Project Report
ATC-388

Evaluation of the Integrated Departure Route Planning (IDRP) Tool 2011 Prototype

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16. Abstract

The Integrated Departure Route Planning (IDRP) tool combines convective weather impact forecasts from the Route Availability Planning Tool (RAPT) with departure demand forecasts from the MITRE tfmCore system to aid traffic managers in formulating plans to mitigate volume congestion in fair weather and during convective weather impacts. An initial prototype was deployed in the summer of 2010 for a very limited field evaluation. A second, more comprehensive field evaluation of the "Phase 2" IDRP prototype was performed in the summer of 2011.

The key focus of IDRP is the planning and implementation of departure reroutes to avoid weather impacts and volume congestion on departure fixes and routes. This evaluation assesses three facets of the IDRP prototype critical to the successful realization of its concept of operations:

1. performance of weather impact forecasts from RAPT and departure demand forecasts from tfmCore,
2. effectiveness of reroute decisions, and
3. potential impacts on procedures and decision making based on observations of IDRP use in the field.

The evaluation concludes with suggestions for future enhancements to improve the performance and realization of potential benefits in operational use of IDRP.

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ABSTRACT

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The key focus of IDRP is the planning and implementation of departure reroutes to avoid weather impacts and volume congestion on departure fixes and routes. This evaluation assesses three facets of the IDRP prototype critical to the successful realization of its concept of operations:

1. performance of weather impact forecasts from RAPT and departure demand forecasts from tfmCore,
2. effectiveness of reroute decisions, and
3. potential impacts on procedures and decision making based on observations of IDRP use in the field.

The evaluation concludes with suggestions for future enhancements to improve the performance and realization of potential benefits in operational use of IDRP.

EXECUTIVE SUMMARY

The Integrated Departure Route Planning (IDRP) Phase 2 prototype capability was deployed to FAA and airline dispatch facilities involved in New York area departure management and a summer-long evaluation was performed. Phase 2 capabilities included the Phase 1 departure fix demand and RAPT route demand prediction counts, plus a forecast demand flight list and automated reroute alternative lists for each flight in the demand list. Flight entries in the demand list included RAPT impact and wheels-off predictions, as well as information about departure queue position where and when ASDE-X surveillance was available. Reroute alternatives included RAPT forecast information and additional miles flown, in addition to other information. The evaluation included both data analysis and observation of IDRP use in the New York ARTCC, TRACON, towers, and selected commercial airline operations centers.

Since IDRP is intended to help in planning and executing reroute decisions, this evaluation focused on the quality of reroute decisions and potential improvements in reroute implementation. This report presents an analysis of the RAPT weather impact and IDRP wheels-off forecast accuracies; proposed and calculated objective metrics for reroute necessity, feasibility, and success; and presented case studies illustrating the relationship between reroute metrics, weather impacts, and traffic management tactics. Data were analyzed from two fair weather days and ten convective weather SWAP days. A summary of reports from ten days of field observations (on three separate visits) was also presented.

Findings

Thirty-minute wheels-off prediction error medians were near 0 for both fair weather and SWAP days. Half of the wheels-off prediction errors on SWAP days fell within the error bound envelope of –10 and +12 minutes (except for August 25, when the error envelope reached 20 minutes). The “extreme” error bound – the “floor” for the highest 10% errors – ranged from 30 to 50 minutes on SWAP days (again with the exception of August 25, when the extreme error bound was approximately 70 minutes). Wheels-off errors for fair weather days were considerably smaller. The volatility in 30 minute wheels-off forecasts – defined as the difference between the latest and earliest forecast wheels-off times between the issuance of the 30 minute forecast an actual wheels-off – was fairly large on SWAP days, with 25% of forecasts having volatility greater than 30 minutes.

RAPT 30 minute RED forecast accuracy ranged from 45% to 96%, with an average accuracy of 70%. GREEN forecast accuracy was greater than 85% on 9 of the 10 SWAP days analyzed (it was 72% on September 7). Observed fix traffic on RAPT RED and YELLOW routes was considerable at times; the median and 90th percentile 30 minute fix traffic counts for RED routes was 3 and 6.2 respectively; for YELLOW the counts were 4 and 8. The operational use of RED and YELLOW fixes varied significantly from one day to the next, depending on the extent and longevity of the weather impacts. Over the course of the 10 SWAP days studied, almost 700 departures were released on RAPT RED fixes, and approximately 430 of those were released during periods of heavy use (4 or more departures per 30 minutes).

Criteria for reroute necessity and feasibility, based on weather impacts and fix congestion, were defined. Over 1,300 reroutes on the 10 SWAP days studied were classified. The daily percentage of necessary reroutes ranged from a low of 53% to a high of 85%, with an overall rate of 70%. Necessity rates were higher for days with more prolonged and/or widespread impacts. In most cases, unnecessary reroutes took traffic from one GREEN, uncongested route to another, and were clustered in the period following the dissipation of weather impacts, as operations transitioned to normal routings. The percentage of necessary reroutes that were characterized as feasible varied considerably from one day to the next; in most cases, infeasible reroutes took traffic from RED fixes onto heavily used and nominally congested YELLOW and GREEN fixes during periods of severe, widespread impacts.

Case study analyses of four SWAP days suggested three modes of operations, each with different operational issues to address: widespread severe impacts that leave few options, prolonged but localized impacts, and relatively short-lived but widespread severe impacts. Common to all modes of operations was the use of merged traffic flows through impacted airspace, something which neither RAPT (merged route blockage) nor IDRP (merged fix capacity) can currently model. Observed fix traffic during periods of impacts, particularly on RED and YELLOW fixes, was more related to the availability of alternative unimpacted fixes than to RAPT status. The sensitivity of achievable fix throughput to operational factors beyond local RAPT weather impact and forecast fix demand needs to be better understood and considered in the IDRP Concept of Operations and training.

The 10 days of field observation included 6 fair weather days, 2 days with rain, and 2 days with moderate convective weather impacts. Field observers reported little use during the fair weather days. The most active use was at the N90 Tactical Reroute Coordinator (TRC) position, primarily to balance fix demand from the satellite airports. Several tower users responded favorably to the reroute alternative listing that could be accessed for individual flights in the flight list, and found the extra mileage entry particularly useful. However, tower users also commented that they would not proactively reroute flights from their filed flight plans unless those flight plans could not be cleared because of departure restrictions, stating that “airlines file a flight plan for a reason.” New York ARTCC users commented that the IDRP flight list would be most useful in the Pit, as an aid to reroute implementation.

The assessment of decision making and decision support in departure management, particular during convective weather SWAP, is difficult and complex. Metrics that characterize weather impacts, predictability, and quality of decisions such as reroute necessity and feasibility, are difficult to define and correlate to outcomes, which themselves are not easily defined. Nonetheless, the attempt to relate objective metrics to overall performance provides valuable insights into the most important problems and the impediments to solving them.

The role of uncertainty in managing departure operations during convective weather is enormous, and proactive planning must take into account the considerable uncertainty present during periods of severe weather impact. Several critical sources of uncertainty were identified:

1. Weather and weather impact forecasts
2. Pilot response to weather
3. Controller response to the workload of managing deviating pilots
4. The myriad of details that result in uncertainty in the wheels-off forecast
5. The state of current airspace restrictions

Arguably, the primary task of traffic management is the management of uncertainty – maintaining consistent and predictable traffic flows while at the same time maintaining flexibility and contingency plans that enable responses to weather and humans that may act in unpredictable ways. Concepts and tools for proactive planning must be developed in harmony with this reality – which leads to the fundamental conclusion of this evaluation:

In a highly uncertain world, forecasts, decision support tools, and/or concepts of operations do not define feasible planning horizons; Mother Nature does. Automated decision support must be sufficiently "self-aware" to guide users to the limits of its utility in different circumstances. Otherwise it will result in poor decisions that compound problems when the world (both natural and human) does not behave as predicted.

Recommendations

Specific recommendations for IDRP enhancements and refinements build upon this finding.

1. **Realistic guidance for the limits of the planning horizon.** Forecasts of the likelihood of long-lived and/or widespread weather impacts are necessary if one wishes to extend the reroute planning horizon beyond 30 minutes with any hope of success.
2. **Development of "extrapolation certainty" guidance.** A forecast that tells traffic managers "Conditions are likely to remain similar to current conditions for the next xxx minutes" provides extremely valuable guidance, enabling managers to extrapolate the most certain information they have – what is going on now – to realistic horizon limits.
3. **Improved RAPT RED accuracy.** The considerable volume of traffic observed occasionally on RAPT RED routes suggests that the criteria for RAPT RED need to be refined, to increase the certainty that RAPT RED fixes are not feasible, without greatly increasing the likelihood that pilots on RAPT YELLOW routes will refuse them.

4. **Refinement of IDRP Concept of Operations and capabilities to account for the observed situational capacity and tactics in the use of RAPT RED and YELLOW routes.** This evaluation identified nearly 700 departures that were released on RED fixes over 10 SWAP days, often using tactics such as flow merging (two or three routes merged into a single stream to avoid the weather) and managed deviations that are not well modeled in either RAPT impact or IDRP demand forecasts. Those flights would have required reroutes according to the current IDRP concept of operations. A better understanding of when and how RED and YELLOW fixes are used successfully to carry high traffic loads, is critical to defining a comprehensive and viable concept of operations for IDRP. Concepts for estimating, forecasting, and presenting blockage and capacity for merged routes and full departure gates should be explored.

5. **Continued refinement of the objective criteria for reroute success, and further analysis to correlate forecast accuracy to rates of reroute success, and to related reroute success metrics to overall departure throughput.**

6. **Focus on the use of the IDRP flight list and reroutes alternatives to improve implementation of reroutes.** A flight list only IDRP interface should be deployed to the Pit for use in reroute implementation. However, in order to be successful, both the wheels-off prediction errors and forecast volatility must be improved considerably.

7. **Improved support for returning rerouted flights to their originally filed plans when possible.**

8. **Meaningful integration with surface systems to reduce uncertainty in forecast departure demand and sequencing.** IDRP should not be modeling what can be controlled and provided by surface systems.

9. **Improved dissemination of information about the current state of airspace restrictions and operational plans.**

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS
(Continued)

LIST OF ILLUSTRATIONS
(Continued)

LIST OF TABLES

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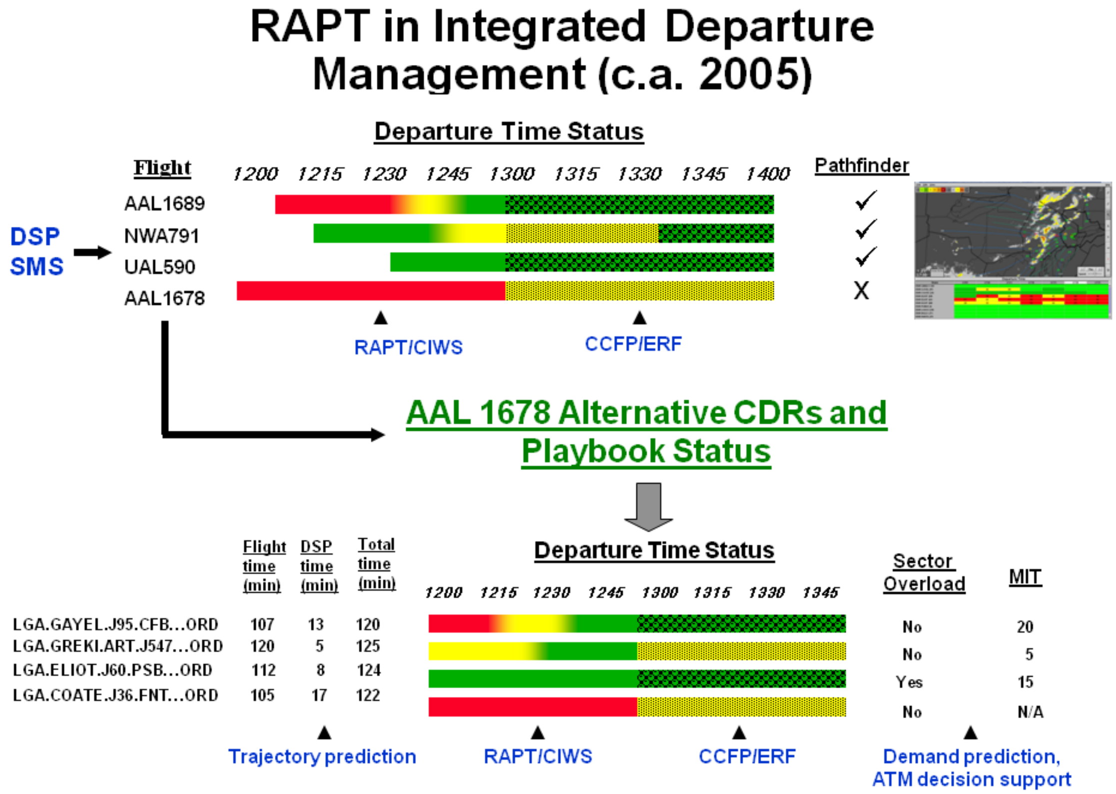
1. INTRODUCTION

The Integrated Departure Route Planning (IDRP) concept was first proposed as an extension to RAPT in 2005 (the name “Integrated Departure Route Planning” was coined in 2009) by New York TRACON (N90) and tower traffic managers when the RAPT prototype was part of the Integrated Terminal Weather System (ITWS) New York prototype. RAPT departure status forecasts were combined with lists of pending departures from the Departure Spacing Program (DSP), and reroute alternatives were automatically identified and presented to the user for consideration. Figure 1 shows the slide illustrating the original concept as presented in 2007 [1]. The initial concept also included an extended planning horizon, along with forecast uncertainty information.



RAPT in Integrated Departure Management (c.a. 2005)

Departure Time Status

Flight	Pathfinder
AAL1689	✓
NWA791	✓
UAL590	✓
AAL1678	X

AAL 1678 Alternative CDRs and Playbook Status

Departure Time Status

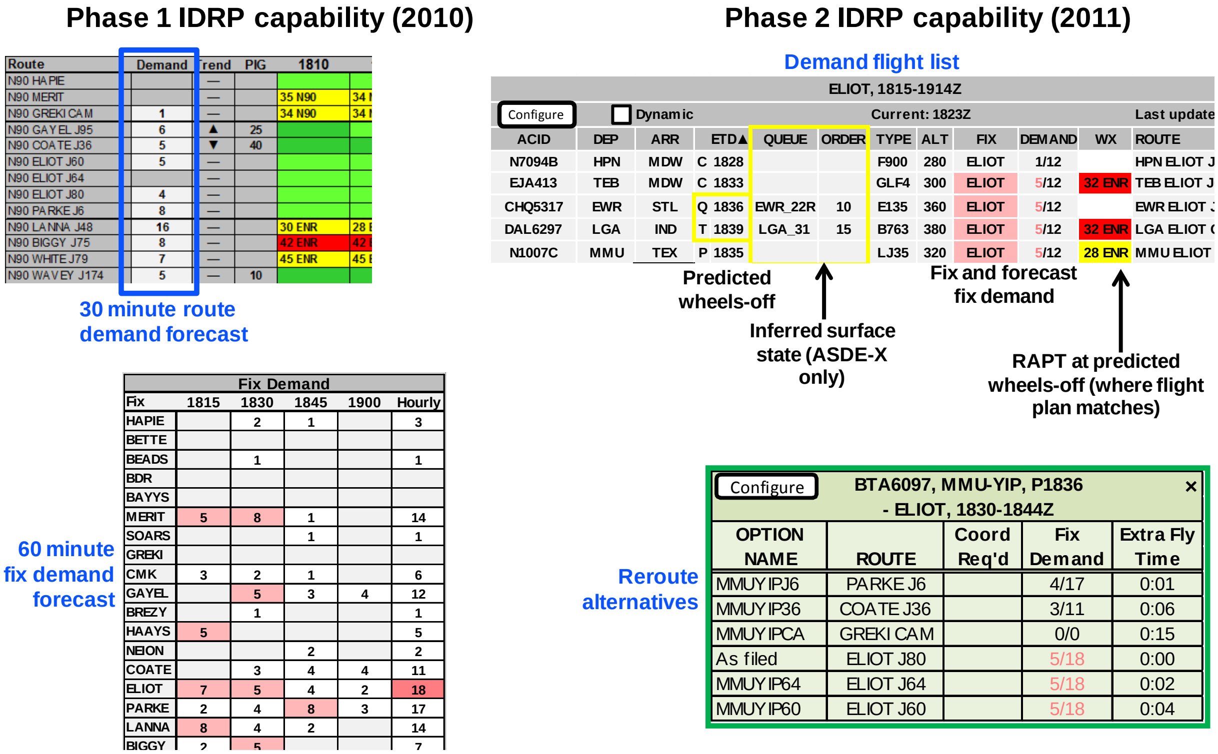
	Flight time (min)	DSP time (min)	Total time (min)	Sector Overload	MIT
LGA.GAYEL.J95.CFB...ORD	107	13	120	No	20
LGA.GREKI.ART.J547...ORD	120	5	125	No	5
LGA.ELIOT.J60.PSB...ORD	112	8	124	Yes	15
LGA.COATE.J36.FNT...ORD	105	17	122	No	N/A

Figure 1. Proposed concept for integration of RAPT weather impact and demand.

IDRP Phase 1 and 2 provide some of the proposed information in four components illustrated in Figure 2 [2]:

1. a fix list giving predicted departure demand and congestion alerts for each departure fix (Phase 1),
2. predictions of departure demand on each RAPT departure route (Phase 1),
3. a departure demand flight list that provides origin, destination, fix, flight plan, predicted departure time and RAPT status (Phase 2), and
4. a reroute alternative list for each flight in the flight list (Phase 2).

IDRP extends the original concept to management of fair weather congestion as well, but does not include the extended planning and uncertainty guidance.



