UAS Safety Case Development, Process Improvement, and Data Collection: Final Report

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16. Abstract

Industry-wide pursuit of scalable and economically viable methods for maximizing the benefits of UAS operations have contributed to an increasing desire for more complex operations that exceed the boundaries of Part 107. To obtain such waivers, applicants must present a safety case comprised of supporting data and information demonstrating a sufficient level of safety for the proposed operations. Given the broad spectrum of applicants and their use cases, backgrounds, and levels of experience, these safety cases vary greatly in structure, content, and the quality/quantity of data and information presented. This presents a major challenge for the FAA.

This project focused on development of a data collection and analysis system, the Test Data Collection and Analysis System (TDCAS), that enables evaluation of safety cases and identification of research needs. It provides a framework that helps users provide the proper information for a valid safety case and, thus, can not only improve outcomes for those submitting safety cases, but can streamline evaluation for FAA personnel. The TDCAS analysis component also provides a framework for identifying research needs by enabling visualization of test results and identification of areas requiring additional focus.

The data collection system was built following a previously-developed design, with significant additions for collecting test summary and degradations data. The analysis component provides numerous built-in reports, with multiple visualizations for each type.

Linkages to standards, rulemaking, and SMS were examined. TDCAS can support standards and rulemaking efforts by collecting and storing test data that inform the need for new standards and aid in validating existing standards. TDCAS may support SMS by providing data to inform Probabilistic Risk Assessment (PRA) and hazard mitigation by providing data regarding probabilities of occurrence of given hazards.

Validation of TDCAS was accomplished by focusing on a BVLOS use case. This enabled completion of a detailed evaluation of TDCAS that considered User eXperience (UX), User Interface (UI), and System Longevity. The team concluded that TDCAS performs well in all areas, providing UX and UI and are intuitive and user-friendly. Moreover, the flexibility of TDCAS and its value for fusing technical and operational capabilities in a combined safety case construct that simplifies and streamlines the submission and approval cycle drives its potential for System Longevity.

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Acronym	Meaning
ANSI	American National Standards Institute
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society for Testing and Materials
BVLOS	Beyond Visual Line Of Sight
C2	Command and Control
Central Processing Unit	CPU
CONOPS	CONCept of OPerationS
CSV	Comma-Separated Values
DAA	Detect And Avoid
FAA	Federal Aviation Administration
FMEA	Failure Model and Effect Analysis
FMECA	Failure Model Effects and Criticality Analysis
NAS	National Airspace System
NPRM	Notice of Proposed RuleMaking
OOP	Operations Over People
ORA	Operational Risk Assessment
PDF	Portable Document Format
PRA	Probabilistic Risk Assessment
ROI	Return On Investment
SDO	Standards Development Organization
SMS	Safety Management System
SQL	Structured Query Language
SRM	Safety Risk Management
sUAS	small UAS
TDCAS	Test Data Collection and Analysis System
UAS	Uncrewed Aircraft System
UI	User Interface
URL	Uniform Resource Locator
UX	User eXperience

EXECUTIVE SUMMARY

Industry-wide pursuit of scalable and economically viable methods for maximizing the benefits of Uncrewed Aircraft System (UAS) operations have contributed to an increasing desire for the ability to conduct more complex operations that exceed the boundaries of Part 107 and a continually growing volume of Part 107 waiver applications seeking Federal Aviation Administration (FAA) approval. To obtain such waivers, applicants must present a safety case comprised of supporting data and information demonstrating a sufficient level of safety for the proposed operations. Given the broad spectrum of applicants and their use cases, backgrounds, and levels of experience, these safety cases vary greatly in structure, content, and the quality/quantity of data and information presented. This presents a major challenge for the FAA.

This project focused on development of a data collection and analysis system, the Test Data Collection and Analysis System (TDCAS), that enables evaluation of safety cases and identification of research needs. As such, it provides a framework that helps ensure that users provide the proper information required to build a valid safety case. In doing so, TDCAS has the potential to not only improve outcomes for those submitting safety cases, but also for FAA personnel who review safety cases. The TDCAS analysis component also provides a framework for identifying research needs by enabling visualization of test results and identification of areas requiring additional focus.

Given the variety of tasks associated with this effort, multiple methods were applied to execute them. These include review of previously developed material/literature, coding/software development, data entry, and revision based upon user feedback.

The data collection system was built following the design of Askelson et al. (2020), with significant additions to the system enabling collection of test summary and degradations data. Test summary data collection was added to support quantitative analysis of results and degradation data collection was added to enable identification and prevention of future incidents and accidents. The analysis component provides numerous built-in reports, with multiple visualizations for each type. Visualizations enable downloading of data to enable further examination, with some also supporting interrogation of data within the visualization.

Data were entered into TDCAS for > 10 projects/safety cases. These data are associated with a variety of projects/safety cases, including Beyond Visual Line of Sight (BVLOS).

Linkages to standards, rulemaking, and Safety Management Systems (SMS) were examined. TDCAS can support standards and rulemaking efforts by collecting and storing test data that inform the need for new standards and aid in validating existing standards. TDCAS may support SMS by providing data to inform Probabilistic Risk Assessment (PRA) and hazard mitigation by providing data regarding probabilities of occurrence of given hazards.

Validation of TDCAS was accomplished by focusing on a BVLOS use case. This enabled completion of a detailed evaluation of TDCAS that considered User eXperience (UX), User Interface (UI), and System Longevity. The team concluded that TDCAS performs well in all areas, providing UX and UI and are intuitive and user-friendly. Moreover, the flexibility of TDCAS and its value for fusing technical and operational capabilities in a combined safety case construct that simplifies and streamlines the submission and approval cycle drives its potential for System Longevity.

1 INTRODUCTION

The purpose of this project, "A24__A11L.UAS.50 – UAS Safety Case Development, Process Improvement, and Data Collection" (A24), was to develop a test data and collection system that enables evaluation of safety cases and identification of research needs. The A24 scope included the following questions:

- Who is best suited to be an applicant for a waiver or exemption and why? Should it be the Uncrewed Aircraft System (UAS) manufacturer or the individual using the UAS?
- How can prior testing on a vehicle which led to successful waiver/exemption be used in future applications?
- Can an applicant with a full review of a previously successful waiver use that information for their application?
- Can prior testing on a vehicle which led to successful waiver/exemption be used or referenced by an applicant without any visibility or review by the applicant?
- Should the Federal Aviation Administration (FAA) develop a list and publish the list of approved vehicles for waiver/exemptions? If yes, what additional requirements should the applicant have, i.e., operating procedures, maintenance procedures, etc.?
- Could an applicant cite another waiver's tests without seeing or reviewing the data? Could an applicant buy an off the shelf drone and apply for a waiver without seeing the test results?
- How can safety cases for Part 107 waivers be improved?

