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ANALYSIS OF OPERATIONAL RISKS ASSOCIATED WITH THE CONSTRUCTION OF JORGE CHAVEZ INTERNATIONAL AIRPORT IN LIMA-PERU

Abstract: In the daily operation of an airport, there are a multitude of hazards that can compromise operational safety; therefore, it is critical to monitor and identify these hazards as well as the associated risks. This work's main objective was to assess the operational risks and hazards that may arise from construction works in the airport environment by applying a methodology for the risk assessment based on historical data of aircraft incidents obtained from SKYbrary Aviation Safety and The Aviation Herald from 2000 to 2015. For this study, it was taken as a reference the expansion work at Jorge Chávez International Airport in the city of Lima, Peru. This is a large-scale project, with the construction of a second runway, a new control tower, taxiways, parking aprons, etc. Ten generic hazards were identified, from which thirty-seven potential risks were derived. However, most of them had a low probability of occurrence, so an "acceptable" tolerability prevailed. Among the recommendations presented (ATIS, NOTAM, visual signs, phraseology, signage, procedures, etc.), these are mainly focused on human factors and in phases 1 and 2 of the construction works, the critical phases where the current runway section is connected to the new taxiways giving access to the second runway.

Keywords: airport, safety, risk management, construction, aviation

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Introduction

All airports need to undertake construction and/or maintenance activities to evolve and grow. However, no matter how necessary these activities may be, airports assume considerable risk in carrying them out. Construction activities at airports can be difficult and dangerous, so airports must take appropriate precautions to reduce potential risks.

There are intrinsic hazards in day-to-day operations that constantly compromise the safety, so it is vitally important to keep these potential hazards and their associated risks identified and under control, since airport construction can lead to ambiguity and confusion for the flight crew and operators, sometimes with catastrophic results.

There are currently a large number of airport construction and expansion projects underway or in the planning stages to meet current and anticipated increases in air traffic demand. These projects include both the construction of new facilities and the expansion of existing terminals, runways, and taxiways. Jorge Chávez International Airport, in Lima, Peru, is undergoing a comprehensive expansion process.

One of the main challenges in the management of works in this type of project is the proximity of construction resources, such as equipment, materials and personnel to critical areas of the airport, which poses a greater risk to the airfield safety. The characteristics of the works developed at Jorge Chavez International Airport make it a case study that meets the ideal characteristics for the development of the identification of the possible potential hazards involved in the execution of such construction works to the operations, and the assessment of the associated risks, resulting in the proposal of a series of recommendations and mitigation measures.

Methodology and scope of the safety study

Airports take proactive steps to address operational vulnerabilities through situational awareness, training, efficient airport infrastructure, procedures, and technology. Airport safety requires a coordinated approach between the various stakeholders and workers involved. Previous literature reviewed have included several articles and publications related airport safety and recommended practices (Bris, 2015; Bassey, 2015; ANAC, 2019; Tirado, 2019), based on the literature review a study methodology was established for the present paper, trying to evaluate the accident risk increase when there is a construction site in progress nearby the aircraft operations at an airport.

The methodology followed includes the extraction of data from previous incidents and accidents occurred from 2000 to 2015 obtained from SKYbrary Aviation Safety and The Aviation Herald where the operational safety of aircraft has been seriously compromised and which were related to the performance of 43 construction works on the runway or its surroundings. Once built the database, data is analyzed, and statistics are produced to identify the possible hazards and assess the risks.

Work on the airside of aerodromes, or on the maneuvering area and apron, is planned and executed in accordance with the requirements established by the International Civil Aviation Organization in relation to the airport accreditation process and its implementation, supported by the safety management system implemented at the airport in question.

Jorge Chávez International Airport is currently being renovated and expanded, with the construction of a second parallel runway, a new control tower, new taxiways, passenger terminal, and related buildings that will allow for a greater flow of passenger arrivals (CORPAC, 2020). The aim of this work is to identify the operational hazards that may arise from the airport expansion works while continuing with normal air operations, as well as to assess the safety scope (the scope refers to the identification of the transcendence or importance, through a qualitative risk analysis of all identified hazards (their tolerability) in the execution of the expansion processes of Jorge Chávez International Airport), establishing a set of recommendations and mitigation measures.

To identify the potential risks in the different activities carried out at the airport, the objective is to start with a study of the airport in question. The specific objectives include analyzing any factor that may influence the different airport operations, such as the physical characteristics of the airport, human factors, the physical environment, traffic density, types of aircraft, etc., and especially during works on the airfield. A set of mitigation measures will be proposed with the aim of minimizing the likelihood and reducing the severity of the risks, concluding this procedure.

