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Tyagi, Alok; Tripathi, Rajesh; Bouarfa, Soufiane

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Learning from past in the aircraft maintenance industry: An empirical evaluation in the safety management framework

Alok Tyagi [a,*], Rajesh Tripathi [b], Soufiane Bouarfa [c]

[a] University of Petroleum and Energy Studies (UPES), School of Business, Department of Transportation Management, Dehradun, India
[b] University of Petroleum and Energy Studies (UPES), School of Business, Department of General Management, Dehradun, India
[c] TU Delft, Department of Aerospace Engineering, Netherlands

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ABSTRACT

The growth of commercial air transport arguably translates into more aging passenger aircraft queuing up for major maintenance, modifications, and/or freighter conversion with the aircraft maintenance industry. In the competitive business environment, this increased maintenance demand possesses the potential to stress the industry and make safety vulnerable. In the aircraft maintenance industry, several aircraft accidents and incidents have resulted from organizational failure to learn from the past. To address this chronic problem, this study aims to (a) establish a learning process model for the aircraft maintenance industry, (b) identify the factors that influence learning, and (c) determine the effect of identified factors on learning from the past. A review of scholarly articles and regulatory publications enabled the development of learning from the past process model and a data collection tool, followed by structural equation modeling to quantify the relationship among influencing factors. The study was conducted in the Indian aircraft maintenance environment and is based on the perspective of the front-line maintenance staff. The study found that safety communication is the decisive stage for learning from the past. Contextualization of the safety information and evaluating the lessons learned during safety communication strongly impact learning from the past, for which existing regulatory provisions are vulnerable. The findings of this study are meant to assist State regulators and management of the aircraft maintenance industry; nevertheless, safety managers and practitioners in other ultra-safe, high-risk sectors may also apply the results in compliance with the respective regulatory guidelines.

1. Introduction

Today, aviation has an experience base of over a century, and the plethora of 'safety data' and 'safety information' derived from the investigation reports supposedly available to stakeholders. However, numerous industrial accidents indicate that organizations have failed to learn lessons from the past [1]. To exemplify this, an Indian scheduled operator flight 9W 2423 met with an accident during the landing roll at Khajuraho, India airport on April 13, 2015 [2]. After touching down the runway, the aircraft deviated to the left from the center line as the left main landing gear (MLG) collapsed. The aircraft's left engine rubbed the runway surface for over 100 meters before stopping. The aircraft sustained substantial damage (one of the criteria to define an aircraft accident). In the post-accident

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[*] Corresponding author.
E-mail address: aloktyagiiaf@gmail.com (A. Tyagi).

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inspection, the left MLG aft trunnion pin (a critical part of the MLG assembly that supports and pivots the landing gear) was found sheared off. Failure of the aft trunnion pin was determined as the immediate cause of the accident. Consequently, the runway was blocked for over three hours before normal operations were resumed. On 03 March 2016, almost a year later, the same scheduled aircraft operator, flight 9W 354, met with an accident during the landing roll at Mumbai, India airport [3]. This time, after touching down, the aircraft veered to the right from the centerline and fortunately cleared the runway before the collapse of the right MLG on the adjoining taxiway. The aircraft sustained substantial damage, and this time, the right MLG aft trunnion pin was found sheared off. Both the trunnion pins were fitted in the aircraft after overhaul from the same agency. The investigation reports of both accidents are available in the open domain and can be studied to get more insight into the accidents. The purpose of citing these two safety occurrences is to draw attention to the aircraft maintenance industry's complexities and underline the organizational learning from the past.

The commercial aircraft maintenance industry, conventionally known as the Maintenance, Repair, and Overhaul (MRO) sector in the aviation business ecosystem, is a critical service provider. The growth of the MRO market is estimated to be around 115 billion US Dollars by 2028 [4]. The commercial air transport sector is poised to grow, especially in the Indian subcontinent and Asian Pacific regions [5,6]. This growth means more airlines, increased aircraft in operations, and additional departures with more accidents and incidents (if the present rate of 1.93 accidents/million departures [7] is maintained). On the other hand, the cascading effect of this growth is expected to translate into more aging passenger aircraft queuing up for major maintenance, modifications, and/or freighter conversion with the MRO industry. This increased aircraft maintenance demand, along with the prevailing competitive business environment, possesses the potential to stress the aircraft maintenance industry and make safety vulnerable [8]. illustrate that "all the low-hanging fruits have already been picked," now, the real challenge for service providers and national safety regulators is improving the safety of an already ultra-safe industry. This statement implies that all the technological innovations, metallurgical advancements, system automation, improved regulations, and human factor interventions are already practiced in managing safety in the aviation industry and, thus, intend to underscore the need for a more micro-level understanding of aviation business processes. Perhaps the solution to improve safety from the present level is probably seen in the all-inclusive participative contemporary safety management framework, which is essentially a pragmatic approach rather than prescriptive [9]. In this framework, one of the essential aspects is learning from the past, which is fundamentally a reactive safety management method to prevent at least the recurrence of accidents and incidents. At the same time, this methodology has the potential for the front-line maintenance staff to gainfully utilize safety information learned from the past for hazard identification and risk management (HIRM) in daily work.

Learning from the past is not a novel concept. Researchers have explored this subject under the different names of "learning from incidents (LFI)," "learning from accidents and disasters," and "learning from experience or experience feedback" etc. [10,11]) [1,12–21]. The abovementioned studies have predominantly viewed the 'past' based on the occurrences of accidents and incidents; this approach may have the possibility to confine learning from the past as aviation is one of the safest means of transportation, and accidents or even incidents are rare. This concept's more significant operational dimension has surfaced in light of the current safety management regulatory framework, which underscores drawing safety data and information from day-to-day maintenance activities rather than relying only on rarely occurring events [22]. In the aircraft maintenance industry, while reporting accidents, serious incidents, and incidents falls under the mandatory occurrence reporting (MOR) category, the hazards and near misses that frontline maintenance staff observe in day-to-day work are reported under voluntary reporting. Contrary to the previously used term 'Learning from Incidents' (LFI), this study uses the term 'LPSIs' (Learning from Past Safety Investigations) for two main reasons. Firstly, 'safety investigation' applies to both the rare accidents (reported under MOR) and the near misses or hazardous conditions observed during the daily maintenance activities (voluntary reporting). Both reports, when investigated, generate safety data and information that can potentially prevent recurrences of accidents and enhance overall safety standards. Secondly, besides the informal and unrecorded experience sharing amongst the maintenance personnel, the 'safety information' drawn from these investigation reports is the solitary organizational learning repository.

The critical aspect of the LPSI is why organizations are not learning, or, in other words, what factors influence the LPSIs despite the necessary regulatory framework? The objective of this research is to identify the influencing (barrier and catalyst) factors (organizational and individual) and measure the impact of each factor on learning from the past in the regulatory framework. Studies mentioned in the previous paragraph have followed the qualitative approach wherein accurate weighing of factors influencing LPSIs is unavailable. Moreover, no study has been conducted in the aircraft maintenance industry where factors influencing LPSIs were identified and measured. Further, unlike previous research, this study views the 'past' from two different perspectives. Firstly, the 'safety information' produced from investigating historical accidents and incidents, and secondly, 'safety information' derived by investigating the hazards, errors, and near-misses reported by the front-line maintenance staff in day-to-day functioning; in this case, the past may be very recent, depending upon organizational agility. Therefore, this research article aims to (a) establish the 'learning from past safety investigation' process model for the aircraft maintenance industry, (b) identify the factors that influence the learning from past safety investigations, and (c) develop a model to determine the effect of identified factors on learning from past safety investigations.

