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DOI
10.3846/aviation.2023.19851

Publication date
2023

Document Version
Final published version

Published in
Aviation

Citation (APA)
Tyagi, A., Tripathi, R., & Bouarfa, S. (2023). Safety management system and hazards in the aircraft maintenance industry: a systematic literature review. *Aviation*, *27*(3), 212-224. https://doi.org/10.3846/aviation.2023.19851

ISSN 1648-7788 / eISSN 1822-4180

VILNIUS TECH
Vilnius Gediminas Technical University

AVIATION

2023
Volume 27
Issue 3
Pages 212–224
https://doi.org/10.3846/aviation.2023.19851

Review

SAFETY MANAGEMENT SYSTEM AND HAZARDS IN THE AIRCRAFT MAINTENANCE INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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Article History:
received 14 November 2022
accepted 25 January 2023

Abstract. In the last decade, the aircraft maintenance industry has experienced a paradigm shift in safety management. This is primarily due to the implementation of Safety Management Systems (SMS) in its business practices. The critical facet of such SMS recognizes hazards ahead of time. This review aims to undertake scholarly research to enable the identification of numerous hazards within the aircraft maintenance industry. This will be done by reviewing research articles indexed in Scopus and Web of Science databases from 2010 to September 2022. Complying with the guidelines of the PRISMA 2020 updated statement, the Systematic Literature Review (SLR) methodology is adopted for the review. The SMS-based framework was formulated to determine the inclusion and exclusion criteria, which identified 39 studies for inclusion. The key outcomes are (i) Thirty-five studies identified six hazard-prone areas and associated hazards of the aircraft maintenance industry, whereas four research studies (two each) underscored the factors impeding the safety critical SMS enactment and organizational learning from past accidents and incidents, (ii) Reviewed literature is a mix of both reactive and proactive methodologies of hazard identification (iii) Learning from past events is critical in safety management.

Keywords: aircraft maintenance, safety, SMS, hazards, safety occurrences, accidents, incidents.

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Introduction

Aircraft maintenance is a high-risk area, with many accidents and serious incidents in commercial aviation attributed to shortcomings in aircraft maintenance practices (Insley & Turkoglu, 2020). Annually published safety reports by the global aviation safety regulating agency, International Civil Aviation Organization (ICAO), and the airline association, International Air Transport Association (IATA), reflect the global commercial aviation safety trends based on accident data. ICAO safety report data (ICAO, 2022) indicate the vital aircraft accident statistics from 2017 to 2021 (see Figure 1). However, while assimilating, the effect of the pandemic should be kept in mind. Data in respect of 2020 and 2021 does not exhibit the usual trend as, during this period, the commercial aviation sector was severely hit, and the number of departures was drastically reduced. It should also be noted that the ICAO safety reports only include accidents; the incident data are not included, which are much more than these numbers and have the potential to cause accidents besides associated social and financial implications. It can be reasonable to summarize from the ICAO safety report data that even though the accident rate is almost constant, the number of accidents is rising.

Gerede (2015) suggests that passengers and the general public usually perceive safety based on the number of aircraft accidents, not the accident rate. Martins (2016), also implies the same and argues that an increased number of safety occurrences might be unacceptable for the public. Therefore, with the predicted growth rate of aircraft, airlines, and the number of departures (Boeing, 2022; Airbus, 2022), the accident rate is to be further reduced to maintain the current number of accidents and the confidence of the passengers. Grant et al. (2018) suggest that retrospective analysis of safety occurrences (accidents and incidents) will learn from the past and prevent future safety occurrences. This approach, with prevailing safety standards, is inadequate. Hence, several research and trend analyses have established that human errors are an integral part of human behavior, technology will continue to evolve, weather conditions and global climate will be more unpredictable with time, and the commercial aviation

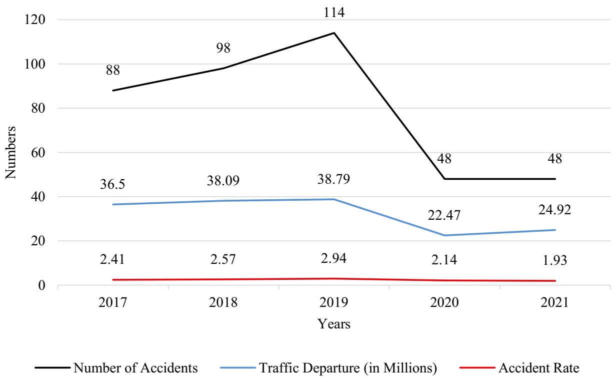

Figure 1. Accident records of scheduled commercial transport operations (source: created by authors based on the data of ICAO, 2022)

market will be more competitive. Therefore, a safety approach that encompasses all these realities and provides a framework to manage safety efficiently is needed. The prevailing safety paradigm of commercial aviation is governed by the ICAO Annex 19 "Safety Management," and all the aviation industry stakeholders, including aircraft maintenance organizations, have been implementing SMS in their business processes in the last decade.

While understanding the current knowledge base of safety in the aircraft maintenance industry, it is prudent to consider the data from annual ICAO safety reports and the argument of Shappell et al. (2007) that civil air transportation is one of the safest modes of transport. The real challenge for national safety regulators and service providers is to improve the safety of an already ultra-safe industry. Improved regulations, automation, technological advancement, and quality research from academia have made the civil aviation industry what it is today in safety parameters. Research studies, for instance, interaction amongst various elements within an organization popularly known as the "SHELL" model, "Dirty Dozen," the human factors related to hazards in aircraft maintenance, "Swiss Cheese Model" of accident causation, concepts of "Practical Drift" and "Maintenance Decision Error Aid" (MEDA) are now part of various ICAO Standards and Recommended Procedures (SARPs) and Guiding Material (GM) and are widely applied in the aircraft maintenance industry as best practices. Therefore, aligned with the safety management approach of the 21st century, i.e., SMS, the systematic literature review aims to comprehend hazards in the aircraft maintenance industry by reviewing research articles. Comprehension of hazards includes but is not limited to the assessment of unsafe acts, conditions, and objects in the aircraft maintenance industry that may have the potential to adversely affect the safety of aircraft operations and the various methodologies researchers have adopted to identify them. The review is meant to assist aviation safety practitioners, researchers, national regulators, Aircraft Maintenance Engineers (AMEs), technicians, component workshop engineers, and hangar managers working in the maintenance departments of airlines or dedicated aircraft maintenance organizations.

1. Method section of a systematic literature review

An updated version (2020) of Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) recommended by Page et al. (2021) is followed for this systematic literature review.