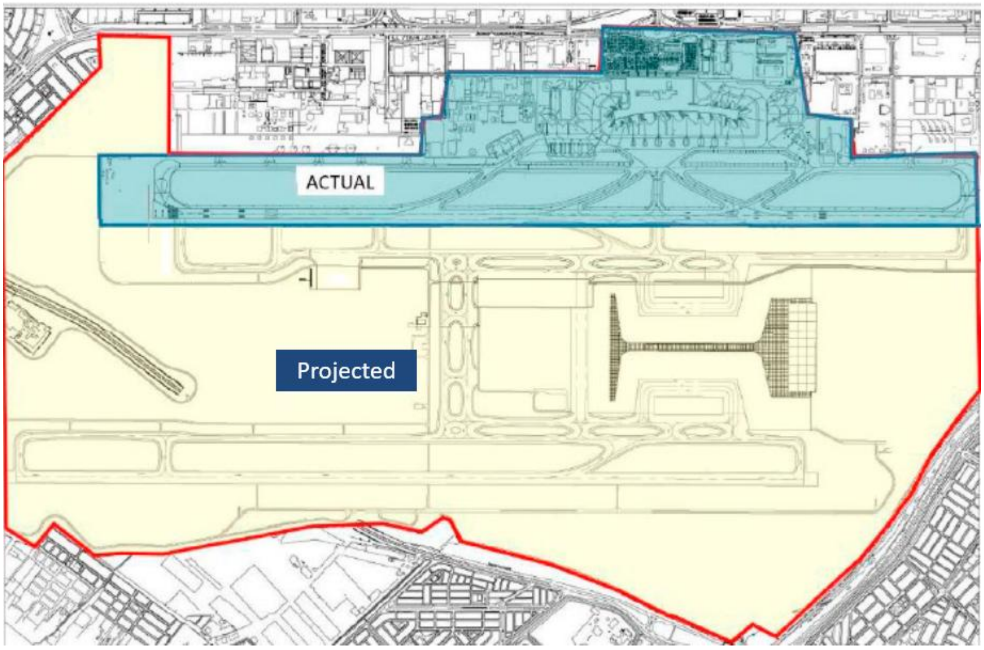

Fig. 1. Projected airport expansion area of the airport
Source: CORPAC, 2020

Risk Management System

The Risk Management System is a process of the Operational Safety Management System that aims to identify, analyze and eliminate or reduce to a tolerable or acceptable level, those hazards that lead to the Operational Safety of an aerodrome being compromised by the threat of such hazards (AESA, 2014; ICAO, 2016).

Consequently, the environment is examined to identify situations that could lead to an accident, followed by the hazards that could threaten operational safety as a result of the daily work at the airport and the associated risks. Once identified, their importance for operational safety is analyzed and, based on this, measures for their elimination or mitigation are proposed. Finally, those responsible for carrying out the mitigation measures are selected and, once implemented, their effectiveness is monitored. This system focuses on those activities, infrastructure and procedures related to operational safety which are carried out on the airside of the aerodrome. For this reason, the system aims to establish a methodology that includes, as far as possible, part of the following points (OACI, 2009; ICAO, 2016):

- Description of the system, i.e., a preliminary study of the scenario under assessment is carried out. Identification of existing hazards at the airport.
- Risk assessment.
- Risk assessment.
- Risk mitigation.
- Monitor existing hazards at the airport.

To carry out this risk assessment process, where risks are first identified and classified, personnel are equipped with a series of specific techniques and procedures to identify the risks associated with each hazard, and to determine the tolerability according to their probability of occurrence, as well as the severity of the consequences. In this work, a five-step process will be used and described that can be used to evaluate all those aspects that may influence the operational safety of the airport under study (ICAO, 2016):

- Detailed description of the scenario.
- Hazard identification.
- Probability and severity of identified risks.
- Assessment of identified risks.
- Mitigation of identified risks.

It should be noted that in most cases risks cannot be eliminated in their entirety, therefore, the objective becomes the reduction of such risks to a level where the probability of an unfavorable outcome is as low as possible. That is, to the extent that is practically and reasonably possible, ALARP (as Low as Reasonably Practical, a term originating in British occupational health and safety legislation. However, it is widely used in guidance material for aviation safety-related matters, where the severity of a risk is reduced as low as is reasonable in practice – ICAO, 2016). Therefore, it can be said that risk management is about taking action to control those risks that are deemed unacceptable while at the same time using resources to increase the quality of operational safety. A key component of risk management is risk ranking. Through ranking, risks can be scored based on their acceptability, thereby providing a benchmark or scale for comparison, regardless of the function, project, or area of the airport on which it is focused. Therefore, applying the same standards allows for comparisons, prioritization, and therefore more rigorous and effective management.