In this study, the frontline maintenance staff of the aircraft maintenance industry is at the center stage. This consideration is based on two reasons. Firstly, they are the first to observe hazards in the aircraft maintenance process, and secondly, their actions are the last before the aircraft is released for flying after maintenance. These two factors make them valuable assets for this study. Moreover, the utility of lessons learned from past safety investigations will likely be demonstrated in hazard identification capabilities while maintaining an aircraft. The standard terms, for instance, "accident," "serious incident," "incident', "safety data," "safety information," "causes," and "contributory factors" are used as defined in ICAO Annex 13, twelfth edition, ICAO Annex 19, second edition and ICAO Safety Management Manual fourth edition. The term "safety occurrences" implies accidents, serious incidents/incidents and the words "maintenance staff" or "maintenance personnel" includes but is not limited to licensed aircraft maintenance engineers (AMEs), hangar floor supervisors, workshop supervisors, non-certifying staff working with AMEs, in tool and component (bonded or quarantine) stores, monitoring and updating components, engine, and aircraft performance and utilization data, etc., working in MRO sector. Finally, the findings of this study are meant to assist State regulators, management of the MRO sector, and safety practitioners working in other high-risk ultrasafe industries in identifying the weak areas in their context in the various stages of the LPSI process model and formulating safety management strategies to enhance safety.

2. Literature review, hypothesis, and conceptual model

2.1. Literature review

This section examines applicable aviation regulations to the aircraft maintenance industry and scholarly research articles on learning from the past concept. The systematic literature review of [23] is the baseline for distinguishing the research articles, whereas updated regulatory publications of ICAO are referred for regulations.

2.1.1. Regulatory framework and LPSIs

The prerequisite for learning from the past is the organization's formally structured learning system wherein safety information is drawn from the occurrences based on investigations and communicated to stakeholders for individual and organizational learning [13]. The aviation industry is highly regulated, and its organizational structure, policies, and procedures comply with global regulations. ICAO Annex 13 [22] deals with aircraft accident and incident investigation, which mandates that each safety occurrence be reported and investigated to prevent at least the recurrences. The critical aspect of preventing recurrence is the extent of individual and organizational learning. To facilitate this, the regulatory framework of ICAO Annex 19, "Safety Management" [24], is currently implemented in the global MRO sector. To comply with the standards and recommended practices (SARPs) of Annex 19, States formulate their State Safety Programmes (SSPs) to ensure that each stakeholder of the aviation industry implements a Safety Management System (SMS) in its business processes. ICAO document 9859, fourth edition [25] is the Safety Management Manual (SMM) intended to assist States and the aviation industry in implementing SSPs and SMS at appropriate levels. These current safety management regulations are a paradigm shift and assert that employees' knowledge, experience, suggestions, and opinions must be drawn to improve safety performance [26]. This is an all-inclusive and participatory approach to safety management, and its implementation and maturity levels will likely differ in the global aircraft maintenance industry.

Hazard Identification and Risk Management (HIRM) is the cornerstone of the current SMS, wherein hazards are typically identified based on two methodologies, i.e., reactive and proactive [25]. Safety information drawn from the safety investigation reports of accidents and incidents can avert the recurrences if appropriately utilized at individual and organizational levels. In contrast, voluntary reporting is directly from the front-line maintenance staff they encounter while performing aircraft maintenance activities on a day-to-day basis. When investigated, this anonymous or confidential reporting system provides safety information about the organization's latent unsafe conditions or acts without legal and administrative obligations [25,27]. A voluntary reporting mechanism offers learning opportunities to maintenance staff and aircraft maintenance organizations without suffering severe consequences if effectively and efficiently exercised [28]. In the regulatory framework, although voluntary reporting is considered a proactive hazard identification method, the safety information drawn from this methodology provides enhanced hazard identification capabilities for safety management, as today's reported hazard is a piece of safety information for tomorrow's safe work.

2.1.2. LPSI process model: generic

Learning is difficult to define and is one of the most intensely studied topics [29]. However, in the industrial safety environment, learning is; drawing information from the personnel involved in the safety occurrence and from the safety occurrence itself and converting it into knowledge for the entire organization, or at least for the stakeholders for whom it is critical [13]. In the context of this study, the learning is described as enhanced hazard identification and risk management capabilities of front-line maintenance staff based on the safety information drawn from past investigations. Ideally, enhancement of capabilities to an extent at least the hazards reported and causes of accidents identified in the past safety investigations are promptly identified and managed. Learning at the individual level (front-line maintenance staff of the aircraft maintenance industry) and learning at the organizational level are different, with the former being necessary but insufficient for the latter [30]. The underpinning of the learning theory [31], the conventional term of single-loop learning, primarily applies to the front-line maintenance staff by demonstrating improved hazard identification skills, while double-loop learning is mainly for the management by reviewing policies, procedures, and resource allocation.

A model of accident investigation and prevention was developed by Ref. [32], also known as the CHAIN model or model of experience feedback. It consisted of five stages; 'reporting,' 'selection,' 'investigation,' 'dissemination,' and 'prevention,' with all the stages contributing to the learning process to varying degrees. Another learning from the past model consisting of eleven steps under four stages was presented by Ref. [1]. The first stage included safety occurrence reporting and analysis; the second stage focused on formulating a practical action plan based on the analyzed results; the third was related to resource allocation for the action plan; the last stage evaluated the learning. This model can also be compared with the [33] Plan-Do-Study-Act cycle, which describes learning as an iterative process in which results are studied, and causes of failure are investigated to formulate revised plans for action. A six-stage LFI process model was developed based on the energy sector studies [18]. All the mentioned models are predominantly in unison and create an envelope for learning with the starting point 'reporting' or, in other words, the origin of learning contents. At a glance, the stages/activities of all three models can be viewed in Fig. 1.

2.1.3. *LPSI process model: aviation industry*

There is no process model based on aircraft maintenance industry studies per se; therefore, to achieve the study's objective and underscore the difference in activities of the aircraft maintenance industry, the researchers have formulated the LPSI process model (Fig. 2) based on the models described in the previous paragraph and the regulatory framework [25]. The critical differences are in the 'reporting' and 'investigation' stages. Aircraft accidents, serious incidents, and incidents are compulsory to report (rather too big to hide, hence reported) and follow mandatory occurrence reporting (MOR) procedures. The state is responsible for investigating such reports by following the SSP based on the SARPs of ICAO Annex 13. In contrast, the frontline maintenance staff and other stakeholders are expected to voluntarily report hazards, unsafe conditions, unsafe acts, errors, and near misses. Voluntary reporting is investigated in-house by the concerned organization. Both safety investigations aim to generate safety information for dissemination to the relevant stakeholders at the 'safety communication' stage. Finally, the effectiveness of LPSI in an organization is evaluated at the 'Safety audit' stage by the organization itself and the regulatory agency. All the stages of the process model have the potential to offer learning value to the stakeholders; however, 'safety communication' is the formal learning zone for the maintenance staff and the organization in which safety data extracted from investigations are contextualized into safety information and is communicated in written (emails, safety circulars, bulletins, newsletters, etc.) and audiovisual (safety training, human factor training, continuity training, safety meetings, etc.) mode to organizational entities.

