NormSTAD Flight Analysis: Visualizing Air Traffic Patterns over the United States

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ABSTRACT

In this paper, we describe the NormSTAD Flight Analysis Tool, a novel interactive visualization application of air traffic patterns using Aircraft Situations Display to Industry (ASDI) data. A web-based visualization is demonstrated which allows users to analyze flight data and make discoveries pertaining to their 4D trajectories which include their time, distance, altitude, and speed. Unique patterns discovered in this application could result in less fuel consumption and more efficient management of departure and arrivals by air traffic controllers.

The application consumes ASDI data then normalizes flight attributes including distance, speed, altitude, and time along the flight path. This information is then displayed on a line chart which can be customized through filtering, coloring and selection. Attributes pertaining to selected flights can be viewed in a details on demand fashion. The result is a both intuitive and visually appealling visualization with the goals of revealing flight paths, spotting trends and revealing outliers.

Categories and Subject Descriptors

H.3.3 [**Information Storage and Retrieval**]: Information Search and Retrieval—*Information filtering*;
H.3.5 [**Information Storage and Retrieval**]: Online Information Services—*Web-based services*;
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces

General Terms

Design, Human Factors, Performance

1. INTRODUCTION

The National Airspace System (NAS) is a complex nondeterministic system that is impacted continually by both major and minor variables including aircraft delays and human decisions that largely cannot be accurately forecasted. The system has developed to offer feedback and response at all levels from gate agents to the Command Center with the intent of restoring the desired efficient state. The result is a self-ordering system that is broadly similar, but has different daily operations. An important point to note is that a seemingly insignificant event such as a delay in obtaining a wheel chair can have large impacts in delays as *slots* are missed and reassigned. At every stage decisions are being made to recover the system and keep it as close to optimal given its current state. However, there is currently no method of quantifying the effects of a decision or comparing them to an alternate decision. NAS operations are recorded concurrently across different systems in different formats. If this information was collated and catalogued, it would be possible to analyze the NAS operations to identify inefficiencies, disruptive events and poor decisions along with the resulting impacts on airspace users.

In 1992 the Federal Aviation Administration (FAA), started a program to provide real-time flight plan and track information for the NAS to airlines and other oganizations. The feed known as Aircraft Situation Display to Industry (ASDI) is a product of the Enhanced Traffic Management System (ETMS). It originates from the Traffic Flow Management (TFM) Production Center located at the William J. Hughes Technical Center in Atlantic City, New Jersey. Figure 1a shows the number of ASDI messages for a single random day while Figure 1b shows the number of supporting records for the main message set. As can be by Figure 1, tens of millions of ASDI messages are recorded each day.

A novel visualization system is needed to aggregate this data in order for users to detect anomalies and discover unique patterns. To be able to compare flights of varying distance or time, the data values are normalized to create a standardized display of time series allowing direct comparison between flights.

The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 explains the ASDI data and its attributes. Section 4 describes the overall architecture and the interface is described in Section 5. Section 6 provides the expert reviews and feedbacks of the implementation. Section 7 discusses future work, while our conclusions are outlined in Section 8.

2. RELATED WORK

There has been a great amount of research in flight data pertaining to algorithms for optimal trajectories, anomaly detection and conflict resolution [8, 9, 12, 17, 20, 21]. Liu et al. [17] studied departure and arrival delays and how these

Message	Total Messages
Arrival Information	46,000
Boundary Crossing Update	84,000
Departure Information	54,000
Flight Management Information	522,000
Flight Plan Amendment	303,000
Flight Plan Cancellation	121,000
Flight Plan	120,000
Oceanic Report	9,000
Track Information	6,259,000
Total Messages	**7,518,000**

(a)

Supporting Record	Total Records
Aircraft Spec	558,000
Airways	1,732,000
Centers	1,692,000
Computer Id	5,551,000
Fixes	6,200,000
Oceanic Planned Position	18,000
Oceanic Reported Position	9,000
Qualified Aircraft Id	532,000
Route Of Flight	721,000
Sectors	1,773,000
Waypoints	7,667,000
Total Messages	**26,413,000**

(b)

Figure 1: (a) Table displaying the number of ASDI messages in a given day (b) Table displaying the number of supporting records for main ASDI message set

delays can propagate to future flight delays and cancellations. Our system instead focuses on in-air flight data to help study why these delays may be happening with respect to time of day, flight number, airline or flight trajectory. Chu et al. [12] had a similar approach to NormSTAD in that they attempted to detect anomalies in aircraft cruise data by using time, location, altitude and speed. They also normalized their data as was done in the NormSTAD tool. However, the NormSTAD tool utilizes historical data while their system studied the results of a simulation. While the study of such algorithms for detection of anomalies and conflict resolution is vitally important to the field of aviation, the goal of the NormSTAD Flight Analysis Tool is to allow easy and timely analysis of large amounts of flight data without the need for such algorithms.

