A Concept for Tactical Reroute Generation, Evaluation and Coordination

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A concept is described that enables traffic managers to efficiently develop and coordinate tactical reroutes around convective weather, facilitating incremental decision making. Tactical reroutes are more precise and efficient than strategic ones, since weather predictions improve as look-ahead time decreases. Currently, tactical rerouting is prohibitively labor intensive as there is little automation assistance to identify flights projected to be affected by weather, to choose appropriate reroutes, and to coordinate them. In the United States, electronic means will soon be available for coordinating reroutes between traffic managers and en route controllers, making tactical rerouting a much more viable option for traffic managers. The Tactical Rerouting concept presented here takes advantage of this technology, and adds decision support capabilities that together increase throughput near a weather constraint and thereby reduce the need for larger scale, strategic Traffic Management Initiatives that frequently produce unnecessary delays.

I. Introduction

REDUCING en route convective delays is a challenging task. It is difficult to balance flows with available capacity when congestion occurs in en route airspace, and convective weather impacts are difficult to forecast accurately. System stakeholders recognize that Traffic Flow Management (TFM) actions are often conservatively applied as a risk mitigation effort due to the long lead times (greater than two hours) needed to accomplish effective air traffic management (ATM). Today's decision support tools do not provide the needed functionality to operate more tactically, and planned enhancements provide little to support tactical reroutes. As the National Airspace System (NAS) progresses into the Next Generation Air Transportation System (NextGen), the opportunity exists to provide traffic managers with decision support tools (DSTs) that utilize probabilistic forecasts and improve coordination capabilities to develop more targeted, flight/flow-specific control actions in addressing congestion.

This paper describes a decision support tool concept to facilitate tactical TFM reroutes. Current TFM strategies rely heavily on pre-departure delay and rerouting in the strategic timeframe (see Fig. 1). Pre-departure reroutes are favored today due to the complexity and time constraints TFM and Air Traffic Control (ATC) personnel face when rerouting airborne flights. The Tactical Rerouting concept bridges the gap between strategic traffic management initiatives (TMIs) based on 2-6 hour convective weather forecasts[1] and just-in-time flight deviations based on cockpit weather radar displays. By utilizing more accurate Corridor Integrated Weather System[2] (CIWS) forecasts in the 15-90 minute timeframe, this work explores the idea that it is better to address potential congestion incrementally as confidence in the weather and demand forecasts increase. Addressing constraints at the local/tactical level ensures that the person solving the problem is most familiar with the airspace and can therefore find the best solution. "By shortening the distance between the point of decision making and the point of impact, better planning can be achieved for the NAS."[3]

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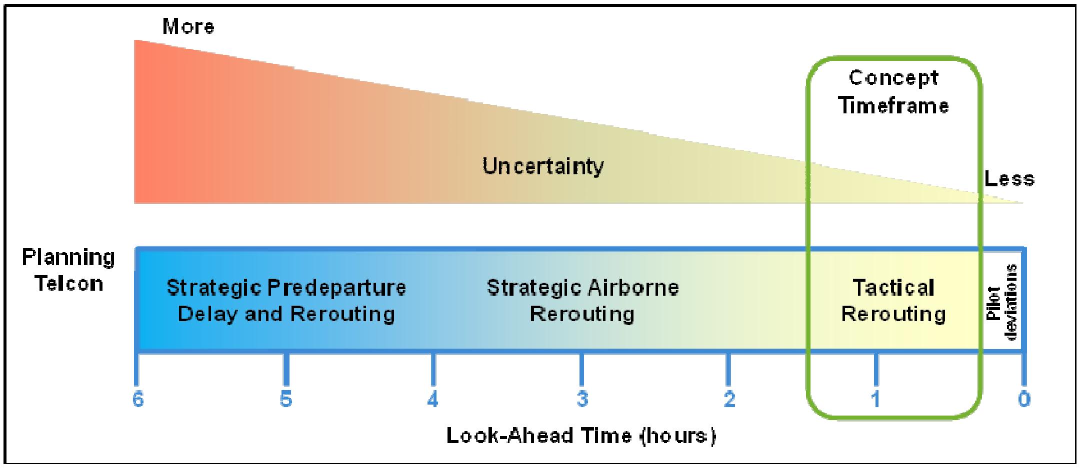
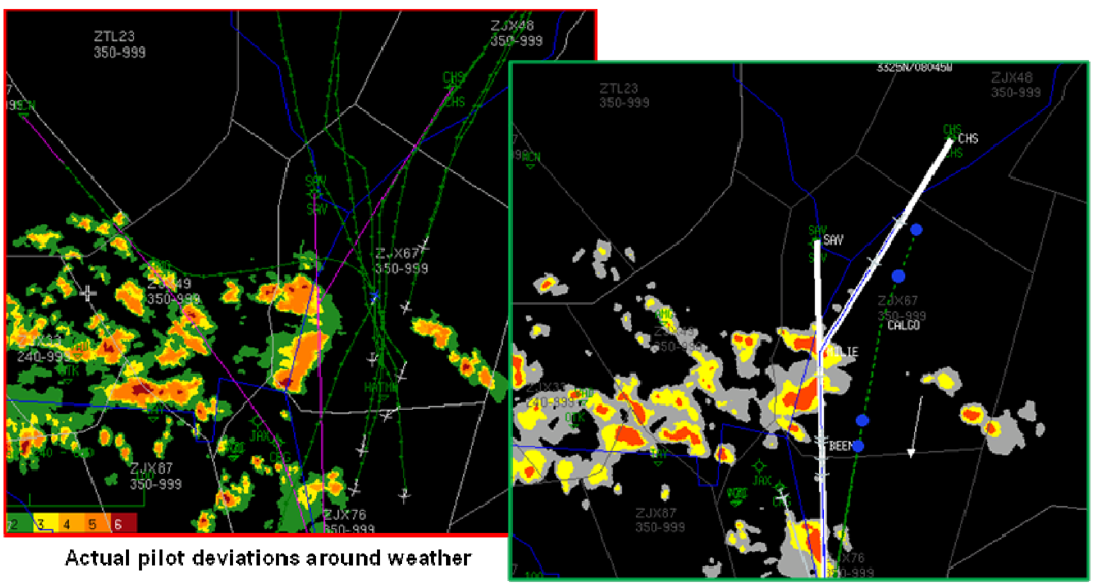


Figure 1. Look-ahead time context for incremental TFM decision making.

