P1.5 OPERATIONAL USAGE OF THE ROUTE AVAILABILITY PLANNING TOOL DURING THE 2007 CONVECTIVE WEATHER SEASON†

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1. INTRODUCTION

Efficient management of air traffic departing metro New York (NY) airports during convective weather is one of the most difficult problems, and largest sources of delay, in the U.S. National Airspace System (NAS). The high air traffic demand in the limited-capacity, complex terminal and en route airspace network requires quick decisions and extensive coordination amongst multiple air traffic control (ATC) facilities in order to prevent rapid escalations in NY air traffic delay and potential airport surface gridlock (e.g., Evans et al. 2007; Robinson et al. 2006; Davison and Hansman, 2001).

The Route Availability Planning Tool (RAPT) is an integrated weather / air traffic management (ATM) decision support tool that has been designed to help traffic managers better anticipate weather impacts on jet routes and increase NY departure route usage efficiency. RAPT uses deterministic precipitation and echo top forecasts, together with airspace usage and flight trajectory models, to indicate the status of the various NY departure routes as clear, partially-blocked, or completely blocked by weather as a function of aircraft departure time (Figure 1). The RAPT algorithm and display features are described by DeLaura et al. (2008a). RAPT is in operational use at all first tier FAA facilities surrounding the NY terminal area and a number of airline dispatch centers (Figure 2).

In the summer of 2007, MIT Lincoln Laboratory (MITLL) and the FAA Aviation Weather Office conducted a comprehensive field study in the NY airspace region to assess RAPT operational use during adverse weather, critique RAPT technical performance at forecasting route blockage, and better understand the overall NY airport departure decision-making environment. Simultaneous real time observations of operations at FAA and airline facilities were carried out on 11 days when convective weather impacted NY air traffic. A description of the design and methodology of this experiment is presented in Section 2 of this paper.

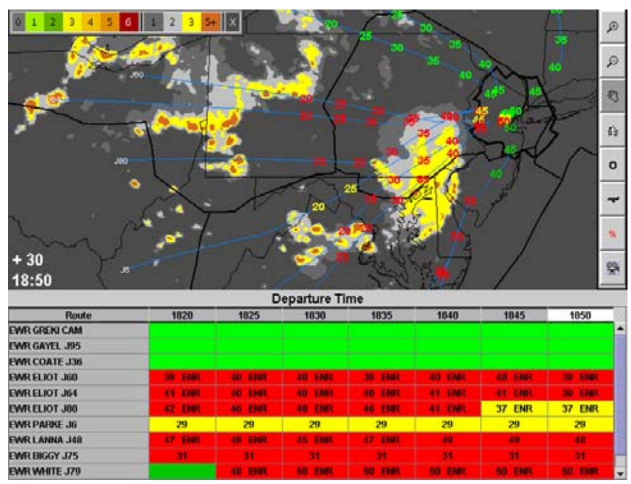

Figure 1. Route Availability Planning Tool (RAPT) display (as seen on 09 Aug 2007). RAPT timelines (bottom) depict anticipated convective weather blockages for select routes and departure times in five-minute increments. Median echo top heights along the route are indicated when RAPT blockage status is yellow (caution) or red (blocked). If the primary route blockage occurs beyond NY airspace, an 'ENR' tag alerts users that the blockage is present "en route". The animated Corridor Integrated Weather System (CIWS) precipitation forecast (top) is shown with graphical depictions of five-minute departure trajectories for increased awareness and improved interpretation of RAPT-derived route blockages.

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†This work was sponsored by the Federal Aviation Administration under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the United States Government.

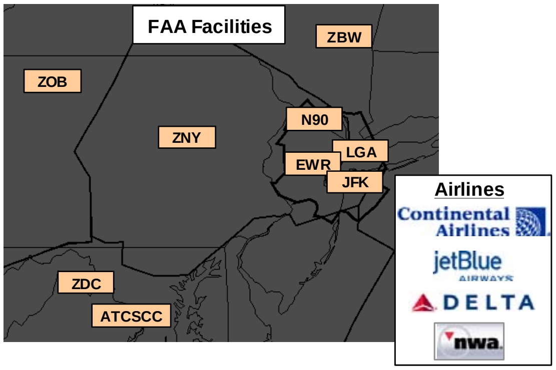

Figure 2. FAA and airline facilities with access to RAPT in 2007. Access to RAPT at Newark (EWR), LaGuardia (LGA), and John F. Kennedy (JFK) airport towers was available via thin-client applications installed on Internet-ready PCs. All other facilities accessed RAPT via dedicated CIWS situation displays.

Observed RAPT operational benefits included increased departure route throughput, improved route impact timing leading to more efficient reroute planning, and more timely decision coordination. Results demonstrating the various observed RAPT delay mitigation and decision coordination benefits, the frequency of RAPT use at each RAPT-equipped FAA and airline facility, and quantified delay savings (per use and as an annual estimate) are presented in Section 3.

Additional objectives of the in-field RAPT usage observations were to (1) develop a better understanding of NY departure management during convective weather in an effort to improve RAPT features, (2) clarify post-event benefits analyses, and (3) support/refine ongoing user training. Empirical data relevant to RAPT usage and potential follow-on enhancements are presented in Section 4 and include observations of the multi-facility departure management decision chain during convective weather, the Air Traffic Control (ATC) concerns, needs, and responsibilities (and how they differ) at specific FAA facilities, and the procedures and pitfalls of the current process for capturing and disseminating pertinent traffic flow management (TFM) information.

Section 5 provides an estimate of the near-term potential increase in RAPT usage and quantifiable benefits expected through enhanced user training, route blockage forecast algorithm and display enhancements, and greater operational user understanding of the role of RAPT in collaborative, tactical decision-making for NY departure management. Specific near-term enhancements to increase RAPT usage and delay reductions benefits are summarized.

2. 2007 RAPT BENEFITS ASSESSMENT METHODOLOGY

The RAPT operational benefits study was modeled after the Corridor Integrated Weather System (CIWS) delay reduction studies conducted in 2003 and 2005 (Robinson et al. 2004; Robinson et al. 2006). Knowledgeable observers were present at several FAA and airline facilities during convective weather events to observe the operational uses of RAPT in real-time. Observations at each facility were made simultaneously in order to better understand the coordination and collaboration efforts associated with departure flow management.

Observation teams from MITLL and the FAA Aviation Weather Office were dispatched to major FAA and airline facilities involved in NY departure management, including three control towers [Newark (EWR), LaGuardia (LGA), and John F. Kennedy (JFK) airports], the NY Terminal Radar Control (TRACON) facility, several Air Route Traffic Control Centers (ARTCCs), including NY (ZNY), Cleveland (ZOB), Washington (ZDC), and Boston (ZBW), the Air Traffic Control System Command Center (ATCSCC), and airline operations centers for Continental (at EWR) and Jet Blue Airlines (Figure 3). Using the methodology summarized in Figure 4, the detailed observations of RAPT-derived departure flow management decisions at each of these facilities were used to determine the various operational benefits of RAPT, estimate the frequency of each benefit category, and obtain data used for RAPT delay saving case studies.

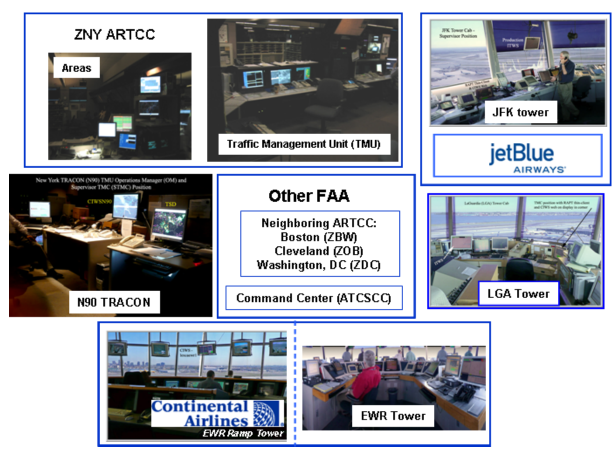

Figure 3. FAA and airline facilities included in the 2007 RAPT field-use assessment experiment. ARTCC observations included RAPT applications and weather-TFM decisions made by in the Traffic Management Unit (TMU) and Area Supervisors.

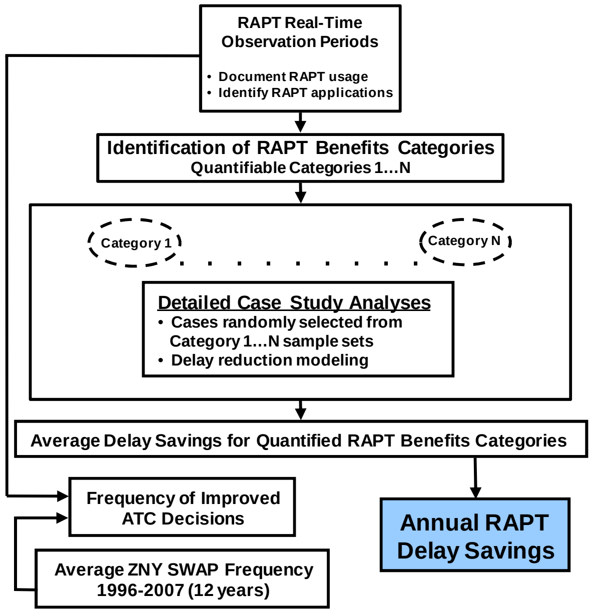

Figure 4. Methodology used to estimate annual RAPT delay reduction benefits. SWAP stands for "Severe Weather Avoidance Program", which is implemented in NY airspace when convective weather causes significant air traffic disruptions.

2.1 Tasks of RAPT Field Use Observers

During convective weather events, MITLL and FAA Aviation Weather Office observers at each selected facility routinely documented the following:

- Weather characteristics/situation
- Weather impact on air traffic
- Weather impact mitigation decisions/plans
- What RAPT depicted
- RAPT operational uses (if any)
- If there were questions about RAPT from the operational users
- Other weather/ATC decision support tools used

Observations were made several times per hour as convective weather evolved; as impacts on NY departure traffic varied; and as traffic management decisions required reevaluation and revision. By focusing on both RAPT and the complete decision-making environment, detailed data were obtained on:

A. RAPT route blockage forecast technical performance (DeLaura et al. 2008a)
B. RAPT operational usage and the frequency of various uses of RAPT
C. Support information for RAPT benefits case studies
D. NY TFM Severe Weather Avoidance Program (SWAP) operations

RAPT observers responded to and documented all RAPT user requests. Past experiences with fielding and supporting the CIWS prototype had shown that users will request additional features or display capabilities, and more willingly make suggestions for potential improvements to a demonstration system, when support personnel work with them during real-time weather events. Traffic managers and airline dispatch coordinators using RAPT during adverse weather this summer identified many additional features they felt would improve RAPT capabilities and increase potential benefits. All user requests and suggestions were forwarded to RAPT algorithm/display development teams.

The RAPT observers at FAA and airline facilities also supported ongoing RAPT training[1]. In order to build user confidence in RAPT and increase user expertise, on-the-spot RAPT training was provided when questions arose. Observers took care to note all instances when RAPT training or additional assistance was provided, removing these events from the database in order to ensure that RAPT benefits calculations discussed below are based only on unassisted usage of RAPT.

2.2 Determining Quantitative RAPT Delay Savings

The RAPT field-use observations were analyzed to determine the operational uses of the information provided. Each individual observation of a specific RAPT application was assigned to a RAPT benefits category. The frequency of each type of observed RAPT benefit was determined for each FAA facility and collectively across all facilities. Final estimates for the RAPT benefits frequency per facility were normalized to account for differences in the number of observed convective weather days at each facility. The historical average number of NY SWAP days was used to convert RAPT benefits frequencies per convective weather day to an annual RAPT usage estimate (see Figure 4).

Analyses of individual RAPT applications for each type of quantifiable benefits category were then conducted to determine hours of delay saved

[1]The importance of repeated, interactive real-time training when introducing new convective weather decision support information or technology to TFM decision-makers operating in a high-stakes environment is discussed in Robinson and Evans, (2008).

per operational use of RAPT. These delay savings were converted to cost savings using standard, FAA-supplied conversion metrics.

Departure delays from metro NY airports are incurred primarily on the ground, where a queue of departing aircraft can quickly build when the departure demand is very close to the fair weather departure capacity (e.g., Allan et al. 2001; Robinson et al. 2004). A queuing model was used to measure delay savings for each RAPT benefits case study[2]. The single server queue model requires only two input fields: air traffic departure demand and capacity as a function of time. The demand profile in the model was set to the scheduled departure rate from each NY airport averaged over two clear-weather weekdays in August 2007. The capacity profile in the model was derived from the departure rates actually achieved on the weather impact day for which RAPT applications were being reviewed. Inspections of flight track data, coupled with feedback from operational traffic managers, were relied upon to estimate differences in airport departure capacity if RAPT-derived traffic management decisions had not been made.

The RAPT delay reduction benefits expressed in hours of delay were then converted to airline Direct Operating Costs (DOC) and Passenger Value Time (PVT). The following cost conversions were used to estimate RAPT monetary operational benefits:

- 2007 airline DOC, incurred on-the-ground: $1828 per hour (FAA, 2007)
- PVT cost: $2173 per hour (Robinson et al. 2004; APO Bulletin, APO-03-01, 2003)

Final estimates of RAPT delay and monetary savings must also account for the ripple effect that arises when an aircraft is delayed on one leg of a flight (e.g., due to adverse weather) such that the subsequent legs flown by that aircraft that day are also delayed (e.g., DeArmon, 1992). In this study, downstream delay reductions are assumed to equal 80% of the initial delay (Boswell and Evans, 1997); however in estimating monetary savings associated with downstream delay reductions, only PVT-related savings are included (i.e., no downstream DOC savings appear in the results). Thus, these computations of downstream delay savings are considered very conservative (e.g., Hartman, 1993; Beatty et al. 1999; Robinson et al. 2004).

3. RAPT BENEFITS EVALUATION RESULTS

Observations of RAPT use in the field were conducted on 11 convective weather days (120 hours of ATC operations) during the 2007 summer storm season. Snapshots of the convective weather coverage and intensity, on the dates on which observers were present in operational facilities, are shown in Figure 5. Convective weather coverage, location, storm type, intensity, and times of storm development and decay varied significantly across the 11 days of field observations, resulting in a large variety of air traffic impacts and subsequent traffic management initiatives to help mitigate delay. Therefore, these observation periods were considered representative of the convective weather events that can disrupt NY air traffic operations and specifically NY departure flow management.

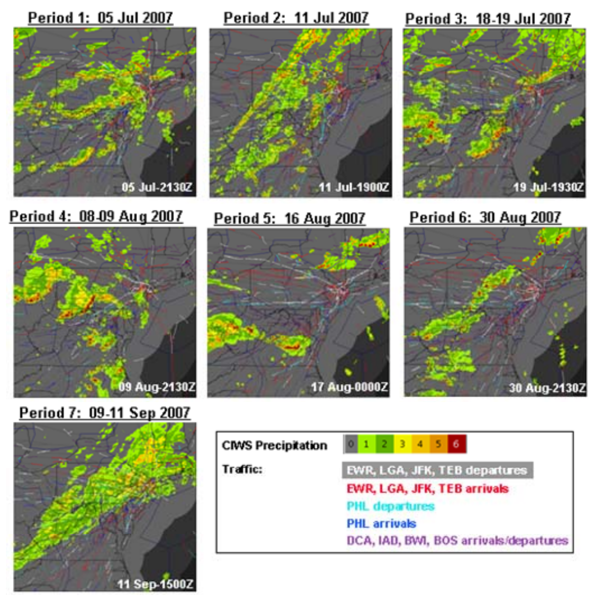

Figure 5. Field-use observation periods for the 2007 RAPT benefits assessment study.

3.1 RAPT Benefits Categories and Frequency of Use

Usage of RAPT by FAA traffic managers and airline dispatch coordinators was partitioned into the following 11 benefits categories:

1. **RO** More timely departure route reopenings; eased departure restrictions

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[2] The queuing delay model, developed by Evans (1997), is discussed in detail in Robinson et al. (2004). In 2007, the modeling group at the FAA William J. Hughes Technical Center examined the RAPT delay modeling approach and considered the queuing model and the design of the RAPT benefits experiment reasonable.

