DATA-DRIVEN DECISION-MAKING PROCESSES, DATA SERVICES AND APPLICATIONS FOR GLOBAL AVIATION SAFETY

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Abstract *– This paper presents analysis solutions, data applications and services developed by the International Civil Aviation Organization (ICAO): indicators, iSTARS, SIMS and iMPLEMENT. These solutions facilitate data-driven decision making and assist stakeholders in identifying and managing safety risks in support of the development and dissemination of safety information and the implementation of State safety programmes (SSPs) and safety management systems (SMSs). Safety management supported by data-driven decision making (D3M) is ICAO's framework in aviation safety, which is the prerequisite for global connectivity and sustainable development. This framework is noted as an innovation as it is one of the first cases of regulatory bodies integrating a data-driven approach into global governance and international regulations. As a UN specialized agency, ICAO supports all Member States to have capabilities to leverage data-driven approaches for the public good.*

Keywords – Aviation safety, data-driven decision making (D3M), International Civil Aviation Organization (ICAO), State safety programme (SSP) , safety management system (SMS), United Nations Sustainable Development Goals (UN SDGs)

1. INTRODUCTION

The aviation industry connects people, markets, and cultures around the world, influencing the economic, social and political landscapes of countries. By fostering world trade and by supporting the global industry and tourism, aviation is a major contributor to economic development and globalization. In fact, the aviation industry supports 62.7 million jobs worldwide and contributes $2.7 trillion, which represents 3.5% of global GDP [1]. And beyond economics, by opening up the world, air transport enriches the social and cultural webs of societies.

Behind aviation's remarkable growth or positive contribution to the socioeconomic fabric of countries, the vitality of the aviation industry is based on the existence of a well-established and solid global partnership.

Aviation is by nature international, and thus the rules related to flights must be clearly defined through international standards and mechanisms that are managed in a globally consistent manner.

This is the role of the International Civil Aviation Organization (ICAO), a UN specialized agency, established in 1944 to promote the safe and orderly development of international civil aviation throughout the world. To support the global air transport network, ICAO has set its strategic objectives as follows: safety; air navigation capacity and efficiency; security and facilitation; economic development; and environmental protection. The strategic objectives are strongly linked to 15 of 17 of the United Nations Sustainable Development Goals (UN SDGs) [2].

Among these strategic objectives, aviation safety has been established as one of the primary goals, as it is considered as central to ensuring that air transport continues to play a major role in driving sustainable economic and social development

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around the world. With continuous and collaborative efforts from the global aviation community, air transportation became one of the safest means of transportation. Accident statistics showed 10 fatal airliner accidents and 44 fatalities in the year 2017, which is the record of the safest year in aviation history [3].

This paper presents the overview of ICAO's works in aviation safety, especially in a data governance view. The paper is organized as follows: The second chapter gives a brief overview of ICAO's actions for aviation safety. The third chapter introduces the ICAO's data-driven decision-making framework and supporting data application and services are presented: indicators, SIMS, iSTARS and iMPLEMENT.

2. TRADITIONAL ACTIONS FOR AVIATION SAFETY

2.1 Standardization and implementation

Aviation safety cannot be achieved by only a few leading entities, but with collaborative actions at a global level. Historically, ICAO was responsible for developing international rules in areas where global consistency is required. The Standards and Recommended Practices, or SARPs, cover technical and operational aspects of international civil aviation, such as safety, personnel licensing, operation of aircraft, aerodromes, air traffic services, accident investigation, and other fields.

However, to fully achieve the desired outcome of standardization, the SARPs shall be implemented in the operating field. Geographically and politically diverse, it has been a serious challenge to maintain the equal level of implementation of SARPs across all regions. To ensure that all States have access to the socioeconomic benefits from safe and reliable air transport, it became the ICAO's key objective to achieve a consistent level of safety throughout the world by promoting effective implementation.

Therefore, ICAO does not limit its role only to developing new standards, but also it proactively specifies building global strategies, performing continuous oversight and monitoring (USOAP CMA: Universal Safety Oversight Audit Programme, Continuous Monitoring Approach), encouraging and supporting the implementation of standards to promote safety performance at national, regional and global levels. With such motivation, ICAO has launched the No Country Left Behind (NCLB) initiative to assist States in implementing SARPs with the assistance of technical support, funding, training and other relevant capabilities.

