Developing a Dashboard Interface to Display Assessment of Hazards and Risks to sUAS Flights

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The Supplemental Data Services Provider-Consolidated Dashboard (SDSP-CD) is a graphical user interface (GUI) that displays the results of predictive tools in a single location. It is intended to be used in the preflight planning phase of an operation to allow users to proactively assess predicted flight hazards off-line; expanding an operator's overall situational awareness of a flight plan and providing an opportunity for decision making and assessing the associated risks prior to flight. Hazard data and risk predictions are informative but can be complex to read and understand. However, presented visually and in relation to flight parameters (such as flight path), the nature and significance of hazards become much more evident. The SDSP-Consolidation Dashboard interface was designed to offer a means to present the results of hazard services in an easy to-use format. Two usability studies were run to explore what features might make a suite of hazard assessment services easy to use, and to assess the SDSP-CD interface. The first study evaluated the presentation of information on the GUI and the second evaluated users' ability to understand and use the information. The studies gathered valuable information about how users approach a hazard assessment task and interpret information from the interface. Many suggestions were given for improving the interface's information display, to allow users to more quickly understand and interpret the information being presented.

I. Introduction

In future Unmanned Aircraft Systems (UAS), multiple Unmanned Aerial Vehicles (UAV) may be supervised by a single operator, who will have to manage all aspects of the operation from flight planning to flight completion. As these operations move from sparsely populated to densely populated regions, operators must have high confidence knowledge of potential risks. Supervision of in-flight UAS operations requires that the operator can efficiently monitor, assess, and intervene, in some instances quickly, at unexpected but necessary times; however, managing

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potential risks for a given flight can begin with preflight planning. If an operator can gain awareness of potential risks to an operation ahead of the flight time, there may be flight paths or strategies that can avoid or mitigate the hazard.

Although safely managing a flight can begin with preflight planning, traditional hazard analysis, modeling, and techniques have been found to be insufficient to ensure safety in high volume, complex Urban Air Mobility systems [1]. The current intention is an approach that can provide a comprehensive overview of hazards associated with a particular flight. A preflight interface that incorporates predictive data is a component of this approach and allows an operator to begin the hazard analysis ahead of the actual flight and in an anticipatory setting. This gives a user the ability to proactively reduce risk where hazards may be unknown. Morphew and Wickens [2] examined the benefits of predictive information presented in flight and found that it enhanced safety by replacing cognitive demand with perceptual information.

Being able to assess predicted hazards gives the user the opportunity to utilize the information available to monitor and assess potential risks *before* they can lead to any accidents. To address and possibly mitigate some of these potential risks, tools to provide assessment and management of safety are being developed, for example, [3] [1]. From NASA's System Wide Safety (SWS) project, Ellis [4] describes how Services, Functions, and Capabilities (SFCs) can support In-Time System-Wide Safety Assurance (ISSA). These SFCs help manage known operational risks, identify unknown risks, and inform improved system designs. Supplemental Data Service Provider (SDSP) SFC interfaces [5] currently support the Monitor and Assess phases within SWS's Monitor, Assess, and Mitigate Safety Assurance Cycle (Figure 1).

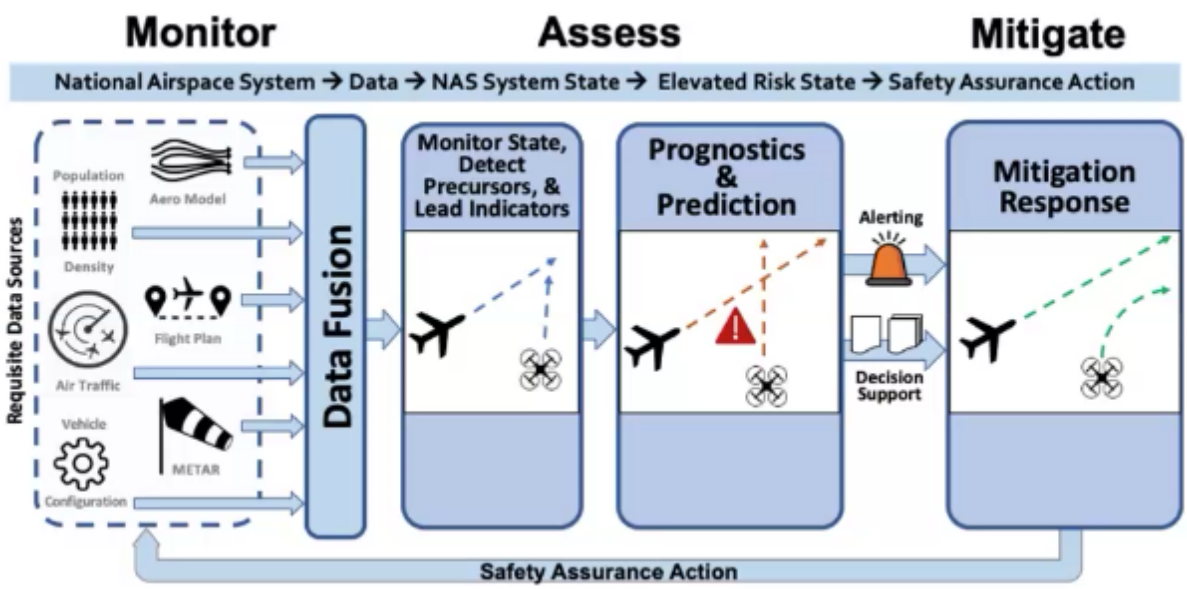

Fig. 1 In-Time System-Wide Safety Assurance (ISSA) method described by [6] Koelling et al., slide 9.

Data sets may be collected from vehicle sensors, airspace monitoring, mapping, and SDSP data repositories as part of the Monitor function to manage and identify risks and may include information classes such as weather and population density. SDSPs may provide individual or multiple services (e.g., battery prognostics, proximity to threats). These capabilities integrate models and display results to the operator to provide prognostic information about any changes and, particularly, predictions about vehicle performance, risks and hazards and system states. The Assess function of the cycle relies on prognostics and prediction modeling [1]. This is important because the "monitoring and assessment functions ultimately determine how well mitigation can occur" (p. 16 [1]). When applied to the preflight planning stage, predictive information may increase hazard detection and improve workload management by allowing users to gather and process pertinent information ahead of flight-time. Advanced knowledge of risks and hazards can assist the operator in maintaining acceptable safety margins and assure that complex UAS operations remain safe.

