Informing New Concepts for UAS and Autonomous System Safety Management using Disaster Management and First Responder Scenarios

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2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC) | 978-1-6654-3420-1/21/$31.00 ©2021 IEEE | DOI: 10.1109/DASC52595.2021.9594356

Abstract*—*As emerging flight operations become more prevalent and increasingly automated and distributed, the capabilities and procedures for managing safety of vehicles and operations will also need to evolve. To address this challenge, the National Academies envisioned an In-Time Aviation Safety Management System (IASMS) resource for a wide range of aviation operations including current commercial operations as well as new advanced air mobility (AAM) operations. The suite of IASMS services, functions, and capabilities (SFCs) would be implemented in a federated approach and would address trends as well as individual operations. Through predictive modeling and data analysis, IASMS is envisioned to identify risks so that they can be mitigated, in-time, before a safety incident occurs.

IASMS and its requisite set of SFCs will leverage a wide range of information. To better understand these new needs, the Flight Safety Foundation (FSF) worked with the aviation and humanitarian communities to develop and validate Disaster Management and First Responder (DMFR) scenarios. These scenarios were then used to identify IASMS data needs andf research issues. These include the ability to quickly "cordon off" airspace through temporary flight restrictions (TFRs) or other means, having clear definitions to enable automation-based algorithms for prioritizing operations, definition of airspace density metrics, standardization of altitude reporting, and an established basis for safety data metrics definition and collection.

I. Introduction

Advances in technology are enabling new concepts of operation that will transform aviation. The innovations for the future air transportation system will span increasingly autonomous capabilities to handle very complex, dynamic ecosystems comprised of a widening mix of vehicles and technologies, performance envelopes, Advanced Air Mobility (AAM) [1], and unmanned and traditional operations. As new entrants transition into the airspace system, maintaining safety will require more proactive risk mitigation of emerging safety issues before they become hazards. Further, traditional human-centric safety management processes may not be scalable to the pace and volume of operations. The In-time Aviation Safety Management System (IASMS) concept of operations (ConOps) [2] looks beyond today's Safety Management System (SMS) by addressing the design of new in-time safety systems and services, enhanced tools and technologies, increased access to data and data fusion, improved integrated data.

A. IASMS Concept of Operations

The concept of an IASMS envisions that as emerging flight operations become more prevalent and increasingly automated, a distributed capability is required to identify known and emergent risks so that they can be mitigated before a safety incident occurs. An IASMS ConOps was recommended as a top priority by the National Academies to ensure that AAM demonstrates the high safety levels expected by the public for modern air transportation systems [3, 4].

This work was funded by National Aeronautics and Space Administration (NASA) grant number 80NSSC20M0248

