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Field & (Data) Stream: A Method for Functional Evolution of the Air Traffic Management Route Availability Planning Tool (RAPT)*

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A method coupling field evaluation with operations data analysis is presented as an effective means to functionally evolve a decision support system. The case study used to illustrate this method is the evaluation of the Route Availability Planning Tool (RAPT), a decision support tool to improve departure efficiency in convective weather in New York air traffic facilities. It was only through a combination of quantitative performance data analysis and field observation to identify key elements of the decision making process that the designers were able to determine the most critical departure management decision requiring support, leading to significant improvements in departure efficiency.

Introduction

According to a recent economics study, nearly three-quarters of nationwide air traffic delays are ultimately attributable to problems originating in the New York region’s airspace (Partnership for New York City, 2009). According to a study (Allan, 2001), even small improvements in departure rates could lead to significant reductions in delays. In order to assist the New York air traffic manager in maintaining departure efficiency during convective weather, the Route Availability Planning Tool (RAPT) was developed. This paper will describe the RAPT decision support tool and the functional evolution that occurred over 6 years of iterative field evaluations. An effective method of directing functional evolution will be discussed as well as lessons learned in air traffic management decision support tool design.

Departure Management

The goal of departure management is to ensure that the aircraft at airports are able to depart as expeditiously as possible. The process of departure management follows a functional loop shown in Figure 1.

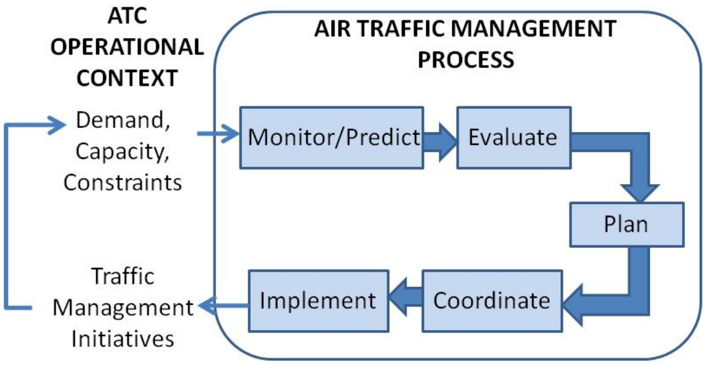

Figure 1: Departure Management Functional Loop.

The air traffic manager must *Monitor and Predict* the situation to determine the current and future demand on departure routes. He or she must also determine whether constraints, such as convective weather (thunderstorms), are predicted to impact the capacity on the departure routes. The air traffic manager must then *Evaluate* whether convective weather has affected the route to such an extent that it needs to be closed for a period of time, or alternatively, whether it can be opened due to improvements in the weather. If the route should be closed, the air traffic manager must *Plan* to close the route for the duration of the weather impact, and either shift demand to another open route or delay it. Alternately, if the route is to be reopened, departures must be staged for release on the route. In either event, a plan will then need to be *Coordinated* with other air traffic managers in other facilities, and with the supervisors of the tactical controllers executing the plan by controlling the traffic. Once agreement has been established for the plan, the air traffic manager can then *Implement* the plan (e.g., closing routes, issuing restrictions).

In clear weather, this process is accomplished without much travail, however it is significantly more difficult with convective weather that changes what routes it affects over time. Even once a plan has been implemented, the air traffic manager must revisit the situation frequently to determine if the weather is behaving as expected and modify the plan based on the new information obtained. This often requires multiple passes through portions or the entirety of the functional loop described above.

Evaluating whether a route is blocked by convective weather to the extent that the route should be closed is not an easy evaluation to make due to uncertainty of whether pilots will deviate and the continual evolution of the weather itself. This difficulty then leads to poor tactical decision-making including opening routes that should be closed and the opposite issue yielding unused capacity in the departure routes. Considering this cognitive difficulty in determining weather blockage on departure routes into the future and the system benefits potentially afforded by improving departure efficiency, the Route Availability Planning Tool (RAPT) was proposed.