2.2. *Barriers in LPSI Process Models*

'Barriers' are the factors that impede learning in one or more learning stages/activities [15]. All four stages of [1] model were identified with barriers that adversely affected the learning process. Another analogous study conducted focus group discussions with seven companies (four chemicals, one manufacturing and service provider to chemical plants, and a construction company) and identified the causes and conditions that impede learning from the past [15]. The study used the same model [1] and underscored the reluctance of the employees to report safety occurrences. Since the ongoing research is specific to the aircraft maintenance industry, the barriers to the different stages (Fig. 2) are viewed in the light of ICAO regulations which all the stakeholders comply with in their business processes.

2.2.1. *Barriers to the 'reporting' stage*

In the case of accidents and incidents (MORs), the 'reporting' stage is not assessed as a barrier. Also, no scholarly literature substantiated the bottlenecks in safety reporting for accidents and incidents, or maybe owing to widespread media coverage and other social implications; these safety occurrences are impossible to conceal for organizations/individuals, hence reported. Nevertheless, reporting hazards, latent conditions, near misses, and events of low safety consequences dependent on the individual maintenance staff (voluntary reporting) remains a concern in the aviation sector. Voluntary reporting is critical for safety management, and (Reason, 1997) illustrates that minor incidents and near misses, not with severe consequences, are not reported. In aviation organizations consisting of typically all operational streams such as flying, air traffic controls, and maintenance, the barriers impacting the effectiveness of the 'voluntary reporting' channel were classified as 'organizational barriers, 'work environment barriers,' and 'individual barriers' [26]. Although the study identified the reporting system barriers based on a military aviation organization survey, most attributes are also consistent with commercial aviation. The motives for aircraft maintenance staff to remain silent and not report unsafe conditions and acts observed at work were investigated and categorized under four broad categories: prosocial, disengagement, fear, quiescence, and acquiescence [27]. [28] highlighted the two most successful voluntary reporting programs, i.e., the Aviation Safety Reporting System (ASRS) and British Airways Safety Information System (BASIS). The identified three essentials for a thriving voluntary reporting culture are the trust between the reporters and management, the ease of reporting experienced by the reporters, and the usefulness of reporting as perceived by the reporters [28]. Based on the abovementioned literature review, obtaining both facets, i.e., the barriers and facilitating factors of 'safety reporting' (voluntary reporting), was possible. Therefore, given the SMS framework's intent of an all-inclusive participatory ecosystem in the organization, this study views the 'voluntary reporting' system primarily as an organizational management function and explores the perception of maintenance staff towards it. Based on the above literature review, the following hypotheses are formulated:

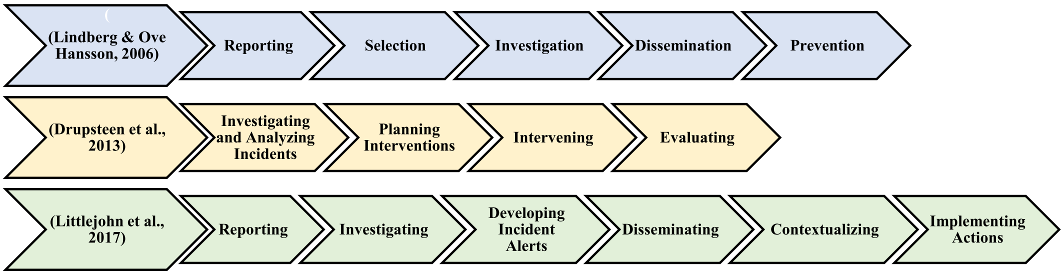

Fig. 1. Lfi process models.

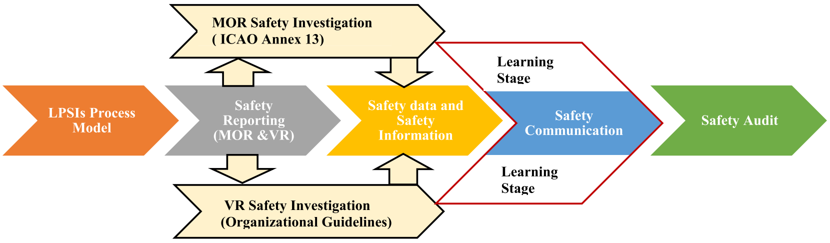

Fig. 2. LPSI Process Model for Aircraft Maintenance Industry
(Developed by the authors based on literature review and the regulatory framework).

H1. In the voluntary reporting stage, a 'lack of trust' between the maintenance staff and management is negatively related to the safety communication stage of the LPSI process model.

H2. In the voluntary reporting stage, the 'complicated voluntary reporting procedure' is negatively related to the safety communication stage of the LPSI process model.

H3. In the voluntary reporting stage, the perception of the 'lack of usefulness of voluntary reporting' in maintenance staff is negatively related to the safety communication stage of the LPSI process model.

2.2.2. Barriers to the 'safety investigation' stage

The next stage after 'safety reporting' is 'safety investigation.' On 'safety reporting,' the investigation route is bifurcated into two streams based on the reporting category, whether MOR or voluntary reporting (Figure: 2). Both streams generate critical 'safety data' and 'safety information' for an individual (maintenance staff) and the organization. In the case of MORs, numerous accident investigation methods are described in the scholarly literature; however, an aviation safety occurrence reported under the MOR category is investigated following ICAO Annex 13 and the associated safety manual (document 9756 part I to IV). To understand the vulnerability of these regulatory guidelines, the first edition of Annex 13 was adopted on 11 April 1951 and regularly amended and revised after that; probably one of the reasons behind these revisions was continued learning. On the analysis of this base document, it was observed that the Accident/Incident Data Reporting System (ADREP) was introduced in the ninth edition of Annex 13 in Feb 2001; the revised provision of 'causes' and 'contributory factors' included in tenth edition in Feb 2010 and so on. Currently, ICAO Annex 13, the twelfth edition (eighteen amendments), is the document that provides SARPs for investigating aircraft accidents and incidents. The purpose of mentioning the developmental background of this regulatory document is to underscore the inadequacy of 'safety data' and 'safety information' generated from past investigations. Based on the past investigation report analysis, it was observed that 'investigation' is an area that lacks objectivity and focus [23], and the regulatory framework does not include the guidelines and quality standards norms of safety recommendations [34]. The example of the Indian scheduled operator quoted in the 'Introduction' section can also be viewed with this reflection. However, the shortcomings of past investigations are beyond the scope of this study, although they are credible barriers to comprehensive learning from the past. This study takes safety data and information produced by past investigations as potential learning content. Since maintenance staff is the core of this study, for this stage, the scope of the study includes the contribution of maintenance staff in safety investigations and the outcomes they perceive from it. ICAO document 9756-part III [35] deals with investigating a safety occurrence and provides guidelines to ascertain maintenance errors on different counts, such as human factors, skill, knowledge, equipment, etc. An honest and proactive contribution of the maintenance staff in the investigation process perhaps generates more credible safety information about the hazardous latent conditions in the organization. Thus, this study evaluates the contribution of maintenance staff to investigating processes in ascertaining the causal and contributory factors of safety occurrences. This aspect will likely provide insight into maintenance staff's perception of the Reason's 'blame cycle,' and the regulatory intent of 'investigation is to prevent a recurrence.' Based on the above literature review, the following hypothesis is formulated:

H4. 'Lack of contribution' of the maintenance staff in the safety investigations is negatively related to the safety communication stage of the LPSI process model.

In the case of investigation of voluntary reportings, management's intent and actions on voluntary reportings determine the quality and quantity of content for LPSI [13]. The generation of safety information through the investigation of voluntary reports is hindered as maintenance staff does not actively participate in voluntary reporting of unsafe conditions and acts because of several factors, including organizational culture, feedback, and trust in management [27]. In other words, if voluntary reportings are not appropriately investigated, this eventually becomes the barrier to 'safety reporting' (included under the barriers to voluntary reporting) and, in turn, to LPSI.

