1.5 RISK MANAGEMENT DECISION SUPPORT FOR TRAFFIC FLOW MANAGEMENT

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1. INTRODUCTION

Federal Aviation Administration (FAA) Traffic Flow Managers have to deal with uncertainty and risk every day. They must make decisions about weather and congestion forecast several hours into the future, where forecasts can have significant uncertainty. Current decision support systems do not process information on forecast uncertainty or probability, so decisions about risk and uncertainty are left to human decision makers.

Forecasts are always being improved and probability and uncertainty will be included in new forecast products. In many cases forecast uncertainty cannot be eliminated, and uncertainty can be significant.

Most people think of weather when forecasts are mentioned, but forecasts of flight density and demand will also be essential. Demand forecasts will be probabilistic and, like weather, significant amounts of uncertainty can occur.

It is difficult for humans to use uncertain forecasts to create decisions for a specific set of flights. Automated decision support tools are needed here to suggest actions that manage risk and are as efficient and fair as possible. These risk management systems will weigh the risks and costs of different approaches for dealing with future problems and recommend the best set of actions to take now based on the uncertain forecast information available. These recommended actions will be reroutes and delays for specific flights.

Concepts for traffic flow risk management automated decision support using uncertain and probabilistic forecasts are being explored at MITRE's Center of Advanced Aviation System Development (CAASD) in the Probabilistic, Automation-Assisted, En Route Congestion Management (PACER) project. This paper presents an overview of a long-term risk management concept. These ideas are in early development, and refinements and changes will be made as concepts are prototyped and explored. This paper also gives some insights into the user perspective of how probabilistic weather forecast information could be used in future decision support systems.

2. WEATHER, DEMAND, CAPACITY, AND CONGESTION FORECASTS

When we talk about future problems for Traffic Flow Management (TFM), people in the weather research community are likely to think of weather. But weather is not the only factor, and there can be congestion problems without weather due to excess flight demand alone. Weather is important, but weather in an area of low traffic density may not be a TFM problem. Also, areas outside the weather can become important congestion areas as flights attempt to avoid the weather.

Figure 1 shows an overview of the relationships between forecasts used for TFM risk management. Weather forecasts will come from external systems, but the demand, capacity, and congestion forecasts will be generated by the TFM risk management systems. Initial concept development is focusing on convective weather forecasts. Potential convective weather forecasts include the Collaborative Convective Forecast Product (CCFP) (Huberdeau et al., 2004), the Corridor Integrated Weather Systems (CIWS) (Robinson et al., 2004), and the National Convective Weather Forecast (NCWF) (Megenhardt et al., 2004). Researchers are investigating probabilistic forecasting, and probabilistic information is now included in CIWS and NCWF-2.

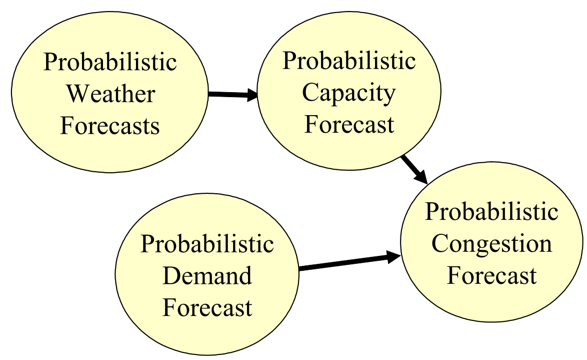

Figure 1. Forecasts Used for TFM Risk Management Decision Support

In order to deal with demand problems and weather problems at the same time, we need to develop a way to equate probabilistic weather forecasts to impact on the capacity of the National Airspace System (NAS). This capacity forecast will be a probabilistic forecast of the time varying capacity of each sector in the NAS based on weather impact from the probabilistic weather forecasts. This capacity forecast will provide a way to view weather impact and demand impact using common units of workload or number of flights a sector controller can handle. Forecasts of demand and capacity will likely be sector-based, since the ability of controllers to safely control the flights in the sector is the primary en route capacity constraint.

The complex relationship between forecast weather and forecast capacity is being studied and is not covered in detail here. Weather and capacity are related because

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the presence of weather can decrease the number of flights controllers can safely manage. Weather can concentrate flights into a smaller airspace, decreasing options and increasing sector complexity. Pilots may make last minute requests to avoid weather, increasing controller workload and decreasing the predictability of what flights will do. While we can say for sure that the presence of convective weather can decrease capacity, there is much about the effect of weather on capacity that is not well-understood, and more research is needed.

