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Managing safety data: the TOKAI experience for the ANSPs

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Abstract

Socio-technical systems such as the Air Traffic Management (ATM) system have become increasingly complex in the last decades and a call for systematic data analyses is necessary to manage operations and related criticalities. In the context of risk and safety management, it thus become central to allow structured and complete in-depth understanding of safety performance, especially in relation to safety events (accidents, incidents, near-misses).
Following relevant international and EU regulations (ICAO Annex 13, EC Directive 2003/42/EC, EU 376/2014, etc.), EUROCONTROL developed the TOKAI (Toolkit for ATM Occurrence Investigation) as a tool to support occurrence investigation and generate a structured repository for safety data management. This paper aims to present the general features of TOKAI, also in line with the legislative context. The paper provides an overview on how incident data from TOKAI may contribute to support an effective data management in aviation, by means of exemplar statistical analysis to support the decision-making at different organizational levels.

Keywords: safety investigation; safety reporting; socio-technical systems; air traffic management; aviation safety.

1. Introduction

A high general level of safety has to be ensured for aviation, with the purpose of reducing the number of accidents and incidents, despite the increasing traffic level and incremental complexity. For international

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harmonization, ICAO International Standards and Recommended Practices (SARPS) contain the nineteen Technical Annexes developed to support technical uniformity for a safe, orderly and efficient development of civil aviation.

About safety occurrences, following ICAO Annex 13 provisions, each State shall investigate (or delegate the investigation of) accidents and serious incidents occurred in their territory. Annex 13 conceives investigation as a process conducted for the purpose of accident prevention, including data gathering and analysis of information, determining causes and proposing safety recommendations. ICAO explicitly acknowledges that investigation represents an opportunity to better understand the events leading up to the occurrence, identify hazards and underlying criticalities with the ultimate purpose of reduce or eliminate risks (ICAO, 2011). Annex 13 does not envisage blame or liability as aspects within the scope of investigation, confirming wider theoretical discussions in several socio-technical domains.

Furthermore, following recent trends in safety management, investigations should shift from individual reliability analysis to embrace systemic properties. Rather than following a reductionist techno-centric perspective, safety investigations should aim at detecting complex systemic interactions, and thus emerging criticalities. If many failures are imputed to human error, a healthy safety management process should rather focus on organizational factors that may contribute to the emergence of specific error (delving into training, team management, procedure management). Similarly, many technical failures should motivate further investigation on equipment usage in normal practices, or even on maintenance planning and control, in addition to technical analysis based on components' reliability (EUROCONTROL, 2003). Formal occurrence investigation is thus necessary to distinguish between systemic threats and random events, providing prioritized safety recommendations for both situations. For large socio-technical systems, such as the ATM system, a variety of occurrences can happen, involving a large number of interacting agents. Subsequently, a large number of different events and associated causal factors is expected to constitute the basis for in-depth analysis of system properties. Investigations should thus abide by structured approaches in order to maintain consistence and significance, following taxonomy-based representations. See (e.g.) the ICAO ADREP Occurrence category taxonomy, which represents a set of terms used to categorize accidents and incidents, and the event chain that led to the occurrence itself. This taxonomy was created to serve the purpose of Annex 13, which itself is entirely focused on the analysis of accidents and serious incidents.

The investigation process should include a large variety of categorization dimensions (for the events, and for the associated factors), whose systemic analysis requires dedicated tools for event recording, data analysis and information sharing, in agreements with EU regulations. This paper emphasizes the relevance of a structured safety reporting and safety information management, as a means to increase safety levels in civil aviation. Following the ANSP's perspective, this paper focuses on EU regulations about occurrence investigation and describes a tool originally developed by EUROCONTROL, i.e. TOKAI (Toolkit for ATM Occurrence Investigation). Presenting TOKAI concepts and related exemplar statistical analysis, the paper aims to provide empirical evidence on how well-structured safety data (e.g. following TOKAI) constitute the basis to support safety decision-making in the aviation domain, with strong implications on everyday operations.