A. Interface Design and Human Factors

Different approaches to interface designs to support this complex role for operators have been conducted [7] [8]. With 50-69% of all UAS mishaps involving human factors, and 16-25% of the mishaps in UAS Ground Control Station designs due to human factors and ergonomics issues [9], integrating human factors into the design process early on can address and inform interface development. Wolter, Martin and Jobe [10] explored human-system interaction (HSI) during small UAS flight tests over five years and identified specific HSI issues. There were instances of both an over-abundance of information (e.g., display clutter) and a lack of information that operators wanted or needed. These situations reduced operator confidence in decision making due to the inadequate quality of the information.

Hobbs and Lyall [12] describe design considerations and guidelines for human-machine interfaces for UAS control stations. Identifying design problems earlier in the development process can reduce the likelihood of design-induced errors proactively. Incorporating the opportunity for feedback in the design and development of interfaces can result in interfaces that better support operators expected tasks and roles, leading to more efficient and effective risk and hazard assessment, which can contribute to safer UAS operations.

Investigations into usability can provide such feedback and examine whether users are able to "make a clear mapping between the systems functionality as presented through the interface and their goals" (p.11 [11]). The design of the interface is imperative for the user to be able to visualize safety critical states. Effective design of the interface to an automated system can significantly improve situational awareness of the system, as well as build trust in the automation [11].

Endsley's paradigm of automation [11], suggests the development of planning tools that highlight key information to the user in the form of risk related alerts. This form of proactive risk management allows the user to take into account safety-critical risks in urban flight environments: unsafe proximity to obstacles, population density and system degradation/failures (e.g., battery). The different services provided by the SDSPs allow for analysis of known-knowns and the opportunity to assess and mitigate known-unknowns; adding an additional proactive layer to monitor, assess and mitigate overall risk.

B. Interface for Services Functions and Capabilities

Services, functions and capabilities that will underpin such interfaces have been, and are being developed, within SWS, as part of the advanced ISSA capabilities, that will identify safety risks. The first step in the development cycle is to use currently available information to develop the capabilities and the second step is to test these capabilities against new data to verify that the function is able to identify hazards as intended. In SWS, services and functions are grouped by the sources from which the data that drive the system are obtained (Figure 2) [3]. The first set of data is acquired from the vehicle and its communication links with the Ground Control Station (GCS), which will allow an analysis of vehicle health and local conflicts. The second set of sources is obtained by monitoring the airspace, which will provide data for conformance, constraint and authorization management services. The third set of sources is those that can be provided on the ground by other entities and ground-based monitoring equipment, including weather and surveillance data. SWS is building SFCs to analyze and identify risks from all three types of sources and has built prototype services to identify hazards in sUAS power health, motor health, navigation and link performance, proximity to hazards, population density and weather models. Details on the construction of each of these services and the research process to develop them can be found in [13], [14], [15], [16], [17], [18], [19], [20].

In addition to the services themselves, interfaces are required to display the analysis results to the user. In this case of a supplemental data service, the interface will need to facilitate access to multiple services from all three areas of risk analysis. Within SWS, three designs for the presentation of these data are being researched and developed – the HATIS tool [21], being developed by the HATS company; and two in-house tools, the Operation Planning Tool (OPT) [22] and the Supplemental Data Service Provider-Consolidation Dashboard (SDSP-CD). The OPT is for use both pre-flight and inflight and the SDSP-CD, which is the focus of the remainder of this paper, is being developed for pre-flight only.

The Supplemental Data Service Provider-Consolidation Dashboard provides an interface through which SDSP SFC analyses can be run by users with respect to a flight they are planning, and a view of the hazard analyses results is presented to them. The SDSP-CD shows the results of four services developed within SWS: a battery end-of-discharge (EoD) prediction [14], an identification of Global Positioning System satellite availability (GPS) [18], a calculation of proximity to ground obstacles, such as buildings and trees (Proximity to threat, PtT) [15], and a human casualty risk assessment (GRASP) based on the local population density and the risk of the UAS's motor failing [13]. The SDSP-CD draws on analysis results from the services to summarize the data and provide an alert at thresholds set by the user for each one. The interface offers two levels of information, showing the presence of a

threshold that has been met or overstepped, i.e., an alert, and, secondly, providing details of the hazard analysis to explain the alert.

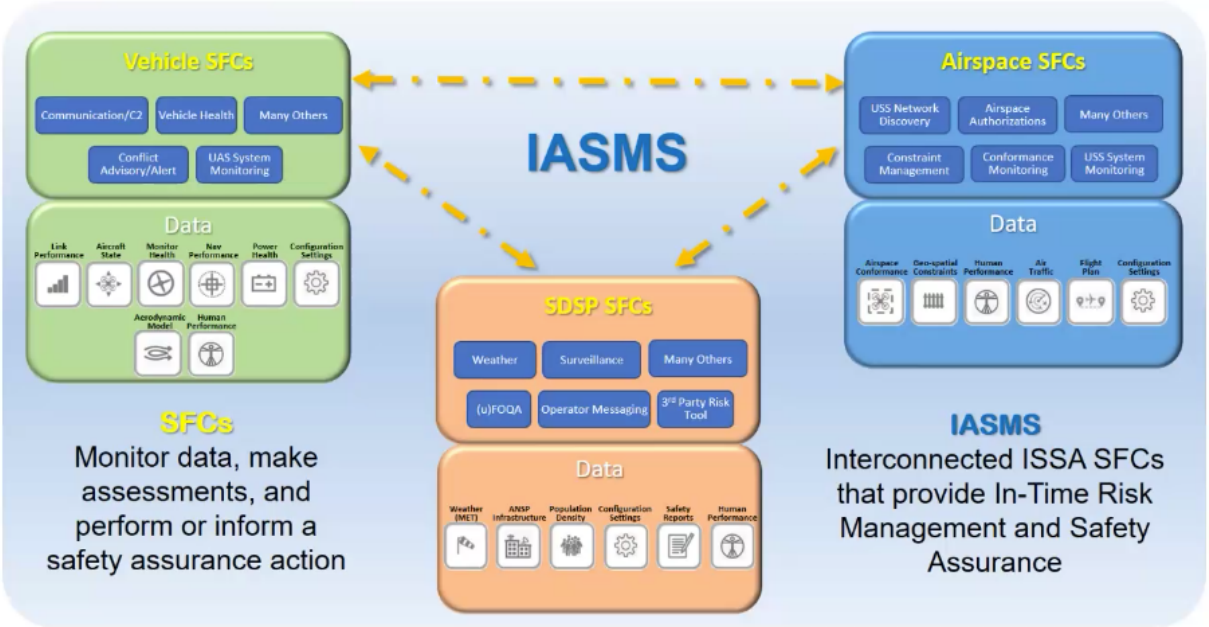

Fig. 2 In-time aviation safety management system approach with three areas of services, functions and capabilities identified ([5] slide 10 and [1] p. 22).