1.1. Search strategy

Since the review aims to comprehend hazards in the aircraft maintenance industry in the SMS era, it was reasonable to initiate the literature search from 01 January 2010 onwards as after the first issue of ICAO Annex 19 in 2013, all the commercial airlines and aircraft maintenance organizations of ICAO member countries (193 countries) are at various stages of implementing the SMS framework in their respective safety management. The Scopus and Web of Science databases were identified to search the research articles as these databases include almost all primary aviation industry-centric journals. Before initiating the literature search, it was decided to evaluate the current status of the reviewed literature in the Scopus and the Web of Science databases. This exercise aims to avoid duplication of work and to offer novel contributions. The keywords associated with the safety of the aircraft maintenance industry were identified, and a systematic search of the Scopus and Web of Science databases for past review articles was conducted. The results of both searches listed 55 review studies (36 from the Scopus database and 19 from the Web of Science database) for screening. The initial screening included an assessment of the title and abstract of all the review studies. Only one study (Clare & Kourousis, 2021c), indexed in both the Scopus and Web of Science databases, was identified as closer to the proposed review subject. The study is a systematic literature review that underlines the learning from past incidents, a reactive hazard identification method under the SMS framework. In contrast, the proposed review addresses the first step toward aircraft maintenance safety, i.e., to assess the aircraft maintenance industry's hazards and the methodologies the researchers have followed to identify them. The hazard identification methodologies are evaluated under the current regulatory SMS framework, including reactive and proactive hazard identification methodologies. Hence, based on the outcome of the review search records mentioned earlier, it is reasonable to conclude that no study was conducted in the past aligned with the proposed review. Therefore, with the intent to add a new approach to aircraft maintenance safety, it was decided to commence with the proposed literature search.

1.2. Inclusion and exclusion criteria

Firstly, a framework is formulated to define the inclusion and exclusion criteria for the scholarly literature. The framework is developed based on appendix two of ICAO Annex 19, second edition (ICAO, 2016), which consists of four components and twelve elements of the SMS framework. Element one, "Hazard Identification" (HI) of component two, "Safety Risk Management" (SRM), is chosen for the review as HI is the core of safety management. The guiding material of the framework is prescribed in the Safety Management Manual (SMM) document number 9859, fourth edition (ICAO, 2018). Based on that, a framework is formulated and exhibited in Figure 2. In the reactive methodology, the contributory and causal factors identified by the investigations and research studies are considered "hazards" for the review; similarly, for the proactive method, non-compliance to the laid down procedure or regulations, deviation, and unsafe acts and conditions observed during the process monitoring and audits are also termed as hazards in this review.

Since "Hazard Identification" is a cornerstone of the study, understanding it in the context of aircraft maintenance safety is unavoidable. The fourth edition of SMM defines a hazard as "a condition or an object with the potential to cause or contribute to an aircraft incident or accident." The definition is generic and applicable to all areas of the aviation industry, for instance, flying operations, air traffic control and navigation, aircraft maintenance, and aerodrome activities. Specific to aircraft maintenance, safety can be viewed from two different angles: firstly, the safety of maintenance staff performing maintenance activities on aircraft, engines, and components: second, the maintenance activities performed on aircraft, engines, and components to provide airworthy aircraft for continued safe flying operations. The study aimed to search literature covering both aspects of maintenance safety as hazardous working conditions can adversely affect the performance of the maintenance staff. Hazards in maintenance are pervasive, and it becomes further complicated due to their association with human factors, technology, and other known and unknown variables. In the SMS framework, typically, two methodologies are employed to identify hazards in aircraft maintenance organizations. While the reactive methods are based on the outcome from past safety occurrences and investigations of Mandatory Occurrence Reports (MORs), the proactive methodologies use safety data generated in the process of aircraft maintenance, for example, monitoring of day-to-day maintenance activities (similar to Line Operations Safety Audit (LOSA)), voluntary safety reporting by the maintenance staff, periodic audit reports, audit reports at the time of organizational changes, feedback from training, aircraft data monitoring and other safety information. The literature screening is focused on articles linked with either of the two methodologies mentioned above, and the review is restricted to commercial air transport category aircraft with a Maximum Takeoff Mass (MTOM) of 5700 kgs and above (excluding helicopters) and is operated by airlines for passengers and cargo transportation. This limitation is evident as the selected domain represents the lion's share of the air transportation sector (EASA, 2017). Maintenance safety studies related to Helicopters, Unmanned Aerial Vehicles (UAVs), and aircraft having an MTOM less than 5700 kgs are excluded from the scope of the review. The inclusion and exclusion criteria for the research studies defined based on the framework are presented in Table 1. The codification is done for ease of handling and avoiding repetitive phrases. Finally, in this review, the understanding and explanation of basic terms, for instance, "maintenance," "hazards," "risk," "safety," "incidents," and "accidents," etc., is based on the standard definitions given in the different ICAO Annexes and terms "maintenance staff," "maintenance personnel," Aircraft Maintenance Technicians (AMTs), Aircraft

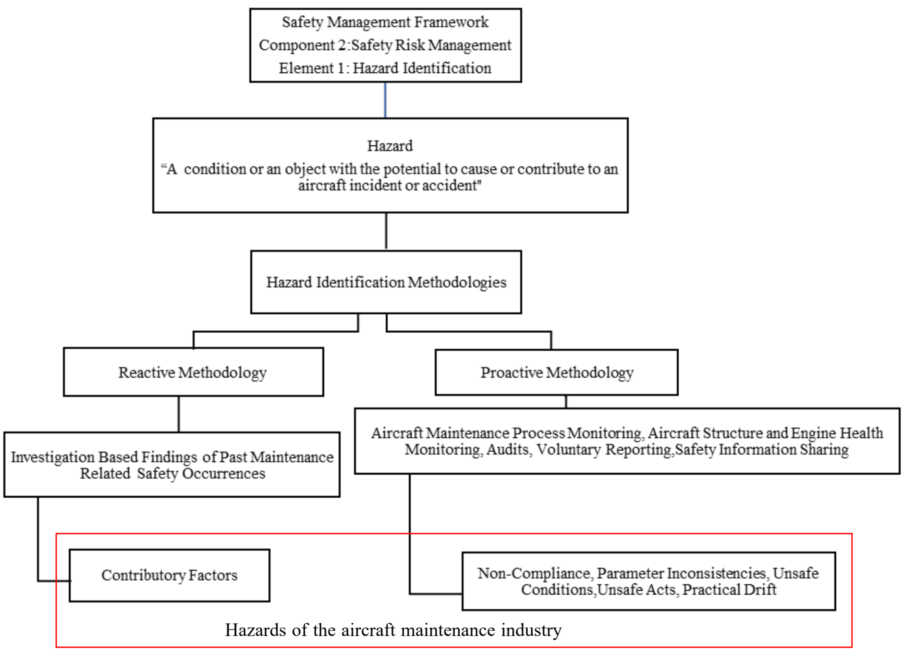

Figure 2. Hazard identification framework in aircraft maintenance industry (source: created by authors based on the ICAO Annex 19)

