LEARNING FROM ALL OPERATIONS

Case Study:
Departing and Arriving Aircraft Spacing

Flight Safety Foundation

OCTOBER 2024

1. Case Short Summary

This case study describes the approach undertaken by ENAIRE, the Spanish air navigation service provider (ANSP) to address a specific safety issue by collecting and analysing data from all operations. This initiative was triggered by runway incursion incidents during mixed-mode runway operations, specifically focusing on the spacing between arriving and previously departing aircraft.

The focus of this case study is the analysis of distributions of times/distances between arrival aircraft passing the runway threshold and key moments of the preceding departure aircraft's take-off and initial climb. This represents an example of the expanded use of system data beyond the historical focus of safety management systems (SMS) on 'exceedance events.'

Flight Safety Foundation (FSF) promotes the expanded use of data as one way of Learning From All Operations. The importance of something is only possible to judge when it is seen in perspective (FSF, 2022). To have perspective, we will need to learn about the entire spectrum of 'things' and to learn continuously in time. This means to consider actual events, as drawn from a distribution of possible events. True understanding requires attention to the whole distribution of possible events, including those that did not occur. This is *learning by distributions*, which builds understanding of the underlying distribution and helps to determine if what you observe is an outlier, how it relates to the entire performance and, ultimately, how it can be better managed. This is what we call Learning From All Operations.

In this case study, the ANSP identified three key moments in the departure process: the start of the line-up, the start of the take-off roll, and the overflying of the departure end of the runway. The ANSP built and analysed distributions of time and distances between arriving aircraft passing the runway threshold and the three key moments in the departure process. Additional distributions were analysed for the evolution of aircraft speeds with the distance to touch-down.

An ENAIRE operations team assessed the risk, supported also by the collected and analysed data, and developed a safety improvement plan. Following the plan's implementation, and as part of the SMS processes, ENAIRE is conducting ongoing safety monitoring through data collection and analysis from all operations.

The study yielded valuable conclusions and recommendations. It provides guidance for controllers to issue a line-up clearance for the departing aircraft, given the minimum time/distance for aircraft on final. The safety performance results observed are highly encouraging — the number of "arrival following a departure" runway incursions have been greatly reduced after the plan's recommendations were implemented and standardised by the entire staff of controllers.

2. The ANSP Three-Pronged Approach to Learning From All Operations.

ENAIRE uses three different approaches within its SMS to Learn from All Operations. One of the approaches is based on observations of everyday operations. A trained team observe normal operations in a unit. After an observation, the team develop proposals for best practices, including a mechanism to extend these practices to other units. This extension, in fact, is the main purpose of the first approach.

The second approach, further described in this case study, involves the use of data collection and analysis tools. ENAIRE has developed and uses a set of tools that can provide precise data for various operational parameters. For example, these tools collect data across the entire range of the performance distributions, not just for specific thresholds or exceedances. This broad data collection allows for various in-depth analyses. For instance, final approaches can be monitored at different approach points and distances from the runway threshold to determine if the aircraft's speed is within published limits. The analysis yields a precise picture of how operations are performed, incorporating data from all the approaches across all the distances from the runway threshold. This is, in other words, Learning From All Operations.

The third approach, currently in development and used by ENAIRE for Learning From All Operations, is based on machine learning. It relies on data from incidents over the last few years, with 30 different parameters or variables that are defined as important factors or aspects. For example, these parameters include controller time on position, time of shift, number of previous shifts, or the level of experience of controllers in the unit. All incidents are analysed, along with some randomly selected data samples from normal operations. The 30 different variables are analysed for their influence in the occurrence scenario. This process highlights some of the factors as more important than others in specific scenarios.

The patterns defined by the 30 parameters are compared to determine if there are differences between the patterns of incidents and the patterns identified in normal operations. This analysis helps answer questions such as whether new controllers are more likely to be involved in incidents than more experienced controllers. If differences in patterns are identified, they can be used to predict the combination of factors that have a propensity to lead to incidents. Data for occurrences is continuously introduced into the system as soon as it becomes available.