2.2.3. Barriers to the 'safety communication' stage

In pursuit of identifying the other barriers to the LPSI process model, scholarly literature suggested that the investigation reports are generally voluminous, and technicalities, including the expression of contents and the taxonomy used, are unavailable in a sufficiently accessible format [12]. This underscores the need to analyze and formulate the extracted 'safety data' and 'safety information' from the 'safety investigations' in the organizational context wherein maintenance staff comprehends the objective aspects of what

Table 1
Influencing factors to LPSI.

Stages	Construct and Description	Research and Regulatory publications
Voluntary Reporting	Lack of Trust: Trust between the frontline maintenance staff and the management of aircraft maintenance facilities. Complicated reporting procedure: The extent to which the frontline maintenance staff finds voluntary reporting difficult. Lack of Utility of Reporting: The degree of benefit (in terms of prompt action by management, recognition, organizational policy, etc.) perceived by the frontline maintenance staff for voluntary reporting.	[26,28], and [27].
Safety Investigations	Lack of contribution: The extent to which frontline maintenance staff participates in a safety investigation.	[28,35].
Safety Communication	Safety Communication: The extent to which safety information drawn from past safety investigations is organized in an organizational context for communicating to maintenance staff through emails, newsletters, safety circulars, bulletins, etc., and safety training, human factor training, continuity training, safety meetings, etc.	[1,36], [20,25,37]
Safety Audit	Organizational Commitment to Safety Communication: The extent to which resources regarding time, technology, and money are allocated to safety communication.	[21,37]
Learning	Indicators to LPSIs.	[13,25]

happened and why the accident/incident occurred [36]. Conceptually, this contextualized safety information indicates hazards in the working system that either have caused/contributed to past events (applicable for MOR) or have the potential to cause/contribute to future events (relevant to voluntary reports) [25]. This is the essence of learning for HIRM and is closely associated with the organization's communication strategies and the 'safety communication' stage of the LPSI process. 'Safety communication' is a formally structured process, and in the aircraft maintenance industry, safety information drawn from safety investigations is communicated to stakeholders in written form through emails, newsletters, safety circulars, bulletins, etc., and audiovisual modes of safety training, human factor training, continuity training, safety meetings, etc., wherein each method of communication have barriers as argued by Refs. [1,20,25,36,37]. Therefore, it is hypothesized that:

H5. The safety communication stage of the LPSI process model is positively related to learning from past safety investigations.

2.2.4. Barriers to the 'safety audit' stage

'Safety audit' in the aircraft maintenance industry can be viewed with two connotations: the internal audit, usually conducted by the organization itself (in some cases, may be outsourced to a third party), and the external audit conducted by the regulatory agency. A safety audit (internal or external) aims to verify compliance with the regulations and conformance with the procedures and good safety aviation practices [38]. However, safety oversight is restricted to only the delivery of training programs rather than verifying their effectiveness during the 'safety audit' stage [21]. Organizations focus more on remedial measures recommended in safety investigations rather than preventing recurrence or remedy quality [1]. The financial implication to the organization is seen as a significant factor when planning safety communication, such as training need analysis, continuity training programs, and human factor training [20]. In the competitive business environment, aircraft maintenance organizations are inclined to demonstrate minimum compliance rather than only consider it a baseline. Based on the above literature review, the following hypothesis is formulated:

H6. Organizational commitment is positively related to the safety communication stage of the LPSI process model.

It is important to note that (mentioned in the previous paragraph) the aircraft safety occurrence investigation procedure has undergone various changes, including common ADREP taxonomy and many such requirements with time. Therefore, converting 'safety data' and 'safety information' in an organizational context is the most critical step for learning effective and efficient HIRM. Finally, to ascertain the effectiveness of the learning of the maintenance staff, "A model for levels of learning from incidents" [13] was taken as a reference along with the regulatory publication [25]. The barriers to various stages of LPSI are summarized in Table 1. It can be assimilated that although the stages are named independently, they are interlinked, and the performance of one stage affects the other stages.

2.3. Conceptual model

The two primary outcomes of the previous section are, firstly, the LPSI model specific to the aviation industry (Figure: 2) underpinned by the models of [1,18,32] and the regulatory framework [25] and secondly, the identification of the factors affecting LPSI based on [13,21,23,26,37]. Combining the two, a conceptual model depicting the effect of variables on safety communication and, eventually, on learning from the past is developed by the researchers (Fig. 3).

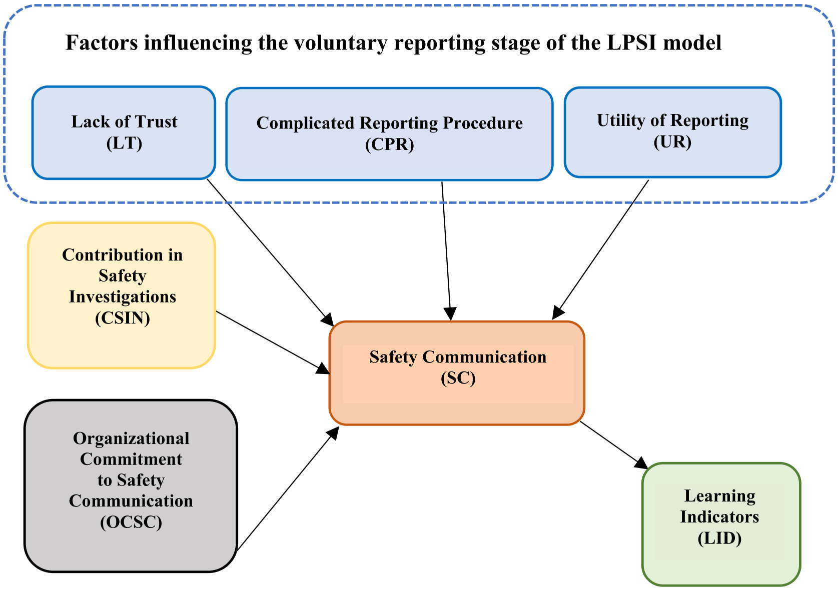

Fig. 3. The conceptual model to assess the effect of barriers on learning from past safety investigations.

3. Research methodology

Partial Least Square-Structural Equation Modeling (PLS-SEM) is a class of multivariate analysis techniques that includes factor analysis and regression, which enables the researchers to simultaneously evaluate the relationship between measurable (items) and unmeasurable variables (constructs) and between the constructs [39]. This method develops more accurate estimates and avoids the indeterminacy problem as its algorithm calculates construct score as precise linear combination of the observed variables [40]. The multivariate normality of the data set was tested using Mardia's multivariate calculator. The skewness and kurtosis were observed to be out of limits of ±1 and ± 20, respectively, thus ruling out the multivariate normality and suitability of the data's parametric statistical analysis Covariance Based-Structural Equation Modeling (CB-SEM). Therefore, in this study, PLS-SEM is preferred over CB-SEM for the complexities of the latent variables and their indicators to identify key driver constructs [40].