2. **RRP** More timely reroute planning or implementation; improved route impact planning
3. **DP** Directing pathfinder requests
4. **DOL** Keeping departure routes open longer
5. **AHD** More timely and proactive resumption of arrival flows; decreased airborne holding; potentially saved diversions
6. **PRSA** Proactive runway sequencing assistance
7. **EP** Enhanced decision-making productivity
8. **I/IC** Enhanced Inter/Intra- facility coordination
9. **SA-1** Enhanced common situational awareness
10. **SA-2** Improved awareness of evolving airspace impacts
11. **SA-3** Decision/plan/information confirmation or evaluation

Canonical examples of each of the benefits categories considered quantifiable (1-6 above) are presented in DeLaura et al. (2008a). Of these, four primary departure route management categories (RO, RRP, DP, and DOL) were the focus of the 2007 delay savings estimates. Results are presented in Section 3.2 and Appendix A.

Though more difficult to translate into tangible delay and cost savings estimates, RAPT benefits categories 7-11 are critical to improving decision-making planning and coordination, which in turn increase the likelihood of implementing other RAPT-derived capacity enhancement decisions such as RO or RRP[3].

Common awareness of rapidly evolving convective weather impacts in the complex NY airspace region is extremely important. The ability of RAPT to calculate and depict the route impact status for specific airport departure times allowed traffic managers to (a) quickly digest the current and near-term status of departure routes (SA-1), (b) proactively ascertain when the availability of specific departure routes was changing – open to impacted to closed, or closed to open (SA-2), and (c) evaluate departure flow management decisions and if needed, offer RAPT-derived alternatives (SA-3).

The frequency of RAPT benefits observations at each facility, normalized by the number of convective weather days on which observations were made, is shown in Table 1. Overall, the per facility frequency of the most common quantifiable RAPT benefits categories – RO, RRP, and DP – ranged from once in two SWAP days to once in ten SWAP days. However, when one considers benefits for RO, RRP, and DP categories across all facilities, one finds that a RAPT-derived delay mitigation decision occurs roughly once per NY SWAP day. Case study results in Section 3.2 (and Appendix A) and extrapolations to annual estimates in Section 3.3 show that the observed frequency of RAPT usage provided significant operational benefits in 2007[4].

At most facilities, 2007 was the first year that the majority of traffic managers attempted to use RAPT to improve NY departure flow management. Therefore, operational users often monitored RAPT to increase their awareness of pending route impacts and to confirm decisions made with other tools such as CIWS, the Enhanced Traffic Management System (ETMS), or their controller scopes. Because of this, instances of the RAPT decision coordination and confirmation benefit categories (EP, I/IC, SA) were more frequently observed than the quantifiable benefits categories (see Table 1). This was particularly true at ZNY, where Supervisor Traffic Management Coordinators (STMC) often consulted RAPT departure status timelines for quick updates on which routes may be blocked by convective weather.

Table 1. Normalized RAPT Benefits Observations by Facility*

	LGA	EWR	JFK	N90	ZNY	ZDC	ZOB	ZBW	Airline	ATCSCC
RO	0.4	0.1	0.2	0.2	0.3	0	0	0	0	0
RRP	0	0	0	0.1	0.5	0	0	0.2	0	0.2
DP	0.1	0	0.2	0.3	0.3	0	0	0	0	0.2
DOL	0.1	0	0	0	0	0	0	0.2	0	0
AHD	0	0	0	0	0.1	0	0	0	0	0
PRSA	0	0	0.2	0	0	0	0	0	0	0
EP	1.3	0.5	0.7	0.3	1.9	0.2	0.3	0.4	0.4	0.4
I/IC	1.1	0.7	0.3	0.7	2.1	0.2	0.1	0.2	0.2	0.4
SA-1	2.5	0.7	0.2	1	3.5	0.4	0.7	1	0.6	0.6
SA-2	1.6	1.1	0.7	0.8	3.5	0.1	0.9	0.2	0.2	0.2
SA-3	2.3	1.1	0.8	0.9	1.1	0	0.7	0.4	0.2	0
# Days	11	10	6	11	11	10	7	5	5	5

RO Route Reopenings; Eased Restrictions
RRP More Timely Reroute Planning/Implementation
DP Directing Pathfinders
DOL Departure Routes Open Longer
AHD Proactively Resuming Arrival Flows; Decreased Airborne Holding
PRSA Proactive Runway Sequencing Assistance
EP Enhanced Productivity; Reduced Workload
I/IC Enhanced Inter/Intra-Facility Coordination
SA-1 Enhanced Common Situational Awareness
SA-2 Improved Awareness of Evolving Impacts
SA-3 Decision Confirmation/Evaluation

**Facility that used RAPT most frequently for each benefit category is shown in red*

[3] A study of decision-making productivity enhancements attributed to CIWS concluded that use of CIWS for improved common situational awareness and enhanced inter/intra-facility coordination resulted in more efficient use of available en route airspace capacity and increased ATC controller productivity during adverse weather (Robinson et al. 2006).

[4] In Section 5, we discuss why the RAPT benefits for 2008 and beyond should be significantly higher than that the observed 2007 RAPT benefits.

Controllers in the LGA Tower often used RAPT to support a “bottom-up-push” for departure management decisions (SA-3 category). Decreasing departure route capacity and increasing NY departure delay ultimately result in runway and taxiway backups at the airports. Therefore the tower controllers are often the first to recognize the need to search for options to release departure traffic. This motivated LGA to use RAPT route availability predictions to collaborate with N90 and ZNY for proactive delay mitigation solutions. Moreover, tower personnel, focusing on jet routes that only impact their operations, are likely able to use RAPT to more closely monitor the status of their departure routes than traffic managers at N90 TRACON and ZNY ARTCC, where the traffic management responsibilities and coordination requirements may be more extensive.[5]

Instances of similar RAPT usage were less frequent at JFK and EWR towers. Although all three towers accessed RAPT via a thin-client display application installed on an Internet-ready PC in the tower cab, the JFK and EWR computers were either poorly placed or hosted additional applications used for critical administrative tasks. This effectively reduced access to the RAPT products at the EWR and JFK towers, which in turn reduced the overall RAPT operational effectiveness there (see EWR and JFK RAPT EP, I/IC, and SA usage frequencies, compared to LGA, in Table 1). Improved access to RAPT information in the towers is considered a very important factor for increased RAPT usage and operational benefits (as will be discussed in Section 5).

3.2 RAPT Delay Savings Case Studies

Case studies of observed RAPT operational usage allowed us to estimate the delay savings associated with the four primary departure route management benefits categories – RO, RRP, DP, and DOL. To prevent double-counting, care was taken when categorizing RAPT usage observations to ensure that only one quantifiable benefit category (see categories 1-6 in Section 3.1) was assigned to each observation. Details of each RAPT benefits case study are provided in Appendix A.

In each case, a queuing delay model was used to estimate delay savings at each of the metro NY airports (LGA, EWR, and JFK). Model results from each of the individual airports were then combined for total savings attributed to the RAPT application under study. In some cases, queuing delay estimates were required for the Philadelphia airport (PHL) as well. Even though PHL departure route guidance is not explicitly included in RAPT, traffic managers occasionally utilized PHL pathfinders to test the availability of previously-closed routes (used by PHL and NY airports) identified by RAPT as clearing (see Cases A-3-1 and A-3-2 in Appendix A).

A total of 11 RAPT benefits cases were analyzed. A summary of RAPT delay savings (hours of delay saved and cost savings) derived from these case studies, for each of the four primary departure route management categories, is provided in Tables 2A-2D. The calculated delay reduction for an individual RAPT-derived decision ranged from 0.9 hours (20 July 2007 - RO case) to 26.7 hours (19 July 2007 – RRP case). This large case to case variability was not surprising; in fact, it is the primary motivation for the multiple case study approach, given the sensitivity and nonlinear characteristics of NY queuing delays. However, since RAPT benefits often occurred over shorter “super-tactical” time periods, and were applied to a smaller sub-region of the constrained NAS network, the variability in RAPT delay savings was not as great as previous CIWS case study results[6].

Mean and median RAPT delay savings per quantified benefits category were computed to determine the average delay reduction per RAPT application[7] (Table 3). Mean delay estimates are likely the most appropriate measure for average delay but given the small case study sample sets, and the wide spread in benefit estimates, unacceptably high variability exists with the mean. Therefore median benefits results were preferred for estimating annual RAPT savings. Median results are currently available only for the RO benefits category. Mean results were used for the other benefits categories.

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[5]This is similar to findings in the 2005 CIWS ATC productivity study, where Area personnel in an ARTCC, more acutely aware of weather impacts and the airspace availability status of their immediate region of responsibility, were able to use CIWS to help develop and refine traffic management initiatives and reduce the decision-making burden of Traffic Management Unit (TMU) personnel (Robinson et al. 2006).

[6]CIWS case study results often impacted larger airspace regions and traffic from more airports in en route airspace. They also often included a mix of linear “time-of-flight” delay savings (which were smaller) and nonlinear queuing delay savings (which were larger) that contributed to case-to-case delay reduction variability (Robinson et al. 2004).

[7]Median delay reduction statistics were computed only for the RO RAPT benefits category, which included six case studies. Mean statistics were computed for RO, RRP, and DP benefits categories, which each contained at least two case studies. Mean/median statistics were not computed for the DOL category, which only contained one case study.

Table 2A.
RAPT Benefit: More Timely Departure Route Openings; Eased Restrictions
(RO) Case Study Delay Savings Results

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Time UTC**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**TOTAL**
05 Jul	2120	7.7	6.2	13.9	14,076	16,732	13,473	44,281
05 Jul	2315	2.4	1.9	4.3	4,388	5,215	4,129	13,732
20 Jul	0040	0.5	0.4	0.9	951	1130	913	2,994
16 Aug	1740	2.5	2.0	4.5	4,515	5,367	4,302	14,184
30 Aug	2130	10.2	8.2	18.4	18,646	22,164	17,818	58,628
11 Sep	1815	4.4	3.5	7.9	8,043	9,561	7,606	25,210

Table 2B.
RAPT Benefit: More Timely Reroute Planning/Implementation
(RRP) Case Study Delay Savings Results

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Time UTC**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**TOTAL**
19 Jul	1340	14.8	11.9	26.7	27,055	32,160	25,860	85,075
11 Sep	1630	7.7	6.2	13.9	14,076	16,732	13,473	44,281

Table 2C.
RAPT Benefit: Directing Pathfinder Requests
(DP) Case Study Delay Savings Results

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Time UTC**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**TOTAL**
16 Aug	2325	1.6	1.2	2.8	2,797	3,325	2,651	8,773
30 Aug	2320	0.9	0.8	1.7	1,700	2,021	1,608	5,329

Table 2D.
RAPT Benefit: Keeping Departure Routes Open Longer
(DOL) Case Study Delay Savings Results

		DELAY SAVED (hr)			SAVINGS ($)			
Date	**Time UTC**	**Primary**	**Downstream**	**Total**	**Direct Operating Costs (DOC)**	**Passenger Value Time (PVT)**	**Passenger Value Time Downstream (PVTd)**	**TOTAL**
11 Jul	1705	8.6	6.9	15.5	15,721	18,688	14,994	49,403

Table 3. Mean/Median RAPT Delay Savings per Departure Route Management Application

RAPT Benefit Category	Delay Saved (hr)	Cost Savings ($)
Mean RO	8.3	26,334
Median RO	6.3	19,697
Mean RRP*	20.4	64,678
Mean DP*	2.2	7,051
DOL[†]	15.5	49,403

**Only two case studies available for RRP and DP categories, so only mean statistics are listed*

[†]Only one DOL case study conducted, so no mean/median statistics are available

NOTE: Statistics shaded in BLUE were used to estimate annual RAPT delay savings

3.3 RAPT Annual (2007) Delay Savings

The normalized frequency of observed RAPT benefits presented in Table 1, summed up across all operational facilities, yields the total observed benefits frequency per convective weather SWAP day. Multiplying observed daily RAPT departure route management benefits (RO, RRP, DP, and DOL) by the historical average number of declared NY SWAP days that occur in a year (Table 4, ZNY Traffic Management Officer, personal communication) yields the annual RAPT benefits frequency (Table 5).

Table 4. Annual NY Convective Weather SWAP Days

1996	41
1997	39
1998	54
1999	61
2000	85
2001	62
2002	66
2003	77
2004	82
2005	68
2006	72
2007	63
12 yr average	64

Table 5. Annual RAPT Benefits Frequency Per Category*

1. RO	77
2. RRP	70
3. DP	70
4. DOL	19
5. AHD	6
6. PRSA	13
7. EP	410
8. I/IC	384
9. SA-1	717
10. SA-2	595
11. SA-3	480

**Benefit Categories in red box were used to estimate annual delay savings*

Annual RAPT delay reduction benefits, computed from mean/median delay savings per RAPT use and the annual RAPT frequency of use, are presented in Table 6. Combined for the four primary departure route management benefits categories, annual RAPT benefits estimates, derived from real-time observations across all RAPT-equipped traffic management facilities during the 2007 convective weather season, were **2,300 hours of delay saved, with a cost savings of $7.5 M**.

Table 6. Annual RAPT Delay Reduction Benefits

	Hours			Monetary Value ($)			
RAPT Benefit Category	Primary	Downstream	TOTAL	DOC	PVT	PVT downstream	TOTAL
RO	270	216	486	483,483	574,728	458,458	1,516,669
RRP	791	637	1,428	1,439,585	1,711,220	1,376,655	4,527,460
DP	88	70	158	157,395	187,110	149,065	493,570
DOL	163	131	294	298,699	355,072	284,886	938,657
TOTAL	1,312	1,054	**2,366**	2,379,162	2,828,130	2,269,064	**7,476,356**

4. NY SWAP TFM OBSERVATIONS

While documenting real-time RAPT usage during weather impact events, MITLL and FAA Aviation Weather Office observers also identified other factors that may enhance our understanding of the NY departure flow management environment in which RAPT was being used. To this end, real-time observations of operations during SWAP were collected and assigned to the following categories:

- RP — RAPT Technical Performance
- TMD — Traffic Management Details
- TMD-S — TFM Airspace Status Uncertainty
- TMD-LOU — TFM “Lack of Understanding”

- UR		RAPT User Requests
- PB		Pilot Behavior

These ancillary observations, critical for understanding RAPT expectations and benefits scenarios, and improving RAPT guidance, were documented frequently during the RAPT benefits assessment field campaign (Figure 6). Detailed findings from documentation of RAPT technical performance are presented in DeLaura et al. (2008a). Pilot behavior in convective weather is discussed in the convective weather avoidance modeling study by DeLaura et al. (2008b). Observations of NY SWAP TFM operations, and their relationship to RAPT performance and operational usage, are discussed here.

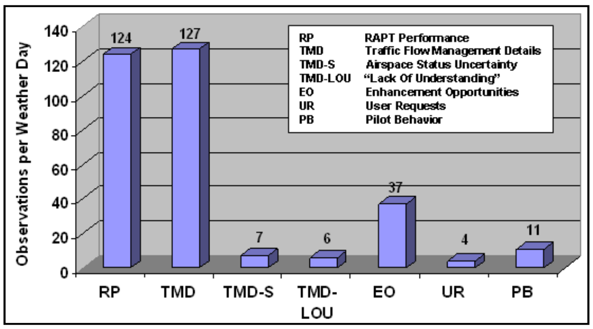

Figure 6. Frequency and type of additional observations of RAPT technical performance and the characteristics of NY operations during SWAP.