As the SDSP-CD is a prototype display and new services are being developed to add to the interface, the current development, with only four services, offers an opportunity to test user understanding of the information presented, user decision making, and the best ways to display such data to an operator. Two usability reviews have been conducted, and the SDSP-CD graphical user interface (GUI) has been updated and improved in line with user feedback. These studies are described below.

II. Initial Usability Review

1. Method

The first usability review was conducted in-house, primarily because this was an initial review of the interface and because restrictions (due to COVID-19) limited opportunities to recruit participants from outside the organization. Our research question was: Does the SDSP-CD GUI convey information clearly and concisely so that a user is able to identify the specific hazards associated with their route of flight?

2. *Participants*

Participants were twelve members of the wider research team. Each participant was an expert in UAS hazard and risk analysis, who therefore understood the goals and aims of the SDSP-CD tool but were not familiar with the interface. They participated in interviews in groups of two or three. Five interviews were completed.

A. Dashboard Design

The initial GUI for the SDSP-CD was a two-panel design. The first panel consisted of an alerting table or dashboard (Figure 3), where each column of the dashboard represented an SDSP service and each row showed the hazard assessment for one flight of a single UAS vehicle. The cells of the matrix show the alerting status of each service with respect to each flight; a dark green bubble was a nominal-state advisory, indicating that the calculated values for that service were above the set threshold and no calculated hazard. Red and yellow buttons were caution alerts, indicating that the predicted values for either the vehicle or its flight path were below the two caution thresholds set for that service, i.e., there was potentially a hazard. For example, in Figure 3, UAL404 has a predicted battery end of discharge that is before the end of the predicted flight, causing that cell in the dashboard to show a yellow caution. The neon green square icon shown next to the SDSP service displayed that connectivity was good.

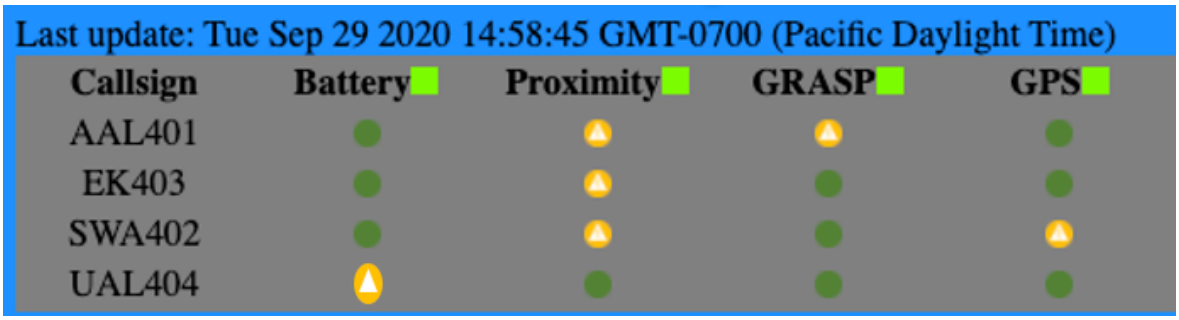

Fig. 3 An example of Panel 1 of the SDSP-CD, with four flights showing cautions for four services: a battery end of discharge (EoD) prediction, a calculation of proximity to ground obstacles (Proximity to threat, PtT), a human casualty risk assessment (GRASP) based on the local population density and the risk of motor failure and an identification of GPS satellite availability (GPS).

The second panel shows a map of the flight area with a line (generated from flight waypoints) to indicate the predicted path of the UAS flight (Figure 4). When the flight path line was either green or grey (green in Figure 4), the service predicted the flight would be below the hazard threshold set for that service. If the flight path line was red or yellow, it indicated the service predicted the flight would be above the threshold, that is, there was a hazard predicted in this area. Figure 4 shows the results from the Proximity to Threat service, which cautioned that the predicted flight path was close to the trees in two areas. For this service additional information is provided in an inset table, in this case showing that the flight path had been set over the trees at an altitude that used 70% of its buffer, with 30% buffer remaining (here the buffer was 10m).

The SDSP-CD displays a slightly different map view for the four services:

- **Proximity to threat service (PtT)**: This view showed all hazards below or close to the flight path highlighted on the map in cyan. The display had an information table that provided proximity information for the vehicle such as time to hazard, type of hazard and safety margin.
- **Battery end of discharge service (EoD)**: This view showed the battery end-of-discharge event on the map and an information table provided the estimated time the EoD will be reached, the estimated remaining flight time available, and the probability of reaching EoD before the end of the mission.
- **GPS coverage service**: This view showed the quality of GPS coverage depending on number of satellites available at each checkpoint along the flight path.
- **GRASP:** This view showed the impact points if the UAS's motors were to fail and the associated probability of human casualty (based on population density) for each impact point. A second layer gave the user the option to see a heat map of population density (gradation of color) showing areas of high, medium, low, and sparse population density in the local area.

The intention is for the operator to be able to use the information shown by the SDSP-CD to assess and potentially revise their flight plans in their flight planning tools (e.g., Mission Planner [23]) to build an amended flight path that assumes less risk. For example, looking at the GRASP information, the operator may design an alternate flight path that goes around the area of high risk (or change the flight day or time) and then reload the new plan to the SDSP-CD and re-run GRASP to confirm the risk is reduced. Users navigated around the SDSP-CD by clicking on the cells of the table in the first panel. This selected and displayed the corresponding map view on the second panel, where the user can see the exact location of the hazard (as described above) and additional information.

B. Study Procedure

A scenario was developed where four (simulated) aircraft flew intersecting rectangular flight paths around a network of five streets. The streets were lined with one- and two-story buildings and the area was surrounded by trees. The four vehicles took off either from parking lots or the roofs of buildings and flew clockwise around their routes. These flights were designed so there were no conflicts among the vehicles. The SDSP-CD was run using the planned routes of flight and the services showed a caution alert when hazards were identified (it was predicted a threshold would be exceeded). In the scenario, one UAS flight plan received a GRASP caution (Figure 3) and another an EoD caution. Dummy data was used for the GRASP service to ensure there was one of this type of caution in the scenario. Three flights received a PtT alert and one a low-GPS coverage alert. As described above, the interface

showed these cautions as red or yellow buttons in the dashboard matrix. When these buttons were selected, the map view updated to show more, specific information about this service (as illustrated in Figure 4, where the PtT service caution for aircraft 3 (SWA402) is shown).

Fig. 4 Panel 2, shows detail for the PtT service, with three caution areas on the flight path for SWA402 and information about the cautions on an inset map.