Table 1. Literature inclusion and exclusion criteria

Included	Excluded
Past maintenance-related safety occurrences (Reactive)	Helicopters, Unmanned Aerial Vehicles (UAVs), and aircraft having MTOM less than 5700 kg. (Code: HUT)
Safety Occurrence Reporting Mandatory reporting: Reactive Voluntary reporting: Proactive	Military, General, and Experimental Aviation maintenance safety (Code: MGE)
Implementation of the SMS (Proactive)	Maintenance process optimization, cost, and efficiency. (Code: ECO)
Process monitoring and auditing (Proactive)	Flying, Air Traffic Control and Navigation, Aerodrome, and Ground Handling related safety occurrences. (Code: OPS)
Qualitative and mixed studies on the safety of maintenance staff and safe aircraft operations after performing maintenance activities. (Reactive/Proactive)	Quantitative, Book Chapters, Review articles, technology application theoretical modeling, machine learning, and Artificial Intelligence (AI) (Code: TECH)

Maintenance Engineers (AMEs), and "maintenance workers" are used in the review essentially to address certifying and non-certifying staff performing maintenance activities on aircraft, engines, and components in maintenance facilities of airlines or dedicated aircraft maintenance organizations.

The literature search was limited to the Scopus and Web of Science databases for only peer-reviewed research articles published in English from 01 Jan 2010 to 12 Sep 2022. The objective to set 2010 as the starting point is based on the alignment of the search with the contemporary safety management approach that the ICAO formally introduced through Annex 19 in 2013, and in the last decade or so, aircraft maintenance organizations have been in various phases of its enactment.

2. Result section of a systematic literature review

2.1. Study selection

Literature search was conducted and the search strings yielded 396 studies (185 and 211 in the Scopus and Web of Science databases, respectively). Initially, 109 studies were identified as duplicates using the "conditional formatting" function of the Excel spreadsheet program. Subsequently, while screening the title, four studies were duplicated but not detected by the Excel program as having the title case or syntax differences. Eventually, 113 records

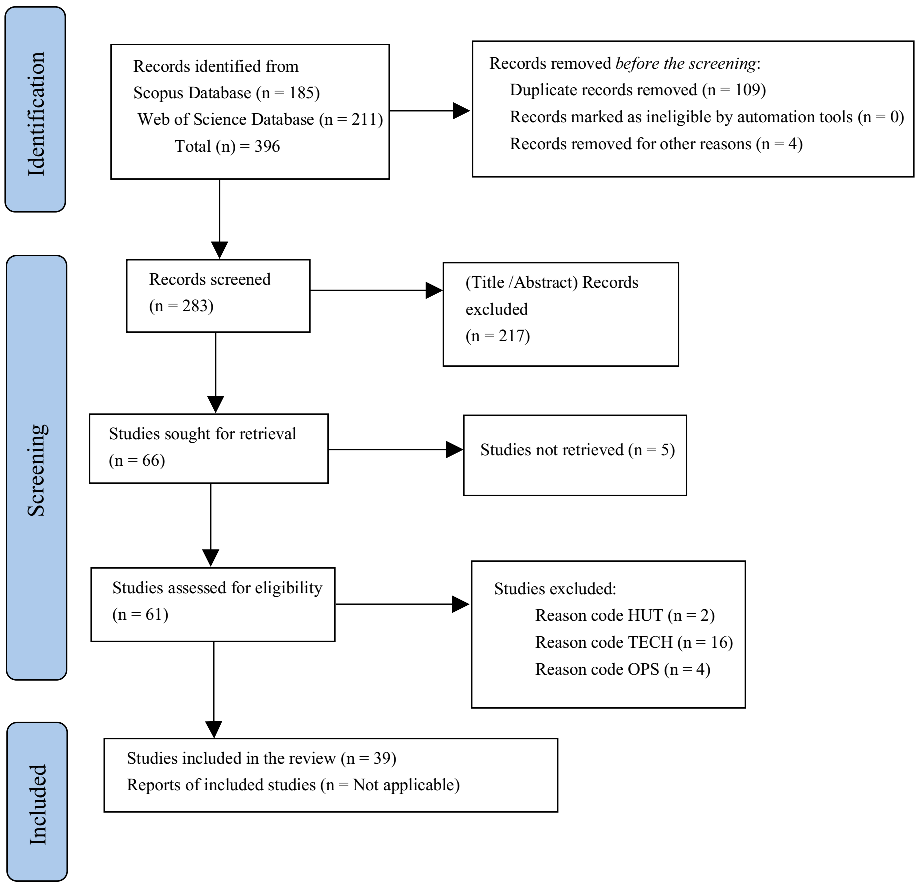

Figure 3. PRISMA flow diagram for the review

were identified as duplicates and removed, and the remaining 283 records were considered for further screening. While performing the "Title/Abstract" screening, it was noticed that a study (different titles with the same abstract and keywords) was published twice in the same Journal in two separate volumes. The study published in the last (volume 94) was retained. Title/abstract screening was performed by the first author based on the formulated criteria. To minimize the risk of bias, screened results were individually validated by the other two authors, which reduced the number of studies to 66, eligible for the retrieval of the complete article. Only 61 studies could be retrieved entirely for further analysis to follow the next step. While analyzing, two sets of research articles by the same author (s) were observed addressing similar issues; therefore, it was decided to include one study from each group more closely aligned with the predefined inclusion criteria. Further screening of the complete research article excluded 22 studies, as 16 were associated with the TECH code, four with the OPS code, and two with the HUT code, thus bringing the eligible study number to 39. Finally, a total of 39 studies were identified to have in the systematic literature review. The search records and screening stages in an Excel spreadsheet are archived for future reference. The PRISMA flow diagram for the literature search is exhibited in Figure 3.

2.2. Descriptive analysis

Firstly, the descriptive analysis of the eligible studies is presented on timelines and geographical regions to provide an overall understanding of the research work. The year-wise distribution of included research studies is exhibited in Figure 4. Over the last decade, researching the hazardous objects and conditions of the aircraft maintenance industry has consistently attracted researchers' attention. In contrast, the year 2021 witnessed the maximum contribution of the research community on the subject.

