Information Filtering using Bayesian Networks: Effective User Interfaces for Aviation Weather Data

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ABSTRACT
Weather is a complex, dynamic process with tremendous impact on aviation. While pilots often have access to large amounts of aviation weather data, they find it difficult and time-consuming to identify weather hazards, due to the sheer amount and cryptic formatting of the data. To address this challenge, we have developed information filtering concepts based on a unified Bayesian network model, integrating text and graphical weather data in the context of specific mission, equipment and personal profiles. Based on these concepts, we have implemented three applications, all of which were to existing technology. Using one of the applications, the AWARE Preflight system, pilots found significantly more hazards in about half the time compared to using the current technology.

Categories & Subject Descriptors
D2.13 [**Software Engineering**]: Reusable Software - *domain engineering, reuse models*

General Terms: Algorithms, Design, Human Factors

Keywords: Data filtering, Intelligent visualization, Information management, Situation awareness, Bayesian networks, Bayesian models.

1. INTRODUCTION
The fundamental difficulty of weather hazard evaluation is the vast amount of cryptic data being evaluated. Ten pages of text are normal for preflight weather briefings. While the data is copious it usually does not provide situation awareness; indeed it may give the pilot information overload, leading to loss of situation awareness.

In order to address the problem of information overload, we have developed an integrated intelligent user interface system, AWARE, for information filtering, hazard analysis, and visualization. The information is personalized according to the pilot's preferences, aircraft characteristics, and the relevant flight plan, while preserving access to source weather data. To accomplish this, we have developed an intelligent user interface layer "on top of" the existing data sources, thus guiding the pilot to the most pertinent pieces of information, as shown in Figure 1.

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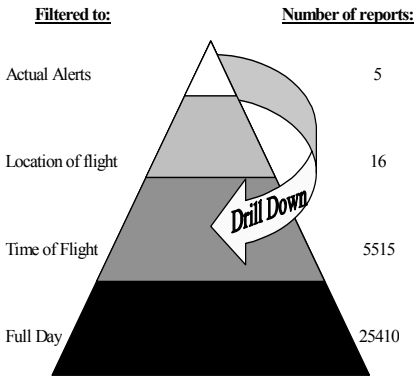

Figure 1: Filtering the data by time, location and hazard preferences reduces the alerts presented to the user by orders of magnitude; nevertheless, the user may still access the raw data with drill down techniques as indicated.

In a typical instance, our filtering by time, preference, and hazard analysis reduced the number of reports from over 25,000 alerts to 5 alerts for the entire flight. The *hazard analysis system*, which is the focus of the present article, is an integral part of three related aviation systems, as summarized in Table 1. What differentiates AWARE from previous work on display of aviation weather data is its context-sensitivity and ability to restrict the amount of data presented to the user based on assessed hazard levels.

System	Purpose	Users
AWARE Preflight	Supports pilots in preflight evaluation of weather hazards	General Aviation Pilots
AWARE In-Cockpit	Provides real-time alerting of hazards during flight	Commercial Pilots
AWARE Dispatcher	Alerts dispatchers to hazards along all relevant flight paths	Commercial Dispatchers

Table 1: Progression of AWARE applications from preflight web-based, through real-time alerting in-cockpit, to real-time, multiple flight alerting.

AWARE is also unique compared to previous work on information filtering using Bayesian networks [1, 2, 4] in that we have exploited the same underlying Bayesian network, weather database, and software infrastructure across three quite different AWARE software systems.

The AWARE project was based on User-Centered Design concepts [5], engaging users for design, reviews of prototypes, and usability testing, following the Usability Engineering

Lifecycle [3]. We evaluated currently approved systems for presenting weather to dispatchers and pilots with varying experience levels, and documented the limitations of these systems from the users' perspective.

Extensive knowledge acquisition with pilots provided the basis of the Bayesian network model discussed below; the pilots described the weather parameters of interest, the interaction of parameters, the data sources and their own preferences, varying with aircraft type and flight modes (visual, instrument, limited instrument). Pilots evaluated prototypes of displays and validated the Bayesian network model results, testing on actual weather data. We conducted formal usability testing of AWARE Preflight and usability walkthroughs of the real-time applications.

This paper presents the underlying intelligent user interface design of AWARE, the specific applications, and usability results for each application.

2. BAYESIAN NETWORK-BASED INTELLIGENT USER INTERFACE

The Bayesian network [4] basis of AWARE differentiates it from other aviation safety programs, providing analysis of context-sensitive data in a personalized graphical format to aid users. In this section we present the approach we have taken to utilize Bayesian networks in the AWARE systems.