All three approaches are built and used within ENAIRE's existing SMS, with the existing processes and the new processes interacting and the associated data being shared. Data is generated by the internal investigation of incidents, from safety data monitoring, or from the reporting system. This SMS integration is considered by ENAIRE to be a key factor for the success of Learning From All Operations.

3. Introduction to a Case Study Problem, Operational Mitigations, and Principles of Learning From All Operations

3.1 The case study problem

This case study was triggered by runway incursion incidents at Malaga-Costa del Sol Airport in Spain involving the simultaneous runway presence of arriving and previously departing aircraft during mixed-mode runway operations (using a runway for both arriving and departing aircraft). Currently, these events are classified as runway incursions. The current safety standard is defined by the requirement for departing traffic to overfly the departure end of the runway before the arriving aircraft overflies the runway threshold.

Malaga airport has two runways, but it typically operates with a single, mixed-mode, runway configuration. The use of the second runway has been increasing, and both runways are usually used 12 hours every day, – from 9 a.m. until 9 p.m.

During mixed-mode operations, approach and tower controllers coordinate and sequence departure and arrival aircraft to comply with safety standards of runway use.

Controllers face a number of challenges during such operations, including adhering to aircraft target take-off times (TTOT) for efficient and safe regional traffic network operations, facilitating safe and efficient aircraft approaches (including approach stabilisation), and supporting aerodrome operations such as runway inspections and wildlife control. Due to the surrounding orography, when preferential south configuration is in use, aircraft commonly experience a tail wind during the approach until they are on short final.

Additionally, the operational environment can be characterised by variable conditions including aircraft with different performance capabilities, varying adherence to published approach speed requirements, differing meteorological conditions, and various mixes of traffic involving instrument flight rules (IFR) flights and visual flight rules (VFR) flights, fixed-wing and rotary-wing aircraft, and departures, arrivals, and overflights.

Malaga controllers hold endorsements as both tower and approach controllers. This supports a shared culture of unity and belonging and is indicative of flexible behaviour not strictly defined by internal procedures. This culture is characterised by an attitude of "we understand it from all possible directions because we work at all positions".

3.2 Operational Mitigations

After some runway incursion incidents, ENAIRE launched a safety improvement initiative. The information from these incidents and data from safety monitoring were analysed by the ENAIRE operations team. The purpose of the initiative was to establish a set of good practices and recommendations concerning the management of the sequence of aircraft taking off and arriving during the single Runway 13/31 operational configuration at Malaga. The goal was to prevent the loss of runway separation between an aircraft that lands and a preceding aircraft that has taken off.

At Malaga airport, whenever operating with the single Runway 13/31 configuration, regulations establish that no landing aircraft may cross the runway threshold on its final approach until the preceding departing aircraft has crossed the departure end of the runway or has initiated a turn.

Therefore, clearance to land can only be granted if there is a reasonable assurance that the required regulatory separation will exist when the arriving aircraft crosses the threshold of the runway in use.

This separation must also be guaranteed in the case of VFR traffic or an aircraft on a visual approach.

Therefore, it is necessary to define specific actions by the tower controller to facilitate the departure-arrival sequence:

- Safely guaranteeing separation between departing and arriving aircraft in order to proactively minimise the need for go-around manoeuvres for traffic de-confliction; and,
- Smoothly ensuring that departure flights adhere to their TTOT.

The ENAIRE operations team concluded that, to ensure adequate runway separation, there was a need to extend guidance to controllers. This extended guidance should include provisions for critical precursors to ensure safe runway separation, specially focussing on three consecutive phases in the departure process:

- Traffic taxiing immediately after being transferred from ground position (GND) to tower position (TWR);
- Traffic waiting at the holding point; and,
- Traffic lined up on the runway, awaiting take-off clearance.

The recommendations outlined in the ENAIRE action plan apply to the majority of commercial aircraft operating at Malaga airport, given their similar flight performances. It is assumed that good weather conditions prevail (good visibility, absence of wind shear and other adverse phenomena); otherwise, greater safety margins must be considered.

The recommended actions are based on the time-to-threshold of established arrivals that controllers can observe in air traffic service (ATS) surveillance systems. A new warning tool was developed and implemented to advise air traffic control officers (ATCOs) if a wrong reference threshold for these times is selected.

