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Using the Systematic Literature Review in Aviation: A Case Study for Runway Incursions

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This research presents the process for a systematic literature review, and demonstrates the application of this process using a case study that investigates the factors that contribute to runway incursions (RIs). Runway safety is a top priority in aviation (Federal Aviation Administration [FAA], 2012a). One factor that threatens runway safety is RIs. In the United States, an average of three RIs occurs daily. Although the reduction of RIs has been a topic of interest for many years, the number of RIs has been increasing since 2012. In this paper, a systematic literature review approach was used to synthesize the results of previous studies in a systematic way, identify contributing factors for RIs, and provide insight regarding the causes for RIs. One hundred and thirty-four articles were identified in the initial literature search from 22 databases, and 22 articles were analyzed after using filtering criteria. As a result of this analysis, six categories of contributing factors to RIs were identified: human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors. Recommendations for reduction of RIs and suggestions for further studies were presented based on these factors.

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Runway safety is a significant challenge and a top priority in aviation (Federal Aviation Administration [FAA], 2012a). One factor that threatens runway safety is runway incursions (RIs). In the United States, an average of three RIs occur daily. Every incident has the potential to cause injury or death, as well as property damage. Although the reduction of RIs has been a topic of interest of the Federal Aviation Administration (FAA) for many years, the number of RIs has been increasing since 2012 with 6,830 RIs occurring between 2012 and 2016 (FAA, 2017). Due to the important safety implication, it is valuable to analyze contributing factors in a systematic way, to assure that mitigation efforts focus scarce resources where they can have the greatest impact (Mathew, Major, Hubbard, & Bullock, 2016).

The systematic literature review approach is popular in other disciplines, such as medicine and health, and its application has a long history of improving safety in these industries. In some cases, medicine has learned from aviation, such as through the use of crew resource management in the operating room, and the application of safety management systems for a systematic approach to safety improvement. In this case, aviation can learn from medicine. This paper demonstrates the application of the systematic literature review methodology, a method that has not been commonly used in the aviation field. In contrast to the traditional literature review which is referred as narrative review, a systematic literature review uses a rigorous research methodology in an attempt to minimize bias, which means it is more objective (Bettany-Saltikov, 2010).

Although many narrative reviews have been published in aviation field, there were very few articles on the systematic literature review for the aviation. In this paper, the systematic literature review approach is used to identify the key contributing factors of RI events. Research papers that reported on the quantitative and qualitative analysis of causes of RIs were selected from a variety of databases in this study. The paper presents the synthesis and analysis of the factors contributing to RIs, based on the results of both quantitative and qualitative research as documented in peer-reviewed articles.

Background

Runway Incursions

The FAA (2015b) defines a runway incursion as, "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft" (para. 1). The FAA (2015b) further defines four categories of RI severity, with Category A being the most severe and Category D being the least:

- Category A: a serious incident in which a collision was barely avoided.
- Category B: an incident with significant potential for a collision; situation may require a time critical corrective response or evasive response to avoid a collision.
- Category C: an incident in which there is ample time and/or distance to avoid a collision.

- Category D: an incident with no immediate safety consequences although it meets the definition of RI due to the incorrect presence of a vehicle, person, or aircraft on the runway or protected area.

The FAA (2015b) also classifies RIs according to the following three major causes:

- Operational incident (OI): a RI due to the action of an air traffic controller. This includes clearing an aircraft for a closed runway or an action that results in inadequate separation between aircraft, or between aircraft and vehicles or other obstacles.
- Pilot deviation (PD): a RI due to the action of a pilot. This includes entering the runway without clearance from air traffic control (ATC) or other actions that violates any Federal Aviation Regulation.
- Vehicle/pedestrian deviation (VPD): a RI due the action of a pedestrian or vehicle. This includes a pedestrian or vehicle entering the runway or any other portion of the airport movement area without ATC authorization.

According to the FAA (2017), the number of RIs has been increasing since 2012. The most common cause for RIs is PD, which comprised 61.9% of the RIs between 2012 and 2016, followed by OI, which accounted for 20.2%, and VPD, which represented 17.5%. Table 1 shows the totals and causes of RIs from 2012 to 2016.

Table 1

U.S. RI Totals by Cause for Fiscal Years 2012-2016

Year	OI	PD	VPD	Other	Total RI per Year
2012	211 (17.9%)	765 (65.0%)	199 (16.9%)	2 (0.2%)	1,177
2013	261 (20.6%)	781 (61.7%)	216 (17.1%)	8 (0.6%)	1,266
2014	264 (20.7%)	776 (60.7%)	234 (18.3%)	4 (0.3%)	1,278
2015	326 (21.7%)	912 (60.6%)	264 (17.5%)	3 (0.2%)	1,505
2016	318 (19.8%)	993 (61.9%)	285 (17.8%)	8 (0.5%)	1,604
Total RIs per Type	1,380 (20.2%)	4,227 (61.9%)	1,198 (17.5%)	25 (0.4%)	6,830 (100%)

Note. Other includes RIs not categorized or RIs that do not meet the OI, PD, or VPD criteria.

Systematic Literature Review

A systematic literature review is an analysis of previous research using a systematic and explicit method to identify, select, and critically appraise relevant studies and to collect and analyze data from them (Siddaway, n.d.). A systematic literature review aims at addressing research questions by identifying, critically evaluating, and integrating the findings of all relevant and high-quality studies.

The main steps in conducting a systematic literature review are as follows (Siddaway, n.d.):

1. Formulating one or more research questions.
2. Searching for relevant data and identifying the publications.
3. Defining the inclusion and exclusion criteria.

4. Selecting the publications that are relevant to the question and extracting the data.
5. Critically evaluating the publications and assessing the data quality.
6. Performing data analysis and combining results.