The geographic spread of the included studies is given in Figure 5. The criteria to allocate the study region is based on the data source; wherever ICAO data is utilized, those studies are labeled "Global." The geographical distribution of the studies represents the European region's dominance in researching the safety of the aircraft maintenance industry, with over 45% of the total studies. In contrast, the Asian region, especially the Indian subcontinent, is yet to explore the subject.

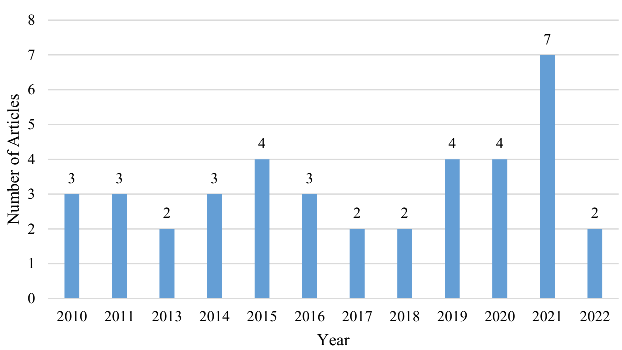

Figure 4. Year-wise distribution of studies

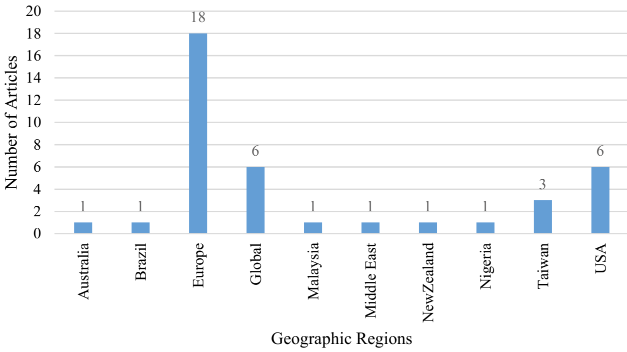

Figure 5. Geographic spread of the studies

2.3. Study characteristics

The aim, theme, and methodology for data collection of retrieved thirty-nine research studies were listed. Since research articles have identified various unsafe acts, conditions, and objects jeopardizing aircraft safety, it became imperative to segregate and categorize each study theme-wise. Categorization yielded recognition of six broad hazard-prone areas (outsourcing, aircraft age, working conditions, maintenance processes, organizational influences, and aircraft design deficiencies) in the aircraft maintenance industry. Implementing the SMS and Learning from Past Safety Occurrences (LPSO) in the industry are closely associated with safety. Therefore, these two themes are combined, and a comprehensive categorization of included studies with the number of studies under each category is represented in Figure 6.

The discussion on the data collection methodologies adopted in the selected studies resulted in the identification of four broad categories. Firstly, data collected through past accidents and serious incidents investigation reports

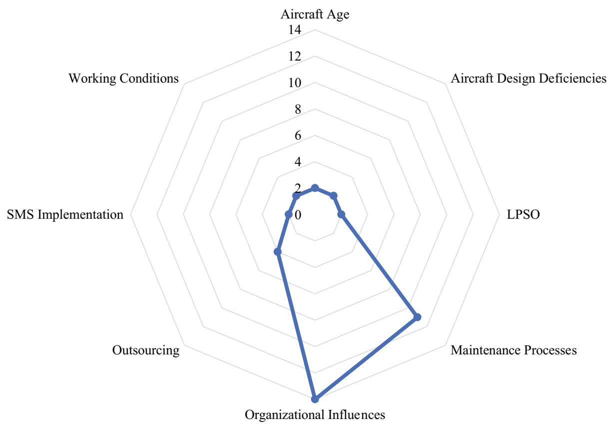

Figure 6. Categorization of the included studies

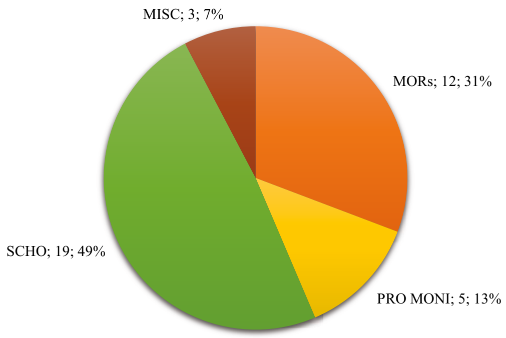

Figure 7. Distribution of data collection methodologies

is codified as MORs (Mandatory Occurrence Reports). One retrospective study used the Service Difficulty Report (SDR) data to synthesize findings; it was also categorized under the MORs code. Second, any data collected through case studies, interviews, surveys, and questionnaires, is codified as SCHO (Conventional scholarly methods of qualitative data collection). The third category is data collected through field observations at the work site, categorized as PRO MONI (Maintenance Process Monitoring). The last category is MISC (Miscellaneous) which includes data from regulatory publications, other research studies, and artifacts. The distribution of data collection methodologies against the included studies is presented in Figure 7.

2.3.1. Learning from past safety occurrences

Continuing with the content analysis, the characteristics of selected studies are described by referring to two research articles (Clare & Kourousis, 2021a, 2021b) centered on Learning From Incidents (LFI), or more systematically, can be said Learning from Past Safety Occurrences (LPSO). In the first study (Clare & Kourousis, 2021a), semi-structured interviews based on qualitative research underscore the importance of just culture and continuity training programs in aircraft maintenance organizations and draw attention to hazards associated with investigations, the contents of training programs and regulatory guidelines applicable to the learning process. The second study analyzed the fifteen MORs from "The European Co-ordination Centre for Accident and Incident Reporting Systems (ECCAIRS)" against the "dirty dozen" taxonomy of human hazards in maintenance. It underlined the inadequacy of learning from past safety occurrences in aircraft maintenance organizations. To briefly summarize, learning from past safety occurrences, a reactive safety management method has the potential for formulating proactive safety management strategies provided organizations have a robust training mechanism, just culture, and regulatory oversight.