2.2 Safety management

As the notion of safety has evolved from focusing on technical failures to human factors and organizational or system-wide aspects, States and industry have embraced the systemic approach of safety management. While previous actions were mainly from reactive feedback of aviation accident reports, the modern safety management seeks to proactively mitigate risks before they result in accidents and incidents, so that states can manage their safety activities in a more disciplined, integrative and focused manner.

ICAO is mandating Member States to implement State safety programmes (SSPs) and safety management systems (SMSs). These SSPs and SMSs require the establishment of safety targets and data analysis systems to track performance in reaching these objectives. The State develops SSPs to manage its aviation safety performance, while the SMSs are developed and maintained by the service providers under its authority [4-5].

Furthermore, the concept of safety management is evolving toward 'predictive risk management'. While the traditional approach was limited to retrospective actions, the new approach is prospective, which is concerned with leveraging safety data and information to develop actionable insights. Such insights are used by an organization's leadership to make data-driven decisions including those related to the most effective and efficient allocation of resources [6].

2.3 The Global Aviation Safety Plan (GASP)

In accordance with the No Country Left Behind initiative and to support the effective implementation of SSPs and SMSs, ICAO developed the global roadmap on safety strategy: Global Aviation Safety Plan (GASP). The GASP initiatives are monitored by ICAO's appraisal of global and regional aviation safety metrics on the basis of established risk management principles — a core component of contemporary SSPs and SMSs.

The draft of the 2020-2022 edition of GASP [7] is structured with the GASP goals, targets and

indicators. First, the GASP goals describe high-level outcomes. In order to better reflect the global objectives, the GASP goals were developed using the structure presented in the United Nations (UN) 2030 Agenda for Sustainable Development. Then, each of the GASP goals contains specific targets, which are the specific actions taken by States, regions and industry to achieve the corresponding goals. Finally, the GASP indicators, as written as quantitative data, were designed to provide the evidence about whether the desired outcomes occurred, as well as to measure the progress in the activities related to the GASP targets.

For instance, the first goal of GASP is "Achieve a continuous reduction of operational safety risks", and it has the GASP target of "Maintain a decreasing trend of global accident rate", and the target is supported by the indicators, such as number of (fatal) accidents, (fatal) accident rate, fatalities, fatality rate, etc. Moreover, in GASP principles, it was highlighted that taking data-driven decisions is one of the key values for enhancing global civil aviation safety. The role of data-driven analysis is essential in identifying challenges and determining priorities, which are the foundations and contexts for developing a State's or region's aviation safety plan in line with the GASP goals and targets.

3. DATA-DRIVEN DECISION-MAKING FRAMEWORK FOR AVIATION SAFETY

3.1 Data-driven decision making

As desribed in GASP, the transition towards a predictive and systemic approach for aviation safety management can be supported by data-driven decision making (D3M). Due to the complexity of global air transportation systems continually increasing, proper data management and analysis is now considered as crucial to improving both global and regional safety performances. Therefore, ICAO has developed Annex 19 – Safety Management and the Safety Management Manual (SMM) containing SARPs and guidance material, respectively, requiring States to establish safety data collection and processing systems (SDCPS) and conduct safety data analysis [8].

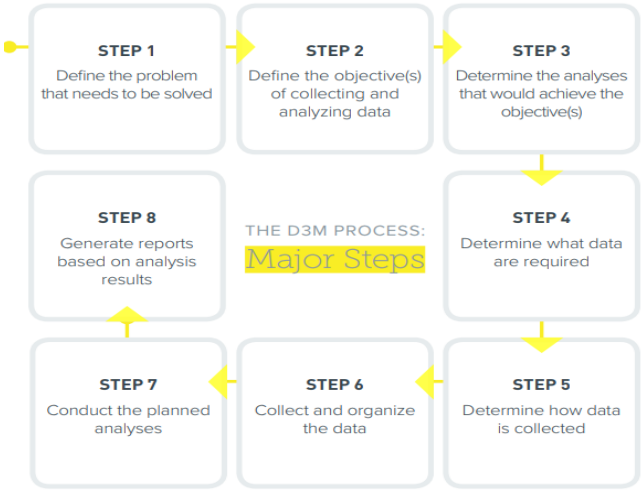


Fig. 1 – The data-driven decision making (D3M) process

Once the decision-making process is based on the right data and information, it is referred to as data-driven decision making (D3M). Data-driven decision making involves making decisions that are backed up by the data and quantifiable evidence, rather than making decisions that are intuitive or based on observation alone [9]. The D3M supports identifying risks and opportunities, mitigating human error, determining a best-fit solution and providing credible evidence to stakeholders and management to ultimately delivering the effective decision through data and information analysis.