Academic contributions must be considered within the context of previous work (Salkind, 2011); however, the number of articles published each year has been increasing dramatically (Borrego, Foster, & Froyd, 2014). Many researchers are not able to read all the published articles that are relevant to the current context for a given study area. Therefore, some research fields have developed the systematic literature review approach to synthesize the primary studies in their respective fields. In fields like education, medicine, and psychology, extensive systematic literature reviews have been conducted. By providing synthesized reviews on important topics or issues, vital contributions to evidence-based disciplines can be made (Gough, Oliver, & Thomas, 2012). For example, systematic literature reviews have demonstrated gaps in recent work and highlighted areas where a concept is accepted as true, despite little evidence to support it (Petticrew & Roberts, 2008). A systematic literature review offers a methodology that can be used by an interdisciplinary research team to design a transparent approach to selecting, analyzing, and synthesizing study to address its research question (Borrego, Foster, & Froyd, 2015). For instance, Wauben, Lange, and Goossens's (2012) research analyzed the similarities and differences of safety between the aviation industry and operation rooms in the hospital.

Systematic literature review in other disciplines. Other disciplines which have utilized systematic literature reviews include medicine, biochemistry, genetics and molecular biology, nursing, pharmacology, toxicology and pharmaceutics, neuroscience, and psychology. Numerous systematic literature reviews have been published in these areas in the past decade. A wildcard search of Scopus, the largest abstract and citation database of peer-reviewed literature, with "systematic review*" in the title, abstract or keywords, showed that the subject area produces the most systematic literature reviews is medicine, with 66,871 documents published from 2007 to 2016. The wildcard search provides results for systematic review and systematic reviews. Figure 1 shows the trend of published systematic literature reviews in subject areas such as biochemistry, genetics and molecular biology; nursing; pharmacology, toxicology and pharmaceutics; neuroscience; and psychology. These are all topic areas that are generated by Scopus. In these areas, the number of published systematic literature reviews is increasing rapidly. However, there were very few articles on the systematic literature review for the aviation field, as evidenced by the results shown, which reflect a search using "systematic review*" and "aviation" in the title, abstract or keywords.

Since systematic literature reviews are very popular in the health field, a search for systematic literature reviews in PubMed was conducted to demonstrate its potential application in aviation. PubMed is the National Library of Medicine's search interface to the MEDLINE database, which includes over 26 million references to articles, from medicine, nursing, basic sciences and related biomedical fields. The PubMed database offers a search option using "systematic reviews" as one article type and therefore has a dedicated collection. According to the search results from PubMed, a total of 80,283 systematic literature reviews were published from 2007 to 2016.

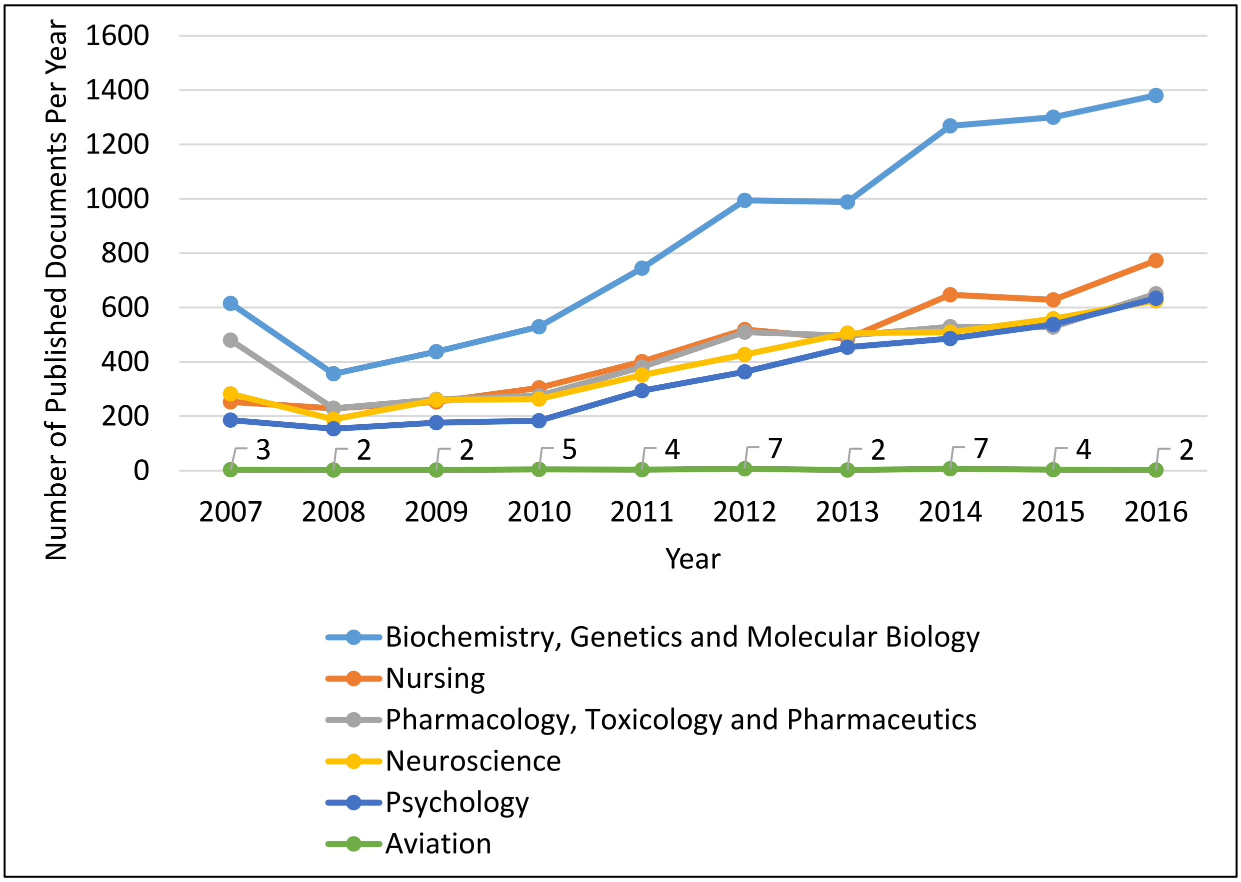

Figure 1. Number of systematic literature reviews by subject and year, 2007-2016, data source: Scopus.

In the medical field, systematic literature reviews have become highly valued evidence for clinical practices and public policies. Lessons learned from other high-risk industries are helpful for improving aviation safety, and perhaps, in this case, the aviation industry can learn from medicine, which has a long history of improving safety through clinical trials and other evidence-based approaches.