Phase 1 IDRP capability (2010)

Route	Demand	Trend	PIG	1810	
N90 HAPIE		—			
N90 MERIT		—		35 N90	34
N90 GREKI CAM	1	—		34 N90	34
N90 GAYEL J95	6	▲	25		
N90 COATE J36	5	▼	40		
N90 ELIOT J60	5	—			
N90 ELIOT J64		—			
N90 ELIOT J80	4	—			
N90 PARKE J6	8	—			
N90 LANNA J48	16	—		30 ENR	28
N90 BIGGY J75	8	—		42 ENR	42
N90 WHITE J79	7	—		45 ENR	45
N90 WAVEY J174	5	—	10		

30 minute route demand forecast

Fix Demand					
Fix	1815	1830	1845	1900	Hourly
HAPIE		2	1		3
BETTE					
BEADS		1			1
BDR					
BAYYS					
MERIT	5	8	1		14
SOARS			1		1
GREKI					
CMK	3	2	1		6
GAYEL		5	3	4	12
BREZY		1			1
HAAYS	5				5
NEION			2		2
COATE		3	4	4	11
ELIOT	7	5	4	2	18
PARKE	2	4	8	3	17
LANNA	8	4	2		14
BIGGY	2	5			7

60 minute fix demand forecast

Phase 2 IDRP capability (2011)

Demand flight list

ELIOT, 1815-1914Z

Configure ☐ Dynamic Current: 1823Z Last update

ACID	DEP	ARR	ETD▲	QUEUE	ORDER	TYPE	ALT	FIX	DEMAND	WX	ROUTE
N7094B	HPN	MDW	C 1828			F900	280	ELIOT	1/12		HPN ELIOT J
EJA413	TEB	MDW	C 1833			GLF4	300	ELIOT	5/12	32 ENR	TEB ELIOT J
CHQ5317	EWR	STL	Q 1836	EWR_22R	10	E135	360	ELIOT	5/12		EWR ELIOT
DAL6297	LGA	IND	T 1839	LGA_31	15	B763	380	ELIOT	5/12	32 ENR	LGA ELIOT
N1007C	MMU	TEX	P 1835			LJ35	320	ELIOT	5/12	28 ENR	MMU ELIOT

Predicted wheels-off

Inferred surface state (ASDE-X only)

Fix and forecast fix demand

RAPT at predicted wheels-off (where flight plan matches)

Reroute alternatives

Configure BTA6097, MMU-YIP, P1836 - ELIOT, 1830-1844Z ×

OPTION NAME	ROUTE	Coord Req'd	Fix Demand	Extra Fly Time
MMUYIPJ6	PARKE J6		4/17	0:01
MMUYIP36	COATE J36		3/11	0:06
MMUYIPCA	GREKI CAM		0/0	0:15
As filed	ELIOT J80		5/18	0:00
MMUYIP64	ELIOT J64		5/18	0:02
MMUYIP60	ELIOT J60		5/18	0:04

Figure 2. IDRP Phase 1 and Phase 2 capabilities.

By integrating forecasts of weather impacts and demand with information about possible weather and congestion-avoiding alternatives, IDRP is expected to improve the effectiveness of reroute decisions and the efficiency with which those decisions are implemented. Ready access to information about the forecast state of departure route demand and weather impacts should support earlier identification of potential capacity/demand imbalances and better use of available capacity to mitigate those imbalances. The shared access among FAA traffic managers and airline dispatch facilities to IDRP and other information about the state of departure resources (e.g., current and anticipated route restrictions and closures) will support a distribution of the workload associated with tactical weather and congestion avoiding reroutes. Procedures could be developed that would enable towers and airlines to easily implement proactive weather- and congestion-avoiding reroutes, reducing the likelihood of bottlenecks in the reroute implementation process. The current IDRP planning horizon is 60 minutes in fair weather and 30 minutes (the limit of the RAPT forecast horizon) in convective weather.

IDRP provides decision support for both coarse- and fine-grained decisions. The fix and route demand counts provide summary, coarse-grained information that enables decision makers to quickly identify routes or fixes where weather impacts and/or high predicted volume may necessitate impact-avoiding reroutes, and to identify reroute targets, where weather and volume forecasts suggest additional capacity to handle impact-avoiding reroutes. Coarse-grained decisions represent “strategic” decisions about traffic flows (departure gates, routes, fixes) that impact several pending departures. Coarse-grained summary demand information was provided in the IDRP phase 1 prototype.

The flight lists and reroute option lists provided in the Phase 2 prototype provide fine-grained, flight-specific information useful in reroute implementation. Individual flights whose filed routes may not be cleared because of forecast restrictions can be identified and selected from the flight list. Viable reroute targets can be identified and selected from the reroute options list. Reroutes must still be manually entered into the host.

The utility of flight lists in making coarse-grained decisions, and the relationship of coarse-grained (i.e., reroute planning) and fine-grained (i.e., reroute implementation) decision making requires further study and clarification in the IDRP concept of operations. The IDRP training suggests that users may identify opportunities for reroutes by reviewing the flight list to find flights with a RAPT RED departure status or forecast fix congestion at the predicted wheels-off time. RAPT GREEN routes selected from the reroute options list may provide weather- and congestion-avoiding reroutes. However, flight lists currently provide no guidance to help users assess uncertainty in wheels-off predictions or flight-specific RAPT status predictions.

This evaluation focuses on potential improvements to reroute planning and implementation that can result from IDRP use. Metrics are defined to measure the accuracy of RAPT and IDRP forecasts, to assess the quality of reroute decisions, and to gain insight into the potential impacts on operations of different reroute and departure management strategies. The metrics provide a basis for future comparisons to estimate benefits due to IDRP use, and for refinements to the IDRP concept of operations that take into account the performance limitations and uncertainty inherent in weather and demand forecasts. An analysis of observed operations in different field sites provides the basis for the evaluation of the potential impact of IDRP on reroute planning and procedures to implement reroutes once the reroute strategy has been decided.

Different aspects of the evaluation are presented in the following four sections:

1. **Accuracy and uncertainty of weather impact, wheels-off and demand forecasts.** Weather impact, wheels-off forecasts, and fix demand forecasts derived from wheels-off predictions are fundamental to the IDRP concept, and their accuracy is critical to the achievement of delay reduction benefits. Forecast uncertainty limits the planning horizon for successful decision making, and an understanding of forecast uncertainty is necessary to ensure that users exercise good judgment in deciding when and how to act upon (or ignore) IDRP guidance. Forecast performance evaluation is needed to guide further development of forecast algorithms, provide an objective measure to evaluate the effectiveness of algorithm improvements, and to establish accuracy requirements for operational use.

   Section 2 presents an objective evaluation of the forecast accuracy of the underlying IDRP decision support models. The RAPT evaluation assesses the accuracy of RAPT blockage status forecasts (e.g., how often are RAPT RED forecasts accurate, compared to RAPT "truth" calculated using observed weather?) and the correlation of observed departure fix traffic to "true" RAPT status (i.e., how accurately do RAPT status colors reflect operational reality?). The accuracy of IDRP wheels-off forecasts and the volatility of those forecasts over the IDRP forecast horizon is analyzed, for both fair weather and weather impact case days.

2. **Ability to identify the most effective reroute strategies (i.e., those most likely to succeed) using IDRP forecasts.** A reroute strategy may be characterized in many ways: by prescribed actions ("reroute on RAPT RED"), restrictions ("only reroute flights that have pushed back"), or by a sequence of procedures ("first manage deviations, then apply mile-in-trail, then implement reroutes"). The effectiveness of a reroute strategy may be evaluated by analyzing the outcomes of reroute decisions on two scales: individual flights and system aggregate. From the point of view of an individual flight, a successful reroute results in a reduction of weather and/or congestion impact, which, in turn, translates into a reduction of departure delay. At an aggregate level, a successful reroute strategy results in a higher overall departure rate for the metroplex for a given level of demand and weather impact, since it makes the best use of available departure capacity.

   The likelihood of success for any reroute strategy is driven by the uncertainty in forecasts of weather, weather impacts, wheels-off, demand, pilot response to weather, and controller response to pilot behavior. In order to predict the likelihood of success for a comprehensive departure management strategy, the strategy must be defined (e.g., "reroute on RED"), outcome metrics must be calculated, and the probabilities of success given available forecast information must be determined. The effectiveness of strategies can be further explored by correlating outcomes to decisions (e.g., for a given level of weather impact, does a higher rate of reroutes result in higher departure throughput?), and by exploring those correlations (e.g., under what circumstances did lower rates of reroutes result in higher departure throughput for a given level of weather impact?). In order to be successful, IDRP must encourage the use of reroute strategies with the highest likelihood of success, and it should provide information that increases the likelihood that the preferred strategy will be successful.

Section 3 presents an analysis of individual reroute outcomes based on a comparison of actual weather impacts and fix volumes on the originally filed flight plan and the flight plan at wheels-off. A follow-on analysis, in which "true" reroute outcomes are correlated to weather impact, demand, and wheels-off forecasts (in order to assess the ability of IDRP guidance to forecast the opportunities for successful reroutes), could not be completed by publication time, and remains as future work. It will also be necessary, as future work, to develop analyses that can objectively identify "missed opportunities," where reroutes that could have increased system capacity were not implemented.

Section 3 also includes several case studies of airspace use and reroute tactics. Individual case day analyses are presented to relate metrics for weather impacts and predictability, use of impacted airspace, and reroute tactics to system outcomes. The case studies identify critical information and refinements to the IDRP concept of operations and capabilities that may improve the effectiveness of reroute strategies during convective weather impacts and inform efforts to develop objective models that relate reroute strategies to system performance.

3. **Procedural opportunities and impediments to realization of benefits through IDRP use ("field evaluation").** Field observations of departure management at IDRP facilities provided critical information about the operational context in which IDRP will be used. This context includes (but may not be restricted to) the division of labor between and within facilities, National Airspace System (NAS) state information that is available and trusted, the factors considered in making departure management decisions, the way information and decisions are disseminated among participants, and opportunities for or impediments to improvement in traffic management planning and implementation. Section 4 presents a summary of departure management operations and IDRP use observed during site visits during the evaluation.

Section 5 presents conclusions and recommendations for next steps.

The evaluation is based on the analysis of data from two fair weather days and ten convective weather Severe Weather Avoidance Program (SWAP) days when weather impacts were largely present in the New York RAPT domain. The field evaluation is based on observations from three field visits.

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2. PERFORMANCE EVALUATION

This section describes the analysis used to evaluate IDRP forecast accuracy, and the potential impacts of forecast uncertainty on the realization of IDRP benefits. Ten New York SWAP days from 2011 were analyzed; Table 1 summarizes the duration and severity of weather impacts on those days. This description presents a summary of the data analyses and highlights results that provide particular insights into IDRP performance.

Table 1. Summary of 2011 SWAP Days Included in the Analysis

Date	Times and gates impacted	Facilities impacted	Weather type
17-June	17-22Z (north, west); 20-23Z (south)	ZDC, N90, ZBW	Line; scattered storms
22-June	10-14Z (north); 20-23Z (north, west, south)	ZBW, N90	Complex of storms
08-July	18-22Z (north, west); 21-03Z (south)	ZDC, ZNY, ZBW, N90	Line; scattered storms
19-July	18-02Z (west, south)	ZDC, ZNY	Scattered storms
25-July	10-22Z (north, west); 21-03Z (south)	ZDC, ZNY, ZBW, N90	Lines; large complexes
29-July	19-23Z (north); 21-23Z (west); 22-03Z (south)	ZNY, ZBW, N90	E-W oriented line, moving W-E
01-August	19-02Z (west); 22-03Z (south)	ZDC, ZNY, ZBW, N90	Complex of severe storms
19-August	16-00Z (north); 20-00Z (west, south)	ZDC, ZNY, ZBW, N90	Line; multiple severe cells
25-August	10-15Z (north, west); 19-03Z (south)	ZDC, ZNY, ZBW, N90	Multiple lines, moving W-E
07-September	12-03Z (north, west); 13-16Z (south)	ZDC, ZNY, ZBW	N-S oriented slow moving line; late summer convection

Forecast accuracy is evaluated with respect to a *planning horizon* (H), which represents the limit, in minutes, of advance planning for weather and congestion avoiding reroutes. A flight enters the planning horizon at the first forecast issuance time (T_f) when the IDRP wheels-off prediction (T_f^o) falls within H minutes of the forecast issuance time ($T_f + H <= T_f^o$). For the evaluation, H is set to 30 minutes, which is the current RAPT status forecast limit. The planning horizon represents a decision maker's point of view; it identifies the forecasts that must be used to support a particular time horizon for proactive planning. Figure 3 illustrates the relationship between wheels-off forecast and the planning horizon.

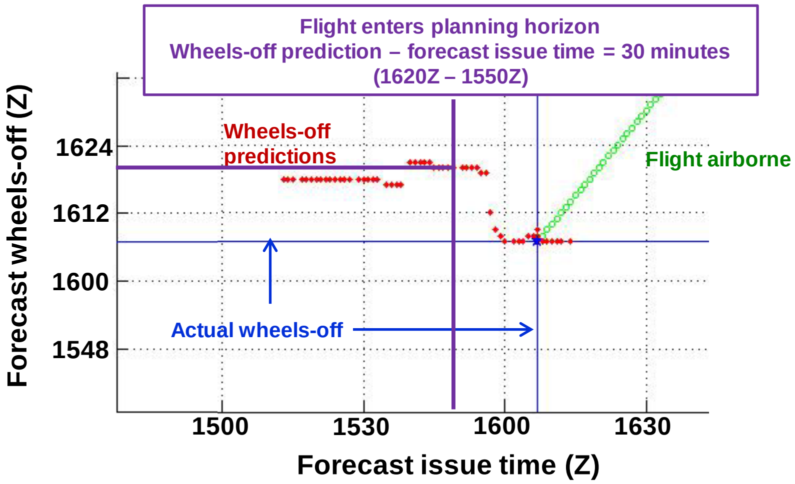


Figure 3. The decision-making planning horizon.

2.1 RAPT STATUS

Two aspects of RAPT forecasts were evaluated: RAPT status forecast accuracy and the accuracy of the RAPT "operational model" (i.e., the relationship between actual RAPT route status and observed route use).

Forecast accuracy was determined by comparing forecast and actual RAPT status, where the actual RAPT status is calculated using the observed ("true"), rather than forecast, weather along the departure trajectory. For the comparison, the 30-minute RAPT status forecast for each route and forecast update was compared to the actual RAPT status for the corresponding departure time.

Figure 4 presents the 30-minute RAPT status forecast accuracy for all RAPT N90 departure routes, aggregated over all 10 SWAP days analyzed. Approximately 2,900 RAPT RED, 6,800 YELLOW, and 18,800 GREEN forecasts were scored. The accuracy of RAPT RED forecasts was approximately 75%, while GREEN forecast accuracy was approximately 90%. RAPT had a tendency to over-forecast impacts, as is evidenced by the higher error rate for RED forecasts (compared to GREEN), and the slight over-forecast bias in YELLOW forecasts (approximately 20% over-forecast vs. 15% under-forecast).

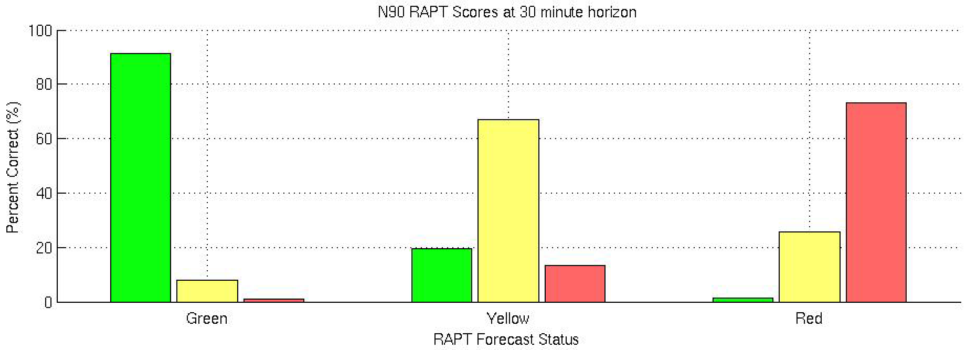


Figure 4. RAPT 30-minute status forecast accuracy score for ten 2011 SWAP days analyzed.

Forecast performance varied by day; RED forecast accuracy on four days was less than 60% and on four other days was greater than 80% (see Figure 5). On the other hand, GREEN forecast scores did not vary significantly by day; only one day (September 7) had a GREEN forecast score less than 85% (72%). Higher accuracy RED forecast days tended to have more severe impacts (three of four high accuracy days had more than 500 RED forecasts; only one low-accuracy day had as many REDs) and periods of widespread, severe forecasts lasting two hours or more. On lower-accuracy RED forecast days, impacts tended to be more scattered, impacting fewer departure gates or routes at any given time. Impact durations on lower-accuracy days varied significantly, from an hour or less to several hours concentrated over a single departure gate. Figure 6 illustrates RAPT impacts, by route and gate, over the complete day for sample low and high accuracy days.

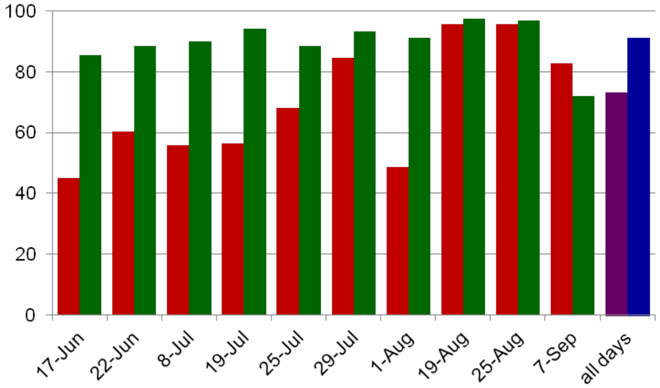
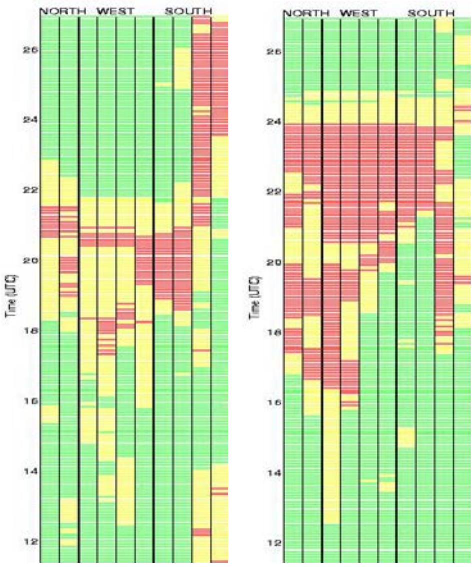


Figure 5. RAPT RED and GREEN forecast accuracy scores by day.



July 8
RAPT RED forecast
accuracy = 56%

Aug 19
RAPT RED forecast
accuracy = 96%

RAPT status throughout the day
Routes ordered from GAYEL to WAVEY (left to right)

Figure 6. Comparison of weather impacts on days with poor and excellent RAPT forecast scores.

These results suggest that an operational real time score of RAPT forecast accuracy (particularly for RED forecasts) may be useful. Previous efforts at forecasting RAPT scores during operations have not been very successful, possibly because they attempted to predict RAPT performance at too fine a spatial scale (by route or individual departure gate), with too much precision (“percent accuracy”), or they were poorly coupled to the operational uses and decision making. These results suggest that a useful real time RAPT performance forecast is possible and need not be as precise as previous scoring efforts, particularly if it is clearly related to specific decisions (e.g., RED/GREEN forecasts and reroute planning).

The accuracy of the RAPT operational model impacts IDRP effectiveness in at least two significant ways. First, RAPT RED status may be less useful as a reroute trigger if/when RED routes and fixes can carry more traffic than expected, since rerouting traffic away from routes that are still viable leaves needed capacity unused (see Figure 7 for an illustration). The presence of traffic on RAPT RED routes and fixes reflects the uncertainty inherent in predicting pilot preference and traffic controller workload limitations in managing deviating aircraft. An appreciation of this uncertainty suggests that a nuanced interpretation of RAPT RED is necessary for effective use of IDRP to plan and implement reroutes; the RAPT RED classification is not sufficiently robust to support a simple “reroute on RED” strategy, and it may result in inefficient use of available resources, or worse, reroutes of traffic onto already congested and scarce unimpacted resources. Second, weather-avoiding reroutes often require the use of partially impacted routes or fixes (RAPT YELLOW), so some understanding of capacity on RAPT YELLOW is needed to ensure that reroutes to/from RAPT YELLOW routes are used efficiently.