Prior to their interview, participants were sent a set of introductory slides. Participants were contacted, in dyads or triads, over Microsoft Teams for the interview itself for a total of five groups. A member of the research team ran a demonstration of the SDSP-CD from a script, selecting the services in turn in real time and giving an overview of the information being displayed. Participants were asked questions about their first impressions of the usability of the interface in a semi-structured interview that was conducted in parallel with segments of the demonstration. Participants could ask the researcher to move backwards (or forwards) onto other views in the SDSP-CD but were not able to manipulate the interface themselves. Each interview was set for an hour but, with the participants' consent, most took between 70 and 90 minutes.

The interviews were recorded through Teams and transcribed. Comments about the perceived usability of the interface and the way the tool might be used were coded by two members of the research team and differences in categorizations reconciled.

C. Findings

The statements transcribed from the five interviews were analyzed descriptively with a focus on feedback about the usability and the usefulness of the interface. The twelve participants offered 239 unique statements about the GUI and the interview process. Sixty-two of the statements were out of the scope of this review, as they raised topics such as the study method or future services. Of the remaining 177 statements, 130 focused on the interface's usability and the remainder were directed at the GUI's usefulness to an operator.

1. Usability of the SDSP-CD interface

Statements fell broadly into three categories: about individual elements of the display, the organization and layout of the display, and the information presented. Individual elements (Figure 5, horizontally shaded bars) were the focus of a third (37.6%) of the comments, giving feedback about icons, GUI color, visibility, and the usefulness of audio alerting. A further third of the statements (37.6%, Figure 5 blue bars) gave feedback about the way information was organized on the GUI, focusing on navigation, integration, and organization. And a quarter of the comments (24%, Figure 5 diagonally hashed bars) discussed the salience and clarity of the information on the interface. As there were interview questions in all three categories, all participant groups gave feedback about the GUI's elements, organization, and clarity. Participants also brought up novel topics for discussion, for example, the use of audio alerting to identify different events, that were only discussed within their group.

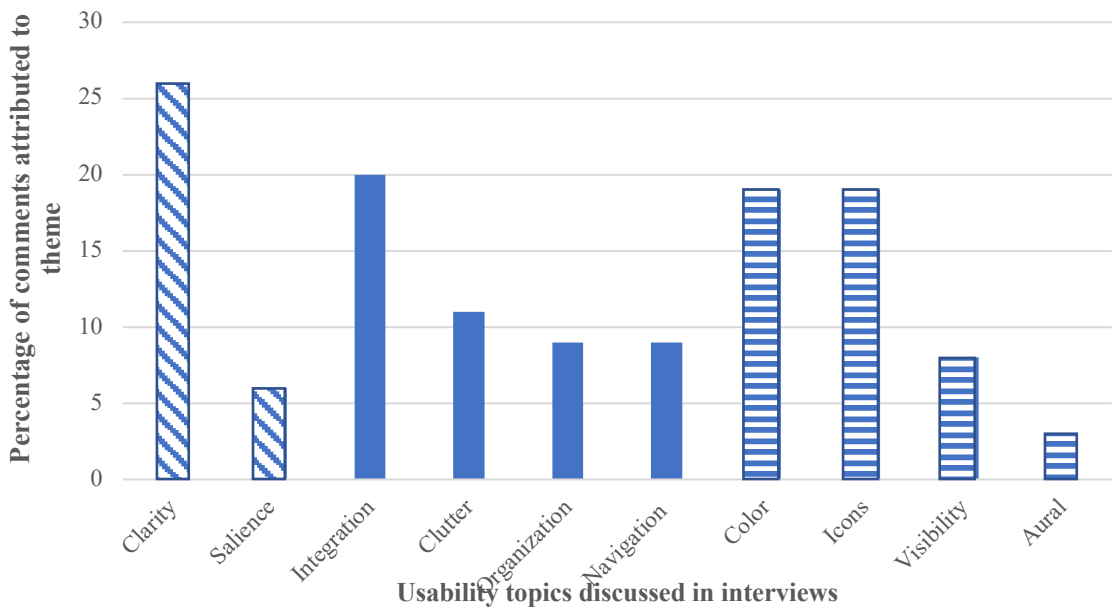

Fig. 5 Chart of the number of statements from the usability interviews referring to an aspect of usability of the interface.

The main theme of the 19 comments about color was to make the palette consistent – use the same set of colors for all four services, e.g., using white, gray, and blue to denote nominal situations and the span of yellow to red colors for the alerts. The icons were well received, with one suggestion to change the PtT icon. The "fence" icon is intended to denote all geospatial constraints, including airspace boundaries and dynamic obstacles [4]. However, it was suggested that labels be added to all icons to ensure users understood the service. And, similarly, the map legends, whilst accurate were too technical. Participants advised that more commonly understandable terms be used to define the map coloring. There were some additional observations about labeling – to make the headings more salient and to combine some icons and labels that conveyed the same information, e.g., move the information located in a pop-up on the PtT map into the table.

Participants expressed a clear preference for combining the panels to have the map and the dashboard available side-by-side to enable comparison. Participants liked the "select multiple alerts" function but wanted to be able to select all the alerts for one flight (a row) in addition to being able to select all the alerts given by one service (a column). Participants suggested combining basic status information into a heading bar, where the user could check for the overall flow of information into the GUI. They also requested a way to customize the interface for their own needs, by being able to set the thresholds for each service themselves.

2. Usefulness of the interface

Some of the feedback was focused on the user's perspective – how easily the user would be able to interpret the information on the SDSP-CD (Figure 6). Participants identified information that could be used for decision making

or prioritizing actions. They also identified areas where they thought a user might be confused or have trouble understanding the information.

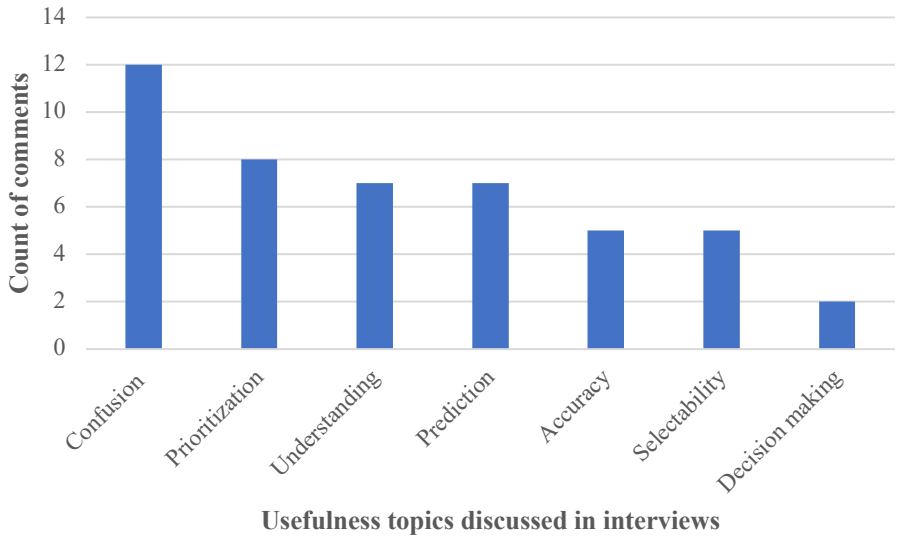

Fig. 6 Chart of the number of comments referring to an operator's ability to use the interface.