4.1 Observations of NY SWAP Traffic Management Details (TMD)

TMD observations identified the following SWAP TFM elements that may affect the overall operational effectiveness of RAPT:

- Resource utilization for departure flow management - use of pathfinders, Coded Departure Routes (CDRs) and implementing MIT restrictions
- NAS Network issues – effect of NY arrival traffic, active ZDC military airspace, and airport surface management issues on departure flow management
- Collaborative Decision-Making – ZNY Area vs. TMU decision-making and multiple options for SWAP TFM decision coordination

4.1.1 Resource utilization RAPT TMD observations

The common approach for reopening a departure route that was closed due to convective weather is first to probe the conditions along the route with a pathfinder (also called a route checker). Often, a request is made by the ZNY TMU, N90 TRACON, or ATCSCC to the airport Tower controllers for a pathfinder volunteer. Once a pathfinder is identified, a new flight plan, that includes the currently closed route, is provided to the pilot and airline dispatch, and the flight awaits its turn in the airport taxi queue to depart. When the pathfinder flight is airborne and on the route in question, the pilot reports back on the weather conditions, while controllers and traffic managers monitor the progress of the flight, watching to see if the aircraft deviates significantly from its filed flight plan. If the pilot reports acceptable weather conditions and any pilot deviations are within the limits acceptable to ATC controllers, the departure route is reopened and flights are allowed to use this airspace.

Unfortunately, the pathfinder process for reopening a closed route often requires a considerable amount of time and coordination, resulting in delayed reopening of routes and missed opportunities to increase NY departure capacity and reduce delay. Occasionally, identifying pathfinder candidates from among the three metro NY airports and locating a pathfinder volunteer could take upwards of 20-30 minutes, and in a few instances, a pathfinder volunteer was never identified (and the departure route to be probed remained closed).

Once a pathfinder was identified, the flight was often buried in an airport taxi queue, behind aircraft with flight plans that had already been cleared by ATC. This occasionally resulted in an additional delay of 20-30 minutes or more before the pathfinder could take off on its route-probing flight. Finally, controllers and traffic managers had to wait to assess the progress of the flight on the departure route in question, along with waiting for the pilot to report back on encountered weather conditions, before the route could be reopened. All together, the entire pathfinder process for reopening a closed route could require 60 minutes or more, during which time convective weather impacts may have evolved to eliminate tactical opportunities to increase NY departure throughput.

One traffic manager suggested that the pathfinder process should be modified so that instead of looking for a pathfinder volunteer for flights that have not been cleared and therefore can not depart until the queue of cleared flights is emptied, a short ground stop should be declared and pathfinders should be solicited from the pool of previously cleared flights at the head of the departure queue. The traffic manager noted however that it was unclear which approach would better serve to mitigate delay in the NY network.

Another complicating factor for the pathfinder process is that it often requires multiple coordination steps across several FAA facilities, (and controller/manager positions within a facility), airline dispatch, and finally pilots. Moreover, approval for pathfinder requests usually must be granted by almost every decision-maker in the coordination chain, and different decision-makers have the ability to modify, postpone, or deny the pathfinder request. Differences arise in coordinating pathfinders because of variations amongst the decision-makers' risk tolerance. For example, ZNY Area Supervisors managing en route air traffic controllers are particularly (and understandably) sensitive to the risk of deviating pathfinders because the resulting increase in ATC complexity increases the possibility for operational errors by controllers.

The pathfinder process for reopening closed departure routes has implications for RAPT usage and benefits realization. The long lead time required to release a pathfinder resulted in missed opportunities to reopen a closed departure route early and improve queued airport delays. On occasion, pathfinder delay eroded RAPT user confidence; RAPT guidance used to make a decision to release a pathfinder at some time T appeared unreliable when the pathfinder was actually released (T+30 or more minutes later) into convective weather that had changed significantly from the time of the initial decision.

When normal departure routes are closed during convective weather, SWAP reroutes are required. RAPT provides guidance along Coded Departure Routes (CDRs) to assist traffic managers and airline dispatch coordinators in identifying viable departure reroutes. CDRs are predefined routes used to route air traffic around areas of significant weather. Some operational users did examine CDR route blockages when searching for reroute opportunities. However, observations from the 2007 storm season showed that CDRs are often not considered for reroute options because CDR usage requires extensive coordination, involving several FAA facilities. During severe NY SWAP events, where the weather impacts are often dynamic and evolving, traffic managers informed observers that they do not have the time to coordinate CDR reroutes. Moreover, they understand that setting up a tactical reroute via a CDR may be counterproductive, given the extensive coordination required to reroute only a small subset of select city-pair departures. Traffic specialists at ATCSCC have also stated that they would prefer to coordinate reroutes for larger "flows" of traffic, rather than plan for reroutes for a handful of city-pair flights at a time.

The operational complications associated with coordinating and implementing NY CDR reroutes diminishes the effectiveness of RAPT guidance for user-selectable CDR routes. However, some operational users did request an expansion of the available CDR city-pair database in RAPT to at least improve awareness of route availability for these reroute options. The ability to quickly assess the viability of CDR routes via RAPT should facilitate CDR reroute coordination.

Miles-In-Trail (MIT) restrictions were used to manage air traffic volume and to maintain the orderly control of departure route reopenings. Reopened departure routes were often accompanied by MIT (or Minutes-In-Trail – MINIT) restrictions in order to manage TRACON volume and complexity as traffic managers from multiple airports each sought to increase throughput through use of newly available airspace. The rationale for this use of MIT restrictions was generally understood by all coordinating decision-makers.

On occasion, however, observers noted departure routes reopening with accompanying MIT restrictions put in place as a cushion against potential deviations off the route. Traffic managers at some facilities stated that the value of the use of MIT restrictions in this manner was unclear, since route deviations had not yet occurred on the newly re-opened route. Other traffic managers argued that use of MIT restrictions to proactively guard against unexpected deviations is the proper way to avoid escalations in weather impacts and delay.

The questions concerning the proper MIT restriction assigned to reopening routes for reasons unrelated to volume management typically arose when restrictions were implemented for routes seemingly clear of significant weather. It is surmised that improved expertise and user confidence in RAPT may prove useful in refining procedures and standard practices for implementing MIT restrictions on reopening departure routes. One traffic supervisor suggested that RAPT route blockage status (all clear, clear of significant weather, partially impacted, or blocked, but with marginal echo top heights) may possibly be used to determine not only when a route may be opened or closed, but also whether a specific MIT restriction should be applied to routes in question. If increased RAPT usage in 2008 were to result in smaller MIT restrictions applied to reopening routes, this would likely lead to increased RAPT delay/cost savings associated with the 'Route reopening' (RO) benefit category.

4.1.2 NAS Network RAPT TMD observations

During the 2007 summer storm season, airborne arrival demand often dictated NY departure route usage. This was especially true if either arrivals or departures on adjacent parallel routes were deviating. In those instances, arrival flows were given priority, and the adjacent departure routes (and sometimes even other additional routes) were closed. This problem became critical if Airspace Flow Programs (AFP) or Ground Delay Programs (GDP) in support of SWAP over-delivered NY and PHL arrivals during significant weather impact events. Under these circumstances, departure routes were forced to close to accommodate the excess arrival demand, which on occasion resulted in gridlock at the airport surface.

In these scenarios operational users questioned why the RAPT guidance, which showed a departure route clear of weather, did not match the operational status of the route in question (closed to accommodate arrivals). This eroded user confidence in RAPT and required additional real-time training to improve understanding of the route availability forecast capabilities. Steps will be taken in 2008 for RAPT to assign increased route-impact sensitivity for departure routes immediately adjacent to arrival airspace.

Some traffic managers recognized the importance of proactive anticipation of arrival route impacts to the overall performance of the NY airspace network. Though not under consideration for the 2008 RAPT deployment, forecasting NY arrival route availability is currently an active area of research.

Another en route airspace variable that is independent of departure route availability, but can directly affect NY departure capacity, is the status of active Warning Areas in eastern ZDC airspace. These Warning Areas, located just off the Mid-Atlantic coast and operationally off-limits to commercial aviation during military exercises and training, significantly reduce the airspace available for avoiding convective weather. Observations made during the RAPT field campaign noted that FAA controllers and traffic managers are much less tolerant of departure deviations along the southbound NY WHITE and WAVEY departure routes (Figure 7) when the ZDC Warning Areas are active.

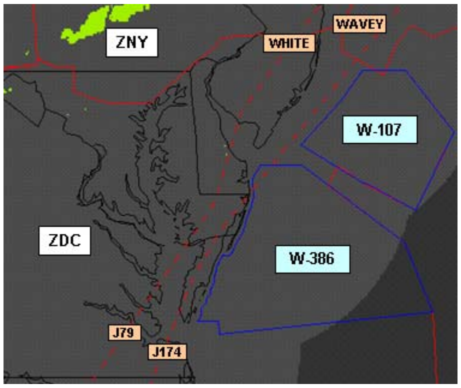

Figure 7. ZDC airspace showing the location of the primary NY WHITE and WAVEY departure routes (dashed red) in relation to Warning Areas (W-386, W-107) used for military exercises off the Mid-Atlantic coast.

Current RAPT guidance does not take the constraints introduced by active Warning Areas into account. Many times in 2007, RAPT would predict the WHITE/WAVEY routes were unimpeded by weather, but local deviations, which RAPT assumed were within the acceptable width of the jet route, were too aggressive when ZDC Warning Areas were active. These situations eroded user confidence when expectations of available southbound departure routes, based on RAPT guidance, did not match the operational reality. Efforts are underway to incorporate this sensitivity into the 2008 RAPT guidance for WHITE and WAVEY route availability.

Airport surface traffic management is a very important factor in departure route usage during SWAP. Several incidents were observed where opportunities to reopen NY departure routes were identified, but airport surface complexities and incompatibly-staged aircraft prevented the timely use of newly-available departure route capacity. As departure aircraft are delayed, taxi (and sometimes runway) backups build, effectively limiting maneuverability and surface management flexibility. This problem is exacerbated when arrivals substantially outpace departures to the point where airport surface gridlock occurs.

Improved airport tower access to RAPT (discussed in Section 3.1) and continued user training support are expected to increase RAPT operational usage for surface management. Some attempts were already made by traffic supervisors in JFK tower to apply RAPT departure route availability forecasts to assist with proactive departure runway sequencing (see PRSA category in Table 1; RAPT usage examples in DeLaura et al. 2008). We expect these types of applications to expand in the future.

4.1.3 *Collaborative Decision Making RAPT TMD observations*

Observations of SWAP operations in the ZNY ARTCC demonstrated that ZNY Area Supervisors and controllers are key SWAP decision-makers. As in other ARTCCs, TMU traffic managers and Area Supervisors in ZNY often coordinate on tactical TFM decisions (Robinson et. al. 2006). On a number of occasions, it appeared that the Area Supervisors in ZNY significantly influenced the final decision regarding NY departure route usage.

During the 2007 storm season, RAPT usage by ZNY Area Supervisors, who were new users, was low compared to RAPT usage in the TMU. This limited the use of RAPT for improved common situational awareness of anticipated departure route impacts. In turn, this reduced the use of RAPT to proactively coordinate and implement departure flow management decisions within ZNY.

The summer of 2007 was also the first storm season that ZNY Area Supervisors had access to CIWS. Given that RAPT predictions are built upon CIWS Precipitation and Echo Tops Forecasts, it was deemed important that Area Supervisors first became accustomed to using the CIWS information before focusing on RAPT.[8] Interactive real-time RAPT training for ZNY Areas will be a high priority in 2008, and expectations are that this focused training will improve ZNY intra-facility coordination and increase the operational effectiveness of RAPT.

Simultaneous real-time observations at all NY FAA operational facilities, as well as at neighboring ARTCCs and the FAA Command Center (ATCSCC) revealed that NY departure route usage decisions can be made during convective weather by staff at many different traffic management positions. Moreover, these decisions follow many different coordination paths. The positions or facilities identified making NY departure route management decisions, and some of the observed interactions for coordinating and implementing these decisions, included:

- Towers to/from N90
- Towers to/from ZNY
- N90 to/from ZNY
- N90 to ATCSCC to ARTCC(s)
- ZNY TMU to/from ATCSCC
- ZNY TMU to/from neighboring ARTCC(s)
- ZNY Area Supervisor to/from ZNY STMC
- ZNY Area Supervisor to/from ZNY TMC
- ZNY Area to Area to TMU
- Areas to TMU in neighboring ARTCC(s) TMU
- ZNY STMC to/from TMC
- ZNY sector to sector (controllers)
- ZNY sector to ZDC/ZOB/ZBW sector
- ATCSCC to/from neighboring ARTCC(s) to ZNY
- N90 to/from neighboring ARTCC(s)
- Towers to/from airline dispatch
- ZNY TMC/STMC/Area Supervisors to NY TMU “Pit” personnel

Obviously, this NY decision-making network is very complex and decision outcomes varied depending on which decision-making chain of interactions was followed. This is because the goals, needs, concerns, primary responsibilities, and priorities of those at the individual positions and airspace management facilities can vary substantially, resulting in different views as to what would be an optimum TFM SWAP decision.

The pathways for coordinating and implementing NY departure flow management decisions during SWAP have implications for RAPT operational utility. RAPT can assist in the complex coordination tasks associated with numerous decision-makers involved in making SWAP departure decisions (or at least contributing to departure planning) by providing a common awareness of opportunities to increase NY departure route usage efficiency (either by increasing departure route capacity or recognizing potential deviation/holding situations before they occur). The large number of individuals at several FAA facilities involved in NY departure flow decisions also underscores the need for continued, interactive RAPT training and for improved access to RAPT information (e.g., NY towers). In addition, continued observations of the TFM SWAP environment will allow us to better understand the decision-making priorities and considerations for various decision coordination interactions. This information can be used to better tailor RAPT guidance to meet the needs of the operational users.

[8] CIWS had been available to the ZNY TMU since 2002, and most traffic management coordinators (TMCs) at ZNY are considered experienced CIWS users.

4.2 NY Airspace Availability Uncertainty Observations during SWAP (TMD-S)

On average, seven times per convective weather day (see "TMD-S" observations in Figure 6), traffic managers across all visited FAA facilities, operating in a fluid and complex NY SWAP environment, were observed to be unaware of the availability status for specific departure routes or fixes. On these occasions traffic managers thought a route or fix was closed when it was actually open or vice versa. Over an entire NY SWAP season, these observations translate into instances of airspace status uncertainty occurring more than **440 times** per storm season.

Field observations suggest that confusion about which departure routes or fixes are available is due primarily to one of the following:

1. Numerous fixes and/or routes are often opened/closed for short periods in response to evolving convective weather impacts; some airspace changes apply to only select NY airports (and not all three metro airports).
2. Decisions to close or reopen a route or fix can come from many different facilities or positions within a facility.
3. Many route/fix status changes are disseminated via the NY SWAP Hotline and this information can be easily missed.
4. Each change in route/fix status is entered into the FAA National Traffic Management Log (NTML), and all traffic managers have access to these data. However, significant effort is required to scroll through often long lists of text describing route availability changes (entered in a nonstandard format) and attempt to mentally catalogue and track status changes.

Incidents where the status of NY departure routes was unknown had implications for effective RAPT usage. On several occasions and at more than one FAA facility, traffic managers did not consider the need to consult RAPT for opportunities to proactively reopen a closed route because they had believed that the particular route had already been reopened. In other instances, traffic managers questioned the validity of RAPT guidance because RAPT depicted a route they believed to be open as blocked, even though the route in question had actually already been closed.

It is no fault of the traffic managers that these episodes of airspace status uncertainty occur – the task of tracking, cataloguing, and updating ever-changing NY route/fix status conditions during fast-paced and dynamic SWAP conditions, without some sort of automated assistance, is monumental. The aviation community recognizes that this problem of airspace status uncertainty is a NAS-wide issue (though particularly difficult in the NY airspace region) and improving NAS status information was a high priority recommendation at the 2007 FAA-airline System Review Meeting. One of the options for improving common situational awareness of route status would be for RAPT to ingest route status information (parsing the data from NTML logs, applying voice recognition technology to collect/parse hotline information, or a combination of the two) and graphically depict the NY departure route/fix status in conjunction with convective weather route blockage forecasts.

