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An Experimental Evaluation of Weather Avoidance using Route Optimization as a Decision Aid

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***Abstract*--This paper describes an experimental plan for the summative evaluation of the AWIN decision support tool in an airline dispatch setting. The evaluation will assess if there are gains in (1) safety, (2) fuel efficiency, and (3) time efficiency when dispatchers must select routes for flights in the face of significant weather that impacts the initial, fuel-optimal route (calculated without consideration of weather intersection). Therefore the experiment will assess route dispatching subject to significant weather in two conditions utilizing the AWIN decision-aid: (1) Concept-A (integrated weather and auto-generated optimized route capabilities), and (2) Concept-B (modify route capability). During days with significant weather, it is the duty of the dispatcher to pull information from multiple, independent weather sources, and to integrate that information with the route planning results to assess the impact of weather on the flights that they are dispatching. Typically an airline will have a pre-defined set of "company routes" and dispatchers select the first company route that avoids weather, with little consideration for fuel or time optimality. In addition, weather avoidance criteria can differ from dispatcher to dispatcher, resulting in different outcomes and safety margins. The proposed paradigm shift to a free-flight environment offers an opportunity to better optimize flight routes when avoiding hazardous weather. The AWIN tool is a decision aide for selecting minimum fuel, optimal, 4-dimensional routes that avoid weather and other hazards. The software will plan a route that is not only optimal for forecast winds and temperatures aloft, but also avoids weather and other hazards. The challenges lie in effectively integrating route and weather information in the same application to facilitate decision-making. In addition, standardizing the definitions of what weather is to be avoided and the thresholds of severity across an airline's dispatchers will lead to more consistent and accountable outcomes.**

Keywords: **Decision-support, route optimization, airline dispatch**

I. INTRODUCTION

Airline dispatchers are the focal point of the System Operations Center's (SOC) mission of flight and schedule management. Dispatchers share operational control of every flight with the Pilot-In-Command (PIC). As such, the dispatchers are responsible for release of the flight, forwarding weather briefings, coordinating operating plans, and providing operational status feedback to the pilot. During days with significant weather, dispatchers look at multiple information sources to determine the impact on the flights that they are dispatching. It is the duty of the dispatcher to pull information from multiple, often independent weather sources, and to integrate that information with the computer-generated route planning results. In bad weather days, when the optimal fuel route (calculated without taking into account weather) intersects hazardous weather, dispatchers need to choose a different route that avoids weather. Typically an airline will have a pre-defined set of "company routes" and the dispatcher will select the first company route that avoids weather, with little consideration for fuel or time optimality. Weather information is not typically integrated into the route visualization and the dispatcher must make routing decisions while looking across multiple screens and applications. In addition, weather avoidance criteria can differ from dispatcher to dispatcher, resulting in different outcomes and safety margins.

The proposed paradigm shift to a free-flight environment offers an opportunity to better optimize flight routes when avoiding hazardous weather. The challenges lie in effectively integrating route and weather information in the same application to facilitate decision-making. In addition, standardizing the definitions of what weather is to be avoided and the thresholds of severity across an airline's dispatchers will lead to more consistent and accountable outcomes. The AWIN tool is a decision aide for selecting minimum fuel, optimal, 4-dimensional routes that avoid weather and other hazards. The software will plan a route that is not only optimal for forecast winds and temperatures aloft, but also avoids weather and other hazards. Integration of weather and routing information allows for the calculation of fuel-optimal routes that avoid hazardous weather. With such a system in place, airlines can expect gains in safety, in fuel efficiency of planned routes, and in time efficiency in the pre-flight dispatch process.

The purpose of the empirical experiment described in this paper is to assess safety and efficiency gains associated with the introduction of the AWIN tool. The next section will describe the AWIN tool. Section III will describe the experimental procedure used to empirically evaluate the tool in a realistic operations setting. Finally, section IV will discuss expected results.

II. BACKGROUND

A. Current Practice

At many major airlines, dispatchers determine a flight's route by picking from a family of pre-defined "company routes." It is possible for a dispatcher to build a new route (usually for weather avoidance), but typically a specialist within the SOC will be called upon to build the route, and often that route will be added to the family of company routes. On heavy convective weather days, Air Traffic Control (ATC) tells dispatchers how to fly between city-pair (playbook routes), depending on what sectors are impacted (East vs. West). Typically, when significant weather impacts the initial planned route, dispatchers will be satisfied with any company route that goes around the hazards, regardless of the route's fuel inefficiency.