Pilots routinely request clearance to deviate around weather using the weather information available to them in the cockpit. This requires verbal coordination of the clearance to deviate between the controller and pilot. Figure 2 provides an example of pilot deviations around weather along with a depiction of how tactical reroutes can create order and predictability. The left half of Fig. 2 shows aircraft deviating through a sector. The flight plan routes are in blue and actual flight paths are in green. The variation in flight paths illustrates the increased sector complexity introduced by the unpredictability of pilot deviations around severe weather. The right half of Fig. 2 shows what might have been done with Tactical Rerouting. With a simple reroute (over CALGO), drawn in a green dashed line, the controllers' problem becomes much more workable. The controller workload associated with deviations includes verbally negotiating the bounds of the clearance with each pilot and managing the resulting disorganized flight paths. If flights flow through weather impacted sectors on routes clear of the weather, deviations and the associated workload are eliminated. Successful Tactical Reroutes can achieve that.



Actual pilot deviations around weather

Tactical reroutes (green dashes) that could have been implemented in upstream sectors

Figure 2. Tactical reroutes can create order and predictability.

Tactical rerouting is difficult for traffic managers today, because there are few tools to help them plan and execute reroutes. Automated problem identification of flights that will be impacted by severe weather in the NAS in the 15-90 minute tactical timeframe would facilitate this process. The En Route Flow Planning Tool (EFPT) prototype has been developed to assist in the Tactical Reroute evaluation and coordination process and to identify key technical and operational issues associated with the process. Prototyped capabilities provide flight-specific problem identification, reroute option generation and evaluation, and coordination of the proposed reroute(s). These capabilities are designed to transform unplanned and reactive flight deviations into targeted, coordinated, and proactive reroutes. The potential benefits of reducing delays from strategic flow planning initiatives through tactical airborne rerouting were analyzed. That analysis is summarized in Section III.B.

II. Tactical Rerouting Concept Overview

A. Description of the Problem

With today's tools and operations, key challenges in today's en route flow management include the following:

1) Severe weather causes unpredictable pilot deviations that increase the complexity facing controllers and reduce sector capacity.
2) Strategic TMIs are used- to reduce demand and give controllers more workable problems, but are frequently overly conservative, due to uncertainty in long-range (2-6 hour) weather and traffic demand forecasts.
3) More tactical solutions (15-90 minutes out) are difficult to implement because current systems do not provide integrated information that facilitates reroute planning and execution.

B. Description of the Solution

Precise, automated identification of flights that will be impacted by severe weather in the NAS in the 15-90 minute tactical timeframe is not available to traffic managers today. EFPT prototyped capabilities provide this problem identification along with the ability to resolve these problems through graphical and text entry reroutes as well as automated reroute suggestions. Metrics to evaluate the reroutes are provided and the functionality to share the proposed reroute with other facilities to assist in coordination. The powerful combination of CIWS weather, an identified set of "problem" flights for the traffic manager to consider, and the means to easily develop and coordinate possible reroutes between facilities all in one Traffic Flow Management System (TFMS) window interface provides a powerful tool. The shared situational awareness afforded by tactical airborne reroute evaluation and coordination capabilities within the tool facilitate improved decision making. The resulting TFM actions will be more measured and incremental to better utilize system capacity and allow more limited use of strategic initiatives such as Airspace Flow Programs[4]/Collaborative Trajectory Options Program[5] (AFP/CTOP) and Playbook Routes.

The Tactical Rerouting concept includes the following five capabilities:

1) *Problem Identification*: Predicts and ranks weather impact (using CIWS), sector congestion, and Special Activity Areas (SAAs) alerts on flows and flights
2) *Reroute Generation*: Generates flight specific solutions (reroutes, delay, altitudes)
3) *Reroute Evaluation*: Ranks solutions according to operational acceptability metrics as shown in Fig. 3. Reroute evaluation metrics include: sector congestion, weather blockage, coordination requirements, airline schedule disruption, added distance, SAA avoidance, sector crossing geometry, return to original route, flow size, and flow consistency. These metrics are described in Section D.4. The individual metric scores are weighted and combined to generate an overall reroute score.
4) *Reroute Coordination*: Facilitates coordination by identifying impacted facilities and communicating both the problem and proposed solution to them through automated capabilities. An example is provided in Fig. 4.
5) *Reroute Execution*: Sends reroutes approved by traffic managers directly to controllers through automation.

An important part of the Tactical Reroute concept is a clear presentation of problems and solutions along with relevant information. The Traffic Display map, which is modeled after the TFMS Traffic Situation Display (TSD) map, shows problems and solutions in the context of airspace geometry and predicted weather, traffic, and congestion alerts. Those predictions can be examined temporally by moving a time slider. The Tactical Reroute window presents summary and flow information at the top and more detailed individual flight data at the bottom. The concept's automation provides valuable support, but the traffic manager drives the process: determining which problems to solve, evaluating the provided solutions, and possibly modifying one or creating one manually.