In their evaluations, participants discussed how they would use the SDSP-CD information, for example how they would prioritize the information or make decisions to redraw the proposed flight path. These comments were valuable because, where participants had trouble describing how they would use the information, we were able to drill down to identify how the information was unclear and what had led to a lack of understanding or confusion. These discussions helped to clarify how the GUI could be improved. One key observation was that knowing the battery EoD was less useful than knowing when the battery is becoming depleted. Participants advised that a prediction, showing 30% of battery remaining would be a more useful alert.

D. Revised SDSP-CD Interface Design

User feedback was incorporated into a revised interface design for the SDSP-CD. The primary change was to bring the two panels together into one. Under the revised design, the alerting dashboard is in the upper part of the display (Figure 7). As before, each column of the dashboard represents an SDSP service, and each row shows the alert status for a single vehicle. The cells of the dashboard show the alerting status of each service with respect to each flight. The green, red, and yellow color coding is the same as in the earlier design, with red and yellow buttons indicating that the predicted values for either the vehicle or its flight path are above the thresholds set for that service. The PtT icon has been changed to a more representative "tree and house" image, and labels have been added to identify the services. And, the EoD service can now be set to show the percentage of remaining charge, not just the EoD.

The map of the flight area is located on the lower half of the display, showing the predicted flight path more consistently as either a white or a gray path for the areas where the services predict the flight will be below the threshold (low risk). As before, if the flight path line is red or yellow, it indicates the service predicts the flight will be above threshold in that area. Legends have been simplified using lay person terminology and added for the inset table under the PtT service. An addition to the display is a map header bar (black banner), where details about what service and aircraft have been selected, and confirmation of the incoming data are listed. Colors have been changed on the GRASP heat map layer, making the display easier to read.

III. Second Usability Study

A. Method

The updated SDSP-CD GUI was used as the focus interface in a second usability study that investigated the usefulness of information it provides and examines how the interface, and the SFCs it is presenting, may increase the level of flight hazard awareness and assist with operator decision making. The study also sought to determine what qualities of interface design enhance situation awareness and allow operators to proactively identify problems.

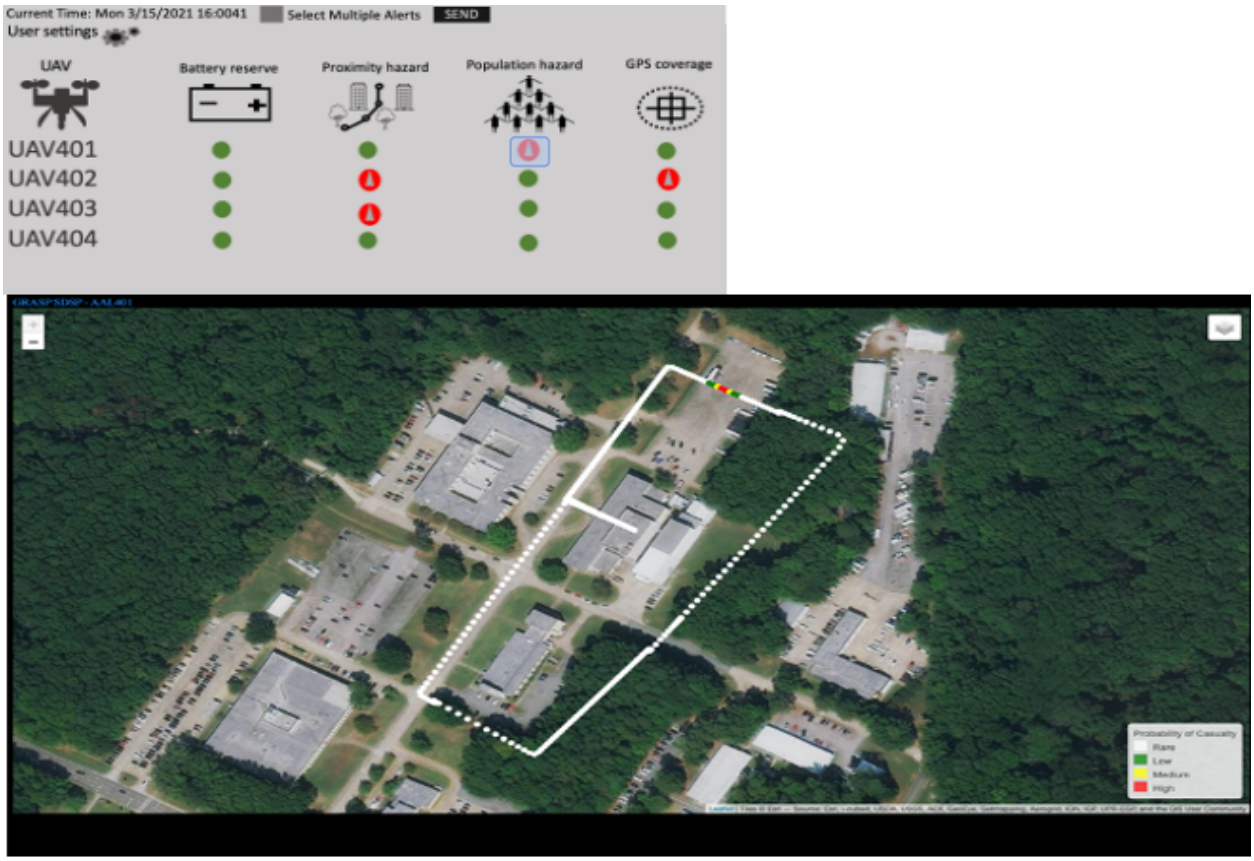

Fig. 7 The updated SDSP-CD GUI shows alerts for four flights in the table and map display of GRASP – Population Hazard service – for second usability study.