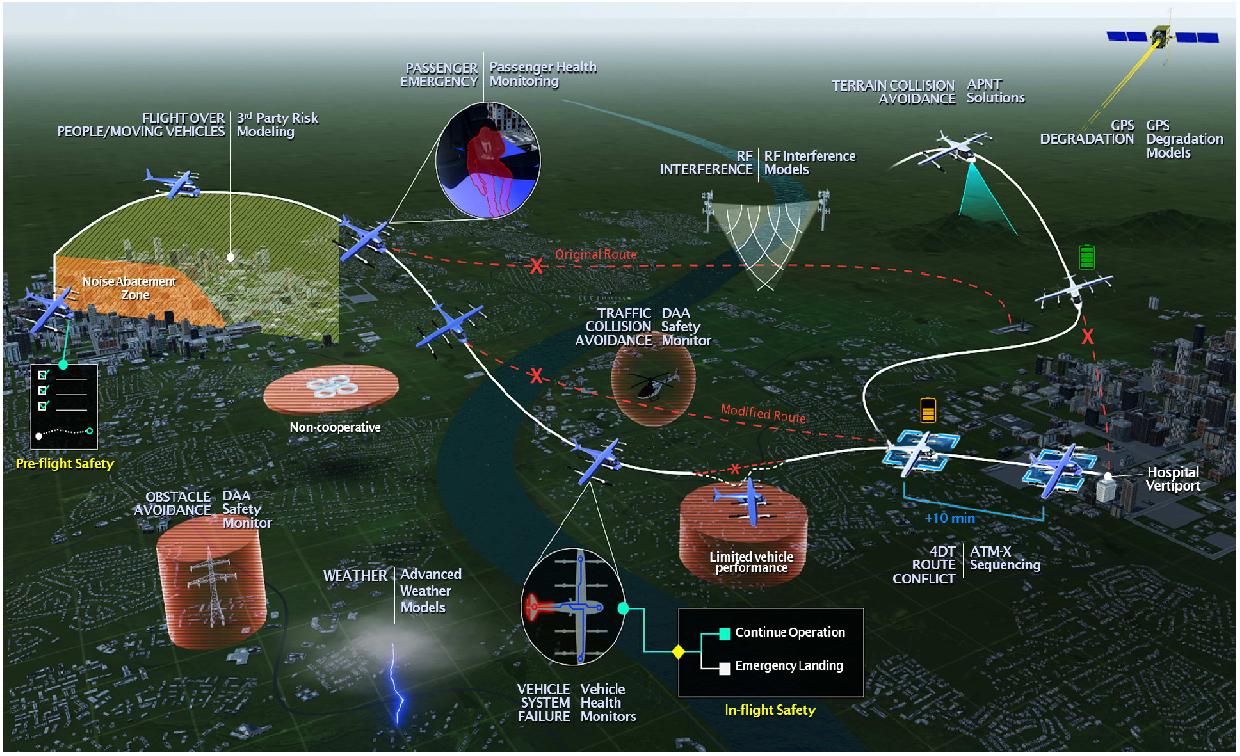

Fig. 1. Operational View of an IASMS

The IASMS addresses risks in the future aviation environment that includes the AAM ecosystem, other emerging operations, and traditional aviation across pre-flight planning, in real-time monitoring of active flights, and in post-flight assessment. The phases of flight and operational states highlighted in the IASMS operational view in Fig. 1 represent the anticipated areas of risk in the AAM ecosystem. For example, in the operational state involving unmanned aircraft system (UAS) Flight Over People/ Moving Vehicles, the vehicle must maintain safe lateral distance around people and other moving vehicles as established in its flight plan or as information is updated during flight, e.g., changes to route of flight or third-party risk assessment. In the operational state titled Traffic Collision Avoidance there would be an on-board real-time operational system that provides detect-and-avoid warning, determines maneuvers away from other airborne vehicles, and executes these maneuvers while communicating with other vehicles and aviation service providers, such as an air navigation service provider (ANSP) or an UAS Service Supplier (USS).

The IASMS ConOps leverages the systems supporting the SMS processes in place today and bridges how those existing systems could evolve and provide an integrated data-exchange that will improve the safety of current and near-term Part 121 (commercial air carriers), Part 91 (General Aviation), and Part 135 (on-demand, unscheduled air service and cargo) operations. The SMS framework including means of compliance for Part 121 is contained in the Federal Aviation Administration (FAA) Advisory Circular 120-92B [5]. The approach integrates the processes for risk management and safety assurance. Risk management involves early hazard identification and designing controls to manage hazards at an acceptable level. Safety assurance monitors operations for how controls are used to mitigate risk as intended.

The IASMS ConOps also leverages the evolving UAS Traffic Management (UTM) [6] concept and architecture. UTM is a distributed, multi-party, aviation architecture where data services provide flight planning, real-time flight support, postflight analysis, regulatory oversite and compliance, and many other aviation functions for UAS, including risk management and safety assurance. This distributed architecture is being implemented in the United States and all over the world. Though ultimately UTM will be a subcomponent of the IASMS architecture, it is the first distributed data-service model to be implemented in aviation.

B. *IASMS Services, Functions and Capabilities*

The current IASMS ConOps envisions technology in the form of Services, Functions and Capabilities (SFCs) that will expand and add to the processes of risk management and safety assurance used in today's traditional safety management systems. These processes are part of the design lifecycle and are also embedded in operations, and the IASMS poses that SFCs accelerate the way the processes perform.

The ConOps defines a Service as a system providing information or data to a user who subscribes to that service. Services use data collected from other vehicles and infrastructure elements. Examples of services important to risk management include Non-Participant Casualty Risk Assessment (NPCRA), Proximity to Threats (PtT), Battery Prognostics (BP), and weather/wind data and forecasts. A

Function is defined as one or more actions that translates a set of inputs to a desired set of outputs. On-board vehicle functions can include autopilot, communications, and navigation. A Capability is defined as the ability to perform a set of Functions to achieve certain outcomes. It uses technology including sensors and models that detect, generate, validate, and distribute information and data to perform Functions and provide Services. Capabilities important to risk management on-board the vehicle could include communication link monitor, constraint monitor, trajectory prediction, and contingency planner.