For each of a departing flight's three phases (from the action plan outlined above), there are generic guidance and recommendations for controllers, including:

- Communication on the tower frequency is always to be done in the English language. The high percentage of foreign traffic at Malaga airport means that, in the vast majority of situations, many pilots at Malaga do not speak Spanish. Furthermore, the presence of foreign pilots in Spanish companies sometimes leads to errors when controllers initially communicate in Spanish and then have to repeat their message in English.
- In the first communication, the traffic will be instructed to proceed to a specific holding point, with instructions to hold short of the runway.
- According to aeronautical information publications (AIP), crews must report if they are not fully ready at the holding point; otherwise, controllers will suppose they are ready to depart.
- Traffic that has not reached the holding point will not be cleared to take off.
- Line-up clearance will not be issued if it is expected that the traffic will be lined up more than 90 seconds before initiating the take-off run.
- Line-up clearance will not be issued if the arriving aircraft has reported "short of fuel/minimum fuel".
- Line-up clearance will not be issued if the arriving aircraft has executed a previous missed approach.
- Line-up clearance will not be issued if the preceding aircraft (whether arriving or taking off) reports a bird strike, which requires that a runway inspection be carried out prior to any take-offs.

Specific timing guidance and recommendations for each of the three phases in the departure process have been stated as follows:

- For an arrival-departure-arrival sequence, once the first arrival has crossed the runway-in-use threshold, clearance for lining up will be issued only if the time to threshold of the next arrival is *greater than two minutes*.
- For a departure-departure-arrival sequence, if the first departing aircraft is of a higher wake turbulence category and/or if plans are for it to fly the same standard instrument departure (SID), the second departing aircraft will be cleared to line up if the time to the threshold of the next arrival is *greater than three minutes*.

- When the aircraft is lined up on the runway, take-off clearance will be issued if the time to the threshold of the next arrival is *greater than 1.3 minutes* (and the runway is cleared of previous traffic).
- When the time to threshold is *between 1.5 and 1.3 minutes*, immediate take-off clearance will be issued, the arrival will be instructed to continue the approach, and essential traffic information will be provided to both flights.
- If, when the time to threshold is *equal to or is less than 1.3 minutes*, the aircraft on the runway has not started the take-off run, the take-off clearance will not be issued, and the arrival will be immediately instructed to go around.
- When the time to threshold is *less than 1.3 minutes,* even if the take-off has begun, if there is no clear acceleration, the take-off must be stopped. The arrival will be immediately instructed to go around.

If, even following the previous recommended actions, the aircraft taking off cannot interrupt its take-off run (roll), and the arrival time is less than the times prescribed above, the following actions are required from the tower controller:

- Coordinate with the departure sector, transmitting the pertinent information;
- Provide essential traffic information;
- Be reminded that separations can be reduced in the proximity of aerodromes under certain conditions; and,
- In no case should an aircraft be vectored below minimum vectoring altitude.

In addition, other recommendations are aimed at avoiding loss of situational awareness; for example. one recommendation discourages moving an ATCO who has been working with a two-runway configuration directly into a position in which he or she will work with a single-runway configuration. The mindset of considering only arrivals or only departures differs greatly from the required mental model for sequencing arrivals and departures on the same runway.

All these recommendations, together with relevant contextual information, are documented in a safety action plan. The specific recommendations are also defined in terms of decision-aiding flow-charts.

3.3 Learning From All Operations Framework

The safety action plan followed the logic of not only standardising the safety outcomes in terms of preserved separation standards but also addressing the critical precursors in normal operations. At the time of developing the ENAIRE action plan, the FSF Learning From All Operations concept notes had not been developed and published. However, it is interesting to see what the ENAIRE case looks like using the terminology and concepts of Learning From All Operations. Here are some specific highlights of the case study elements using the Learning Form All Operations principles (Figure 1):

- The study was triggered by a specific subject, and it involved safety monitoring after the implementation of the safety improvement plan.
- The studied operational system is defined as ATC traffic sequencing during airport mixed-mode operations at Malaga airport. Relevant flight crew actions, such as speed control on final approach, are considered within the boundaries of the studied system.
- Within the system, entities include ATC working positions of tower, approach, ground; the arriving, departing, and going-around flights; the ATC automated system, which includes surveillance and time-to-touchdown indication functionality; and the ATC meteorological information system.