3.1. Measuring tool

This study views the influencing factors to LPSIs based on the perspective of the front-line maintenance staff. To measure their perceptions, a qualitative data collection tool, 'survey,' was developed by the researchers. The survey questionnaire was drafted on the literature review outcomes, which yielded an item pool of 48 questions to reflect on seven constructs. Underpinned on the developed LPSI process model, while three constructs reflect the factors influencing the voluntary reporting stage, the other three represent the 'safety investigation,' 'safety communication,' and 'safety audit' stages. The last construct is an indicator of learning. The items under each construct of the survey questionnaire are adapted from previous research articles and/or regulatory publications. For instance, two studies associated with the aircraft maintenance industry [26,27] have identified the factors that adversely influence voluntary reporting by the maintenance staff, whereas [28] underscores the essentials for a successful voluntary reporting system. Hence, in the questionnaire, three essential features of a successful voluntary reporting system, i.e., trust, ease of reporting, and usefulness, are defined as constructs, and the items are adapted based on [26,27]. The items of constructs 'safety investigation,' 'safety communication,' and 'safety audit' stages were adapted from Ref. [18] and subsequently developed in the aviation context as the study was based on energy sector findings. Finally, a construct 'learning indicator' was developed to manifest the learning from the past. As mentioned earlier (para 2.1.2), the scope of this study is limited to viewing learning from the past as a continual demonstration of improved hazard identification and risk management capabilities of front-line maintenance staff based on the safety information drawn from past safety investigations. The items of this construct are based on the regulatory requirements of ICAO Annex 19 and SMM. In the validation process of the questionnaire, two academicians (one from organizational behavior and another one from a decision science background) and three aircraft maintenance experts were invited to validate the formulated item pool. Researchers designed a validation form for this purpose, and each expert's opinion was sought independently for each item. The validation form had 3 Rs (Retain, Remove, and Review) options against each item, and experts were requested to elaborate on the reason in case "Remove" is recommended. Finally, a 42-item data collection tool was developed to reflect seven constructs on a 5-point Likert-type scale for data collection, having a neutral point to eliminate the forced response. To maintain unidimensionality, all the items of a construct are either positively or negatively worded [41]. Finally, a mix of positive (for three constructs) and negative (for four constructs) items are used in the questionnaire. The formulated survey form was piloted with nine maintenance staff for face validation, and all 42 items were retained for subsequent data collection and quantitative analysis. The coding details of each construct along with other acronyms used in this study and survey questionnaire are provided in Appendix 1 and Appendix 2 respectively.

3.2. Sample size

PLS-SEM is characterized to obtain solutions with small sample sizes of the models with multiple constructs and items [42]. Contrary to this [43], suggest the possibility of questionable results if fundamental sampling theory guidelines are not complied with. An extensively used "10-times rule" suggests ten times the maximum number of arrows pointing to a particular latent variable to ascertain the minimum sample size in PLS-SEM [44]. Although this sample size estimation is simple and user-friendly, it has been attributed to inaccurate estimation in the past [45]. The "inverse root square method" for minimum sample size estimation is reasonably accurate and straightforward [44]. Specific to this study, while the "10-time rule" suggests a minimum sample size of 100, the "inverse root square" method with a minimum path coefficient between 0.11 and 0.20 at a 5 % significance level and a power of 80 % recommends the minimum sample size of 155 [46]. A-priori online calculator with a medium (0.3) anticipated effect size, 0.8 statistical power level, and p-value of 0.05 suggests the minimum sample size of 170 to detect the effect and 200 for model structure [47]. Based on these three different approaches, it is reasonable to summarize that the minimum sample size of 200 is sufficient to get credible results. Therefore, this study is synthesized on the sample size of 287 valid participants to achieve its objectives.

3.3. Data collection

To achieve the study's objectives, the target population is maintenance staff (defined in the introduction section), recently retired and/or working in the Indian aircraft maintenance industry. A mix of purposive and snowball sampling was used for data collection. While the purposive sampling approach guides toward the object of the study and provides essential views of the participants [48], the snowball sampling approach relies on networking and referrals for data collection [49]. Mixing both sampling approaches will likely induce relevancy and efficiency in the data collection. The data was collected through a survey questionnaire. The first author was a delegate at an International Conference on Emerging Trends in Aviation MRO Industry [EAMRO 2023] organized on 22 April 2023 at the Indian Aviation Academy, India. The event had the participation of experienced maintenance staff from Indian MROs. Following the networking and referrals approach, this opportunity was utilized for data collection, and eventually, 311 responses were received against the distribution of four hundred survey forms. Eventually, 287 survey forms are identified as valid by applying the filtering criteria that respondent must have completed formal SMS training organized by the employing organization or with the regulatory agency-approved establishment.

4. Results

4.1. Demographic profile

In the survey form, the licensed AMEs are classified into two broad categories, category A1 and category (B1, B2, and/or C), primarily to differentiate the maintenance expertise of the maintenance staff directly working in aircraft line maintenance, hangar floor, component workshops, and engine shops. Non-licensed maintenance staff, personnel working in tool stores, spare warehouses, and/or having limited maintenance approvals are placed under the ‘others’ category. Further, only those forms were included in the study wherein the respondent has completed formal SMS training organized by the employing organization or with the regulatory agency-approved establishment. This filtering criterion aims to include responses aligned with the current regulatory framework, resulting in 287 valid participants out of 311 received responses. The demographic and professional details of the valid respondents are depicted in Table 2.

4.2. Measurement model

The outer model is a reflective measurement model as a particular latent variable’s independent measurable variables (indicators) are substantially correlated, and removing any indicator does not change the nature of the latent construct [42]. The reporting sequence of results largely complies with the [42] recommendations. Analysis of the measurement model is carried out in three steps. First, the reflective indicator loading assessment; second, the reliability and the convergent validity check; and lastly, the constructs’ discriminant validity assessment.

4.2.1. Indicator loading

The latent variables, a brief description of associated items with the codes, and the psychometric analysis of the measurement model are given in Table 3. Three items, SC1, SC2, and SC5 of the ‘Safety Communication (SC),’ and CSIN5 of the ‘Contribution to Safety Investigations (CSIN)’ constructs are below the acceptable reflective indicator loading limits (0.708). The SC construct’s Average Variance Extracted (AVE) (0.480) is also below the minimum acceptable level (0.500). While items SC1 and SC2 are far below the threshold value of loading SC5 at 0.646 and CSIN at 0.658, loadings are at the margin. Therefore, only two indicators highlighted in red (SC1 and SC2) are discarded from the analysis as they appear to reflect some other constructs. Discarding these two items from the study, the revised AVE (0.593) of the construct also falls within acceptable limits.

4.2.2. Reliability and convergent validity

The second step of assessing data reliability is measuring “composite reliability” and “Cronbach’s alpha.” While the measurement of the former is too liberal, the latter is considered too conservative, and the actual reliability of the construct lies within these two extreme values [42]. To address this issue [50], suggested a more accurate measure of construct reliability in the form of “rho-a,” which varies between 0.881 and 0.915 for the data set. The convergent validity of each construct measures the variance of its items, and the metric used for this is the average variance extracted (AVE), with 0.50 as the minimum acceptable AVE. The AVE values of constructs lie between 0.593 lowest to 0.704 maximum (see Table 4).

Table 2
Demographic and professional profile of the respondents.

Age	n	Academic Qualifications	n
Less than 30 years	58	High School	22
30–40 years	97	Intermediate (10 + 2)	46
41–50 Years	85	Bachelor’s	176
More than 50 years	47	Postgraduate and above	43
Gender		**Aircraft Maintenance Experience**	
Male	278	Ten years or less	56
Female	09	11–20 years	105
Others	00	21–30 years	97
		More than 30 years	29
License Details			
Category A1	76		
Category (B1, B2, and/or C)	113		
Others	98		

Table 3
Properties of measurement model.