ICAO is supporting several analysis solutions and initiatives and facilitating the data-driven decision-making process to the global aviation community. These solutions, collectively referred to as air navigation integration analysis solutions, include datasets, tools, methodologies and training courses that facilitate data-driven decision making and help stakeholders identify and manage safety risks.

3.2 Indicators

Indicators are measures that indicate and provide specific information on the status, level or condition of targeting items. As defined in GASP, an indicator is tied to an objective or goal and expresses the achievement of that objective or goal. Thus, the indicators are the basic requirements of data-driven decision making by measuring the achievement of goals in various areas.

It is essential to develop, harmonize, formalize and manage indicators, considering their importance in measuring factors that contribute to the success of operations, programmes and organizations. Drawing from the work done by the United Nations Inter-Agency Expert Group on Sustainable Development Goals, ICAO sought input from the Safety Performance Indicator Task Force (SPI-TF) of the Global Aviation Safety Plan Study Group (GASP-SG). The SPI-TF, which consists of various stakeholders representing regulators, industry and international organizations, developed and reviewed the initial list of indicators using a standardized methodology established by ICAO. ICAO then formalized the indicators considering the availability of data for analysis, measurement and monitoring and published the indicators through the online catalogue [10]. The ICAO indicator catalogue is not an exhaustive list, and may be subject to change in the future.

Table 1 – ICAO indicator catalogue

1.001	Effective implementation (EI)
1.002	Runway inspections by finding category and inspection period
1.101	Accident rate by operation type
1.102	Number of accidents by operation type, risk category and injury level
1.103	Fatality rate by operation type
1.104	Number of fatalities by operation type and risk category
1.201	Runway safety occurrences by occurrence category and occurrence class
1.202	Wildlife strikes by occurrence class and flight phase
1.204	Long landings
1.205	Tailwind landings by threshold level
1.206	Runway remaining
1.303	IFR-IFR loss of separation (IFR-IFR LOS)
1.304	Large height deviation (LHD) in RVSM airspace
1.305	TCAS events by advisory type
1.306	Emergencies by squawk code
2.301	Horizontal flight efficiency (HFE) – network
2.302	Horizontal flight efficiency (HFE) – local
1.401	Missed approaches
1.403	EGPWS alert events
2.402	Continuous descent operations (CDO)

This indicator catalogue is intended to be used as safety performance indicators as per the requirements outlined in Annex 19 — Safety Management [5]. These indicators help users analyse aviation data and draw actionable information and implement data-driven decision making, and ultimately, contributing to an increased level of safety, capacity and efficiency.

For example, the indicator 1.001 Effective Implementation (EI) rate is an indicator that ICAO uses to measure a State's safety oversight capability. This EI indicator is tied to the ICAO's strategic objective of safety and indicates the level at which an ICAO Member State has implemented SARPs, or protocol questions (PQs). The EI indicator is also included in GASP indicators for Goal 2: Strengthen State's safety oversight capabilities. The effective implementation rate can be computed as in Equation 1 [11].

$$EI = \frac{number\ of\ satisfactory\ PQs}{total\ number\ of\ applicable\ PQs} \times 100 \quad (1)$$

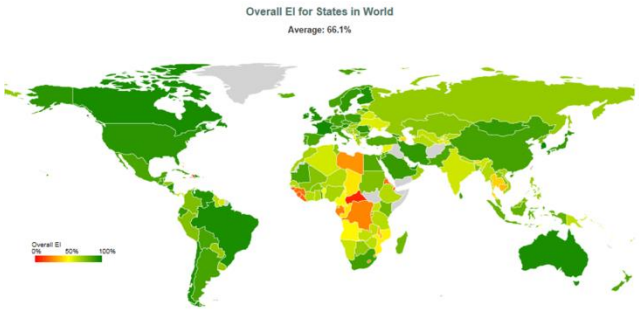


Fig. 2 – The overall EI by State (as in June 2018)

The defined indicators are the building blocks that link between data gathered from field operations to useful information, or analysis results, which is the key component of the D3M process. Therefore, ICAO Member States and other stakeholders are invited to use this global indicator framework when building their own list of indicators.