This project was conducted with the following tasks:

1. Initial Build of the Test Data Collection and Analysis System (TDCAS)
    a. Front End Data Collection System
    b. Development of Initial TDCAS Analysis System
2. Exercise System using Advanced Operations
3. Develop Linkage to Industry Consensus Standards, Operations Over People (OOP) Notice of Proposed RuleMaking (NPRM), Other Rulemaking, and FAA Safety Management System (SMS) Risk Management Guidance
4. Validation of the TDCAS—Operations Over People Part 107 Waiver
5. Final Report/Project Closeout

This is the product of Task 5: Final Report/Project Closeout. To manage the length of this report, tasks are summarized herein. For greater detail, the interested reader may review individual task reports, as appropriate.

A24 was built upon the preceding effort A19_A11L.UAS.50 – UAS Test Data Collection and Analysis (A19), which was split into two phases. The first phase was a design phase for TDCAS, detail for which is provided by Askelson et al. (2020). The second phase focused on development of a prototype data collection component of TDCAS. This prototype closely followed the framework defined by Askelson et al. (2020). Subsequent updates to the system as part of A24 are described later in this report.

2 TASK 1: INITIAL BUILD OF THE TDCAS

2.1 Objectives

The objectives of this task were:

- Identify the eventual host of the TDCAS system.
- Establish computational resources for TDCAS.
- Develop the initial data collection system.
- Develop the initial analysis system leveraging input from the FAA.

2.2 Methods

Input regarding the data collection and analysis components of TDCAS were obtained by reviewing other relevant systems such as SMSs, by engaging with the FAA through Technical Interchange Meetings and additional meetings as required, and through discussion amongst the performer team. The combined set of personnel between the FAA and the performers had deep experience with the types of challenges encountered when collecting and analyzing test data such as those handled within TDCAS.

The computational resources were identified by evaluating potential disk space usage and Central Processor Unit (CPU) requirements. Given that no specifications regarding number of safety cases to be stored or simultaneous users to support were available, the team applied a conservative approach. For storage, it was estimated that each safety case would require ~100 megabytes of storage. Thus, a 4 terabyte system, when accounting for ~1 terabyte for the operating system and software (including the analysis component of TDCAS), would hold data for ~30,000 waivers. The team determined that any modern CPU would perform well, as the tasks being performed with TDCAS (data storage, retrieval, plotting, etc.) are relatively light from a computational perspective. A modern CPU is also expected to handle numerous (in the 10s) simultaneous users well. The host for TDCAS was determined to be the FAA.

TDCAS was developed using JavaScript (e.g., https://en.wikipedia.org/wiki/JavaScript), which enabled development of a web-based interface that affords easy access for users. Data are stored in a Structured Query Language (SQL) database to enable structured data handling and convenient data queries. TDCAS was built within a Microsoft® Windows® environment.

2.3 Summary of Results

2.3.1 Data Collection System

2.3.1.1 Users/Account Management

Access to TDCAS is managed through usernames and associated passwords. The types of users are provided in Table 1. As indicated in Table 1, many user types are organized under the concept of a team, which is a collection of users. A team can be created by a system administrator, and has a unique name. Upon creation of a team, the system administrator will also assign a user as the team administrator. Each project within TDCAS is associated with a single team.

Table 1. TDCAS user types.

User	Description
System Administrator	User with full control of the system and able to do everything other users can do. This is the only type of user that can create a new team or user.
FAA Reviewer	An FAA user who can review a project submission. An FAA reviewer can perform analysis queries on data in the system. They can view submitted projects, as well as those that have been approved, but not ones that have been rejected.
Team Administrator	A team administrator performs user management for a team. This includes adding existing system users to the team, removing users from the team, and updating a user's roles within the team. They can also update the team name.
Team Lead	A team lead can create a new project associated with the team, as well as submit it to the FAA. They also have the permissions associated with a team member.
Team Member	User able check out a project associated with the team and perform data entry. They also have the permissions associated with a team reporter.
Team Reporter	A team reporter can view the snapshots for a project associated with the team.

2.3.1.2 Data/Field Types

Data/Field types are described in Table 2. As indicated in Table 2, TDCAS has numerous types of input that afford significant flexibility for the user and alignment with the different types of data needed by TDCAS.

Table 2. TDCAS data/field types.

Data/Field Type	Description
Checkbox	A checkbox
Chips Input	A single-line input; pressing ENTER will create a "chip" (a small oval with the entered text and an X button to delete it; each is limited to 256 characters). Multiple chips are allowed by default and they are easily searchable. This data type has an autocomplete subtype that displays a drop-down list of suggestions that are filtered as the user types—clicking a suggestion adds that as a new chip.
Date Input	A single-line input. Clicking on the input opens a date picker that allows a user to select a single date.
Field Group	A group of different fields. Multiple sets of these fields are allowed by default.
File Upload	A single-line input. Clicking on the input will open the browser's file upload dialog, allowing a user to select a single file for upload. Once uploaded, a file is saved with a random filename.
Radio Group	A group of radio buttons that allows specific values only. Only one may be selected at a time.
Rich Text	Multi-line input with unlimited characters and some basic formatting functionality.
Text Input	Single-line input with a maximum of 256 characters. Subtypes include autocomplete (drop-down list with suggestions filters as the user types), character (single character), decimal (decimal/floating-point number), email address, integer, link [absolute or relative Uniform Resource Locator (URL) link], and phone number.
Text Select	A drop-down list that allows specific values only.
Text Area	A multi-line input with unlimited characters.
Time Input	A single-line input. Clicking on the input opens a time picker that allows a user to select a single time.

2.3.1.3 Project Flow

Project flow follows that defined in Askelson et al. (2020), with the primary steps (phases 1-4) illustrated in Figure 1. A project can be created within a team by a team lead. If a project is not currently "checked out," a team member can check it out. When checked out, a user can create a new "draft" if there is not one already. While in a draft state, a user can make changes and save it at any time. Once satisfied with the state of the draft, it can be saved as a "snapshot," removing its draft status. Snapshots can be viewed at a later time by users in the team. If a project is currently checked out, other team members can view saved snapshots. Once a team lead is satisfied with the state of the latest snapshot, they can submit the project, sending it to the FAA for review.

A submitted project cannot be checked out or edited. FAA users can access submitted projects, viewing snapshots for purposes of approving or rejecting the project. When viewing a snapshot, an FAA user may add comments to the project. These comments are viewable by members of the project team and by other FAA users. An FAA user may approve or reject a submitted project. If a project is rejected it reverts to its status before being submitted (un-submitted), allowing it to be checked out and edited. If a project is approved it is locked from further editing, but can be viewed by both team members and FAA users.