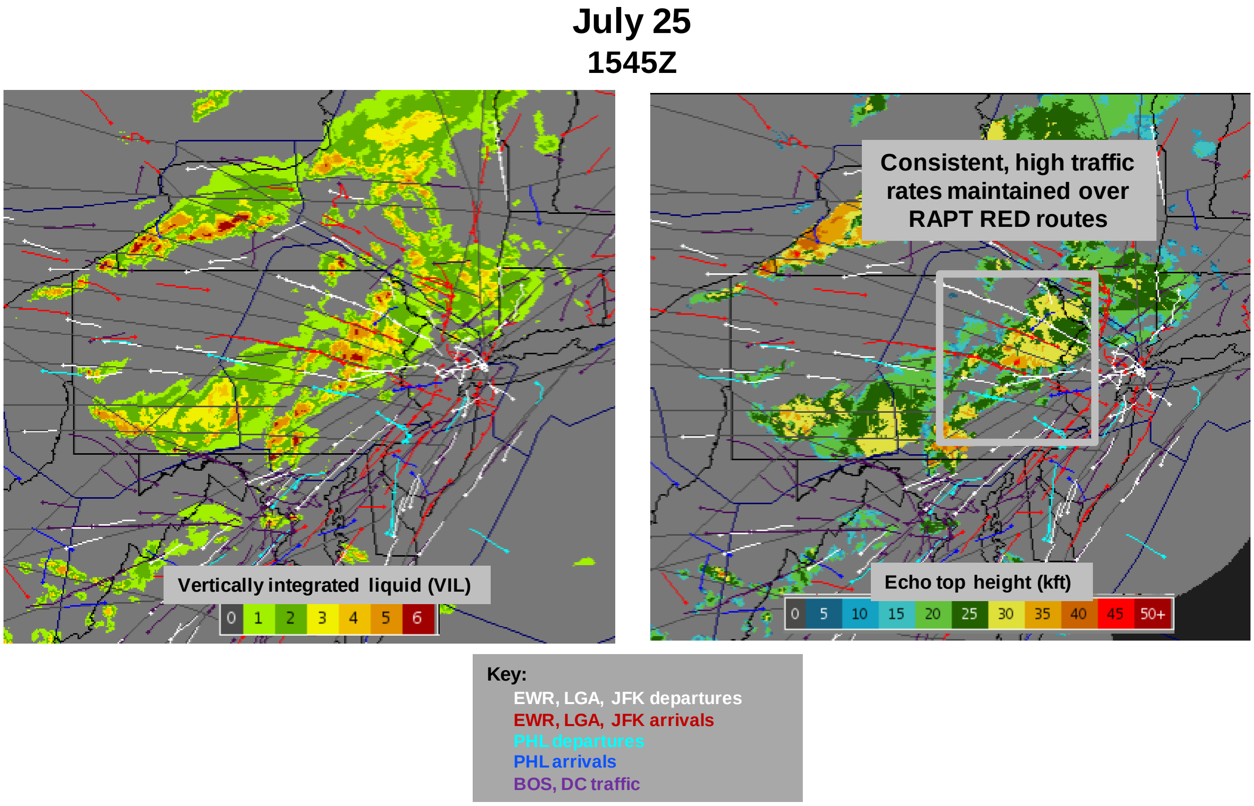


Figure 7. Illustration of heavy use of RAPT RED fixes.

A previous statistical analysis [3] and several field evaluations [3, 4, 5] provided evidence that the RAPT operational model is sufficiently accurate to support the effective use of RAPT to reopen closed routes and plan reroutes of traffic off impacted departure routes. A more complete statistical analysis of the RAPT operational model, based on an analysis of the ten SWAP case study days, is presented here. The accuracy of the RAPT operational model was assessed by comparing the actual RAPT status (based on true weather) to the observed traffic throughput on RAPT departure fixes. Observed fix traffic, defined as the number of departures passing through a departure fix during a 30-minute period, were correlated to a 30-minute "characteristic" RAPT status for the fix. The 30-minute bins spanned 18 hours of the day, from 0900Z to 0300Z the following day, starting on the hour and half-hour boundaries. The analysis was carried out only for departure traffic using the 9 RAPT fixes for north, west, and south gate departures: GAYEL, COATE, ELIOT, PARKE, LANNA, BIGGY, RBV, WHITE, and WAVEY.

A flight was assigned to a particular departure fix if its trajectory passed within 1/6 of a latitude and longitude degree (approximately 10 nautical miles) of the fix. A trajectory passing within that distance of more than one fix was assigned to the fix with the minimum approach distance. Traffic that did not pass within the threshold distance of any fix was not assigned, but there were few instances of unassigned flights. The flight was assigned to the time bin that included its wheels-off time. The "characteristic" RAPT fix status for a 30 minute bin was simply defined as the RAPT status color that occurred most often in the true RAPT timeline for that fix during the bin. If there was a tie between two status colors for most frequent, the more severe RAPT color was assigned. For purposes of this analysis, DARK GREEN and GREEN status were aggregated and defined simply as GREEN.

Figure 8 presents histograms of observed traffic counts as a function of RAPT guidance, aggregated over the ten SWAP days analyzed. RAPT guidance generally reflects operational behavior, as the distributions of fix use tend more toward the right (higher counts) as RAPT status moves from RED to YELLOW to GREEN. The median and 90th percentile values of the GREEN distribution are artificially reduced due to the large number of zero departures that correspond to low demand periods early and late in the day, when convective weather impacts are relatively rare and a RAPT GREEN status is more likely. The prevalence of GREEN departure counts between 8 and 12 per half-hour suggests that the nominal IDRP fix demand alert level of 20 per hour is a good estimate of sustainable GREEN capacity.

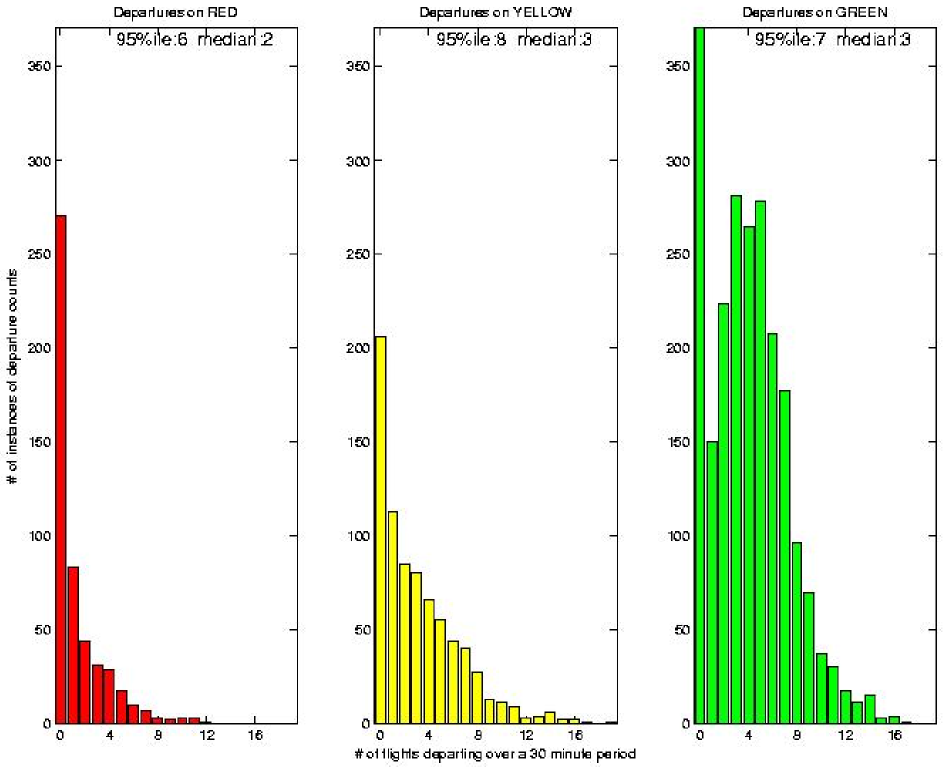


Figure 8. Observed fix traffic in 30-minute periods by RAPT color.

It is interesting to note that fairly high departure fix counts – 4 or more per half hour – are not uncommon on RED routes. On the ten SWAP days studied, 691 departures in total were released on RED fixes. Of these, 427 departures were released during periods of “aggressive” use of RAPT RED fixes (i.e., instances where observed departure traffic counts were 4 or more in 30 minutes). Rerouting flights based on RAPT RED alone would have required reroutes of these 691 flights on the ten SWAP days, a 50% increase in reroutes of flights filed through RAPT fixes which likely would have had negative impacts on departure efficiency. The aggressive use of RED and YELLOW fixes was not consistent over all SWAP days, or even over the course of a particular day. Figure 9 presents the percentage of RED and YELLOW fixes with heavy 30 minute traffic counts (4 or more for RED, 6 or more for YELLOW), and the total number of RED departures per day, along with the number of those that were released during periods of heavy fix use. On five days – July 19, July 25, August 1, August 25, and September 7 – more that 15% of all RED fixes carried heavy traffic loads and total departures on RED fixes ranged from 55 to 149.

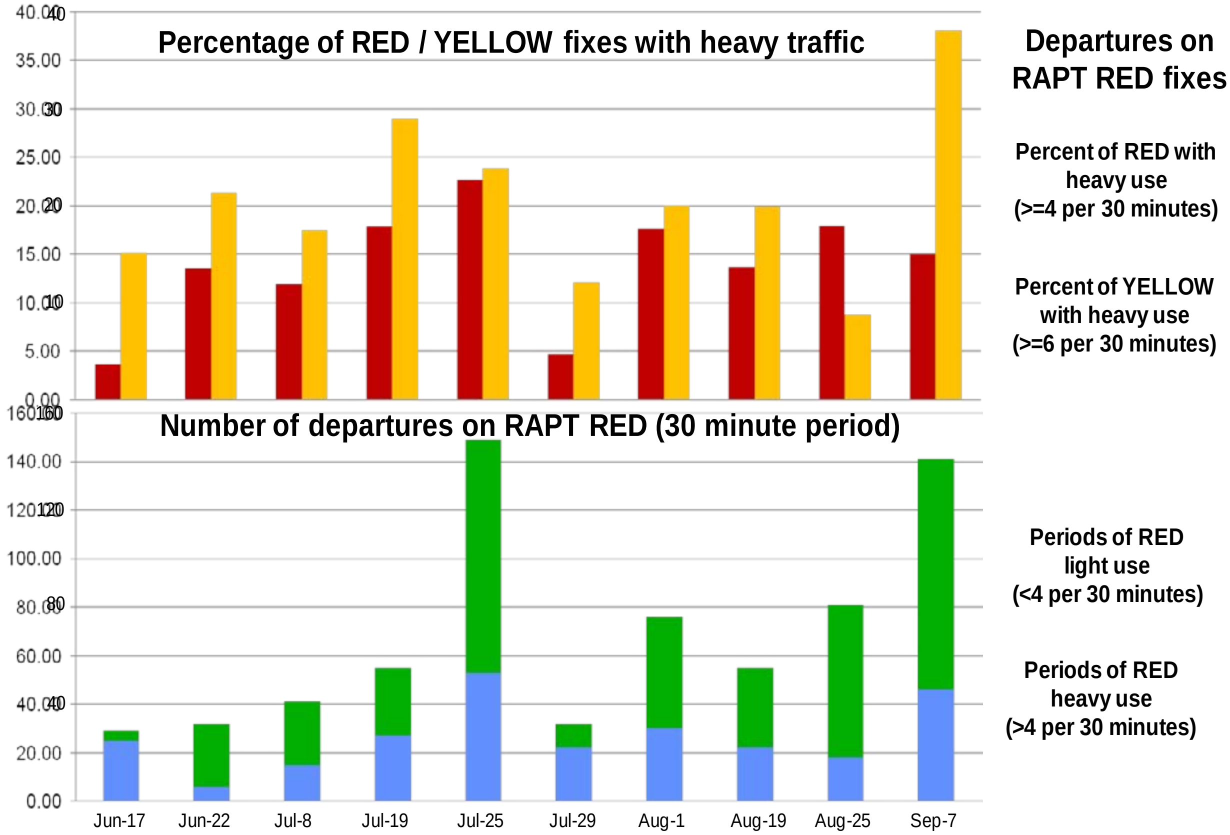


Figure 9. Observed use of RAPT RED and YELLOW fixes by day.

Figures 10 and 11 illustrate a comparison between days when RED fix use varied considerably. On June 22 (Figure 10), severe impacts were largely scattered over two periods: early morning (10-14Z) over GAYEL, and late afternoon (20-22Z), impacting different fixes out the north, west, and south gates at various times. Over the complete day, RED and YELLOW fix use was average (14% RED periods and 21% of YELLOW had heavy traffic loads). The early morning impacts were restricted largely to the GAYEL and GREKI fixes, and traffic was easily moved to COATE, which was GREEN throughout most of the period. By contrast, later in the day when severe weather in N90 severely impacted both north and west gates, aggressive traffic management moved a considerable number of departures out the RED fixes (10 departures on one 30-minute RED period, 11 on another). Since the impacts were relatively short-lived, the routes were never closed. By comparison, on July 25 (Figure 11) severe impacts were widespread, simultaneously impacting most north and west gate departure fixes, over a prolonged period of time (16-21Z). There were few unimpacted options for departure traffic, and as a result, traffic management made heavy use of both RED and YELLOW fixes (23% of RED and 24% of YELLOW had heavy loads). The challenge to traffic management on this day was to find and take advantage of the best of several severely impacted options, as thunderstorms grew, decayed, and regenerated on a very dynamic and difficult to predict weather day.

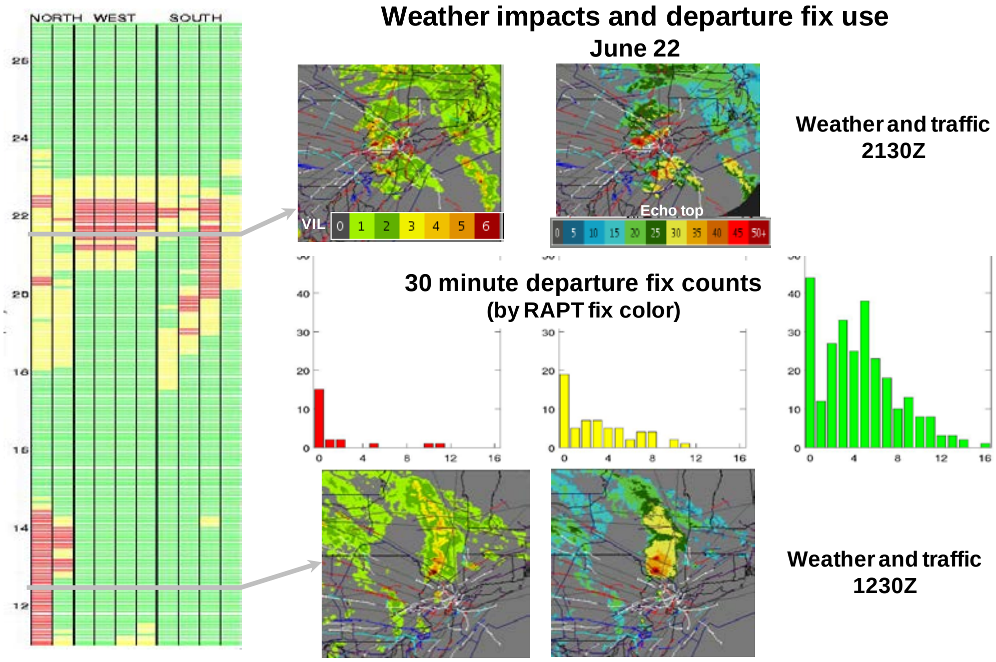


Figure 10. Weather impacts and fix use on June 22.

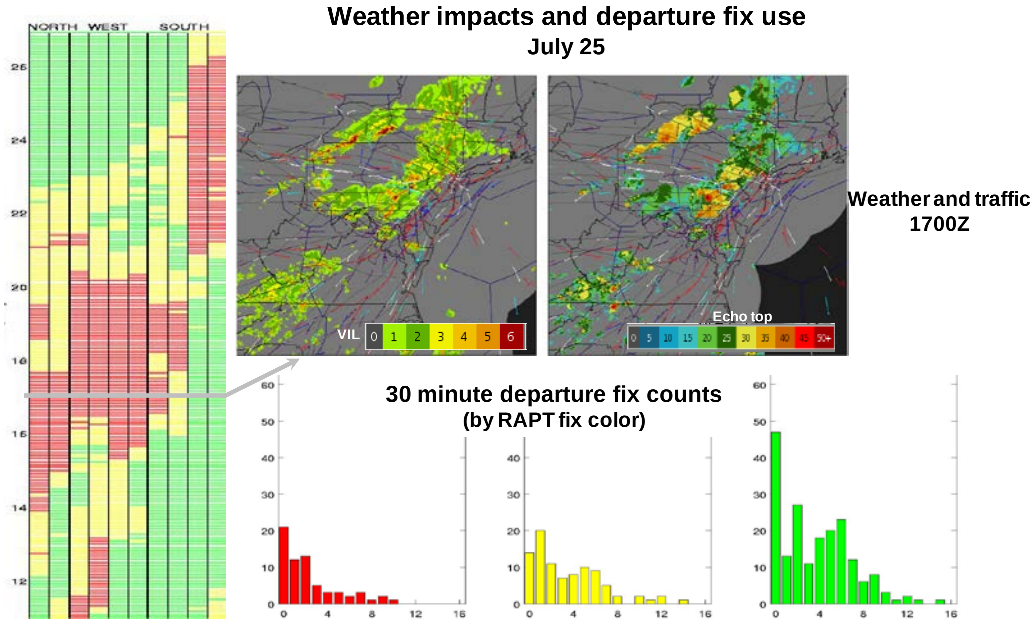


Figure 11. Weather impacts and fix use on July 25.

The evaluation of RAPT operational accuracy suggests that a RAPT RED status by itself is not a highly reliable predictor of route closure; roughly 14% of all RAPT RED 30-minute departure bins had 4 or more departures. Furthermore, the operational nuances that determine when and where RAPT RED routes can be used effectively are not sufficiently well understood that automated, objective guidance can be given about when RAPT RED fixes can or should be used. More research is needed to improve the operational accuracy of RAPT RED and to identify the additional criteria – beyond individual RAPT route status – that must be incorporated into decision support that can help traffic managers choose reroute strategies that are efficient, adaptive, and operationally feasible.

2.2 DEMAND PREDICTION

The prediction of wheels-off time for individual flights is fundamental to IDRP demand, congestion, and weather impact predictions shown in the fix demand summary tables and the flight lists. Two aspects of the IDRP wheels-off prediction were analyzed: wheels-off prediction error and prediction volatility. Errors and volatility were calculated for each departure from the five major New York airports (EWR, JFK, LGA, HPN, and TEB) captured by the IDRP flight list that was not rerouted and that could be correlated to an ASPM wheels-off time. In all, the dataset included over 15,000 flights; Figure 12 summarizes the number of departures from each origin airport on each day; the relatively low counts from TEB and HPN reflect lower operational volumes from these airports and data quality issues in correlating IDRP flight lists with ASPM wheels-off times.