Another objective of the assessment is to determine the level of tolerability to have the risks identified and controlled through subsequent mitigation measures (ICAO, 2016):

- High risk category: operation is restricted or ceased if deemed appropriate, mitigation measures are implemented as a matter of urgency.
- Medium risk category: those located between the high and medium risk categories, the airport applies the ALARP methodology.
- Low risk category: no extra work for security officers, just management of the measures already in place.

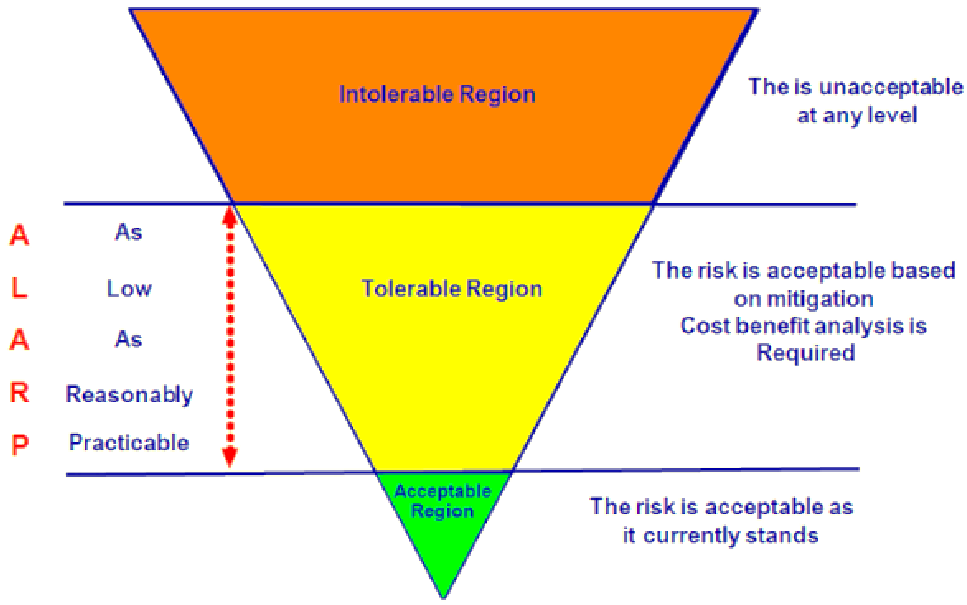

Fig. 2. Safety Risk Management
Source: ICAO, 2016

The likelihood of these risks is then indicated in terms of the proportion that these risks may contribute to the occurrence of an incident or accident. There are two main ways of assessing likelihood, either qualitatively or quantitatively.

At the qualitative level, when there is not a substantial amount of data on incidents or accidents and therefore it is not feasible to perform a quantitative assessment in a precise way. This situation is common as data are scarce in most cases and are not sufficient to perform a quantitative assessment, so previous experience must be applied by making a judgement on the likelihood of a hazard resulting in an accident or incident.

From a quantitative approach, numerical analyses tend to be carried out with a statistical adjustment of the data collected on accidents and incidents at the airport. Thus, depending on the number of times an accident is expected to occur, the authorities have established guidance material illustrating different categories (ICAO, 2016).

Table 1. Safety Risk Probability Table

Event probability		
Probability	Qualitative definition	Value
Frequent	Likely to occur many times (has occurred frequently)	5
Occasional	Likely to occur a few times (has occurred infrequently)	4
Remote	Unlikely to happen, but not impossible (it has rarely happened)	3
Improbable	Very unlikely to occur (not known to have occurred)	2
Extremely unlikely	Almost inconceivable that the event would occur	1

Source: Own elaboration based on ICAO, 2016

The next step in this risk assessment is the assessment of the consequences of undesirable events on the course of operations. Severity is considered as the second component of the risk, the one corresponding to the most unfavorable case will always be applied. These categories are purely qualitative, and the criteria used for their description are based on previous experience, as are the various databases containing statistics on accidents and incidents (ICAO, 2016).

Table 2. Safety Risk Severity Table

Gravity of the event	Meaning	Value
Catastrophic	- Destruction of equipment - Multiple deaths	A
Dangerous	- Significant reduction in safety margins, physical damage, or a workload such that operators cannot perform their tasks accurately and completely - Serious injuries - Major damage to equipment	B
Major	- Significant reduction of safety margins, reduction in the operator's ability to respond to adverse operational conditions as a result of increased workload, or as a result of conditions that impede their efficiency - Serious accident - Injuries to people	C
Minor	- Interference - Operational constraints - Use of emergency procedures - Minor incidents	D
Insignificant	- Little consequences	E

Source: Own elaboration based on ICAO, 2016

Once the severity and probability assessment has been carried out, the level of risk present is calculated by cross-referencing the information in tables 1 and 2 regarding probability and severity, obtaining table 3 for risk level. This level of risk identified can also be known as risk tolerability, proceeding to classify it according to whether it is a high, medium or low risk. The matrix shows three clearly differentiated zones, according to the type of risk, as indicated above, high, medium, or low, the probability of this event taking place and finally the severity associated with its consequences (ICAO, 2016).