2.3.2. Outsourcing

In the 21st century, aviation service providers and other entities have focused more on their core competencies and resort to outsourcing for operations that are not aligned with their scope of business. For airlines, outsourcing aircraft maintenance is a usual practice as the primary objective of airlines is to earn revenue by providing passengers and cargo air transportation. This subject has attracted the attention of researchers. Four studies have been conducted at almost regular intervals since 2010 to understand the dimensions and hazards associated with outsourcing maintenance work. In case-study-based research, Quinlan et al. (2013) examined the MORs investigated by National Safety Transportation Board (NTSB), where maintenance was outsourced to a third Maintenance Repair and Overhaul (MRO) party in the United States. The study narrated several safety occurrences attributed to lapses in maintenance and oversight besides highlighting a range of potential hazards, for instance, evasion of procedures, disorganization, cost-cutting attitude of the management (likely to result in poor training regimes, and high labor turnover) in the aircraft maintenance practices. Another analogous study (Quinlan et al., 2014) described the inadequacy of regulatory control and oversight of outsourced aircraft maintenance. The study analyzed several reports on the safety implications of outsourced aircraft maintenance and indicates that "a risk-based approach is only as effective as the quality of the risk assessment, including the extent to which it identifies and addresses potentially critical hazards (such as those associated with outsourcing) and the degree to which the associated safety management systems are robust and closely monitored." The third questionnaire-based qualitative exploratory research related to outsourcing was conducted in the context of Brazilian aircraft maintenance (Machado et al., 2016). The study evaluated the maintenance management practices of aircraft repair organizations on seven factors, including safety, and in unison with the previous studies that outsourcing aircraft maintenance could jeopardize airworthiness and safety of operations. The study identifies hazards of the maintenance industry, such as "lack of skilled maintenance staff, lack of availability and control of spare parts," lack of an established identification process for segregating materials, poor training, planning, and supervision." The fourth study (Bağan & Gerede, 2019) on the topic is qualitative research using the nominal group technique (interviews and group discussions). It includes aircraft maintenance departments of all the airlines and MRO organizations in Turkiye. In a proactive hazard identification methodology, the study identified 55 safety hazards expected to ascend due to maintenance outsourcing. "Inexperienced technicians in MRO providers" was identified as the most critical hazard, followed by "time pressure on employees of MROs due to commercial concerns."

2.3.3. Aircraft age

One of the critical objectives of aircraft maintenance is to ensure the continued airworthiness of aircraft during its utilization. Two studies highlight that the maintenance of old (aging) aircraft is more hazardous than new ones. It is difficult to differentiate between old and new aircraft;

nevertheless, qualitative research (Le & Lappas, 2016) illustrated that because of technological advancements, operating efficiency, and passengers' comfort, airlines prefer to use aircraft for passenger services during the first 12 to 16 years and after that largely get converted to freighter roles. The study emphasizes the challenges and hazards in ensuring continued airworthiness with aging aircraft and highlights the safety implications in the conversions of old passenger aircraft to freighter roles. The study also underlines the need to harmonize the international regulatory framework with national regulations on the maintenance of older aircraft. It proposes a change maintenance management framework to deal with the challenges and hazards of old and converted aircraft. Another mixed study by (MacLean et al., 2018) suggested a theoretical framework for aging aircraft based on the Service Difficulty Report (SDR) database and described that structural cracks and Widespread Fatigue Damage (WFD) are primary hazardous conditions in old aircraft, among many others such as deterioration of electrical wiring, avionics, and hydraulic system.

2.3.4. Working conditions

AMEs and maintenance staff perform maintenance activities on aircraft, systems, and components. Their working conditions include but are not limited to access to the working place on the aircraft while performing maintenance tasks, working posture, temperature (heat, cold, and humidity), noise, workplace illumination, and the presence of toxic fumes and chemicals in the working place. The scope of aircraft maintenance is vast since AMEs and technicians carry out repetitive physical tasks, for instance, removal and installation of heavy aircraft components, inspection, and repair in aircraft areas not easily accessible. These difficult working conditions have a detrimental effect on their health. A mixed research study (Yazgan et al., 2022) was conducted based on the response of the maintenance staff against the questionnaire of an unspecified location. The study aimed to assess various hazards which may cause musculoskeletal disorder (MSD) risks to maintenance staff. It suggests that prolonged use of seat belts on height-raising equipment (lift platform, scissors lift), manual handling of heavy materials, environmental factors (vibration, humidity, and illumination), and resting times significantly impact the MSD risks. Another mixed research (Gharib et al., 2021) based on the formulated framework was conducted in an aircraft maintenance environment in the Middle East. The data was collected through questionnaires, observations, and measuring the physical parameters such as noise intensity and temperature of the work site. The study aimed to assess safety hazards to aircraft maintenance staff and to evaluate the relationship between safety measures and safety climate in the organization and within the different working groups. It was observed that noise, falls, ergonomics, heat stress, and lack of personal protective equipment (PPE) are major hazardous areas.

2.3.5. Maintenance process

It includes nearly every action and set of activities performed by the maintenance staff inside the hangar and component workshop. The aircraft maintenance process broadly includes defining the scope of the maintenance work, planning work sequence, tools drawing and depositing procedures, spare handling, inspection and testing of aircraft systems, fault isolation, removal and installation, repair and replacement of components and structural parts of aircraft, functional tests, use of reference documents, and job completion entries in various records. Insley and Turkoglu (2020) in qualitative inductive research analyzed the "Aviation Safety Network's (ASN) Accident Database" for the period between 2003 to 2017, which included aircraft accidents and serious incidents related to the maintenance safety of the Commercial Air Transport (CAT) sector. The thematic analysis study developed a "MxFACS' (Maintenance Factors Analysis and Classification System)" taxonomy by coding the process into a three-level hierarchy. The study identified numerous hazards and established the primary maintenance causation factors as "inadequate maintenance procedures, inspections not identifying defects, incorrect installation, and incorrect procedures.". Analogous research (Habib & Turkoglu, 2020) included aircraft maintenance-related incidents and accidents in Nigeria between 2006 to 2019 and 2009 to 2019, respectively. Accident and mandatory occurrence reports were investigated using the MxFACS taxonomy for accidents and Hieminga's taxonomy for serious incidents. The study results discovered that the maintenance hazards contributing to these accidents are "operator and regulatory oversight," "inadequate inspection," and failure to follow procedures. The research also underscores that the highest causal and contributory factors to aviation incidents in Nigeria from 2006 to 2019 are "installation/removal issues, inspection/testing issues, working practices, job close up, and lubrication and servicing." In mixed research (Khan et al., 2020) investigated the official ICAO accidents database attributed to the maintenance deficiencies. The study described five broad categories of maintenance hazards areas such as "general (substandard practices, insufficient maintenance, qualification, training, etc.), engine, parts, Airworthiness Directives/Service Bulletin" (failure to follow ADs or SBs), and PD (repaired previous damage)." The study also established the effect of aircraft age and attempted to determine the relationship between aircraft age, maintenance hazards, and damage to the aircraft in accidents. A qualitative study (Virovac et al., 2017) described the impact of human factors on the aircraft maintenance process. The study analyzed 28 MORs of an aircraft maintenance organization and presented various hazards that lead to adverse consequences. The study classified the types of maintenance errors and described "improper parts installation, testing and inspection failures, and improper use of equipment" top three maintenance errors. The study also explored the contributory factors (hazards) to these maintenance errors.