Systematic literature review in the aviation field. Although reducing the severity, number and rate of RIs was ranked as the most important goal to improve runway safety by the FAA (FAA, 2012b), the systematic literature review has not been used in aviation research to address runway safety or RIs. There were few systematic literature reviews related to aviation. A total of 38 systematic literature reviews in aviation were published during the past decade with most related to medical and health-related aviation topics, such as the examples below:

- "Learning from Aviation to Improve Safety in the Operating Room – a Systematic Literature Review," described the similarities and differences between aviation and medicine industries and discussed methods and solutions with a systematic approach to reduce errors in operating rooms (Wauben, Lange, & Goossens, 2012).
- Huster, Müller, Prohn, Nowak, & Herbig (2014) researched the medical risks faced by older pilots, and investigated whether the pilot risk of incapacitation for medical reasons increases with age.

Study Motivation and Scope

RIs are a critical concern for the safety of the air transportation system. In the worst case, a RI can result in a collision and loss of life. In 1977, the catastrophic collision of two Boeing 747 aircrafts on the runway in Tenerife, Canary Islands, resulted in the death of 583 passengers and flight crew members (Netherlands Aviation Safety Board, 1979). On October 14, 1984, Aeroflot Flight 3352, a Tupolev Tu-154B-1, hit maintenance vehicles on the runway in Omsk, Russia (Aviation Safety Network, 2017). One hundred and seventy-four people aboard the aircraft were killed, as were four people in the maintenance vehicles.

While not all RIs result in an accident, a few serious RIs challenge aviation safety each year. According to the FAA (2017), 32 Category A RIs and 43 Category B RIs occurred in the five years between 2012 and 2016. During this time period, there were more than 6,000 RIs classified as Category C or Category D. This is consistent with research conducted by Heinrich (1941), who found that for every accident that causes a major injury, there are 29 incidents that cause minor injuries and 300 incidents that cause no injuries. Identifying and reducing RIs of all categories will help reduce the likelihood of severe RIs that cause injury or death. Figure 2 illustrates the Heinrich pyramid and its application to RI severity levels.

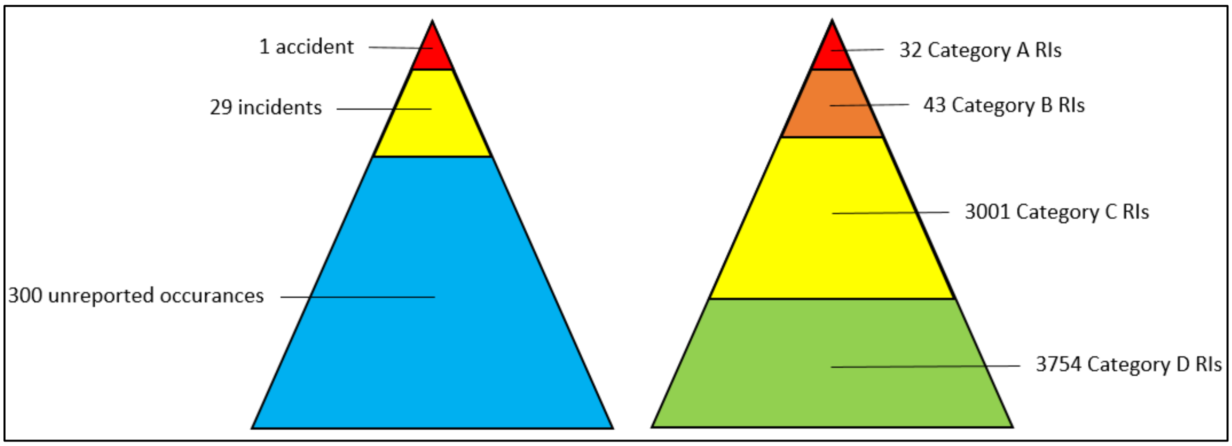

Figure 2. (Left) Heinrich (1941) pyramid and (right) its application to RIs severity (data source: FAA Runway Safety Office - Runway Incursions).

There have been numerous programs and systems put in place to reduce RIs. FAA announced the Runway Incursion Mitigation (RIM) program to identify the locations at airports where airport geometry might be a risk factor that contributes to RIs, and to develop strategies to help airport sponsors mitigate risk at these locations (2015a). Runway incursion avoidance and alerting systems are one approach to reduce RIs (Schönefeld & Möller, 2012). These systems include traffic information services, traffic information service broadcast, automatic dependency surveillance-broadcast, runway incursion prediction and detection algorithms, vehicle and airport sensors, human-machine interfaces, and airport traffic signals.

Despite the progress through RIM initiatives, the rate of RIs in the United States has steadily risen. According to the Bureau of Transportation Statistics (2017) and the General Aviation Manufacturers Association (2017), the number of flights in the United States has decreased slightly since 2012; however, the number of RIs has continued to increase during the same time period. In other words, both the number of RIs, and the rate of RIs, have increased steadily during the past five years.

However, it is still useful to closely examine the factors that have been identified to contribute to RIs. The objective of this paper is to present a methodology for systematic literature review, and apply this method to identify factors that contribute to RIs. In this research, a replicable and transparent systematic literature review approach is applied to identify, analyze, and synthesize the contributing factors to RIs. The methodology section describes the scope and procedures followed to conduct the systematic literature review. The results section presents the search and selection results, as well as the synthesis and analysis of factors that contribute to RIs. The recommendations section includes suggestions for preventing and mitigating RIs, as well as recommendations for future research studies.

Methodology

The methodology used in this study was a systematic literature review based on guidelines outlined in the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement” (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009). These guidelines were used to conduct a systematic literature review of correlating factors contributing to a higher incidence of RIs. This section describes the scope and procedures, including the data sources, the search strategies, inclusion and exclusion criteria, and the method of data extraction.

Data Sources and Search Strategies

The search was conducted using the 22 databases shown in Table 2. Among the databases searched were three key databases for aviation: Engineering Village, ProQuest Technology Collection, and Transportation Research Information Database (TRID) Engineering Village is an essential engineering research database which offers access to 12 engineering literature and patent databases that provide coverage from a wide range of trusted engineering sources. ProQuest Technology Collection is a major database in technology field. The Technology Collection is a full-text database which brings more value and access than other citation and abstract resources. The TRID is the world’s largest and most comprehensive bibliographic resource on transportation research information and it covers all modes and disciplines of transportation. The other databases shown in Table 2 include some aviation journals and topics, but typically have fewer results related to aviation.