To test the revised SDSP-design, the study focused more on the usefulness of the information on the GUI. It also was conducted remotely via Microsoft Teams as restrictions (due to COVID-19 variants) limited opportunities to conduct this study in-person. Operators (both Ground Control Station Operators (GCSOs) and non-GCSOs) were trained on the software, presented with a multi-vehicle simulation, and administered semi-structured interviews as they interacted with the SDSP-CD interface. In these semi-structured interviews, some of the questions asked about notifications or issues with respect to the different services (EoD service, PtT, GRASP, and GPS service) and, whether anything was confusing, and how this kind of information might affect their flight planning. Questions delved deeper into users' understanding of the GUI asking about settings and thresholds, alerting of hazards and risks, effort to use the tool, and how this interface would affect their work. Our research question was: Does the SDSP-CD efficiently convey information well enough to enhance user awareness of, and decision making about, specific hazards associated with their route of flight?

1. Participants

Participants were four members of the wider research team, recruited from within the organization but across different locations (i.e., time zones). Each participant was either an expert in UAS hazard and risk analysis and qualified as a GCSO or was familiar with and had some experience as an operator but was not certified as a GCSO.

2. Dashboard design

The design of the dashboard was as described in section II, D above (Figure 7) as a two-panel design, with an alerting table and a second panel below the first showing a map of the flight area.

3. Study procedure

Two sessions were scheduled with each participant. The first was a one-hour training session, scheduled either individually or in groups of two, and included PowerPoint slides with video vignettes of the SDSP-CD functions and

capabilities throughout the presentation. The training scenario was the same as previously described (section II, B above). During the session, participants were asked to assume the role of a flight manager and to look across the three flight plans presented as a fleet of operations they were responsible for planning. They were encouraged to ask questions and could re-review any slides or vignettes. At the end of the presentation, participants received a link, shared their screen with researchers, and were able to interact with the dashboard themselves, e.g., click on alerts and navigate through the display. For reference and prior to the scheduled interview, participants were given Teams access to both the slides and video from the training.

Participants were interviewed individually at the second session. A similar but different scenario involving three aircraft flying intersecting patterns around the same network of streets was created. Due to interface connectivity and access most, but not all, participants were given about five minutes to "refresh" their memories and interact with the interface. Then, a semi-structured interview was conducted for the remainder of the hour. Participants were asked questions related to navigation and organization, and understandability and risk assessment (see Appendix A for a sample set). Participants were prompted to express their thoughts aloud as they interacted with the dashboard. Discussion among the participant and researchers was encouraged during the interview. Both training and interview sessions were set for an hour, but with participants' consent, some took 75-90 minutes. Most training sessions, and all interview sessions were recorded and transcribed.

4. Coding methodology

As the interview was semi-structured, participants' responses were used to guide the course of the discussion. The variation in their opinions over the course of the interviews affected the order and number of questions that were asked during the sessions, and not all participants provided feedback on every question. Participants were encouraged to verbally express their thoughts, so in some cases portions of the interviews were participant driven. Responses were recorded via Teams, and notes were compiled during reviews of the video and audio content.

Each recording was transcribed and timestamped and then categorized by at least two coders. Researchers used a template to code participants' statements into different categories, or topics, that emerged from the interviews. For example, if a participant made a statement about risk, that statement was coded into the Risk Assessment category. Only statements where both coders identified the same specific statements and coded these statements into the same categories were counted in these summarized results. Some statements were coded into more than one category; for example, a participant may talk about wanting to see alerts on a particular vehicle (e.g., situation awareness) and also report which vehicles they had selected (e.g., priority/process). Both coders needed to have coded that type of statement in the same way for those data to be included in the analysis. Other comments and observations, beyond this coding criteria, are included in a general summary section. These data were not categorized but are considered additional interesting feedback from participants about the SDSP-CD interface.

B. Findings

The statements transcribed from the four interviews were analyzed descriptively with a focus on participants' responses about the usability and the usefulness of the interface. The four participants offered over 400 unique statements about the GUI. Statements that were either out of scope (e.g., additional comments) or filler words were not included in the analysis. Statements made prior to the interview (e.g., during the training session) were also not included in the analysis.

Of the remaining statements, 142 focused on the interface's usability and usefulness to an operator. Nine general categories resulted from the coding methodology. They are: (1) Positive/negative impressions, (2) Alerts/colors/icons, (3) Process/priority, (4) Changes to flight plans/thresholds, (5) Efficiency/workload, (6) Need for clarification, (7) Risk assessment/predictions, (8) Situation awareness, and (9) Suggestions or improvement. These categories spanned both the usability and usefulness of the interface (see Figure 8). Broadly, although there is some overlap between usability and usefulness, the nine topics used to code these data can be grouped as bearing primarily on usability or on usefulness, and this grouping is used to present the content of participants' comments.

Participants' frequency of responses within each category is reported. The distribution of the four participants' responses, presented in order of most to least number of responses, can also be seen across the nine categories (see Figure 9).

1. *Usability of the SDSP-CD interface*

Participants' statements about the interface were grouped into four categories: alerts and colors, need for clarification, efficiency and workload, and suggestions or improvements (bars 2, 5, 6, and 9 in Figures 8 and 9). The feedback related to alerts, colors, icons, and the inset table (PtT Service) was largely positive, and participants stated that many aspects about the CD were "intuitive" to use.