The remainder of the paper is organized as follows. Section 2 presents relevant EU regulations for occurrence investigation and safety data management. Section 3 discusses TOKAI history and basic structure. Section 4 provides examples of statistical analysis starting from data collected using TOKAI. Lastly, the Conclusion summarizes the contribution of the paper and presents the possibility for further research.

2. EU regulation about occurrence investigation

As mentioned in the introduction, an obligation to investigate accidents and serious incidents in civil aviation dates back to the ICAO 1944 Chicago Convention on International Civil Aviation, and in particular ICAO's Annex 13 to the Convention: Aircraft Accident and Incident Investigation. The very first edition of this Annex was published in 1951. It is now at its 11th Edition, published in 2016 influencing both the 1980 EU Council Directive 80/1266/EEC and the subsequent 94/56/EC. The former referred to the cooperation and mutual assistance between member states in air accident investigation, while the latter established the principles of investigation for civil aviation accident and incidents. Later on, the EC Directive 2003/42/EC detailed the traits for a harmonized reporting structure for incidents, lowering the threshold for the occurrences that would enter in the scope of detection for regular analysis (Arnaldo Valdés and Gómez Comendador, 2011).

In effect, Annex 13 actually looks primarily at the most serious events, namely accidents. It also covers serious incidents, i.e. an event where an accident did not happen purely by chance, but where otherwise all barriers were broken and only providence, or luck, saved the day. However, the much lower category events do not enter in the scope of Annex 13. Within the EU, it was considered that more precise, as well as more extensive regulations were necessary. The advent of the Single European Sky (applicable only for the ATM part of the aviation) has also helped focus attention on performance and on safety, which is one of the key performance indicators, in accordance with the EU Reg.549/2004 as well as the EC Reg. 390/2010.

While in principle all ICAO Annexes are obligatory for all ICAO signatory States, in practice ICAO effectively lacks the teeth to impose their implementation. Regular audits by ICAO or by the FAA have highlighted shortcomings in implementing these rules, not always actually succeeding in pushing states to their full and proper implementation. Furthermore, the ICAO standards are drafted in such a way that they remain at a relatively high level, allowing implementation by all States, regardless of their geographic position or maturity. While Europe, and in particular the EU/EEA are among the safest aviation areas in the world, according to data published regularly by ICAO, the Flight Safety Foundation or the Aviation Safety Network, the EU legislator took the extra steps of strengthening further the ICAO regulatory framework, both from an enforcement perspective, but also from a technical one. A good example is the ICAO Annex 13 (Aircraft Accident and Incident Investigation) which was transposed within the EU legal order through the Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

Historically, as safety was assessed based on failures, the focus of ICAO and of initial EU regulations was for detection of such failures. This type of failure-driven safety worked quite well for many years, from the beginning of aviation safety, as it was largely based on detection of failures of technology, primarily around aircraft systems. Up to the late ‘80s or even to the mid-‘90s, technical reasons were the main identified causes for incidents and in particular for accidents. It may however be a chicken-and-egg situation, whereby the technology was the main cause, but human factors were not particularly examined, thus technology always being considered as the reason for failures. It is however important to note that some very high-profile accidents in civil aviation, including the biggest-ever accident (Tenerife, 1974) which was a runway collision between two fully loaded Boeing B747s, has as a main cause human factors. Other such cases can include the first-ever mid-air collision (Grand Canyon, 1956) and more recent cases, such as the mid-air over Überlingen, Germany, in 2002. As the technology evolved and it became more and more reliable, human factors became the main identified cause. In the past, systems were by and large simpler and more tractable than today. Furthermore, most such systems were easy to decompose and could be considered rather linear, thus being possible to easily identify a cause-to-effect chain. Today’s systems have become hugely complex, intractable and non-linear, such that a simple cause-to-effect source of an occurrence is no longer plainly obvious. Human factors are considered to be more complex and involved in causes, as well as solutions to incidents. Clear examples of technological failures in recent years where the humans have certainly saved the day are the so-called “miracle on the Hudson” (NYC, US Airways 1549, 2009), the uncontained engine failure of Qantas 32 flight in 2007, the missile-hit DHL flight at Baghdad in 2003, the 2001 Transat 236 fuel starvation flight landing in the Azores or even the BA9 flight encounter with volcanic ash in 1982. Many more incidents can be quoted where human ingenuity and flexibility saved the day or at least helped to minimize the outcome.