4.3 TFM "Lack Of Understanding" Observations During NY SWAP

Each of the facilities involved in NY SWAP TFM decision making oversees unique airspace regions that vary in terms of configurations, air traffic density, and sensitivity to convective weather. FAA Aviation Weather Office and MITLL observers noted during the 2007 storm season that coordinating facilities often do not fully understand the airspace concerns and constraints of other facilities. Examples of "Lack Of Understanding" (LOU) observations noted in real-time included:

- Constraints were assumed to occur within ZNY airspace, when in fact airspace closures often occurred elsewhere
- Constraints associated with N90 volume constraints were not well understood by other FAA facilities
- Tower operations were severely disrupted by frequent departure fix stops and restarts that were required by N90 to control volume
- Increased constraints on WHITE/WAVEY departure route availability when ZDC Warning Areas were active were not accounted for
- Constraints within ZNY were often not fully understood by other facilities

When the information or knowledge is limited as to why a particular TFM decision has been made or as to what type of impacts a decision can have on other airspace operations, team collaboration and decision-making is not optimized. "LOU" can hamper collaborative decision-making because it may negatively affect the cooperative effort of the decision-making team. This in turn can cause LOU to contribute to "Why fight the fight" sentiments among coordinating ATC facilities.

Increased understanding of the different TFM concerns amongst collaborating facilities could improve NY departure flow management. RAPT guidance may help to increase understanding of network-wide SWAP needs and constraints through explicit depictions and forecasts for weather-related departure flow impacts.

5. POTENTIAL NEAR-TERM RAPT BENEFITS

Annual RAPT delay reduction benefits in 2007 were significant (see Section 3.3). However, several observations lead the authors to conclude that the RAPT operational benefits in 2008 and beyond should be much higher than were observed in 2007. Increased RAPT usage and operational effectiveness is expected to increase in the near-term as the following occur:

A. User experience increases

Operational traffic managers and controllers often used RAPT in 2007 as a confirmation tool – both to help confirm decisions based upon other information and to verify the operational fidelity of RAPT guidance. As user confidence and expertise in the use of RAPT increases, traffic managers are expected to become more aggressive in making proactive NY departure flow management decisions based upon RAPT forecasts for route blockages.

B. Identified RAPT enhancements and technical performance improvements are implemented

Field observations of RAPT performance and user requests for specific enhancements are guiding RAPT algorithm and display enhancement and redesign efforts. By improving RAPT route blockage forecasts, providing explicit information about forecast uncertainty, including a better representation of weather deviation sensitivity for individual departure routes/fixes, and adding more departure routes deemed important by FAA and airline personnel, RAPT will become both more reliable and better tuned to operational needs.

C. Access to RAPT at several FAA facilities improves

RAPT access issues at EWR, JFK, and LGA towers have already been discussed in Section 3.1. Options are being explored for providing RAPT in the NY towers via dedicated displays (similar to how RAPT is accessed at the ARTCCs). This would greatly increase RAPT usage at the metro NY towers, leading to improved coordination and enhanced collaborative decision-making for departure flow management.

Adding a dedicated RAPT display at the Teterboro airport (TEB) tower would also likely increase RAPT usage and the operational effectiveness of departure routing decisions for this airport. TEB departure delays during NY SWAP events can be severe. Route blockage forecasts for all nominal TEB departure routes are already available in RAPT, and with a RAPT display and training, controllers at TEB tower would have the same awareness of near-term departure route impacts derived from RAPT as those at all other NY ATC facilities.

RAPT product access should also be improved at the FAA Command Center (ATCSCC). Here, RAPT is available on the dedicated CIWS display provided in the National System Strategy Team (NSST) Unit. However, due to a reconfiguration of duty positions within the NSST, the CIWS/RAPT display is now located on the other side of the Unit from the NY-desk. Therefore, an NSST traffic management specialist working the NY-desk would have to leave his / her position, walk across the Unit to review RAPT information, and then return to the NY position, attempting to coordinate NY departure decisions with the RAPT data now committed to memory. This is obviously not an ideal setup for RAPT usage within the ATCSCC. Preliminary efforts are underway to either move the current RAPT display to the NY-desk area of the NSST Unit or add an additional display at this position.

D. Interactive user training and real-time in situ support continues

RAPT will continue to be supported by a multi-faceted RAPT training regime. As in 2007, RAPT training in 2008 will include pre-SWAP season, small-classroom training and demonstration sessions for all FAA and airline dispatch personnel who may use RAPT during the upcoming season.

Real-time in situ RAPT training will also be provided at all RAPT-equipped facilities in 2008, with extra focus on real-time RAPT training for ZNY Area Supervisors.

An important addition to the 2008 RAPT training plans will be the introduction of RAPT Missed Opportunity Scenario Training (MOST). After each significant NY SWAP event where observers are in the field to study RAPT performance and usage, instances of potential missed opportunities to increase NY departure capacity or mitigate airspace complexity will be documented and presented to operational traffic managers for discussion. MOST is considered a key element to expanded RAPT training efforts because:

1. Recognition of RAPT missed opportunities is considered crucial to refining the Recognition-Primed Decision (RPD) model for NY SWAP decision-making (Evans and Robinson, 2008)
2. Given that RAPT seeks to change long standing SWAP-TFM practice, it is hoped that MOST will more quickly build acceptance and user understanding of RAPT
3. User discussions centered upon MOST may increase "Team mind" decision-making for NY departures (Klein, 1998; Robinson and Evans, 2008)
4. MOST discussions may contribute to RAPT development, as users identify other TFM-related issues that must be overcome or accounted for in order to take advantage of the SWAP departure opportunities identified by RAPT.

In order to estimate the potential increase in RAPT usage and benefits in the near term (e.g., 2008-2010), field observations were reanalyzed to identify "potential" benefits. Potential benefits include instances where RAPT clearly showed that a departure route was available, but the route was not used in a timely manner, that there were missed opportunities for improved inter/intra-facility coordination, or instances where more ready access to RAPT would have enhanced traffic management productivity. In some instances, potential benefits are identified under the assumption that RAPT improvements 5A-D have been implemented.

The annual frequency of potential RAPT usage for all FAA and airline facilities currently with access to RAPT is shown in Figure 8. Given that not all capabilities and usage enhancements outlined above in A – D may be fully achieved in the near-term (2008-2010), and inherent ATC/TFM constraints and NY decision-collaboration complexities will likely still limit RAPT usage in the near-term, 40% of full "potential" benefits is considered to be a more realistic estimate for the expected near-term increase in RAPT operational benefits (see Figure 8).

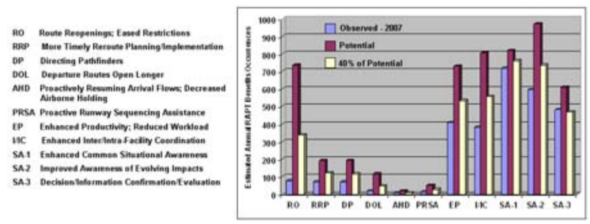

Figure 8. Estimates of the annual frequency of RAPT benefits for observed usage in 2007, full, near-term potential usage, and 40% of full potential RAPT usage.

Increased potential RAPT delay savings include both an expected increase in RAPT usage and greater delay reduction benefits on the occasions where RAPT is used (for example by making decisions earlier or implementing them more aggressively). Increased "potential" delay savings were found to exist for 4 of the 11 RAPT benefits case studies provided in Table 7. For those cases, more timely implementation of RAPT-derived decisions resulted in delay savings that were at least a factor of two greater than the delay savings in 2007. Using the estimated annual frequency of 40% of potential RAPT benefits (Figure 8), and mean/median case study delay savings that incorporate potential increased delay reductions, the estimated annual near-term potential RAPT benefit for NY is **8,800 hours of delay saved, with a cost savings of $28.3 M.**

Table 7. Observed vs. Potential RAPT Delay Savings per Benefits Case Study*

Type	Date	Time UTC	OBSERVED RAPT Delay Savings: Delay Saved (Hours)	OBSERVED RAPT Delay Savings: Cost Saved ($)	POTENTIAL RAPT Delay Savings: Delay Saved (Hours)	POTENTIAL RAPT Delay Savings: Cost Saved ($)
RO	05 Jul	2120	13.9	44,281	13.9	44,281
RO	05 Jul	2315	4.3	13,732	4.3	13,732
RO	20 Jul	0040	0.9	2,994	11.5	36,688
RO	16 Aug	1740	4.5	13,163	4.5	13.163
RO	30 Aug	2130	18.4	58,628	37.8	120,527
RO	11 Sep	1815	7.9	25,210	19.4	61,898
RRP	19 Jul	1340	26.7	85,075	26.7	85,075
RRP	11 Sep	1630	13.9	44,281	13.9	44,281
DP	16 Aug	2325	2.8	8,773	2.8	8,773
DP	30 Aug	2320	1.7	5,329	1.7	5,329
DOL	11 Jul	1705	15.5	49,403	41.0	130,772

**Case studies shaded in gray demonstrated increase potential delay savings for that event*

6. CONCLUSIONS

RAPT is a pioneering automated integrated weather-ATM decision support tool designed to help traffic managers identify weather impacts on jet routes and increase the efficient use of available jet route capacity. A RAPT operational-use assessment was conducted in 2007 by MITLL and FAA Aviation Weather Office observers at 11 FAA and airline dispatch facilities during 11 convective weather SWAP impact events. The assessment covered simultaneous real-time documentation of RAPT operational usage and technical performance. Detailed observations of the NY SWAP TFM environment were also gathered to help support RAPT post-event studies and investigations into potential RAPT enhancements.

Eleven unique RAPT benefits categories were identified during the assessment. Observed RAPT applications included quantifiable departure capacity enhancement benefits [e.g., more timely reopening of departure routes (RO)] and improved collaborative decision-making applications such as increased awareness of departure route impacts caused by weather. The frequency of each type of RAPT application was tabulated for each FAA and airline facility and rolled-up to an annual RAPT benefits frequency estimate based upon the historical average number of NY SWAP days per year.

Several RAPT benefits case studies were analyzed in an effort to quantify the delay savings associated with the four primary RAPT departure flow management benefit categories. Results show per use RAPT benefits ranged from 0.9 to 26.7 hours of delay saved, with per use cost savings ranging from $2,900 to $85,000. The large variation in case-to-case delay savings was not surprising given that NY departure delays arise from highly nonlinear queues.

Mean or median (where possible) case study delay savings per benefit category were multiplied by the estimated annual frequency of the various

RAPT operational uses to determine the annual 2007 RAPT delay reduction benefits. **Annual RAPT benefits in 2007 totaled 2,300 hours of delay saved, with a cost savings of $7.5 M.**

While documenting real-time RAPT usage, field observers also sought to identify characteristics of the NY departure flow management environment in which RAPT was being utilized. Real-time observations of NY SWAP operations helped to better understand the RAPT case study results and highlighted opportunities for improvements in RAPT operational effectiveness. The SWAP TFM observations focused on route pathfinder procedures, use of Coded Departure Routes (CDRs), and the use of MIT restrictions for reopening departure routes.

"NAS Network" factors had a significant impact on RAPT effectiveness. These factors included how NY *arrival* flow management, the effect of active ZDC Warning Areas, and airport surface management complexity can impact the effective use of available NY departure capacity.

The decision-making environment for NY departure flow management is also very important. The ZNY Area Supervisors appear to be key decision-makers for NY departure route usage whose operational acceptance of RAPT will be critical to achieving higher RAPT operational benefits. The numerous pathways in which many empowered decision-makers at several different FAA facilities can coordinate and implement departure flow management decisions is also a potentially important factor that has not been considered previously.

A key finding during the RAPT field observations was that traffic managers were unsure of the status of NY departure airspace (i.e., open or closed) an estimated 440 times during the 2007 SWAP season. This airspace status uncertainty arises from the dynamic, ever-changing state of departure route/fix impacts during convective weather, poor information system infrastructure for route status data management, and the high workload associated with cataloguing available routes and tracking airspace status changes. Improved route status information displayed graphically via the RAPT display is being explored. The expected benefits, not only in terms of RAPT effectiveness but for improved SWAP TFM in general, of readily-accessible route status information for improved common situational awareness would be significant.

As the operational user experience with RAPT increases, RAPT technical performance enhancements are implemented, RAPT access issues (at NY towers and ATCSCC) are addressed, and expanded interactive training occurs, the RAPT benefits should increase substantially. Assuming these expected improvements occur, the RAPT benefits frequency and per case study quantifiable benefits were recalculated in order to estimate RAPT operational benefits achievable in the near-term. We estimate the annual near-term "potential" NY RAPT benefits would be on the order of 8,800 hours of delay saved, with a cost savings of $28 M.

6. ACKNOWLEDGEMENTS

The following individuals participated as observers in the 2007 RAPT assessment field campaign: Brad Crowe (MITLL), Richard Ferris (MITLL), Mike Garwood (FAA Aviation Weather Office), Colleen Horan (FAA Aviation Weather Office), John Kelley (FAA Aviation Weather Office), Diana Klingle-Wilson (MITLL), Frank Law (FAA Aviation Weather Office), Anna Merkel (FAA Aviation Weather Office), and Darin Meyer (MITLL). Special thanks to FAA personnel at ATCSCC, EWR, JFK, LGA, N90, ZBW, ZDC, ZNY, and ZOB – and traffic dispatch personnel at COA (EWR Ramp Tower) and JBU airlines - for accommodating RAPT observers, taking time to explain ATC operations at their facility, and taking part in numerous helpful discussions, all during busy storm impact events.

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APPENDIX A
INDIVIDUAL RAPT CASE STUDY DESCRIPTIONS

RAPT Benefit 1: More Timely Departure Route Reopenings; Eased Departure Restrictions (RO)

CASE STUDY A-1-1

Date: 05 July 2007
Facilities Using RAPT: N90

Benefit: N90 used the RAPT forecasts for departure route status to anticipate improving conditions for the ELIOT-J80 jet route. With this information, N90 coordinated with ZNY to reopen ELIOT-J80 early, despite the presence of strong convection along the route at the time of the decision. Access to RAPT information provided increased confidence in this decision and the departure route was reopened without requiring that it first be probed with pathfinders.

- Wiithout RAPT, the J80 route likely would have remained closed until convective weather cleared the route 40 minutes later.
- Three additional EWR departures and 4 additional LGA departures were released via the ELIOT-J80 route during benefit period.