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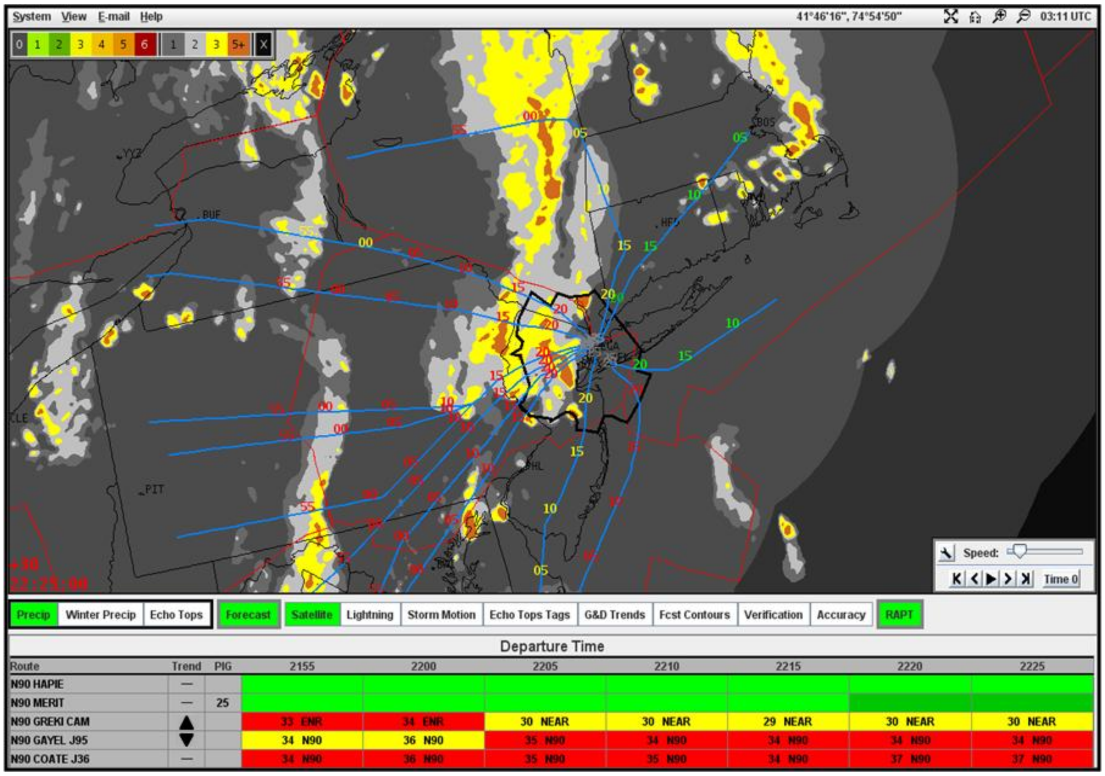
Route Availability Planning Tool (RAPT)

RAPT (DeLaura, 2003) is an automated decision support tool (DST) designed to help air traffic managers determine the specific departure routes and departure times that will be affected by operationally significant convective weather. RAPT helps users to determine when departure routes should be opened or closed and to identify alternatives to closed departure routes that are free of convective weather. RAPT, whose interface is shown in Figure 2, assigns a status color-“red” (blocked), “yellow” (impacted), “dark green” (insignificant weather encountered) or “green” (clear) - to each route for departure times up to 30 minutes into the future. The status is determined by combining deterministic weather forecasts from the Corridor Integrated Weather System (CIWS) with a route blockage algorithm that incorporates a model for departure airspace usage. The route blockage model calculates the severity of convective weather impact on the first 45 minutes of flight time of the departure route.



			Departure Time						
Route	Trend	PIG	2155	2200	2205	2210	2215	2220	2225
N90 HAPIE	—		🟩	🟩	🟩	🟩	🟩	🟩	🟩
N90 MERIT	—	25	🟩	🟩	🟩	🟩	🟩	🟩	🟩
N90 GREKI CAM	▲		🟥 33 ENR	🟥 34 ENR	🟨 30 NEAR	🟨 30 NEAR	🟨 29 NEAR	🟨 30 NEAR	🟨 30 NEAR
N90 GAYEL J95	▼		🟨 34 N90	🟨 36 N90	🟥 35 N90	🟥 34 N90	🟥 34 N90	🟥 34 N90	🟥 34 N90
N90 COATE J36	—		🟥 34 N90	🟥 36 N90	🟥 35 N90	🟥 35 N90	🟥 34 N90	🟥 37 N90	🟥 37 N90

Figure 2: 2009 RAPT interface.