During days with significant weather, dispatchers look at multiple information sources to determine the impact on the flights that they are dispatching. Especially during thunderstorm season, dispatchers watch the weather constantly, and may have three or four radar sources on their workstation at once. Typically, the dispatcher will look at the weather at the origin and destination airports, to determine if takeoff and destination alternates are called for. If so, then the dispatcher will also check the weather at all or some of the potential alternate airports around the destination airport. Then the dispatcher will look at AIRMETs (Airman's Meteorological Information) for turbulence, SIGMETs (Significant Meteorological Information), satellite radar, and other weather tools to see if weather will impact the flight en-route. See [2] for a more complete description of the weather information sources used by dispatchers.

The dispatcher has at his or her disposal a number of tools and information sources to visualize weather. For instance, at one major airline, four tools are "approved," in the sense that dispatcher decisions can be based on the information found in them. All other information sources are advisory. However, dispatchers make heavy use of advisory weather sources during the course of planning routes for flight releases. There is a wide range of tools available to dispatchers, and different dispatchers will use a different subset of tools.

Hazard information and route information are usually on separate displays in the present system. The only time when they are on the same display is when the Aircraft Situation Display (ASD) weather overlays are used, but only one overlay is visible at a time. Only lateral company route information is available on typical displays.

B. Overview of Proposed AWIN-Based System

The AWIN tool is a decision aid for selecting minimum fuel, optimal, 4-dimensional routes that avoid weather and other hazards. The software will plan a route that is not only optimal for forecast winds and temperatures aloft, but also avoids weather and other hazards. The user can specify that routes be optimized for winds only, weather only, or both winds and weather. The tool also allows visualization of potential routes in both lateral and vertical dimensions. The tool, in addition, allows comparison of potential routes for estimated duration, fuel use, distance, and hazards encountered.

Specific weather hazards supported by the tool are convection, icing, ozone, turbulence, and ash. The tool also supports custom hazards that can be used to specify weather hazards, special use airspace, or other restrictions. Hazards are represented as convex polygons and hazard thresholds are user selectable. Hazards and options are displayed in a single user interface as shown in Figure 1. For a more complete description of AWIN, see [3].

In the proposed AWIN-based system, hazard information will be integrated with route information on the same display. Dispatchers will be able to view both vertical and lateral route information. All airline company routes will be available in AWIN. In addition, AWIN-generated routes will be available. Fuel information will be provided with the routes. Dispatchers can use the fuel information for route comparisons.

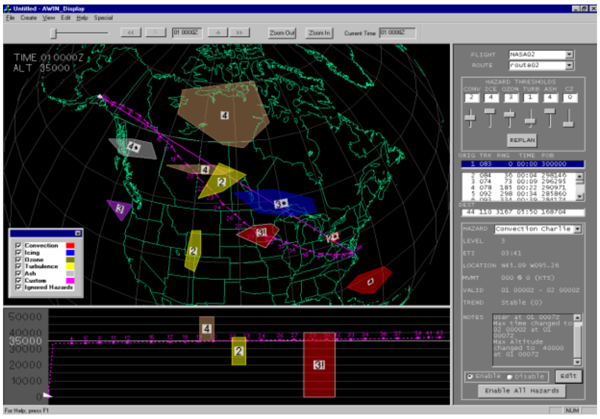

Figure 1. AWIN tool User Interface.

Company policy will be followed for entering weather hazards. The company meteorologist is responsible for entering the weather hazards and their severity levels. Dispatchers will be able to choose a route that is expressly optimized to go around the weather and other hazards. Non-weather hazards can also be more easily distributed as they are entered once and then appear integrated with each dispatcher's route information. The next section will describe the empirical evaluation to assess the proposed AWIN-based system.

III. EXPERIMENTAL METHOD

The AWIN tool will be evaluated at the Embry-Riddle Aeronautical University (ERAU). We will be able to test 32 student or recently certified dispatchers. There are three evaluation goals for this experiment: assess if there are gains in (1) safety, (2) fuel efficiency, and (3) time efficiency. Dependent measures were chosen to support the evaluation goals, and are described below.