Table 3. Safety Risk Assessment Matrix

Probability / Severity	Extremely improbable (1)	Improbable (2)	Remote (3)	Occasional (4)	Frequent (5)
Catastrophic (A)	1A	2A	3A	4A	5A
Hazardous (B)	1B	2B	3B	4B	5B
Major (C)	1C	2C	3C	4C	5C
Minor (D)	1D	2D	3D	4D	5D
Negligible (E)	1E	2E	3E	4E	5E

Source: Own elaboration based on ICAO, 2016

Database

Table 4. Database of previous accidents or incidents

Tamale (TML)	Oct-15	A BAe 146 received substantial damages in ending its landing in the works of a runway extension.
Krasnodar (KRR)	Aug-15	LD of a BAe 146 on a runway closed for rehabilitation. No injuries.
Oslo (OSL)	May-15	A 737 ended its landing on the paved surface of the RESA.
El Paso (ELP)	Apr-15	733 cleared to land on a closed runway. Workers evacuated when seeing the ACFT. No injuries.
Katowice (KTW)	Jul-14	LD of a CRJ on a RWY in construction. Closed by two white crosses on a black square. No injuries.
Abuja (ABV)	Dec-13	A 747 overran the RWY and collided with machines, trucks and a construction cabin. No injuries.
Prague (PRG)	Jul-12	Too long takeoff of an A319 based on full RWY lengths. Construction cleared by a short margin.
Vnukovo (VKO)	May-11	Landing overrun of a Yak 42.
Menorca (MAH)	Apr-11	LD on a runway closed by ICAO white crosses. Agents and a vehicle on the RWY. No injuries.
Mumbai (BOM)	Nov-09	Two interrupted approaches of an A320 over the initial THR before landing on the DTHR.
Mumbai (BOM)	Oct-09	Landing overrun of an ATR72 on a wet and shortened runway.

Chicago (ORD)	Sep-09	Too long takeoff of a 747 based on full RWY lengths. Construction cleared by a short margin.
Chicago (ORD)	Sep-09	Too long takeoff of a MD10 based on full RWY lengths. Construction cleared by a short margin.
Chicago (ORD)	May-09	Touchdown of a MD80 before the temporary DTHR and Go Around.
Chicago (ORD)	May-09	A CRJ ended its landing after the temporary end of the runway and stopped on the pavement.
Paris (CDG)	Aug-08	Too long takeoff of a 737 based on full RWY lengths. Blast fences cleared by a short margin.
Perth (PER)	May-08	Two interrupted approaches of a B737 over the initial THR before landing on the DTHR.
Auckland (ACK)	Mar-07	Too long takeoff of a 777 based on full RWY lengths. Work vehicles cleared by 28 m (92 ft).
Yerevan (EVN)	May-05	Landing short of an A300-600 before the temporary DTHR.
Paris (CDG)	Jul-05	3 ACFT cleared to T/O only by the TWY providing the longest TORA, entered by intermediary TWY.
Perth (PER)	Apr-05	Landing short of an A340-200 before the temporary DTHR.
Auckland (AKL)	Nov-04	Landing short of a B777 before the displaced threshold on a construction area.
Manchester (MAN)	Jul-03	Too long takeoff of a 737 based on full RWY lengths. 14 ft-high machine cleared by 17 m (56 ft).
Manchester (MAN)	Jul-03	Too long takeoff of a 737 based on full RWY lengths. 14 ft-high machine cleared by 17 m (56 ft).
Taipei (TPE)	Oct-00	Takeoff of a 747 from the wrong closely-spaced and parallel runway. Crash into the construction.

Source: Own elaboration based on: the Aviation Herald, 2022; SKYbrary Aviation Safety, 2022; Bris, 2015

Table 5. Database statistics

Description	Number
Landing short before the temporary DTHR	6
Landing below the approach path to the DTHR	1
Takeoff long toward the constructions	7
Runway excursion toward the construction site	3
Runway excursion back to the construction site	3
Take-off / Landing on a closed runway	5

Source: Own elaboration

Results of the Hazard Identification and Risk Assessment

Risks to air operations arise when airport operating patterns are modified or interrupted due to work being carried out at the airport. As a result, both pilots and airport personnel are forced to perform their work in an unusual environment.