3.3 Safety Information Monitoring System (SIMS)

In 2015 the second high-level safety conference was held in Montreal; it was recommended to introduce a phased approach for global information exchange. The implementation of this recommendation resorted in launching the Safety Information Monitoring System (SIMS), in 2017. SIMS promotes the cooperation among States and industry to collect and analyze all available information pertinent to the monitoring of safety performance. In theory, SIMS is a web-based data and information system comprised of applications generating indicators to support States in their safety management efforts. In practice, a system such as SIMS, facilitates and encourages States to not only collect data, but also to convert this data into information, analyze and draw knowledge for decision making.

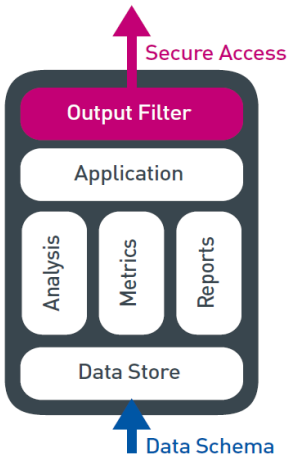


Fig. 3 – The SIMS structure

The first phase of SIMS invites States and their service providers to participate in a collaborative manner as SIMS participants, while only having access to their own information. In the second phase, SIMS allows the participants to securely exchange the generated safety information with each other. ICAO has developed a supporting legal framework that addresses data privacy and safety data protection elements for SIMS [12].

As described in previous chapters, Safety Management mandates States to establish the system that captures, stores, aggregates and enables the analysis of safety data and safety information. In the absence of data, it is not possible to either generate indicators or to conduct analysis of safety information for the improvement of safety. Therefore, for the prerequisite for such systems, data availabillity is dealt as one of the key objectives of SIMS. In data collection, States and international organizations mainly collect accident data and its root causes, for example, standard operating procedures, aircraft maintenance requirements, aircraft parts, and cabin crew training, on national, regional and international levels. In addition to occurrence data, States collect data via audits and inspections in order to monitor the compliance with their safety regulations by the service providers, which is also known as a compliance-based approach. Data is not only a prerequisite for SIMS, but also for the analysis of safety risks and the monitoring of a State's safety performance.

The collection, processing and management of high volume, complex and highly volatile data, consumes financial and human resources for a State. Therefore, SIMS facilitate this problem by being providing as an online platform. Member States can use the online SIMS platform to display their data into meaningful information, as a cost-effective way to gain direct insights into their stored data without developing any complex in-house information technology systems.

Currently, the first phase of SIMS has 12 Member States who have become participants and contributors to the system, with already 105 users. The evolution of SIMS continues gradually with not only the continuous approach by Member States to become participants, but also with the involvement of aviation and data experts in the aviation sector, to contribute to safety improvement on a global scale, without any financial benefit. The sole purpose is to share safety information for analysis by using existing and innovative methodologies that all States can benefit from. Further to the proactive approach, moving to a predictive approach for the prediction of safety performance will be the next step of transition and research; this will be conducted by experts in the field and subsequently applied to the Safety Information Monitoring System with no charge to the participating States.

3.4 Integrated Safety Trend Analysis and Reporting System (iSTARS)

The integrated Safety Trend Analysis and Reporting System (iSTARS) is a web-based system on the ICAO secure portal (https://www.icao.int/safety/iStars). iSTARS provides a quick and convenient interface to a collection of safety and efficiency datasets and web applications to make safety, efficiency and risk analysis. There are currently over 30 different web applications accessible to over 4,700 registered users. The applications were developed to support the analysis and visualization of big aviation data and to enable data-driven decision making.

In the bottom layer of the iSTARS architecture, data is extracted from multiple sources, transformed to a common usable format and loaded into the MongoDB database. This data could come from other internal databases, external websites or from the S3 cloud storage.