The initial search was developed based on the key phrase “runway incursion.” The search criteria were customized for each database to reflect database-specific subject headings. The specifications are detailed below:

- Engineering Village: the search term was “runway incursion*” in subject/title/abstract for journal articles.
- ProQuest Technology Collection: the search term was “runway incursion*” in all fields for peer-reviewed and full-text articles.

- TRID: the search was limited to "aviation" subject area, with "runway incursion*" in all fields for articles and papers.
- Other databases: the search term was "runway incursion*" in all fields for peer-reviewed and full-text articles.

Table 2

Databases Used to Identify Sources

Citation Source	
1. Aerospace Database	12. ProQuest Advanced Technologies & Aerospace Collection
2. Civil Engineering Abstracts	13. ProQuest Computer Science Collection
3. Computer and Information Systems Abstracts	14. ProQuest Engineering Collection
4. Digital Commons (Bepress)	15. ProQuest Materials Science Collection
5. Electronics and Communications Abstracts	16. ProQuest Technology Collection
6. Engineering Village	17. SAGE Journals
7. Institution of Engineering and Technology (IET) (CrossRef)	18. Science Citation Index Expanded (Web of Science)
8. Materials Business File	19. ScienceDirect Journals (Elsevier)
9. Mechanical & Transportation Engineering Abstracts	20. Scientific.Net (Trans Tech Publications)
10. OneFile (GALE)	21. Scopus (Elsevier)
11. Social Sciences Citation Index (Web of Science)	22. Transportation Research Information Database

The base search was restricted to articles written in the English language published after October 2007, which is when the FAA adopted the current definition for RI. As of October 2007, the FAA definition became the same as the definition used by the International Civil Aviation Organization (ICAO). Prior to 2007, an event that involved only vehicles or pedestrians was classified as "surface incident" by the FAA (2007). After October 2007, some events that were formerly classified as surface incidents by the FAA are now classified as Category C or D RIs. Although this change does not affect the level of safety achieved, it increases the number of reported RIs.

Inclusion criteria. For this review, the articles were original contributions published since 2008 in English that provide quantitative and/or qualitative assessment and include any of the following contents:

- Statistics of RIs.
- Severity of RIs.
- Type of RIs.
- Factors that contribute to RIs.

Exclusion criteria. For this review, articles with the following criteria were excluded from further study.

- Focus on evaluating specific methods and technologies to prevent or reduce RIs.
- Focus on validation of the new technologies about RIs.

- Focus on air traffic safety.
- Not peer reviewed (e.g., books, news articles, presentations, & government regulatory institution reports).

Results

Based on the search strategies described above, a total of 134 articles were retrieved in February 2017. This included 44 articles from Engineering Village, 43 articles from ProQuest Collection Technology, 21 articles from TRID, and 26 articles from 19 other databases. The search included 37 duplicate articles.

During the screening stage, 100 articles were initially reviewed. This included 97 articles from 22 databases and three additional articles identified through the references of primary articles. Seventy-eight of 100 articles were excluded from further study for the reasons described below.

Twenty-three articles were excluded because they focused on specific technologies to prevent or reduce RIs. These excluded articles documented studies evaluating or validating the effectiveness of specific technologies. Some technologies evaluated included incursion monitoring, detection, and alerting systems, including airport surface indications and alerts. Other technologies used logic-based reasoning to predict RIs and give explicit instructions to pilots and drivers to avoid RIs.

Thirteen articles were excluded because they focused on air traffic management and air traffic safety. These articles included analysis of air traffic incidents using event trees with fuzzy probabilities, and systematic assessment of air traffic accident risk using Monte Carlo simulation.

Forty articles were excluded because they did not address RI. Four articles of these discussed runway safety but did not specifically address RIs. For example, one included a framework for introducing and sequencing system improvements to provide greater assurances in enhancing safety, and another addressed runway excursions. Thirty-six of these articles were not relevant to RIs or runway safety. For example, one article discussed the significance of demographic characteristics in airport driver training programs and another addressed taxi route scheduling between taxiway and runway at a hub airport.

Article selection and exclusion reflected timeframe as well as subject matter. One article was excluded because it studied RIs before 2008, when FAA's definition was not the same as ICAO's.

The selection stage resulted in 22 articles, which included six articles from Engineering Village, two articles from ProQuest Collection Technology, nine articles from TRID, and five articles from other databases. The results at each stage of the searching, screening, and selection processes are illustrated in Figure 3, which is modeled after Borrego et al (Borrego, Foster, & Froyd, 2015). Of these final 22 articles selected, six used quantitative analysis, ten used qualitative analysis and six included both quantitative and qualitative methods, also referred to as mixed-methods. The results from these 22 research papers are presented in Table 3 and Table 4, with the author, year of publication, title, and analysis method used.