- The inquiry studies both the sharp end (operations) and blunt end (organisation) of the system — operations as well as relevant procedures and training.
- The adopted learning approach was top-down, starting from an undesired aircraft state (critical proximity of aircraft on the runway) and inquiring backwards to normal operations (take-off and line-up clearances).
- The information sources were based on incident information, automatically collected system data (including surveillance), and expertise elicited from sharp-end (front-line) professionals.
- The studied key learning parameter is the spacing between the arriving and previously departing aircraft using the same runway.
- The safety control envelope is defined as a near collision between arriving and previous departing aircraft, which establishes the actual boundaries of what is safely recoverable in operations though preventive or recovery measures. (Outside this boundary, safety control becomes marginal to non-existent).
- The system hazardous state is defined as a runway conflict — the simultaneous presence of arriving and previously departing aircraft on the runway.
- The operational limits are defined as specific timing guidance and recommendations for each of the three phases — as described in the previous section. To simplify the presentation, the safety prevention envelope (beyond which the system becomes unstable in terms of safety, shown as the yellow space in Figure 1) is considered to be at the operational limits (the timing guidance).
- The system critical state is defined as the infringement of the specific timing guidance and recommendations for any of the three phases of the departure process.
- Recovery from a system critical state (infringement of the specific timing guidance) can be achieved, for example, through instructions to stop the take-off and to go around.
- Collision avoidance is performed as a last resort action to manoeuvre the aircraft away from the other, conflicting aircraft.
- The main safety margins used for building and analysing informative distributions are the time/distance between the arrival aircraft passing the runway threshold and the key moments defined by the specific timing guidance.

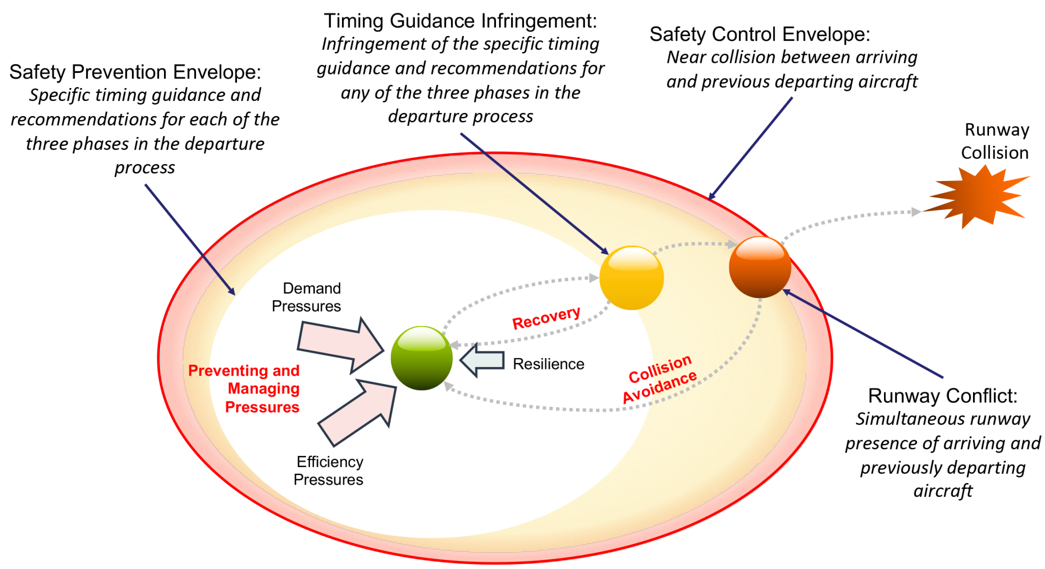

Figure 1: Learning From All Operations Concepts as Applied to the Case Study

4. Safety Monitoring Using Data From All Operations

Following the implementation of the safety action plan, ENAIRE designed a safety monitoring approach to determine the effectiveness of the implemented plan. Safety performance monitoring and measurement is one of three elements that comprise the safety assurance component of the International Civil Aviation Organisation (ICAO) SMS framework. Safety assurance consists of processes and activities undertaken by the service provider to determine whether the SMS is operating according to expectations and requirements. Safety performance monitoring and measurement represent the means to verify the safety performance of the organisation and to validate the effectiveness of safety risk controls. (ICAO Doc 9859–Safety Management Manual).