Latent Variables (Constructs) with Codes	Brief Description of Observable Variables (Items) with Codes	Indicator Loading	AVE
CRP (Complicated Reporting Procedure)	CRP1: Additional workload	0.776	0.677
	CRP2: Reporting is Time-consuming	0.823	
	CRP3: Narrative format of reporting	0.770	
	CRP4: Investigation is time-consuming.	0.864	
	CRP5: Lack of clarity on what to report and not to report	0.876	
CSIN (Contribution in Safety Investigations)	CSIN1: Blame someone	0.884	0.685
	CSIN2: Legal implications	0.928	
	CSIN3: Not to improve safety	0.897	
	CSIN4: Possibility of getting into trouble	0.737	
	CSIN5: Fault-finding rather than establishing the root causes	0.658	
LID (Learning from Past Indicators)	LID1: Awareness of the hazards at my workplace	0.836	0.674
	LID2: Evaluation of learning outcomes	0.827	
	LID3: Integration of safety information with procedures	0.844	
	LID4: Repeated communication	0.811	
	LID5: Application at work	0.787	
LT (Lack of Trust)	LT1: Trouble-creator for management	0.813	0.704
	LT2: Adverse effect on career growth	0.770	
	LT3: Lack of “Waiver of Disciplinary Action” policy	0.865	
	LT4: No independent report-receiving agency	0.841	
	LT5: Management is production centric	0.900	
OCSC (Organizational Commitment to Safety Communication)	OCSC1: Management participation in the safety training	0.783	0.616
	OCSC2: Learning evaluation by employing organization	0.784	
	OCSC3: Learning evaluation by the regulatory agency	0.832	
	OCSC4: Evaluation of safety contents by the regulatory agency	0.817	
	OCSC5: Creativity in safety training	0.777	
	OCSC6: Training needs analysis	0.766	
	OCSC7: Integration of technological tools in safety training	0.732	
SC (Safety Communication)	SC1: Contextualized written safety communication	-0.101	0.480
	SC2: Written safety communication on safety occurrences	-0.304	
	SC3: Written safety communication on hazards	0.758	
	SC4: Quality of written safety communication	0.819	
	SC5: Audiovisual safety communication on safety occurrences	0.646	
	SC6: Audiovisual safety communication on hazards.	0.752	
	SC7: Audiovisual safety communication on human factors	0.732	
	SC8: Retention of safety communication	0.759	
	SC9: Safety communication and hazards of the workplace	0.819	
	SC10: Safety communication and hazards identification	0.827	
UR (Lack of utility of Reporting)	UR1: Benefit for reporting.	0.838	0.698
	UR2: Reporting is not a piece of safety information.	0.871	
	UR3: Word ‘reporting’ as being against someone.	0.822	
	UR4: Lack of policy related to investigating reports	0.774	
	UR5: Time frame to investigate voluntary reporting	0.869	

4.2.3. Discriminant validity

The next step is to assess the discriminant validity of the data set to understand the extent to which each construct is statistically distinct from others. Various methods are recommended to determine the discriminant validity. One way associated with variance and AVE suggests that all model constructs ‘shared variance’ should not be more significant than their AVEs [51]. In contrast [52], argue that the Fornell-Larcker measure does not hold well, especially when the indicator loadings are too close and differ only slightly, and proposed “Heterotrait-Monotrait” ratio (HTMT) to assess the empirical distinction among constructs. HTMT value above 0.90 indicates the nonexistence of discriminant validity; however, when the constructs are conceptually more distinct, a more conservative value such as 0.85 is suggested. The data set displays the maximum HTMT ratio of 0.607 (see Table 5) and thus establishes the discriminant validity.

Table 4
Reliability and convergent validity.

Constructs	Cronbach’s alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average Variance Extracted (AVE)
OCSC	0.896	0.897	0.918	0.616
CPR	0.882	0.915	0.913	0.677
CSIN	0.882	0.910	0.914	0.684
LID	0.879	0.881	0.912	0.674
SC	0.901	0.903	0.921	0.593
LT	0.894	0.896	0.922	0.704
UR	0.893	0.905	0.920	0.698

4.3. Structural model

4.3.1. Collinearity assessment

The first step is evaluating the collinearity of the model's predictor constructs and separating the potential collinearity sets for further evaluation. Collinearity describes the linearly related predictor variables in the statistical model, which may lead to unstable parameters and biased inference statistics [53]. The Variance Inflation Factor (VIF) estimates the degree of collinearity. Its recommended value ranges between 0.20 and 5; in the case of exceedance, the model will be reviewed, and constructs will be merged or eliminated (Hair et al., 2016). This study's data set demonstrates the VIF values for the pair of constructs between 1.000 and 1.546, which is well within the acceptable limits (see Table 6).

4.3.2. Common method bias

A single measuring scale (Likert scale 1 to 5, used in this study) for all survey questions can introduce measurement errors, usually known as common method bias [54]. argues that if all VIFs are within the threshold (3.3), the model may be treated free from common method bias. In this study, the maximum value of VIF is 1.546, which is well within the defined limits. However, for this study, the common method bias was also tested using the most widely used method, 'Harman's single factor test,' which resulted in the average variance against a single item being 26 % (within the limits of 50 %). Therefore, it is concluded that the data received in this study is free from common method bias.

4.3.3. Significance and relevance of the model relationship

On verifying the degree of collinearity and absence of common method bias, the model is assessed as suitable for further assessment and hypothesis testing. Hypothesis H1 states that a lack of trust between the management and the maintenance staff in voluntary reporting is negatively associated with safety communication. The results reveal that 'lack of trust' has a significant and negative impact on 'safety communication' ($B = -0.308$, $t = 5.085$ and $p = 0.000$), and thus H1 is supported. Similarly, hypotheses H2 to H6 are tested, and the results are summarized. All the hypotheses are endowed with significant p values. The results are presented in Table 7, and the structure model is shown in Fig. 4.

4.3.4. Coefficient of determination (R^2) of endogenous constructs

After ascertaining the non-existence of collinearity, common method bias, and significance of model relationship in the structural model, the third step is evaluating the R^2 values of endogenous constructs, also implied as in-sample predictive power [55]. R^2 value describes the variance in the endogenous variables by the exogenous variables and is also considered to measure the explanatory power of the model [56]. The range of R^2 varies from 0 to 1, and as a guideline, the values of 0.25,0.50 and 0.75 are treated as weak, moderate, and substantial [42]. In this study's structural model, the R^2 of learning indicators (LID) and safety communication (SC) are 0.277 and 0.503, respectively.

4.3.5. Effect size (F^2 value)

F^2 value indicates the change in R^2 when an exogenous variable is deleted from the model and varying effect size is defined by the [57] rule of thumb as, ≥0.02 is small, ≥0.15 is medium, and ≥0.35 is large. The effect size results on this study's endogenous variable are given in Table 8.

4.3.6. Predictive relevance (Q^2 value)

The Q^2 of the PLS path indicates the model's predictive accuracy, and a model is considered to have predictive relevance if the Q2 value is more than zero. In the case of this study, the Q2 values for both the endogenous constructs (LID and SC) are 0.152 and 0.478, respectively, indicating that the model has predictive relevance, and these values conform to small and moderately large predictive relevance [42].

5. Discussion

As the conceptual model depicts (Fig. 3), 'safety communication' is the heart of learning from past safety investigations. Based on the conceptual model, the structural model was developed, where the predictive relevance of the 'safety communication' construct is observed as moderately large, which supports the conceptual model and the relations of safety communication with other constructs.

Table 5
HTMT values of constructs for discriminant validity.