The SFCs leverage existing systems and integrate them with novel technologies required to assure both design and operational safety for an integrated National Airspace System (NAS) that includes new AAM entrants. In-time safety is assured through threat detection and assessment that support trusted methods for dynamic multi-agent planning, evaluation, and execution of real-time risk mitigation actions to ameliorate hazardous events. The SFCs would be specified to quickly manage known operational risks at scale, quickly identify heretofore unknown risks, and quickly inform design for improved resilience.

The IASMS represents a federated system-of-systems comprised of interconnected SFCs that perform key elements of risk management and safety assurance. Implementing IASMS is envisioned to be incremental, starting with simpler SFCs and leading to a far-term development of digitized network architectures for the vehicle, fleet operator, USS, and information management systems (IMS) such as the Flight Information Management System (FIMS) and Supplemental Data Service Providers (SDSP). Transitions in design toward increased autonomy with reduced levels of human manual interaction provide dramatically increased operational responsiveness (in-time) for risk mitigation. That is, a fully developed IASMS provides in-time risk prioritization, system monitoring and data fusion, system analytics and assessment functions, mitigation capabilities and implementation.

II. METHODOLOGY TO IDENTIFY IASMS DATA REQUIREMENTS

A set of 16 classes of information has been identified to support risk monitoring and assessment functions envisioned for the IASMS and the selected operational domain [7]. This set of Information Classes spans a broad range of observables related to known safety risks, while also allowing for tailoring to user/operator preferences and risk tolerance. Each Information Class has a defined set of data parameters associated with it. Challenges with defining data requirements for an IASMS involve aligning these Information Classes across the necessary transactions and understanding and scaling the SFCs as part of mission analysis for the use cases being studied and planned.

A. A Risk-Centric Approach to Data Requirements Discovery

Our team used a risk-centric approach to identify data requirements for IASMS by examining the risks associated with certain AAM operations to uncover data requirements for IASMS. We formed a group of international aviation and humanitarian communities to develop and validate three scenarios that include traditional aviation operations, UAS, and AAM operations intermingled for Disaster Management and First Responder (DMFR) situations. We used these scenarios to gain better insight about how an IASMS would be used, and to explore the information needs associated with risk management services and air traffic management (ATM). These scenarios capture the diversity and complexity in the operational environments that the industry is and will be facing. Each of the three scenarios is postulated to occur in a different time frame.

B. DMFR Scenarios

The three scenarios that were developed highlight the needs of first responders and those in the humanitarian sphere. The DMFR scenarios include multiple types of UAS as well as crewed aircraft flying in various concurrent operations that exercise different scenario drivers including real-time and tactical management, post-event assessment, urban complications, and error situations, such as loss of the communications and control (C2) link. The roles and responsibilities of each actor are described, and the process flow for each phase of the scenario is outlined. The timeframes for the scenarios are staggered to cover a wide range of technological timeframes from two years out to ten years in the future.

Our near-term natural disaster response scenario occurs in 2023 after a Category 4 Hurricane results in severe flooding, extremely limited communication capability and a compromised transportation infrastructure. The hurricane has knocked out all communication in the region, transportation is challenging due to debris on the road. Much of the local infrastructure is down, and many organizations are trying to organize their response plan with limited information. The events and needs for this scenario are also applicable to many other post-event natural disasters actions like earthquake, mudslides, tornado, and more.

After the hurricane has decayed, beyond visual line of sight (BVLOS) and visual line of sight (VLOS) UAS operations fly missions to identify persons who need help, to document damage, and to assist emergency responders allocating emergency response resources. In addition, several media organizations are submitting media drone requests to fly in the temporary flights restrictions (TFR) airspace. Much of the population has evacuated the area, leaving fewer than 100 people per square mile. Local police, local fire department, and Federal Emergency Management Agency (FEMA) work together to coordinate their response. The airspace is managed by an Airboss, who has internet connectivity through a satellite internet link. Radios are used for aircraft C2 and Airboss-to-pilot communications. FEMA is flying BVLOS fixed wing drones to map the island and document damage, including identifying road outages for emergency response ground units. The fire department has multirotor drones flying VLOS to assist in identifying people who need to be rescued. Multiple media organizations are seeking to fly multirotor and fixed wing drones to inform the public of the situation on the ground.

Our wildfire scenario is envisioned to occur in 2025, in the summer season in northern California's coast range. As a result of recent storms and lightning strikes, there are three fires burning in a remote wildland area. After two days of firefighting efforts, the fires have not been controlled and have spread. In one area of national forest, two of the fires have joined to become a much larger wildfire while additional smaller fires are being discovered. This scenario may also be relevant to other large rescue operations with integrated drone swarming operations and complex manned aircraft flight paths in shared airspace.