In this context, the latest EU legislation tries to dig a little more beneath the immediate surface and causes of any incident. EU 376/2014, together with reg. 1018/2015 set up the rules for mandatory and voluntary reporting, aiming at identifying precursors to such major incidents or accidents, by putting in place a permanent system of reporting, investigation and lesson learning. This is double-down by a protection system for the aviation personnel, which should feel empowered to report without fear of undue retribution. Well before such EU regulations have been put in place, EUROCONTROL has created a regulatory framework, theoretically still in place in its Member States, but overtaken by EU legislation where applicable, whereby States had to collect data and use a common taxonomy for the analysis and information sharing. Furthermore, organizations also needed to have a clearer method to collect and analyze the data. The need for a common taxonomy being even more stringent, as they often need to look at cross-border events or communicate with their partners in order to solve an issue. Thus, TOKAI has been widely adopted by over 50 ANSPs in Europe as the tool enabling them to comply with these requirements, including that of generating data in accordance to the EU data-standard, the ECCAIRS, using the ICAO ADREP taxonomy. However, TOKAI is far from being purely useful solely in Europe, something that is proved by the decision of the CANSO

Safety Standing Committee (comprised of the safety directors or managers of all CANSO member ANSPs), who, at its annual conference in 2016 decided to adopt the Risk Assessment Tool (a sub-tool of TOKAI) as a standard for all its members. TOKAI is already in use with a handful of non-European ANSPs and a few more are lined up for its adoption in the near future, which tends to prove its versatility.

3. TOKAI

3.1. A brief overview of TOKAI history

Following the establishment of the Safety Regulation Commission and its supporting Unit back in 1998, as an early implementation of the EUROCONTROL Revised Convention, work started in earnest to collect safety data at European level in order to perform analyses, identify trends, top risks and other relevant safety aspects. This approach was at the time strictly reactive, i.e. based solely on events (incidents and accidents). This was before the creation of EASA or indeed the EU's Single European Sky programme. However, it was clear very soon that data was very scarce and where it existed, it was inconsistent. Aggregating data from all organisations was practically impossible, as each organisation or State used different flavours of terminology, although they were supposedly using the ICAO ADREP taxonomy. Thus, the need for a tool was clear. Such a tool would not only assist the resource-challenged organisations (then like now), but would also harmonise the taxonomy, thus allowing aggregation at European level. At European level, TOKAI is seen by EUROCONTROL as an opportunity to:

- Provide support to many ATM service-providers and safety regulators, who experience limited resources, expertise, training and tools.
- Investigate and share lessons from ATM occurrences.

In its first form, TOKAI was a standalone tool, which could be installed on any MS Windows PC. This concept obviously had some shortcomings, in the fact that each user had to have a copy of the programme installed on their individual machines. Data sharing was not possible, as many other network facilities were not present or indeed possible. All changed with the arrival of the new TOKAI version, which is currently a web-based application. This latter has opened a whole new range of facilities, including, but not limited to, a strong user management system, whereby users can be given different rights depending on their roles in the organisation and in the SMS, concurrent access by more than one user to the tool, a strong data protection mechanism, easier sharing of the data when and as needed, etc.

3.2. TOKAI main features

TOKAI is a tool that needs to be easily usable by a very wide range of organisations, starting with a small AIS provider with perhaps two or three people and no more than a few dozen events a year, all the way up to some of the largest ANSPs in Europe, with dozens of units, thousands of users and tens of thousands of events each year (EUROCONTROL, 2018). Such a flexibility would only be possible with a tool that was designed from the onset to allow creation of multiple configurations, depending on the parameters of the organization. For example, TOKAI allows the creation of an indefinite number of units, each of which can have its own reporting and analysis templates and can generate its own statistics. Conversely, all units can use a common set of templates and statistics, all of this depending solely on the desires of the organization.