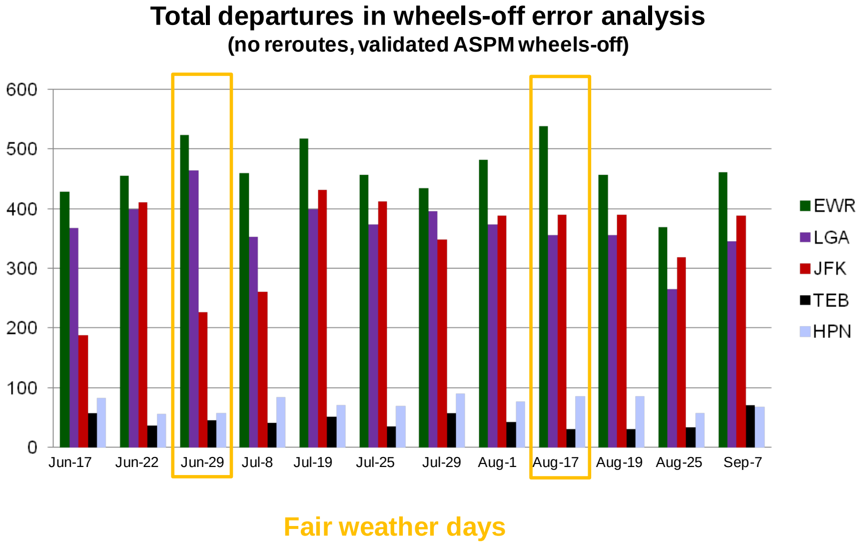


Figure 12. Summary of departures included in the error analysis of wheels-off time predictions.

For each flight, the wheels-off prediction error was calculated for the wheels-off prediction at the time when the flight entered the planning horizon (the 30-minute wheels-off forecast). The error was defined as

$$\text{Error} = (\text{ actual wheels-off time - predicted wheels-off time }) .$$

A negative error indicated a flight that departed before the predicted wheels-off time (a "late" prediction). Wheels-off errors were analyzed only for flights that were not rerouted, since rerouting may have resulted in significant changes in departure time as the reroute was coordinated and filed. Volatility in the wheels-off forecasts was also calculated for each flight in the analysis. The volatility was defined as

$$\text{Volatility} = (\text{ latest forecast wheels-off time – earliest forecast wheels-off time }) ,$$

where the latest and earliest forecast wheel-off times are defined for the time interval between the entrance of the flight into the 30 minute planning horizon and its actual wheels-off. A highly volatile forecast may be difficult to use in planning and reduce user confidence.

Figure 13 shows the time series of IDRP wheels-off predictions for several flights, illustrating various pre-departure "phases":

1. pre-taxi (prior to Airport Surveillance Detection Equipment (ASDE-X) capture),
2. entry into the planning horizon,
3. wheels-off prediction limits (earliest and latest, used in the volatility analysis), and
4. actual wheels-off time, according to ASPM.

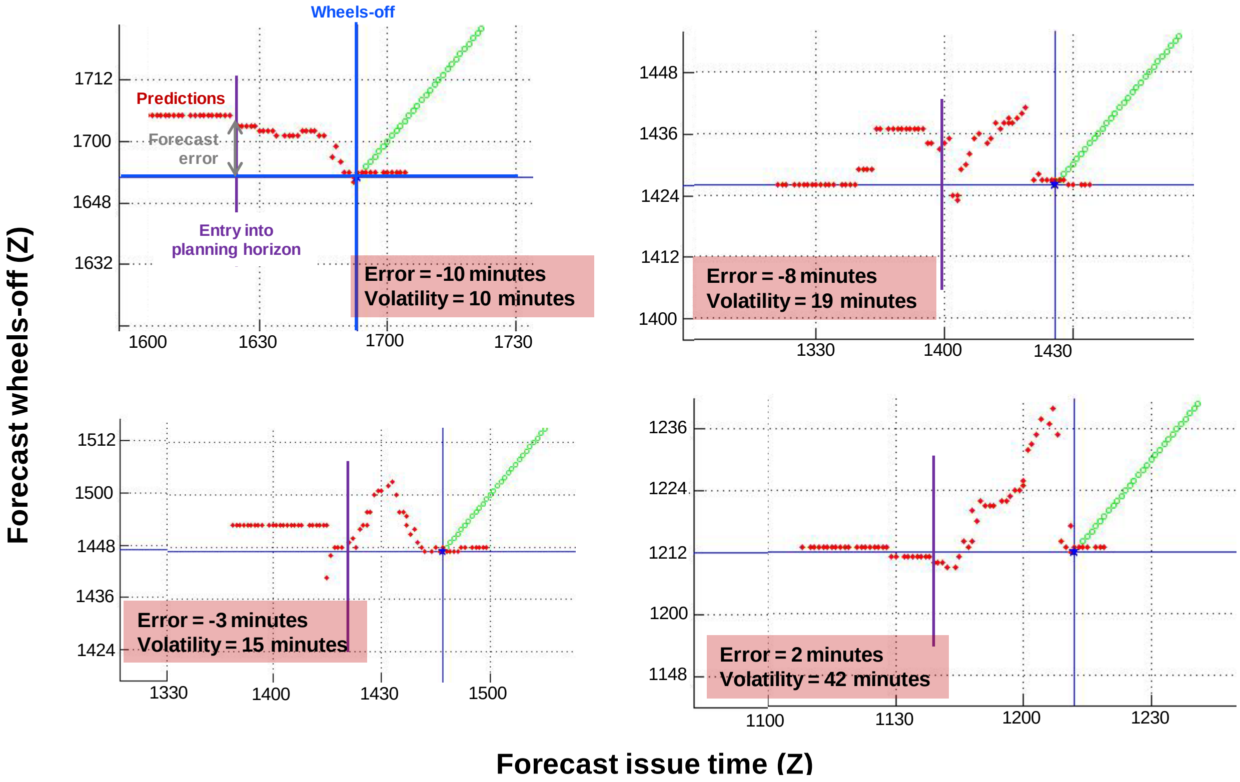


Figure 13. Time series of typical IDRP wheels-off predictions for individual flights.

Wheels-off predictions were updated every minute, and were generally constant until aircraft entered into ASDE-X coverage. Several different prediction behaviors were observed. In some instances, predictions steadily converged toward the actual wheels-off time, and errors decreased as the actual wheels-off time approached. However, forecasts often showed considerable volatility, as the wheels-off time forecasts moved later and earlier, sometimes not approaching the actual wheels-off time until just a few minutes before takeoff. It is not clear how this volatility affected the fix demand predictions or the flight list; however, both forecast volatility and flight list reliability need to be within operationally tolerable limits to support regular and beneficial IDRP use.

Wheels-off error histograms, aggregated separately for the fair weather and SWAP days are presented in Figure 14. Median errors are near zero for both datasets. The error distribution falls off more slowly for SWAP days than fair weather days. Figure 15 presents the wheels-off error statistics (10th, 25th, 50th, 75th, and 90th percentile) for each individual day. Half of the wheels-off prediction errors on SWAP days fell within the error bound envelope of –10 and plus 12 minutes (except for August 25, when the error envelope reached 20 minutes). The "extreme" error bound – the "floor" for the highest 10% errors – ranged from 30 to 50 minutes on SWAP days (again with the exception of August 25, when the extreme error bound was approximately 70 minutes).

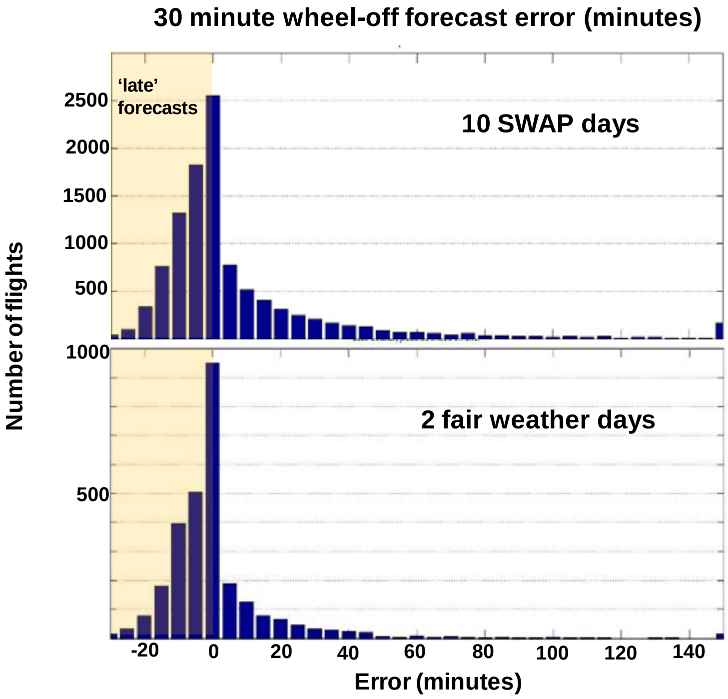


Figure 14. Histograms of wheels-off prediction errors for SWAP and fair weather days.

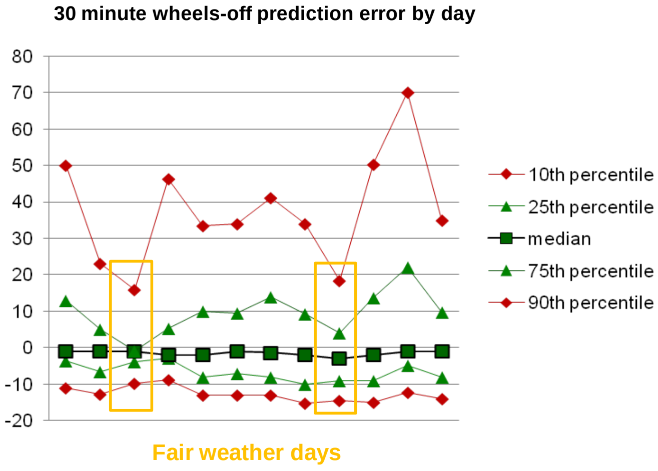


Figure 15. Wheels-off prediction error bounds by day.

Figure 16 presents histograms of forecast volatility on fair weather and SWAP days. Wheels-off forecast volatility on fair weather days was 20 minutes or less for the majority of forecasts. On SWAP days, the volatility was typically 20 minutes or less for many flights, but there was a very long tail to the distribution, and several wheels-off predictions had volatility in excess of 30 minutes. Figure 17 presents the wheels-off forecast volatility statistics (10th, 25th, 50th, 75th, and 90th percentile) for each individual day. The volatility of wheels-off forecasts on SWAP days was generally 30 minutes or less for 75% of departures. The “extreme” volatility bound ranged from 50 to 70 minutes on SWAP days (with the exception of August 25, when the extreme volatility bound was approximately 90 minutes). The analysis of the impact of forecast volatility on IDRP fix demand forecasts, flight list stability, and tactical planning is an area for further analysis.

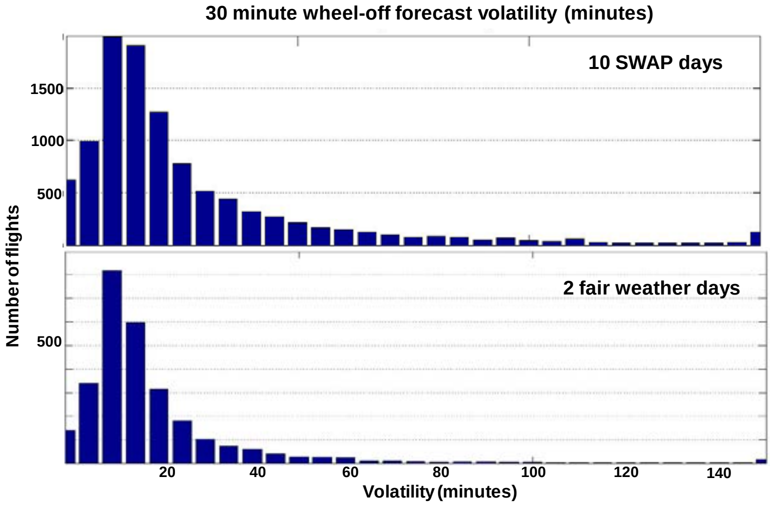


Figure 16. Wheels-off prediction volatility histograms for SWAP and fair weather days.

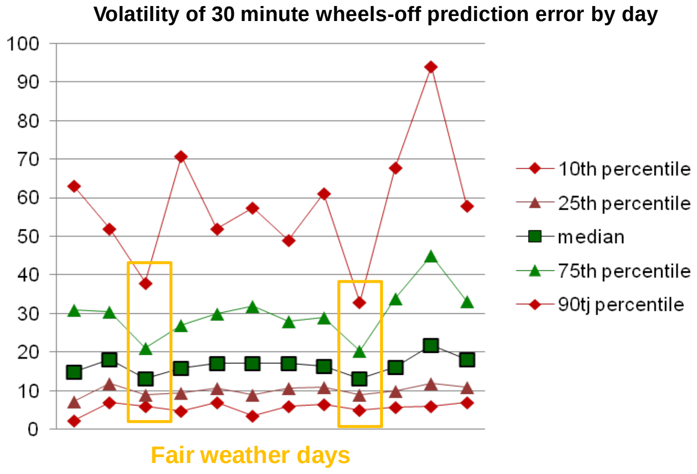


Figure 17. Wheels-off prediction volatility bounds by day.

3. EFFECTIVENESS OF REROUTE STRATEGIES USING IDRP FORECASTS

Fully assessing the impacts of reroute decisions on departure operations is a complex task because each reroute decision affects multiple traffic flows. Reroute decisions impact the rerouted flight, the traffic flow on the originally filed route, the traffic flow on the new route (the reroute “target”), and in aggregate, departure operations as a whole. This section proposes metrics for the evaluation of reroute outcomes, and presents an analysis of departure performance based on those metrics. Performance measurement should provide an objective basis for the identification of successful strategies, which IDRP should enable, and points of failure, which IDRP should reduce. Performance metrics also supply an objective baseline against which improvements due to IDRP use may be compared. Finally, metrics that define reroute success may be used to determine the sensitivity of reroute success to errors in RAPT impact and wheels-off forecasts. This description presents a summary of the data analyses and highlights results that provide particular insights into the evaluation of reroute strategies.

3.1 REROUTE NECESSITY AND FEASIBILITY

A successful reroute should result in a reduction of the weather impact for the rerouted flight, reduce congestion on the originally filed route, and not result in congestion on the reroute target. It should also be necessary, implemented because weather or volume impacts rendered the originally filed route unusable, or because the departure slot was needed to accommodate another necessary reroute onto the originally filed route. The following algorithm was applied to assess reroute success:

1. Was the reroute necessary? The reroute was necessary if
   a. the filed route was closed (a fix was considered closed if observed fix traffic on the filed fix for the 30-minute time bin that included that actual wheels-off time – the “outcome bin” – was less than 2 flights), OR
   b. the filed fix was congested (a fix was considered congested if the observed fix traffic count for the outcome bin exceeded the congestion threshold minus a nominal congestion-reducing reroute count).

2. Was the reroute feasible? The reroute was feasible if
   a. the actual RAPT status on the reroute target was not RED and
   b. the target fix was not congested, based on the same congestion criteria in 1b.

3. A reroute that was both necessary and feasible is considered successful.

The congestion thresholds were defined as the 90th percentile of the distribution of the observed 30-minute fix traffic counts for RAPT RED (6 flights) and RAPT YELLOW (8 flights), or 12 flights for GREEN. The nominal congestion-reducing reroute count was set to 2, so RED fixes with observed 30 minute traffic counts > 4, YELLOW fixes with observed 30 minute traffic counts > 6, and GREEN fixes with observed 30 minute traffic counts > 10 were considered congested. The RAPT status color was assigned according to the method described in the previous section for calculating the traffic distribution. A departure was identified as a reroute if a departure fix change was captured in the IDRP flight list; the analysis presented here is based on the subset of those reroutes for which RAPT status could be assigned to both the originally filed route and the reroute target. In all, 1,325 reroutes from the 10 SWAP days were included in the analysis; Figure 18 presents the daily totals of analyzed reroutes.

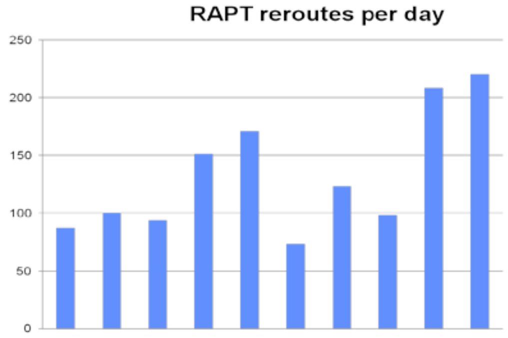


Figure 18. Number of RAPT reroutes, by day, included in the reroute analysis.

The percentage of observed reroutes that were necessary and feasible, based on the above criteria, was determined for all reroutes in the dataset. The results are illustrated in Figure 19, which plots the percentage of reroutes that were deemed necessary, divided between feasible and infeasible, for each day and overall. The use of IDRP to plan and execute reroutes should result in an increase in the percentage of successful (both necessary and feasible) reroutes. A successful reroute should increase the departure capacity of the system, since the rerouted flight takes advantage of unused capacity (i.e., capacity over an alternative fix that will not be congested by the inclusion of the reroute), and the effects of that increase in capacity can be modeled and monetized. Likewise, unsuccessful reroutes impose a capacity penalty; unnecessary reroutes may decrease the efficiency on the originally filed fix by removing demand that could have used it, and infeasible reroutes may decrease efficiency by causing or worsening congestion on the reroute target. In order to attribute improvements in the reroute success percentage to IDRP use, evidence is needed that successful reroute decisions are more likely when IDRP is used.

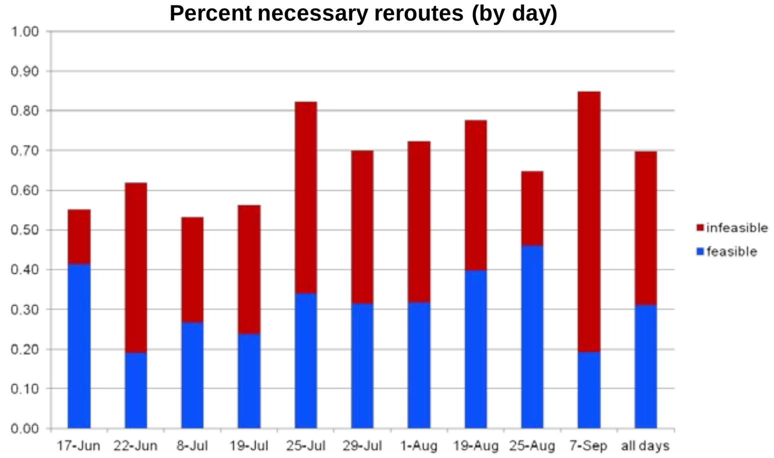


Figure 19. Percentage of necessary and feasible reroutes by day.