RAPT Delay Savings Calculations:

Benefit Period: 0.67 hr (2120 – 2200 UTC)		
EWR Primary Delay Reduction:		3.6 hr
Downstream Delay Reduction:		2.9 hr
Direct Operating Cost (DOC) Savings:		$ 6,581
Passenger Value Time (PVT) Savings:		$ 7,823
Downstream Cost Savings:		$ 6,302
EWR Total RAPT Delay Reduction:	**6.5 hr**	
EWR Total RAPT Cost Savings:	**$20,706**	
LGA Primary Delay Reduction:		4.1 hr
Downstream Delay Reduction:		3.3 hr
Direct Operating Cost (DOC) Savings:		$7,495
Passenger Value Time (PVT) Savings:		$8,909
Downstream Cost Savings:		$7,171
LGA Total RAPT Delay Reduction:	**7.4 hr**	
LGA Total RAPT Cost Savings:	**$23,575**	
Total RAPT Delay Reduction:	**13.9 hr**	
Total RAPT Cost Savings:	**$44,281**	

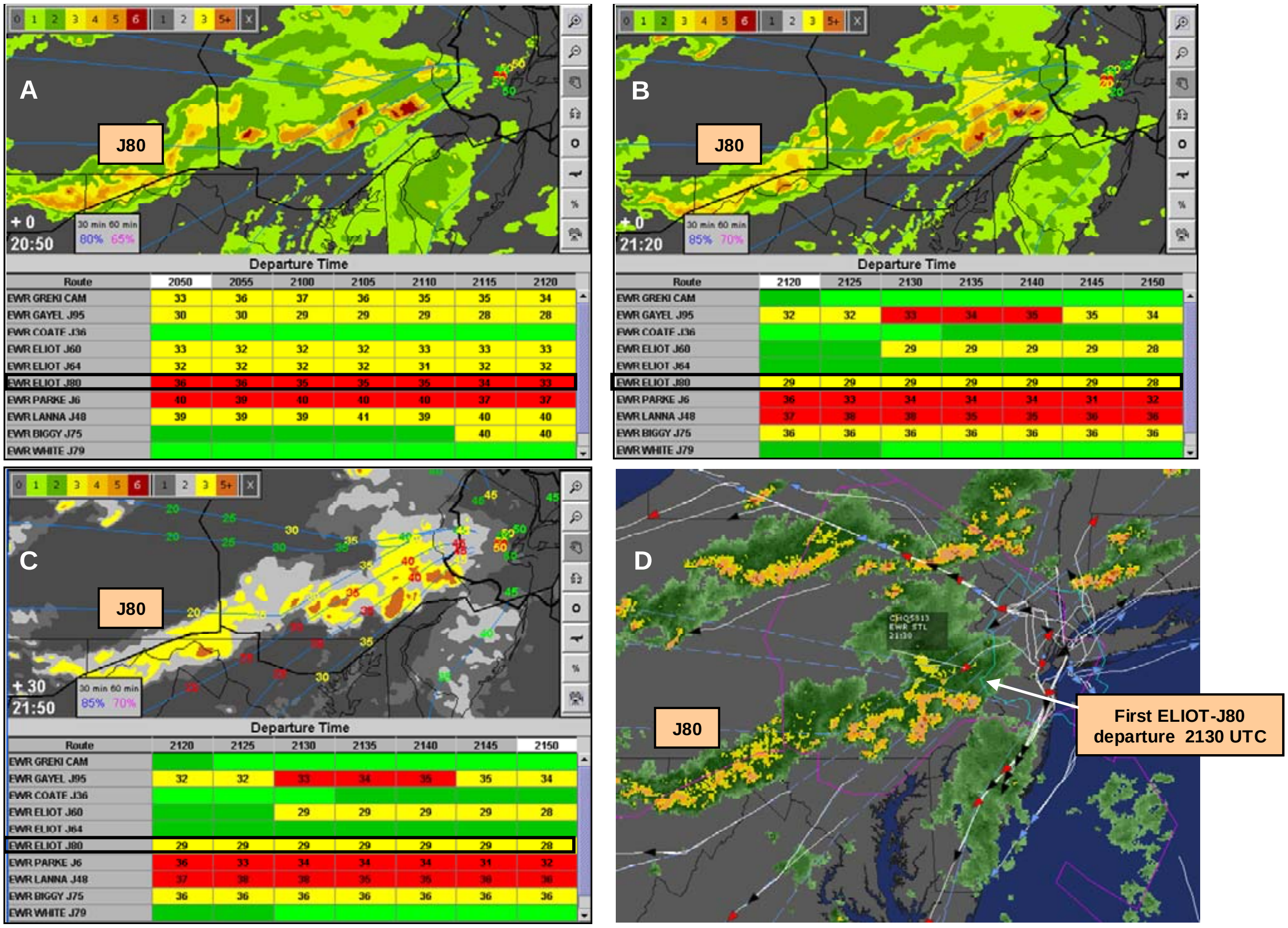


Figure A-1-1-1. (A) RAPT EWR departure route status at 2050-2120 UTC on 05 July 2007, when the J80 jet route was heavily impacted by thunderstorms and RAPT guidance accurately predicted the ELIOT-J80 route (timeline in black box) as blocked. (B) RAPT EWR departure route status at 2120-2150 UTC, when the current weather depiction showed strong convection still impacting J80 but the timeline forecast for this route (black box) predicted decreased echo top heights and overall reduced route impact as the convective line dropped slowly south of the route (see Figure (C), showing the graphical depiction of the 30-minute precipitation forecast). (D) Flight Explorer flight tracks and WSI composite reflectivity at 2145 UTC, showing EWR (red), LGA (black) and JFK (blue) departures. The first ELIOT-J80 flight after the route was reopened departed from EWR at 2130 UTC.

CASE STUDY A-1-2

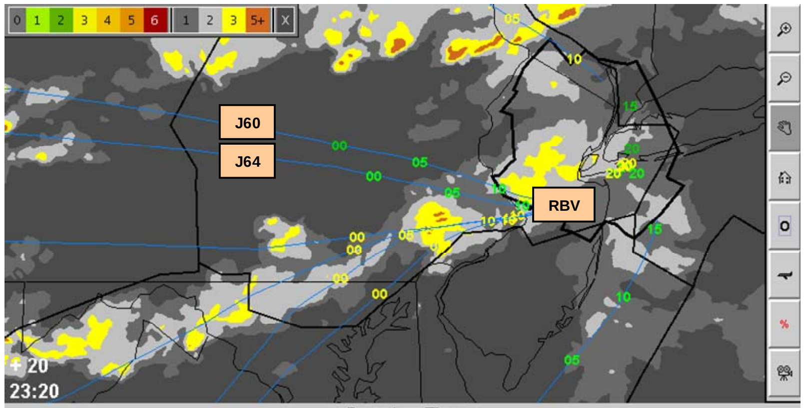
Date: 05 July 2007
Facilities Using RAPT: N90, Jet Blue Airlines, ZNY

Benefit: Despite level 4+ convection near RBV departure fix (key departure corridor for JFK westbound traffic), Jet Blue dispatch and N90 TRACON independently used RAPT forecast timelines to proactively identify improving conditions. With this information, N90 placed RBV-J60/J64 pathfinder request with ZNY. ZNY traffic managers were concerned that continued eastward movement of a level 3+ cluster of weather (discerned from the CIWS precipitation forecast product) would impinge on the route, forcing deviations if RBV departures were to resume. However, ZNY also used RAPT to note that RBV-J60/J64 timeline forecasts, accounting for both precipitation and echo top height, suggested that this weather would not impact these departures. ZNY reopened RBV J60 and J64 routes with 15 MIT (and without requiring a pathfinder) at 2326 UTC, based upon the RAPT-derived request from the TRACON and airline dispatch. The first RBV flight departed JFK at 2350 UTC.

- Without RAPT, the gap in level 3+ weather along J80 likely not discernible as a viable routing option until 2345 UTC.
- Since it took approximately 25 minutes for RBV traffic to resume after the route was reopened, it is assumed that without RAPT, RBV traffic would not have restarted until 0010 UTC (25 minutes after the available gap would have been visible without RAPT). This assumption is considered conservative because it also assumes that the route would have reopened without first testing its availability with a pathfinder.
- Four additional JFK departures were released via RBV fix during benefit period.

RAPT Delay Savings Calculations:

Benefit Period: 0.33 hr (2350 – 0010 UTC)	
JFK Primary Delay Reduction:	2.4 hr
Downstream Delay Reduction:	1.9 hr
Direct Operating Cost (DOC) Savings:	$ 4,388
Passenger Value Time (PVT) Savings:	$ 5,215
Downstream Cost Savings:	$ 4,129
Total RAPT Delay Reduction:	**4.3 hr**
Total RAPT Cost Savings:	**$ 13,732**



Route	2300	2305	2310	2315	2320	2325	2330
JFK GAYEL J95	24	24	24				
JFK RBV J60							
JFK RBV J64							
JFK RBV J80	29	30	30	30	30	30	28
JFK RBV J6	30	30	30	30	30	30	30
JFK RBV J48	29	30	30	30	30	30	28
JFK RBV J75	33 ENR	33 ENR	29	30	30	30	30
JFK WAVEY J174							

Figure A-1-2-1. RAPT JFK departure route status at 2300-2330 UTC on 05 July 2007. RAPT guidance shows negligible (dark green) and no (green) impacts anticipated on RBV-J60 and RBV-J64 departure routes (see timelines in black box). Dispatch at Jet Blue Airlines and N90 Traffic Managers used this RAPT guidance to request that ZNY reopen these routes. ZNY traffic managers used RAPT during this period to confirm that the cluster of level 3+ weather northwest of the RBV fix would not adversely affect released departures – and reopened the route.

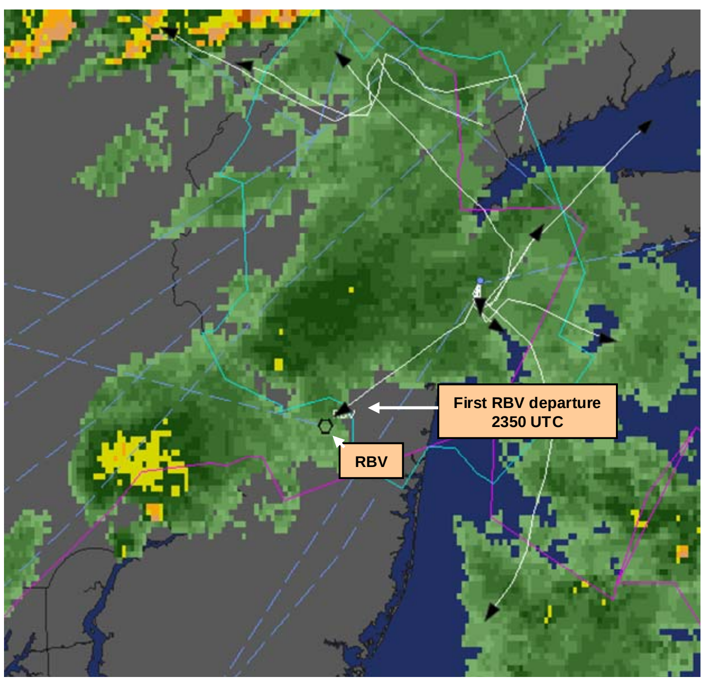


Figure A-1-2-2. Flight Explorer flight track and WSI composite reflectivity information at 0000 UTC on 06 July 2007. Black triangles denote airborne departures from JFK airport. The first of four JFK RBV departures to take advantage of the RAPT-derived early route reopening is approaching the departure fix at this time.

CASE STUDY A-1-3

Date: 19-20 July 2007
Facilities Using RAPT: JFK

Benefit: Traffic managers at JFK Tower used RAPT guidance to identify improving conditions for the WAVEY departure route. At 0042Z, JFK used this RAPT information to request that WAVEY be reopened. The N90 TRACON and ZNY ARTCC reopened the route immediately (with 15 MIT restrictions) upon this request.

- Even though the route reopened at 0042 UTC, airport surface and coordination complexities resulted in only one JFK departure using WAVEY (departing 0159 UTC) before the route was forced to close again at 0200 UTC because of building convection in east-central ZDC.
- RAPT delay savings associated with reopening WAVEY for 1.3 hours longer equal the JFK delay reduction for releasing one extra aircraft during that period.

RAPT Delay Savings Calculations:

Benefit Period: 1.3 hr (0042 – 0200 UTC)

JFK Primary Delay Reduction:	0.5 hr (31 min)
Downstream Delay Reduction:	0.4 hr
Direct Operating Cost (DOC) Savings:	$ 951
Passenger Value Time (PVT) Savings:	$ 1,130
Downstream Cost Savings:	$ 913
Total RAPT Delay Reduction:	**0.9 hr**
Total RAPT Cost Savings:	**$ 2,994**

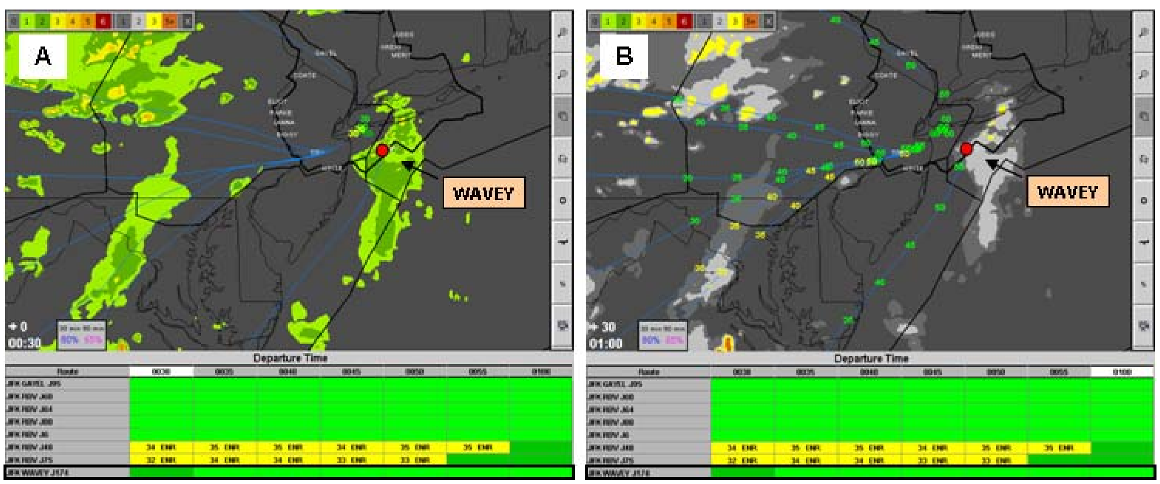


Figure A-1-3-1. RAPT guidance at 0030 UTC on 20 July 2007 showing (A) current weather impacting the WAVEY departure fix at 0030 UTC and (B) the 30-min forecast showing level 2 weather moving off the WAVEY fix and this key JFK departure route. RAPT timelines for anticipated JFK route conditions shows the WAVEY route (boxed) clear of significant weather for the next 30 minutes.

CASE STUDY A-1-4

Date: 16 August 2007
Facilities Using RAPT: LGA

Benefit: At 1742 UTC, traffic managers at LGA Tower used the RAPT forecast to proactively identify improving weather conditions along the WHITE departure route (despite heavy weather near the WHITE fix at the time of this observation). At this time, WHITE departures were only being released with individual Approval Requests (APREQ). LGA used RAPT guidance to request that N90 decrease WHITE departure restrictions and open the route without APREQs. This request was approved and the route was reopened at 1750 UTC.

- Without RAPT, we assumed WHITE would have remained open only for APREQ flights until 1800 UTC.
- From 1750-1800 UTC, 2 EWR aircraft and 1 LGA aircraft departed via the WHITE departure route.
- We assumed that had the RAPT-derived decision to reduce WHITE restrictions (and open the route), one of these three flights still would have departed using this route; Model assumes that RAPT benefit increased EWR and LGA departure capacity by one flight each during the period from 1745 – 1800 UTC.

RAPT Delay Savings Calculations:

Benefit Period: 0.25 hr (1745 – 1800 UTC)		
EWR Primary Delay Reduction:		2.0 hr
Downstream Delay Reduction:		1.6 hr
Direct Operating Cost (DOC) Savings:		$ 3,656
Passenger Value Time (PVT) Savings:		$ 4,346
Downstream Cost Savings:		$ 3,477
EWR Total RAPT Delay Reduction:	**3.6 hr**	
EWR Total RAPT Cost Savings:	**$11,479**	
LGA Primary Delay Reduction:		0.5 hr (28 min)
Downstream Delay Reduction:		0.4 hr
Direct Operating Cost (DOC) Savings:		$ 859
Passenger Value Time (PVT) Savings:		$1,021
Downstream Cost Savings:		$ 825
LGA Total RAPT Delay Reduction:	**0.9 hr**	
LGA Total RAPT Cost Savings:	**$2,705**	
Total RAPT Delay Reduction:	**4.5 hr**	
Total RAPT Cost Savings:	**$14,184**	

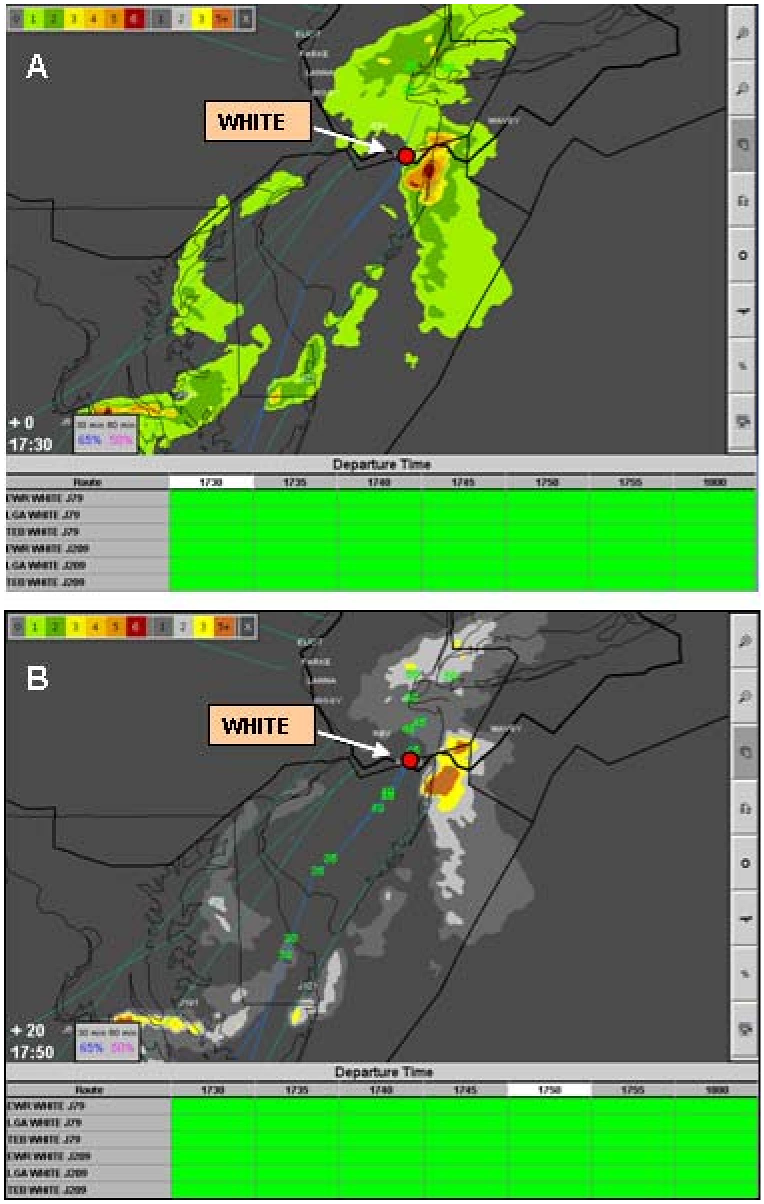


Figure A-1-4-1. RAPT guidance at 1730 UTC on 16 August 2007 showing (A) a strong storm just east of the WHITE departure fix and (B) the 20-min forecast showing the level 5+ thunderstorms moving eastward and away from the WHITE route. RAPT timelines for WHITE departure routes from all NY airports correctly predicted that significant weather would clear the route and that the route would remain viable for the forseeable future.