Landry [16] and Khoury et al. [14] stress the importance of informative visualizations for the study of air traffic control systems. Landry reviewed and analyzed the current air traffic control system which has evolved around the air traffic controller and pilots while not updating to the increasing air traffic. Landry states that the current visualizations may not concisely display the operator with the necessary information. Khoury et al. focus their attention on construction of a 3D model of only airport operations. Their analysis of delays is limited in that they do not include flight sensory data in their analysis.

Many other researchers have created flight data visualizations [11, 13, 15, 18, 19]. Hurter et al. [13] designed a metro style visualization for flight paths in the Air Traffic Control context in order to avoid severe overlaps of the lines along with a complete method to produce an efficient layout. This visualization is clear and visually appealing, but fails to inform the user of differences in flight paths since it does not use the actual latitude and longitude coordinates of the flight. The AIRNET platform by Pestana et al. [19] provides a 3D model for surveillance, control, guidance and decision support services by airport operators. The NormSTAD tool avoids 3D visualization to reduce complexity by allowing the axes to be changed by the user.

After reviewing the current state-of-the-art of flight visualizations, we decided to follow Wehrend's ideas [22]. Wehrend believes that visualizations should break problems into smaller problems and find applicable techniques for each of these smaller problems. The visualization is then a unified representation of the smaller problems in order to solve larger problems. It is with this belief that the NormSTAD Flight Analysis Tool was based and designed using four connected view panels for information display and interaction. The Filters panel allows for data filtering which is separated from our data visualization and selection Line Chart. Details on demand are displayed in two separate panels, the Map and Details on Demand panel. Using this application, airline operators will be able to better determine flight plans, discover holding and slow-down patterns caused by disruptive events, consume less fuel and save time, money and the environment in the process.

3. ASDI DATA

In this section, we introduce ASDI data and its attributes. In addition, we describe the data normalization process that NormSTAD uses.

The ASDI subsystem of the Traffic Flow Management System (TFMS) [7] allows near real-time air traffic data to be disseminated to members of the aviation industry. The data stream is made available through the U.S. Department of Transportation's Volpe Transportation Center. The data stream consists of data elements which show the position and flight plans of all aircrafts in the United States. Attributes include the location, altitude, airspeed, destination, estimated time of arrival and tail number or designated identifier of air carrier and general aviation aircraft operating on IFR flight plans within the United States airspace.

Due to the limitations in the web tools employed by NormSTAD, only a subset of the historical ASDI data was used. The data set included Delta Airlines' and Delta Connection, Atlantic Southeast Airlines' flights departing from Seattle Tacoma Airport (KSEA) for the duration of July and August 2012.

Flights pertaining to Delta Airlines consisted of the following flight numbers:

- DAL842, departing from Seattle Tacoma and arriving at New York JFK
- DAL1043, departing from Seattle Tacoma and arriving at New York JFK Airport
- DAL2410, departing from Seattle Tacoma and arriving at Detroit Metropolitan Wayne County Airport

Flights pertaining to Delta Connection, Atlantic Southeast Airlines consisted of the following flight numbers:

- ASA24, departing from Seattle Tacoma and arriving at Boston Logan International Airport

- ASA678, departing from Seattle Tacoma and arriving at Denver International Airport

The dataset was generated by merging a subset of various message types including:

- Departure Information
- Track Information
- Flight Management Information

The process yielded the following fields:

- Source Date
- Source Time
- Aircraft Id
- Speed
- Altitude
- Latitude
- Longitude

In addition, certain values were normalized so that various flights or time series of different flights could be overlaid on the same line chart. Normalized values for interactive visualization included:

- Altitude
- Speed
- Distance
- Planned Flight Time
- Actual Flight Time

Normalized values range between 0 and 1 where 0 denotes the minimum possible for a given value (i.e. the departure airport in the case of distance) and 1 denotes the maximum possible for a given value (i.e. the arrival airport in the case of distance) for all values with the exception that Actual Flight Time may exceed 1 or be below 1 due to the fact that it does not correspond exactly to the Planned Flight Time.