Safety performance monitoring was conceptually performed by collecting and analysing data for the periods before the implementation of the safety action plan and for the period after the implementation of the safety action plan as described:

- Between 21 September 2019 and 31 January 2021; and,
- Between 1 February 2021 and 31 of August 2021.

The data source is predominantly based on the radar and multilateration tracks for aircraft flights in the vicinity of Malaga airport.

Specific and representative samples were selected for the population of all flights within the studied periods. In this way, two data sets for comparison were defined, as illustrated in Figure 2.

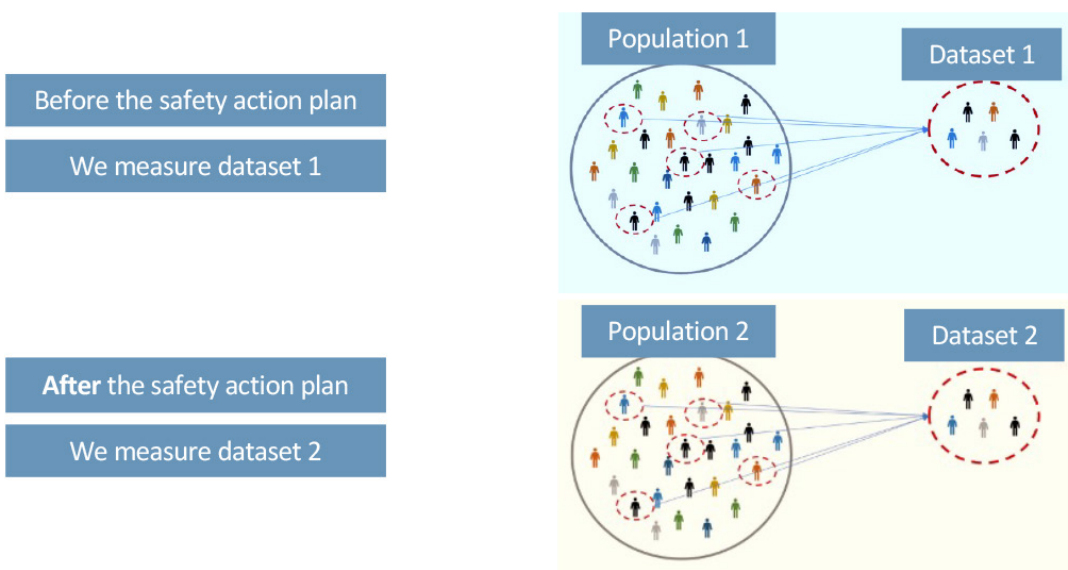

Figure 2: Defining Two Data Sets for Comparison

The resulting distributions are demonstrated visually in Figure 3. Both datasets are measured in terms of distance and time to have a better understanding of geometry and dynamics. In both cases, the monitored parameter is the position of each arrival when the preceding departure traffic starts the line-up on the runway (crossing the holding-point stop bar). Two illustrations are provided for each of the distributions for the two runway directions.

Although not very visually distinguishable, it was observed that dataset 2 (after the safety plan) has a slight right bias (a tendency for slightly greater distances and times).