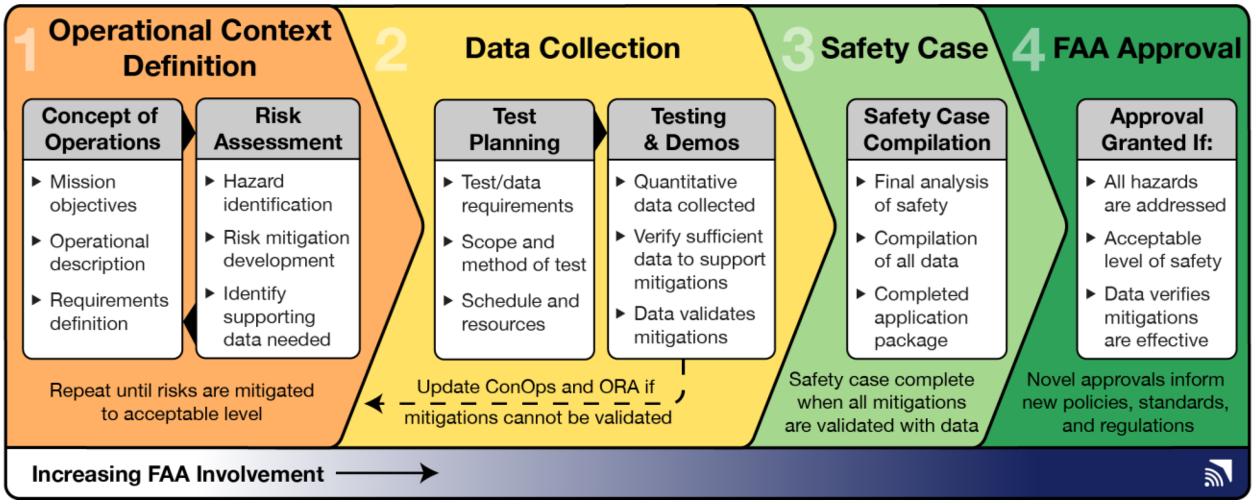

Figure 1. Virginia Tech Mid-Atlantic Aviation Partnership Safety Case Development Process.

2.3.1.4 Schema

The TDCAS data elements/schema generally follow those defined by Askelson et al. (2020). The A24 team, however, identified areas where additional data or modifications to the schema defined by Askelson et al. (2020) were needed. Only significant modifications are discussed herein. Addition of a data element or two in a phase is not considered to be a significant modification.

One significant modification relative to Askelson et al. (2020) is addition of collection of quantitative test summary data. During the design phase (Askelson et al. 2020), such data would be provided within a Portable Document Format (PDF) file. However, mining PDFs for such data is not simple. Thus, the team added this capability to TDCAS. A screenshot that illustrates data elements of test summary data is provided in Figure 2. As shown in this Figure, the data elements are:

- Test Metric: The metric that was tested [e.g., Detect And Avoid (DAA) system detection range].
- Description: A place for the user to provide a description of the metric.
- Testing Start: A date picker where the user can choose when testing began.
- Testing End: A date picker where the user can choose when testing ended.
- Testing Hours: The number of hours associated with the testing.
- Number of Testing Events: The number of separate testing events.
- Test Type: The type of test. Options are System, Design, Procedure, Crew Qualifications, and Mission.
- Value Units: A box that expands for entry of the metric value and associated units. Units are pre-filled for predefined metrics.

The test metric data element is a drop-down menu based upon metrics identified in American Society for Testing and Materials (ASTM) standards for UAS, with an “Other” option that enables entry of metrics that are not contained in that set of standards. Selection of a metric type (other than “Other”) pre-selects the metric units based upon units prescribed in the ASTM standards. It is noted that Test Types are described in Askelson et al. (2020), which is replicated here for convenience:

1. System: This is hardware, software, or both. Generally, the objective is to illustrate that a system provides the desired functionality, although tests could also be conducted to evaluate reliability. This can be further decomposed into what types of functions the system supports [e.g., DAA, Command and Control (C2), airworthiness, flight management/execution, etc.). The A19 Phase I team has retained a flexible, text-based approach to input of test objectives.
2. Design: This type of test evaluates whether a system is properly designed. An example would be testing of a Human Machine Interface.
3. Procedure: This would typically be tests to determine if a procedure provides the desired amount of risk mitigation.
4. Crew Qualifications: Such tests would evaluate whether a defined set of qualifications enables performance of tasks at the desired level. Such tests could be categorized according to types of tasks (e.g., UAS operation, communication, use of supporting systems, etc.).
5. Mission: Flights are conducted to evaluate whether UASs would function well for particular missions (e.g., linear inspection). Thus, while this category is a bit of an outlier in that the tests may not be conducted to evaluate a mitigation that enables integration into the National Airspace System (NAS), it is a type of test that occurs.

A user can enter information regarding as many test summary metrics as desired.

Figure 2 also illustrates the look and feel of TDCAS. The team directed significant effort at creating an interface that was both appealing and intuitive. As described by Askelson et al. (2020), symbols with embedded question marks (as in Figure 2) are provided. When a user selects these, a pop-up help box provides information to explain what input is expected. While the team has endeavored to provide as much assistance as possible through this type of tool, undoubtedly broader use of TDCAS will result in a new set of questions and suggestions for improving the help material.