U.S. Air Force personnel and aircraft are called upon to support the firefighting efforts by dropping fire-retardant from C-130 aircraft. The C-130 tanker is not equipped with Automatic Dependent Surveillance-Broadcast (ADS-B), but USS service proximity alerting is being used. There are also manned helicopters helping to transport personnel and supplies between firefighting sites. The local fire department deploys small, multicopter drones operated swarm-style and flying BVLOS to monitor the progress of the fire and to identify areas of focus for firefighting efforts. The fire department is also operating a single, fixed wing drone to maintain firefighter safety by supporting firefighter beacon location transmission. The servicing USS generates and distributes the UAS operational volume notification to the USS network.

In the 2029-2031 timeframe, our urban medical equipment delivery scenario is postulated to occur in an urban city center near a class C airport where multiple autonomous operations interact with piloted operation carrying hazardous payload. This scenario looks at the further future urban airspace with many different types of aircraft operating in complex, dense airspace around people. Some of the considerations that arise here are prioritization, onboard fail-safe operations, hazardous payload handling and emergency situations.

A variety of different aircraft are in flight above buildings where an emergency medical delivery drone is working to deliver a defibrillator. Its pre-programmed operational objectives are to maintain airspace safety while it navigates urban areas with dense air traffic. The delivery drone encounters two higher priority autonomous vehicles: an air taxi with passengers and a piloted ambulance helicopter carrying radiopharmaceuticals. As the drone reroutes around the first vehicles it loses connectivity with the ground station. The ground station recognizes the loss of C2, and the remote pilot also informs the UTM system. The drone autonomously initiates the pre-uploaded emergency backup flight plans. As the drone passes the second vehicle the C2 link is reestablished. The remote pilot notifies the UTM that the situation has been corrected and the vehicle continues its mission

C. *IASMS SFCs Analysis*

To identify significant risks in the scenarios, we hosted a series of interactive workshops involving representatives with expertise in the area of humanitarian operations, urban and rural emergency response, air traffic management, UAS operations, and traditional flight operations. In the workshops, the experts reviewed the operational flow of the scenario, validated roles and responsibilities for different actors, examined the appropriate utilization of UAS, and then identified risks associated with the mission and the environment.

After the team captured and characterized the risks, we examined how these risks could be monitored, assessed and/or mitigated by IASMS SFCs. The SFCs included previously identified Services from IASMS and UTM, and additional Services that will likely be needed with the presence of hazardous conditions or hazardous payloads. Next, we analyzed the data needed to execute all transactions in all phases of the scenarios and developed an extensive list of data elements that are needed for risk monitoring, assessment and mitigation. Finally, we allocated these data elements across the IASMS 16 Information Classes and observed that there was a significant number of data elements related to checklists, maintenance actions and procedures. This grouping of data elements was valuable enough to form an additional Information Class, which we have called Procedural Documents.

D. *Key Risk Areas Identified*

Our team identified safety critical risks through interviews with SMEs and by performing a deep dive into the pre-flight, flight, and post-flight phases of operations during each of the scenarios that were examined. The risk discussion addressed both risks to other airborne traffic and risk to infrastructure and people on the ground. Please note that that we did not run a formal risk analysis.

In this document, we use the term "safety critical risk" to mean a risk that impacts the safe operation or performance of an UAS. A safety critical risk can be associated with a system, a condition, event, operation, process, or item, but it must impact the safety of the public. For the three scenarios explored with stakeholders, a common set of safety critical risks emerged with similar levels of severity. Our team identified fourteen risks, from which we could highlight what data were likely to be needed to monitor the presence of any risk and assess its severity. These risks are listed in Table 1.

TABLE 1: COMMON RISKS ACROSS HUMANITARIAN SCENARIOS

Reference Altitude Calculation Errors	Ground station loss of power or functionality	Separation deterioration (cooperative and non-cooperative)
Failed Information Sharing	Loss or degraded GPS/Nav aid	Human pilot loss of situational awareness
Loss of C2 link, single unit failure	Airframe and component failure	Physical ground interference (ex. rock throwing)
System-wide C2 Loss, Ground or Air	Weather rapid deterioration or change	Out-of-date Reference Info - Terrain and Obstacles
Physical air interference (ex. Rogue aircraft)	Cyber security attack	

III. RESULTS

While the focus of our work was to identify the data needed to manage key IASMS risk areas, the team also identified new

IASMS SFCs while reviewing UTM documentation from the National Aeronautics and Space Administration (NASA), FAA, and ICAO [2,6,8]. By analyzing UTM services, we can determine additional IASMS services that will be needed beyond those published today for UTM.