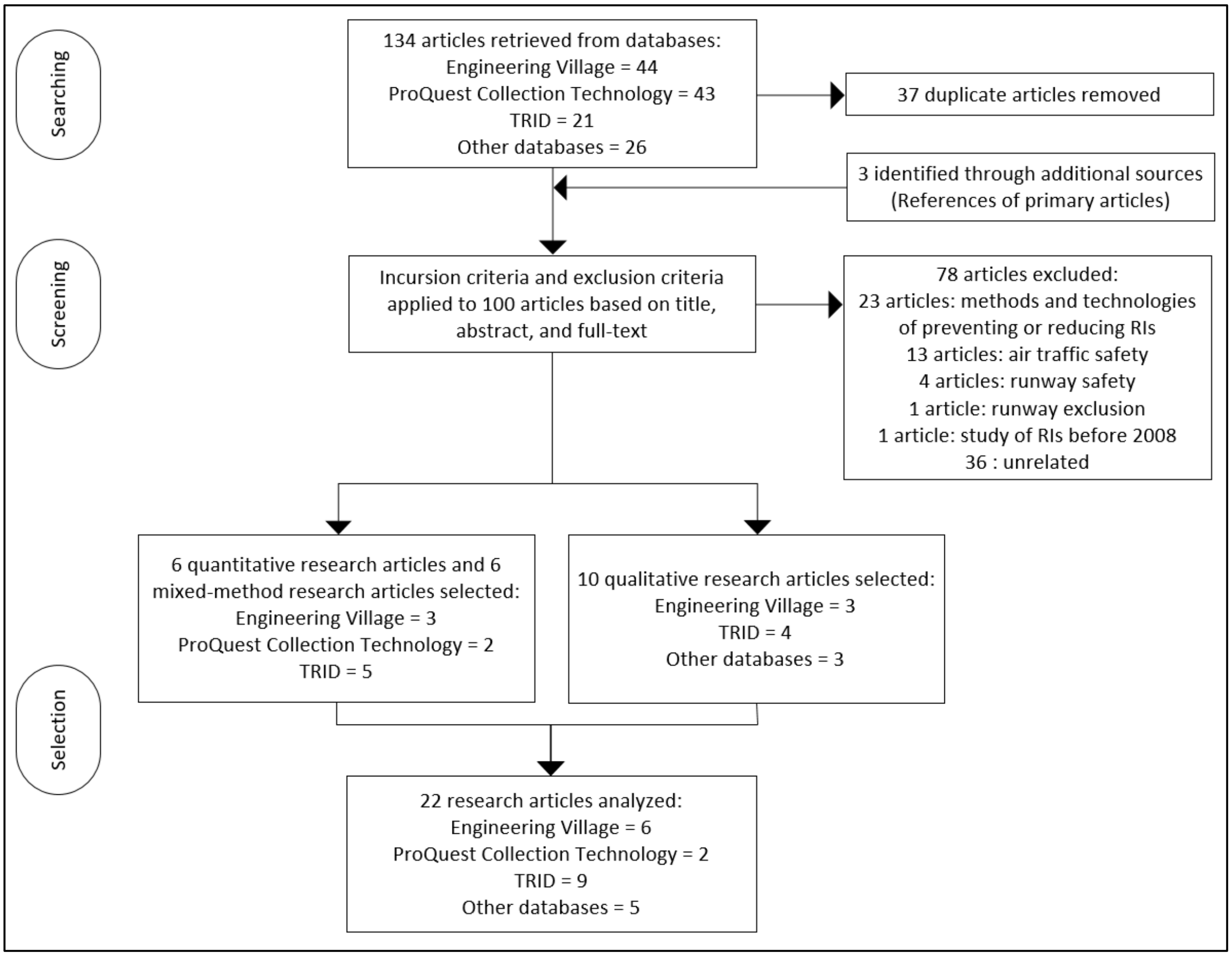

Figure 3. Number of articles searched, screened and selected at each stage.

Table 3

Articles with Quantitative Research of RI Contributing Factors

Author (Year)	Title	Statistical Method
Chang & Wong (2012)	Human risk factors associated with runway incursions	Fuzzy Delphi method Likert scale Analytic hierarchy process Improvement-achievability assessment
De Reuck, Donald, & Siemers (2014)	Factors associated with safety events in air traffic control	Multivariate logistic regression
Goodheart (2013)	Identification of causal paths and prediction of runway incursion risk by means of Bayesian Belief Networks	Bayesian Belief Network model
Johnson, Zhao, Faulkner, & Young (2016)	Statistical models of runway incursions based on runway intersections and taxiways	One-sided test Multiple regression model
Joslin, Goodheart, & Tuccio (2011)	A mixed method approach to runway incursion rating	Cronbach's Alpha *t*-test
Ju (2011)	Reason analysis of runway incursions based on Grey Theory	Grey Theory
Kim & Yang (2012)	Evaluation of the risk frequency for hazards of runway incursion in Korea	Preliminary hazard analysis Analytic hierarchy process Fault tree
Mathew, Major, Hubbard, & Bullock (2016)	Statistical modelling of runway incursions	Multinomial logit model
Mrazova (2014)	Runway Incursions - clear and constant danger	Descriptive statistics
Stroeve, Blom, & Bakker (2013)	Contrasting safety assessments of a runway incursion scenario: event sequence analysis versus multi-agent dynamic risk modelling	Event tree Multi-agent dynamics risk model
Wilke, Majumdar, & Ochieng (2015a)	Modelling runway incursion severity	Kolmogorov-Smirnov test Shapiro-Wilk test Kruskal-Wallis test Mann-Whitney U test Pearson Chi-Square test Logistic regression Maximum likelihood estimation
Wilke, Majumdar, & Ochieng (2015b)	The impact of airport characteristics on airport surface accidents and incidents	Kolmogorov-Smirnov test Kruskal-Wallis test Pearson Chi-Square test Logistic regression

Table 4

Articles with Qualitative Research of RI Contributing Factors

Author (Year)	Title	Qualitative Method
Asare & Ford (2008)	Reducing runway incursions - A simple, yet effective next step	Thick descriptions
Cardosi, Chase, & Eon (2010)	Runway safety	Historical research
Leon (2009)	Combating runway incursions	Thick descriptions
Oetzell (2008)	Avoiding runway incursions	Thick descriptions
Redzepovic (2009)	Prevention of runway incursions at joint use aerodromes	Narrative
Rogerson & Lambert (2012)	Prioritizing risks via several expert perspectives with application to runway safety	Hierarchical Holographic Modeling (HHM) Risk Filtering, Ranking, and Management (RFRM)
Rogerson, Lambert, & Johns (2013)	Runway safety program evaluation with uncertainties of benefits and costs	Hierarchical Holographic Modeling (HHM) Risk Filtering, Ranking, and Management (RFRM)
Stroeve, Som, van Doorn, & Bakker (2016)	Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions	Severity-based assessment
Wilke, Majumdar, & Ochieng (2012)	Holistic approach to airport surface safety	Survey Semi-structured interview Structured communication
Wilke, Majumdar, & Ochieng (2013)	Airport surface operations: A holistic framework for operations modeling and risk management	Business Process Model (BPM)

In quantitative studies, a variety of statistical and mixed-methods are used. Quantitative methods include *t*-tests, multiple regression models, Pearson Chi-Square tests, and multinomial logit models, all of which are used extensively in many aviation-related research studies. Qualitative methods which are incorporated into mixed-method research studies include the Likert scale, analytic hierarchy process, preliminary hazard analysis, and fault tree analysis. These methods are not only used in aviation and runway incursion studies, but are also commonly used in other disciplines. The qualitative methods used in aviation research are more generalized and include narrative research, surveys, and semi-structured interviews.