Bayesian networks (BNs) can evaluate uncertain data, providing insights into both probability and criticality of impending hazards. In this project, context-sensitive means taking **pilot** preferences, **aircraft** capabilities and specific **flight** locations into account, while processing available weather data sources. The Bayesian

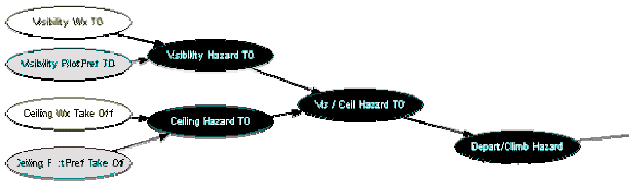

Figure 2: A subset of the takeoff portion of the Bayesian network model, with visibility & ceiling hazard analysis.

network model determines the possible aviation weather hazards based on multiple weather sources, as constrained by pilot preferences, aircraft requirements, and airport status. A small subset of the model is shown in Figure 2.

One of the key challenges to developing intelligent user interfaces based on BNs is to build a generic model that can be re-used across different applications, in our case the three AWARE applications. It is time-consuming to handcraft a different Bayesian network, a different database, etc., for different systems. It is better to develop a general approach, a generic hazard model, based on what different applications have in common and then instantiate that generic model with parameters for the application at hand. In our case, the three applications have in common the notions of flight path (or mission), time frame, and personalization.

Flight path: In the AWARE Preflight system, this is the planned flight path F_1. In the AWARE In-Cockpit system, this is the current flight path F_1. In the AWARE Dispatcher system, this is a set of flight paths, $\boldsymbol{F} = \{F_1, F_2, ..., F_n\}$. Each flight plan F_i consists of three legs, i.e. the temporal phases of takeoff, cruise, and descend, and both the Bayesian network and some of the displays are organized according to these legs. See Figure 2 for the takeoff part of the Bayesian network.

Time frame: Time frame means the time interval $[t_1, t_2]$ during which the flight(s) take place. In the AWARE Preflight system, the time frame may be either future or past, while the AWARE In-Cockpit and AWARE Dispatcher systems represent present time.

Personalization: The BN evidence nodes E are partitioned into pilot preference nodes R, aircraft nodes A, weather nodes W, and location specific parameters L. The pilot preferences are input once per pilot or dispatcher; the aircraft nodes once per aircraft, and the weather nodes are specific to the time frame and flight path.

The Bayesian network developed for AWARE was designed to be complete enough to represent pilots of varying levels of experience and interest; it is flexible enough to support multiple variations in the user-community. Within application execution,

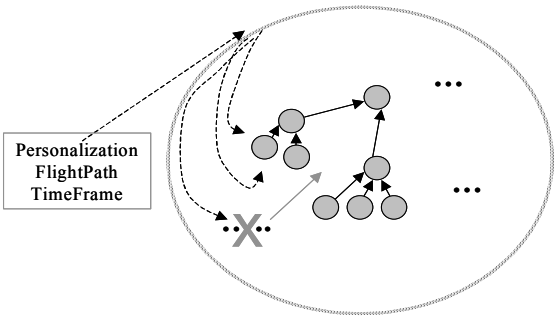

Figure 3: The Bayesian network Wrapper obtains flight path, personalization, and temporal parameters and passes them to the Bayesian network model.

the instantiation of the model is determined by an application interface that "wraps" the model, as shown in Figure 3.

This BN Wrapper is responsible for determining the current mode of operation, the preferences, and for defining the source paths for flight data and evidence. The BN Wrapper then executes based on the varying context parameters, including mode, preferences, and spatial-temporal context. With these parameters, the wrapper determines the relevance of all portions of the model.

3. AWARE SYSTEMS

All AWARE systems include:

- Procedures for acquisition and interpretation of text and graphical weather data, from the Internet and from satellites.
- A temporal-spatial database to support queries specific to flight times and locations.
- Bayesian network-based decision support for analysis of weather hazards.
- A user-centered display of weather and weather hazards.

In this section we present each of the AWARE systems – AWARE Preflight, AWARE In-Cockpit, and AWARE Dispatcher – in more details.

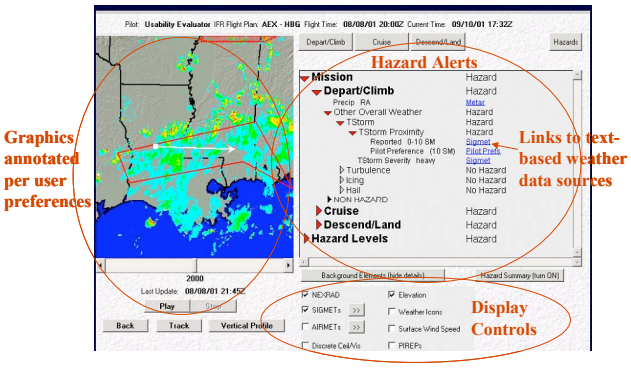

Figure 4: AWARE Preflight briefing graphical and hazard analysis display, with graphical indication of precipitation, pilot reports, significant events within a corridor of the flight plan, and hierarchical analysis of hazards.