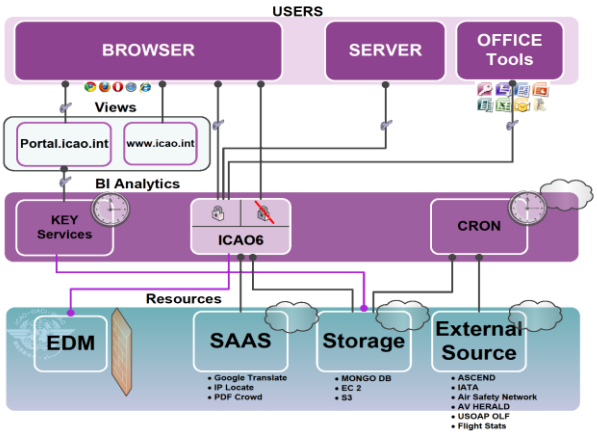


Fig. 4 – iSTARS architecture

One example from iSTARS applications is Air Transport Accessibility. It assesses the physical access of people to the nearest airports. The inspiration came from the UN SDG 9.1.1 [13]. This notion of accessibility was extended to the air transport system to determine which ICAO Member States are the least connected to the aviation network and thus could be candidates for assistance. The assumption here is that similar to roads, airports connect people to the world and generates positive economic impact.

Fig. 5 – Data transformation for air transport connectivity application

The 2015 "Gridded Population of the World" dataset from the Socioeconomic Data and Applications Center (SEDEAC) [14] was used for this study. The population data is processed and combined with the airport location data. The output of the computation is a document per Member State which contained the total number of airports, the total number of international airports, and the population living within 100km of these airports. The iSTARS application uses this data to load all the relevant information automatically according to the State and region selection by the user in the iSTARS application interface. The user can easily access the visualized analysis result through iSTARS web as shown in Fig. 6 below.

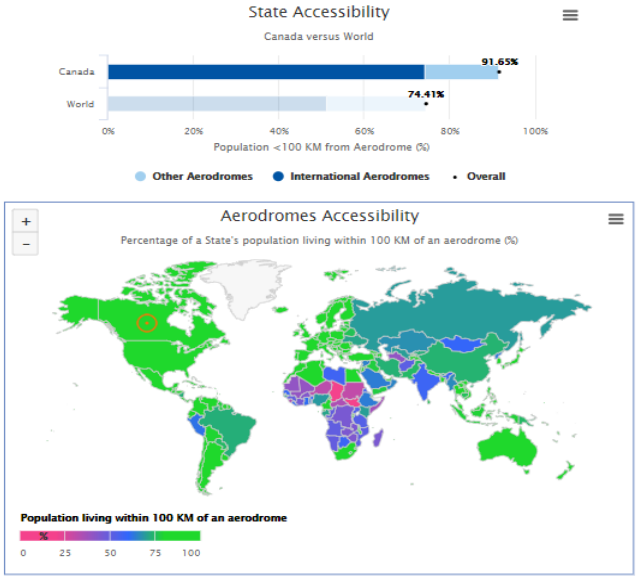


Fig. 6 – Air Transport Accessibility application interface.

ICAO also supports the API (application programming interface) data services for users who want to access raw data. The ICAO API Data Service (APIDS) is a website containing a catalogue of over 50 datasets. The users can request a free key to query or download the available datasets.

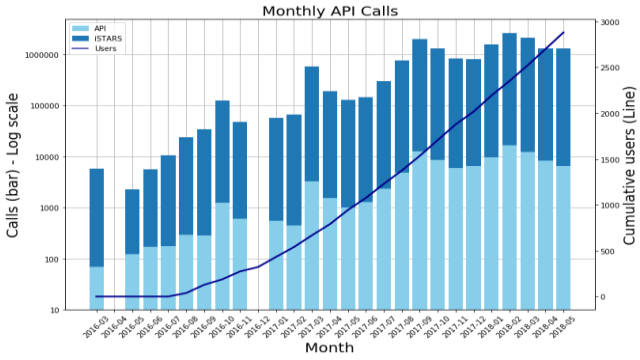


Fig. 7 – Monthly API and iSTARS calls, and cumulative users[1]

Fig. 7 shows the incresing number of API calls including iSTARS usage. Note that the y-axis is defined in a logarithmic scale with base 10. The monthly API and iSTARS calls were 6,679 in March, 2016. In 2 years, the calls were sharply increased to 1,516,324 calls in March 2018, which is about 227 times larger than the calls from 2 years ago. In addition, the number of registered iSTARS users has increased from 2,139 in 2011 to 4,700 in 2018 (June 2018). The affiliation of users varies from civil aviation authorities, airlines and airports to

[1] API calls in April and December 2016 are not applicable.

researchers, economic analysts and media. This trend demonstrates that the iSTARS and API data service are successfully meeting their purpose of providing users an accessible, quick and convenient interface.