CASE STUDY A-1-5

Date: 30 August 2007
Facilities Using RAPT: EWR

Benefit: Prior to 2130 UTC, the COATE/J36 departure route was closed for an extended period as a result of earlier pilot deviations around a large region of thunderstorm “blow-off”. At 2130 UTC, some blow-off was still present over J36, but EWR, citing “clear-route” status for COATE/J36 in the RAPT timeline guidance, requested of N90/ZNY that the route be reopened. Based on this RAPT-derived request, COATE/J36 was reopened at 2130 UTC. New, quickly developing convection along the route shortly after this reopening forced the route to close at 2200 UTC.

- With RAPT, COATE/J36 was opened for an extra 30 minutes (2130-2200 UTC).
- During the 30 minute RAPT benefits period, EWR, LGA, and JFK departure capacity was increased by 6, 2, and 4 aircraft, respectively.
- We assert that these 12 aircraft (and the subsequent reduction in airport queuing delay) benefitted from the RAPT-derived COATE reopening, even though without RAPT the weakening trend in convection was likely still visible, because:
    - Pilots had been unwilling to penetrate similarly weak precipitation during the previous 2+ hours, making controllers and en route traffic managers hesitant to reopen the route.
    - Once COATE/J36 reopened, a new small cell quickly developed and intensified along J36, but the flow of traffic on this route had resumed and the departure aircraft were effectively managed in the face of this weather until 2200 UTC. Had J36 remained closed beyond 2130 UTC, the new convective development would have continued to limit Northgate departure capacity.

RAPT Delay Savings Calculations:

Benefit Period: 0.5 hr (2130-2200 UTC)

EWR Primary Delay Reduction:		5.1 hr
Downstream Delay Reduction:		4.1 hr
Direct Operating Cost (DOC) Savings:		$ 9,323
Passenger Value Time (PVT) Savings:		$ 11,082
Downstream Cost Savings:		$ 8,909
EWR Total RAPT Delay Reduction:	**9.2 hr**	
EWR Total RAPT Cost Savings:	**$29,314**	
LGA Primary Delay Reduction:		1.4 hr
Downstream Delay Reduction:		1.1 hr
Direct Operating Cost (DOC) Savings:		$2,559
Passenger Value Time (PVT) Savings:		$3,042
Downstream Cost Savings:		$2,390
LGA Total RAPT Delay Reduction:	**2.5 hr**	
LGA Total RAPT Cost Savings:	**$7,991**	
JFK Primary Delay Reduction:		3.7 hr
Downstream Delay Reduction:		3.0 hr
Direct Operating Cost (DOC) Savings:		$ 6,764
Passenger Value Time (PVT) Savings:		$ 8,040
Downstream Cost Savings:		$ 6,519
JFK Total RAPT Delay Reduction:	**6.7 hr**	
JFK Total RAPT Cost Savings:	**$21,323**	
Total RAPT Delay Reduction:	**18.4 hr**	
Total RAPT Cost Savings:	**$58,628**	

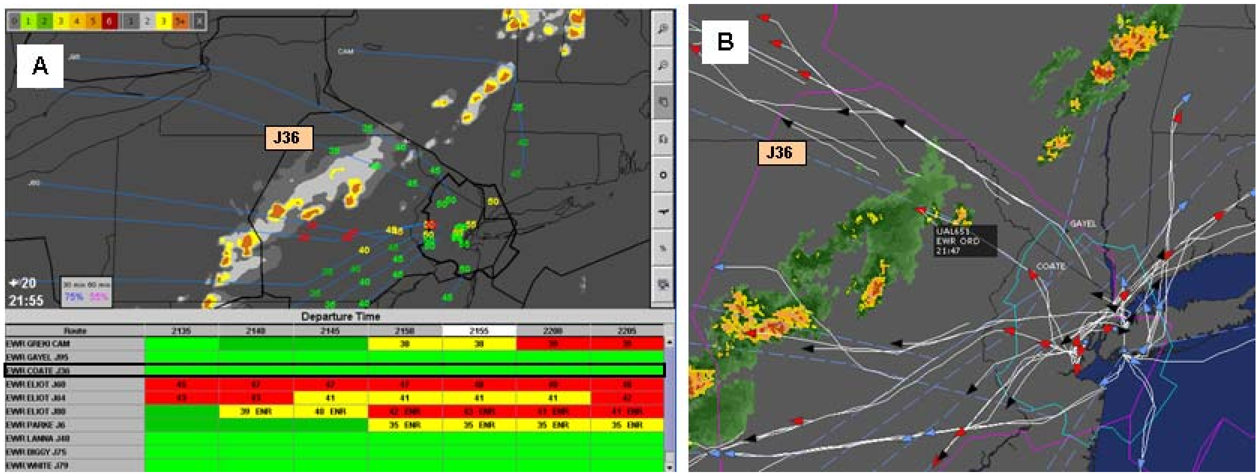


Figure A-1-5-1. (A) RAPT guidance at 2135 UTC on 30 August 2007. RAPT timelines show COATE/J36 (in box) clear of significant weather for near-term departures, while the animated precipitation forecast shows a strong persistent storm cell remaining south of the route. (B) Flight Explorer flights tracks and WSI composite reflectivity at 2155 UTC show NY departures actively using the COATE/J36 departure route.

CASE STUDY A-1-6

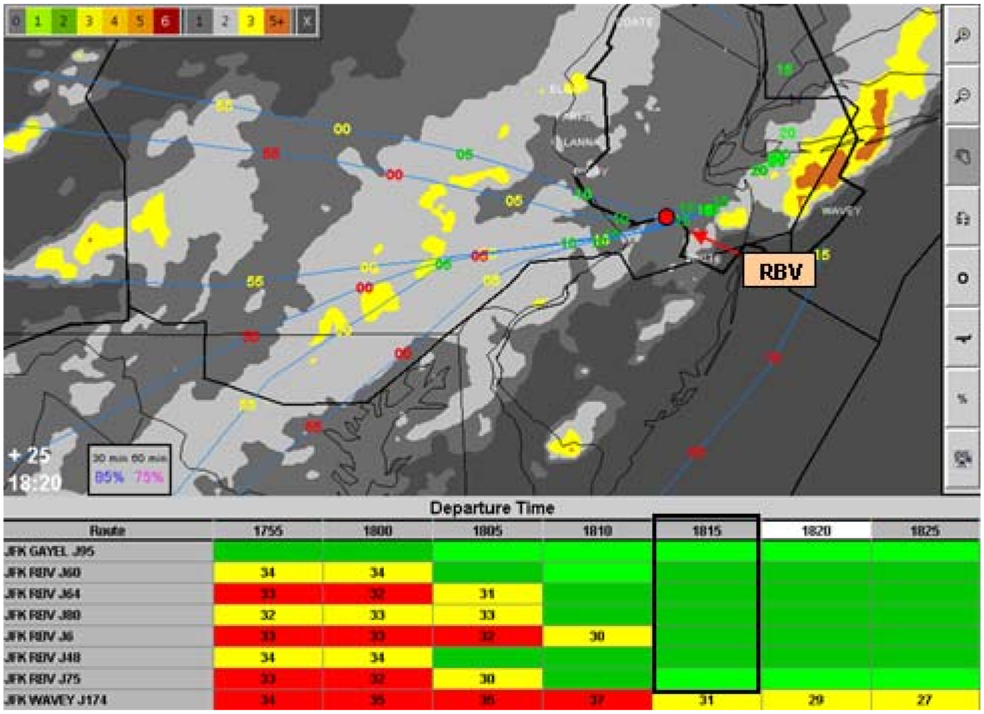
Date: 11 September 2007
Facilities Using RAPT: ZNY

Benefit: The RBV departure route was closed at 1625 UTC because of a short line of strong thunderstorms directly impacting the route. At 1815 UTC, JFK and N90 requested that ZNY allow RBV departures to resume. At ZNY, the STMC had been routinely monitoring RAPT during this specific weather episode, and noted that RAPT had consistently predicted that the JFK RBV departure routes would be clear of weather by 1810-1815 UTC. With this information, the STMC quickly agreed to allow four JFK RBV departures to test the route (five RBV flights were released). These aircraft successfully navigated the routes which allowed RBV to reopen with 10 MIT restriction at 1839 UTC.

- We assumed that without using RAPT, aggressive TFM by the ZNY STMC may still have allowed 1-2 RBV "route checkers", but not 4-5 RBV flights. Therefore, we assumed that had RAPT not been available, JFK departure capacity between 1815-1840 UTC would have been decreased by 3 aircraft.
- Results are considered conservative because even without the successful passage of 5 RBV route checkers and accurate RAPT guidance, RBV would have likely been reopened at 1840 UTC – but with greater in-trail restrictions. This benefits case study did not analyze the RAPT delay savings attributed to decreased in-train route restrictions – only the savings resulting from the early release of 3 extra JFK departures.

RAPT Delay Savings Calculations:

Benefit Period: 0.4hr (1815-1840 UTC)	
JFK Primary Delay Reduction:	4.4 hr
Downstream Delay Reduction:	3.5 hr
Direct Operating Cost (DOC) Savings:	$ 8,043
Passenger Value Time (PVT) Savings:	$ 9,561
Downstream Cost Savings:	$ 7,606
Total RAPT Delay Reduction:	**7.9 hr**
Total RAPT Cost Savings:	**$ 25,210**



Route	1755	1800	1805	1810	1815	1820	1825
JFK GAYEL J95							
JFK RBV J60	34	34					
JFK RBV J64	33	32	31				
JFK RBV J80	32	33	33				
JFK RBV J6	33	33	32	30			
JFK RBV J48	34	34					
JFK RBV J75	33	32	30				
JFK WAVEY J174	34	35	35	37	31	29	27

Figure A-1-6-1. RAPT guidance for JFK departure routes at 1755-1825 UTC on 11 September 2007, showing strong weather exiting the eastern N90 TRACON and heavy precipitation predicted to completely clear the RBV fix by 1815 UTC (see box in RAPT timelines).

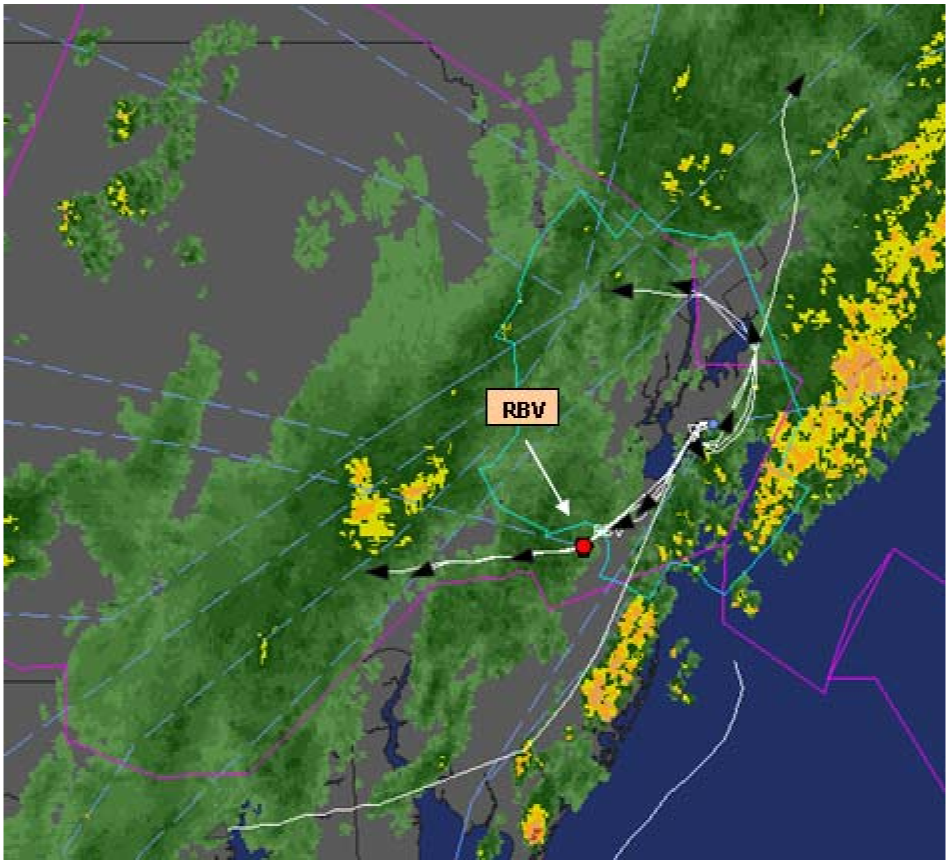


Figure A-1-6-2. Flight Explorer flight tracks and WSI composite reflectivity at 1840 UTC on 11 September 2007 showing JFK departures. At this time, all five JFK departures released via the RBV route between 1824-1837 UTC are airborne. ZNY used RAPT guidance (which predicted improving RBV conditions) to aggressively request five RBV departures at 1815 UTC.

RAPT Benefit 2: More Timely Reroute Planning or Implementation; Improved Route Impact Planning (RRP)

CASE STUDY A-2-1

Date: 19 July 2007
Facilities Using RAPT: ZNY

Benefit: RAPT guidance used to anticipate impacts on J36 and J95 Northgate parallel departure routes. At the time of the decision, J36 was closed and J95 was open. RAPT predicted when, based on departure time, conditions would reverse and J95 would be blocked by weather. With this information, ZNY proactively planned a Northgate reroute – moving J95 departure traffic to J36. By planning for the reroute ahead of time, and using RAPT to aniticipate when departures would require a move from J95 to J36, the reroute was quickly implemented, and no stoppage of Northgate departures occurred at the airports. J95 route was closed at 1306 UTC and J36 was opened as the reroute at 1307 UTC. The first J36 flight (after the RAPT-derived reroute became available) departed JFK at 1309 UTC.

- Without RAPT, an unplanned and uncoordinated departure route closure and reroute would likely have resulted in a 10 minute ground stop for N90 Northgate departures.
- The queuing model analysis was conducted over an hour, in order to represent an expected hold up in the airport departure lineups as pilots, dispatchers, and traffic coordinators and controllers react to the need for a new departure route. Moreover, without RAPT, it may not have been explicitly clear that J36 was immediately available as a viable reroute given convective weather was still present along the route.
- Additional Northgate departures via J36 during 1307-1407 UTC:
  EWR – 5, LGA – 3, JFK – 3.