A. Independent Variables

The purpose of the experiment is to assess if there are safety and/or efficiency gains associated with introducing the AWIN tool. To reach this objective, there will be two independent variables manipulated during this experiment. The first independent variable, *Tool Configuration* has 2 levels, Concept-A ("standard AWIN") and Concept—B ("modified AWIN"). The second independent variable, *Route* has 12 levels.

The resulting ANOVA design is a 2 (Concept-A, Concept-B) x 4(3) (weather condition (city-pair)). The ANOVA table is shown in Table 1, where a = Tool configuration (standard-AWIN, modified-AWIN) =2, b =Weather condition = 4, c=City-pair=3, n=32.

Table 1. ANOVA design: 2 (Concept-A, Concept-B) x 4(3) (weather condition (city-pair))

Sources of variance	Degrees of Freedom	DOF
E_a	a-1	1
E_b	b-1	3
E_c	b(c-1)	8
E_{ab}	---	
E_{bc}	---	
$E_{a(bc)}$	(a-1)(bc-1)	11
Subjects (Error within)	a(n-1)	62
Error (residual)	a(bc-1)(n-1)	682
Total	abcn-1	767

B. *Experimental Environment*

The intention of the experiment is to set up a simulated operations area for the dispatchers to work in. They will be given scenarios in which they are presented with stored routes for a particular city-pair and aircraft type. A diverse set of external weather information sources is represented by a stand-alone display (MOCK), containing the weather data typically used by dispatchers.

The experiments will make use of stored weather. Each experimental scenario (trial) will involve route selection between a unique city-pair. A unique weather case will be used for three trials. Additionally, the scenarios will be in randomized sequence. Of the twelve unique trials, a single participant will conduct six trials in Concept-A, and six trials in Concept-B

MOCK is the presentation interface for weather information that has been pre-recorded, and every attempt is made to present the information in the format that dispatchers are accustomed to when looking at live weather data feeds. Finally, a flight planner is responsible for all the fuel calculations.

1) *Mock Weather Information Sources*

In all conditions, the dispatchers will have access to pre-recorded weather information sources that dispatchers typically use when re-routing such as ADF Quick Brief, Collaborative Convective Forecast Product (CCFP), and others. Candidate city-pairs to be used were selected by ERAU and HL scientists based on the weather data recorded as case studies in the COMET [1] database, a weather database that extends back to 1997. Significant weather information sources were determined by a field study of the procedures and processes used by dispatchers when diverting around significant weather (for more detail see [2]). Recorded weather was captured and presented to the dispatcher in each trial, and the different weather information was used for each set of three trials to minimize learning effects.

For all city-pair scenarios, subjects were provided a set of weather information graphics, accessible through a web page, illustrated in Figure 2. Weather data for the trial was gathered from actual weather events. There were four sets of weather data, each from a different date. Each weather data set is valid for a set of three experimental trials. The left-side column of MOCK provides links to each case, and the right-side main window displays links to all the weather data available for that case.

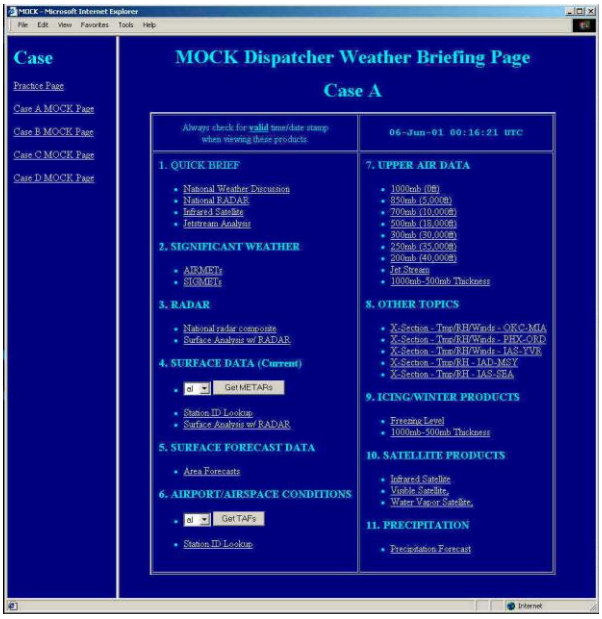

Figure 2. MOCK Weather Information Briefing Page.