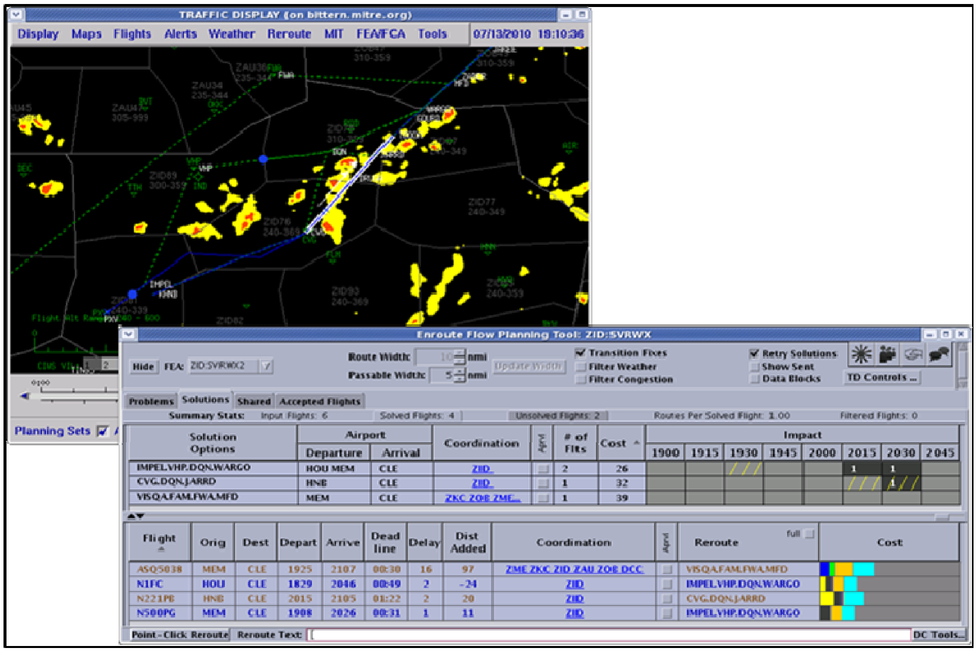


Figure 3. Problem identification, reroute generation and evaluation.

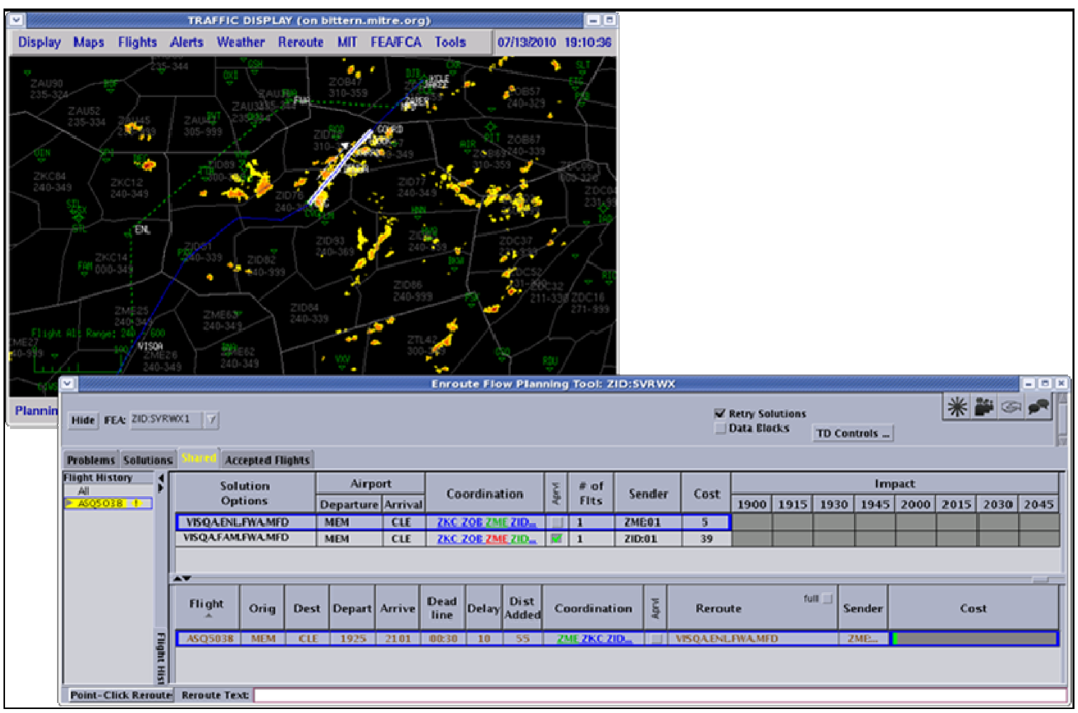


Figure 4. Tactical reroute coordination.

C. Example

The following example will illustrate these capabilities. Figure 5 shows a map display with a Flow Evaluation Area (FEA) that an Indianapolis Air Route Traffic Control Center (ZID ARTCC) traffic manager has created around a region of severe weather in ZID. The severe weather product displayed is the CIWS Vertically Integrated Liquid (VIL), which has current weather plus predicted weather up to two hours in the future. That product and the CIWS echo tops prediction product are used to create a Weather Altitude Avoidance Field (WAAF) that predicts where and when flights are likely to deviate around the weather.[6] The other window in Fig. 5 is the EFPT window. Its "Problems" tab displays the impacted flights grouped by impacted route segment in the middle section of the window. In this example, three parts of Cleveland's ZABER1 Standard Terminal Arrival Route (STAR) are selected. Selecting a flow in the EFPT window causes it to be displayed on the TSD map, where the impacted part of the flow is highlighted in a wide, white border. Selecting a flow also causes the individual flights in the flow to be listed in the bottom part of the window. Information about each flight is shown, including the time it is predicted to reach the impacted segment of its route. Additional information displayed in the "Problems" tab includes a quarter hour time grid (titled "Impact") that shows when each segment is impacted (indicated by a dark gray background), counts of flights entering the impacted segment, and any sector alerts at the segment (indicated by red or yellow hash lines). When the Traffic Management Coordinator (TMC) hovers the cursor over the sector alert indicator, the alerted sectors as well as the number of aircraft over the monitor alert parameter (MAP) value will be displayed.