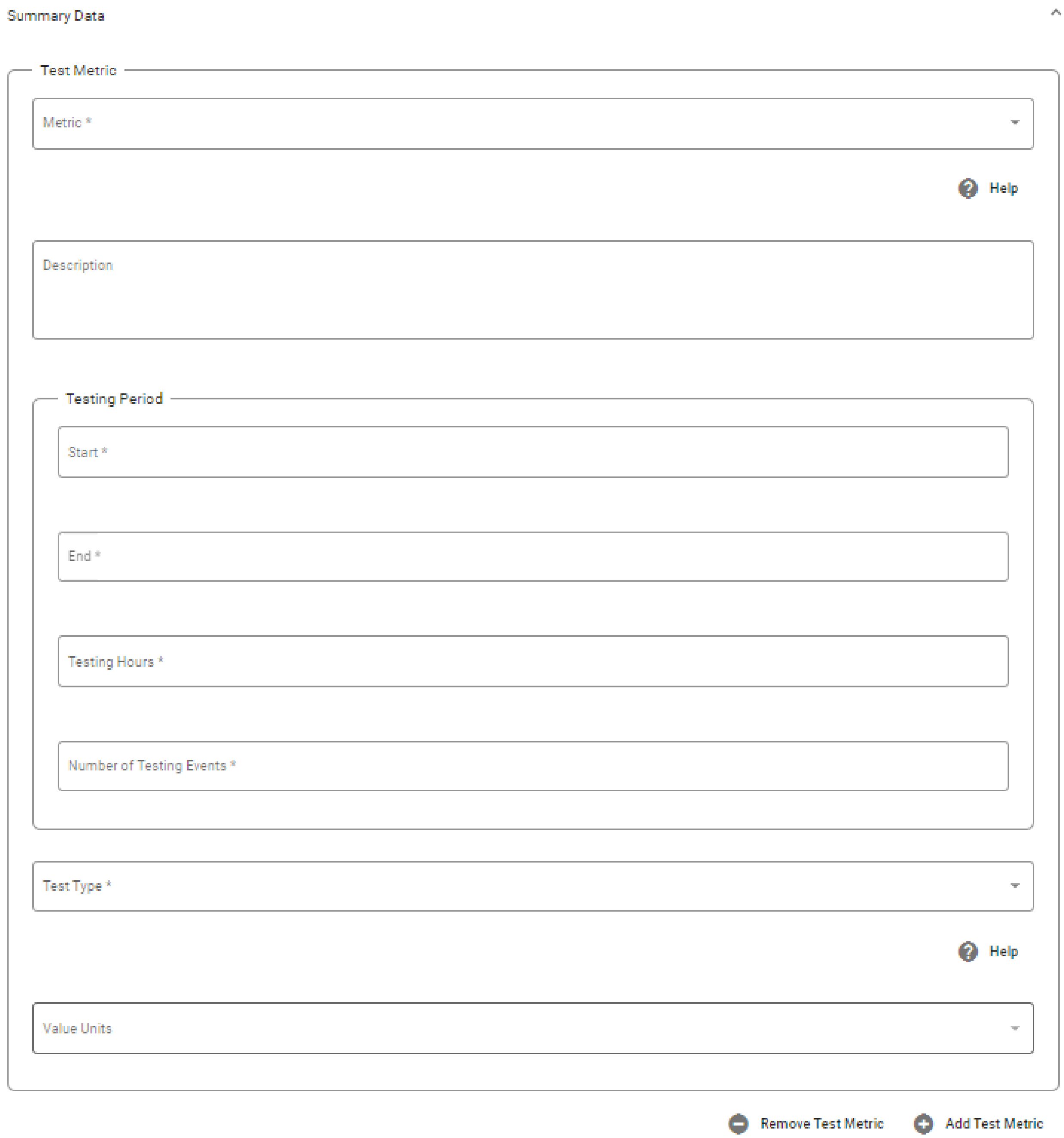

Figure 2. TDCAS screenshot showing data elements of test summary data.

The other significant modification relative to Askelson et al. (2020) was addition of information regarding degradations (Figure 3). These are, as in indicated in Figure 3, ones that occur that are not part of the test design (tests are commonly designed to evaluate mitigations for degradations). As indicated by Sugumar et al. (2022; the Task 3 report for A24), the need for information regarding such degradations is high, as such data enable prevention of future incidents and accidents.

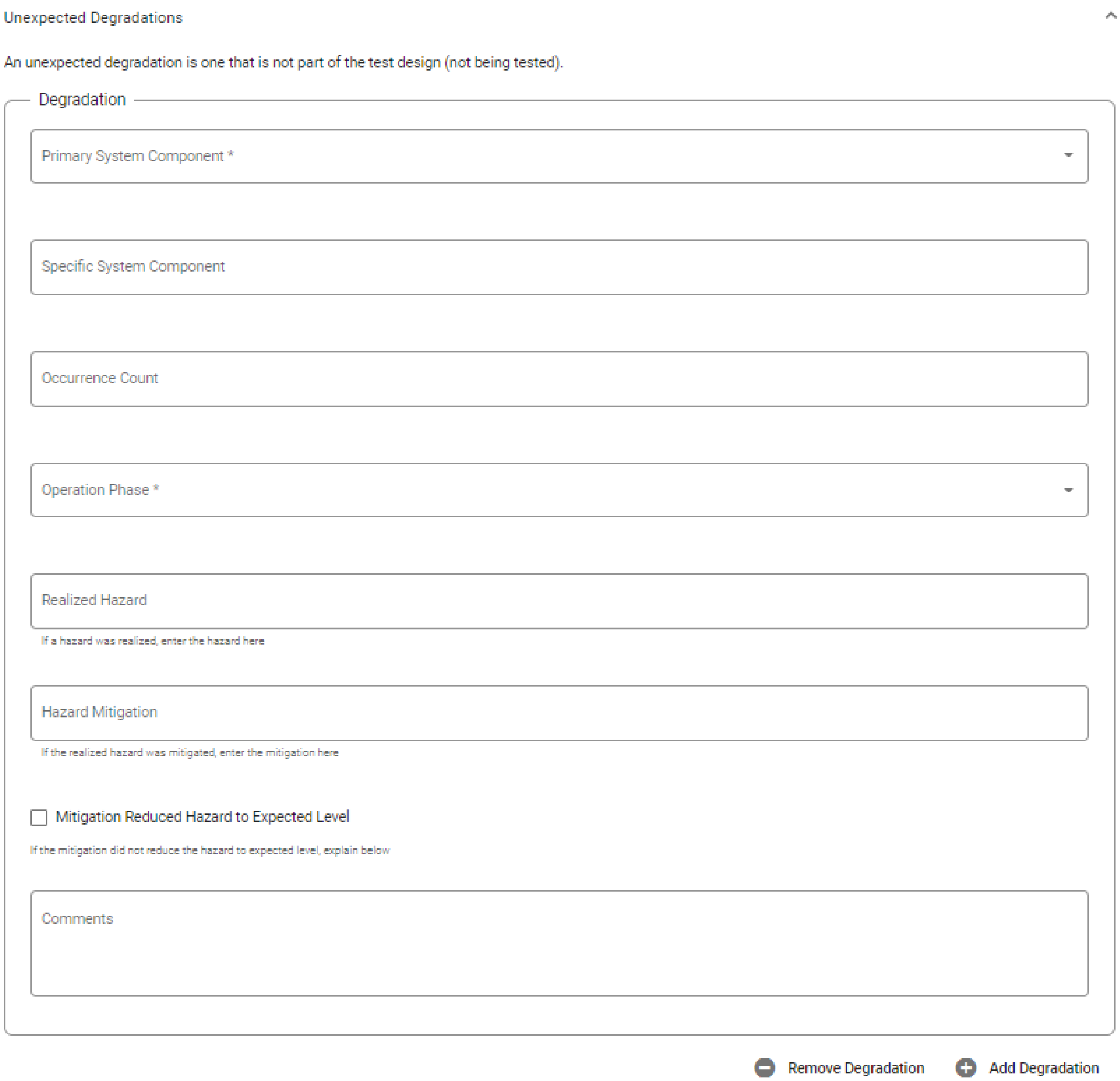

Figure 3. TDCAS screenshot showing data elements of degradations.

As shown in Figure 3, the unexpected degradations data elements that are collected are:

- Primary System Component: The primary component impacted. Options are People, Hardware, Software, Firmware, Information, Procedures, Facilities, and Services.
- Specific System Component: A text input field that enables the user to specify what specifically was impacted.
- Occurrence Count: An integer field for how many times the degradation occurred.
- Operational Phase: The operational phase during which the degradation occurred. Options are Preflight, Ground, Air, and Postflight.
- Realized Hazard: A text input field that enables the user to specify the hazard that occurred. This can reference hazards identified in Phase 1b—Risk Assessment (Figure 1).

- Hazard Mitigation: A text input field that enables the user to specify a mitigation if the hazard was mitigated. This can reference mitigations identified in Phase 1b—Risk Assessment (Figure 1).
- Mitigation Reduced Hazard to Expected Level: A checkbox where the user can indicate if the hazard was mitigated to the expected level.
- Comments: A rich text input field where the user can provide any comments (e.g., additional context regarding the degradation).

The user is able to provide information regarding as many degradations as desired/necessary. It is noted that while this structure for degradation information was derived from the combined experiences of the A24 team, it is expected that this set of information will evolve with increased system use.