It stated that "human factors, communication, equipment, and working environment are the major contributory factors for aircraft maintenance-related safety occurrences. Qualitative research (Zimmermann & Mendonca, 2021) illustrated the communications inconsistencies of written maintenance instructions in the context of human factors, ultimately attributed to safety occurrences. The study included 12 MORs attributed to maintenance that occurred in the U.S. between 2003 to 2017 in the scheduled and unscheduled civil air transportation industry, and analysis was carried out by using the PEAR (People (P), Environment (E), Actions (A), and Resources (R)) framework. A range of conditions was identified by the research which has the potential to cause maintenance-related safety occurrences. Inconsistencies in written maintenance procedures, work cards, and maintenance manuals were observed to be most influential towards maintenance safety. Questionnaire-based mixed research (Chang & Wang, 2010) investigated the human risk factors associated with AMEs, in the airline industry. The research was synthesized on the SHEL model and presented the SHELLO model by incorporating an additional organizational interaction path with livewire (AMEs). Each interaction path was assigned probable risk factors based on the research references, subject matter experts' advice, and regulatory sources. A total of nine risk factors were categorized in all the interaction paths, and the safety attitude of the AMEs was identified as the most critical hazard. Trifonov-Bogdanov et al. (2013), described a range of hazards leading to safety occurrence in various processes of the maintenance, for instance, hazards while carrying out engine start-up, undertaking adjustments in control systems, system fault detection, dismantling and assembly, documentation, and replenishing of consumables such as oil and fuel. In the Australian aircraft maintenance industry (Hobbs et al., 2010) conducted qualitative research and utilized the Skill-Rule-Knowledge (SRK) framework to study the influence of circadian rhythm-related hazards on human errors in aviation maintenance and concluded that "skill-based errors were the most common form of error, followed by procedure violations, rule-based errors, and knowledge-based errors." The study also suggested that early morning hours maintenance activities are more hazardous as maintenance staff is at maximum risk of being "absent-minded." In participatory action research (Ward et al., 2010), the ongoing maintenance activities in the aircraft maintenance environment were mapped using an Operational Process Model (OPM) and Blocker Report (akin to a problem reporting form in the maintenance process). Essentially, the Blocker Report identified the potential hazards, thus making the maintenance activities safer and more efficient. A Federal Aviation Administration (FAA) supported research (Ma et al., 2011) on the application of the Line Operation Safety Audit (LOSA) concept to the aircraft maintenance process as maintenance LOSA (m-LOSA) enumerated an example where a 37-page maintenance procedure was reduced in 2 pages thus saving time, efforts and eliminating hazards which were likely to be induced due to shift changeovers and misinterpretation. The m-LOSA concept was further explored by Langer and Braithwaite (2016) as Maintenance Operations Safety Survey (MOSS). The study examined that all the maintenance process monitoring observations had the presence of hazards (@7.8 hazards per observation), and errors were noticed in 86% of findings contributed by various unmitigated risks associated with hazards.

2.3.6. Organizational influences

Aircraft Maintenance organization is an entity where aircraft maintenance activities are organized to achieve predefined objectives. Organizational influences typically include but are not limited to the prioritization of safety policy while achieving the operational and financial objectives, supervision mechanism for the maintenance processes, action on voluntary safety reports, training quality to the maintenance personnel, production planning, physical working condition, information sharing with other organizations, and most importantly the organizational culture. Balcerzak (2017) argues that knowledge gained from the safety data generated by the safety occurrences is critical for improving the overall safety of air transportation. Therefore, through investigation of the safety occurrences, participation and reporting from all the stakeholders are imperative to generate high-quality safety data. The study underscores the impediments and hazards to safety reporting. In Atak and Kingma (2011) ethnographic case study, based on the participant's observations, documentary analysis, and interviews of an aircraft maintenance organization, specifies the interaction between safety culture and organizational culture. They argue that the safety culture of the maintenance organization is closely connected with the different phases of the organization's evolution (initial, expansion, growth, and stability). The study mapped the approach of AMTs toward safety in each step of the organizational progression. They observed that as the organization attains maturity and becomes more stable, AMTs adopt a more professional approach toward safety. Therefore, various hazards likely to be introduced in the maintenance organization during the change and transition phase must be identified and suitably managed. Mixed research (Yazgan & Yilmaz, 2018) explained the interdependence of hazards attributed to the errors by the maintenance staff. The study identified the 67 hazards contributing to maintainers' error, and "time pressure, organizational culture, safety culture, supervision, peer pressure and situational awareness" are the most critical hazards contributing to AMT error. The study observed that these hazards contribute to 76% of the errors committed by the maintenance staff. A qualitative study based on an international online survey by Santos and Melicio (2019) on three critical hazards of dirty dozen, i.e., fatigue, stress, and pressure, indicates the inadequacy of mitigating regulations to deal with the dirty dozen hazards and highlights the need to regulate working time for maintenance staff also as being regulated for Flying Crew and Air Traffic Controllers. The study suggests that fatigue, stress, and pressure have numerous sources, generally because of personal reasons or working conditions. The study also identifies a range of hazards leading to fatigue and 33 symptoms commonly manifested by the maintenance staff under fatigue and stress. A questionnaire-based mixed research study by Signal et al. (2019) investigated the personal and work-based hazards leading to fatigue-induced error in aircraft maintenance setup. The study suggests that 75% of AMEs need formal training or education to manage fatigue and cope with the changes in their work schedule. Prolonged working hours, inadequate sleep, and unexpected duty roster changes increase fatigue-related errors at work. A questionnaire-based mixed research study (Wang & Chuang, 2014) examined physiological and psychological fatigue variations and the impact of this hazard on the line maintenance workers of two major airlines in Taiwan. The study considered 20 physiological and 19 psychological conditions associated with fatigue hazards and determined four major ones affecting fatigue and maintenance safety. A survey-based qualitative study (Wang & Zimmermann, 2021) investigated the changes in aircraft construction material and technology with the technical skills of the maintenance personnel and their impact on the safety of aircraft maintenance. The study aimed to understand various hazards and safety threats from the maintenance perspective that may likely to encounter from the increased use of composite materials in aircraft construction. The results of the study indicated that training of aircraft maintenance staff for composite maintenance and repair is not adapted to the needs of the industry, and challenges faced by maintenance staff pose potential safety hazards. Usanmaz (2011) compiled details of safety occurrences attributed to maintenance-related hazards and investigated the training process of aircraft maintenance personnel to correlate with skills and knowledge. The study underscored the shortcoming of the existing training model and determined that the module examinations are academic and insufficient to evaluate the required skill sets for maintenance personnel. The study proposed a training model for maintenance personnel by including structured On Job Training (OJT) to reduce the skill-associated hazards in the maintenance process. A case study based on qualitative research by Shukri et al. (2021) in the Malaysian aviation industry investigated the significance of the English language in achieving desired safety level in the maintenance processes. This study was included as it brings out a rather unusual hazard related to a language, as many safety occurrences are associated with misinterpretation and miscommunication of maintenance instructions. Under and Gerede (2021), studied the numerous reasons for employees' silence in aircraft maintenance organizations. Silence in this context means that employees are not reporting to the higher management the hazardous conditions, acts, and other such things having the potential to jeopardize the safety they observe in their functioning at the workplace. In the SMS framework, employees' voluntary reporting of unsafe conditions, acts, and incidents are recognized as a critical source for hazard identification, potentially making the working environment safer. The study identified four factors for silence or not reporting voluntarily. However, the study was conducted in Turkiye, and it would be anticipated that the participants would be influenced by Turkish culture. More studies in different cultures may add more value to this aspect. At the same time, identifying the motivating factors for the employees who voluntarily report may be more helpful in understanding the subject better. Field observations in qualitative ethnographic research in an aircraft maintenance organization in Greece (Tsagkas et al., 2014) identified specific hazards driving aircraft maintenance staff to deviate from the procedures. The study examined 12 cases of deviation and determined five generic hazard zones that may influence maintenance technicians' decisions. Another qualitative ethnographic research on Greece's aircraft maintenance industry (Nathanael et al., 2016) examined the decision-making characteristics of maintenance staff in the dual demanding environment of operational objectives and regulatory compliance. The study enumerated several cases where maintenance staff decisions compromised on at least one parameter out of schedule, cost, airworthiness, and accountability while undertaking a maintenance activity. A questionnaire survey based on mixed research (Chen, 2021) synthesized on the Job Demand and Resource (JD-R) model identified several hazards influencing aircraft maintenance staff's passion for their job. The study highlights that the aircraft maintenance working environment is full of hazards and collaborative efforts (both the maintenance staff and management of the organization they work for) are imperative in maintaining a high level of job passion as it ultimately leads to a greater level of safety motivation. Another research by Elvira et al. (2020) developed a decision support tool, "Risk Management in Aviation Safety" (RIMAS), for risk management in collaboration with the Spanish aviation regulatory agency and the Royal Academy of Science. The study applied Operations Research (OR) tool, and 88 types of safety occurrences in Spain were categorized into five levels of severity and eight consequences. The study primarily concentrated on the analytical methods to forecast safety occurrences and suggested dynamic resource allocation.