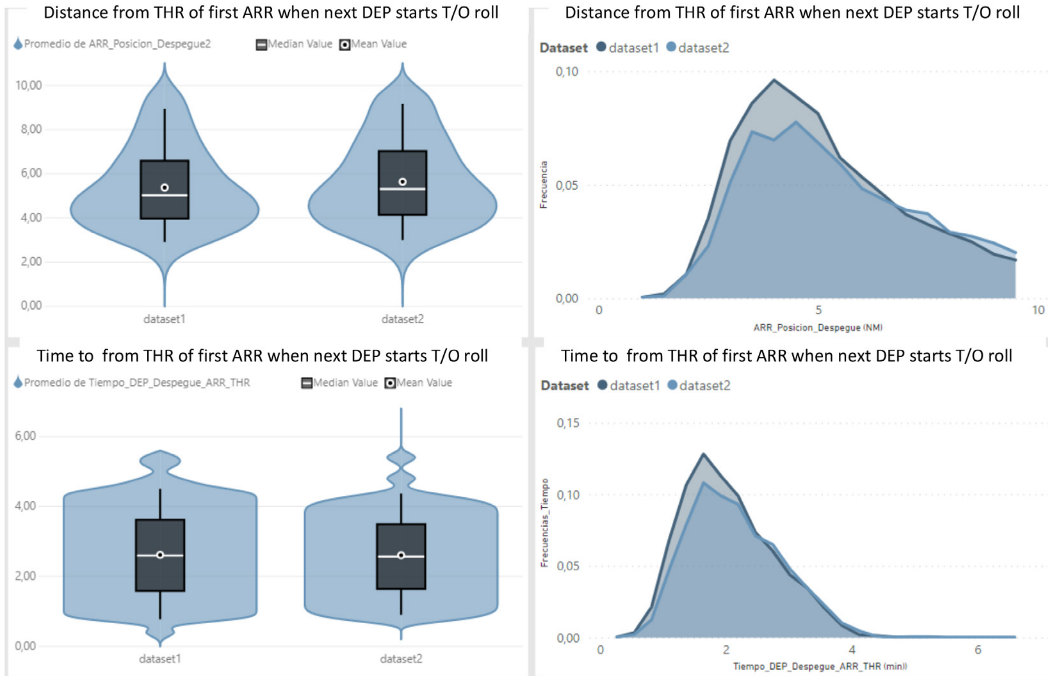

Figure 3: Time and Distances Distributions

Another way to illustrate the monitoring results is through heatmaps. For example, in Figure 4, heatmaps represent the position of each arrival when the preceding departure traffic starts the line-up on the runway (crossing the holding point stop bar). Blue represents less traffic, red represents a medium concentration, and white represents the highest concentration of spots.

Figure 4: Arrival Position When Preceding Traffic Starts Line-Up

Similar analyses, with time/distance distributions and heat maps, were performed for:

- Position of each arrival when the preceding departure traffic starts the take-off roll; and,
- Position of each arrival when the preceding departure traffic crosses the opposite threshold.

After reviewing the distributions and heatmaps, it was concluded that heatmaps were expected to be a bit further away from the threshold positions (longer times/distances). Although the white part of Runway 13 (upper left corner of the right illustration) is away from the runways and is visually noticeable, it was concluded that a firm conclusion cannot be made by visual reference only and there is a need for statistical analysis.

Having distributions of times/distances between arrival aircraft passing the runway threshold and key moments of the preceding departure aircraft was indispensable in performing the statistical analysis.

The following hypothesis was outlined to be the subject of the statistical test:

- The null hypothesis consists of considering the data obtained during the first and second monitoring periods as part of different statistical distributions.
- Consequently, the hypothesis was based on considering that Population 1 and Population 2 displayed different overall behaviours.
- If the hypothesis was confirmed, this could be interpreted as an overall system behaviour change, and hence, that the safety plans had had a noticeable effect. Moreover, this could also be assessed considering other overall system behaviours such as the number of occurrences.

The following steps were performed as part of the statistical analysis:

- Observed frequency distributions were tested for normality. This verified whether the observed distribution behaves like a normal (Gaussian) distribution. The test confirmed that the distributions cannot be considered as normal (Gaussian).
- Observed frequency distributions were tested for homoscedasticity. Homoscedasticity, or homogeneity of variances, is an assumption of equal or similar variances in different groups being compared. This is an important assumption of parametric statistical tests because such tests are sensitive to any dissimilarities. This test measures whether dataset 1 and dataset 2 have similar variances. The test confirmed that variances are similar.
- With the results of steps 1 and 2, a set of statistical tests was selected, since not all tests are valid for testing our hypothesis.
- In this case, a t-test, Mann-Whitney -U, and Kolmogorov tests were used. These tests verify if the hypothesis (distributions are different and data come from different populations), hence the hypothesis is considered valid with a certain degree of confidence.
- The tests results suggested that the hypothesis was accepted, so it is assumed that the populations are different.