RAPT Delay Savings Calculations:

Benefit Period: 10 min (queuing delay for 1.0 hr)		
EWR Primary Delay Reduction:		1.1 hr
Downstream Delay Reduction:		0.9 hr
Direct Operating Cost (DOC) Savings:		$ 2,011
Passenger Value Time (PVT) Savings:		$ 2,390
Downstream Cost Savings:		$ 1,956
EWR Total RAPT Delay Reduction:	**2.0 hr**	
EWR Total RAPT Cost Savings:	**$6,357**	
LGA Primary Delay Reduction:		10.6 hr
Downstream Delay Reduction:		8.5 hr
Direct Operating Cost (DOC) Savings:		$19,377
Passenger Value Time (PVT) Savings:		$23,034
Downstream Cost Savings:		$18,471
LGA Total RAPT Delay Reduction:	**19.1 hr**	
LGA Total RAPT Cost Savings:	**$60,882**	
JFK Primary Delay Reduction:		3.1 hr
Downstream Delay Reduction:		2.5 hr
Direct Operating Cost (DOC) Savings:		$ 5,667
Passenger Value Time (PVT) Savings:		$ 6,736
Downstream Cost Savings:		$ 5,433
JFK Total RAPT Delay Reduction:	**5.6 hr**	
JFK Total RAPT Cost Savings:	**$17,836**	
Total RAPT Delay Reduction:	**26.7 hr**	
Total RAPT Cost Savings:	**$85,075**	

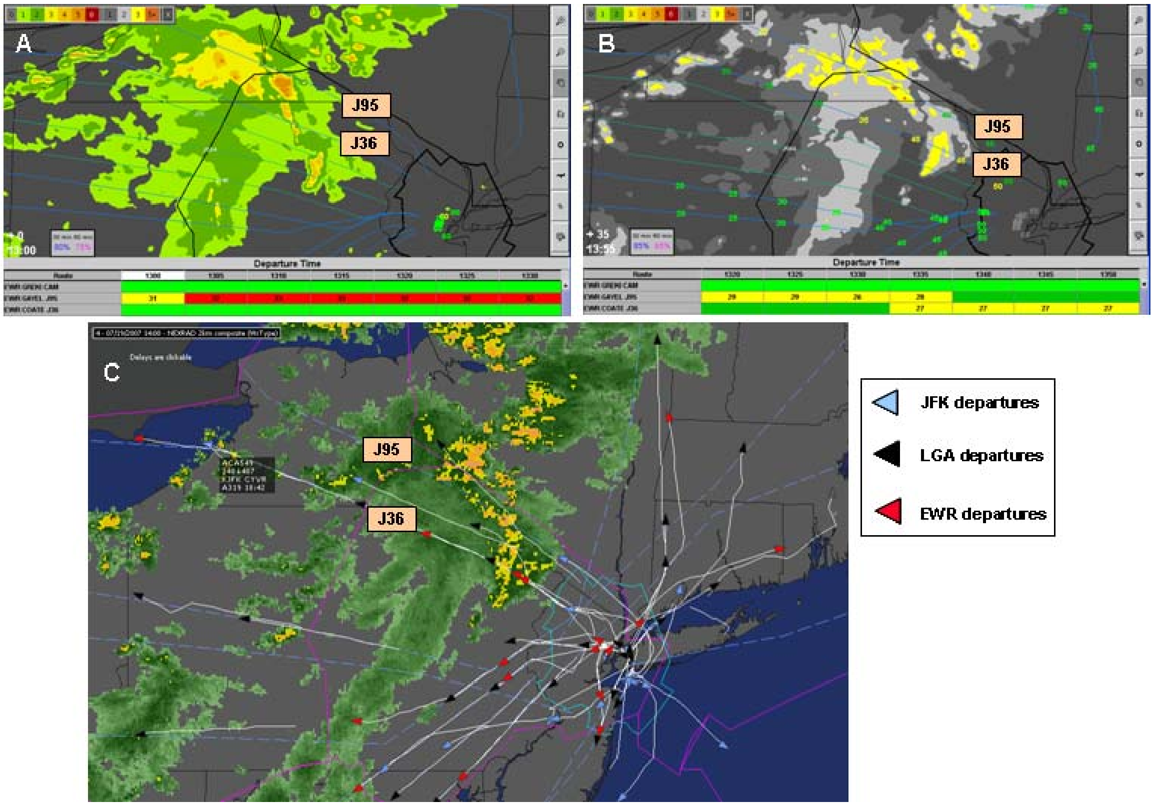


Figure A-2-1-1: (A) RAPT guidance issued at 1300 UTC on 19 July 2007 shows that the previously available (and in use) J95 jet route will soon be blocked by strong weather with moderately-high echo tops. Armed with this information, ATC quickly coordinated and implemented a reroute of Northgate departures from J95 to J36 and prevented a departure backlog at metro NY airports. (B) At 1320 UTC, level 3+ precipitation moved across the J36 jet route; but RAPT guidance accurately depicted minimal impacts as well as improving conditions along J95. (C) Flight Explorer flight tracks and WSI composite reflectivity at 1400 UTC on 19 July 2007, shows the flow of JFK (blue), LGA (black), and EWR (red) departures that had been using J36 since J95 was closed. Aircraft information is shown for the first flight to depart J36.

CASE STUDY A-2-2

Date: 11 September 2007
Facilities Using RAPT: ZNY

Benefit: ZNY uses RAPT guidance at 1630 UTC to identify that the WHITE departure route will remain unblocked by weather for at least 30 min and agrees to rerouting NY to ATL traffic onto this route.

- LANNA/J48 jet route, the nominal route for NY flights to ATL, was impacted by a line of severe weather after 1600 UTC (Last NY-ATL flight, EWR TRS1695, departed on J48 at 1621 UTC).
- ATL reroute agreed to and implemented at 1630 UTC; ATL WHITE reroute open until 1730 UTC, when the route becomes blocked by convection.
- With RAPT-derived reroute implementation, three ATL flights depart N90 via the WHITE fix:
  - DAL513, LGA to ATL – departed 1649 UTC
  - COA1159, EWR to ATL – departed 1706 UTC
  - DAL1457, JFK to ATL – departed 1727 UTC
- At 1730 UTC, the WHITE reroute was closed and NY to ATL traffic returned to the J48 departure route.
- With RAPT, three additional ATL flights were able to depart N90 prior to 1730 UTC.

RAPT Delay Savings Calculations:

Benefit Period: 1.0 hr (1630 – 1730 UTC)

EWR Primary Delay Reduction:		2.7 hr
Downstream Delay Reduction:		2.2 hr
Direct Operating Cost (DOC) Savings:		$ 4,936
Passenger Value Time (PVT) Savings:		$ 5,867
Downstream Cost Savings:		$ 4,781
EWR Total RAPT Delay Reduction:	**4.9 hr**	
EWR Total RAPT Cost Savings:	**$15,584**	
LGA Primary Delay Reduction:		2.6 hr
Downstream Delay Reduction:		2.1 hr
Direct Operating Cost (DOC) Savings:		$4,753
Passenger Value Time (PVT) Savings:		$5,650
Downstream Cost Savings:		$4,563
LGA Total RAPT Delay Reduction:	**4.7 hr**	
LGA Total RAPT Cost Savings:	**$14,966**	
JFK Primary Delay Reduction:		2.4 hr
Downstream Delay Reduction:		1.9 hr
Direct Operating Cost (DOC) Savings:		$ 4,387
Passenger Value Time (PVT) Savings:		$ 5,215
Downstream Cost Savings:		$ 4,129
JFK Total RAPT Delay Reduction:	**4.3 hr**	
JFK Total RAPT Cost Savings:	**$13,731**	
Total RAPT Delay Reduction:	**13.9 hr**	
Total RAPT Cost Savings:	**$44,281**	

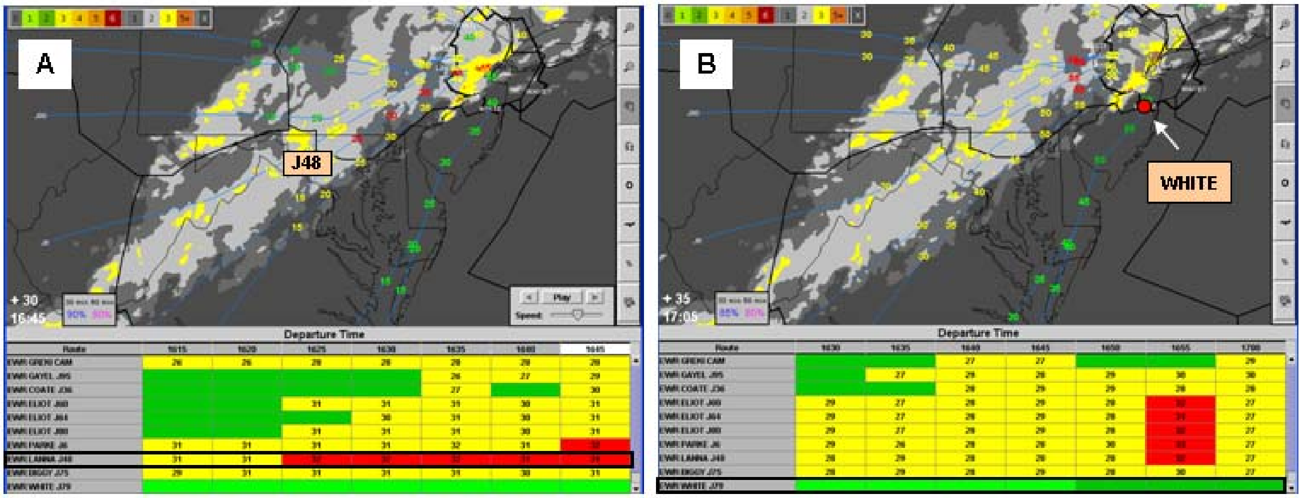


Figure A-2-2-1. RAPT guidance on 11 September 2007 at (A) 1615 UTC, accurately predicting when the J48 departure route (in box) would become blocked by weather, and at (B) 1630 UTC, accurately predicting that the WHITE fix and departure route (in box) would remain clear of weather and thus depicting a viable reroute for J48 NY-ATL traffic.

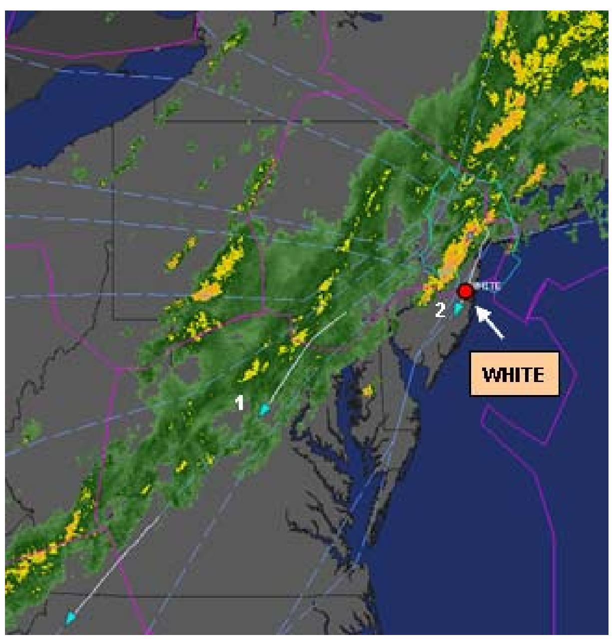


Figure A-2-2-2. Flight Explorer flight track and WSI composite reflectivity information at 1705 UTC on 11 September 2007, showing the last NY-ATL flight using the J48 jet route (see (1) - EWR TRS1695) and the first ATL flight rerouted via the WHITE fix (see (2) – LGA DAL513).

RAPT Benefit 3: Directing Pathfinder Requests (DP)

CASE STUDY A-3-1

Date: 16-17 August 2007
Facilities Using RAPT: ZNY

Benefit: ZNY used RAPT at 2325 UTC to convince ZDC to accept J48 pathfinders. At this time, strong convection was clearing the J48 route in ZDC airspace, and RAPT showed that a gap in weather would persist in the near-term.

- Three J48 pathfinders were released at 0000 UTC; one departure from EWR (COA1711 to IAH) and two departures from PHL.
- These three flights made it through ZDC via J48, but new convection developed along J48, eventually filling into a solid E-W line of severe weather across ZDC which kept the route closed.
- RAPT benefit for this application was in increasing EWR and PHL departure capacity by one and two flights, respectively, between 0000-0015 UTC. Without the request for pathfinders from ZNY, spurred on by "clear-route" guidance in RAPT, these three flights would not have departed and would have continued to contribute to the departure queue at each airport.

RAPT Delay Savings Calculations:

Benefit Period: 0.25 hr (0000 – 0015 UTC)

EWR Primary Delay Reduction:		0.6 hr
Downstream Delay Reduction:		0.4 hr
Direct Operating Cost (DOC) Savings:		$ 969
Passenger Value Time (PVT) Savings:		$ 1,152
Downstream Cost Savings:		$ 913
EWR Total RAPT Delay Reduction:	**1.0 hr**	
EWR Total RAPT Cost Savings:	**$3,034**	
LGA Primary Delay Reduction:		1.0 hr
Downstream Delay Reduction:		0.8 hr
Direct Operating Cost (DOC) Savings:		$1,828
Passenger Value Time (PVT) Savings:		$2,173
Downstream Cost Savings:		$1,738
LGA Total RAPT Delay Reduction:	**1.8 hr**	
LGA Total RAPT Cost Savings:	**$5,739**	
Total RAPT Delay Reduction:	**2.8 hr**	
Total RAPT Cost Savings:	**$8,773**	

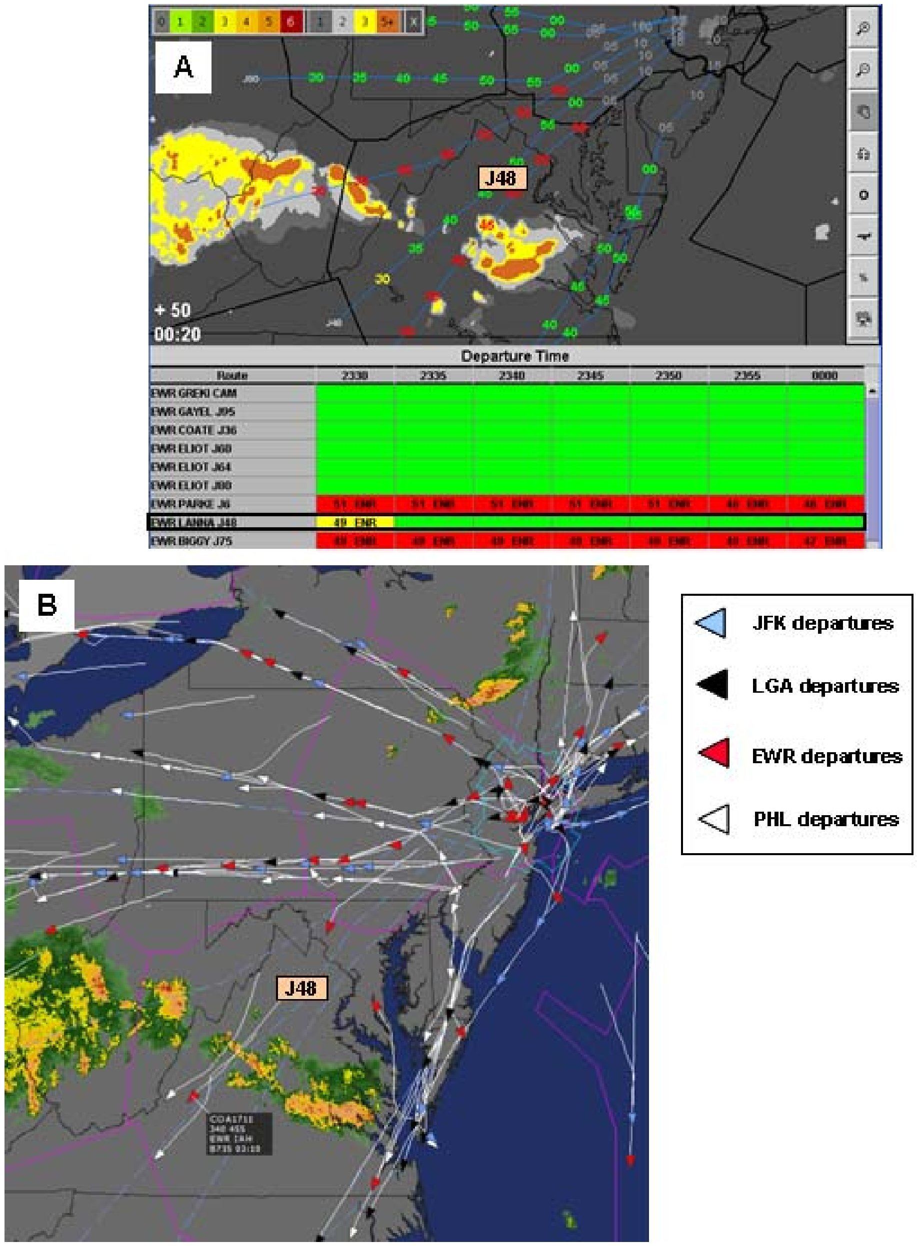


Figure A-3-1-1. (A) RAPT guidance at 2330 UTC on 16 August 2007, showing weather clearing the J48 departure route (in box) and a possibility to test the viability of this route via a pathfinder flying through a gap in severe weather. (B) Flight Explorer flight tracks and WSI composite reflectivity at 0100 UTC, showing the three pathfinder flights traversing ZDC airspace via J48. Strong convection began to fill in the previously available weather gap forcing J48 to remain closed after the pathfinders cleared the weather impact region.