4. IMPLEMENTATION

The NormSTAD Flight Analysis Tool is a web-based implementation which is primarily built using the D3 JavaScript library. D3, which stands for Data-Driven Documents, is a library that allows users to bind arbitrary data with a Document Object Model (DOM) and achieve data-driven transformations [1]. NormSTAD utilizes a predefined API of D3 to import our data from a local file and store the normalized values of time, distance, speed and altitude for each flight. Flight information including flight number, airline and date are also imported using D3. After the data is finished being imported, the filters are dynamically created.

All filters in the Filters section are created using HTML syntax and JavaScript apart from the input text bar to search for a specific flight which is created using jQuery [4]. Filters to select airlines and flights are bound to the imported data using D3 so that they can update the visualization accordingly. Filters to select the date of flights are created using the DHTMLX [2] JavaScript library.

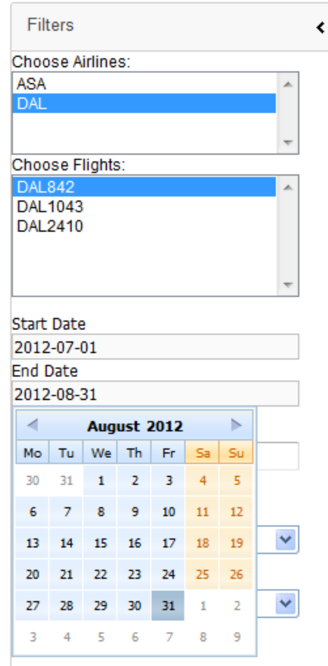


Figure 2: Filters of NormSTAD Flight Analysis Tool's interface where date selection text box displays a calendar allowing users to select a date.

Drop down menus for choosing the line chart type and color and the checkbox for map display are implemented in JavaScript with events handled in D3 to link filters with the line chart. The NVD3 [6] JavaScript library is used for the line chart, horizontal axis selection and the legend. The Google Maps JavaScript API [3] provides our flight path map, airport markers and flight path drawing. The Details on Demand panel is a dynamic HTML table which changes as a result of selection in the line chart.

5. USER INTERFACE

The NormSTAD Flight Analysis user interface initially shows four panels of display as seen in Figure 5a labeled Filters, Line Chart, Map and Details on Demand. Each panel allows for direct interaction or display of the data and can be minimized to give more room to the other panels by selecting the arrow in the upper right corner of the specific panel. In the following sub sections, we will introduce each panel to give readers a better sense of the functionality of the NormSTAD Flight Analysis Tool.

5.1 Filters

On the left-side of the tool, there is a Filters panel which allows the user to limited the results taht they see on the Line Chart. The first section, "Choose Airlines", is for selection of airlines to display in the Line Chart which is set to all airlines by default after the data is loaded. Upon selection of an airline, the Line Chat is updated accordingly and the "Choose Flights" section is populated with all flights for the selected airline(s). Note that a user can select multiple adjacent rows for both the Choose Airlines and the Choose Flights sections by holding the Shift key and selecting rows or multiple rows by holding the Control key (Apple key on