Subjects were given training to assist them in assessing weather boundaries and severities. During each trial, subjects were asked to assess the weather to decide if it impacts the planned route between a city-pair. In all trials, subjects had access to raw weather data via MOCK. Subjects were tasked to assess if weather was significantly severe to cause a reroute around it. Table 2 describes four severity levels, in general and for specific weather types (convection, turbulence, and icing). Examples in Table 2 were given to help calibrate subject assessment of weather severity for each type of weather. For all weather types, routes should not pass through weather of severity level 3 or severity level 4.

Table 2. Description of weather classification scheme per weather type.

Lv	General	Convective	Turbulence	Icing
1	Weak or poorly organized system exists, low to moderate potential for development	Current RADAR reflectivities in the 20-30 DBz range	Modest wind shear (speed or direction) across layer, mountainous influences need to be accounted for.	Shallow layer of high relative humidity (>= 70%) with temps from 0C to -20C.
2	Weak or moderate system exists	Current RADAR reflectivities in	Significant wind shear (speed or	Moderate layer of high relative

	with strong potential to develop further	the 30-40 DBz range	direction) across layer, mountainous influences need to be accounted for.	humidity (>= 70%) with temps from 0C to -20C. (current or forecast)
3	Moderate to strong system already exists or development of strong system imminent / likely	Current RADAR reflectivities in the 40-50 DBz range	Large wind shear (speed or direction) across a layer, mountainous influences need to be accounted for.	Moderate to deep layer of high relative humidity (>= 80%) with temps from 0C to -20C. (current or forecast)
4	Extremely strong system, intensity could remain as is over the forecast period	Current RADAR reflectivities >50 DBz	Very large wind shear (speed / direction) across layer, mountainous influences need to be accounted for.	Deep layer of high relative humidity (>= 90%) with temps from 0C to -20C. (current or forecast)

Before each set of three flights, subjects spent five minutes of dedicated time becoming familiar with the weather (the Weather Familiarization Session) via the graphics on the MOCK display. The goal of the familiarization period was to allow subjects a dedicated amount of time to browse the data (weather graphics) and gain a general appreciation of the weather situation. Once the dedicated Weather Familiarization Session was over, subjects conducted three trials, one after another. The weather was valid for all three trials, and subjects continued to have access to all the weather information found during Weather Familiarization Session. After the third trial, subjects spent five minutes of dedicated time becoming familiar with a new set of weather data, which were applicable to the next three trials. The second block of six trials follows the same pattern where the first three trials occurred with one weather data set, and the second three trials occurred with another weather data set.

2) *Flight Planning Tool*

In the experiment, subjects conducted flight planning tasks in two conditions, Concept-A and Concept-B. Subjects used two different versions of the AWIN flight planning software. It was the job of the subjects to decide on a fuel-efficient route for the flight that flies between the city pair, and avoids hazardous weather. Each city-pair has an associated set of "company routes". A company route is a route pre-approved by the airline. These routes were created with no consideration of weather. The flight planner in each experimental condition is capable of assessing the predicted fuel usage of each route, based on the day's wind and temperature information. This experiment assumes motivations for route selection are for choosing best route as defined by weather avoidance and fuel efficiency. Other constraints that may be motivating performance in actual operations are not relevant in these scenarios.

In the Concept-A system, weather hazard information in the form of polygons will be integrated with route information on the same display. Dispatchers will be able to view both vertical and lateral route information. All company routes will be available in the tool. In addition, an auto-generated route will be available that optimizes fuel while avoiding hazardous weather. Fuel information will be provided with the routes. Dispatchers can use the fuel information for route comparisons. A company (ERAU) meteorologist was responsible for generating the hazard polygons, and their severity levels, using the images and weather information found in MOCK. Company policy (encapsulated in Table 2) was followed when the entering weather hazards and defining severities.

In the Concept-B system, subjects are able to view both vertical and lateral route information. All company routes will be available in the tool. In addition, the user can modify any company existing route manually to create a route that optimizes fuel while avoiding hazardous weather. Fuel information will be provided with the routes. Dispatchers can use the fuel information for route comparisons. The Concept-B system does not have weather information (except winds) incorporated with route information. Current weather information can be found in the images and weather information found in MOCK. Company policy (encapsulated in Table 2) should be followed by subjects when the deciding which weather is hazardous and should be avoided.