Overall, the percentage of reroutes that were identified as necessary was fairly consistent, ranging from just under 53% up to 85%, with an average of 70%. The majority of reroutes deemed unnecessary were instances where the actual impact on the filed route was GREEN or YELLOW, and the observed fix traffic count was well below the congestion threshold on the originally filed route. In many of these instances, the actual weather and/or fix traffic volume was worse on the reroute target than on the originally filed route. However, on two days, July 19 and September 7, approximately 1/3 of the unnecessary reroutes took traffic from originally filed routes that were RAPT RED but still appeared open and uncongested according to the feasibility criteria (traffic counts of 3 or 4 in the 30-minute bin). In these instances, the reroute criteria may have underestimated the true percentage of necessary reroutes.

The percentage of necessary reroutes whose reroute target was feasible varied considerably from one day to the next. In fact, the characterization of what is a “feasible” count of traffic on a particular departure fix given a particular severity of local weather impact may be very much dependent on the operational context. As the comparison of June 22 and July 25 operations in the RAPT evaluation section suggested, traffic managers will make more aggressive use of impacted fixes if severe weather impacts are widespread and/or prolonged, and may be less aggressive if there are convenient reroute alternatives available. Case studies presented in the following section examine the different operational modes that correspond to different degrees of weather impact severity and prevalence.

Data on IDRP use in 2011 were insufficient to link IDRP use and reroute success rates. However, it is possible to investigate if IDRP forecasts could have identified necessary and successful reroutes, and differentiated them from those that were not. For each flight in the reroute analysis, the RAPT status and IDRP fix demand forecasts for both the filed and target routes can be examined to determine if IDRP predicted necessity and feasibility, and to estimate how many unsuccessful reroutes would have been suggested due to forecast errors in RAPT status and/or IDRP demand prediction (i.e., IDRP reroute "false alarm rate"). This forecast analysis was not completed prior to the publication deadline.

The reroute analysis described here cannot identify missed opportunities, where reroutes may have been needed to relieve congestion, but were not implemented. We have not yet developed a methodology for an objective identification of missed opportunities.

3.2 CASE STUDIES

Table 2 presents a summary of metrics and characterizations of the ten SWAP days studied. The weather impact characterizations are as follows:

1. **Score.** The impact score is an overall "average" measure of weather impact throughout the day, calculated using the formula

   $$\text{Impact} = (\text{RED} + 0.5 * \text{YELLOW})/(\text{RED} + \text{YELLOW} + \text{GREEN}),$$

   where RED, YELLOW and GREEN = the total number of 30 minute periods of fix impacts with that RAPT status color, and the 30 minute status for a given fix is determined using the method in the RAPT evaluation section above.

2. **Scale/duration.** Scale may be widespread (W) or local (L). Impacts are widespread when nearly all routes in two or more departure gates are RED; impacts are local when REDs are restricted to 2–4 adjacent routes only. Long (l) duration impacts are consistent REDs lasting two hours or more; short (s) duration impacts are less than two hours. Some days may have multiple impact periods with different characteristics.

3. **Weather predictability.** The predictability metrics are the percentage of RED and GREEN 30 minute forecasts that were correct.

4. **Airspace use.** Airspace use is characterized by the percentage of RED and YELLOW fixes with heavy 30 minute traffic counts (4 or more departures for RED, 6 or more for YELLOW), and the total number of departures on RED fixes.

5. **Reroute strategy.** The reroute strategy metrics are percentage of reroutes that were deemed necessary, and the percentage of necessary reroutes that were feasible, using the reroute evaluation criteria presented above.

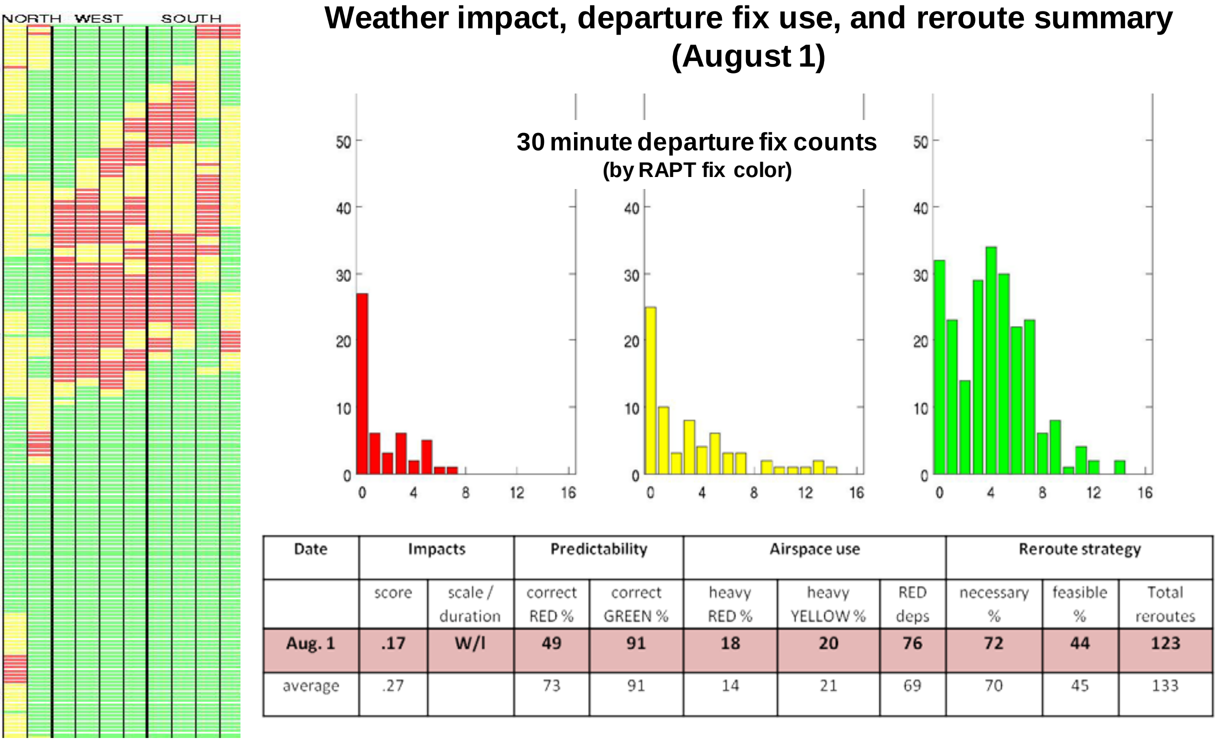
Table 2. Summary of Case Study Days

Date	Impacts		Predictability		Airspace use			Reroute strategy		
	score	scale / duration	% correct RED	% correct GREEN	% heavy RED	% heavy YELLOW	RED departures	% necessary	% feasible	Total reroutes
June 17	.32	W/s, L/s	45	85	4	15	29	55	75	87
June 22	.24	W/s, L/l	60	90	14	21	32	62	31	100
July 8	.24	W/s, L/l	56	93	12	17	41	53	50	94
July 19	.17	L/l	56	97	18	29	55	56	42	151
July 25	.31	W/l, L/l	68	88	23	24	149	82	41	171
July 29	.17	W/s	85	94	5	12	32	70	45	73
Aug. 1	.17	W/l	49	91	18	20	76	72	44	123
Aug. 19	.33	W/l, L/l	96	97	14	20	55	78	51	98
Aug. 25	.28	W/l, L/l	96	89	18	9	81	65	71	208
Sept. 7	.43	W/l, W/l	83	72	15	38	141	85	22	220
average	**.27**		**73**	**91**	**14**	**21**	**69**	**70**	**45**	**133**

Five of the ten SWAP days studied were characterized by periods of widespread, long-lived, and severe impacts (red backgrounds): July 25, August 1, August 19, August 25, and September 7 (salmon-colored rows in Table 2). On all of these days, heavy RED fix use was greater than or equal to the average. On four of these days, the percentage of reroutes deemed necessary was greater than average, and just slightly less on the fifth day. The percentage of reroutes deemed feasible varied considerably. Four days (purple backgrounds) were characterized by short duration widespread impacts, secondary periods of localized impacts: June 17, June 22, July 8, and July 29. The use of impacted fixes varied considerably over these days. Necessary reroute percentages were lower than average, and reroute feasibility was highly variable. One day had a single period of long-lived local impact (July 19). Days with "highly predictable" weather – correct forecast percentages > average for both RED and GREEN – are outlined in blue. In order to gain some insight into how the nature and predictability of weather impacts, the use of impacted fixes, necessity, feasibility, and number of observed reroutes are related, case studies of four days – August 1, September 7, June 17, and July 19 – are presented. Appendix A provides more detailed analysis of observed reroutes on each day.

August 1

Figure 20 illustrates the timeline of RAPT impacts throughout the day and the 30-minute traffic counts on departure fixes as a function of RAPT status on August 1. RAPT RED impacts covered west gate departure routes for both west and southwest departures from 19–23Z. South gate departures were heavily impacted from 22–00Z, and severe impacts returned to the southwest departure routes from 00–02Z on August 2. Figures 21 through 23 illustrate the progression of traffic flows and weather over the course of the day. North and south gate departure flows were fairly constant throughout the day, except for a brief period (2230–2300Z) when southbound departures were virtually stopped by severe weather in southern NJ. West gate departure fixes were used very aggressively until 2000–2030Z, when a line of severe thunderstorms closed all west gate fixes; by 20Z offloads of westbound departures to the north departure gate had begun. A heavy push of west gate departure traffic from Philadelphia resumed around 21Z; New York west gate traffic resumed in earnest around 23Z as the weather began to clear. Since impacts were so widespread, the percentage of necessary reroutes was relatively high (72%). The weather was very dynamic, potentially limiting planning horizons, and the RAPT RED forecast score (49%) was the second lowest of the ten SWAP days analyzed.



Date	Impacts		Predictability		Airspace use			Reroute strategy		
	score	scale / duration	correct RED %	correct GREEN %	heavy RED %	heavy YELLOW %	RED deps	necessary %	feasible %	Total reroutes
Aug. 1	**.17**	**W/I**	**49**	**91**	**18**	**20**	**76**	**72**	**44**	**123**
average	.27		73	91	14	21	69	70	45	133

Figure 20. Weather impacts and fix use on August 1.

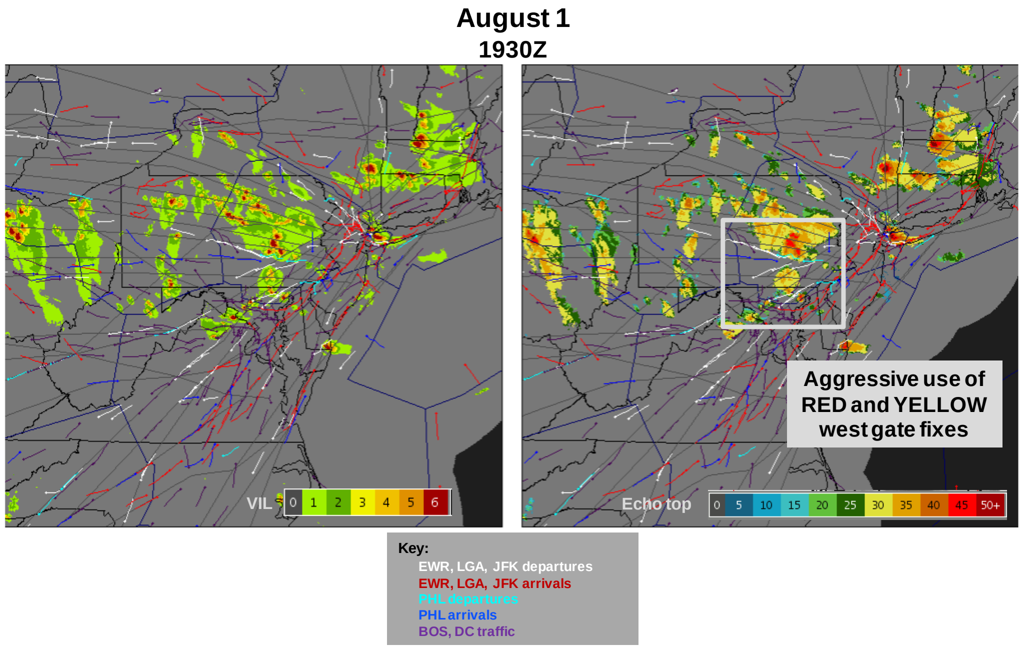


Figure 21. Traffic and weather at 1930Z on August 1, illustrating aggressive use of RAPT RED and YELLOW fixes.

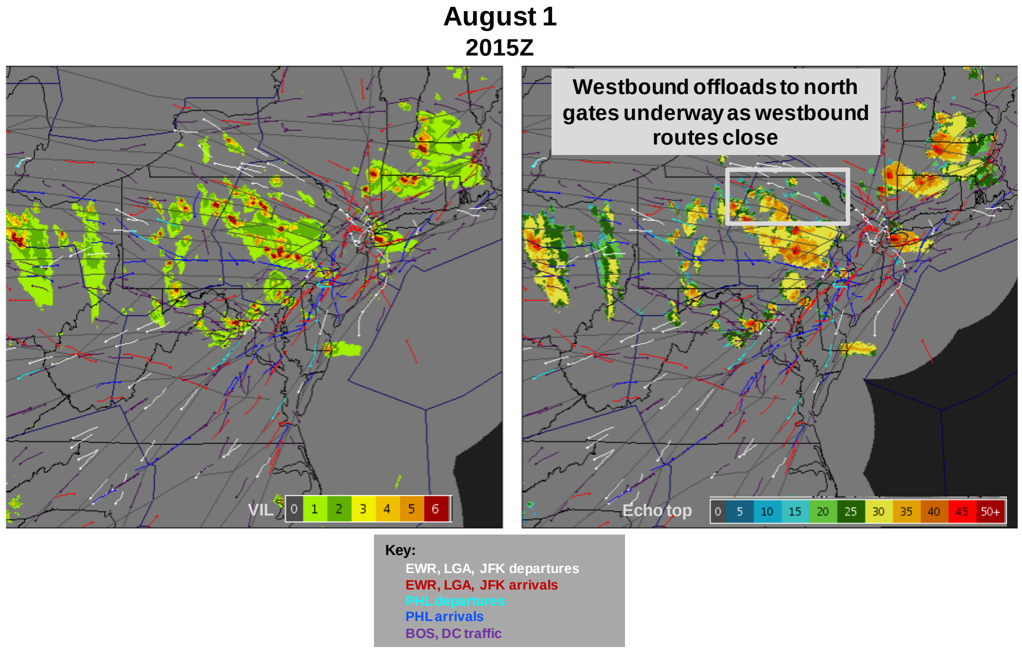


Figure 22. Traffic and weather at 2015Z on August 1, illustrating reroute offloads to avoid weather.

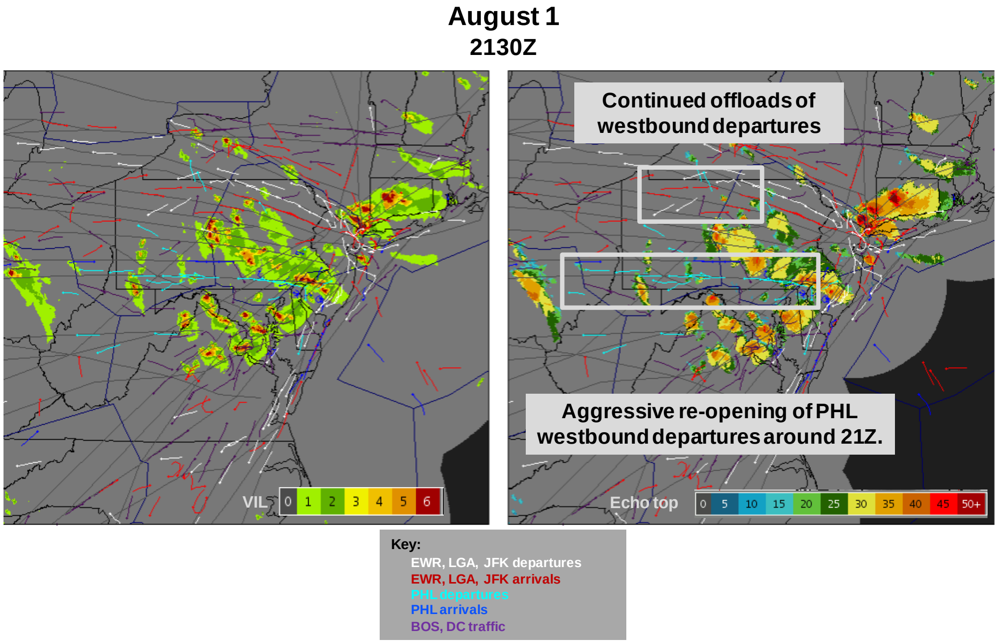


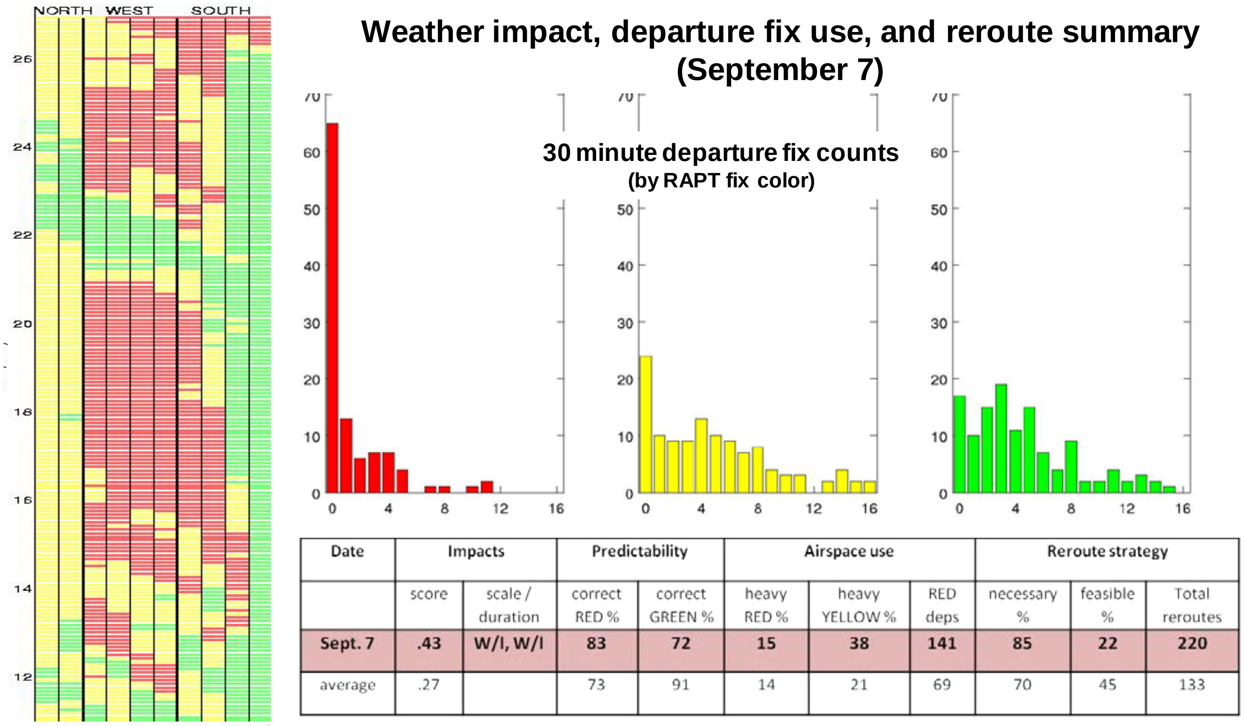
Figure 23. Traffic and weather at 2130Z, showing aggressive use of newly opened fix and continued reroute offloads.