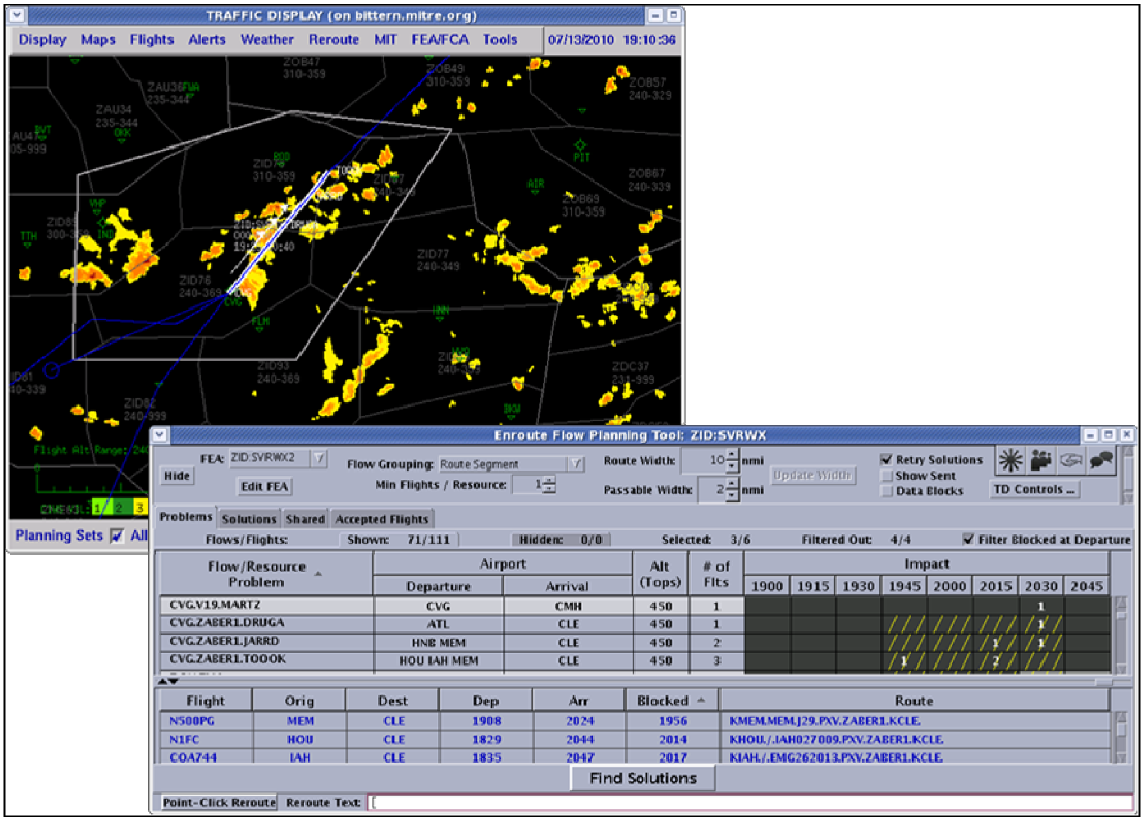


Figure 5. Problem identification.

The tactical rerouting concept embodied by EFPT relies on the judgment of traffic managers to decide which predicted problems to take action on and which will be left to sector controllers and pilots to resolve. The concept is for the automation to present potential problems in a clear, concise manner that facilitates quick decisions. As will be shown next, if a traffic manager decides to seek a resolution to a problem presented by the automation, the automation then suggests several solutions along with some evaluation information about each one. The traffic manager may choose one of those solutions, modify one, or create one manually based on one of those reroutes or on the original route. The concept is to provide automation support in the form of integrated information and suggestions to assist traffic managers in making better informed decisions.

Continuing with the example, pressing the "Find Solutions" button at the bottom of the "Problems" tab causes EFPT to generate proposed reroutes for the selected flights. The three solutions generated for the ZABER1 flights are shown in Fig 6. All of the solutions are selected in the EFPT window, so they are all displayed on the TSD map. A "time slider" allows the user to advance the weather and traffic on the existing routes and the proposed reroutes to watch the interaction with the advancing weather.

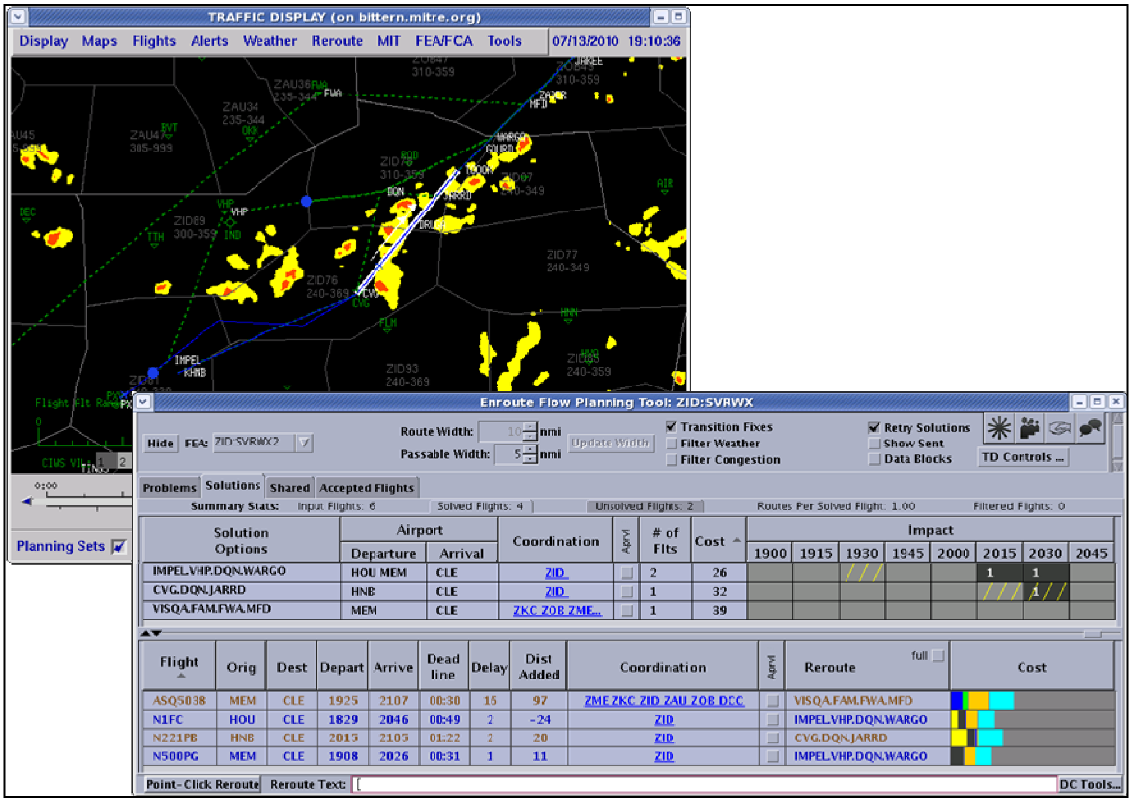


Figure 6. Reroute generation and evaluation.