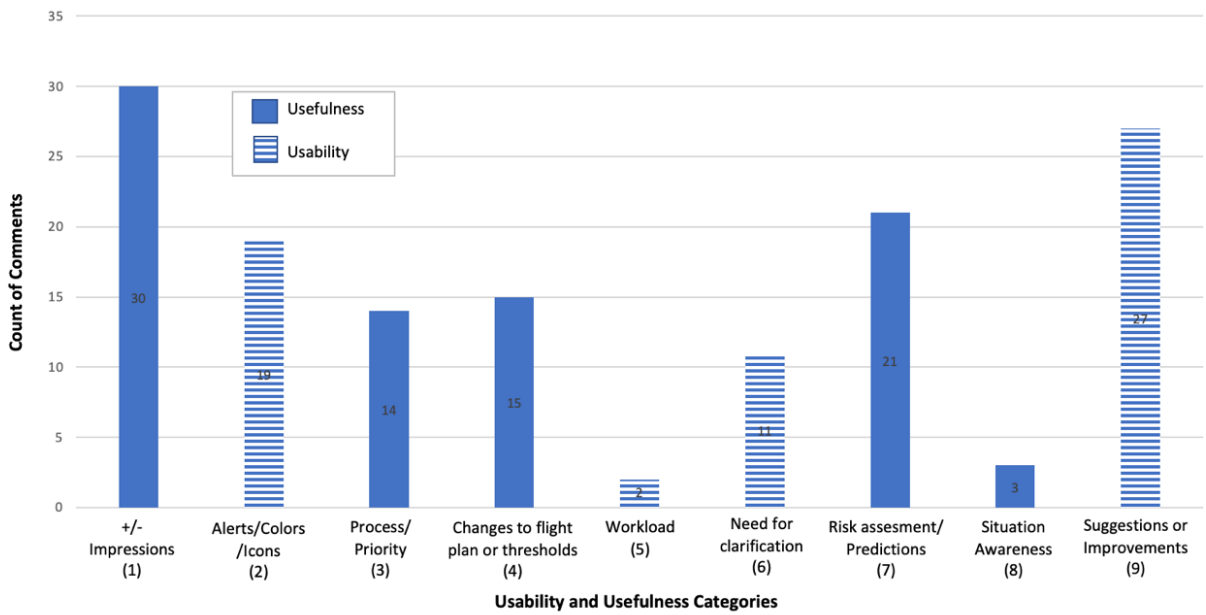

Fig. 8 Chart of the number of statements from the interviews referring to the usability and usefulness of the interface.

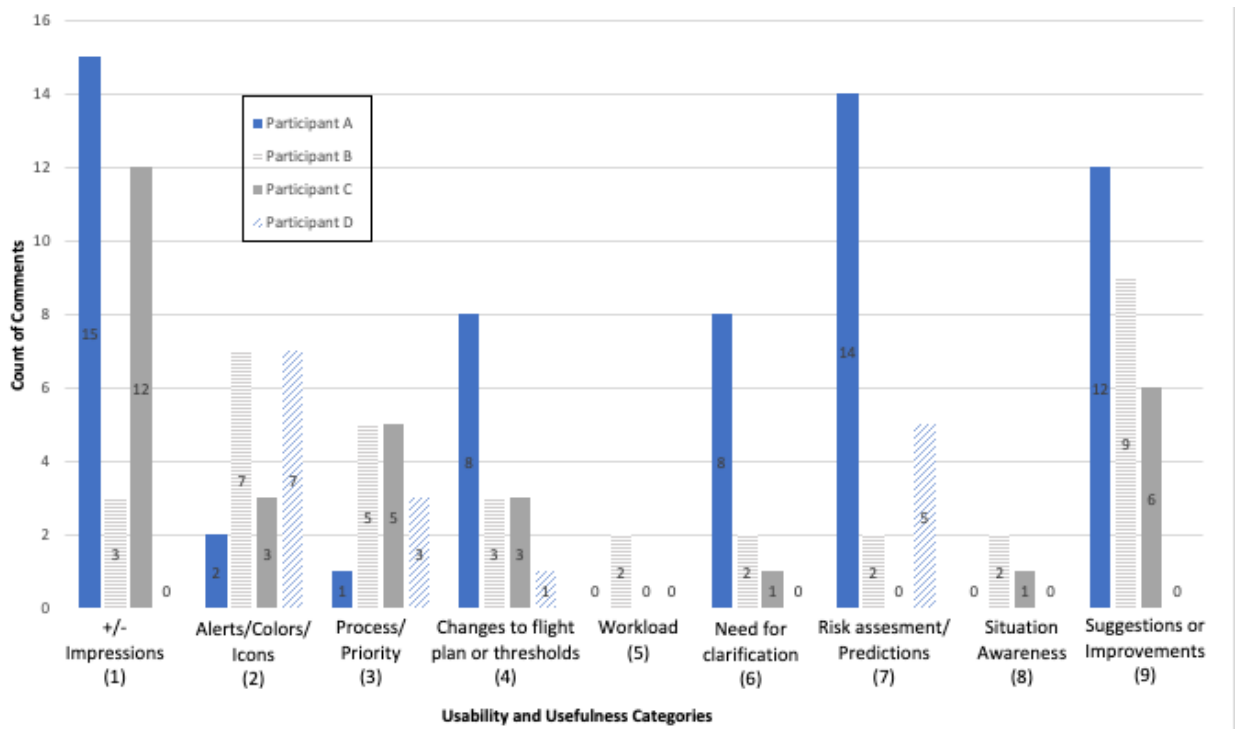

Fig. 9 Distribution of participants' responses across categories.

Responses were mixed with respect to icons and color – with color choices either being described as familiar, easily understood, or needing clarification (e.g., a key to show meaning). This was similar to the previous study where

more understandable terms for defining the map coloring was advised. Red, yellow, and green were easily understood; however, the color gray was confusing to some (e.g., being associated with no satellites rather than the intended "excellent" coverage displayed on the map for quality of GPS). The color magenta in the inset table was also visually challenging for some. The meaning of the icon for the EoD point on the map was unclear to most (e.g., "looks like a paintbrush"). Participants also requested ability to move the inset table so that it does not restrict viewing of the larger map, and some type of marking to note when hazards may be co-located (e.g., if proximity to threat overlaps with poor GPS signal quality) was requested.

Participants' experience and training likely influenced their need for clarification and understanding of their imagined role as a flight manager using this preflight planner tool. Reminders that it was a planning tool, with deconflicted flights, and not using live, active, or changeable data were necessary. Participants requested having more information (e.g., for planning alternate flight path options) available to them when deciding to change a flight plan. Clarification was also needed about information provided in the inset table (e.g., what the distances mean), as well as some interest in having the threshold settings available on the main display.

Participants perceived that the effect on workload and efficiency would be challenging when having to "go back and forth...sequentially ask different SDSPs" (i.e., switch between views of services) to identify an acceptable flight plan. The possibility that an operator could adjust one aspect of the flight to mitigate a hazard, and that this could then affect another hazard was raised. For example, an operator might notice an alert for PtT (e.g., trees), and decide to extend the flight area; however, this may affect the length and time of the flight in a way that would directly affect the battery charge, resulting in another alert.

Participants provided many suggestions and possible improvements while interacting with the SDSP-CD. Some of these include showing the horizontal dilution of precision (HDOP) for the GPS service, access to weather data (wind, cloud ceiling, magnetic interference), indications of direction of travel, and waypoints. Also, having a radius (e.g., a circle around the vehicle location point) of satellite coverage quality was mentioned. The presentation of additional information simultaneously via layers and also, more guidance in generating an acceptable flight path were described.