2.3.7. Aircraft design deficiencies

Two studies provide insights into how aircraft design deficiencies can lead to maintenance errors. A qualitative case study based on research by Kourousis et al. (2018) evaluated the modification of the fan cowl door of the Airbus 320. The study presented several error-prone scenarios of maintenance activity in complying with the modification and underscored the importance of the human-centric design of the systems. Another qualitative case study based on research (Marretta & Bedson, 2015) investigated the findings of a fatal accident in which maintenance staff installed an incorrect Fuel Quantity Indicator (FQI) because of shape and interchangeability (ATR 42 FQI was installed rather than ATR 72). The study highlighted the human factor associated with maintenance hazards owing to inconsistencies in aircraft design and maintenance instructions.

2.3.8. SMS Implementation

Two research articles explored the implementation of SMS in the aviation industry. Gerede (2015) studied the performance of SMS in aircraft maintenance organizations in Turkiye. The study focused on the problems and challenges confronted by aircraft maintenance organizations while implementing the concept of SMS at the activity level. A total of 52 professionals from aircraft maintenance organizations, SMS specialists, and representatives of regulatory authorities participated in the brainstorming and group discussion for a consensus-based conclusion of 8 themes with 42 items as hazards for implementing the SMS at the activity level. The perception of maintenance staff about the "Just Culture" in the aircraft maintenance organization holds the key to SMS's success. Another action-based research (Ulfvengren & Corrigan, 2015) collaborated with a major European airline to implement and develop SMS that credibly demonstrates safety performance and compliance with regulations. SMS is a systemic and all-inclusive approach toward safety; all the departments and sections of the organization need to integrate data and people. The study underscores that the lack of trust or appropriate mechanisms across organizational boundaries is the critical hazard that prevents data and safety information integration within an organization. Although SLR is focused on the commercial aircraft maintenance industry, the elements of the SMS framework are likewise applicable to military aviation as the transport and helicopter maintenance of military aviation pose considerable similarities with commercial aviation. Chatzi (2018) explored the opportunities and challenges of SMS implementation for military aviation by comparing the safety occurrences of two military organizations; one with the SMS framework implemented and another without it. The study also highlighted the influence of "just culture" on the "safety culture," as brought out in the context of the commercial aircraft maintenance industry by the previous study (Gerede, 2015).

3. Discussion

In this section, included studies are summarized, and the limitations are underlined. The discussion is initiated with the two broad concepts from the research studies. Firstly, the challenges suggested by Shappell et al. (2007) that "low-hanging fruits" (technological advancements, improved regulations, and human factors studies) have already been picked (implemented in the aircraft maintenance industry to achieve existing safety standards). Secondly, the arguments of Grant et al. (2018) that conventional approaches (learning from the past and preventing future safety occurrences) to manage safety have reached the saturation point and are no longer considered adequate to improve safety. Therefore, the SMS framework recommends a mix of reactive and proactive methodologies in identifying the hazards in the aircraft maintenance industry. In the SMS framework, a summary of reviewed studies about hazard identification and data collection methodologies is presented in Figure 8. Sixteen studies (41%, rounded off) identified the hazards using the reactive methodology, whereas twenty-three studies (59%, rounded off) used the proactive methodology.

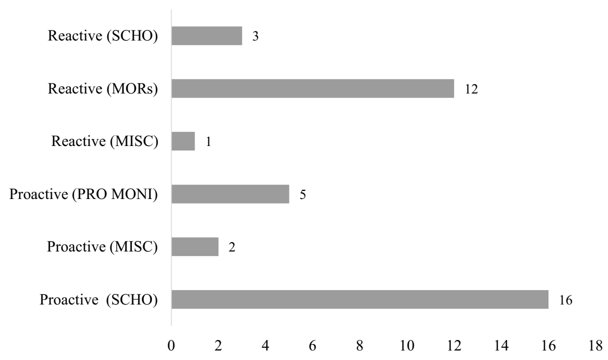

Figure 8. Hazard identification and data collection methodologies

Out of thirty-nine reviewed studies, 41% of studies have examined past safety data to identify unsafe acts, objects, and conditions in the aircraft maintenance industry. In the SMS framework, hazards identified from past safety occurrences must be integrated with safety management strategies to enable a safer aircraft maintenance industry. That is where the organizational learning abilities from the past become critical and are considered one of the limitations in applying past safety data in continuing safety management. A notional relationship between reactive methods of hazard identification, proactive safety management strategies, and learning from the past is drawn and exhibited in Figure 9. While picture-perfect learning from past safety occurrences is a fallacy, maximizing and applying it in continuing safety management practices is a reality and has the potential to enhance the safety of the aircraft maintenance industry.