The three solutions provide different degrees of weather avoidance. One (CVG..DQN..JARRD) is a short routing and is internal to ZID. Another (starting at IMPEL) is also internal, but goes outside of most of the weather in the FEA. The third (over FWA) is even farther from the weather and will likely require coordination with other Centers. The automation determines the coordination requirements of each reroute and lists the necessary facilities in the "Coordination" column. The automation also assesses the operational acceptability of each reroute using eleven metrics, such as weather avoidance, sector congestion and flow agreement. Those metrics are described in Section D.4. The resulting operational acceptability score is displayed in the "Cost" column. The term "cost" derives from network terminology and is not based on monetary considerations.

Other reroute evaluation information is provided in the time grid and in the flight list at the bottom of the EFPT window. The time grid shows predicted weather impacts and sector alerts for the first two reroutes. Any active SAA penetration would also be indicated. The flight list shows when the reroute leaves the current route (the "Deadline"), the delay and distance added by the reroute, the coordination Centers, and the reroute itself. This reroute evaluation information is provided as an aid to the traffic managers, to augment what they know from just the reroute text and the TSD map display. This additional reroute evaluation information concisely points out issues with the reroutes that may otherwise be missed. Depending on the time available, they may investigate any of the evaluation information (such as the weather impact or sector alerts) further. Again, the concept is to provide clear, concise, actionable information in a timely manner

The last step in the concept, automated coordination of the proposed reroute between decision makers, will now be illustrated. The ZID traffic manager accepts the third reroute, the one over FWA. As a result, the reroute is automatically sent to the coordination Centers, who are notified by automation in some manner, possibly by an alert on the TSD toolbar similar to the one for the National Traffic Management Log (NTML). On demand, the automation will present the problem and the proposed solution along with the evaluation data in the "Shared" tab. A traffic manager in the Memphis ARTCC (ZME) reviews that information and sends back a modified version of the reroute that takes a slightly more direct routing over the Centralia VORTAC (ENL). ZID is notified of the counter proposal and a traffic manager reviews it on the "Shared" tab as shown in Fig. 7. Any flights with actions pending are listed in the "Flight History" column on the left. When a flight is selected in that list, the reroutes that have been proposed for the flight are listed chronologically with the most recent proposal at the top. The "Sender" column shows who proposed a particular reroute. The color coding in the coordination column shows who has accepted (green), rejected (red), or taken no action (blue) on a reroute.

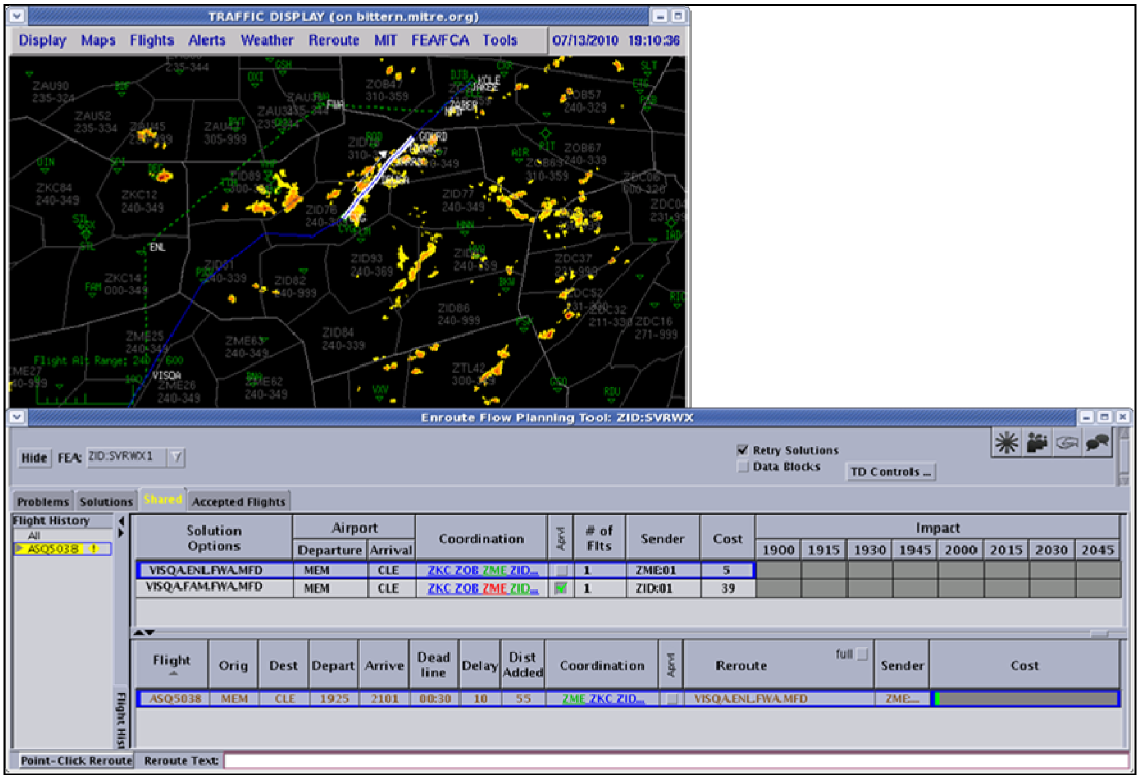


Figure 7. Reroute coordination.