A. New IASMS SFCs Identrified

Through our work to identify data requirements for IASMS, we also identified ten additional IASMS services. A brief discussion of each new IASMS service is listed below.

Centralized Airspace Coordination - This service refers to a need for a centralized coordinator in certain emergency situations. For example, when a TFR is in place for an emergency UAS operation, the Airboss, or Airspace Coordinator needs to be able to ingest and provide feedback and guidance for all flight plan or airspace volumes submitted to him or her. This service would almost be like a geo-defined controller – enablement.

Airspace Congestion Forecast & Alerting - As the airspace becomes increasingly crowded, there will need to be a service which ingests flight plans and trends and provides alerts for those intending to use the airspace to ensure operations do not become too crowded. For emergency situations, there will be a need to unreserved airspace for emergency operations.

Realtime Risk Assessment Service - As airspace density, weather, population, and other factors change, there should be a way to identify how safe current and planned flights will be. This service could set a threshold for airspace safety which did not allow any flights less safe than that threshold. In the DMFR scenarios, this service was identified as necessary particularly in rapidly changing situations, such as with a wind shift, or with many operations entering the airspace.

Ground System Interference Monitoring – With many new aircraft, communication systems, and new stakeholders communicating with one another, there is an increased risk for ground system interference. This service could detect when communication was flowing clearly and when technical issues or bad actors were creating challenges for communication infrastructure.

Global Positioning System (GPS) Network Monitoring – Most aircraft rely on GPS as a key part of their navigation; however, GPS coverage does not reach the entire airspace all the time. To improve navigation airspace-wide, providing a service that lets navigation systems know when they can and cannot rely on their GPS would be beneficial to correctly analyzing the risks for a given flight.

Predictive Health Monitoring – Utilizing large sets of data on past component failure information and current environmental information to predict when a vehicle component could fail could provide key safety data to help regulators, operators, and vehicle control systems make informed operational decisions.

Sharing Intended Frequencies - The amount of frequency spectrum is limited and is projected to become increasingly more utilized. One way to reduce the risks of overuse is to create a service which would share the current spectrum use in a given area, and identify underutilized spectrums, while giving warnings when a frequency is saturated. Perhaps this could create a more even, reliable use of frequencies.

Dynamic Frequency Allocation - With high frequency spectrum utilization, it may be beneficial to be able to dynamically allocate frequency use based on factors such as prioritized vehicles, higher risk vehicles, or vehicles carrying people. Perhaps also, frequencies could be utilized with categories at different time intervals, so for example one category of aircraft could use a frequency for the first, third, fifth ten seconds of every minute and another could use :10-:20, :30-:40, :50-60, or some other scheme. In general, there is an identified need to allocate frequencies in some manner to ensure that greater numbers of vehicles may still use the radio.

Reference Altitude Service "Translator" - UAS and traditional aircraft generally use different altitude measurements. There is a need for a standardized way for different aircraft to communicate their altitudes to one another. Potentially, this service could translate MSL to AGL and provide a standardized outcome for measurement.

Adaptive Buffer Zone Guidance - With many vehicles in a shared airspace, there will need to be guidance for separation distances. This guidance may change based on the weather conditions, type of aircraft operating nearby, riskiness of operations, and information on activity occurring below, for example. Adaptive Buffer Zone Guidance would be a recommendation for different types of aircraft and mission types on the distance to maintain between operations).

B. Additional IASMS Information Needs

After using risks to assess IASMS data needs and then analyzing the data needed in the scenario transactions, we compared the combined list of data elements with a previous data catalog for IASMS as proposed by NASA. This resulted in an expanded set of information needs that could generally be allocated to the 16 information classes and the related 70 data parameters; our analysis identified an additional 170 items for a total of 240 data parameters.

Some of the additional data parameters are new, while others expand or elaborate upon the originally defined parameters to cover the information needs of disaster management and first responders. All of the identified data parameters are functional indicators of the information that is needed amongst shareholders throughout the operation of UAS. By evaluating these parameters, it is possible to identify which data are key or critical in certain scenarios, and thereby which require a method of management. Management of this data would be performed by a type of service which would transmit, store, calculate, or distribute the identified data. The data sources can come from operators, their vehicles, or the supporting infostructure and act as integrated pieces.