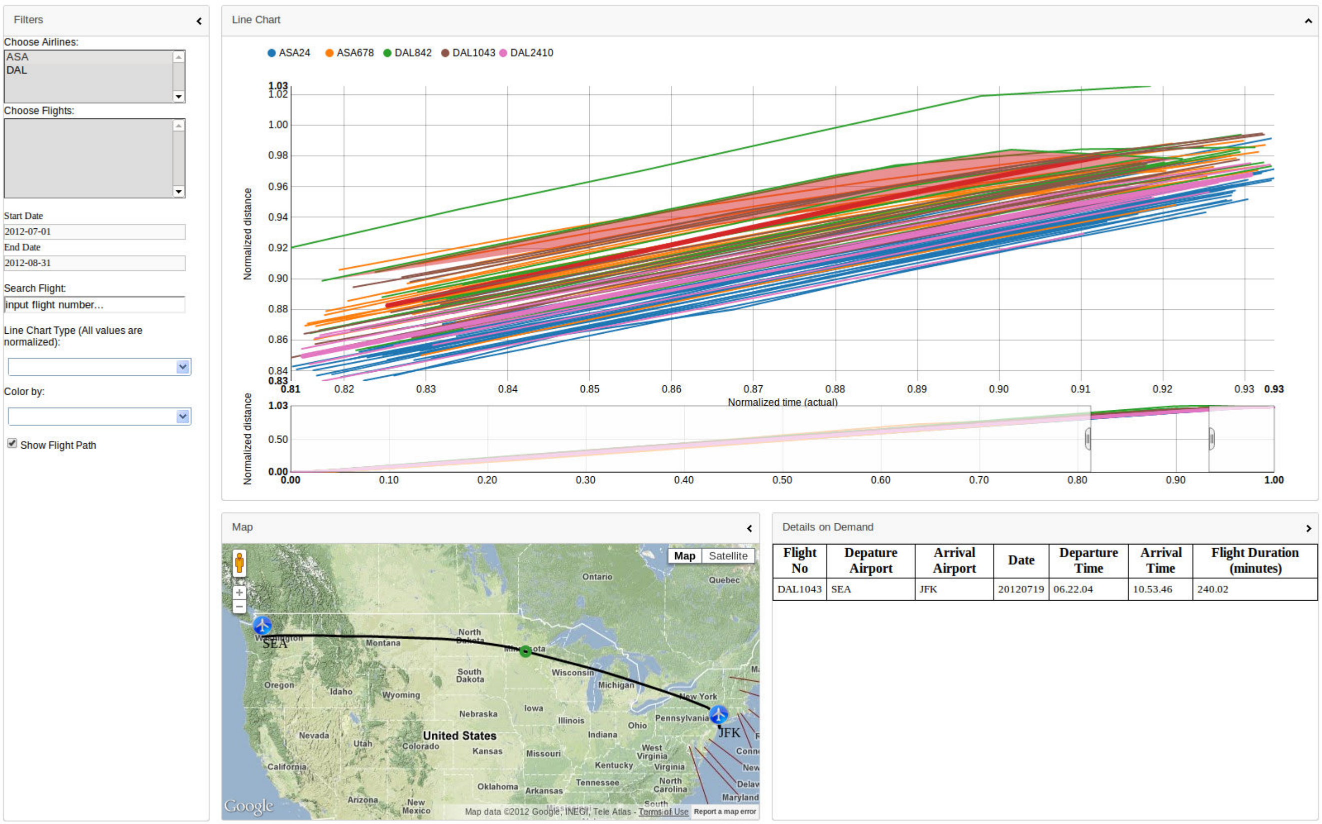


Figure 3: NormSTAD Flight Analysis Tool's interface showing Normalized Actual Flight Time for the range from 0.81 to 0.93 with respect to Normalized Distance. One flight is selected (red line) with its corresponding path shown on the map and details in Details on Demand.