This coordination process is asynchronous, like email, allowing the participants to work on their aspect of a problem or request and move on to the next without waiting for external responses. Like email, this works efficiently for coordination that is straightforward, but may still need to be supplemented with telephone coordination in more complicated situations. In those cases the concept and prototype also provide a synchronous alternative that includes window sharing and chat and potentially an audio connection. That real-time capability is integrated within the application, connecting to the coordination facilities seamlessly. The sharing of integrated information between decision makers provides a powerful decision support tool beyond today's manual processes.

This specific example illustrates the concepts and flow of tactical airborne rerouting evaluation and coordination. The general decision support process flow for the concept is depicted in Fig. 8.

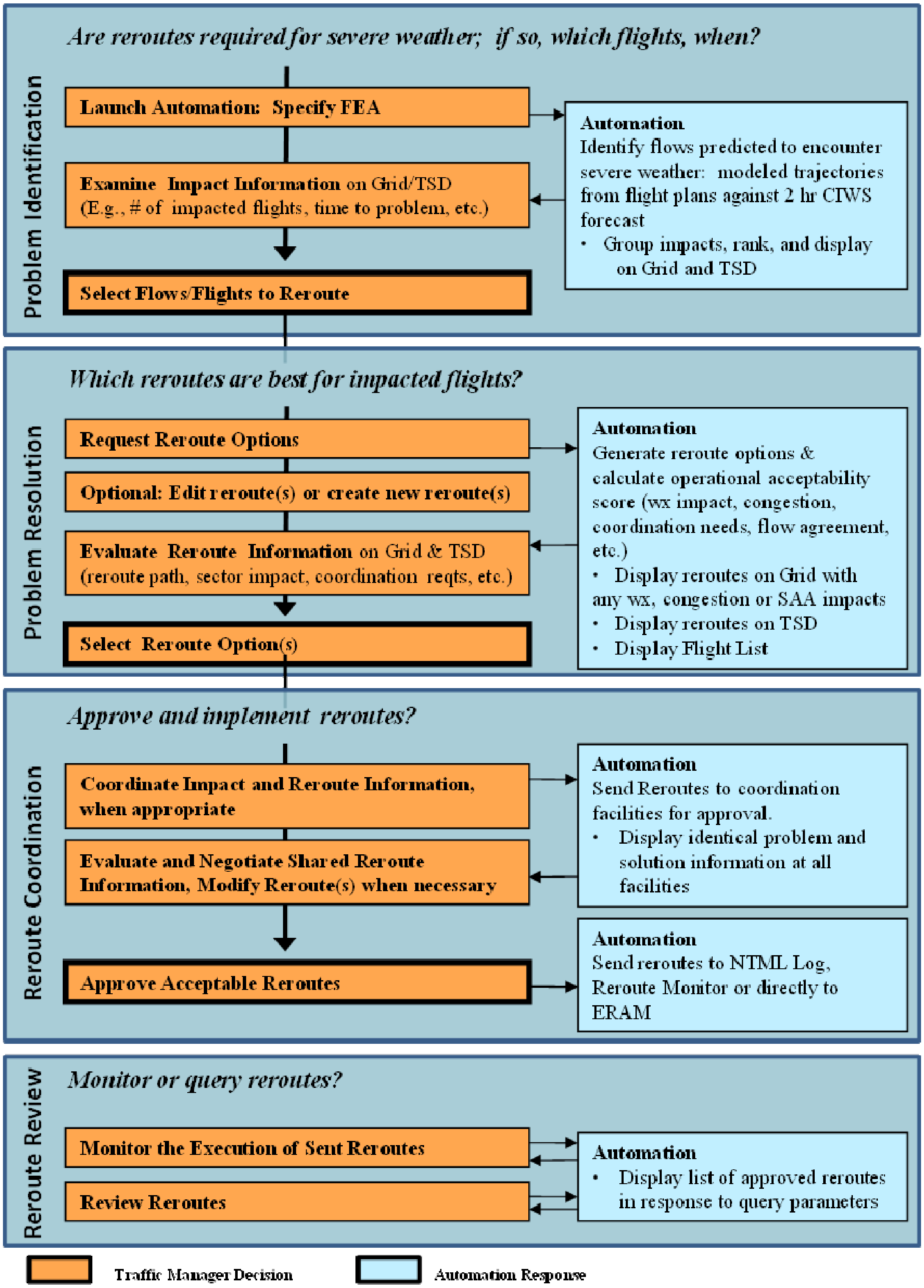


Figure 8. Tactical airborne rerouting decision support process.

D. Algorithms

1. Weather Impact Identification

Defining a FEA or Flow Constrained Area (FCA) is the first step of the Tactical Reroute concept. The defined area encompasses the weather area of interest and can be filtered to select only flights or flows of interest. The automation then probes the flights in the list against the weather to determine which flights are impacted by the weather. The weather impact detection capability is based on the WAAF,[7-8] a four-dimensional (i.e., 3-D plus time) prediction of where flights will deviate due to weather. Only the part of the WAAF within the FEA/FCA airspace is considered in creating the problem list (solution evaluation includes all parts of the WAAF).

To account for uncertainty in weather predictions the probe of each flight trajectory is broadened to include a corridor centered on the route (MIT's Lincoln Labs introduced this approach[9]). Between each fix pair segment of the route, the corridor is divided into a grid of one kilometer cells as shown in Fig. 9. Across the width of the fix segment, a minimum number of cells (the "clear width") must have WAAF altitudes below the flight trajectory altitude. Although Fig. 9 implies a requirement for a contiguous clear width and a continuous clear flight path, neither is required due to both weather prediction uncertainty and performance limitations.

Included in the concept and prototype is the ability for the traffic manager to change the route width and clear width settings to adjust the aggressiveness of the automation's problem reporting. The clear width parameter used to probe potential solutions can be set independently of the clear width parameter for problems. The ability to set a higher "clear width" for solutions than for problem identification allows the traffic manager to adjust how conservative (i.e., clear of the weather) the solutions must be.