CASE STUDY A-3-2

Date: 30 August 2007
Facilities Using RAPT: ZNY

Benefit: ZNY notes that RAPT predicted improving conditions along the J64 departure route – J64 was impacted and partially blocked by high-topped precipitation and thunderstorm blow-off. At 2325 UTC, ZNY places an open request on the NY hotline for a J64 pathfinder, based upon the RAPT forecast.

- One pathfinder each from JFK and PHL tested J64 between 2330-0000 UTC; both pathfinders deviated and evaded storm blow-off. The route remained closed.
- RAPT benefit calculated for increasing JFK and PHL departure capacity by one aircraft during this 30 min period.

RAPT Delay Savings Calculations:

Benefit Period: 0.50 hr (2330 – 0000 UTC)		
JFK Primary Delay Reduction:		0.5 hr
Downstream Delay Reduction:		0.3 hr
Direct Operating Cost (DOC) Savings:		$ 786
Passenger Value Time (PVT) Savings:		$ 934
Downstream Cost Savings:		$ 739
EWR Total RAPT Delay Reduction:	**0.8 hr**	
EWR Total RAPT Cost Savings:	**$2,459**	
LGA Primary Delay Reduction:		0.5 hr
Downstream Delay Reduction:		0.4 hr
Direct Operating Cost (DOC) Savings:		$ 914
Passenger Value Time (PVT) Savings:		$1,087
Downstream Cost Savings:		$ 869
LGA Total RAPT Delay Reduction:	**0.9 hr**	
LGA Total RAPT Cost Savings:	**$2,870**	
Total RAPT Delay Reduction:	**1.7**	
Total RAPT Cost Savings:	**$5,329**	

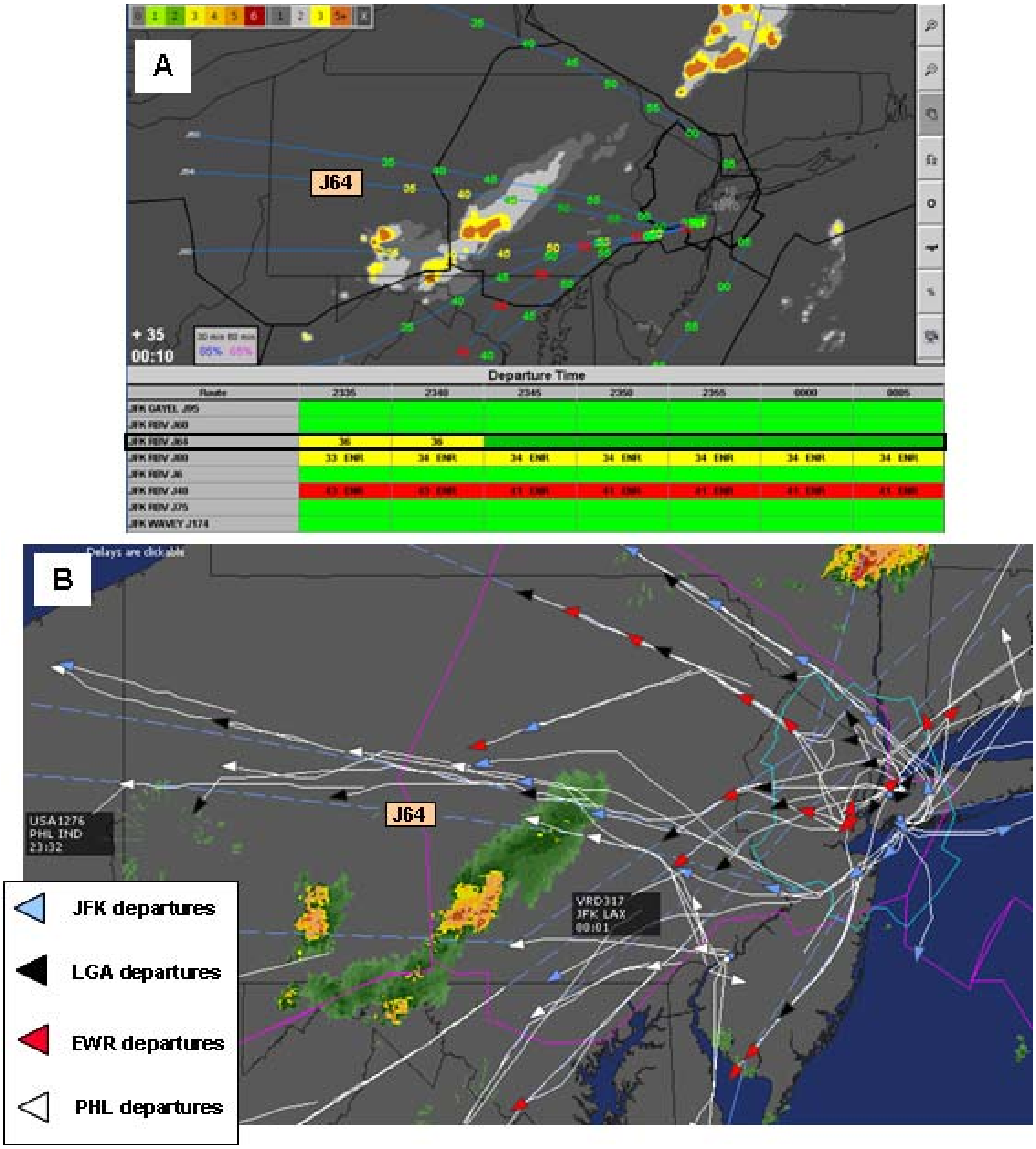


Figure A-3-2-1. (A) RAPT guidance at 2335 UTC on 30 August 2007 predicting weather blockages by high echo top precipitation becoming less severe for departures at 2345 UTC and beyond (see boxed timeline). (B) Flight Explorer flight tracks and WSI composite reflectivity at 0020 UTC showing the PHL (white) and JFK (blue) pathfinders (flights tagged with departure information) airborne and testing the route at this time.

RAPT Benefit 4: Keeping Departure Routes Open Longer (DOL)

CASE STUDY A-4-1

Date: 11 July 2007
Facilities Using RAPT: LGA

Benefit: LGA used RAPT timeline guidance, showing J75 unblocked by weather despite developing convection along the route in southern ZNY, as a basis for denying a request (assumed to have come from dispatch for a commercial airline) to close the route and offload traffic to another route.

- Decision to keep route open made at 1704 UTC
- LANNA/BIGGY fixes and J75 departure route closed due to weather at 1827 UTC
- Between 1705-1825 UTC, three additional LGA flights depart via J75
- We assumed that if LGA had not had access to RAPT timeline guidance and VIL precipitation/forecast in the RAPT animation, they likely would have passed concerns about the vaiability of J75 on to N90. The consequence would have been more stringent MIT restrictions or route closure; especially if ETMS weather depictions were used in the absence of RAPT (ETMS composite reflectivity typically looks more intense than VIL (RAPT) precipitation).

RAPT Delay Savings Calculations:

Benefit Period: 1.3 hr (1705-1825 UTC)

LHA Primary Delay Reduction:	8.6 hr
Downstream Delay Reduction:	6.9 hr
Direct Operating Cost (DOC) Savings:	$15,721
Passenger Value Time (PVT) Savings:	$18,688
Downstream Cost Savings:	$14,994
Total RAPT Delay Reduction:	**15.5 hr**
Total RAPT Cost Savings:	**$49,403**

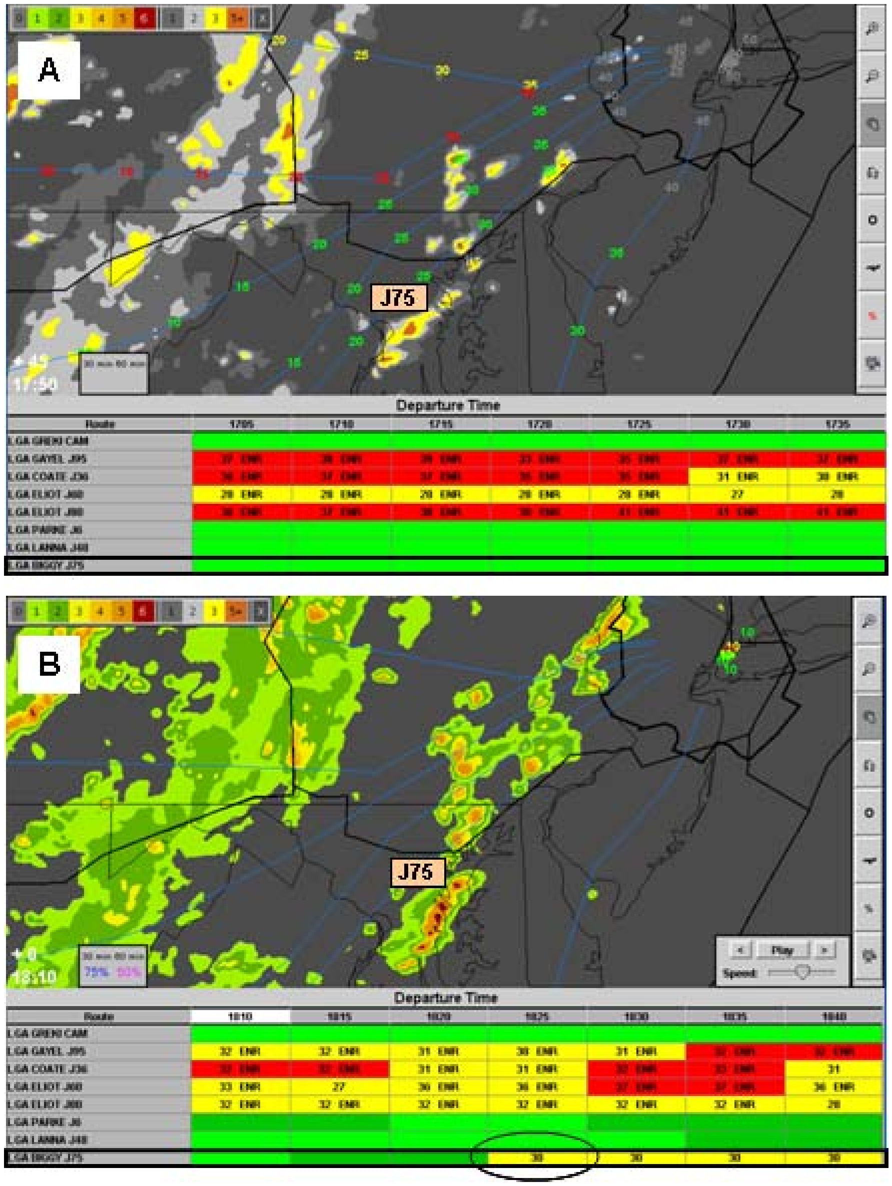


Figure A-4-1-1. RAPT guidance at (A) 1705 UTC and (B) 1810 UTC on 11 July 2007. At 1705 UTC, a cluster of storms was developing in southeast PA, but RAPT showed that J75, through this region, was unblocked by weather (in box in (A)) LGA traffic managers used this information to argue against a route closure and to keep the J75 departure route open. The cluster of storms slowly intensified and eventually caused pilot deviations large enough to close J75 at 1825 UTC. RAPT guidance at 1810 UTC correctly anticipated that conditions for J75 departures would deteriorate starting with 1825 UTC departures (circled). Note yellow timeline which indicates partial blockage or "caution".

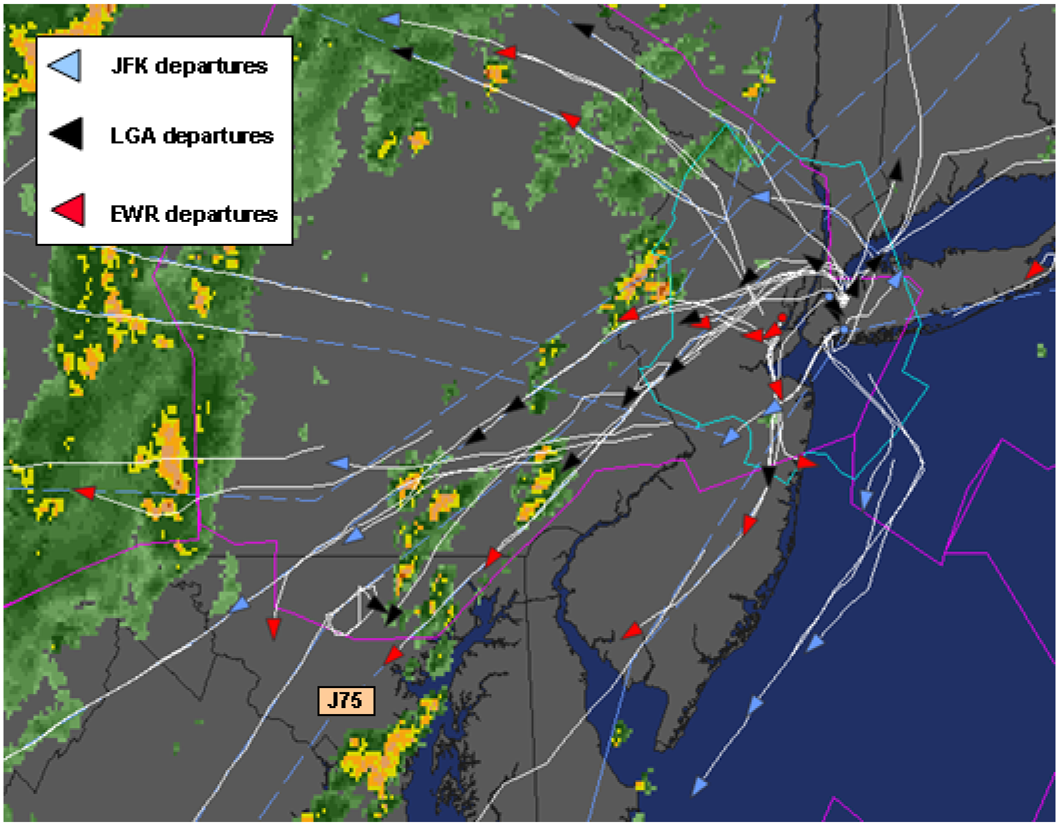


Figure A-4-1-2. Flight Explorer flight tracks and WSI composite reflectivity at 1705 UTC on 11 July 2007, showing the steady stream of J75 departure traffic (with more flights about to load onto the route) remaining on the route and overflying developing convection in southern ZNY airspace.