Nineteen studies (49%, rounded off), a combination of qualitative and mixed studies, were conducted using conventional qualitative data collection techniques, for instance, questionnaires, surveys, case studies, interviews, and group discussions. While three case study-based research are categorized under the "Reactive (SCHO)" category, sixteen studies proactively identified several aircraft maintenance-related hazards and were categorized as "Proactive (SCHO)". Each study aimed to address specifically identified aircraft maintenance industry problem areas. Another aspect that emerged is proactive hazard

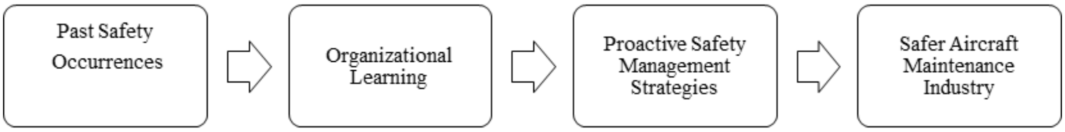

Figure 9. Relationship between the reactive, proactive safety management strategies and learning from the past

identification studies based on the maintenance process monitoring in the aircraft maintenance industry. Five studies (13%, rounded off) have identified unsafe acts and conditions by monitoring the aircraft maintenance processes where researchers collaborated with aircraft maintenance organizations and conducted ethnographic research. These studies are categorized as "Proactive (PRO MONI)". However, restricted access to the aircraft maintenance site because of security concerns could be cited as the main limitation to conducting such studies.

The systematic literature review enabled authors to recognize six hazard-prone areas in the aircraft maintenance industry. However, no study was found based on the aircraft maintenance organization's safety data (audit reports, voluntary safety reports, safety information, etc.). The limitation to conducting studies based on the safety data is acknowledged owing to the data-sharing policies in vogue and the dilemma of the maintenance industry between the benefits of sharing safety data and the risk of losing reputation. However, eventually, it impedes the contribution of researchers in conducting studies on proactive methodology.

To conclude the discussion, the aspect associated with SMS implementation and associated challenges. Two studies have addressed the subject of the implementation of SMS in the industry. Although both studies were conducted in the European region, the findings highlight different challenges and problems in the SMS enactment. Lack of data is a limitation in assessing the maturity level of SMS in the industry. Chatzi (2018) in the context of military organizations underscores the inconsistencies in the perception of "safety" amongst aircrew, technical and other support staff and advocates the implementation of a military culture blended SMS framework in the defense aviation industry for improved safety.

Conclusions and future research

Each study indexed in the Scopus and Web of Science databases had its specific aim. However, well-defined literature search, inclusion, and exclusion criteria could identify thirty-nine studies to assess numerous hazards in the aircraft maintenance industry along with the methodologies followed in identifying them. The review could align the findings of the selected studies with the hazard identification methodologies of the regulatory SMS framework. Also, it was established that no such literature review was conducted in the past using those criteria. Therefore, it is reasonable to presume that this review provides a fresh approach and introduces the possibilities of expansion in the existing knowledge base. The findings, along with trends and gaps in the scholarly literature exhibited in the literature review process, are listed below:

- The study identified a total of six hazard-prone areas and two critical factors associated with the safety management of the commercial aircraft maintenance industry.
- Trend analysis illustrates that 41% of studies have identified the hazards based on the reactive methodology.
- A clear research gap is associated with the hazards identified from reactive methodology. To bridge this gap, researchers may identify the barriers to learning from past safety occurrences in an organizational setting for improved hazard identification.
- Most of the studies (64%, rounded off) were devoted to two categories of hazard-prone areas of the aircraft maintenance industry, i.e., "Organizational Influences" and "Maintenance Processes" out of this eleven studies (28%, rounded off) have identified the hazards in the "Maintenance Processes."
- Each safety occurrence attributed to maintenance shortcomings possibly indicates the need for a more rigorous mapping of hazards in the maintenance processes. Therefore, "Proactive (PRO MONI)" method-based research studies could be one of the solutions. An opportunity for researchers wherein maintenance activities on an aircraft's critical systems and subsystems, such as aircraft structure, landing gears, flight controls, engines, brakes, hydraulics, and fuel systems, can be studied to identify deviations and non-compliances (hazards) and may be the standard procedure itself.
- Only two studies explored SMS implementation in aircraft maintenance organizations. Although both studies were conducted in the European region, the findings highlight different challenges and problems during the SMS enactment. Thus, research gaps can be seen in the SMS implementation itself. These gaps are evident as the SMS approach is a paradigm shift compared to the conventional safety management approach. Therefore, more studies may be conducted, preferably geographic region-wise, to understand the complexities of the issues involved while implementing SMS in maintenance organizations. Similarly, the researchers engaged in military aviation safety may also explore SMS implementation in the military aircraft maintenance industry.
- No study was found based on the aircraft maintenance organization's safety data (audit reports, voluntary safety reports, safety information, etc.).

- The limitation to conducting studies based on the safety data is acknowledged owing to the data-sharing policies in vogue and the dilemma of the maintenance industry between the benefits of sharing safety data and the risk of losing reputation. This could be overcome by deidentifying the data source and including the academic community, which offers more domain competencies than the technical experts with maintenance organizations and regulators.

This review is not comprehensive as limited to only two databases with various restrictions mentioned in the method section. Nevertheless, it indicates the trends and gaps in the existing research literature, which opens up opportunities for future research. Based on the findings of this review, aircraft maintenance organizations and regulators can assess the implementation of SMS and the learning abilities of the maintenance organizations from past safety occurrences. Researchers and safety practitioners may also map the critical aircraft maintenance processes (PRO MONI methodology) to identify the hazards in critical maintenance activities (in the forms of deviations, non-compliances to standard procedures, and inadequacy of the standard procedure itself) for timely mitigation of the associated risks.

Authors' contribution

First Author: Conceptualization, Methodology for the Review, Data Screening, Analysis, Writing – original draft.
Second Author: Validation of Concept and Methodology, Validation of Screened Data, Review of Findings.
Third Author: Validation of Analysis, Data Screening, Findings, and Review of the original draft.

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