	OCSC	CPR	CSIN	LID	SC	LT	UR
OCSC							
CPR	0.077						
CSIN	0.222	0.055					
LID	0.356	0.157	0.275				
SC	0.607	0.150	0.452	0.590			
LT	0.400	0.100	0.590	0.358	0.605		
UR	0.166	0.038	0.174	0.129	0.330	0.113	

Table 6
Collinearity test for the pair of different constructs.

Construct Pair	VIF
CRP - > SC	1.010
CSIN - > SC	1.416
LT - > SC	1.546
OCSC - > SC	1.171
SC - > LID	1.000
UR - > SC	1.041

Table 7
Direct relationships.

Hypothesis	Beta Coefficient	Standard Deviation	T statistics	P values
Trust - > Safety Communication (H1)	−0.308	0.061	5.085	0.000
Complicacy - > Safety Communication (H2)	−0.097	0.042	2.231	0.026
Utility - > Safety Communication (H3)	−0.201	0.047	4.224	0.000
Contribution - > Safety Communication (H4)	−0.144	0.056	2.539	0.011
Safety Communication - > Learning Indicator (H5)	0.526	0.043	12.134	0.000
Commitment - > Safety Communication (H6)	0.370	0.050	7.448	0.000

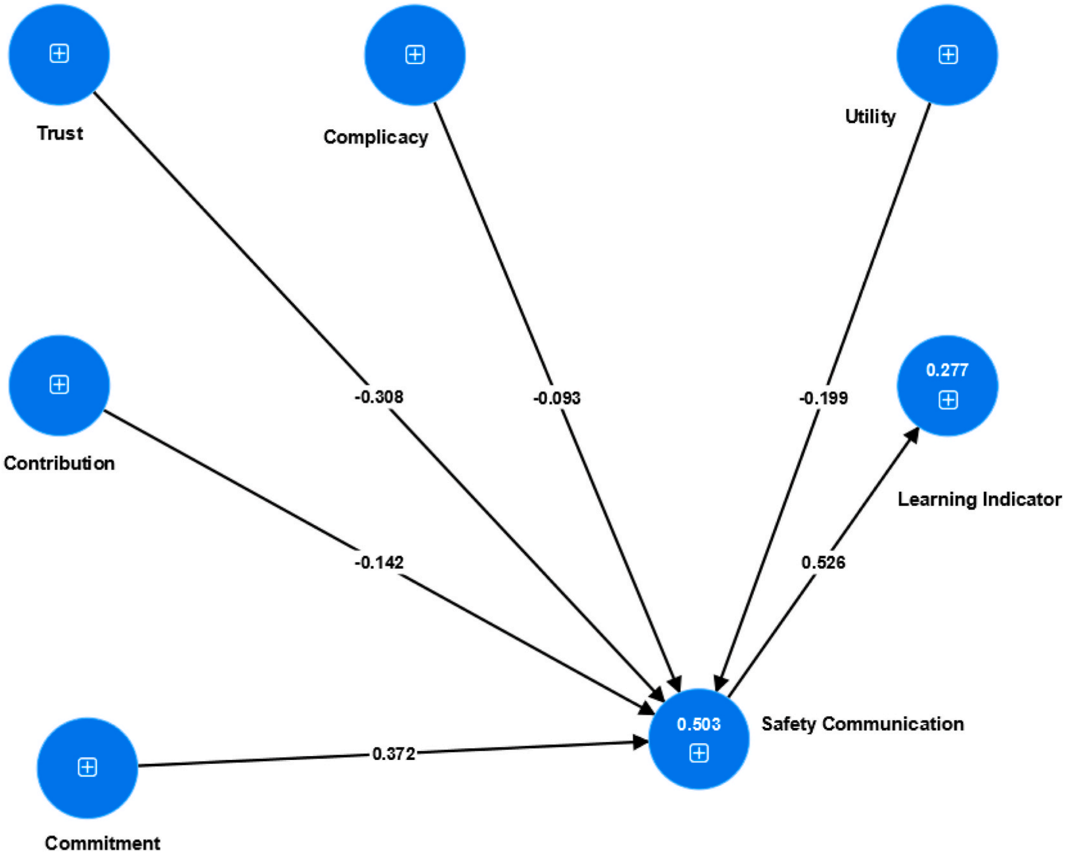

Fig. 4. Path coefficient and t-values for the structural model.

Also, the results derived based on the [42] recommendations indicate the model's validity with values of different parameters within acceptable limits. This study was conducted keeping maintenance staff at the center stage with the participation of 287 maintenance staff with varying experience in the aircraft maintenance domain (Table 2). However, the opinions of other stakeholders, for instance, safety managers, quality control managers (QCM), Accident/incident investigators, and accountable managers (AM), may add more value to understanding this reactive methodology. Thus, an opportunity exists for future research to explore organizational

Table 8
Effect size.

Exogeneous-Endogenous Relations	F^2	SE	T Stats	P values	Effect Size
Commitment - > Safety Communication	0.237	0.025	1.156	0.248	Medium
Complicacy - > Safety Communication	0.017	0.017	1.032	0.302	Insignificant
Contribution - > Safety Communication	0.029	0.052	2.353	0.019	Small
Safety Communication - > Learning Indicator	0.382	0.073	3.233	0.001	Large
Trust - > Safety Communication	0.123	0.088	4.32	0	Small
Utility - > Safety Communication	0.076	0.04	1.897	0.058	Small

management and investigators' perspectives on learning from the past.

In the SEM, the three constructs (LT, CPR, and UR) relate to the factors that influence the 'voluntary reporting' stage of the LPSI process model. In other words, the first three hypotheses (H1, H2, and H3) establish the relationship between the 'voluntary reporting' stage and 'safety communication' stage of the LPSI process model (Fig. 2). The results indicate that among the factors that influence voluntary reporting, 'lack of trust' (LT) between the maintenance staff and the management is the most muscular construct for safety communication (−0.308), followed by the 'Usefulness of reporting' (UR) at (−0.199). In contrast, the construct of a 'complicated reporting procedure' (CPR) is evaluated to have the least impact (−0.093) on voluntary reporting, as perceived by the maintenance staff. As measured in the model, the lack of trust between the maintenance staff and the organization's management is the prime reason that prevents maintenance staff from reporting hazards and near misses they observe in the aircraft maintenance facilities. This condition makes the all-inclusive and participatory pillar of contemporary SMS weak. Safety information about these hidden threats is not communicated at the 'safety communication' stage as it does not exist in the organizational repository. This adversely affects learning from the past because organizations fail to collect safety data and information. Moreover, non-reporting by the maintenance staff keeps the safety threats hidden until combined with other conditions to get converted into incidents and accidents. When viewed from the maintenance staff's perspective, the other interpretation of these three latent variables is the importance of the 'trust' and 'usefulness' components in voluntary reporting. This implies that when maintenance staff are convinced of the usefulness of voluntary reporting and have high trust in the organizational management, procedural complicacy and inconvenience in voluntary reporting are likely to be diminished. Aligned with this finding [58] suggested a conceptual model, "Diagnosis in Communication and Trust in Aircraft Maintenance (DiCTAM)," which established a positive relationship between the maintenance staff communication (voluntary reporting) and their trust in organizational management. Analogous studies [59,60] conducted in military and civil environments also present similar results to define the relationship between the attitude of maintenance staff in communicating their errors and the trust they perceive with other organizational entities. The structural model is useful in prioritizing the problems; for example, the various indicators that reflect the 'lack of trust' indicator LT5 (management is production-centric, so I prefer to find my safe solution rather than reporting) has a maximum impact (0.901) as perceived by the maintenance staff. The management has to be cautious about this aspect as it may lead to 'disengaged silence' of maintenance staff [27] and defy the fundamental tenet of the participative and all-inclusive approach of the current safety management system. The accountable manager and the senior management of the aircraft maintenance organization may utilize the indicators impact factor to address and prioritize the problem areas.