Essentially, all such templates and functionalities are based on a common taxonomy and ANSPs are coerced by the tool, as well as by EUROCONTROL, who remains the custodian of the tool, to use such a common taxonomy, which is far from being a trivial task. As it often happens, although the adoption of a new tool may be seen as an opportunity by an organization to take a step back and analyse its current operations, review its needs and renew its methods, often there is a certain fear of change and the old habits, forms or methods are simply transposed in the new technology, thus carrying over a legacy that may date back many years. Therefore, EUROCONTROL is often faced with requests for new items in the taxonomy or for functionalities that do not necessarily make much sense in an electronic environment, but they have their origins in the old operating procedures of certain organisations simply being afraid or finding it difficult to adapt to the new thinking. Usually, EUROCONTROL tries to review such attempts together with the concerned organization, in the vast majority of cases supported by TOKAI structure.

What needs to be avoided is that each organization creates a subset of its own taxonomy, which is injected in the common TOKAI taxonomy, afterwards using only that subset, thus ending up with a huge so-called common taxonomy, but whereby the truly common part used by all ANSPs is in fact a really small set of the larger taxonomy. By combining support, flexibility and guidance, so far TOKAI has managed to avoid slipping into such a practice, which would have meant the end of any common taxonomy and a return of 20 or more years back.

3.3. Information management in TOKAI

Figure 1 presents an overview of the TOKAI information management process flow.