The results were interpreted as showing a change in the overall system behaviour: **When each departure crosses the stop bar** (**starts take-off roll and crosses the opposite threshold**)**, the next arrival is a bit further away, when compared to the pre-safety plan situation.** No impact on throughput or declared capacity was identified due to the plan implementation.

Additional verifications were made to monitor the overall system's behaviour. The automated monitoring data was also used to determine the rate of automatically detected runway incursions. The automated detection events were assessed by safety experts and investigators. Each time an event candidate was detected, the situation was assessed to determine whether the situation matched the arrival-departure safety occurrence type; situations not matching this type (mainly helicopter-airplane situations were not considered safety occurrences and were discarded).

Since the operational envelope consisted in ARR-ARR nominal gaps of seven miles, but where speed management issues had been detected in previous incidents, approach speeds were also monitored. A set of actions in the third part of the safety plan involved a reinforcement of standard operating procedures (SOPs) and an awareness campaign with the airlines through the local runway safety team.

The approach speeds were also monitored before and after implementation of specific safety actions targeted towards increasing speed stability and coherence amongst aircraft. The initial analysis showed strong differences in the speeds of the two main aircraft families using the aerodrome when speed was measured at the threshold and four miles out. The adherence to the SOP airspeeds positively evolved after the speed-related actions were implemented.

The occurrences involving a loss of separation between arrivals and departures using single runway were also monitored in number and rates per 100.000 flights, and reductions were measured in number and aggregated severity.

There was a drawback in assessing systemic safety in such an intensive and systematic way. The usage of automated tools to detect losses of separation removes the underreporting and under-detected factors. Nearly 100 percent of occurrences were detected, even the low-severity occurrences or those not having safety effects. However, regardless of how well safety communication is managed, there is a strong difference in the number of reported occurrences and the automatically detected rates at which this happens. This raises concerns about the safety of the operation and may adversely and unfairly impact the perception of safety performance. Other parts of the air traffic management system are monitored relying only on reporting, which provides a much-blurred picture of the real safety situation. Under-detection plays a role (situations are detected, or not, by visual perception of the ATCO and his/her judgement as to whether there was a loss of separation), but under-reporting also plays a role if the ATCO does not consider the situation unsafe and hence, the situation is not reported and remains out of the overall safety record.

5. Conclusions/

The three-pronged approach adopted by ENAIRE is an efficient example of integrating new processes and procedures supporting Learning From All Operations into the existing SMS. Observation of normal operations, including eliciting feedback from the system's front-end actors, using data and analysis tools that allow collecting and analysing data across the entire range of the performance distributions for key operational parameters (not just for specific thresholds or exceedances), and using machine learning to determine if there are differences between the patterns of incidents and the patterns of normal operations are a complimentary and powerful enhancement of the SMS.

This case study demonstrates how safety monitoring processes can be enhanced with the use of data collection and analysis of distributions. The results obtained in gaining key insights about the efficiency of a safety action plan could not have been obtained in another way. This confirms the principles and practices of Learning From All Operations as not just a "nice to have" but also as an imperative in order to ensure an efficient SMS.

6. Acknowledgements

This case study was drafted by Tzvetomir Blajev, Flight Safety Foundation; Jesús Romero Hernández, ENAIRE; Leticia Sanchez-Palomo, ENAIRE; Alberto Rodriguez, ENAIRE; David Gonzalez, ENAIRE. Thank you to the members of Flight Safety Foundation's Learning From All Operations Working Group, who contributed to the content and clarity of this report.

Suggested citation: Flight Safety Foundation. (2024). Learning From All Operations Case Study: Departing and arriving aircraft spacing.

References

Flight Safety Foundation. (2021, July). Learning From All Operations: Expanding the Field of Vision to Improve Aviation Safety. Retrieved from https://flightsafety.org/toolkits-resources/special-reports/

Flight Safety Foundation. (2022). Learning From All Operations Concept Note 1: The Need for Learning From All Operations. Retrieved from https://flightsafety.org/toolkits-resources/learning-from-all-operations/