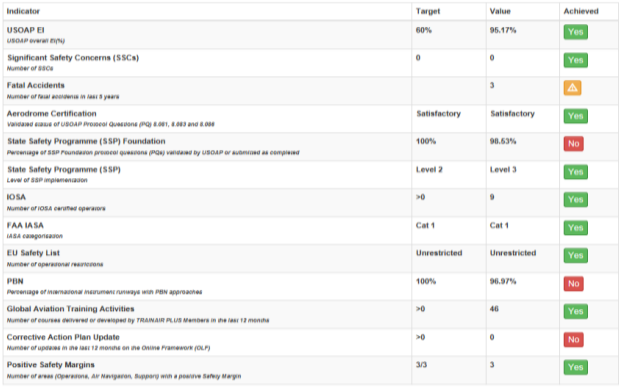
3.5 iMPLEMENT programme

Closely tied to the self-explanatory No Country Left Behind initiative, iMPLEMENT was launched to support the evolution of safety performance according to safety management practices. It is a data-driven decision-making process aimed at helping decision makers such as directors general of civil aviation authorities or transport ministers to take well-informed decisions by following a number of steps:

- the assessment of the current status of aviation in terms of connectivity and safety;
- the identification and prioritization of areas with the potential of improvement and/or development;
- the identification of the best solutions available to address prioritized needs;
- the production of advice on how resources can be utilized efficiently to maximize the potential of the aviation sector; and
- the identification of potential donors and investors through existing national, regional or global mechanisms.

For each step, a number of tools available on the iSTARS platform have been created to fulfil different purposes. These tools may be used following the logical sequence provided by the iMPLEMENT methodology to achieve the required results. Many of these applications use the safety audit data from ICAO's audit programme (USOAP CMA) and merge it with other data available such as traffic as sources for the analyses they produce.

A first example of these tools are the regional, State and airport safety briefings, designed to facilitate access to safety-critical information. They contain relevant safety information such as USOAP EI values, significant safety concerns, fatal accidents, aerodrome certification based on audit questions, the State safety programme implementation based on the SSP gap analysis tool and PBN implementation. By using this information available in the briefings, it is possible to derive a prioritization suggestion on which areas and protocol questions a State should work on to increase the overall implementation rate.



Indicator	Target	Value	Achieved
USOAP EI *USOAP overall EI(%)*	60%	95.17%	Yes
Significant Safety Concerns (SSCs) *Number of SSCs*	0	0	Yes
Fatal Accidents *Number of fatal accidents in last 5 years*		3	⚠
Aerodrome Certification *Validated status of USOAP Protocol Questions (PQ) 8.001, 8.003 and 8.006*	Satisfactory	Satisfactory	Yes
State Safety Programme (SSP) Foundation *Percentage of SSP Foundation protocol questions (PQs) validated by USOAP or submitted as completed*	100%	98.63%	No
State Safety Programme (SSP) *Level of SSP implementation*	Level 2	Level 3	Yes
IOSA *Number of IOSA certified operators*	>0	9	Yes
FAA IASA *IASA categorization*	Cat 1	Cat 1	Yes
EU Safety List *Number of operational restrictions*	Unrestricted	Unrestricted	Yes
PBN *Percentage of international instrument runways with PBN approaches*	100%	96.97%	No
Global Aviation Training Activities *Number of courses delivered or developed by TRAINAIR PLUS Members in the last 12 months*	>0	46	Yes
Corrective Action Plan Update *Number of updates in the last 12 months on the Online Framework (OLF)*	>0	0	No
Positive Safety Margins *Number of areas (Operations, Air Navigation, Support) with a positive Safety Margin*	3/3	3	Yes