2.3.1.5 Data Collection Best Practices

The team developed best practices while developing the data collection component of TDCAS. These include:

- Keeping the data collection limited so as to not overwhelm those providing data while requiring information that is needed to ensure a proper safety case is developed.
- Utilizing pre-defined options for fields is preferable when possible. Doing so avoids ambiguities such as users providing different input for the same entity (e.g., different spellings for aircraft names).
- Providing help wherever possible is beneficial, especially for users who are relatively new to TDCAS.
- Providing some training regarding TDCAS prior to use is helpful.

2.3.2 Data Analysis System

The analysis component is JavaScript-based to ensure compatibility. Much of it was developed using Angular (e.g., https://angular.io/), which greatly enabled generation of many different types of plots.

The analysis component is easily accessible to application administrators or FAA users from the TDCAS home page by clicking on "Reports" (not shown). The user has the option of selecting the following "Built-In" reports:

- Aircraft Equipages by Category
- Aircraft Makes
- Aircraft Payloads by Category
- Minimum Crews
- Operation Types
- Pilot-to-Aircraft Ratios
- Proximities to Non-Participating Aircraft
- Testing Hours

This is by no means an exhaustive list of the types of plots a user may desire to create. These were created for TDCAS to illustrate the capabilities of the system. With time as the database is populated, many more plot types can be added. In fact, the A24 team discussed providing the user with the ability to choose the variables and plot types to make the system as dynamic as possible.

This capability was not added because of the need for further population of the database to enable creation of such plots.

Because of the relative lack of data, "ghost" data were used to illustrate different means for visualization.[1] Plots types that are demonstrated are generally bar charts, x-y charts, and box-and-whisker charts. An example bar chart is provided in Figure 4 and an example x-y chart is provided in Figure 5. As indicated in Figure 5, the user can "mouse-over" and interrogate the plots to interactively extract desired information. Moreover, the user can click on the arrow to the right of the titles in these plots to download the associated data in Comma Separated Values (CSV) format.

Figure 4. Example TDCAS bar chart.

[1] The A24 team added a significant amount of data to the system, including complete data sets associated with at least 4 safety cases. However, because of the breadth of the data elements within TDCAS, these data result in only a few points (or less) for many of the data types.

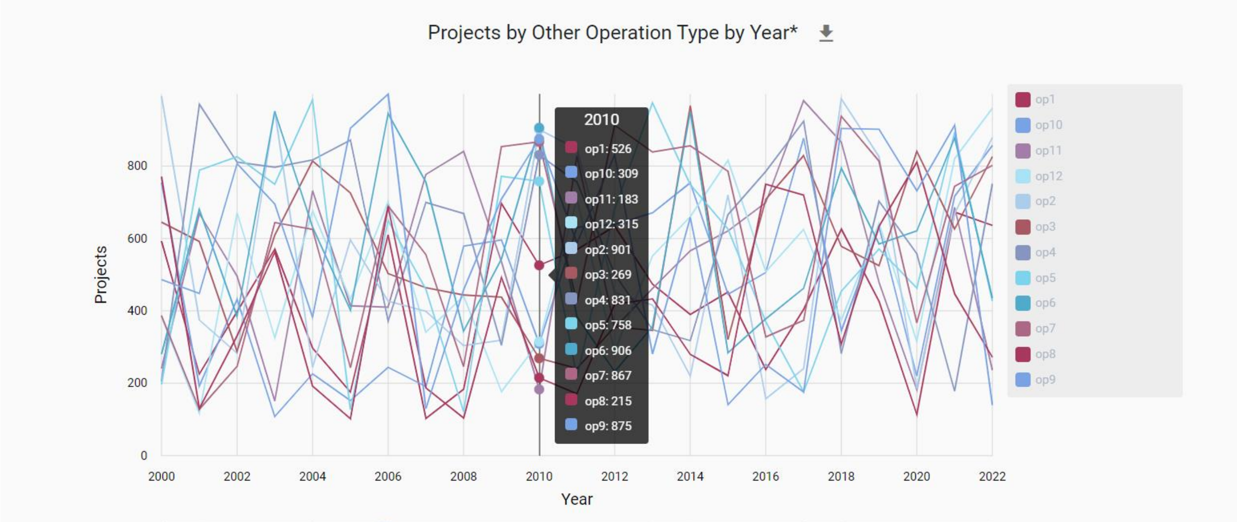

Figure 5. Example TDCAS x-y chart.

As TDCAS evolves, it is expected that additional analysis types and charts will be added. TDCAS was built with this expectation, and enables modification through its design that supports a dynamic and evolving set of needs.

3 TASK 2: EXERCISE SYSTEM USING ADVANCED OPERATIONS

3.1 Objectives

The objective of this task was further population of the TDCAS database (beyond any data provided as part of Task 1).

3.2 Methods

A24 performers from the Northern Plains UAS Test Site, the Alaska Center for UAS Integration, the New Mexico State University UAS Flight Test Site, and MAAP entered data into TDCAS. This process not only enabled further population of the TDCAS database, it also resulted in feedback/questions that were used to enhance TDCAS.

3.3 Summary of Results

Data associated with >10 projects were entered into the system. These data are associated with a variety of projects/safety cases, including BVLOS (DAA, software, etc.).

4 TASK 3: DEVELOP LINKAGE TO INDUSTRY CONSENSUS STANDARDS, OOP NPRM, OTHER RULEMAKING, AND FAA SMS RISK MANAGEMENT GUIDANCE

A separate and more in-depth report for this task is provided by Sugumar et al. (2022).

4.1 Objectives

TDCAS has potential value to the FAA beyond the categorization and presentation of data for research safety cases. It has the potential to link industry consensus standards and impact the methods by which safety case data are collected and presented. In short, TDCAS offers a systematic framework to inform industry approaches building safety cases by leveraging crosscutting data. In doing so, TDCAS offers a pathway to link the usage of industry consensus standards, inform standards development, and influence FAA rulemaking efforts via a procedural approach to gathering, presenting, and analyzing key safety data.

The objective of this task was to explore how TDCAS may link industry standards and FAA rulemaking efforts. This task presented an opportunity to explore questions regarding use cases for TDCAS and identify how TDCAS, as a system, can leverage existing standards to inform safety cases.

Overall, with this task the team analyzed the relationship between standards development and rulemaking, identifying touchpoints where TDCAS could leverage standards to enable data-driven decision making – both for the development of safety cases and to inform them. Figure 6 highlights the relationship between standards and rulemaking for the FAA.