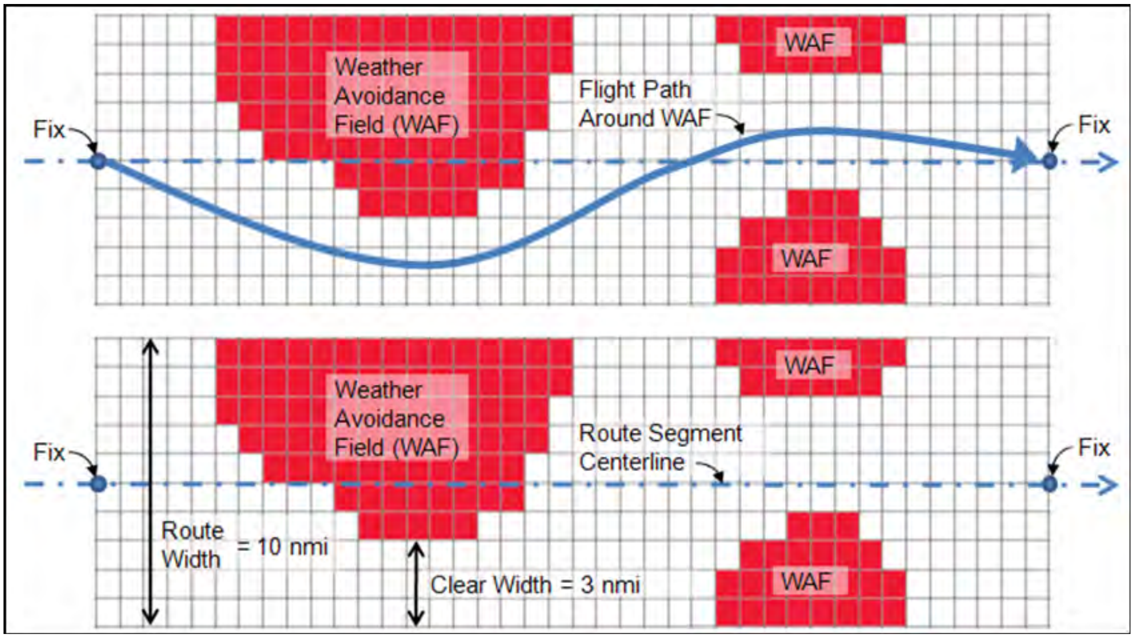


Figure 9. Illustration of route width and passable width.

2. Flow Aggregation

Traffic managers generally prefer taking action on a traffic flow, rather than individual flights, to increase the impact of their actions and to maintain uniformity of flight patterns. Tactical Reroute supports this by presenting problems as flows. Operationally, flows can be defined many ways, and the concept supports several flow definitions. The most basic is by impacted route segment. A flight's impacted route segment starts at the last fix before predicted weather impact and continues until the beginning of a non-impacted segment is reached. The automation finds all impacted route segments for all flights and then combines those into impacted flows. For example, all flights with weather impacts on the route segment "SAV.CHS.J121.JMACK" would be grouped together in a flow of that name. A traffic manager can select that flow and request solutions from the automation.

Other flow definition or grouping categories are: airway, fix, sector, arrival airport or city pair. This capability allows the traffic manager flexibility to identify flights affected by constraints in various ways. This may depend on the type or scope of the constraint the traffic manager is monitoring.

3. Route Generation

The Tactical Reroute concept provides for manual reroutes (text entry field or point-and-click on the traffic display map) and automation-generated reroutes. A number of automated reroute generation algorithms have been explored: a heuristic method, a network algorithm (k-shortest path, or KSP[10]), and a simulated annealing (SA) method.[11] All are based on a route database that is constructed from Coded Departure Routes (CDRs), FAA preferential routes, Playbook reroutes, and historically flown routes. To date, although the heuristic algorithms do not always generate large solution sets (sometimes no solutions are found), only they are fast enough to support real-time use.

Heuristic rerouting starts from fixes on the original route that precede the weather impacted segment. The reroute generation capability stops looking for reroutes once a parameter number (currently 50) of clear reroutes are found for a flight. It favors solutions that start closer to the weather (i.e., follow the original route longer), but will look for solutions that start near the flight's current location if insufficient close reroutes are found.

At each upstream fix the capability generates reroutes using all of the following methods:[12]

1) *Fix to destination*: This method looks for routes in the database that go through the upstream fix to the same destination as the flight.
2) *Rejoin routes*: If a fix to destination reroute crosses the original route downstream of the weather impact, a reroute is constructed that follows the fix to destination reroute to that crossing and then rejoins and follows the original route the rest of the way.
3) *Fix to Fix*: This method creates ad hoc routes between the upstream fix and fixes on the original route past the weather. Fix to fix segments from historically flown routes are pieced together to connect the two fixes. Each segment used must have been flown at least a parameter number of times (currently 50 times) in the past year and must be within some range of headings toward the second fix.
4) *Enhanced fix to destination*: This method is a hybrid of the fix to fix and fix to destination methods. The reroutes start with a historical fix to fix segment within a range of headings toward the destination, and then transition to fix to destination routes starting from the fix to fix endpoint. In other words, the resulting routes fan out from the original route for one fix to fix segment and then follow fix to destination routes from there.
5) *Try again*: This method starts with a reroute generated by one of the other methods that will not work due to weather impct within the FEA but only when that weather impact is closer to the flight's destination than the original weather impact (i.e., the reroute is made it past the original blockage but is blocked further downstream). The failed reroute is taken as a new starting point to use the other methods.