In the following Table.5., will be identified the type of operation, the generic hazards, specific causes, consequences related to the hazard, probability associated as well as severity and finally the assigned tolerability. Available information from the Jorge Chávez International Airport was taken into consideration (LAP, 2014; LAP 2018 a; LAP, 2018 b; LAP 2021).

Table 5. Hazard identification and risk assessment

Generic Hazard	Specific component (causes)	Consequences related with the hazard(risk)	Probability	Severity	Tolerability
Landing/ aircraft takeoff on closed runway	- The crew does not have aeronautical information on the closed runway. - The pilots confuse two ways. - Pilots mistake ATC clearance. - Runway closure markings are missing or not clearly visible.	Collision with the construction site and/or with heavy vehicles that causes the accident of the aircraft.	Rare	Hazardous	1A
		Collision or explosion of a jet on the workers with the consequent serious or catastrophic injuries that it may cause to the employees.	Rare	Catastrophi c	1A
Taxiing operations while construction work is being carried out at the airport	- Reopening of airfield areas without adequate conditions for traffic. - Deficient vertical and horizontal signaling. - Incorrect aircraft guidance. - Vehicle incursion. - Poor stockpiling of work materials.	Aircraft collision with obstacle on the ground.	Improbable	Hazardous	2B
		Aircraft collision with passing vehicle.	Improbable	Major	2C
		Damage to airport facilities.	Improbable	Minor	2D
		Damage to vehicles and ground handling equipment.	Improbable	Major	2C
		Aircraft collision due to taxiway departure.	Improbable	Major	2C
		Aircraft hydroplaning / sliding.	Negligible	Major	1C
Aircraft excursion in construction work zone	- Deficient horizontal and vertical signaling on the airfield. - Incorrect aircraft guidance. - Aeronautical information is not clear and simple. - External factors. - Reopening of areas of the airfield without suitable conditions for traffic.	Aircraft collision with obstacle on the ground.	Improbable	Hazardous	2B
		Aircraft collision with passing vehicle.	Improbable	Major	2C
		Injuries to persons by FOD (Foreign Object Damange) impact due to motor jet.	Improbable	Hazardous	2B
Obstacles in construction sites	- Materials improperly stockpiled and in violation of permitted height limits. - Reopening of areas of the airfield without	Aircraft collision due to taxiway or runway departure.	Negligible	Major	1C
		Injuries to persons by FOD (Foreign Object Damange) impact due to motor jet.	Improbable	Hazardous	2B

	suitable conditions for traffic.				
Deficiencies in the accesses to the site	- Deficient horizontal and vertical signage on the airfield. - Deficient communication protocol between site personnel and the airport manager. - Confusing signaling of accesses to the construction site.	Vehicle incident.	Remote	Major	3C
		Incident with aircraft on the ground.	Improbable	Major	2C
		Collision of vehicle with aircraft.	Negligible	Major	1C
		Vehicle collision with stationary object.	Remote	Minor	3D
		Vehicle collision with airport facilities.	Improbable	Major	2C
		Physical injuries to workers at the construction site.	Occasional	Minor	4D
		Inadvertent access of unauthorized vehicles on the construction site.	Occasional	Minor	4D
Incursion into areas open to aircraft traffic	- Inadequate passage of vehicles through areas open to air traffic. - Deficient horizontal and vertical signaling. - Deficient communication protocol between site personnel and the airport manager. - Lack of knowledge or incorrect information of the contractor's personnel regarding Operational Safety.	Incident with aircraft on the ground.	Negligible	Major	1C
		Vehicle incident.	Improbable	Major	2C
		Aircraft-vehicle collision.	Negligible	Hazardous	1B
		Unnoticed access of unauthorized vehicles in the movement area.	Improbable	Hazardous	2B
		Damage to vehicles and ground handling equipment.	Improbable	Major	2C
Generation of dust and/or FODs	- Dust from the construction area can be carried by the wind to the airfield. - Lack of knowledge or incorrect information of the contractor's personnel regarding Operational Safety. - Incorrect stockpiling of materials and construction machinery.	Aircraft incident on the ground.	Negligible	Major	1C
		Damage to vehicles or injury to persons due to impact of FOD absorbed/projected by engine jet.	Improbable	Hazardous	2B
		Damage to vehicles or injury to persons due to impact from wind driven FOD.	Improbable	Hazardous	2B
		Damage to aircraft due to impact of FOD projected by engine jets.	Negligible	Hazardous	1B
		Damage to aircraft due to absorption of objects by the engines.	Negligible	Major	1C