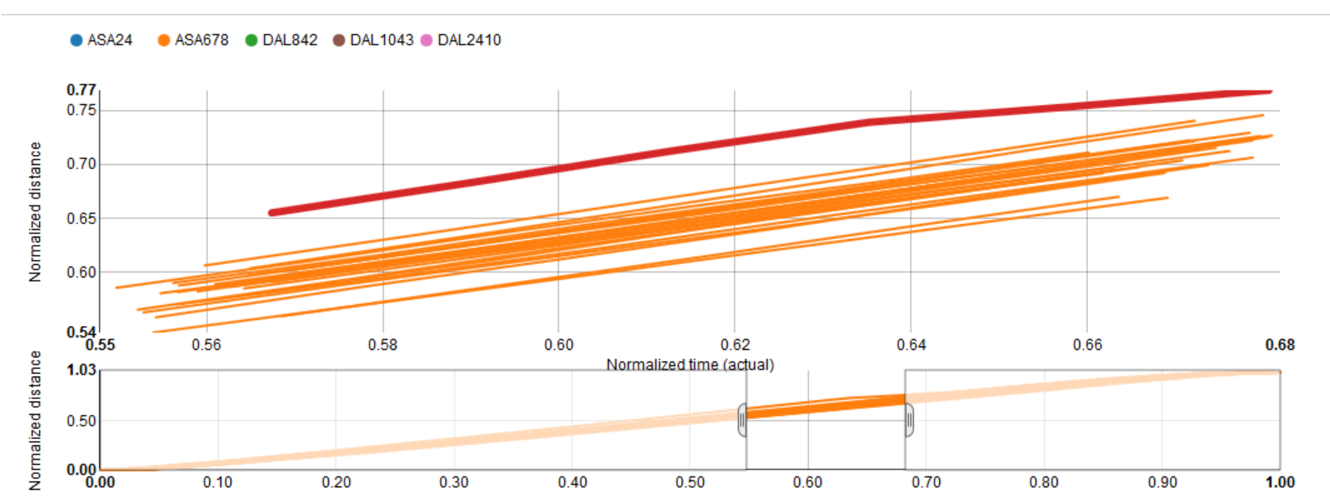
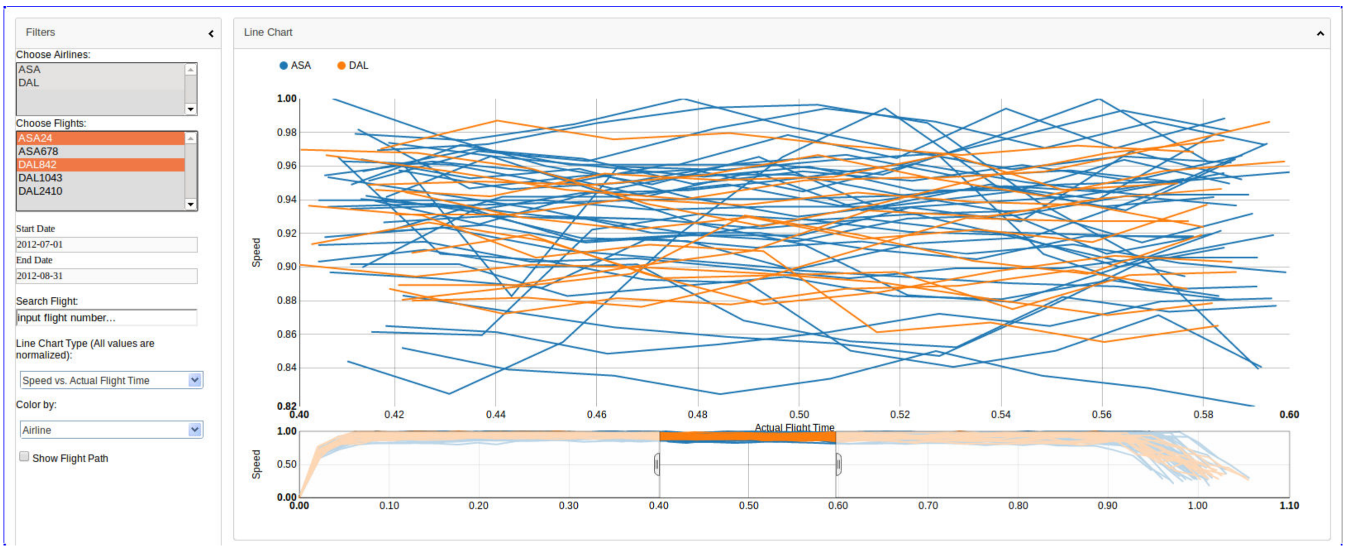
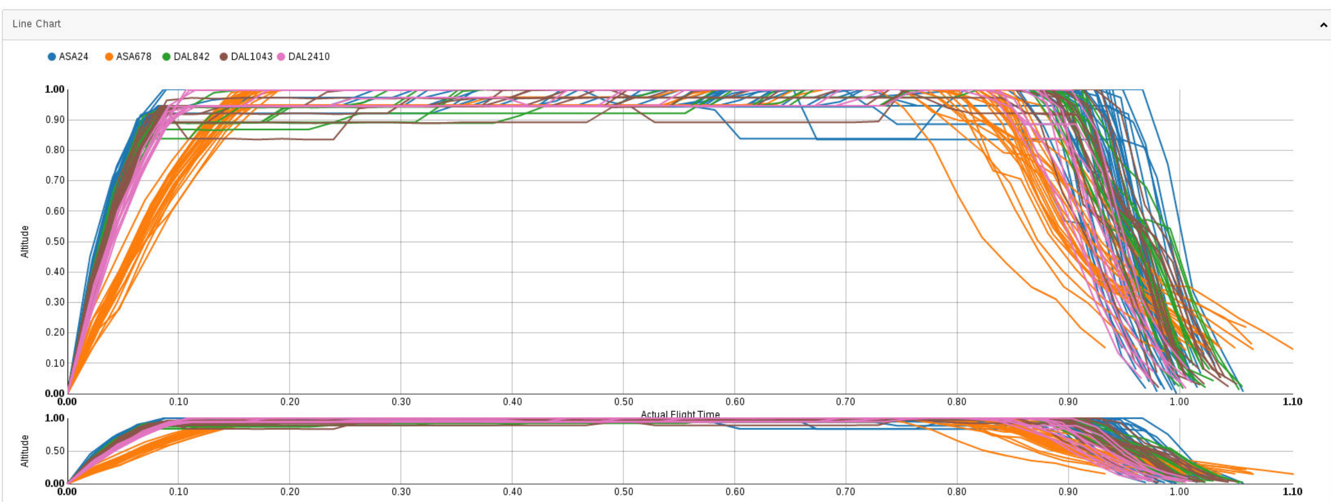