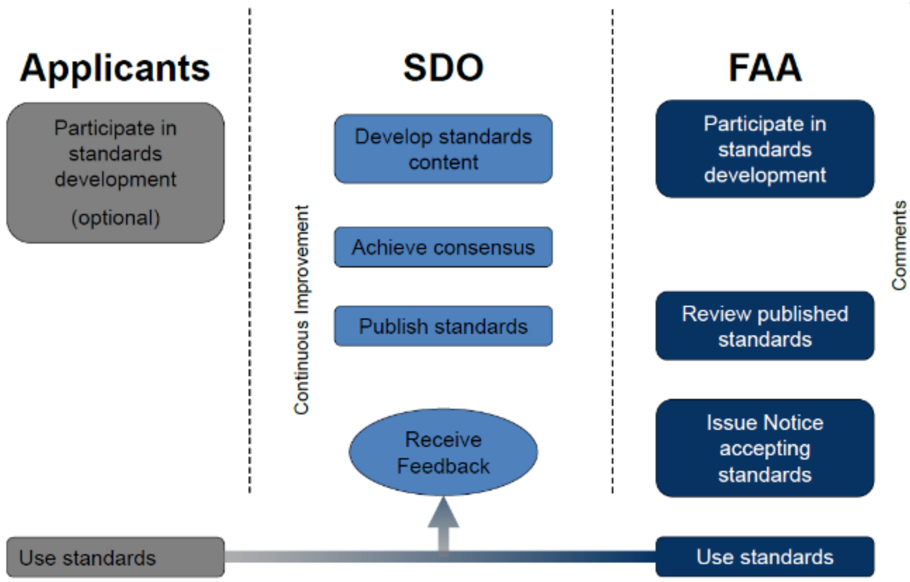

Figure 6. Relationship between standards and rulemaking (Federal Aviation Administration 2018).

Furthermore, the team explored these connections through the lens of Safety Risk Management (SRM), with roots in the FAA's Safety Management Continuum (Figure 7); a continuum that exists between applicants who use standards, Standards Development Organizations (SDOs), and the FAA. This concept views TDCAS as a tool for creating a feedback loop for the use of standards in building safety cases, which, in turn, inform standards and policy.

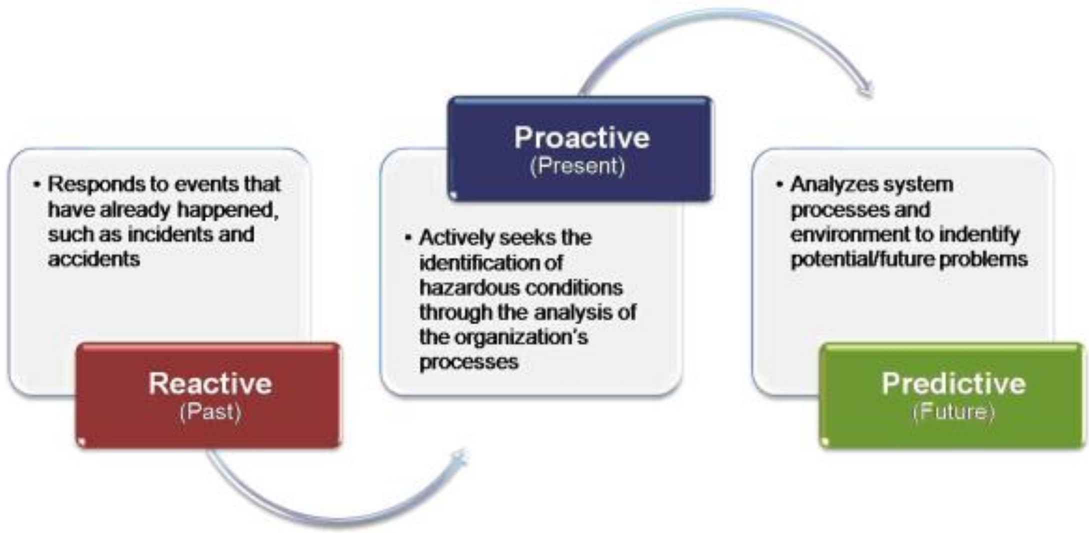

Figure 7. The FAA safety management continuum (Federal Aviation Administration 2021).

The research team's approach to this task evaluated at TDCAS as a potential SRM tool with implications for rulemaking and standards development.

4.2 Methods

The methodology for Task 3 consisted of a literature review to identify the primary conduits through which TDCAS may influence standards and policy. For this task, the research team consulted a wide variety of sourced, ranging from regulations, FAA guidance material, and the American National Standards Institute (ANSI) publication (2020). Through this literature search, the research team identified four key enablers that pointed to a means for TDCAS to facilitate expanded operations, leverage standards, and influence policy:

1. DAA technology,
2. Reliable C2 data and communication link functionality,
3. Overall system reliability and airworthiness, and
4. Remote pilot training and proficiency.

The research team's conceptual approach was based upon the notion that TDCAS offers capability to consolidate data generated using industry standards. Successful waivers built on those safety cases could (1) validate existing standards, (2) identify gaps/needs for new standards, and (3) inform FAA policy based upon precedent. Through this concept, TDCAS intrinsically links the fundamental tenets of SRM by creating a feedback loop based upon successful waivers, safety cases, and data-driven decision making.

4.3 Summary of Results

The development of standards and rulemaking is a parallel process, often with multiple common touchpoints. The FAA often delegates the task of developing or refining standards to SDOs based upon a defined need, often expressed in a Terms of Reference. In this way, SDOs support FAA rulemaking and standardization by working with regulators to develop standards to (1) fill regulatory gaps, or (2) supplement existing regulations in a way that is accessible. TDCAS may support this process by collecting and storing test data that inform the need for new standards and aid in validating existing standards. Furthermore, TDCAS offers the means to collect empirical data from UAS Test Sites, providing the FAA a basis for making decisions on policy and rulemaking, and establishing precedent for such activities.

Regarding DAA, C2, small UAS (sUAS) type certification, and remote pilot training, the research team identified several areas where TDCAS may support standardization and rulemaking efforts. The research team identified a significant standardization gap regarding DAA and DAA testing. A system such as TDCAS could provide a means of collecting data relating to DAA system performance. Similarly, TDCAS could offer an avenue for data collection to inform standards regarding C2 performance and for use in type certification for sUAS. Additionally, TDCAS may provide insight into observable trends related to remote pilot training and proficiency through the collection of remote pilot data as part of safety case development.

TDCAS may support SRM along two primary avenues, providing data to inform Probabilistic Risk Assessment (PRA), and hazard mitigation through Failure Model and Effect Analysis/Failure Model Effects and Criticality Analysis (FMEA/FMECA) by providing data regarding probabilities of occurrence of given hazards. TDCAS supports these by providing the ability to collect and reference test data. These data facilitate the use of predictive, data-driven approaches to risk assessment. Such risk assessment practices may employ the use of Bayesian statistics or neural networks to support PRA and offer predictive solutions for maintaining aviation safety.

5 TASK 4: VALIDATION OF THE TEST DATA COLLECTION AND ANALYSIS SYSTEM (TDCAS)—OPERATIONS OVER PEOPLE PART 107 WAIVER

A separate and more in-depth report for this task is provided by Delano and Wehr (2022).

5.1 Background

The desire for operations that exceed the boundaries of Part 107 (https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107) has been significant, resulting in a growing volume of Part 107 waiver applications. These have been driven by lower barriers to entry in the aviation space, rapid technological innovation, and industry-wide pursuit of scalable and economically viable methods for maximizing the benefits and Return On Investment (ROI) of UAS operations.

To obtain Part 107 waivers, applicants must present a safety case comprised of supporting data and information demonstrating a sufficient level of safety for the proposed operations. Given the broad spectrum of applicants and their use cases, backgrounds, and levels of experience, these safety cases vary greatly in structure, content, and the quality/quantity of data and information presented. This presents challenges to both industry and the FAA.