Quantitative Research Results

Six main categories of contributing factors were identified based on the 12 quantitative research papers. These six main categories are shown in Figure 4 and include *human factors*, *airport geometry*, *technical factors*, *airport characteristics*, *environmental factors*, and *organizational factors*.

Author's Last Name (Year)	Human Factors	Airport Geometry	Technical Factors	Airport Characteristics	Environmental Factors	Organizational Factors	Number of Factors Discussed in Each Article
Chang & Wong (2012)	✓		✓	✓			3
De Reuck et al. (2014)	✓		✓			✓	3
Goodheart (2013)	✓	✓			✓	✓	4
Johnson et al. (2016)		✓					1
Joslin et al. (2011)	✓						1
Kim & Yang (2012)	✓						1
Mathew et al. (2016)				✓	✓		2
Mrazova (2014)	✓	✓		✓			3
Stroeve et al. (2013)	✓		✓				2
Wilke et al. (2015a)		✓					1
Wilke et al. (2015b)		✓					1
Total number of articles identifying each factor	7	5	3	3	2	2	

Figure 4. Factors contributing to RI identified in quantitative analysis.

Human factors. Human factors are the most often cited contributors to RIs, and were identified as a contributing factor in seven of the 12 quantitative articles. Human factors can affect pilots, air traffic controllers, pedestrians, and ground vehicle drivers. For pilots, failure to hold short is the most frequently cited cause of RIs, followed by: crew coordination, situational awareness, misunderstanding of air traffic control (ATC) instructions, the cross-checking of instructions, lack of familiarity with airport layout, conducting checklist while taxiing, and reading back instructions. Task saturation, momentarily forgetting or confusing of an issued clearance, issuing incomplete clearances, and misidentification of an aircraft/vehicle or its location are four major causes of RIs for controllers. The communication between pilots and controllers and their attitude toward safe flight operations or air traffic management are also important human factor considerations that play important roles in runway safety.

Airport geometry. Airport geometry is the second most often identified contributor to RIs. Five of the 12 quantitative studies identified factors related to airport geometry as contributors to RIs. Generally, as the complexity of airport geometry increases, RIs increase.

Intersecting runways, intersections of runways and taxiways, the number of conflict points, complex intersections or airport layouts all increase airfield complexity and all contribute to a higher incidence of RIs.

Technical factors. Technical factors refer to the use of standard technologies which have been widely used, such as runway incursion prevention systems (RIPS), flight dynamics and surface guidance systems (SGS), radar and visual monitoring systems, and ATC alert systems. The effective use of these systems or combinations of these systems is crucial to the prevention of RIs. This is substantiated by the research findings that demonstrate risk is reduced significantly through the combined actions of pilots, controllers and alert systems (Stroeve, Blom, & Bakker, 2013). Furthermore, RIPS and SGS were identified as risk factors which have small influences on RIs (Chang & Wong, 2012).

Airport characteristics. Airport characteristics include inadequate lights, inadequate or ambiguous signs and markings, traffic volume, construction, and airport size. Numerous studies have been conducted on runway lighting systems, since they are powerful tools in the prevention of RIs. The FAA has developed Runway Status Lights, which provide direct warnings to pilots and drivers of ground vehicles of a potential runway incursion or collision. Mathew et al. (2016) found that RIs' severity depends on the size of the airport, with OI more likely at large airports, and PD more likely for less severe (C and D) incursions at GA and non-hub airports.

Environmental factors. Environmental factors include weather, daylight and glare, and were identified as a contributing factor for RIs in two quantitative articles. Mathew et al. (2016) noted that the probability of category D incursions is higher at most GA airports during the winter. Since GA operations are lower in winter, the probability of a severe incursion with another aircraft decreases. This research modeled RI as a random parameter; a small number of general aviation (GA) airports had a higher probability of category A incursions and a lower probability of less severe incursions. This was attributed to the fact that GA airports in Florida and California do not have harsh winter weather and operations may even increase during winter months.

Organizational factors. Organizational factors include poor standards and inadequate supervision, both of which have a negative impact on RIs. In De Reuck's et al. (2014) study, poor coordination standards resulted in ineffective coordination and communication among controllers, between controllers and pilots, and between pilots in the cockpit. In some cases, communications are considered a human factor, as noted previously. In this case, communications are considered an organizational factor and research indicates that a well-designed standard for coordination and communication is the first step in improving safe operations. The effect of inadequate supervision and safety climate also influenced RI events (Goodheart, 2013).

Some of the research also included analysis of the causation factors for RIs, specifically the designation OI, PD, and VPD. According to Ju (2011), VPDs are the key factor influencing Category A and B incursions, and PDs are the key factor influencing Category C and D incursions. Using different analysis methods, Wilke, Majumdar and Ochieng (2015a) also found that PDs are more likely to contribute to lower severity incursions, but found that ATC (OI) is often a contributor for more severe (A and B) incursions.

Qualitative Research Results

These same six main categories that were identified by the quantitative research were also applicable to the qualitative research. The results are shown in Figure 5 and discussed below.

Author's Last Name (Year)	Human Factors	Airport Geometry	Technical Factors	Airport Characteristics	Environmental Factors	Organizational Factors	Number of Factors Discussed in Each Article
Cardosi et al. (2010)	✓	✓	✓			✓	4
Leon (2009)	✓	✓					2
Redzepovic (2009)	✓		✓	✓		✓	4
Rogerson & Lambert (2012)		✓		✓	✓	✓	4
Rogerson et al. (2013)		✓		✓	✓	✓	4
Stroeve et al. (2016)	✓						1
Wilke et al. (2012)	✓	✓	✓	✓	✓		5
Wilke et al. (2013)	✓	✓	✓	✓	✓		5
Total number of articles identifying each factor	6	6	4	5	4	4	

Figure 5. Factors contributing to RI identified in qualitative analysis.