The map segment of Figure 2 depicts the key departure routes out of the New York area overlaid on a CIWS precipitation forecast. The bottom segment shows the RAPT timeline display. Each row represents a departure route with subsequent rows showing the next route progressing counter-clockwise from the east. Each of the colored-block columns indicates the blockage status along the route for a particular departure time, progressing in 5 minute intervals. The number within the colored block is the altitude of the echo tops (a measure of storm height) at the point of the blockage in thousands of feet. The text following the number indicates the location of the blockage (e.g., “N90” is in the New York terminal area). The “trend” column summarizes the route availability trend over the *preceding* 30 minutes (improving, deteriorating, stable, or uncertain). The “PIG” column (PIG= Post-Impact “Green”) indicates how long a departure route has been “green” after a storm has passed through.

The RAPT was deployed in the New York air traffic control facilities in late 2002. As funding was available, field evaluations of the tool occurred yearly to improve operational usage of the tool to enable improvements in departure management performance. Throughout the years, the method of evaluation evolved to better investigate the departure management process and RAPT’s role in supporting it.

Evaluation Method

Figure 3 depicts a generalizable evaluation method that was used to evolve the RAPT system functionally. This method is different from iterative user interface design methods such as those presented in (Nielsen, 1993), (Bury, 1984), and (Buxton & Sniderman, 1980), because it explicitly uses both field observation data and operations data analysis as complementary, but separate, means to improve the design.

In the qualitative data loop, *Field Observations* were used to understand how the operational process worked and the procedures that led and constrained the actions of the operators. Field observations also provided initial suggestions by the operators of areas in which they thought decision support would be beneficial. This information was used to develop the project's *Operations Model* upon which assumptions for appropriate decision support were made. By creating a developed model of the operational environment, informed hypotheses about which decisions would be aided by decision support could be made. With knowledge of the operational problem to be solved and the procedures and constraints within which the tool would be used, *Decision Support* algorithms and information were created or refined. Subsequently, knowing the unique decision support offering and the operational context allowed an appropriate *Graphical User Interface (GUI)* to be designed to be well-integrated into the environment. Concurrent *Training* with GUI deployment/updates allowed the rationale for the decision support tool to be presented to the operators.

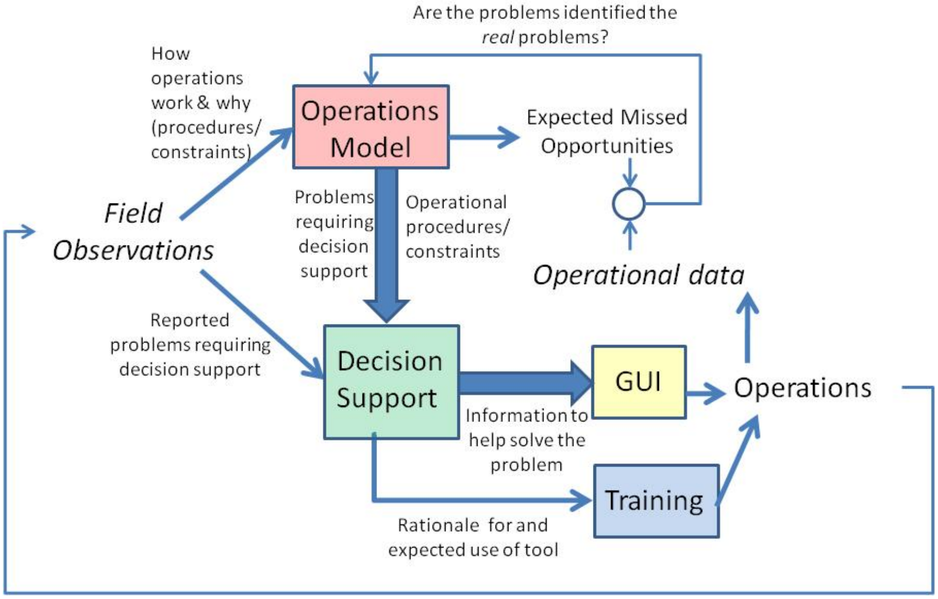


Figure 3: Qualitative + quantitative method for evolving system functionality.