The demand forecast will be a probabilistic forecast of the time varying traffic demand in each sector. Traditionally, demand has been measured as the predicted peak number of flights in the sector within a 15 minute interval. More advanced demand concepts are also being researched, where the measure of demand could more accurately reflect the complexity and workload for controllers, and one flight may have more impact on demand than another, if the flight is expected to require more controller attention. Probabilistic demand forecasts have been studied extensively (Masalonis et al., 2004, Wanke et al., 2004, Wanke et al., 2003) and have been implemented in the PACER prototype.

Finally, the congestion forecast will provide probabilistic time varying chance of congestion for each sector based on demand/capacity imbalance. This will be derived by convolving the demand and capacity forecasts. This provides warning of the possibility of future problems that could lead to sector controller overload.

Figure 2 shows a concept graph of the forecast demand and capacity for one sector. The example is for sector ZID78, a high altitude sector in western Ohio controlled by Indianapolis Center. ZID78 is roughly 100 nm by 75 nm and controls flight levels from 31,000 ft to 36,900 ft. Examples of other sector sizes and shapes can be seen in the red and yellow highlighted areas in Figure 3.

The capacity forecast is shown as the blue background graph in Figure 2. This is where the weather impact will be reflected, and we can see that weather will start to impact the sector about 1 hour into the future. The range or spread of the blue bars represents the probability curves for each 15 minute interval into the future. These could also have been shown as box and whisker charts, but this simplified graph shows the capacity, demand, and congestion forecasts all at once. The y-axis is in units of demand, initially predicted flight counts. The top of the blue graph represents the 30% likely capacity, where capacity is 30% likely to be more than this value. Capacity is 80% likely to be higher than the bottom of the blue graph, and there is a blue marker in the middle for 50%.

Under normal circumstances and when weather is not a factor, the capacity of a sector is expected to remain constant and deterministic. The effect of weather is shown by the dip in capacity and the increasing uncertainty over time. If the forecasts stop predicting weather for the sector in the future, the uncertainty will decrease and capacity will again become more deterministic.

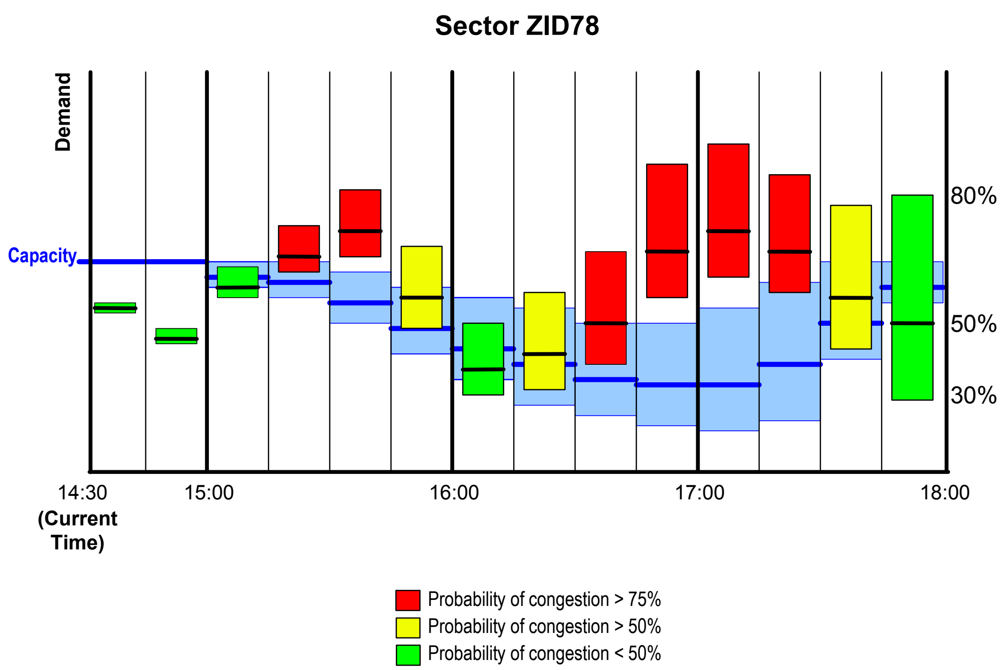

Figure 2. Forecast Capacity, Demand, and Congestion for One Sector

The demand forecast is shown as green, yellow, and red rectangles, where the color represents congestion and is described later. The top of the rectangle represents the 80% demand, where there is an 80% chance the demand will be less than this level. Most of the time demand uncertainty will increase with time, as shown by the larger demand rectangles with larger look-ahead times. Demand will be based on predictions of flight trajectories using flight plans, Rapid Update Cycle winds, and historically flown routes. Uncertainty in the demand forecasts will come from departure delays, cancelled flights, late flight additions, and late changes to routes and schedules.