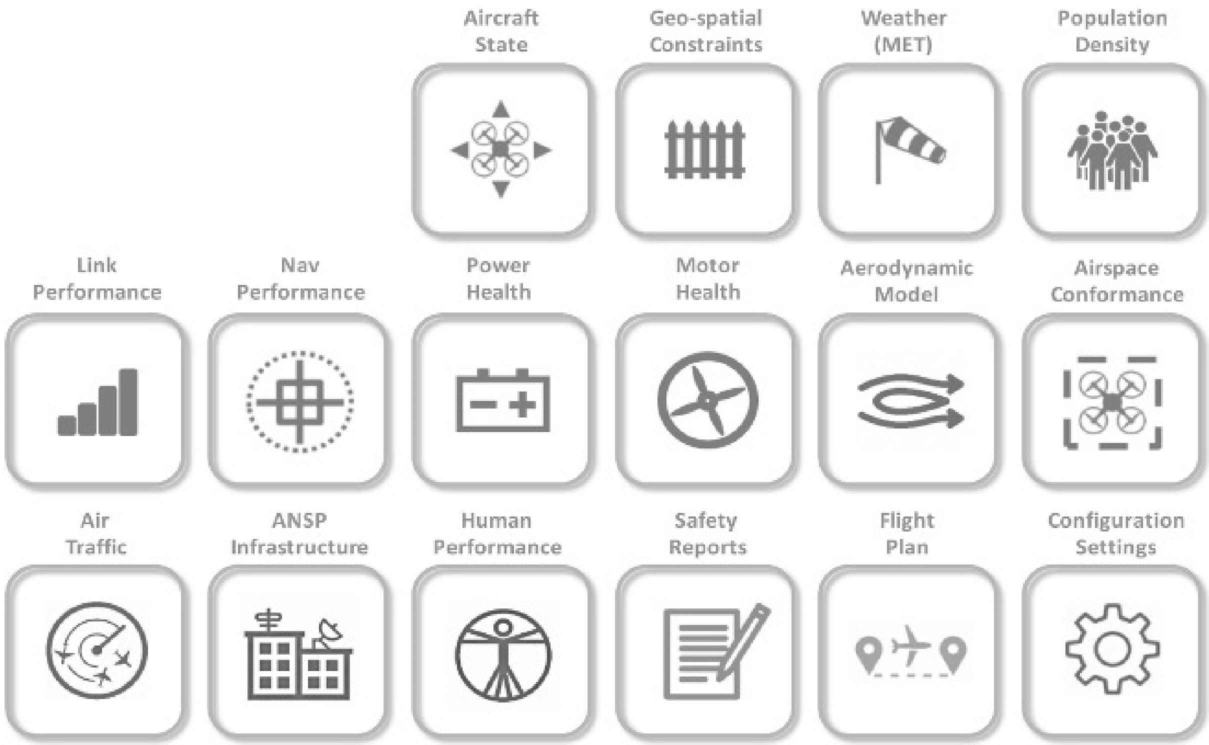

Fig. 2: Original UAS safety Information Classes

Additionally, our analysis of the IASMS SFCs revealed the value of designating a new Information Class, Procedural Documents. This new information class includes data such as checklists, maintenance documents and records, and operational handbooks. The full set of information class icons is shown in Fig. 2, and the icon for the new class and the parameters we identified for it are shown in Table 2. Being able to track compliance and use of checklists and maintenance procedures, for example, not only encourages their use but also provides the user with the most accurate history of the vehicle

and best practices, which is an essential safety practice.

TABLE II. PROCEDURAL DOCUMENTS INFORMATION CLASS ICON AND PARAMERTERS

Information Class	**Parameters**
Procedural Documents 	Checklist Completion/ Conformance
	Emergency Checklists
	Contingency Procedures
	Operating Handbook
	Maintenance Manual
	Batch/SN Numbers
	Maintenance Intervals
	Flight Cycles
	Time to Next Inspection
	Mean Time Between Failure

IV. KEY ISSUES AND NEXT STEPS

Moving towards an in-time system-wide safety management system will be an incremental process to evolve today's aviation infrastructure to include new capabilities, expanded services, broader data collection and access, and a wider range of actors. More work is needed to understand the interactions between individual actors and how services will be delivered. For example, will the instruction for an immediate tactical maneuver be sent to the operator/pilot in command (PIC) or will it be delivered directly to the in-flight vehicle, bypassing any human oversight? And if so, under what conditions would this be acceptable?