A review of the National Traffic Management Log (NTML) found that SERMN EAST, NORTH, and SOUTH reroutes were all in effect starting around 1730Z; DUCT NORTH and WEST reroutes went into effect around 1845Z, and stayed in effect until 00Z on August 2. PHLYR NORTH, WEST, and SOUTH reroutes for PHL departures also went into effects around 18Z. Severe weather just to the north of N90 precluded any use of the GREKI offload routes (figures). Most of the reroutes identified and analyzed took departures off RAPT RED routes and rerouted them to GREEN, YELLOW, and even RED targets. Nearly all of the reroutes that were characterized as infeasible were the result of very high traffic volume on the few available routes. The 30-minute traffic counts on reroute targets exceeded the nominal congestion limits, and traffic counts of 10 or more per half hour on GREEN, YELLOW, and even RED reroute targets were common. The relatively few unnecessary reroutes occurred mostly between 23–00Z, during the transition back to normal operations on the west gate.

Despite the very aggressive use of available airspace, delays on August 1 were very high, and it was widely acknowledged to be a “bad day” for New York operations. However, traffic management made very good use of the few options available to them, and much of the delay could be seen as unavoidable. It is also apparent that under such conditions where, severe impacts are widespread and long-lived, high fix volumes are inevitable, and cannot be avoided by rerouting traffic to balance fix loads. The high traffic counts on open departure fixes, irrespective of RAPT status, suggests that more “typical” congestion limits do not apply in such circumstances, at least for as long as traffic controller and manager workload does not become unbearable. Finally, the unpredictability of the weather made advance planning beyond very short horizons very difficult.

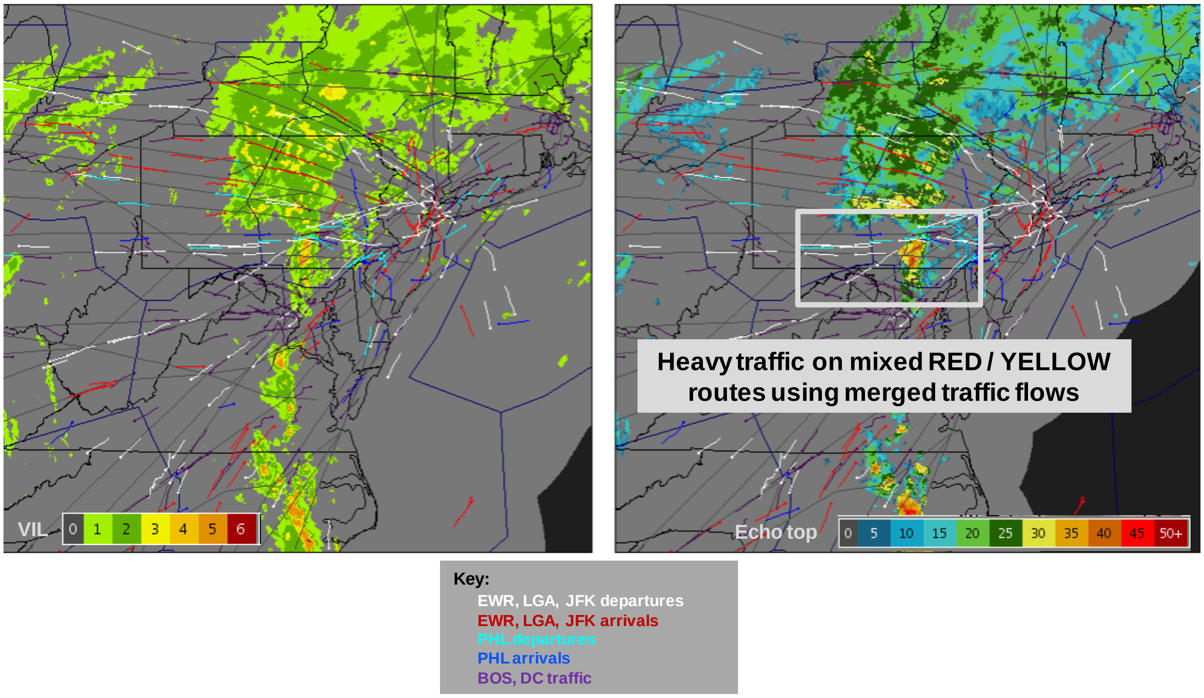
<u>September 7</u>

Figure 24 illustrates the timeline of RAPT impacts throughout the day and the 30-minute traffic counts on departure fixes as a function of RAPT status on September 7. West gate departures, both to the west and southwest, were severely impacted from approximately 15–21Z, and again from 23–03Z on September 8. North gate departure routes were YELLOW throughout the day; south gate routes were relatively unimpacted, except for a brief period from 13–15Z when the WHITE departure route turned RED. Unlike August 1, the weather was a well-organized, north-south oriented line that was easily forecast; RAPT RED forecast accuracy for the day was 83%. Furthermore, although convection was severe enough to result in widespread RAPT RED, it was typical late summer convection – more organized and less severe than midsummer convection exemplified by the August 1 case. Figures 25 through 27 show the progression of weather and traffic throughout the day.



Date	Impacts		Predictability		Airspace use			Reroute strategy		
	score	scale / duration	correct RED %	correct GREEN %	heavy RED %	heavy YELLOW %	RED deps	necessary %	feasible %	Total reroutes
Sept. 7	**.43**	**W/I, W/I**	**83**	**72**	**15**	**38**	**141**	**85**	**22**	**220**
average	.27		73	91	14	21	69	70	45	133

Figure 24. Weather impacts and fix use on September 7.



September 7

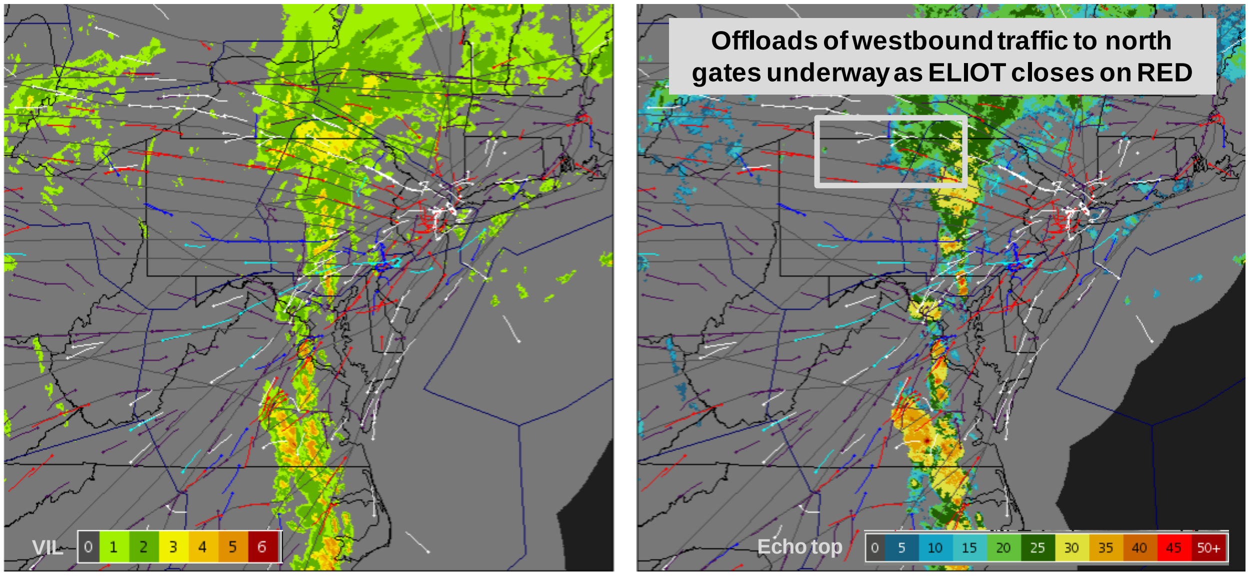
1215Z

Heavy traffic on mixed RED / YELLOW routes using merged traffic flows

Figure 25. Traffic and weather at 1215Z, showing aggressive use of RAPT RED and YELLOW fixes.

September 7

1400Z



Offloads of westbound traffic to north gates underway as ELIOT closes on RED

Key:

- EWR, LGA, JFK departures
- EWR, LGA, JFK arrivals
- PHL departures
- PHL arrivals
- BOS, DC traffic

Figure 26. Traffic and weather at 1400Z, showing offload reroutes underway as weather closes the ELIOT fix.

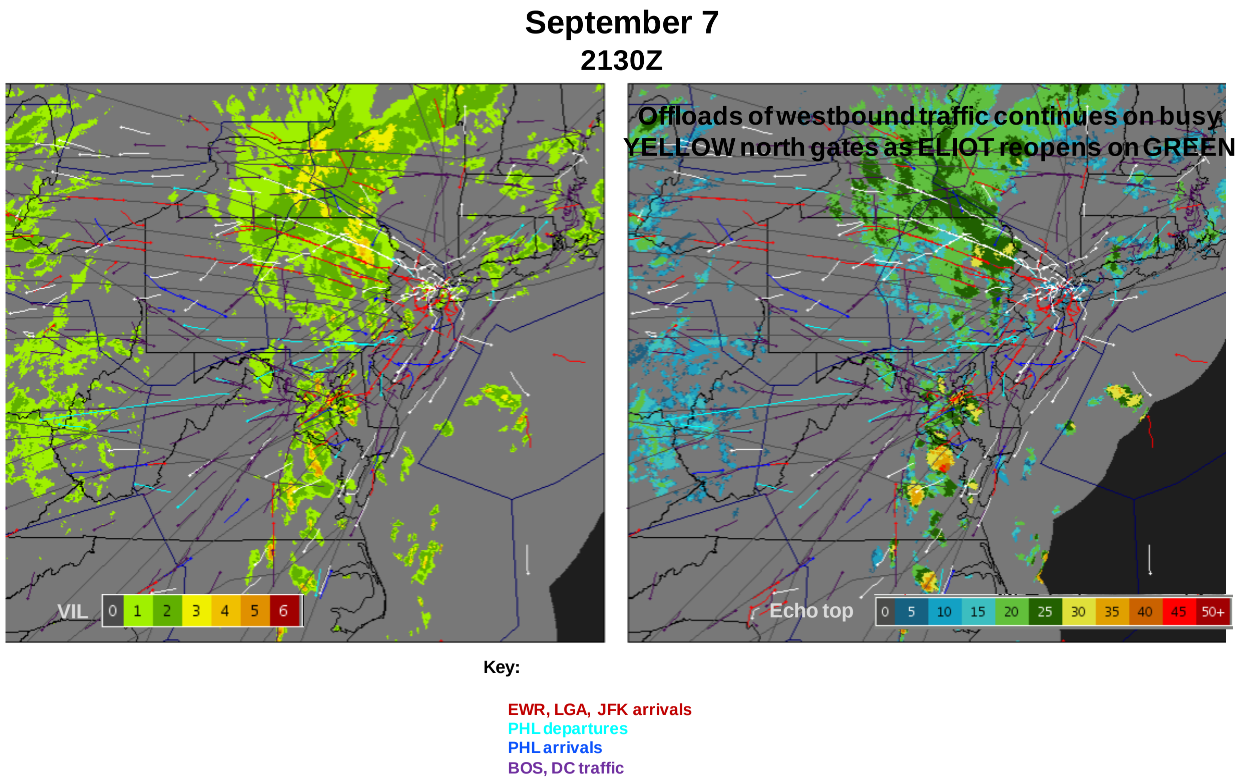


Figure 27. Traffic and weather at 2130Z, showing reroute offloads continuing, even as the ELIOT departure fix is reopened.

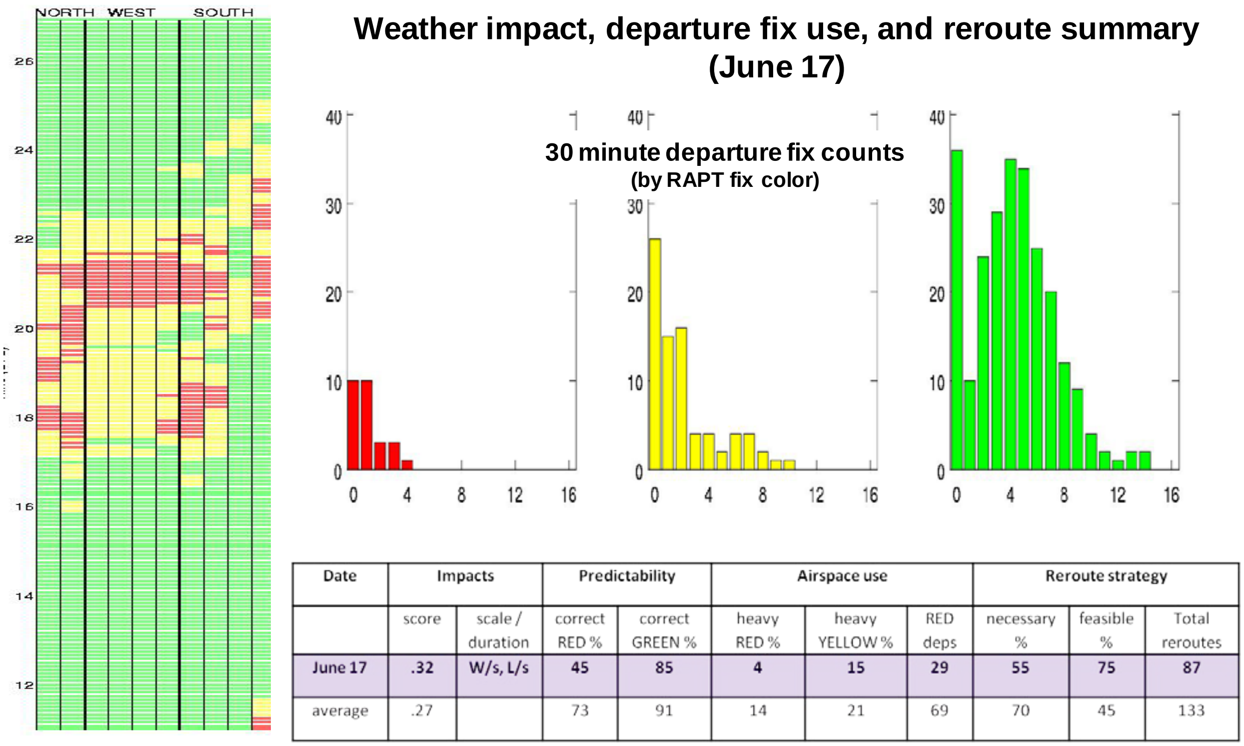
The NTML recorded implementation of DUCT WEST, SERMN NORTH, SERMN SOUTH, and PHLYR NORTH, SOUTH, and WEST from approximately 13–03Z on September 8. DUCT NORTH reroutes were in effect from 21Z to 03Z on September 8. As on August 1, the vast majority of reroutes took traffic from RED routes onto very heavily trafficked YELLOW and GREEN fixes; a small number of reroutes took traffic from highly congested YELLOWs to YELLOWs with lower demand, or from closed RED routes to other RED routes that were still carrying traffic. Overall, traffic counts on YELLOW routes were very high, and there were a significant number of high traffic RED periods as well. Traffic on north gates, which were YELLOW throughout the day, was consistently heavy (see figures), while traffic flows on highly impacted west and southwest departure routes was consistently high early in the day. Westbound departures were stopped out ELIOT around 14Z (on RAPT YELLOW), as offloads began out north gate fixes, and heavy traffic continued to the southwest through a mixture of RED and YELLOWs. Severe weather impacts finally shut down all west gate departures around 1530Z. Regular traffic, plus reroute offloads, continued to be heavy out the YELLOW north gate and GREEN south gate routes. Westbound departures re-opened around 22Z, approximately one hour after weather impacts cleared. The relatively small number of unnecessary reroutes occurred around 14Z and 21–22Z, during relatively light impact periods immediately following the dispersal of severe weather impacts.

Like August 1, traffic management made very aggressive use of available capacity, occasionally running considerable traffic on RED routes, and running traffic on YELLOW routes well in excess of the nominal fix congestion level for extended periods. However, unlike August 1, the less severe, more organized and more easily forecast (at least for RED impacts) late summer convection made the use of YELLOW and RED routes and the maintenance of reroute offloads more reliable due to reduced uncertainty about the weather impacts.

June 17

Figure 28 illustrates the timeline of RAPT impacts throughout the day and the 30-minute traffic counts on departure fixes as a function of RAPT status on June 17. Severe impacts affected several fixes for approximately an hour, starting around 2030Z; impacts were primarily due to small scale storms inside or near the TRACON. Additional scattered impacts were present over the north gates and southwest departure routes earlier in the day, and over WAVEY (southbound) later in the day. RED and YELLOW fix use was light to moderate. The weather was fairly unorganized, and the RAPT RED forecast score (60%) was the in the lower third of the 10 SWAP days. Field observers were also present on June 17.

Figures 29 through 31 illustrate the progression of traffic flows and weather over the course of the day. North gate departures were maneuvered through weather, merged "as one" through mixed RED/YELLOW impacts until approximately 1730Z, when weather impacts and holding arrivals resulted in a shutdown of departures. GREKI offloads were started up about the same time. A review of the NTML found that, in addition to the observed GREKI offloads, SERMN EAST, NORTH, and SOUTH reroutes were all in effect starting around 1730Z through 01Z on the 18th; SERMN offloads were evident during the periods of heaviest impacts from 1830–1930Z and 21–22Z. The N90 field observer recorded a period of IDRP use between 1800 and 1822Z, in which the Tactical Reroute Coordinator position at N90 (TRC) used IDRP to attempt to coordinate reroutes of LGA traffic filed through ELIOT to the RBV departure fix. The reroutes were not implemented, and westbound departures appeared to run consistently throughout the period of impact, except during a brief period when closure due to RAPT RED impacts directly over LGA (approximately 1827–1839Z). For the day, the reroute feasibility percentage was very high, reflecting both the availability and efficient use of unimpacted offload routes. The vast majority of unnecessary reroutes identified on June 17 took traffic from one relatively lightly loaded GREEN fix to another; the originally filed fix was at the nominal congestion limit on only four of the reroutes analyzed. Most of these reroutes occurred later in the day, after the impacts had passed. This pattern of unnecessary reroutes was also observed on June 22, July 8, and August 25.