Glare to pilots or operators caused by work or machinery lighting sources	- Incorrect control of the lighting elements used on site. - Poor lighting or low visibility in operational areas. - Loss of situational awareness or even disorientation on the part of the crew and/or operators.	Aircraft incident on the ground (taxiway).	Improbable	Major	2C
		Aircraft collision with obstacle on the ground.	Improbable	Major	2C
		Aircraft collision with obstacle in flight.	Negligible	Catastroph ic	1A
Violation of obstacle limitation surfaces.	- Incorrect marking of elements that violate maximum heights. - Poor stockpiling of materials and construction machinery. - Lack of knowledge or incorrect information of the contractor's personnel regarding Operational Safety.	In-flight aircraft incident.	Negligible	Catastrophi c	1A
		Aircraft collision with obstacle in flight.	Negligible	Catastrophi c	1A
Fuel leakage and/or different types of potentially flammable liquids on the airfield.	- Vehicle accident transporting flammable material. - Hose or pipe rupture causing leakage. - Lack of knowledge or incorrect information of the contractor's personnel regarding Operational Safety.	Fire	Remote	Major	3C
		Aircraft damage due to hydroplaning/sliding.	Negligible	Hazardous	1B

Source: Own elaboration

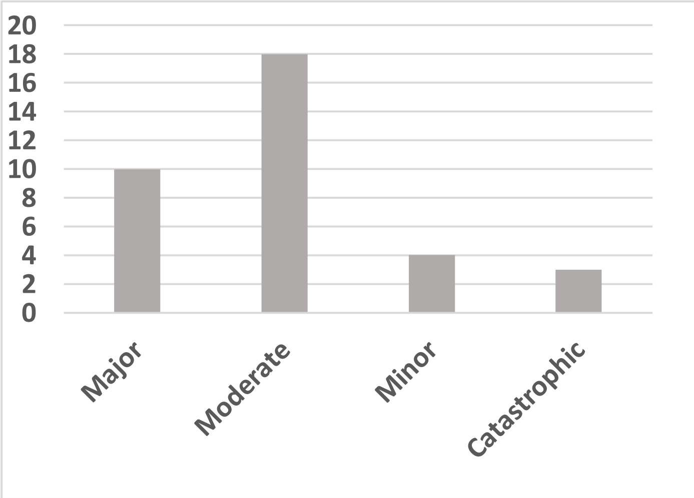

Fig. 3. Severity of the identified hazards
Source: own elaboration

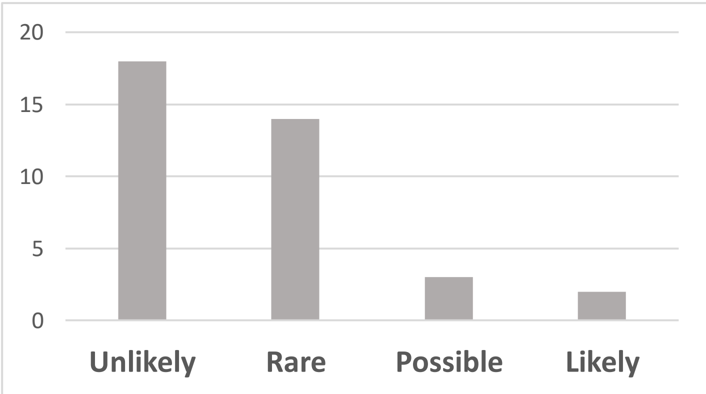

Fig. 4. Likelihood of the identified hazards
Source: own elaboration

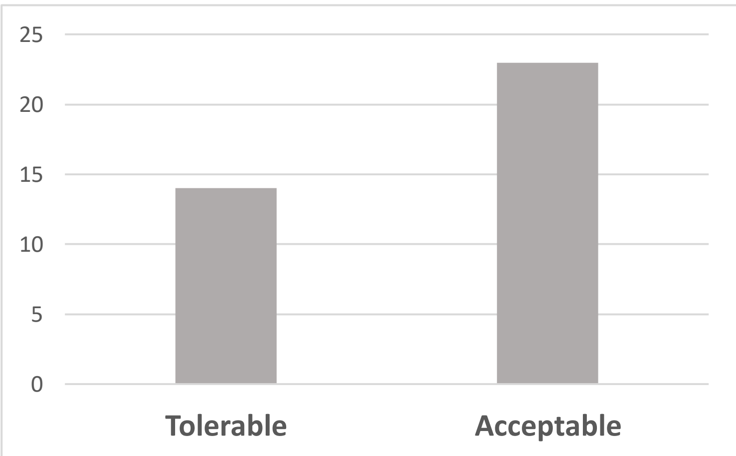

Fig. 5. Tolerability of risks
Source: own elaboration

After completing the corresponding risk identification tables, different readings have been obtained. Regarding the qualitative assessment of risks related to the expansion of Jorge Chavez International Airport, it is concluded that ten generic hazards were identified, resulting in a total of 37 potential risks of the construction works to air operations.