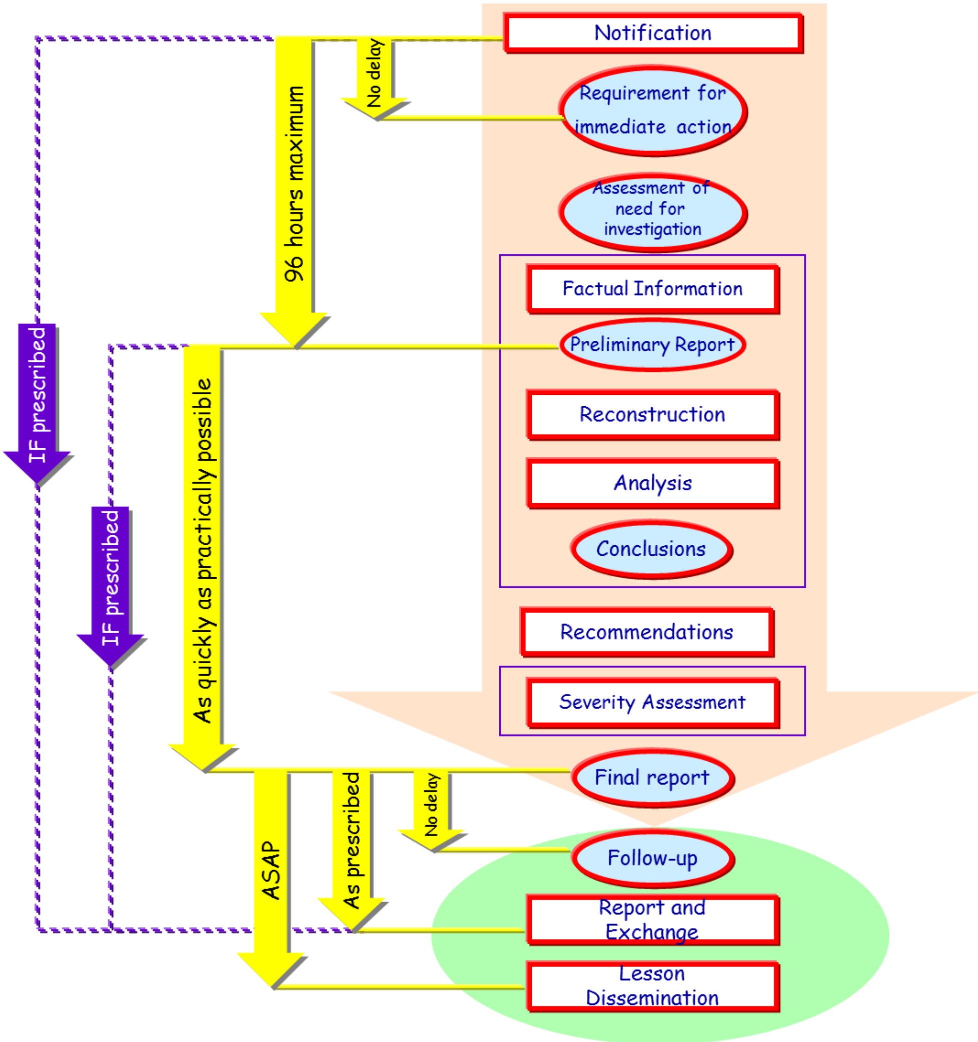

Fig. 1. Process flow of the TOKAI application.

As any event collection, the TOKAI data flow must start with an initial notification from an operator. This latter resides in the Notification module: (e.g.) an ATCO is presented with a relatively simple template, where the basic information from a freshly occurred incident can be entered. This information is then transmitted to the appropriate people, depending on how the tool was configured (e.g. the Safety Manager, the chief investigator etc.). The next phase starts with the investigation, where a responsible investigator takes over the notification and turns it into an occurrence, or not. There may be cases when the notification is deemed to be irrelevant for safety, then the investigator in charge can simply dismiss it, sending a feedback to the person having notified the event (through TOKAI). All these actions are logged within the tool, which will later allow an easy traceability of the process, should the need for this arise. As suggested in Figure 1, the whole investigation flow is contained within TOKAI, starting with the initial notification, followed by the opening of an investigation through a preliminary assessment, then (if needed) a thorough investigation, finalised with conclusions and recommendations.

A risk assessment is also an essential part of the investigation, so this is another sub-tool of TOKAI, through which the organization also fulfils its obligations towards the Performance Scheme, by applying the Risk Analysis Tool (RAT) and allocating a risk score. Throughout this process, TOKAI keeps a tag on the event and if it falls under the requirements of Reg. 376/2014, which requires certain steps to be taken within certain deadlines, the tool will alert the responsible people as to the impending deadlines, thus allowing them to concentrate on the most pressing events.

TOKAI will further assist organisations with the collection of data, as not only the facts entered (typed) in manually will be stored within each investigation file, but also other data can be attached, such as radar screenshots, transcription of voice recordings, or any other files related to the investigation. At any point during the investigation, which may take anything between a few hours to a few weeks or months, depending on the complexity of the occurrence, users with the appropriate rights can generate feedback to the initial reporters, can generate pdf reports for external use (TOKAI allows the generation of an unlimited number of reports, in an unlimited number of layouts, these being freely created by the organisation, without any limitation). TOKAI can also generate the appropriate E5X files, which is a specific format required by the EU legislation in order to feed the EU's European Central Repository (ECR) through ECCAIRS. This file is required by the EU Reg. 376/2014 from all aviation organisations and it is imposed as the only legally acceptable format to feed the ECR. This function allows European ANSPs and any other organisation willing or obliged to report data to EU authorities to discharge their legal obligations.