If operational data are available to the tool developers/ evaluators, a quantitative evaluation loop can also exist to validate the rationale for the decision support tool. Through development of the Operations Model, hypotheses about where decision support is required can be generated. If decision support is "required," there must be in the existing system certain missed opportunities for better system performance. The circumstances and performance metrics that define missed opportunities, and the cost associated with them, should be identified. These expected missed opportunities can be compared with the actual operational data to confirm/deny the hypothesis. This data analysis then provides quantitative information upon which to base a rationale for decision support, and this grounded rationale can be communicated to the operators during training. With decision support, the missed opportunities should then be reduced or eliminated, manifesting in improved system performance that can be validated, assuming the tool is implemented with knowledge of the operational context, reasonable GUI design and the appropriate training. In the following section, the RAPT evaluations will be used to demonstrate how this process was accomplished and its benefits for one project.

RAPT Evaluation Findings

Table 1 provides a summary of the field evaluation findings over the first 6 years of RAPT deployment. The first column in the table states the problem discovered in the evaluation and how the problem was addressed in RAPT design. The second column itemizes the evaluation methods used. The third column indicates the concept of RAPT use followed during that year's training and evaluation.

In 2003 RAPT was deployed, and the air traffic managers were trained to direct aircraft through "green" routes, with the purpose of squeezing out an extra 2-3 departures per hour. Evaluation was primarily qualitative, using interviews with participating air traffic managers and observational logs mentioning RAPT. A departure queuing model (Evans, 2007) was also used to identify the delay saved in these instances. During this season, operational data indicated that pilots often were able to fly over thunderstorms on routes that RAPT had flagged as "red", leading to the realization that the operations model needed to account for the height of echo tops encountered along the departure route.

Therefore, in 2004 the primary improvement to RAPT was incorporation of the echo tops into the blockage considerations (DeLaura & Allen, 2003). Increased acceptance of the tool was observed using remote monitoring of the deployed system and observations revealed that air traffic managers and airlines beginning to use RAPT as a basis for traffic management negotiations.

In 2005-6, little funding was available to the RAPT project that would allow adequate field evaluations. Thus, minor improvements in the interface and algorithm were made over

Table 1: RAPT Field Evaluation Findings Summary 2003-2009.

	RAPT Problem	RAPT Solution	Evaluation Method	Concept for RAPT Usage	Delay Reduction (hours)
2003	-	Original RAPT	Mainly qualitative: •Anecdotal •Queuing model	Direct aircraft through "green" gaps	-
2004	Overwarning blockage	🟥 Incorporating echo tops into algorithm	Mainly qualitative: •Observation of RAPT output & traffic	No change	-
2005-6	-	🟨🟥 Minor improvements	No funding available for data collection	No change	-
2007	Need RAPT business case support	-	Qualitative + Quantitative: •Field Evaluation •Anecdotal •Queuing model	No change	2300
2008	Volatility between departure time blocks for a route	🟥 Improving stability	Qualitative + Quantitative: •Data Analysis •Field Evaluation	Encourage pattern recognition of weather movement using timeline grid (the "hard" problem)	2600
2009	Disappointing improvements in calculated delay	🟨🟩 Re-evaluate decision needing support & add PIG timer to GUI	Qualitative + Quantitative: •Departure management metrics (e.g., PIG)	Encouraging the re-opening of departure routes after a storm impact (the "easy" problem)	5600

🟥 Operations Model Improvement
🟩 Decision Supported Improvement
🟨 GUI Improvement

this period, including revising the departure routes to better reflect the New York traffic flows.