The envisioned benefits of an IASMS depend on a combination of technical, operational, economic, and policy decisions, as well as an incremental implementation and requirements refinement approach.

A. Design, Technical and Operational Considerations

From an enterprise architecture or "system of systems" point of view, SFCs are capabilities of potential IASMS architectures and the data services and participating systems' functions that enable those capabilities. An architecture will consist of the IASMS and its capabilities, as shown in Fig. 3, and associated Functions, as shown in Fig. 4. Data and actors, along with their behaviors, are modeled by use cases and scenarios that are constrained to use the elements of the architecture structure as they are defined. Use cases are a particular set of people/organizations and the systems they use to accomplish a goal, e.g., avoid damage and injury during flight. Then we can define scenarios for each use case: a flow of activity with particular assumptions (i.e., begin, decision, and end points) showing what is done and communicated by which people and systems. This allows formalized definition and structure of the data to be measured, derived, communicated, the actors using it, and the visualization of their connection with more abstract concepts, such as the information classes and risks.

Within this structure, we will need to establish the transactions of the IASMS and tag them for particular scenarios where we can explore when they need to be centralized or distributed. We may manage the risk list and maintain their association with the SFCs that mitigate them. Predefined views of IASMS architectures by individual actor, e.g., small UAS (sUAS) pilot, or by organization and their key issues, e.g., requirements and their traceability, may give insight that will assist in developing their roles and responsibilities. As SFCs are validated and developed in response to risks explored for different scenarios, these capabilities and their associated services and functions can be added and refined to build up an architecture of IASMS Capabilities and the Use Cases that describe how the IASMS will exhibit those Capabilities.

An IASMS resource will need to be scalable to the anticipated volume of BVLOS UAS operations and the data associated with monitoring their safety. As volume grows, we anticipate the need for managing airspace density. With the wide range of UAS capabilities and performance characteristics, tools will be needed that support human (or automation) decision-making. What are the metrics associated with density with these types of operations? How is complexity and resiliency factored in so that unplanned flight deviations do not cause significant downstream interactions?

We also note that additional technology and standardization may be important to reduce collision risk. In addition to technologies such as Detect and Avoid (DAA), our outreach to humanitarian operators highlighted issues associated with the need for improved situational awareness among participants (e.g., weather conditions affecting the ability to maintain safe separations, the presence of hostile individuals or groups). With the likelihood of much smaller separations both horizontally and vertically among these aircraft, we also captured risks stemming from different practices for measuring altitude (e.g., GPS vs barometric), units (e.g., meters versus feet), and the reference altitude. For the latter, when altitude is measured as "AGL" it is highly dependent on the launching point. A UAS launched from a nearby location could then calculate a an AGL flight altitude that may appear to be deconflicted but is actually much closer vertically due to the different starting point.

Additionally, the monitor and assess functions of an IASMS are highly dependent on the availability of data, especially real-time performance information associated with UAS. Currently, there is no mechanism or institution in place to collect or monitor data, even post-operational data, similar to the Aviation Safety Information Analysis and Sharing (ASIAS) program that assembles Flight Operational Quality Assurance (FOQA) data. With the scale of UAS operations, key questions to address include:

- What entity will collect and analyze safety data? What is the economic model that enables this entity to perform that function?
- What policy and economic mechanisms are needed to motivate UAS operators to share data, either real-time or post-performance?
- What mechanisms are needed to protect data integrity for operators and manufacturers?

B. *Economic and Policy Considerations*

Examples of the economic and policy choices that will need to be addressed include the following: Understanding airspace complexity and how to prioritize different missions or operators will be an increasingly important issue to resolve as the pace of operations expands. Our review of the DMFR scenarios identified TFRs as one mechanism to "clear the airspace". If this is to be the continued mechanism, more work will be needed to deploy TFRs efficiently when there are emergency or humanitarian needs that require access to airspace. Further, an overall prioritization scheme may be called for beyond "first come first served" depending on local considerations, USS financial models, or the overall level of trust in a given operator and vehicle.