The 'lack of contribution' of maintenance staff to the safety investigation negatively affects safety communication (−0.142). Lack of contribution invariably results in a shortfall of safety information generated by the investigations. Thus, safety information about some causal or contributory factors or latent unsafe conditions will likely be excluded from safety communication. The critical indicator reflecting this barrier, as seen by the maintenance staff, is CSIN2 (investigation is time-consuming, with many legal implications, so I refrain from associating with it unless called for by the investigating team), with an impact factor of 0.928. This indicates that the maintenance staff generally view the investigation process differently than the purpose it is meant for. The role of management and the investigating team is crucial to address this point. Honest communication with the organization's maintenance personnel highlighting the investigation's intent before commencing the investigation may encourage maintenance staff to participate without their self-imposed fear. The factors influencing the learning from past old investigations reports are not included in the scope of this study as firstly, it is not aligned with the target population (maintenance staff) of this study, and secondly, contextualization of the safety information of old investigation reports in the current context may be a separate area of research.

'Safety communication' has a positive and significant impact (0.526) on learning (Fig. 4). This stage of the LPSI process model is also the formal learning zone where the learning product is delivered to maintenance staff. The learning product's delivery is typically accomplished by first contextualizing the safety information drawn from the investigation reports, followed by communicating it in written and audiovisual modes. The latent variable 'safety communication' was defined by eight indicators. The indicators measure all aspects of safety communication, i.e., contextualized safety information followed by delivery in written and audiovisual methods. SC9 and SC10 are the most significant indicators, with load factors of (0.819) and (0.827), respectively. These two indicators relate to maintenance staff awareness about the hazards at the workplace and their ability to identify them based on learning at the safety communication stage. This aspect makes contextualizing safety information one of the critical activities for safety communication. Safety managers must ensure that the safety information drawn from investigation reports is contextualized in the organizational working processes and environment before communicating it in written and audiovisual modes. The learning indicators of construct 'LID,' which explores the perception of maintenance staff on learning from the past, also supports that safety information is to be integrated with their work procedures (LID3) with the maximum load factor (0.844), which eventually establishes that maintenance staff perceives learning when safety communication is in their working context.

Organizational commitment to safety communication (OCSC) is the most influential variable that affects safety communication (0.372). The construct 'OCSC' relates to the 'safety audit' stage of the LPSI process model. The measurement model indicator OCSC 3 (The regulatory agency evaluates my learning in safety training) with the maximum load factor (0.832) underscores the importance of assessing the knowledge acquired by the maintenance staff in the safety communication stage. As stated in the previous study [21], regulatory safety oversight is restricted to delivering safety communication rather than verifying its effectiveness. If the organization and regulatory agency are not evaluating the learning outcomes of the safety communication stage, learning from the past is negatively affected. The measurement model provides each indicator's impact while measuring the organizational commitment to safety communication in the Indian context. This may vary, and some more indicators (not considered in this study) be surfaced. Therefore, management must holistically assess their organizational working culture and consider the indicators applied in this study as a baseline.

6. Conclusion

The LPSI process model and the structural model developed in this paper provide a systematic and comprehensive understanding to the decision-makers on the chronic issue of the aviation maintenance industry, i.e., learning from the past. The application of these models allows the state regulators and senior management to estimate the impact of various factors on learning from the past. In this study, research articles were viewed through the prism of regulatory framework primarily to include the practicalities of hangar floor level. Firstly, the word 'past' was evaluated with two different considerations; one is based on accidents and incidents occurrences (rare), while another is associated with hazards and near-misses encountered by the maintenance staff at the workplace (frequent). This approach considerably enhances the safety data availability besides aligning with the contemporary systemic safety management strategy. Secondly, based on the research articles and regulatory publications, an aircraft maintenance industry-specific learning process model was developed, which can also be applied to other high-risk ultra-safe industries by combining with the applicable regulatory guidelines to study the learning from past issues. Finally, the structural equation model establishes the relationship between learning from the past and its influencing factors. The primary outcome of this study is as follows:

- When maintenance staff are convinced of the usefulness of voluntary reporting and trust the management, they intend to voluntarily report the hazards and near-misses to the organizational system even if the reporting procedure is complicated and inconvenient.
- Generally, maintenance staff avoid contributing to safety investigations because they perceive it as time-consuming with legal implications. This eventually leads to the loss of safety information and adversely impacts learning from the past. It is the need for State regulators and the management to create an atmosphere where frontline aircraft maintainers proactively involve in the safety investigation process.
- Safety communication has a substantially strong impact on learning from past safety investigations. Presently, no regulatory framework exists to assess the effectiveness of safety communication and associated learning from the past. This may lead to organizations conducting safety communication as an activity without paying much attention to its intent. Demonstrating 'minimum compliance' (of safety communication) to regulators eventually wastes resources if the objectives of safety communication are not achieved.
- Contextualization of safety information is critical for effective safety communication as maintenance staff perceives learning from the past when safety communication is related to their work processes and environment.
- Maintenance staff perceive learning from the past to be manifested in enhancing their capabilities to identify workplace hazards.

This study underscores the criticality of the 'safety communication' stage in learning from the past process; as such, it is the only established and policy-driven mechanism in aircraft maintenance organizations to share learning content with maintenance staff. State regulators and management can easily adapt the models developed in this study to assess the weak areas in their context in the various stages of the LPSI process model. This study can also be the foundation for further building up the concept of learning from the past, as it is based only on the perception of the frontline maintenance staff. The experience of regulators, management, and accident investigators can also be included to understand the issue comprehensively. Another aspect, the organizational commitment towards safety, was also limited to 'safety communication.' The other dimensions of organizational commitments to learning from the past, such as financial support, human resource allocation, and technological interventions, can also be considered while developing more detailed models.

Data availability statement

Data included in article and supplementary material.

CRediT authorship contribution statement

Alok Tyagi: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rajesh Tripathi:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis. **Soufiane Bouarfa:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1. Abbreviations and Acronyms

ADREP	Accident/Incident Data Reporting System
AM	Accountable Manager
AME	Aircraft Maintenance Engineer
ASRS	Aviation Safety Reporting System
AVE	Average Variance Extracted
BASIS	British Airways Safety Information System
CB-SEM	Covariance Based-Structural Equation Modeling
CPR	Complicated Reporting Procedure
CSIN	Contribution to Safety Investigations
DGCA	Directorate General of Civil Aviation, India
EAMRO	Emerging Trends in Aviation MRO
HIRM	Hazard Identification and Risk Management
HTMT	Heterotrait-Monotrait
ICAO	International Civil Aviation Organization
LFI	Learning From Incidents
LID	Learning Indicators
LPSI	Learning from Past Safety Investigations
LT	Lack of Trust
MLG	Main Landing Gear
MOR	Mandatory Occurrence Report/Reporting
MRO	Maintenance, Repair, and Overhaul
OCSC	Organizational Commitment to Safety Communication
PLS-SEM	Partial Least Square-Structural Equation Modeling
QCM	Quality Control Manager
SARP	Standards and Recommended Practice
SC	Safety Communication
SMM	Safety Management Manual
SMS	Safety Management System
SSP	State Safety Programme
UR	Utility of Reporting
VIF	Variance Inflation Factor

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21620.

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