The congestion forecast is shown by the green, yellow, and red colors. Green means the probability of congestion is below 50%, yellow is from 50% to 75%, and red is above 75%. Congestion is the possibility of demand exceeding capacity and will be derived by convolving the demand and capacity forecasts.

The cutoff percentages used in Figure 2 (30%, 50%, 80%, etc.) are examples, and the implementation in the PACER prototype will allow the use of other thresholds for displaying these charts. This concept graph may contain too much detail for many TFM decisions, especially if there are many sectors with future congestion problems. However, these graphs are useful to help concept developers understand the forecasts of demand, capacity, and congestion and what information risk management systems will need to use.

3. RISK MANAGEMENT CONCEPT

TFM risk management decision support systems will continuously monitor probabilistic forecasts and automatically identify times and places with future risks of congestion and will automatically recommend actions to manage those risks. The recommended actions will be specific reroutes and delays for specific flights.

When the probability of future congestion is low, the best action is often to do as little as possible now and reevaluate when more accurate demand and weather forecasts are available. Deciding to do as little as possible now helps avoid delays and reroutes that turn out to be unnecessary. Deferring action also allows more time for airlines and other flight operators to make their own risk management decisions and self-manage congestion problems. Allowing flight operators to make decisions whenever possible is one goal of TFM risk management, since many decisions depend on factors only known to flight operators, such as economics and scheduling of crews and equipment.

There are exceptions where action should not be deferred to wait for better information. These include:

1. Cases in which the likelihood of sector congestion is high. In these cases, there is little benefit to deferring action, even if it is possible to wait and still solve the congestion problems at a later time. The advantages of users knowing what TFM actions are needed will usually outweigh the small chance that those actions will be unnecessary.
2. Cases in which, if action is not taken now, there will no longer be sufficient flexibility to manage the congestion in the future should it occur.

Examples of the first case of highly likely congestion may include the time periods when the demand boxes are red in Figure 2. The actions that the risk management decision support will recommend should take some flights out of these sectors at these congested times by either delaying flights to later time periods, or rerouting flights into different sectors. Many of the flights will be left alone and allowed to enter the sector. These flights can have a risk of encountering weather, but that risk should be managed by the flight operator, and they should find alternate routes if the risks are deemed too high. TFM should only remove flights from a sector when the flight density in the sector is estimated to be too high for controllers to safely manage, given the forecast weather impact in the sector.

The second case of whether sufficient flexibility exists to manage congestion in the future is focused on the options available to solve congestion, and when in the future options will be lost or diminished. An example of flexibility for one flight is the option to hold the flight on the ground. This flexibility decreases as the departure time approaches, and at some point the option to hold the flight is no longer available.

An example of diminished flexibility is comparing rerouting a flight at the current position to avoid a congested area, or waiting for better forecasts and rerouting the flight at a later time, if necessary. In the majority of cases, waiting to reroute will involve sharper turns and longer reroutes for a flight than turning earlier. Waiting too long to reroute may leave no viable reroute options, either because the flight has insufficient fuel for the longer route, or the flight has moved to a place where reroutes around the congestion area are blocked by other congested sectors.

When the TFM risk management system decides that action is needed, in many cases the risk has been known for a while and flight operators have had a chance to consider taking action themselves. An exception could be when forecasts are rapidly worsening. When forecasts changes are minor, the recommended actions will likely be a few at a time and spread out over time. The system may recommend four flight plan changes now, and 10 minutes later recommend another six changes.

These recommended flight plan changes are delays and reroutes for specific flights. This set is called the action flights. Determining a small specific set of flights to act on now from among the many flights in a sector is a difficult decision. Many factors have to be considered, including whether the recommended actions are distributing delays unfairly. Detecting all cases of unfair distribution can be difficult for automation, and human decision makers may have to assist. If decision makers think the recommended risk management actions are unfair or problematic, the decision support tools will have the ability to run what-if scenarios with different settings before TFM approves one of the recommended action flight sets. The types of changes allowed for what-if scenarios will include the ability to exempt individual flights from reroutes or delays, and the ability to change parameters to make the risk management calculations more or less proactive.