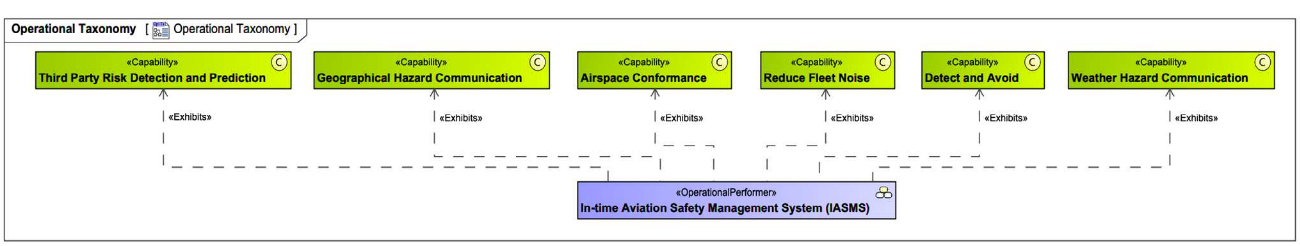

Fig. 3. The IASMS resource and its primary capabilities as a view of the architectural model.

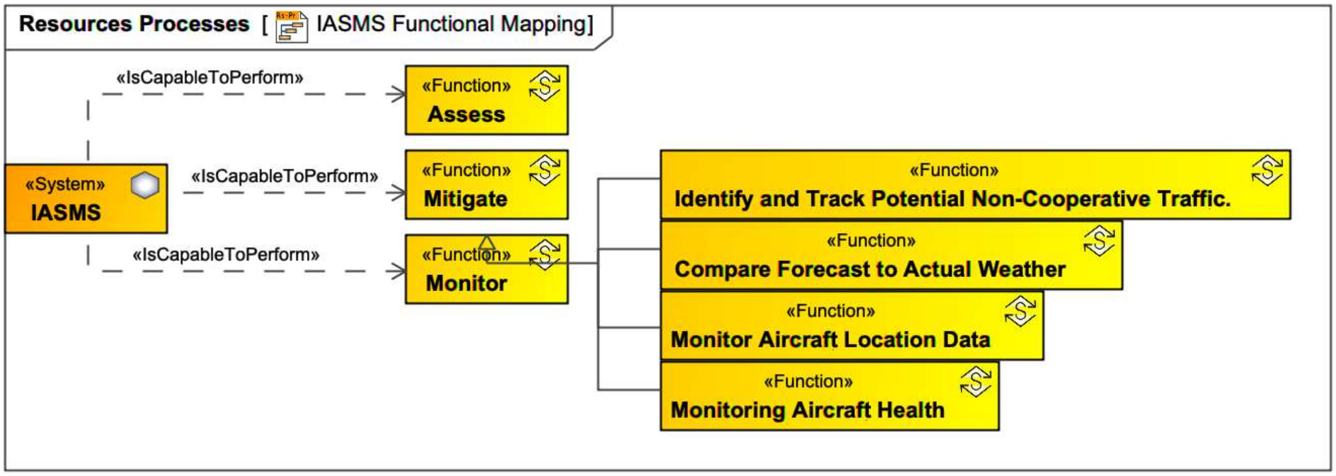

Fig. 4. The IASMS resource and its primary functions with a view of the decomposition of one Function.

Critically, we will need to address how overall risk is determined as well as what an acceptable level of risk is for a given mission and operational environment. For example, does the acceptable risk level change with expected outcome/impact? In the case of humanitarian missions or disaster situations, how do we factor in the benefits of potentially saving human lives? Is a higher risk acceptable in this situation? How do we factor in hazardous payloads in weighing overall risk of the operation? And what conditions are we willing to impose on traditional modes of aviation to reduce the risks associated with these new vehicles and capabilities?

It is imperative to develop an overall investment strategy so that all stakeholders can understand the financial contributions needed to implement IASMS. What is the role of the private sector? Of the ANSP and the national government? What incentives will be established for individual entities to make required investments?

V. CONCLUSIONS

Our exploration of three humanitarian scenarios provided a tangible way for understanding the interactions associated with an IASMS and the data required to provide timely safety management. It also assists to identify the challenges that will face an IASMS in different environments. Understanding the data needs for these scenarios has the broader promise of reducing human suffering through future efforts that enable the needed services, functions, and capabilities supporting these mission types. We found a number of unique data needs that are likely to be present for a broad range of UAS operations that go beyond today's aviation data services – more validation will be helpful in identifying priorities for new data types or service volumes.

We also note that IASMS resources will need be resilient:

- In the presence of damaged infrastructure where reliable communications are unavailable
- In remote areas where needed infrastructure has to be brought in
- In areas of dense traffic or in urban areas where buildings may affect connectivity and micro-climates

Finally, IASMS will depend on technological advancements to enable real-time monitoring, assessment, and mitigation of risks. There will also be a need for policy and regulatory mechanisms in place that motivate individual actors to share data and to include in their own domains the needed elements of IASMS.

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