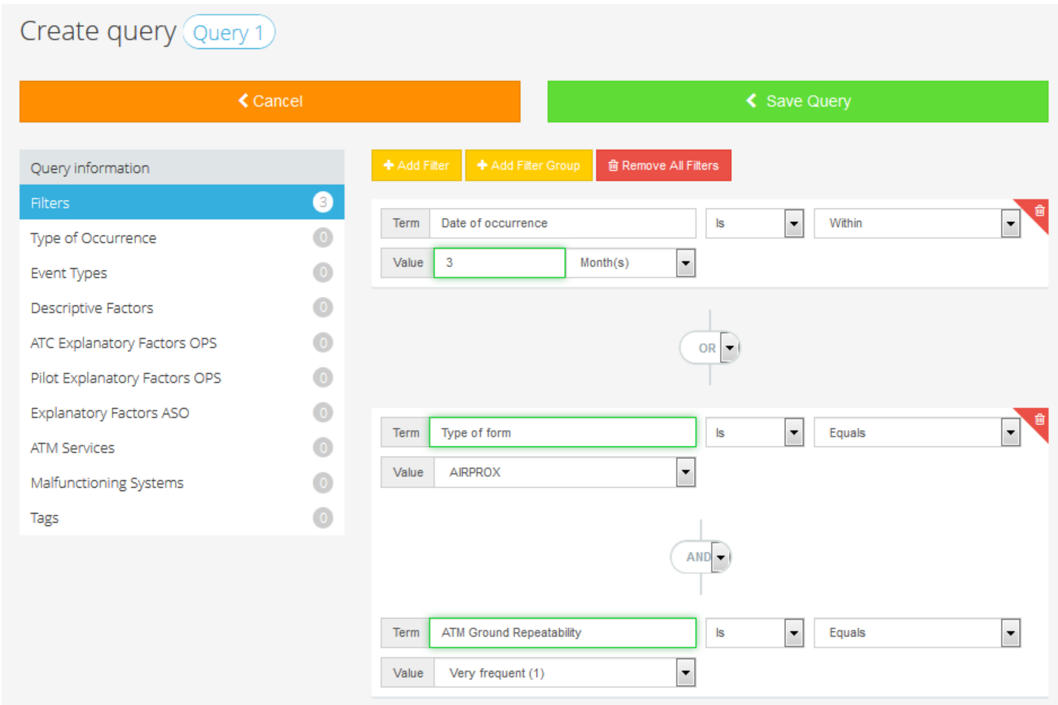

Fig 2. An example of a simple query

Finally, independently of the investigation process, the tool is capable to generate certain statistics, based on dynamic filters, as defined by the user, drawing from the events already stored in its database. The creators of

TOKAI have recognised the difficult balancing act between the need for quick statistical data from the TOKAI database and the difficulty, potentially daunting task of developing a proper statistical module, to rival the kind of Business Intelligence tools widely available on the market. As such, it has been decided that only a small, limited set of very basic statistics are generated by TOKAI, which would respond to the most pressing, quick and basic needs in terms of data mining, however as the potential is unlimited and no two organisations have the same needs, it would prove next to impossible to create a full statistical function within TOKAI that would satisfy any user. Therefore, TOKAI is able to export data in excel form, data that would normally be initially filtered within TOKAI through a query. For even more heavy data analysis and report generation, TOKAI allows connection directly to its database which can be interrogated by more complex BI-type tools, capable of complex data mining and statistics. While the tool has been conceived and continues to be developed by EUROCONTROL, it has long since ceased to belong solely to its creators and owners, as its wide user base has made a considerable contribution to the development, by feeding back to EUROCONTROL their experience, their needs and even their daily struggles with regulatory compliance and the almost incessant demands of their regulators. Thus, TOKAI must prove its versatility constantly, as occasionally requirements from various users may be contradictory, they have various priorities and can have unintended consequences. To give an example, an initial notification submitted by a technician, following a technical failure, is considered sealed by some ANSPs, thus locked for editing, while others consider that the technician can change his mind, learn additional details or simply want to correct and error, and should be able to edit his own notification, even after it was submitted. Which is fine, provided an investigation hasn't already started, in which case the investigator would not necessarily know what was modified, may not take it into account or simply the facts found by then might contradict the modified statement of the technician. It is important that TOKAI continues to respond not only to the operational needs of its users, but also to the regulatory requirements in the easiest way possible, so that ANSPs are not unduly burdened with compliance, which is not their primary objective or business. The constantly enlarging user base and their feedback contributes to the strength of the tool and will continue to do so for many years to come. In order to achieve these results, it is also important that the tool be capable to manage access rights and permissions, all of this being made possible through a rather complex user-management system, which is embedded in the tool. As such, certain users can be given certain rights, such as creating or editing an investigation, filing an initial notification, running statistical queries or simply viewing the data. By combining the right and the units, the flexibility of the tool is basically limited only by the imagination of its managers.