In 2007, the Federal Aviation Administration (FAA) sponsored an extensive investigation into the operational benefits of RAPT to determine if they were interested in expanding the usage beyond New York. An evaluation of RAPT use, supported by traffic data, weather data and in-situ field observations for 11 days was conducted (Robinson, DeLaura, Evans & McGettigan, 2008). This evaluation focused on three critical areas: validity of the RAPT operational concept ("Does RAPT provide information needed to realize improved departure efficiency? Is that information being distributed to the key participants in the decision making process?"), operational fidelity ("Does the RAPT blockage algorithm work?") and improvements needed to increase the realization of RAPT benefits (e.g., timeliness, reliability). Each instance observed in the field for which RAPT had an impact was translated into delay savings by joining flight data with feedback from air traffic managers to estimate the difference in capacity had they not had access to RAPT. Using this method, a delay savings of 2300 hours was attributed to RAPT usage in this year.

The 2007 evaluation identified a key impediment to RAPT use: excessive volatility in RAPT departure status predictions (REDs, GREENS, etc.), due to oversensitivity of the RAPT blockage algorithm to small details in the input weather forecasts. The algorithm's sensitivity was adjusted and another thorough analysis was conducted. In 2008, the RAPT-attributed delay savings only increased by 300 hours (Robinson, Underhill & DeLaura, 2009).

The marginal improvements in delay saved in 2008 were disappointing, so the operational data were re-visited to ensure that there were no missed opportunities in making the "easy" decision of route re-opening after a storm impact. It was in this analysis that it was determined that late re-opening of departure routes during post-impact "greens" (or PIGs) accounted significantly for departure inefficiency (Robinson, et. al., 2009). Once this missed opportunity was identified, specific decision making scenarios and relevant metrics (e.g., time to first departure during a PIG) were defined. In training, the decision making scenarios and PIG metrics were presented to *all* of the decision makers that had been identified in previous field observations. Finally, a PIG timer was included in the RAPT GUI that indicated how long a route had been green after an impact to encourage air traffic managers to re-open the route as soon as possible. When the GUI improvement was coupled with training that focused the air traffic managers on this missed opportunity in 2009, the delay savings attributed to RAPT more than doubled to 5600 hours.

Discussion

In the RAPT evaluation cycle, the joint qualitative and quantitative loops allowed designers to make major improvements in the decision support and resulting operational benefit afforded by RAPT. The first five years of mostly qualitative evaluations were focused on improving the operational model of the departure management process and refining the validity and robustness of the decision support information. Ensuring the operational model was correct was critical in establishing the air traffic managers' trust in the information that RAPT provided. In the last year, operations data analysis supported a revision of which decision in the departure management process required support. Instead of focusing on supporting the "hard" decision of squeezing out an extra departure or two in "green" areas of a departure route, it was determined that it was the "easy" decision of re-opening a route that required support. The provision of a clearly defined operational decision-making scenario (reopen closed departure routes when the PIG appears) and objective performance metrics during training alerted air traffic managers to significant missed opportunities to improve departure throughput. The combination of improved focus and training, and a simple GUI addition of the PIG timer, resulted in a significant operational benefit.

Considering the value of the two closed loops of the evaluation process presented, the RAPT project was fortunate to have been given access to both the field environment and the operations data. It is understood that not all environments are so fortunate. Without access to operations data, hypotheses about appropriate decision support remain hypotheses and can only be, at best, loosely validated with expert input. Without the ability to observe the decision support tool in the field, operational acceptability and tool integration into the operational context cannot be easily established. In this case, interviews with users of the tool would provide value. Where designers cannot be given access to the field environment, possibly due to issues of safety and/or security, an operational model must still be generated, but this model is built alternatively on expert hearsay and/or the developers' experience with analogous systems. This model is necessarily less well-developed and therefore any hypotheses about appropriate decision support have a higher potential to be invalid. The more information that a developer can access about the operational context including procedures, goals, constraints, and expert descriptions of critical decisions and /or incidents, the better to increase the probability of success of the decision support tool design.

Finally, it is of value to notice that the GUI must follow the functionality of the decision support. While a good decision support tool necessarily must have a logical and usable GUI to present the information, a usable GUI does not ensure adequate decision support. Throughout the RAPT functional evolution, few changes were made to the core GUI. The critical updates to make RAPT effective decision support originated from ensuring that there was a correct operations model around which to build a decision support function.

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