In many cases industry pursues operational approvals lacking the supporting data and information to obtain them, and the FAA must contend with a multitude of waiver applications that vary in consistency, and in many cases are bereft of the necessary information and supporting data to properly analyze and issue approvals. By providing a safety case framework, TDCAS has potential to augment the waiver process by:

1) Serving industry as a guide to support safety case production, and
2) Assisting the FAA with its review of safety cases by standardizing content, categorization, and presentation.

5.2 Objectives

The objective of this task was to exercise TDCAS and evaluate its effectiveness in its intended role and function (from both applicant and FAA perspectives) by developing a safety case for advanced operations leveraging pre-existing work where applicable, and utilizing the system to submit a safety case to the FAA for review and consideration of appropriate waivers. In parallel, continual observations of the system would be documented to fully understand its effectiveness from an applicant perspective in relation to its intent, purpose, and objectives. Originally, the intent was to obtain a Part 107 OOP waiver through a case study demonstrating acceptable ground collision severity and laceration injury protections. However, the operational focus of the waiver effort shifted during the course of the project due to the FAA's publication of the Operation of Small Unmanned Aircraft Systems Over People final rule in January of 2021. As a result, the focus of the safety case and waiver effort transitioned from OOP to BVLOS operations, and rather than pursuing a waiver to Part 107.39 (Operations Over Human Beings), the objective became pursuit of waivers for Part 107.31 (Visual Line of Sight Aircraft Operation) and 107.33 (Visual Observer).

The full evaluation cycle and determination of system efficacy within the scope of this task and its objectives hinged not just on the front-end applicant portion of the task, but also on the back-end safety case review and waiver decision processes to be conducted by the FAA. Approval/denial of the appropriate waivers and the reasoning behind the decision would give an indication of system viability as well as provide insight into the shortcomings of the system.

However, due to resource constraints, FAA review/analysis of the safety case submitted in TDCAS and a subsequent waiver approval/denial decision was not completed. Therefore, a truncated evaluation cycle was performed that included a front-end evaluation from a system-user perspective.

5.3 Methods

The process in Figure 1 was used as a baseline for safety case development for this task. Previous safety case data were leveraged to generate a BVLOS Concept of Operations (CONOPS) based on an established operational concept known as Extended Visual Line of Sight. An updated Operational Risk Assessment (ORA) was performed that included test data from prior validation efforts. Due to the similarity in CONOPS to previous successful waiver efforts, no mitigations required re-testing. An overall level of safety was assessed, and the safety case was finalized for entry into TDCAS. Concurrent with safety case development, familiarization with the TDCAS was conducted to review the system and to develop a strategy for the most efficient data entry workflow. The safety case framework provided in TDCAS through the system's structure/organization and content was used in conjunction with the process in Figure 1 as both a comparison and a guideline for development.

Personnel tasked with data entry were assigned phases/sections in TDCAS based upon subject matter expertise and experience in the relevant areas. For example, an aviation safety expert was utilized to enter data pertaining to hazards and mitigations derived from the ORA. Each person entering data was responsible for documenting observations that arose during system familiarization and data entry corresponding to their assigned phases/sections. These observations would later be combined to produce the holistic system evaluation (from the system user perspective) established as the primary objective of the task.

Safety case data were then entered into the system with simultaneous documentation of observations and feedback, which was divided into three categories: 1) "User Experience (UX)," 2) "User Interface (UI)," and 3) "System Longevity." In the context of this task and given the nature and purpose of TDCAS, the following descriptions were applied to the categorical nomenclature:

- User eXperience (UX):
    - Ease of TDCAS use for applicant seeking FAA waiver to submit a safety case for advanced operations
    - System navigation instructions
    - Intuitiveness of processes and workflows
    - Quality, quantity, and relevance of guidance provided
    - Ability of system to accommodate a broad spectrum of users/applicants, especially regarding specifics of proposed operations and experience in safety case development
- User Interface (UI):
    - Data entry and presentation of data fields and information
    - Efficiency and logic of processes and workflows (time on task, etc.)
- System Longevity
    - Essentially describes "future proofing" and system flexibility enabling adaptation to the evolving regulatory environment

System Longevity was considered to be TDCAS' ability to support industry development and FAA evaluation of safety cases as the regulatory environment changes and processes evolve without requiring significant/fundamental system modifications.

The research team then conducted an overall assessment from the applicant perspective of the effectiveness of the system in consideration of its intended function and purpose as a tool to support industry safety case production.

5.4 Summary of Results

5.4.1 User eXperience (UX)

5.4.1.1 Results

UX while exercising and evaluating TDCAS was generally positive. The workflow and system navigation were intuitive, and the process was mostly self-explanatory. Guidance, context, explanations, and examples included with the data fields were generally informative and useful, where provided. The data and information requested were relevant and in scope, and the order in which they were presented was logical, serving as a guide and catalyst for system users who may be less experienced in safety case development.

5.4.1.2 Recommendations

The researchers recommend exploring potential improvements to the existing multi-user functionality of the system and providing greater quality and quantity of guidance and data context and examples.

5.4.2 User Interface

5.4.2.1 Results

The UI was fairly intuitive and simplistic, providing a clean interface and clear input-output logic. Given the amount of information, data, and documentation being requested and entered, the design of the UI was found to be overall sufficient and user-friendly.

5.4.2.2 Recommendations

The researchers recommend exploring potential methods for streamlining data entry and developing/implementing methods to condense large data entry requirements; and providing easier methods for both the applicant and the FAA to observe and review data entered.

5.4.3 System Longevity

5.4.3.1 Results

Regarding System Longevity, TDCAS in its current form possesses the needed flexibility, and allows the applicant to include and leverage information and data relevant to demonstrated rules and industry standards. TDCAS has potential value for fusing technical and operational capabilities covered by rule with those requiring waiver/exemption in a combined safety case development and submission construct that simplifies and streamlines the operational analysis and approval process cycle.

5.4.3.2 Recommendations

The primary recommendation is continued collaboration between the Alliance for System Safety of UAS through Research Excellence (ASSURE) research team and the FAA to investigate the potential for introducing further efficiency in TDCAS regarding hybrid safety cases that leverage certified/compliant UAS and associated technologies as part of a waiver effort.

5.4.4 General

Overall, evaluation of TDCAS determined that the system fulfills its intended function as a tool to support industry safety case production. It provides the system user with a framework for safety case development by establishing a baseline set of requested information and data that support solid safety case development and by presenting this content in a structure and order that are conducive to an efficient and effective development cycle. Each entity/individual pursuing operational waivers to Part 107 will likely have unique methods for developing safety cases to demonstrate that they can conduct the proposed operations safely, and the TDCAS provides the flexibility to accommodate for this variance while establishing an ideal baseline set of requested information and details that comprise a solid safety case.

Given the inevitable wide range/spectrum of applicant backgrounds and experience levels, the TDCAS was also observed to serve well as a guide for entities and individuals who might be new to the safety case process, providing them with scope, objectives, an understanding of potential resource needs/requirements, and a baseline for designing a schedule and process by which a safety case can be efficiently developed. It is believed that TDCAS can provide less experienced applicants with a guiding roadmap and informational "how to" for starting the development of a safety case from the ground up, or assist in the augmentation/improvement of previous or current safety case development efforts.