3.1 AWARE Preflight

The first AWARE application, AWARE Preflight, was implemented as a preflight Web-based presentation of weather and hazard alerts for general aviation pilots. The Bayesian network model acquires user preferences from visual, instrument or limited instrument flight mode tables. In this original application, the user can peruse past or current weather sources. As shown in Figure 4, AWARE Preflight provides a presentation of graphical and textual displays, augmented by the context-sensitive hazard analysis for each leg of a flight plan F_1.

The hazard analysis is tailored to the specific pilot's preferences for visibility, ceiling, thunderstorm proximity and other parameters, as well as the aircraft type, and the specific flight path including a corridor around the path. The display, as shown in Figure 4, includes an analysis of hazards specific to the pilot's preferences and aircraft along the takeoff, cruise, and landing phases of the planned flight. As indicated, the pilot can drill down through the hazard analysis to the actual text of the weather data report, preserving the integrity of the raw data.

3.2 AWARE In-Cockpit

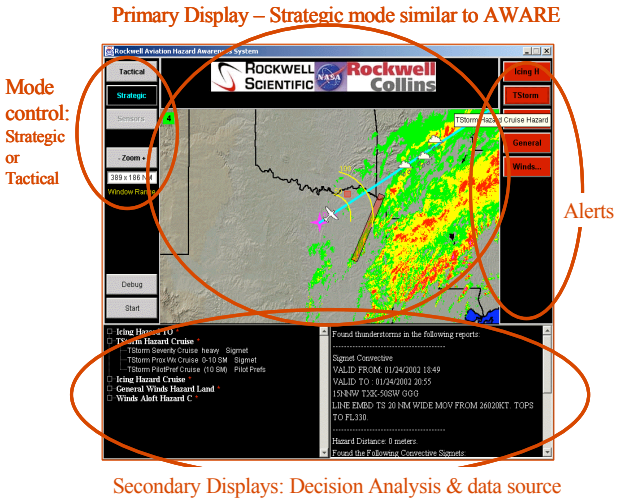

Figure 5: AWARE In-Cockpit strategic display with evaluation of flight. Alerts appear on the right, with text details at the bottom.

The second application, AWARE In-Cockpit, is again focused on one pilot's flight plan F_1, but is different from AWARE Preflight in that it implements the weather hazard alerting system real-time **in-cockpit.** In limited instrument flight mode, the Bayesian network Wrapper eliminates visibility and endurance checks en-route for real-time mode, and the database timeframes are limited to access only current weather sources. Weather sources include those available in AWARE Preflight. A screen shot of AWARE In-Cockpit is shown in Figure 5 with hazard alerts displayed on the right and text details of hazard analysis/weather source shown below.

The hierarchy of hazard analysis is organized by distance from the current aircraft position; the model is executed each time additional weather sources are received, or every 5 minutes, to dynamically present the hazards currently associated with the flight plan.

3.3 AWARE Dispatcher

Commercial dispatchers are responsible for alerting pilots on multiple flights of weather hazards. Consequently, AWARE Dispatcher, shown in Figure 6, extends AWARE In-Cockpit by presenting multiple flight paths $\{F_1, F_2, \ldots F_n\}$. Again, the presentation of hazard alerts is based on the unified BN model. In this case, it is instantiated uniquely for each flight F_i in order to compute flight-specific alerts. A BN Wrapper controls each BN model instantiation. The strategic display is similar to prior applications with the same overlays available. For alert buttons,

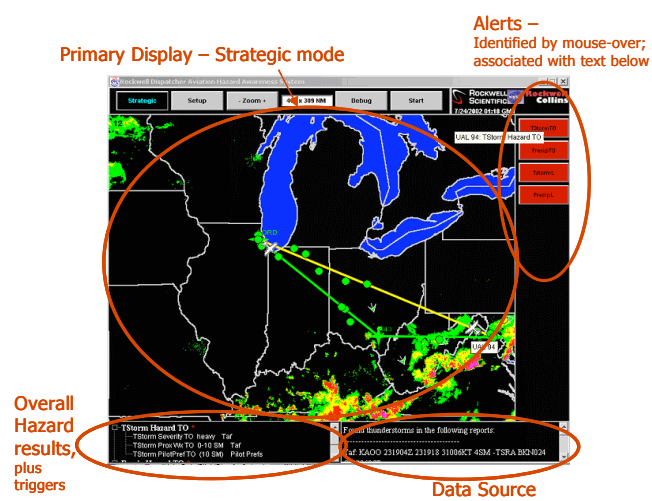

Figure 6: AWARE Dispatcher hazard alerts for two flights; mouse-over gives details. Green circles indicate visibility and ceiling values en-route. The hazard hierarchy and text source are shown in lower frames.

mouse-over provides details for both the hazard and the relevant flights. Mouse-over capability provides a short textual feedback on–screen when the mouse hovers over an item, after a short period of time.

