189.

PENG, Tong; LI, Chao; ZHOU, Xinbin. **Application of machine learning to laboratory safety management assessment.** Safety Science, 2019. Vol. 120 pp.263-267.

PETERSEN, Kai; VAKKALANKA, Sairam; KUZNIARZ, Ludwik. **Guidelines for conducting systematic mapping studies in software engineering: An update.** Information and Software Technology, 2015. 64, pp.1-18.

RANKIN, William; HIBIT Rebecca; ALLEN Jerry; SARGENT Robert. **Development and evaluation of the maintenance error decision aid (MEDA) process.** International Journal of Industrial Ergonomics, 2000. 26(2):261-76.

RASHID H.S.J.; PLACE C.S.; BRAITHWAITE G.R. **Eradicating root causes of aviation maintenance errors: Introducing the AMMP.** Cognition, Technology and Work, 2014. Vol. 16 pp.71-90.

RASMUSSEN, Jen. **Human errors. A taxonomy for describing human malfunction in industrial installations.** Journal of Occupational Accidents, 1982. Vol. 4 pp.311-333.

RASMUSSEN, Jen. **Risk management in a dynamic society: A modelling problem.** Safety Science, 1997. Vol. 27 pp.183-213.

REASON, James. **Human error: models and management.** Western Journal of Medicine, 2000. Vol. 172 pp.393-396.

REASON, James. **Understanding adverse events: human factors**. Quality in health care: QHC, 1995. Vol. 4 pp.80-89.

REASON, James. **Managing the risks of organizational accidents,** 2016.

REASON, James; HOLLNAGEL, E.; PARIES, J. **Revisiting the «Swiss Cheese» Model of Accidents.** EUROCONTROL, EEC, 2006. Vol.- pp.-

SASOU, K.; REASON, James. **Team errors: Definition and taxonomy.** Reliability Engineering and System Safety, 1999. Vol. 65 pp.1-9.

ŞENOL, Mehmet B. **Evaluation and prioritization of technical and operational airworthiness factors for flight safety.** Aircraft Engineering and Aerospace Technology, 2020. Vol. 92 pp.1049-1061.

SMITH, David J. **Reliability, Maintainability and risk: practical methods for engineers**, (1993) Butterworth-Heinemann, 2005.

STOOP, John; DEKKER, Sidney. **Are safety investigations pro-active?** Safety Science, 2012. Vol. 50 pp.1422-1430.

TRANFIELD, David; DENYER, David; Smart, P. **Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review.** British Journal of Management, 2003. Vol. 14, 207–222

WEBSTER, Jane; WATSON, Richard T. **Analyzing the past to prepare for the future: Writing a literature review.** MIS Quarterly, 2002. xiii–xxiii.

WILKE, Sabine; MAJUMDAR, Arnab; OCHIENG, Washington Y. **A framework for assessing the quality of aviation safety databases.** Safety Science, 2014. Vol. 63 pp.133-145.