It can be seen that this is a high-risk quantity, although more than half of them have a severity ranging from "major" or "hazardous", the probability of occurrence is low, as more than half of them are rated "Improbable" to "Negligible". This results in a major "acceptable" tolerance for the identified risks. However, 40% of the risk is tolerable, demonstrating the need for constant effort to identify and propose mitigations, and then apply them, as described in the next section of this article.

Discussion of recommendations and mitigation measures

The review of construction-related safety events reveals a set of frequently recurring causal factors that should be considered with special focus during construction work at Jorge Chavez International Airport, such as: the Automatic Terminal Information Service (ATIS), the "notice to airman" (NOTAM), characteristics of visual signals, air traffic controllers' phraseology, airport diagrams and graphics, signage indicating runway closures or modified operational procedures. (FAA, 2006).

The ATIS broadcast at large airports usually contains a significant amount of information in addition to airport construction data. Construction NOTAMs are sometimes mixed with other operational information and may not be heard by the crew. In other cases, the ATIS does not include declared distances and other critical construction-related information, especially when the TORA (Take-off Run Available) is modified. For this reason, the airport's aeronautical information office must emphasize the clear, concise, and complete transmission of relevant information on the construction work carried out that may affect the operational safety of aircraft. (Ratto, 2016).

Large airports, such as Jorge Chavez, in general tend to have a significant number of NOTAMs, and this number is especially increased during construction works. This can lead to information being unnoticed by the people who really need it: pilots, dispatchers, and air traffic controllers. In addition, the information contained in NOTAMs sometimes slips out of the memory in critical phases: during takeoff or landing phases, when workload and risk tend to reach a peak. In addition, the format of NOTAMs (capital letters and rarely used abbreviations) is often difficult to interpret and subject to misunderstanding.

Driver phraseology can sometimes lead to ambiguity or misleading conclusions about the actual condition and specifications of the surfaces affected by the construction, as well as the content of the signage and how it is written. Airport signage, taxiway markings and runway markings for airports are runways, and other visual cues can help or hinder flight crews when trying to dis88tinguish enclosed from active surfaces, as was well noted in the section on accident and incident compilation. The lack of visual cues or deficiency of visual cues has contributed to aircraft operating on closed surfaces and to runway excursions impacting machinery, landing before the displaced threshold, narrowly missing obstacles at the end of the runway heading, etc. (ANAC, 2019).

Over the years it has become evident that the publications of airport diagrams generally tend to lag the terms of the works and are sometimes not updated as frequently as desired while the works progress. Increasing the workload of the crews and affected parties who must constantly compare these diagrams and the content of the NOTAMs to obtain an overview of the status of the work. In some cases, an airport may publish a certain configuration before the construction is completed, so that the diagram does not correspond to the actual configuration at the date of publication, compromising safety. For this reason, when airfield diagrams are published, some operators assume that the latest surface configurations are represented, however it is possible that these may be omitted due to the temporary nature of the work. (Bris, 2015).

The development and distribution of NOTAM charts to present critical NOTAM information in an intuitive and user-friendly format. These graphics are based on the information system. The active promotion of the development and implementation of checklists to ensure consistently safe construction projects through process documentation. Improvements to airport signage and lighting to increase pilot and operator situational awareness of the impacts of airport construction on aircraft operations. Both signage and lighting can be considered as one of the first safety "nets".

As previously stated, at Jorge Chavez International Airport, once the second runway is completed, a maintenance process of the first runway, currently in operation, will be carried out, at first it is planned to close this runway entirety for the corresponding work, being from an operational safety point of view one of the most conservative measures. However, if such planning is altered and for different reasons to be assessed by the airport operator, LAP, it is deemed convenient to carry out the maintenance work in a staggered manner, a series of recommendations are presented below:

If a threshold displacement is intended, the markings on the runway should be precisely erased or hidden, avoiding any trace. The eventually closed section should be clearly marked as unusable. Signage and lighting are considered the first safety net; therefore, simplicity and clarity must prevail.

In the most plausible case, which is to close the runway in its entirety, it is worth noting that in a document presented by Gaël Le Bris, Director of airside development at Charles de Gaulle Airport (Bris, 2014), where safety in the construction of runways and taxiways was analyzed, it was found that in runways closed 24H:

- Crossings are not always in place when the runway is closed;
- The crossings are not always on the runway (69%);
- They do not always comply with the regulations (incorrect size, dissymmetry, etc.), (69% non-compliance with Annex. 14 and 31% with Part. 139 (FAA)).