2. Usefulness of the SDSP-CD interface

Statements were grouped into five categories: process and priority, changes to plans/thresholds, risk assessment, situation awareness, and general impressions (bars 1, 3, 4, 7, and 8 in Figures 9 and 10). Participants described how they would address the alerts, not being concerned with, but monitoring the green notifications (e.g., "keep an eye to see if the green stays green"), while focusing more on the red (e.g., "I would look at whatever's red first") and yellow alerts. Participants clicked through the different services and determined more details about the alerts by referring to the representation of the service on the map. They navigated between alerts (e.g., between GPS coverage and population) to describe what they would do – in some cases saying they would change the flight plan –to avoid any issues. A situation of "double jeopardy" was described in segments with co-located alerts-- for example, an alert relating to poor GPS quality in the same location as an alert relating to proximity to trees (e.g., "flight segment has two problems"). It was suggested the SDSP-CD should identify where two (or more) hazards are co-located; one participant suggested using a double line. Based on the SDSP-CD alert information, participants made suggestions for how they would decide to change the flight plans for example, by raising the altitude, extending flight paths (given GRASP alert information), shortening or shifting the flight path, or changing out the UAS batteries.

Descriptions about risk assessment or predictions from using the SDSP-CD interface tied into usability issues of workload and efficiency – namely, the challenge that fixing one alert could affect predictions from another service and absorb a lot of time working across the services to find the clear path. One participant asked, "How do you fix the conglomerate?" The capability of a risk assessment interface that addresses this concern is noteworthy.

Generally, participants shared largely positive feedback during their interaction with the SDSP-CD, reporting their situation awareness was "raised" using this interface. Information provided in color-coded heat maps, for example, showed the density of the population in a particular area. Population density information has not been readily available to operators, so this information did raise their awareness of "potential bystanders in the area." Participants were able to be aware when vehicles had multiple issues at a time. The location of the dashboard (top left) and the alert colors (red, yellow, green) caught participants' attention. The features they particularly liked were the PtT information ("having that information is definitely valuable"), the key for the GRASP service and the ease and intuitiveness of the dashboard. Not only did it raise awareness, but operators commented that for status alerts, "I could evaluate the plan pretty quick." Information provided by the GPS coverage was valued (e.g., "I know exactly where the problem is") – as this can involve some guesswork or must be surveyed in the field. Comments about the clarity and information provided by GRASP maps and heat maps were positive. The ability to have predictive information was appreciated – as this (e.g., population density) is not currently available to some operators. Comments about the

battery service were also largely positive, particularly when showing how far into a flight an issue is expected to occur.

C. Second Revision Phase to SDSP-CD Design

Analysis of the participant feedback to the second usability study is ongoing. Future work will include incorporating this feedback into a revised display and functionality for the SDSP-CD. Since the second usability study focused more on participant strategies for using the interface, and the way they understood the information presented, improvements to the SDSP-CD interface will be concerned with helping the operator identify and understand its information. An example of these types of improvements would be to enable operators to compare alerts across two services, e.g., see the EoD point at the same time as the PtT alerts for a given flight. To do this the user will need to be able to overlay the results from one service's analysis onto the second. An extension to this feature would be to indicate whether and where there are options for a clear flight path that avoids these hazards within the parameters set for the flight.

In addition to improvements in the functional usefulness of the SDSP, participants provided a host of interface presentation suggestions. Among these are:

- Overlaying the various maps and being able to examine different services on top of each other as layers. E.g., overlaying the population heat map with the GPS map.
- Users liked having the drill down menu, found it helpful to have a more detailed visual of the extent of the hazard and would like to have that option within all of the services.
- Ensuring consistency across services in the way the information is presented. In particular, making the color coding for the GPS service consistent with the other services, add data tags for the GPS service display similar to other services and ensure that every service shows a clear legend.
- In addition to the suggestions and improvements previously reported, some described wanting more detailed GPS quality information (e.g., range of accuracy).

IV. Summary

The Supplemental Data Service Provider-Consolidation Dashboard provides an interface through which SDSP services functions and capabilities can be run by users and view the results presented to them. The SDSP-CD draws on services developed within the SWS project to summarize data and to display alerts at specific thresholds for parameters such as proximity to ground structures and battery prognostics. The interface offers two levels of information. At the higher, dashboard, level an overview of the status of all the services is presented – the user can see if any of the services have exceeded a risk threshold and been alerted. The second level drills down into the selected services to offer more detail about identified hazards relative to the underlying data.

Two studies were conducted to evaluate the usability of the prototype SDSP-CD. The first study was a review of the GUI elements where participants were given a demonstration of the interface, and the second was a walkthrough where participants were able to interact directly with the tool. The focus of inquiry during the first study was on the consistency and coherence of the way the services were represented on the interface – the color palette, icons, and information organization. Having improved the GUI, the second study focused on the information a user could glean from the SDSP-CD and, by self-report, the contribution this may have to their hazard awareness.

Findings from the first study highlighted a lack of consistency in the interface and an awkwardness in having to look across two panels to understand information. Changes made to rectify these issues were confirmed to be improvements in the second study, as participants had no difficulty comparing across the co-located panels and far fewer GUI presentation comments. Findings from the second study are currently undergoing analysis, however, the key feedback received centers around users' need to compare across services. More than one participant commented on the conundrum that if they altered their proposed flight path (during planning) to assuage a risk on one of the services, they may inadvertently move into a hazardous area for another service.

There are some limitations to the studies completed, most due to restrictions imposed by COVID. Due to remote working conditions, participants reviewed the SDSP-CD and then took part in the training and interview sessions remotely. For the second study, they were able to interact with the SDSP-CD directly over a secure network. However, this connection was only available within the organization and, hence, participants for the second study had to have credentials within the organization, i.e., be "in-house." A second limitation occurred due to scheduling issues. For the second study, the interval between training and interviewing a participant varied. Those who completed these sessions with a two- or three-week interval, had, understandably, some difficulties recalling the way to navigate the SDSP-CD, which was not the case with participants who completed both sessions within the same week. A third limitation was participant background. The training was presented in the same way to every participant and did not consider their

different backgrounds/knowledge levels which affected their insight and understanding about the information being presented.

Assessments, of user feedback and interaction with the SDSP-CD, captured various considerations when operators used this newly developed interface. Hazard and risk data were presented in an easy-to-use format. The predictive data and services presented by the SDSP-CD were well received overall and contain features that show promise as a capability for both raising awareness and proactive assessment of safety risks. Specific features of this planning tool may contribute to enhancing preflight safety, and in furthering improvements to SDSP interface design.

Appendix A: Example Interview Protocol Questions

Some sample questions from the semi-structured interview protocol for the second study.

Asked for each specific service

1) What are you drawn to first?
2) What is the notification telling you?
3) Is there anything that is confusing about the information on the screen?
4) What is this information telling you about risk?

Overall interface questions

1) How would having this interface affect your work? Help or hinder?
2) How would you rate the clarity of information you received from the display?
3) How much effort/time would it take to use this tool in the preflight process?
4) Would you add any hazards to this display?

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