4. Reroute Evaluation

The reroute generation automation can create hundreds of reroute solutions per flight. Subject Matter Expert (SME) feedback during concept evaluations has suggested that the presentation of the 3-5 "best" reroute options is optimal. There has been some progress in assessing the validity of various numeric attributes of reroutes.[13] Advances in that research will be integrated into the Tactical Reroute Concept as they are made. The current metrics are:

1) *Weather avoidance*: Probability of weather impact
2) *Sector congestion*: Probability of encountering congestion; penalizes sending flight into congestion more than congestion existing on original route
3) *Flow agreement*: Favors more commonly flown route segments in the same direction
4) *Inter-facility coordination*: The cumulative cost factor associated with the coordination facilities
5) *Point outs*: Penalizes problematic sector boundary crossings
6) *Distance*: Flying distance added by reroute
7) *Delay*: Delay includes airline schedule disruption cost factors
8) *Active SAA incursion*: The best available SAA schedule is used
9) *Weather avoidance*: Probability of weather impact
10) *Flow size*: Favors reroutes that work for multiple flights
11) *Return to route*: Favors flying more of the original route

Overall reroute cost is a weighted sum of the individual metrics. Flow consistency, coordination and congestion are currently the most heavily weighted metrics based on SME feedback.

III. Concept Development and Evaluation Progression

A. Field Evaluations

The Tactical Reroute concept has evolved from predicting impacts on standard, pre-adapted routes without regard to specific flights into one that predicts weather impacts based on individual flight trajectories responding to the dynamic nature of the en route environment.

Functional requirements for the initial phase of the Tactical Reroute concept have matured over the past three years. Development of initial Tactical Reroute capabilities entailed collaboration with operational personnel to refine the capabilities implemented in a prototype system. Scenario-based evaluations were conducted to structure TMC interactions with a prototype and collect feedback on the implementation of capabilities. This has been an iterative process of developing the concepts and prototype to enable concept validation and refinements using feedback from SMEs from within MITRE and several ARTCCs. Most recently, evaluations at Jacksonville (ZJX) and ZID Centers, in May 2011, provided feedback and further validation that these tactical airborne rerouting capabilities were of value.

B. Initial Benefits Study/Analysis

As previously discussed, the implementation, management and monitoring of flights deviating around weather by sector controllers takes more effort than controlling flights following tactical reroutes that are clear of weather. In addition, the Tactical Reroute concept spreads en route sector controller workload from weather-impacted sectors to underutilized non-impacted neighboring sectors. It is hypothesized that these effects will allow for increases in throughput in the weather area.

Based on this hypothesis, a quantitative benefits assessment of tactical airborne rerouting operating under conditions of severe en route weather was undertaken in 2011, using a “pool of benefits” approach.[14] The basic approach was to tabulate the delays for flights subject to an AFP on a sample bad weather day, and to then estimate how much tactical airborne rerouting could reclaim of that total. This analysis concludes that the potential delay savings total $15M annually (which includes airline direct operating costs, passenger value of time, and propagation of delay). A human-in-the-loop (HITL) study will be conducted next year to validate and refine that figure. The planned HITL is described in Section C.3.

C. Future Research

1. Expand Research to Non-Weather Problems

The tactical airborne rerouting evaluation and coordination concept is to provide a tactical TFM decision support tool that:

1) Predicts and ranks problems
2) Generates and ranks solutions
3) Facilitates coordination by identifying impacted facilities, communicating both the problem and proposed solution

The research to date has focused on convective weather impacts on air traffic. However, the numbered description of the concept above does not confine our research to weather-related problems. Some areas for further tactical airborne rerouting research include non-weather congestion resolution, altitude solutions, parallel route offsets, expanded stakeholder collaboration, and integration with other systems/tools (e.g., Time-Based Flow Management [TBFM] for automated arrival fix load balancing).

The basic Tactical Reroute concept is based on identifying weather impacted flows. We are extending the concept to include non-weather congestion. A simple approach to this starts with the selection of a congestion alert for a sector, fix or some other resource and the ability to request solutions. As with the weather impact capability, the automation generates solutions for all of the involved flights and presents them in a list ranked by “cost”. This approach can provide quick solutions that maximize positive impact and minimize negative impact.

Potential benefits of tactical airborne rerouting discussed in this document are based on reducing delay due to weather only. There will be additional benefits for the tactical resolution of congestion not caused by weather to be explored in the future.

2. Continuous Problem Solving/Monitoring

It is not expected that traffic managers will have time to solve every congestion problem. Therefore it is logical to focus their efforts on the worst problems and the problems for which there are good TFM solutions. Part of our future research will center on a method to maximize the impact of TFM efforts. This method is based upon changing from an “on demand” problem solving model to a “near continuous” model. This new model eliminates wait time for specific solution generation, particularly when the automation fails to produce any solutions. This will help traffic managers do their job more effectively while still staying tightly in the loop.

3. Human-in-the-Loop Experiment

The proposed experiment is intended to evaluate whether the Tactical Reroute concept can increase airspace throughput during severe weather events by reducing the controller workload associated with flight deviations around weather and moving flights to less congested sectors. In this experiment we will model controller workload[15] in the region of the severe weather with and without Tactical Reroute capabilities. Several scenarios with en route weather impacts will be chosen for the study. Measurements of controller workload "as flown" will be taken as the baseline. HITL runs with SMEs – former TMCs or Supervisory Traffic Management Coordinators (STMCs) – using EFPT will be performed. The simulation environment will replay all traffic as it was at the time of recording and will allow the SMEs to reroute flights around severe weather based on their expertise and the information provided by EFPT. Separation between rerouted flights and other flights will be maintained through the use of a simulated sector controller.[16] The modeling of controller workload will include the workload of the simulated controller actions along with an estimate of reroute implementation workload.

IV. Conclusion

A new concept and prototype capability for supporting tactical rerouting by traffic managers has been described. Tactical Rerouting will reduce flight deviations around weather, which will increase order and predictability in en route weather-impacted sectors. This will result in increased system throughput during severe weather situations and allow reductions in the delay imposed by strategic TMIs. This hypothesis will be tested and quantified in an upcoming experiment.

Acknowledgments

The authors would like to thank Craig Wanke, Steve Zobell, David Chaloux, Kevin Workman, Dan Lei, Bill Bateman, Mike Klinker, Lixia Song, Claude Jackson, Laurel Rhodes, and Gretchen Jacobs for their contributions to the ideas, algorithms, and software used in this study.

Notice

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