Date	Impacts		Predictability		Airspace use			Reroute strategy		
	score	scale / duration	correct RED %	correct GREEN %	heavy RED %	heavy YELLOW %	RED deps	necessary %	feasible %	Total reroutes
June 17	**.32**	**W/s, L/s**	**45**	**85**	**4**	**15**	**29**	**55**	**75**	**87**
average	.27		73	91	14	21	69	70	45	133

Figure 28. Weather impacts and fix use on June 17.

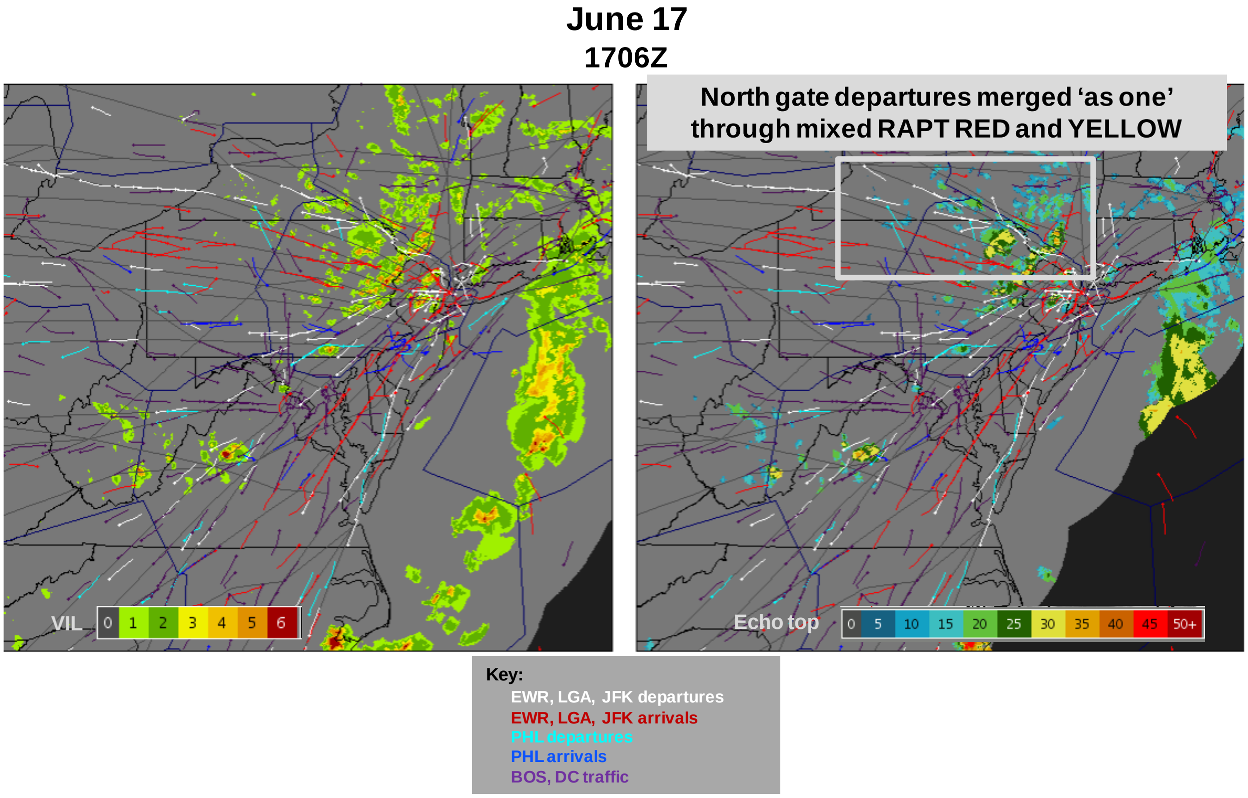


Figure 29. Traffic and weather at 1706Z, showing merging of RED and YELLOW fix traffic.

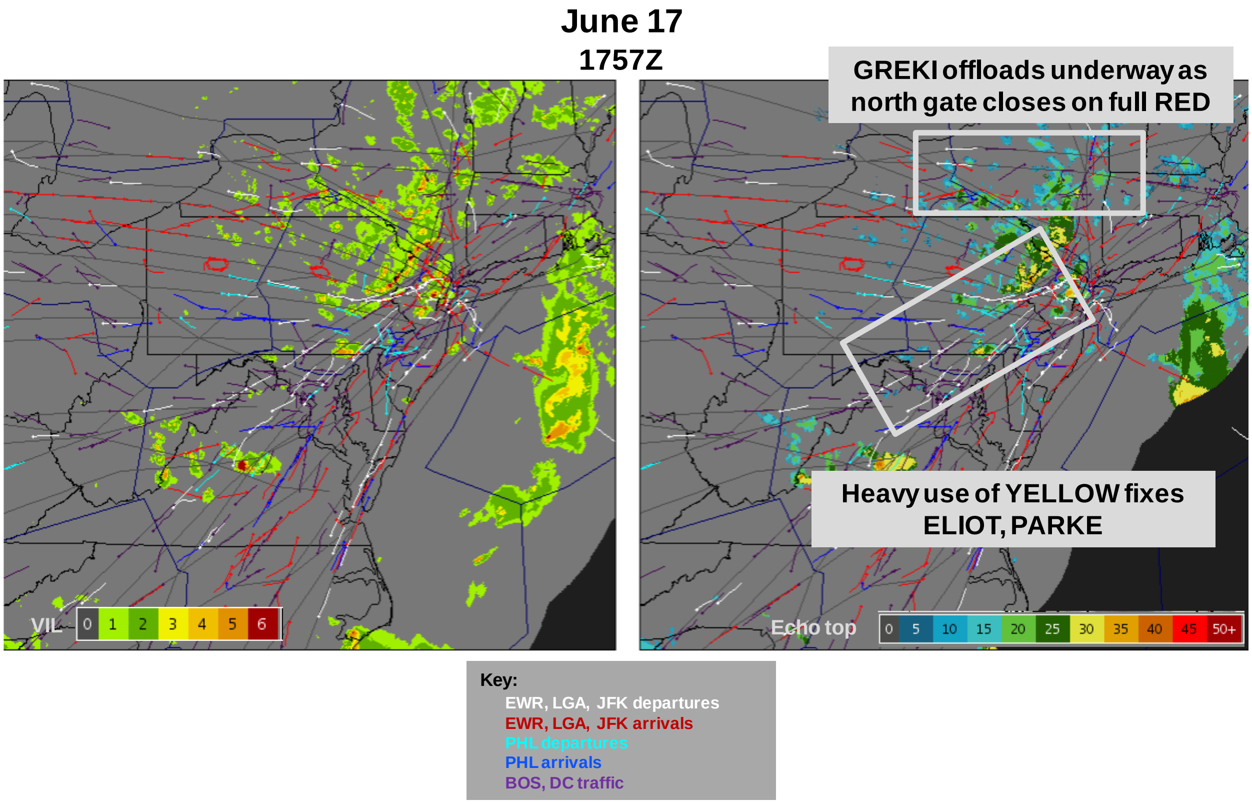
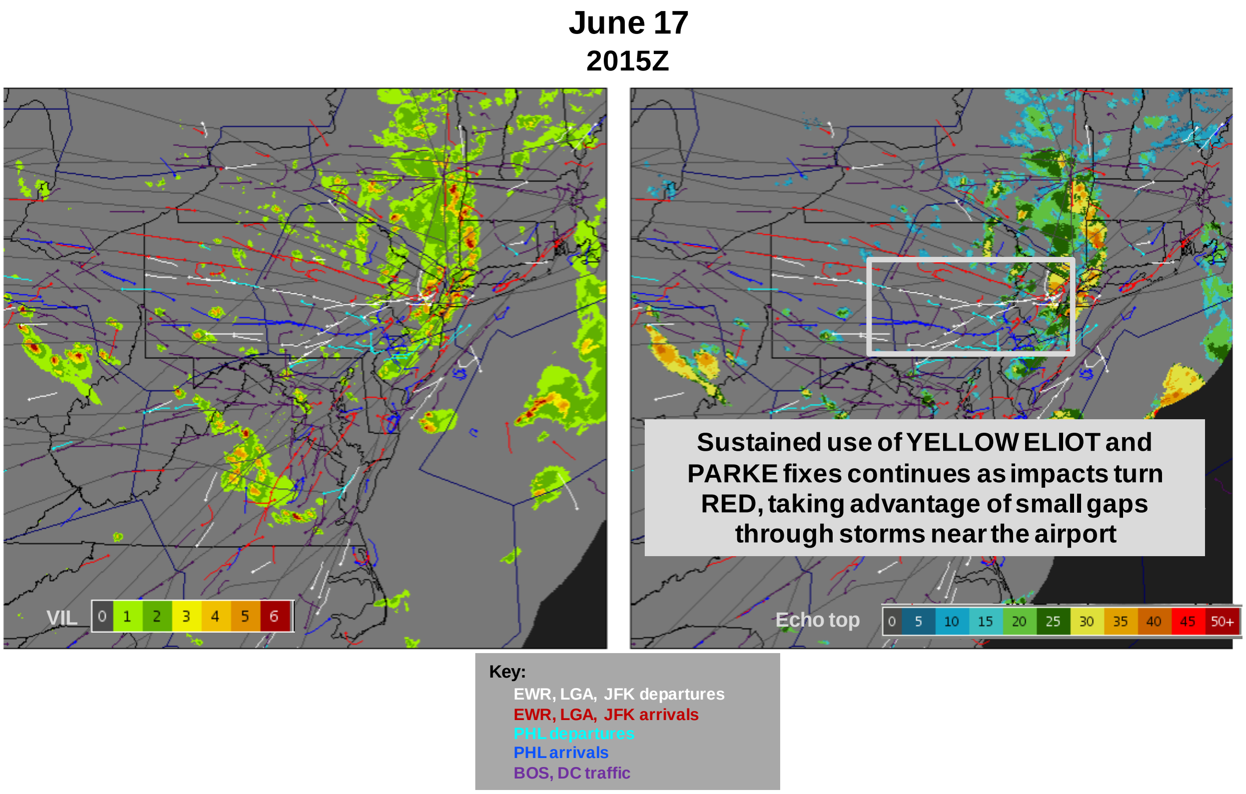


Figure 30. Traffic and weather at 1757Z, showing reroute offloads to GREEN, and heavy use of YELLOW fixes.


June 17

2015Z

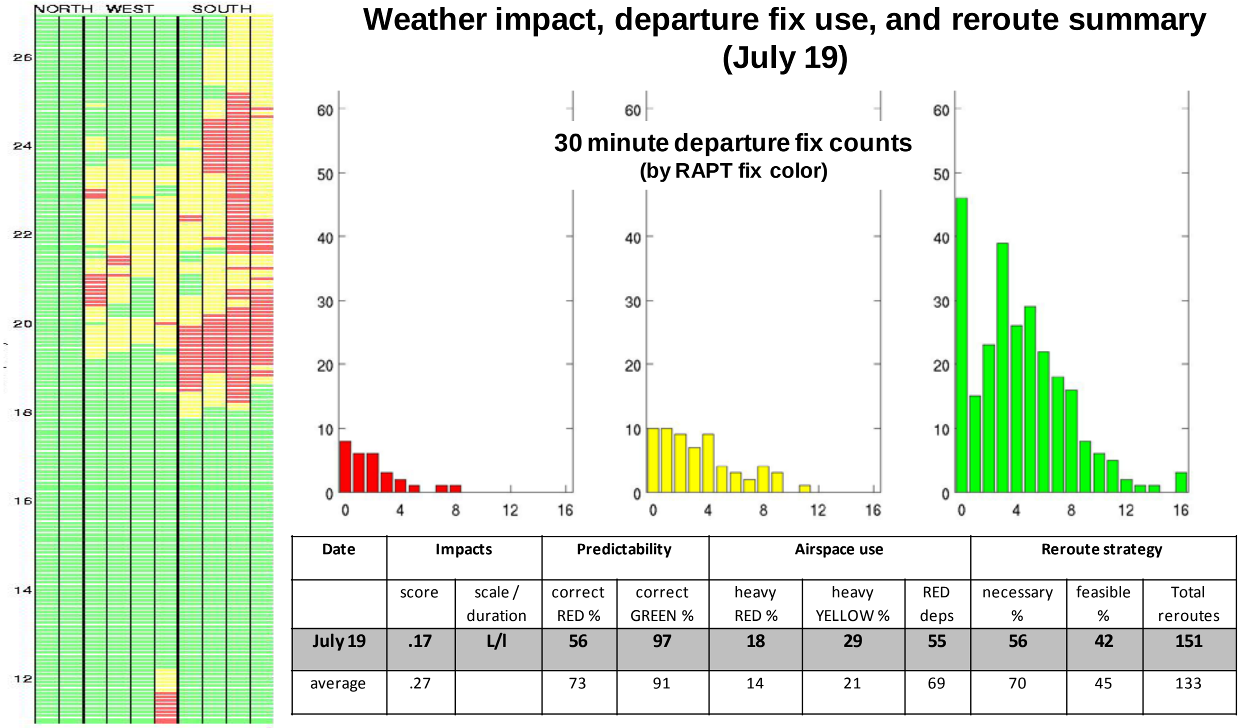
Sustained use of YELLOW ELIOT and PARKE fixes continues as impacts turn RED, taking advantage of small gaps through storms near the airport

Figure 31. Traffic and weather at 2015Z, showing sustained use of RAPT RED and YELLOW fixes.

<u>July 19</u>

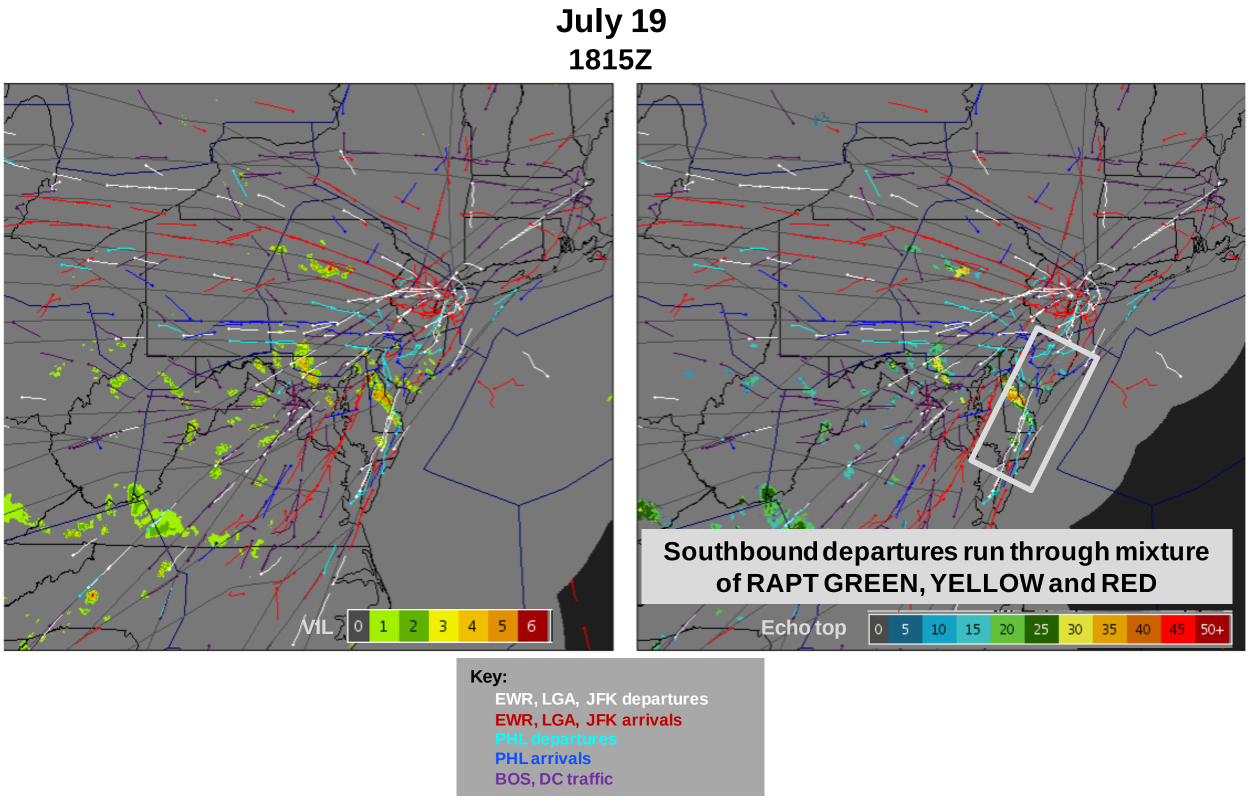
Figure 32 illustrates the timeline of RAPT impacts throughout the day and the 30-minute traffic counts on departure fixes as a function of RAPT status on July 19. Severe impacts were fairly localized, the result of a cluster of severe storms that rapidly grew, decayed, and regenerated for several hours over southern New Jersey, eastern Maryland, and northern Virginia. Severe impacts affected primarily departures to the south, starting around 18Z and continuing until approximately 01Z on the 20th, and southwest, from about 18–20Z, and again from 23–01Z on the 20th. RED and YELLOW fix use was higher than average, perhaps as a result of the longevity of the impacts. The weather was fairly unorganized, and the RAPT RED forecast score (60%) was the in the lower third of the 10 SWAP days. Field observers were present for this day.

Figures 33 through 36 illustrate the progression of traffic flows and weather over the course of the day. Traffic streams to the southwest and south were maintained by a combination of tactics, including both flow merging and reroutes. In the first hour of severe impacts on the southbound routes (18–19Z), a steady stream of departures was maintained through YELLOW and RED impacts. Southbound traffic was then rerouted to the west and southwest through ELIOT (mixed GREEN/YELLOW), PARKE, and LANNA (mixed YELLOW/RED). Reroutes appeared to ripple, as westbound departures were offloaded out north gate routes, until approximately 22Z. The reroute offload resulted in a difficult traffic pattern around 22Z, as west gate offload traffic had to cross airspace being used by arrivals holding due to thunderstorms impacting arrival routes. The southwest departure routes were heavily used from about 2230Z through mixed RED and YELLOW impacts for the remainder of the day. One cluster of unnecessary reroutes, identified between approximately 21–22Z, took traffic from lightly loaded YELLOW routes, possibly as a result of continuing to run the westbound offloads after weather impacts cleared ELIOT. A second cluster was identified late in the day (0030–0100Z on the 20th), after all impacts to the south and southwest had been reduced to YELLOW; however, the clearing was not well forecast and the unnecessary reroutes were likely unavoidable. On this day, the presence of fairly local, but very dynamic, long-lived, and difficult to predict severe impacts made it very difficult to develop and maintain a consistent plan to manage departures through the weather.