In addition to the action flights, there are many other flights that have a risk of future action. These are called deferred flights. Airlines and flight operators will be able to see their flights that are candidates for deferred action. The notification that a flight is at risk will include estimates of the probability that the flight will become an action flight later if no changes are made for the flight.

When an airline is notified that they have action and deferred flights, they can investigate alternative routes and schedules. For action flights, the airline may look for other routes and schedules if they are not satisfied with the TFM accepted reroutes and delays. For deferred flights, the airline may want to trade longer flying time for less risk, and plan their flights through sectors that are predicted to have lower traffic levels than the problem areas.

Figure 3 shows an example of a flight with risk of delays. A flight is scheduled to fly from Dallas to Newark on the northern green route through several sectors colored coded yellow and red for forecast congestion. The airline has been warned there is a 50% risk of future delays and reroutes for the flight. The airline can search for alternatives or have automation systems present options. One option is to reroute on the southern route with 13 minutes additional flying time. This reduces the risk to 20%. Another option is to delay departure for 45 minutes and stay on the original route. This reduces the risk to 40%. The airline can choose to fly the original flight plan and accept the risk, or may prefer to accept additional delays and fuel costs to reduced risk.

Additional concepts are being explored to allow an airline to decrease delays on priority flights by adding delays to less important flights. These concepts are analogous to swapping techniques used for Ground Delay Programs (GDPs). Concepts are also being explored to handle capacity opening up, either due to decreased severity in forecasts, such as reduced chance of weather, or reduced demand due to cancellations or flights rerouting around a congested area. These concepts are analogous to compression in GDPs. The techniques used for airline collaboration in GDPs (Chang et al. 2001) are good starting points for exploring en route collaboration and congestion management, but the en route domain will be far more difficult to manage.

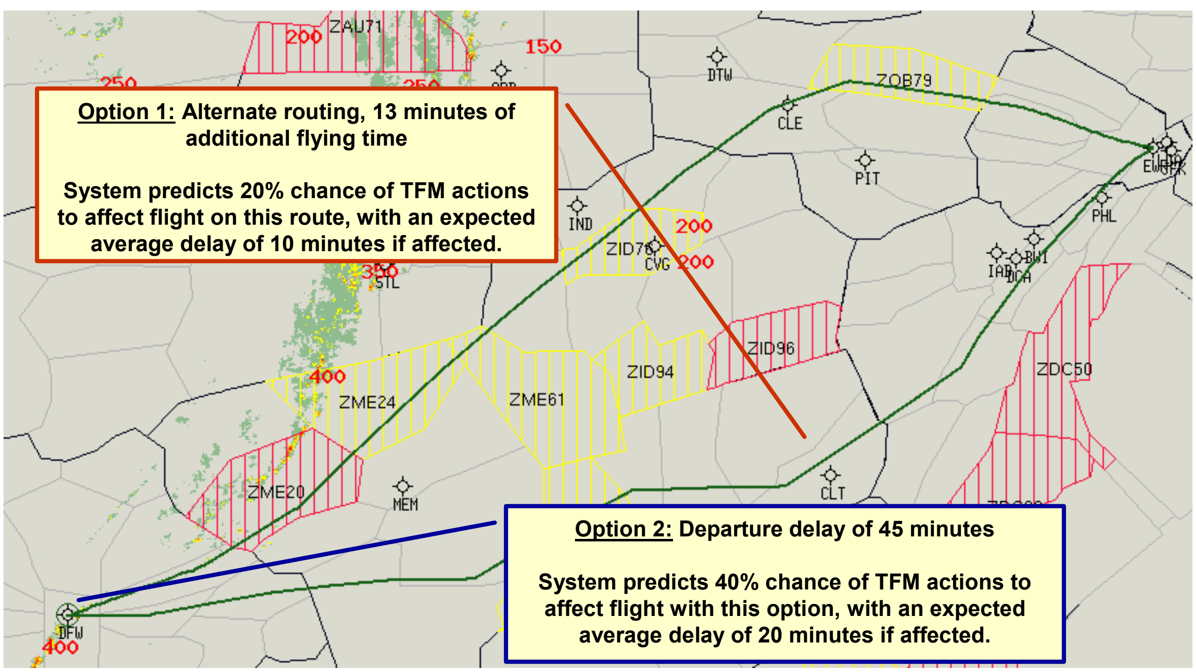

Figure 3. Flight Planning Options to Reduce Risk

4. SUMMARY OF EXPECTED FEATURES AND BEHAVIORS OF TFM RISK MANAGEMENT SYSTEMS

Many of the implementation details have to be worked out for the concepts presented here, and in some cases there are several implementation approaches. But any implementation of risk management decision support systems to support this concept will be expected to have the following key features and behaviors:

- Use of probabilistic weather and demand forecasts that quantify uncertainty,
- Periodic reevaluation and partial solutions with the tendency to recommend a few actions at a time,
- Tendency to defer decisions on many flights when forecasts are uncertain, provided there is sufficient flexibility to manage forecast problems at a later time,
- Tendency to hold future flexibility in reserve as a hedge against a possible pessimistic future,
- Airlines and flight operators are given as much time as possible to make their own decisions,
- Flight operators have access to the probabilistic weather demand, capacity, and congestion forecasts and to warnings of the risk of future action for their flights,
- Flight operators have the ability to run what-if evaluations of alternative routes and schedules for their flights, and see the risks and acceptability of the alternatives,
- When a flight plan is filed, quick feedback will be available on whether the flight is at risk for future TFM action or is an unacceptable plan because the flight will enter sectors that are already congested.

5. IMPLEMENTATION APPROACHES

One approach to implementing TFM risk management decision support systems would be to apply formal decision analysis. This approach may yield the most optimal and efficient results in terms of delays and impacts on flights. Although deferring decisions, recommending minimal reroutes and delays at any time, and holding flexibility in reserve may not be explicitly coded as goals of this risk management approach, these behaviors and the other behaviors of risk management that have been discussed are likely outcomes.

There are difficult problems to overcome to implement formal decision analysis techniques. First, costs have to be assigned for many factors, and in many cases these costs are difficult to quantify. Another problem is that optimized solutions can be time consuming to calculate. Spending extra time to produce more optimal results may sometimes be a bad approach, because the changes to the forecasts of demand and weather during the calculation may have a larger impact than any gains from additional optimization. Also, slow processing reduces the opportunities for decision makers to try alternative approaches. Additionally, many important factors are difficult to determine in a TFM risk management system, such as the constraints and costs on the airlines and flight operators. These factors can be very dynamic and hard to capture and provide to the automation. Any information flight operators can provide to the automation can be helpful, but we expect there will always be important factors that the automation does not know about. In this case, any speed increase in making decisions can outweigh the advantages of a slower but more highly optimized decision that is based on a subset of the important factors.

The PACER project is investigating proposals for faster risk management processing. A fast decision support tool will allow decision makers to try different alternative approaches to search for the most acceptable solutions that adequately manage risk. One approach relies on an ability to look at forecasts optimistically and pessimistically. Looking at a forecast optimistically will mean that we assume the outcome will be towards the best case prediction of the forecast. The optimistic analysis is used to identify nearly inevitable future problems, for which intervention is almost certainly required.

The pessimistic analysis is used in conjunction with a simulation of running the clock forward in time and moving the traffic and weather forward according to the forecasts. How far into the future will be determined through experimentation, but this will likely be from 5 to 30 minutes. If the pessimistic future can still be managed in this simulated future, then we can assume that it is safe to wait and check again later, if something needs to be done. If the problems cannot be managed in the simulated future, then we know that some actions need to be taken now, and there will be insufficient flexibility to handle problems if we wait. The details of this approach are complex, and have not yet been completely worked out.

6. CONCLUDING REMARKS

Forecast uncertainty will always be present and cannot be completely eliminated. These uncertain forecasts include weather and demand forecasts based on predictions of flight traffic. TFM risk management decision support systems are being developed to deal with forecast uncertainty provided the level of uncertainty is included in the forecast products. When forecasts are uncertain, attempting a full solution for future congestion will lead to large and unnecessary delays if the congestion does not develop as the forecasts predicted. TFM risk management decision support systems will constantly monitor weather and demand forecasts and may recommend slow changes to flight traffic over time to manage risks. When there is sufficient flexibility to solve congestion at later times, the systems will often defer action and reevaluate later when new forecasts are available. This gives airlines and other flight operators opportunities to make their own risk management decisions.

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