Nowadays, mobile crosses are an excellent alternative, due to the cost reduction and flexibility with respect to painting. There are different options, from fabrics of different colors and backgrounds to create greater contrast, to a wooden frame covered by a white fabric and with wheels at the bottom for easy transport, which can be removed and repositioned very easily.

As for the color of the signs, different studies have been conducted and several airports in the United States and other countries have tested different alternatives. The feedback from pilots and operators is that orange background with black lettering, where there is a short but clear message is the best type of sign. It is therefore an economical, simple, and efficient mitigation measure to prevent miscalculated takeoffs with respect to TORA, for example.

Fig. 6. Yellow cross over the runway
Source: Bassey, 2015

Fig. 7. Signal with orange background and black letters
Source: Bris, 2014

Aeronautical information is a major concern during construction work. Best practices include:

- Transmitting clear information on ATIS,
- Sending emails to information providers (LIDO, Jeppesen, among others),
- Reporting directly and by email to airlines and pilot representatives.

Information before and during this process of continuous airport change is a real challenge, where the information in Annex 15 is useful but perhaps not sufficient.

To avoid take-offs from closed runways it is considered essential to block all possible access to the runway, and to avoid using sections of the runway for new taxiing procedures. If there is no other alternative, the trajectories through the closed runway should be protected by a continuous line of red and white concrete blocks and red edge lights. Thus, following the ALARP methodology, it could be reasoned that it is less severe for an aircraft to hit a concrete block at taxi speed than a construction machine at takeoff speed.

The following is an illustration of what is mentioned in the previous paragraph, where it is suggested to close all possible accesses to the runway out of operation.

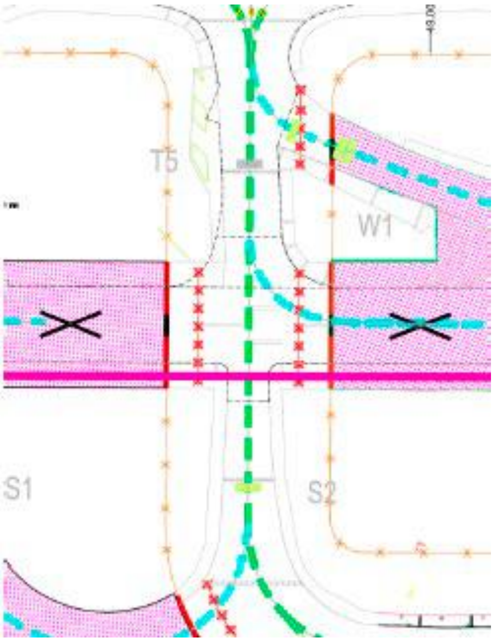

Fig. 8. Closure of access to inoperative runway due to construction work
Source: Bris, 2014

Most of the measures presented in this section are useful for the works at Jorge Chavez International Airport, where, although most of the construction works are being carried out in the west, and do not directly affect the current runway in operation, in Phase 1 of the work there will be a part where operations will be affected and takeoffs and landings must cease, and in Phase 2 it is also planned to maintain runway 16–34, which will be renamed 16L–34R.

In this Phase 2, the impact will be greater as it involves the closure of the runway, resulting in all operations being carried out on the new runway. Passenger boarding and disembarkation operations will be carried out from the current apron as well as from the forward apron.

Conclusions

The identification of hazards and risk management applied to the airport was supported by the thorough compilation of accidents and incidents that occurred over an extensive period, where construction work on the runway or its surroundings were determining factors in increasing both the severity and probability. In this way, the risk identification table focused on the airport expansion process, obtaining ten generic hazards which result in a total of thirty-seven potential risks.

As mentioned above, although this is a high number of risks and more than half of them have severities ranging from "important/major" or "hazardous", it should be considered that the probability of occurrence is quite low because more than 50% are subject to a rating of "improbable" to "negligible", prevailing an "acceptable" tolerability of the risks identified. However, 40% of the risks are tolerable, which is why it is vitally important to reinforce the process of identification, risk management and definition of mitigation measures, as well as their subsequent application.

The recommendations and mitigation measures presented in the paper cover a wide selection of alternatives to ensure operational safety throughout the works, especially during Phase 1 and 2 of the project when the current runway will be connected through taxiways L3 and L5, as well as the closure of runway 16–34 for maintenance.

It is worth mentioning that this safety analysis has its limitations. Data was extracted only from two sources over a period of 15 years, so the sample may not reflect most of the incidents or accidents occurred; future studies can include a larger database from different sources and time periods. Looking ahead, into areas worthy of further research would be the ones related to human factors and communication in an airport environment undergoing construction works.

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