Human factors. Human factors are one of the most often identified contributing factors of RIs, and were identified in six qualitative studies. For pilots, crossing the hold short line without authorization and loss of situational awareness are the two most frequent causes of RIs. Other causes include missing a turn or taking a wrong turn, accepting another aircraft's clearance, and distraction due to unnecessary flight deck conversations or the performance of head-down tasks. Inadequate coordination, forgetting about an aircraft or a closed runway are common causes of RIs that resulted from controllers (OI). Fatigue, read-back and hear-back errors, as well as communication problems are contributors to RIs caused by either pilots (PD) or controllers (OI). Redzepovic's (2009) research at joint-use airports suggests that RI may have different contributing factors for military and civilian operations. For civilian pilots, RIs may result because civilian pilots may not be familiar with the operational performance of military aircrafts. For military pilots, RIs may result because military pilots may not be familiar with ICAO standards for airport signs, lights and markings.

Airport geometry. Airport geometry is another contributor often identified in qualitative articles. It was identified in six articles, and includes complex and confusing airport layouts. Crossing runways, T-intersecting runways, closely- aligned runways, parallel runways, taxiways crossing many runways, short taxi routes and close thresholds are all more likely to increase the likelihood of RI occurrence.

Technical factors. Technical factors were studied in four qualitative articles, and results are divided into two categories: communication-related technical factors and aircraft-related technical factors. In Cardosi et al. (2010), three communication-related technical factors were studied: frequency congestion, blocked or partially blocked voice communications, and a high rate of false alarms from Airport Movement Area Safety System (AMASS). According to this research, the rate of false alarm from AMASS was so high that controllers ended up ignoring valid alerts. Other research found that aircraft malfunction contributed to RIs; this would be considered as an aircraft-related technical factor (Wilke, Majumdar, & Ochieng, 2012; Wilke, Majumdar, & Ochieng, 2013).

Airport characteristics. Airport characteristics were identified as a contributor to RI in five qualitative research studies. Airport infrastructure components such as inadequate lightning and ambiguous markings or signals contributed to RIs, findings that were consistent with the results of quantitative research. Characteristics such as flight school near the airport, federal contract tower, and number of flights at the airport were also factors that contributed to RIs and reflect airport characteristics.

Environmental factors. Environmental factors were identified in four qualitative articles. According to Rogerson and Lambert (2012), yearly snowfall, rainfall, freezing conditions, heat, and variation in day length are all influential causes of RIs. Three other studies also found that the weather plays an important role in RIs (Rogerson, Lambert, & Johns, 2013; Wilke, Majumdar, & Ochieng, 2015a; Wilke, Majumdar, & Ochieng, 2015b).

Organizational factors. Organizational factors appeared in four qualitative articles. Redzepovic (2009) noted that organizational factors are the most important factor at joint-use airports, since many military operations differ from purely civil operations, and reflect different standards and procedures. At joint-use airports, military pilots and controllers use non-standard International Civil Aviation Organization (ICAO) phraseology or local language, and military operational procedures for ground lighting may deviate from ICAO standards. The application of different rules and procedures can create confusion during operations. Deviation from standard operating procedure (SOP) is a cause of RIs, because the successful adoption of a non-obligatory procedure depends on the operator, and confusion may be created when some operators follow the SOP but others do not (Cardosi, Chase, & Eon, 2010).

Comparison of Quantitative Research and Qualitative Research

There were numerous similarities between the findings of the quantitative research and qualitative research. Not surprising, the six contributing factors of human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors were adequate to describe the research findings for both quantitative and qualitative research. There were some notable differences between the quantitative and qualitative findings, however, as described below.

The qualitative research tends to identify more contributing factors for RIs than the quantitative research. Six of eight qualitative research studies identified at least four contributing factors for RIs, whereas only one of 12 quantitative research study identified four contributing factors. One possible explanation for the difference is that the qualitative research utilized a systematic and holistic approach, and focused on a higher level of analysis. Numerous quantitative research papers focused only on one or two specific contributing factors. This reflects the fact that it may be challenging to study some categories of factors with statistical methods. For example, analysis of environmental factors and organizational factors may be challenging with existing databases. It is also notable that all of the quantitative research studies were published after 2011, whereas most of the qualitative research studies were conducted before 2013. Perhaps researchers used qualitative methods to study RIs and identify contributing factors, and then subsequent research used statistical methods to analyze the contributing factors originally identified by qualitative research. It is also likely that internet databases have made quantitative analysis possible for more researchers. Similarities and differences between the findings for each category of factor for the qualitative and quantitative research are discussed below.

Human factors. Human factors are studied frequently in both quantitative research and qualitative research, which is logical since human factors accounted for the majority of RIs. The causes of human factors resulting in RIs were basically the same for quantitative and qualitative research and included failure to hold short, loss of situational awareness, miscommunication, and crew coordination.

Airport geometry. Airport geometry is frequently included in both quantitative and qualitative research studies, and include complexity correlates with more RIs. Airport geometry was cited as a factor in qualitative research as early as 2008, and it is included in quantitative research with increasing frequency after 2012.

Airport characteristics. Airport characteristics studied in qualitative research articles encompassed more components than those identified by quantitative research. Quantitative research addressed inadequate lights, inadequate or ambiguous signs and markings, aircraft traffic volume, construction and airport size. Qualitative research addressed these components as well as the mix of air traffic (e.g., nearby flight schools) and ATC factors. Statistical methods may be able to quantify and document the impact of specific airport characteristics, but qualitative assessment methods may be able to identify a broader range of airport characteristics that may not be included in standard aviation databases.

Environmental factors. Environmental factors were identified in four qualitative research articles, but only one quantitative research article. This may be because environmental factors are not included as an explicit field in the FAA runway incursion database, making it more difficult to analyze using quantitative research methods. In some cases, quantitative research that included environmental factors was based on inferences using the month of the year (season), the time of day (light), and the weather conditions (airspeed, wind direction, temperature, and visibility); seasonal effects and sun glare were most frequently addressed by quantitative research. Environmental factors are much more likely to be included in qualitative analysis, and the qualitative approach may be more comprehensive, addressing a wider range of factors including variation in day length, snowfall, rainfall, and temperature.

Organizational factors and technical factors. Organizational and technical factors are also more likely to be addressed by qualitative articles than quantitative articles. The reason organizational factors are hard to analyze using quantitative research methods is that the enforceability of procedures, the ability to execute standards, and the effectiveness of supervision may be difficult to measure in quantitative ways, and are not reported in any public database. Technical factors in qualitative research articles analyzed the causes resulting from communication equipment problems and aircraft malfunctions. Technical factors addressed by quantitative research but not qualitative research include the effectiveness of widely-used technologies such as radar and visual monitoring systems and ATC alert systems.