4. AWARE USABILILTY STUDIES

For AWARE Preflight, we conducted two sets of formal usability studies. For AWARE In-Cockpit we completed usability walkthroughs and have initiated formal usability tests, and for AWARE Dispatcher, we performed usability walkthroughs.

4.1 AWARE Preflight Usability Studies

In the AWARE Preflight project, full usability testing was completed for both visual (VFR) and instrument-based (IFR) modes of the project. Three measures were evaluated in the analysis: efficiency, effectiveness, and satisfaction of using AWARE and using currently available text-based data (DUAT). Simple statistical analysis was performed on data acquired both by timing and from evaluation forms.

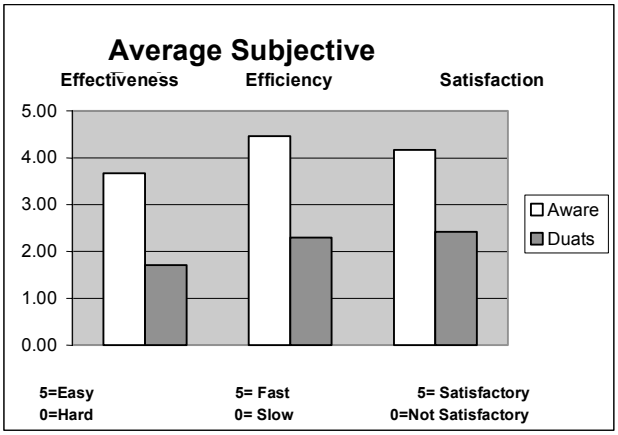

Figure 7: Subjective evaluations of AWARE Preflight for functionality, speed, and satisfaction.

Both VFR and IFR tests showed that AWARE provided faster and more effective weather evaluation; all subjects graded AWARE higher for effectiveness, efficiency, and satisfaction. The subjective evaluations of the AWARE Preflight system are summarized in Figure 7. In general, AWARE Preflight supported subjects in more effectively finding more complex details, especially cumulative for all phases of the flights and for interacting parameters. By the subjects' final evaluation, AWARE also provided a higher level of analysis than in either text or web-based evaluations; it approximated that of a human weather briefer.

4.2 AWARE In-Cockpit Usability Studies

In iterative prototyping mode, we worked with pilots at a commercial flight operations center, initially to determine their response to AWARE Preflight concepts and then to prototypes we designed specifically for in-cockpit use. It was determined that many of the AWARE Preflight visualization overlays would be of value in-cockpit, and alerts based on the pilot's preferences and on real-time weather sources would be invaluable.

AWARE In-Cockpit was tested in-flight on NASA 757 Aries flights in early 2002. While these were not formal usability tests, the feedback was very favorable. Formal in-cockpit usability tests will be completed with NASA pilots during 2003.

4.3 AWARE Dispatcher Usability Studies

We worked iteratively with dispatchers at three flight operations centers, to determine the relevance of hazard alerts for multiple flights, and to determine their response to designs for AWARE Dispatcher. AWARE Dispatcher was implemented to represent multiple flights per dispatcher, with a separate Bayesian network model instantiated per flight. Alerts were specific to a flight, but if there were replicates among flights, they were grouped.

In summary, we found that dispatchers want automated alerts for multiple flights, primarily for hazards they're not already trained to identify from visual data. These alerts may be based on additional data sources, single or multiple-parameter calculations, or requirements for alternate data, and the AWARE Dispatcher system provides such alerts.

5. CONCLUSIONS

We have developed a unified Bayesian network that provides automated weather hazard alerting for pilots and dispatchers. The underlying Bayesian network and the associated BN Wrapper provides the architecture by which we can adapt the alert system to the preferences and abilities of different application settings and user groups. Using our approach in three different AWARE systems, we have decreased the amount of data that users must immediately evaluate by, typically, three orders of magnitude. Users still have full access to the raw data that lead to the alerts. In user evaluations, we found that each of the three AWARE applications was more effective in alerting the user to weather hazards than currently existing systems.

The underlying hazard analysis allows us to tailor alerts to specific situations, and allows the user to have overall control over both the alerts reported and the level at which the alerts should be shown. Using the AWARE systems, whether for preflight, in-cockpit, or dispatcher applications, alerts are automated, user-personalized, and can warn the user of weather conditions that individually are non-hazardous but together comprise a hazard.

6. ACKNOWLEDGEMENTS

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