Consequently, despite the truncated evaluation cycle that excluded FAA safety case content analysis and waiver decision, the research team believes a fully-developed version of TDCAS will help streamline the safety case development and review processes conducted by industry and the FAA, respectively, and assist with acceleration of UAS integration into the NAS.

6 CONCLUSIONS

6.1 Answers to Scoping Questions

The A24 team developed answers to the project scoping questions presented in the Introduction. They are:

1. Who is best suited to be an applicant for a waiver or exemption and why? Should it be the UAS manufacturer or the individual using the UAS?

    It could be either depending on the situation. For broad use/sharing of the waiver capability, a UAS manufacturer acquiring the waiver could be helpful. For more challenging situations, the operator should request the waiver.

2. How can prior testing on a vehicle which led to successful waiver/exemption be used in future applications?

    It seems that the ability/permission to share test results should reside with the entities that performed the testing. Some may not want to share as they invested significant resources (time, money, etc.) to execute the tests. Others may want to share (e.g., a manufacturer) because doing so is advantageous (e.g., enables selling a product). Such information can be utilized to enhance safety.

3. Can an applicant with a full review of a previously successful waiver use that information for their application?

    It seems that the answer is "yes" if they are allowed to access that information.

4. Can prior testing on a vehicle which led to successful waiver/exemption be used or referenced by an applicant without any visibility or review by the applicant?

    Yes, although it seems that for an applicant to properly leverage those previous results, assuming they have permission to access them, they would need to review the results. The context of the results likely matters a great deal with regards to how they relate to whatever waiver the applicant is pursuing.

5. Should the FAA develop a list and publish the list of approved vehicles for waiver/exemptions? If yes, what additional requirements should the applicant have, i.e., operating procedures, maintenance procedures, etc.?

    Yes, if those who obtained the waivers/exemptions allow this. All CONOPS information relative to the aircraft should be provided (operating limitations, etc.). Likely the development of durability & reliability process supersedes this.

6. Could an applicant cite another waiver's tests without seeing or reviewing the data? Could an applicant buy an off the shelf drone and apply for a waiver without seeing the test results?

    The first question is closely aligned with 4. The team expects that the applicant would need to understand those test results to put them in context with respect to the current application. The answer to the second question is a tentative "yes". However, the operator would need to understand the operational limitations.

7. How can safety cases for Part 107 waivers be improved?

   This is addressed throughout the team's A19 and A24 reports.

6.2 Future Work

Numerous future work opportunities were identified while executive this project. They include:

- Enhancing the data collection system, including:
  - Enabling searching of unstructured text, which supports safety case evaluation.
  - Modifying input field limitations (e.g., increasing the character limit for Text Input) as needed.
  - Establishing a notification system such that stakeholders are alerted regarding safety case status changes.
  - Further analyzing data elements associated with degradations and updating the system.
  - Further analyzing the structure of the risk assessment component and updating (e.g., provide a more detailed break-out for hazards) as appropriate.
- Providing the user with the ability to choose variables and plot types to make the analysis system as dynamic as possible.

6.3 Summary

This project focused on development of a data collection and analysis system, the Test Data Collection and Analysis System (TDCAS), that enables evaluation of safety cases and identification of research needs. As such, it provides a framework that helps ensure that users provide the proper information required to build a valid safety case. In doing so, TDCAS has the potential to not only improve outcomes for those submitting safety cases, but also for the FAA personnel who have to review safety cases. The TDCAS analysis component also provides a framework for identifying research needs by enabling visualization of test results and identification of areas requiring additional focus.

The TDCAS was developed and evaluated through execution of 5 tasks:

1. Initial Build of the TDCAS
2. Exercise System using Advanced Operations
3. Develop Linkage to Industry Consensus Standards, Operations Over People (OOP) Notice of Proposed RuleMaking (NPRM), Other Rulemaking, and FAA Safety Management System) SMS Risk Management Guidance
4. Validation of the TDCAS—Operations Over People Part 107 Waiver
5. Final Report/Project Closeout

Given the variety of tasks, multiple methods were applied to execute them. These include review of previously developed material/literature (Tasks 1 and 3), coding/software development (Task 1), data entry (Tasks 3 and 4), and revision based upon user feedback (Tasks 1, 2, and 4).

Results for Tasks 3 and 4 are provided in separate reports. The interested reader is directed to those for a detailed description of results (citations are provided in the respective sections of this report). A high-level summary of results is provided herein.

TDCAS was built with two primary functions: data collection and data analysis. The system was built using JavaScript, which enabled development of a web-based interface that affords easy access for users. Data are stored in an SQL database to enable structured data handling and convenient data queries. The data collection system was built following the design of Askelson et al. (2020), with significant additions to the system enabling collection of test summary and degradations data. Test summary data collection was added to support quantitative analysis of results and degradation data collection was added to enable identification and prevention of future incidents and accidents.

The TDCAS analysis component was also developed in JavaScript, with extensive leveraging of Angular, which greatly enables generation of multiple types of plots/visualizations. Numerous built-in reports are provided, with multiple visualizations for each type. Moreover, some visualizations enable user interrogation of data, and data from each plot can be easily downloaded to enable further data examination. As TDCAS continues to evolve, additional reports/capabilities can be added.

Data were entered into TDCAS for > 10 projects/safety cases. These data are associated with a variety of projects/safety cases, including BVLOS. Data entry resulted in useful feedback for software developers, which resulted in TDCAS improvements/enhancements.

Linkages to standards, rulemaking, and SMS were examined in Task 3. TDCAS can support standards and rulemaking efforts by collecting and storing test data that inform the need for new standards and aid in validating existing standards. TDCAS offers the means to collect empirical data from UAS Test Sites, providing the FAA a basis for making decisions on policy and rulemaking, and establishing precedent for such activities.

TDCAS may support SMS along two primary avenues, providing data to inform PRA, and hazard mitigation through Failure Model and Effect Analysis/Failure Model Effects and Criticality Analysis (FMEA/FMECA) by providing data regarding probabilities of occurrence of given hazards. TDCAS offers the ability to collect and reference test data. These data facilitate the use of predictive, data-driven approaches to risk assessment. Such risk assessment practices may employ the use of Bayesian statistics or neural networks to support PRA and offer predictive solutions for maintaining aviation safety.

Validation of TDCAS (Task 4) was accomplished after a change of emphasis away from OOP towards BVLOS owing to the OOP rule issued by the FAA during execution of this effort. While an FAA adjudication of the waiver compiled in TDCAS was not possible, this task did enable the team to provide a detailed evaluation of TDCAS. This evaluation considered User eXperience (UX), User Interface (UI), and System Longevity. The team concluded that TDCAS performs well in all areas, providing UX and UI and are intuitive and user-friendly. Moreover, the flexibility of TDCAS and its value for fusing technical and operational capabilities in a combined safety case construct that simplifies and streamlines the submission and approval cycle drives its potential for System Longevity.

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