Figure 4



(a)



(b)

Figure 5: (a) Filtering to display only the Normalized Speed vs. the Normalized Actual Flight Time for the range from 0.4 to 0.6 along the horizontal axis for flights ASA24 and DAL842. Flights are colored by airline. (b) Displaying Normalized Altitude vs. the Normalized Actual Flight Time colored by flight number.

Apple computers) and selecting rows as seen in Figure 5a. Selection of row(s) in the Choose Flights section allows for updating of the Line Chart by the flight number. The flights can be further filtered by limiting the flight date using the "Start Date" and "End Date" drop-down calendar menus. The Start Date refers to the departure date of a flight while the End Date refers to the arrival date of a flight. As shown in Figure 2, a calendar is popluated after a user clicks the text box. Users can then easily select two dates to filter the date range of flights to show in the Line Chart. Below the date selector, there is a search bar which allows specific flights to be shown.

Apart from filters to control the flights shown in the Line Chart, NormSTAD also allows changing of the attributes displayed and the color of the lines in the Line Chart. The "Line Chart Type" value changes the axes and updates the normalized data displayed. By default, this value is set to "Distance vs. Actual Flight Time", but it can be changed to "Distance vs. Planned Flight Time", "Altitude vs. Actual Flight Time", or "Speed vs. Actual Flight Time". The line can be colored by their airline or by their flight number using the "Color by" drop-down menu. After changining the color, the legend above the Line Chart updates with the new color scheme. In Figure 5a, we show "Speed vs. Actual Flight Time" colored by airline and in Figure 5b we show "Altitude vs. Actual Flight Time" Line Chart colored by flight number.

5.2 Line Chart

The top center of the browser is occupied by the Line Chart which provides a graphical visualization for different attributes. When the application is first opened, the Line Chart panel of NormSTAD presents two graphs with all flights displayed for the loaded dataset. In implementing the Line Chart, we encountered a noticeable issue in that lines are often close together and hard to distinguish. It is almost impossible for users to find any useful insights given such crowded lines. To combat this issue, we introduce an additional graph below the main Line Chart allowing for selection of a range of the horizontal axis. By selecting a range along the horizontal axis, the coordinate system of the top graph is redrawn to have only values contained within the selected subset creating a zoom-in effect. This range can be expanded or contracted and even moved by clicking, holding, and dragging the range window. A mouse hover on a line turns the line thicker then a mouse click turns the line read making it easier to see. Another click on the selected line changes the line into its original color (airline color or flight color depending on which mode is currently selected).

We note that it is easy to find abnormal patterns or outliers using the normalized Line Chart. We present an example in

6. EXPERT REVIEWS AND FEEDBACK

In this section, we present the experts' reviews and feedback of the NormSTAD Flight Analysis Tool. Due to the niche nature of our subject matter, Air Traffic Management, we decided that an expert review aided by a questionnaire would be the best way to get detailed information pertaining to the NormSTAD tool. Three subject-matter experts were selected to be reviewers. Of these three subject-matter experts, one was from academia with research interest in flight data analysis and two were from industry.

We began by giving a brief introduction and twenty-minute tutorial of the NormSTAD Flight Analysis Tool which was followed by ten minutes where the expert was allowed to interact with the tool on their own. Following the training and interaction, the experts were each given three specific tasks to complete. During this process, we encouraged the experts to "think-aloud" and recorded their thought process. The goal of this step was to determine if the NormSTAD tool met the experts' expectation and to use their responses in order to make the tool more intuitive and interactive. Upon completion of the tasks, the experts were given a questionnaire modelled after Chin et al. [10] and the NASA ARC Project [5] in which they were asked to rate the tool from various perspectives including its capabilities, terminology, graphical user interface, learning, and overall reaction. The experts were also alloted space to record their feedback and comments in open-ended text forms.