Fig. 8 – State safety briefing – Performance dashboard

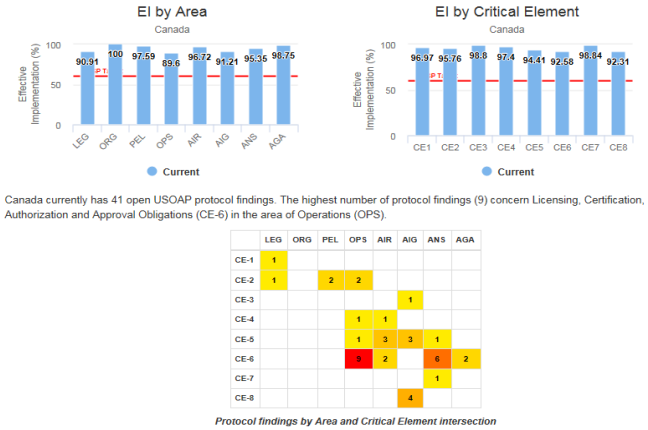


Fig. 9 – Example of a State safety briefing – Details

Another tool, the Solution Center application is designed to identify the best solutions available to address the prioritized needs by linking available global aviation training packages in order to ultimately address implementation issues identified through the USOAP.

Another useful tool is the Human Resource toolkit for Civil Aviation Authorities (CAA-HRT), which is an online application designed to respond to the needs expressed by States on the scaling of their staff, in particular regarding how many inspectors are needed to address the oversight responsibilities of a State. The tool contains two main components: (1) a benchmarking tool, which compares States on their reported number of staff and their activity in terms of number of aircraft, aerodromes and operators overseen and (2) the Manpower Planning tool which provides a basic approach for the calculation of inspector man-hours based on the various types of certification and surveillance activities of a State.

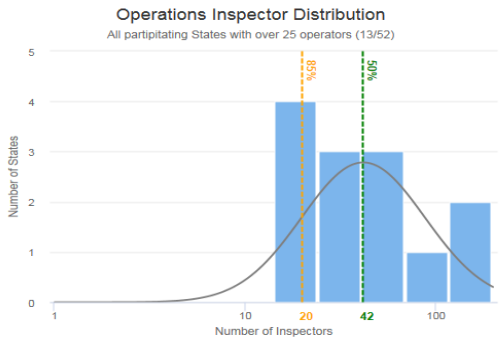


Fig. 10 – Manpower Planning application

By combining the analysis generated by a selection of tools available on the iSTARS platform, iMPLEMENT helps experts produce a high-level report showing State information which is aimed at identifying risks and opportunities, determining best-fit solutions, prioritizing activities and ultimately facilitating the enhancement of a State's implementation rate. This processed and logically sequenced information provides senior management with projects and solutions to fully realize the socioeconomic benefits of aviation at the State level.

4. CONCLUSION

There was some considerable ambiguity in the political or legal process of aviation safety, as it is challenging to deliver a clear picture of operational safety risks to the regulatory bodies. Due to complex interactions between latent errors and threats, which are subjective and uncertain by their nature, it became almost impossible to identify, track and derive a solution at a global governance scale. Therefore, the series of ICAO's data applications and services is the first step towards effective implementation of data-driven decision making into the regulatory bodies, supporting all Member States having capabilities to leverage a data-driven approach for aviation safety.

The successful implementation of data-driven decision making will be achieved with the active participation of Member States. However, due to the gathered raw data being too diverse, States are struggling to implement data-driven decision making into its aviation safety governance. To overcome the current problem, it is crucial to establish the centralized and standardized data exchange framework, as well as the accessible environment for effective data gathering, exchange, analysis and utilization at a global level.

In order to manage big data for the benefit of aviation in terms of improving safety, efficiency and effectivity of the air transport system, ICAO strongly recommends implementing data-driven decision making, with the following actions: (1) taking into account the ICAO catalogue of safety and air navigation indicators, within their safety and air navigation activities and to build data analysis capacity; (2) using the ICAO's air navigation analysis solutions, especially during the initial development of their State safety programmes; and (3) joining the ICAO SIMS project to exchange safety and air navigation information, and thus, better utilize their stored data.

ICAO will keep further promoting its analysis solutions through the "Aviation Data-driven Decision Making (AD3M)" training course and workshops, as well as developing predictive analysis by actively exploring the potential application of artificial intelligence technology. Thus, ICAO endorses the active participation and discussion of how the aviation industry shall incorporate data management and artificial intelligence technologies in a human-centric and globally harmonized manner.

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