4. TOKAI data structure and analysis

4.1. Data structure

Once the user accesses the TOKAI dashboard, he/she has the possibility to report data about the occurrence and start the signalling actions. Main parameters to be potentially reported in the occurrence refer to a TOKAI taxonomy refined over years of interaction with ANSPs, in compliance with EU 376/2014.

- Generic Data
    - National incident reference number. A string used to identify a unique record in a local database environment.
    - Date and Time of occurrence
    - Location of occurrence. Field useful to define the position of a certain event, possibly adding its geographical co-ordinates (Latitude e Longitude)
    - Name of ATS unit involved
    - Type of Occurrence (Following taxonomy provided in ESARRs (EUROCONTROL, 2009, 2001)
    - Description of occurrence. A narrative about the occurrence, possibly including relevant photos or operational material. This fields can be filled up with free text.
- Further detailed data about the event
    - Data about Runway (e.g., Runway in Use, Configuration used, Eventual further information about the airport)
    - Data about Weather (Visibility, Light conditions, Meteorological conditions, RVR, Winds, Clouds)

  - Explanatory Factors (both Contributing and Mitigating)
- Risk Classification (following RAT logic). It can be further detailed depending on ATM Ground or Overall contribution, and in both cases expressed by two sub-parameters:
  - Repeatability. The classification scheme specifies five qualitative frequency categories, from 1 (very frequent) to 5 (extremely rare); this classification indicates the likelihood of reoccurrence and it is fundamental for safety prevention, as it is based primarily on systemic factors.
  - Severity. The severity classification scheme specifies five qualitative frequency categories, where A means a serious occurrence, B major, C significant, E no safety effect, D not determined. This classification indicates how “bad” an incident was, or how close to an accident, and it is exclusively backward looking and fact-based. The severity alone has very little use, if any, for safety improvement and for the prevention of further events.
- Further data about the flight (if any)
  - Aircraft type
  - Aircraft wake vortex category
  - RTF call sign
  - Aircraft operator
  - Phases of aircraft operations applicable (e.g. Standing; Taxiing; Take-off; En-route; Approach; Landing Maneuvering)
  - ACAS triggered

4.2. Example of analyses

TOKAI allows creating a multi-parameter database for each reported occurrence, to be used as a basis for retrieving data and generating statistical parametric analysis. Even though some general analyses remain certainly meaningful for any organization using TOKAI (e.g. most common event types, distribution of occurrences per location, distribution of occurrences over time, etc.), this latter allows flexibility about both the software to be used for database management, and the custom analyses to be performed and visualized. The following examples refer to anonymized data of an EU ANSP TOKAI database, and to exemplar statistical analyses which could remain meaningful to support middle and top level decision-makers.

Firstly, the data stored in TOKAI support a risk classification of occurrences, using a two-dimensional traditional risk matrix based on the values of Severity and Repeatability. Figure 3 presents an exemplar analysis, which clarifies the possibility to filter the most critical occurrences in order to prioritize mitigating actions. Note that the risk profile in the risk matrix depends on relevant international and national regulation, also following the risk appetite of the ANSP. In addition, Figure 4 gives an overall geographical representation of the number of occurrences and associated risk level.

		ATM Severity				
		D	E	C	B	A
ATM Repeatability	5	70	165	1	3	2
	4	47	143	24	3	1
	3	58	453	106	15	4
	2	2	318	65	13	1
	1	1	3	2	1	2

Fig.3. Risk matrix (Severity vs Repeatability) including the statistics in TOKAI.