Based on the feedback that we received in the questionnaires, the following changes were made NormSTAD tool as a direct result of the comments listed below:

Comment: The tool displayed an unnessary amount of detailed information in the Details on Demand panel

Solution: Only summary information is now displayed in a stack view

Comment: Limited selection of data representation in the line chart

Solution: Added three additional modes to display different sets of data on the line chart

Comment: Terminology was unclear or repetitive

Solution: Terminology was changed to clarify and shorten labels. For example "Normalized Estimated Time" was replaced with "Planned Flight Time" and a note was added to inform the user that all values were normalized

Comment: Would like to be able to use multi-select using the Control key

Solution: Added multi-select for the Control and Shift keys

Comment: Unclear color-coding of line chart

Solution: Legend with color codes added to line chart

Comment: Hard to see which lines were selected as they were just larger, but stayed same color

Solution: Lines are now enlarged and changed to red on selection.

The NormSTAD Flight Analysis Tool still has room for improvement with the help of more expert reviewers. Appendix A includes a copy of the questionnaire that was given to each of our expert reviewers.

7. FUTURE WORK

Throughout the design, development and review process a few features were brought to our attention that did not end up being in the current version of NormSTAD. A limitation that we were not able to incorporate in our data was in displaying all sensory data that we have for a given flight without sampling. While this was our initial intention, we quickly realized that this reduced the usability of our tool by making it much slower to update. We plan to utilize faster algorithms and load the data as necessary in order to give more accurate data points. We also plan to extend the data displayed beyond flight sensory data. In the current NormSTAD tool, we only display flight sensory data which is in-air data, but we plan to add information from departure gate to arrival gate to show the entire flight.

8. CONCLUSION

This paper demonstrated the NormSTAD Flight Analysis Tool for analysis of flight data with respect to normalized actual flight time, normalized planned flight time, normalized altitude, and normalized speed in an interactive line chart. Filtering can be applied to the visualization without data manipulation via simple selection. Selection of lines in the line chart allow for the flight trajectory to be overlaid on a map and displaying of flight summary information.

By using our tool, it is our belief that researchers and those in the aviation field will be able to design better flight plans and discover problem flights from by viewing holding or slow-down patterns in an intuitive interactive visualization. As a result of these potential findings by our users, savings in time and money could be seen as efficiency is increased and fuel consumption is decreased. While future features would benefit the NormSTAD Flight Analysis Tool as outlined in Section 7, it is already ready for deployment after undergoing extensive analysis from our expert reviewers and testing from the developers.

For a demonstration of the NormSTAD Flight Analysis Tool, please see the video located at http://goo.gl/ZXLyz.

9. ACKNOWLEDGEMENTS

We would like to thank all of the participants who helped us evaluate alpha and beta versions of the tool. We were able to make improvements based on their expert reviews, and feedback. We would especially like to thank Professor Michael Ball of the Smith School of Business at the University of Maryland at College Park for his valuable guidance on determining a niche area in air traffic control and management to work on and overcoming issues pertaining to design and implementation of the NormSTAD Flight Analysis Tool. We would also like to thank Professor Ben Shneiderman for his advice that motivated us and kept us focused along the way.

10. CREDITS

Samet Ayhan Flight data finder, parser, analyzer and stored it in a data structure. Found and setup appointments for our expert reviewers. Helped with design of the interface. In charge of expert reviews and relaying feedback to others. Wrote Abstract, Introduction, Related Work, ASDI Data, and the Expert Reviews and Feedback sections along with supplying both of the tables for this paper. Wrote the manuscript for the video demonstration.

Brendan Fruin Helped with the design of the interface. Implementation of the line chart with horizontal range selection and the updating of the map to display the flight path. NormSTAD tool tester for all panels. Wrote Related Work, Interface, Future Work, and Conclusion along with supplying both of the interface figure for this paper. Editor and formatter for this paper. Narrator for the video demonstration.

Fan Yang Helped with the design of the interface and choosing of tools to use for implementation. Implementation of the filters and the details on demand panels. Extensive work done in the line chart selection functionality and work done in flight path display in the map. NormSTAD tool tester for all panels. Wrote the Architecture section for this paper and was the recorder for the video demonstration.

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