Conclusions and Recommendations

Systematic literature reviews provide an evidence-based approach to facilitate reliable and accurate conclusions from multiple studies, and a strong basis for decision making. This paper introduces the concept of the systematic literature review to the aviation sector, and provides an example application to the study of RIs, an important factor for runway safety and a priority for the FAA.

The findings of this systematic literature review suggest that human factors and airfield geometry are the most influential factors affecting RIs, based on the findings of both quantitative and qualitative research. Other factors that affect RIs include airport characteristics and technical factors, followed by organizational factors and environmental factors. Environmental and organizational factors are important, but have not been addressed as often by quantitative research, perhaps because these factors are not explicitly included in many aviation databases. Qualitative research was much more likely to identify contributing factors from multiple topic areas, and often provided a higher level perspective on RIs.

The quantitative, qualitative and mixed-methods literature provide a number of recommendations to reduce RIs. These recommendations reflect the factors identified, including human factors, organizational factors and airport factors, such as airport geometry and airport characteristics, as well as technical factors related to both airports and aircraft. There were limited recommendations related to environmental factors.

One way to address human factors is to conduct initial and continuous training for pilots, air traffic controllers and ground operators. This training would address all causes of RI, including PD, IO and VPD incursions. Training may focus on both technical and non-technical skills. Technical skills include decision-making and the ability to deal with rapidly changing situations. Non-technical skills include communication skills, one of the most important components for safe ground operations. This training would mitigate errors made by controllers such as forgetting about an aircraft or a closed runway (Cardosi, Chase, & Eon, 2010). Training can also provide information regarding practices that help memory, such as writing instructions down or repeating them, as well as conditions that impair memory, such as environmental distractions and temporary or abnormal situations (Cardosi, Chase, & Eon, 2010). Training can also reinforce the importance of using standard aviation phraseology, including proper call signs and read back protocol and simple and short messages in communication, and the importance of requesting clarification when instructions are confusing (Leon, 2009; ICAO, 2007; Eurocontrol, 2011). Training should also include the development of organizational factors that support a systemic approach for human factors. This recognizes the importance of solutions that address both human factors and organizational factors that may affect human factors.

Organizational factors may best be addressed with support from the FAA and ICAO. These entities can support the reduction of RIs through the identification of best practices, standards and procedures. The airport ATC tower and ground control are responsible for different areas of the airport. As aircrafts and vehicles pass through different areas, responsibility passes from ATC controllers to the ground control operators responsible for that area (and vice versa). It is important that controllers and ground control operators remain in constant communication with each other throughout these transitions (De Reuck, Donald, & Siemers, 2014). It is also important that operational procedures and standards be consistent for everyone at joint-used airports, particularly where civil and military aircraft share a maneuvering area (Redzepovic, 2009).

Recommendations also address airport facilities, including airport geometry, airport characteristics, and airport technical factors. In some cases, RI can be addressed by reducing airfield complexity, including the number of intersections and conflict points. Airports with airside intersections (runway/runway, runway/taxiway or taxiway/taxiway) should have a long-term goal to revise the airport layout and reduce intersections. Modifying airport layout is an effective but an expensive way to reduce RIs and improve runway safety, and is consistent with the FAA (2015a) RIM program activities. Short term recommendations to address complex airport geometry include pilot review of the likely path for taxiing to the departure runway well before the aircraft leaves the gate or ramp. Similarly, pilots should also review the likely path for taxiing to the ramp or the gate before leaving cruise altitude (Oetzell, 2008).

Airport characteristics include airport construction, as well as inadequate lights, signs and markings. To address airport construction, controllers should notify pilots about construction before landing, and pilots should determine the location of construction areas at the origin and destination airports before they even start the engines (Torres, Metscher, & Smith, 2011). Inadequate airport lights, signs and markings can be addressed by enhanced airport surface markings, which make the hold short lines more distinct and highlight the centerline leading up to the hold short lines, providing an additional cue that there is an approaching runway (Cardosi, Chase, & Eon, 2010). Enhanced markings can reduce the likelihood that pilots and ground vehicle operators will cross the runway threshold when they intend to hold short.

Technology can also be used to reduce RIs, and may include technical enhancements for airports and in aircrafts. Airport technology includes airport surface detection equipment (e.g., ASDE-X) to provide robust information about aircraft and movement on the ground at airports. In the aircraft, technologies include enhanced displays for the commercial flight deck, which reduce the chance of being "head-down" and ensure continuous watch while taxiing (Leon, 2009). Enhanced displays in the cockpit may be particularly helpful for airline pilots taxiing at airports with unfamiliar or complex airport layouts. The wide range of recommendations reflect the complex operating environments of airports, and the variety of factors that contribute to RIs.

Future research in this area is recommended, including the use of the systematic literature review methodology to investigate other topics in aviation, as well as an expanded investigation of RIs. Expansion of the systematic literature review for RIs could include research conducted in other languages, and the inclusion of reports that have not been peer-reviewed. While the inclusion of only peer-reviewed research assured that all research included reflected quality publication standards, it also meant that publications from regulatory institutions such as the FAA and the European Aviation Safety Agency (EASA) were not included. Often significant findings from FAA and EASA research is documented not only in agency reports, but also in peer-reviewed conference proceedings and journal articles, however, this may not always be the case. Expansion of the study to include agency reports could encompass the findings of the FAA Runway Safety Reports between 2008 and 2014, the FAA National Runway Safety Plan for 2015 to 2017, and The European Action Plan for the Prevention of Runway Incursions published by the Eurocontrol.

The reduction of RIs is a top priority for FAA and an important activity to ensure aviation safety. In order to reduce the incidence of RIs, it is valuable to systematically investigate the research that has been conducted regarding contributing factors of RIs. This paper presents the process for a systematic literature review, and demonstrates the application of this method to synthesize the factors that correlate with RIs for quantitative, mixed-method and qualitative analysis published in peer-reviewed journal and conference papers. Six contributing factors to RIs were identified; these include human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors. This research demonstrates the value of this systematic approach, which provides a useful tool to synthesize research findings from multiple studies, and is one way to advance research, increase safety, and optimize efficiency in the aviation sector.

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