The combination of parameters inherently supports an identification of the riskier areas, which do not necessarily correspond to the areas with a higher number of events. These combined analyses may support the prioritization of further analyses. For example, it might be desirable to delve into operations at the location with the highest number of occurrences in order to see if there is any underlying factor for the event types being reported (e.g. an airline frequently reported for call sign confusion events). Alternatively, it could be useful to audit the operational practices at the airports with the higher risk level (e.g. checking the narrative, and the respective explanatory factors, or even interviewing the operators involved in the accident).

Fig. 4. Geographical distribution (manipulated geographical coordinates) of number of occurrences and associated risk level.

On a similar perspective, Figure 5 represents the number of occurrences over time combined with the risk level averaged on the number of occurrences, showing the evolution over time of criticalities in the system.

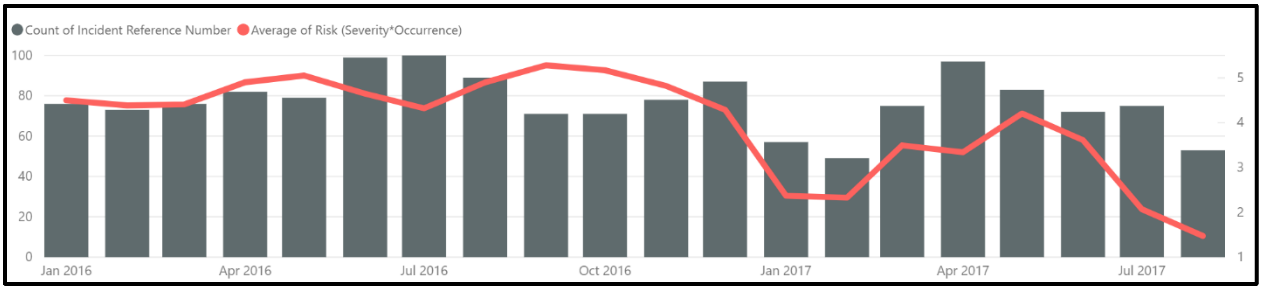

Fig. 5. Number of occurrences (columns) vs average risk level (line).

Note that further statistical analyses may be needed to gather an in-depth knowledge about operational practices and support both actions and quality checks of the databases.

5. Conclusions

In a complex system such as the ATM system, data represent the core element to improve products and processes. In recent years, interest in aviation data-oriented research has grown rapidly, proving to be key for delving into the complexity of operations in a systematic and structured way. Such an approach remains valid in the risk and safety management domain, where ICAO pushes the need for standardization occurrence reporting. At EU level (and beyond), TOKAI represents a solution to support occurrence investigation and manage investigation data systematically. This paper presents an overview of TOKAI and how its structured data can be used effectively to get organizational knowledge usable for safety and performance management. This research aims at stimulating the possibility of performing data analysis on an occurrence database in order to increase the knowledge about system operations and prioritize mitigating actions, for example extending it through the Aerospace Performance Factor, see (Di Gravio et al., 2015b, 2016; Lintner and Smith, 2009), or the potential for predictive analyses (Di Gravio et al., 2015a). It can also be noted that in its current version, TOKAI includes the so-called explanatory factors, for the purpose of systematically reconstructing occurrence narratives. The assignment of the explanatory factors forces the analyst to gather operational data, formalize their assumptions and then explain the event, following a fixed taxonomy. This taxonomy is based on a neutralized representation of performance, not following reductionism-oriented perspectives to detect errors. Such neutralized analysis represents an incremental approach to manage safety not only based on failure, but also on performance variability statistics, in line with recent trends emphasizing the need to delve into system properties rather than restrict the analysis only to negative aspects, such as errors and failures (cf. Safety-II, and Resilience Engineering, (Woods and Hollnagel, 2006; Pinska-Chauvin et al. 2013; Patriarca et al., 2018)). This research emphasizes the need to extend current research in risk and safety management for the aviation domain promoting Safety-II data analysis to further increase the organizational learning capabilities. Further research should explore the potential of using TOKAI as a core element for this kind of analyses.

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