The routes will have been pre-ordered for the exercise in 'fuel efficiency order' but they will not have been modified to avoid the weather except in the case of one route generated by the AWIN system. The dispatcher will be required to choose the most appropriate and efficient flight plan route in the displayed weather conditions. The route may be modified manually or may be chosen from those automatically displayed.

C. *Dependent Variables*

Dependent measures were chosen to support the evaluation goals. To assess if there are safety gains we will measure the types and severity of the weather avoided, the distance planned in weather hazards, situational awareness, workload, and trust in system. To assess fuel efficiency effects we will measure fuel use. To assess if there are dispatcher job efficiency effects we will measure overall planning time and weather sources accessed.

D. *Experimental Procedure*

The experiment will begin with a meteorologist (or trained experimenter) entering weather hazards and corresponding severity levels in the AWIN tool. The weather hazards will be based on interpretation of the pre-recorded weather conditions for the experiment as encapsulated in MOCK.

Subjects will be given a total of 12 flights to dispatch, in two blocks of six flights, one block in the "Concept-A condition", and one block in the "Concept-B condition". The two conditions each use a different version of the Honeywell prototype AWIN flight planning system. In both blocks subjects will have access to weather information sources normally found in a flight dispatch environment (e.g. convective weather plots, turbulence plots, wind charts, etc).

Subjects are briefed on what weather types and severity are considered hazardous.

Then the dispatcher will conduct a block of trials with the Concept-A tool and a block with the Concept-B tool. Each block will be preceded by a practice trial with the experimental setup. Practice trials will involve pre-flight routing with city-pairs not used in the experimental trials themselves. To minimize order of treatment effects, the Concept-A/Concept-B trials will be counterbalanced with half the dispatchers receiving the block of Concept-A trials first and the other half receiving the block of Concept-B trials first. During a trial (scenario run), a dispatcher is asked to route a specific aircraft between a pre-determined city-pair. A trial terminates as soon as a route is selected, without the dispatcher having to complete the remaining steps for a release. In all conditions, the dispatchers will have access the pre-recorded weather information sources that dispatchers typically use when re-routing.

It is the job of the subjects to decide on a fuel-efficient route for the flight that flies between the city pair, and avoids hazardous weather. Each city-pair has an associated set of "company routes". A company route is a route pre-approved by the airline. These routes were created with no consideration of weather. The flight planner in each experimental condition is capable of assessing the predicted fuel usage of each route, based on the day's wind and temperature information. This experiment assumes motivations for route selection are for choosing best route as defined by weather avoidance and fuel efficiency. Other constraints that may be motivating performance in actual operations are not relevant in these scenarios.

Each dispatcher will be asked to fill out a pre-test questionnaire. After each trial, subjects filled out a NASA TLX workload scale. After each block of trials, subjects filled out a short questionnaire. Finally after both blocks were completed, subjects filled out a more extensive post-experiment questionnaire that asked questions comparing the two Concepts, questions on trust in the system, and open ended questions to gather more formative feedback.

IV. Expected Results

As of the writing of this paper, the experiment has been run with 32 subjects. Data analysis is underway, so this section will briefly discuss the results we expect to find.

There are three evaluation goals for this experiment. The first goal is to assess if there are safety gains from using the AWIN tool as opposed to other weather tools. The second goal is to assess if there are fuel efficiency gains from using the AWIN tool as opposed to other weather tools. Finally, the third goal is to assess if there are dispatcher job efficiency gains from using the AWIN tool versus other weather tools.

We expect that there will be a slight, overall, safety advantage for using the AWIN tool as opposed to the other weather tools that dispatchers typically use. We expect this difference to be more pronounced when the weather is extreme or particularly dynamic. Additionally, we expect to see more significant gains in safety when the dispatcher is experiencing a period of especially high workload.

We expect that there will be a significant fuel efficiency gain. Previous interviews have shown that most dispatchers, after ruling out the company recommended route because of weather, will typically, and randomly, choose another route that avoids the weather. Workload considerations typically prohibit calculating, by hand, the fuel cost of the remaining routes. AWIN mitigates this problem since it automatically suggests the route that avoids the weather *and* is the most fuel efficient.

We expect that there will be a dispatcher job efficiency gain from using AWIN as opposed to the other tools, due to shorter analysis and comparison times afforded by the integrated nature of information within AWIN. We also expect shift changes to be faster with the AWIN tool, due to improved situational awareness by both dispatchers.

V. Acknowledgements

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