Date	Impacts		Predictability		Airspace use			Reroute strategy		
	score	scale / duration	correct RED %	correct GREEN %	heavy RED %	heavy YELLOW %	RED deps	necessary %	feasible %	Total reroutes
July 19	**.17**	**L/l**	**56**	**97**	**18**	**29**	**55**	**56**	**42**	**151**
average	.27		73	91	14	21	69	70	45	133

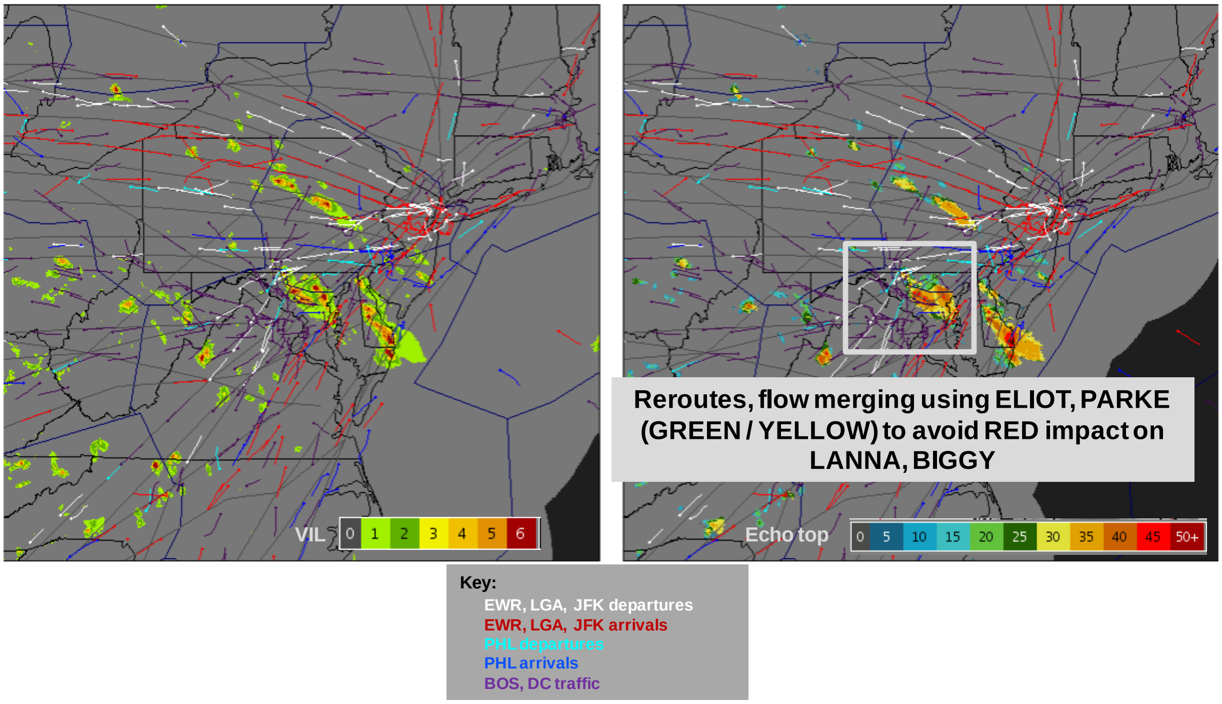
Figure 32. Weather impacts and fix use on July 19.



Southbound departures run through mixture of RAPT GREEN, YELLOW and RED

Figure 33. Traffic and weather at 1815Z, showing merged RAPT RED, YELLOW, and GREEN traffic.

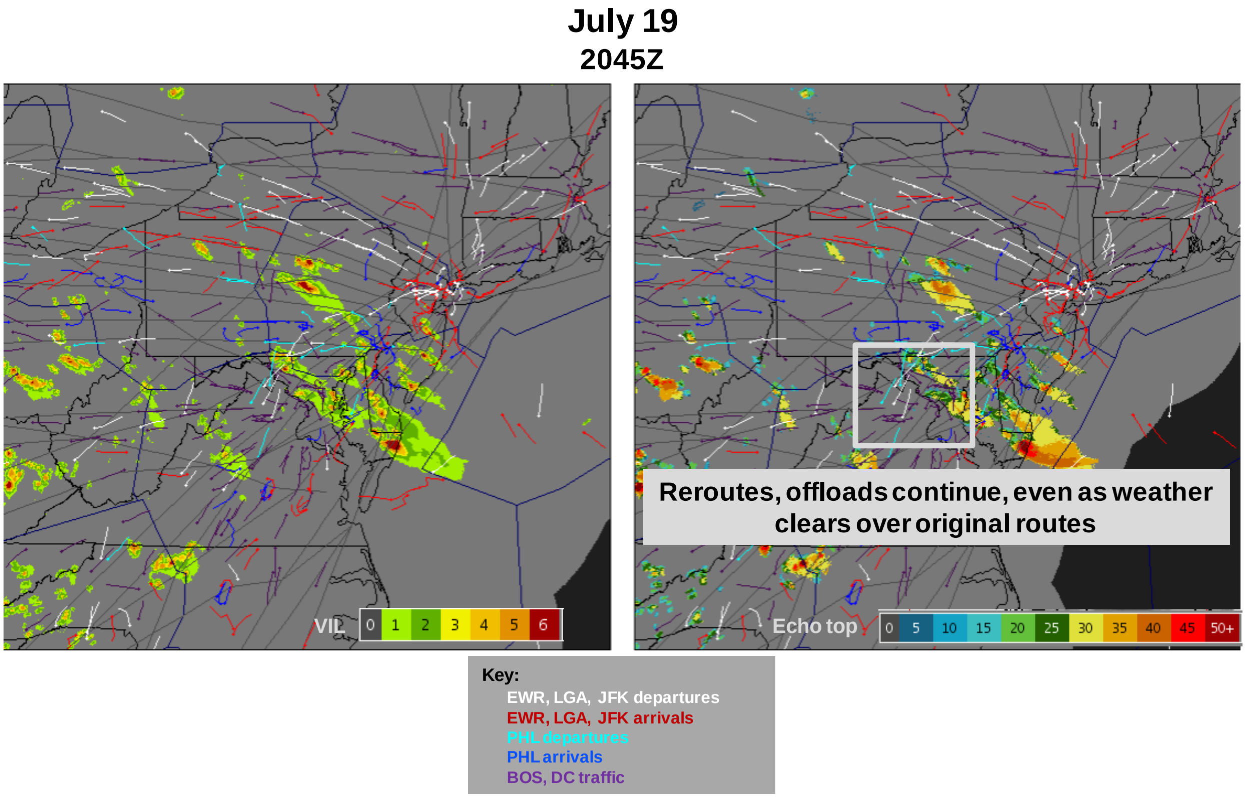
July 19
1930Z



Reroutes, flow merging using ELIOT, PARKE (GREEN / YELLOW) to avoid RED impact on LANNA, BIGGY

Key:
- EWR, LGA, JFK departures
- EWR, LGA, JFK arrivals
- PHL departures
- PHL arrivals
- BOS, DC traffic

Figure 34. Traffic and weather at 1930Z, showing flow merging and reroutes to avoid RED impacts.



Reroutes, offloads continue, even as weather clears over original routes

Figure 35. Traffic and weather at 2045Z, showing continued reroutes after clearing of weather on impacted routes.

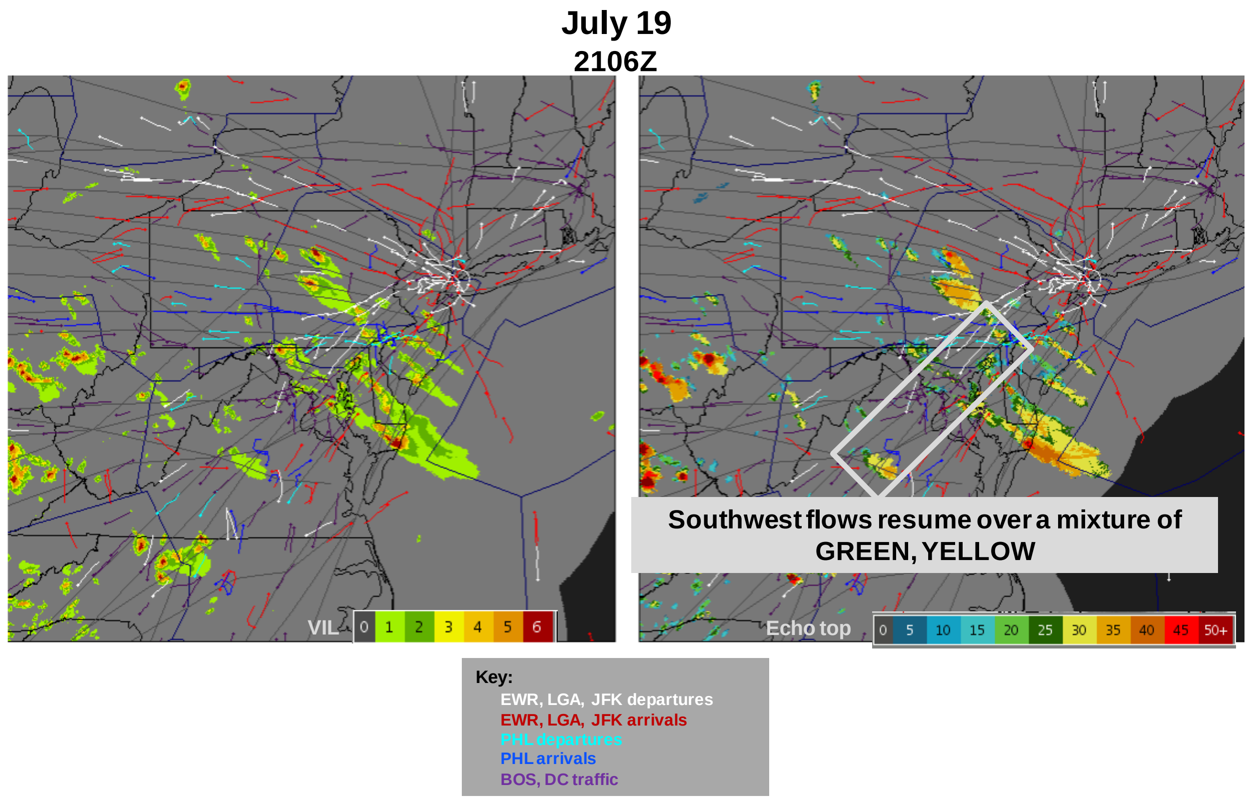


Figure 36. Traffic and weather at 2106Z, showing resumption of normal flows after weather impacts cleared.

The case studies suggest three modes of operations, each with different operational issues to address:

1. widespread severe impacts that leave few options,
2. prolonged but localized impacts (moving or stationary), and
3. relatively short-lived but severe impacts affecting several fixes, mostly due to weather in the or near the TRACON.

Common to all modes of operations was the use of merged traffic flows to take advantage of available capacity in impacted airspace, something which neither RAPT (merged route blockage) nor IDRP (merged fix capacity) can currently model. Fix traffic, particularly on RED and YELLOW fixes, was observed to vary widely, more often appearing correlated to demand and the availability of alternative unimpacted fixes rather than any objectively determined local weather impact. Where weather was highly predictable, it was easier to maintain consistent flows through impacted airspace, keeping efficiency high and minimizing the number of unnecessary reroutes. Finally, most of the observed unnecessary reroutes occurred after major impacts had cleared, suggesting that support for ending proactive reroutes is also important. In short, RAPT/IDRP should help traffic managers answer three questions: Will I need to make heavy use of RED and YELLOW routes/gates? Which of those RED and YELLOW routes/gates are most likely to be feasible? When can I return to normal traffic flows?

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4. PROCEDURAL OPPORTUNITIES AND IMPEDIMENTS TO IDRP BENEFITS REALIZATION (FIELD EVALUATION)

The procedural evaluation was based on three multi-day field visits, one each in June, July, and August. Table 3 summarizes the evaluation visits, including weather conditions on each day. Weather impacts in ZNY, ZBW, ZOB, and/or ZDC were significant on only two days (June 17 and July 19) of the evaluation. Two other days (June 14 and June 16) were characterized by brief periods of light impact (non-convective rain), and the remaining 6 days had no weather impact whatsoever.

Table 3. Summary of Field Evaluation Visits

Date	Observation period	Weather impacts
June 14	1330-2130Z	Light rain
June 15	1330-2030Z	None
June 16	1330-2200Z	Light rain, west gate convection after 21Z
June 17	1230-2015Z	17-23Z (primarily west gates)
July 19	1330-2145Z	18-02Z (south, west gates)
July 20	1330-2200Z	None
July 21	1330-2100Z	None
August 2	1330-2100Z	None
August 3	1330-2130Z	None
August 4	1430-2000Z	None

Lincoln Laboratory observers were deployed to the tower at Newark International Airport (EWR), the New York TRACON (N90), the New York ARTCC (ZNY), and on some days, to the Delta airline operations center in Atlanta (DAL). Observers recorded specific uses of IDRP and noted whether the uses were prompted by the observer. Observed uses were characterized as operational decisions, which can be monetized, and situational awareness enhancements, which do not have a direct corresponding economic benefit, but may be precursors to future use for decision making resulting in measurable delay reduction benefits. Observers also recorded user opinions about the potential uses for IDRP, and capabilities that could improve its value. Finally, observers recorded decisions, actions, procedures, communications, and other factors that affected traffic management operations and provide insights into the overall operational context for decision making and execution. The discussion here describes overall trends in observed use and highlights observations that may provide insights into particular operational functions.

User comments were favorable. Many suggested potential uses and identified features that they found particularly useful. Observed use followed a pattern similar to one documented in the early stages of the introduction of other novel tools such as CIWS, and RAPT [6, 4]. Users rarely made operational decisions based on IDRP information, but did consider the information at times to determine if its information either matched their perception of the current situation, or how IDRP information could be used to improve decision making or implementation.

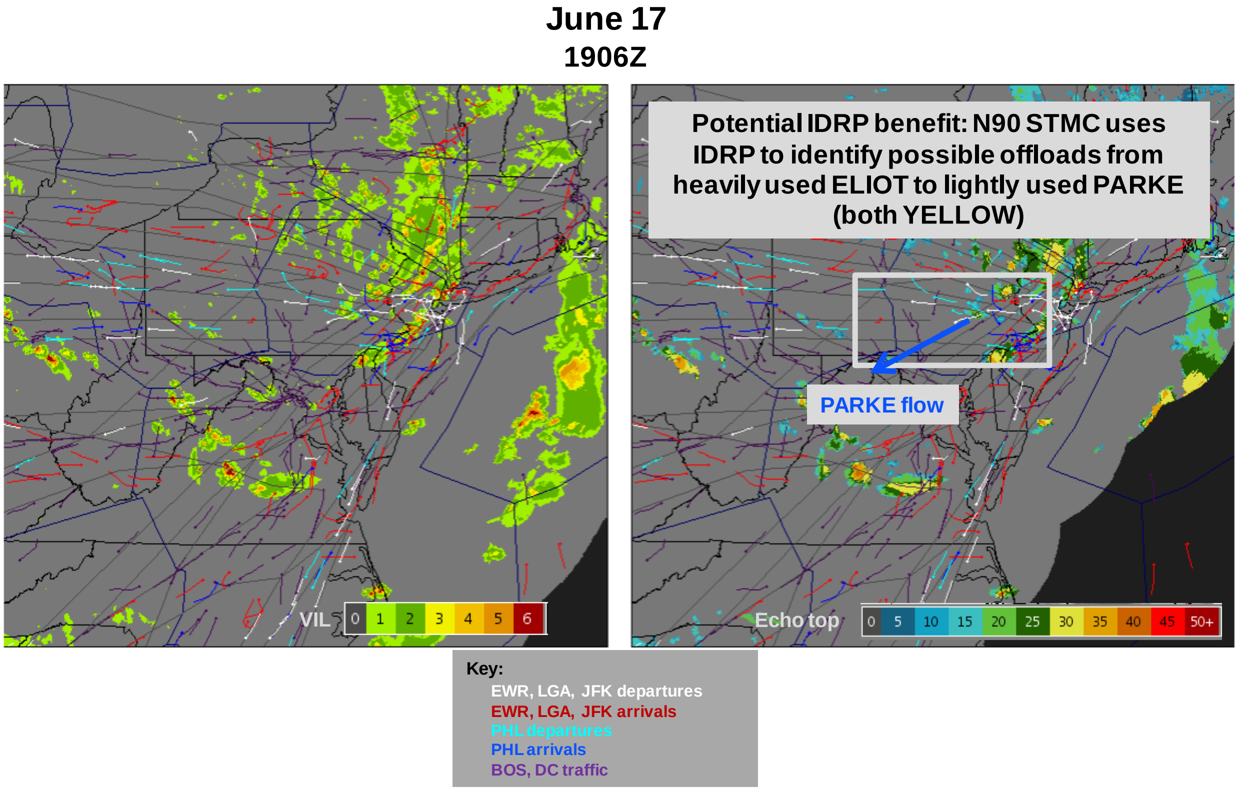
Flight lists and fix demand predictions are the *lingua franca* of air traffic management, and users readily understood the presentation of IDRP demand information and its integration with RAPT impact forecasts. However, there is a tendency, when presented with such information, to interpret it literally, without regard for the need to assess the uncertainty in the information. The current IDRP user interface, functional capabilities, and training do little to address this reality. Users must have a good sense of the reliability of IDRP information in different circumstances if they are to use it to proactively plan and implement reroutes.

4.1 OBSERVED USE

The most frequent observations of IDRP use (decision making or situational awareness) were on the weather-impact days (June 17 and July 19), primarily at N90 in the Tactical Reroute Coordinator (TRC) position. Four of these observations could be associated with potential benefits, and are described in the following paragraphs. No IDRP use was observed during five of the fair weather days (July 20–21, August 2–4).

On June 14 at 1544Z, pilots began deviating around rain (primarily level 1–2, with scattered level 3 cells, echo tops below 25 kft) on the north departure gates. The N90 Supervisory Traffic Management Coordinator (STMC) consulted the IDRP fix demand list, and noting that the demand was light, determined that traffic could be managed with deviations and that no reroute was necessary. Traffic flow continued out the north gates without interruption. This use was assisted by the observer from MITRE.

Two potential benefit uses were observed in N90 on June 17, both of which were assisted by the MITRE observer. From 1800–1822Z, the N90 TRC position used the Departure Spacing Program (DSP), the IDRP flight list and the Flight Schedule Monitor (FSM) to try to secure reroutes of LGA traffic filed on ELIOT to the RBV fix (RBV is usually used as a departure fix for JFK, and for arrivals to LGA). Weather impacts inside the TRACON were significant at the time, with level 4–6 VIL, echo tops up to 35 kft, and RAPT REDs and YELLOWs on all of the westbound departure fixes. The observer noted that the reroutes were not implemented. Figure 30 from the June 17 case study illustrates traffic and weather just prior to the observation (1757Z), showing north gate closures due to weather impacts, reduced westbound departure flows through ELIOT, PARKE and RBV, and widespread arrival holding impacting departure airspace and limiting departure fix options, possibly rendering the proposed reroutes infeasible (the observer also noted that the proposed reroutes required a runway configuration change for JFK). Later on the same day, at 1905Z, the TRC used the fix demand table and flight list to attempt to balance departures out the ELIOT and PARKE fixes (both YELLOW). However, no reroute action was taken. Figure 37 illustrates traffic and weather at the time, showing moderate traffic levels on ELIOT and light use of PARKE. Approximately 45 minutes later, traffic flow on PARKE showed a marked increase.



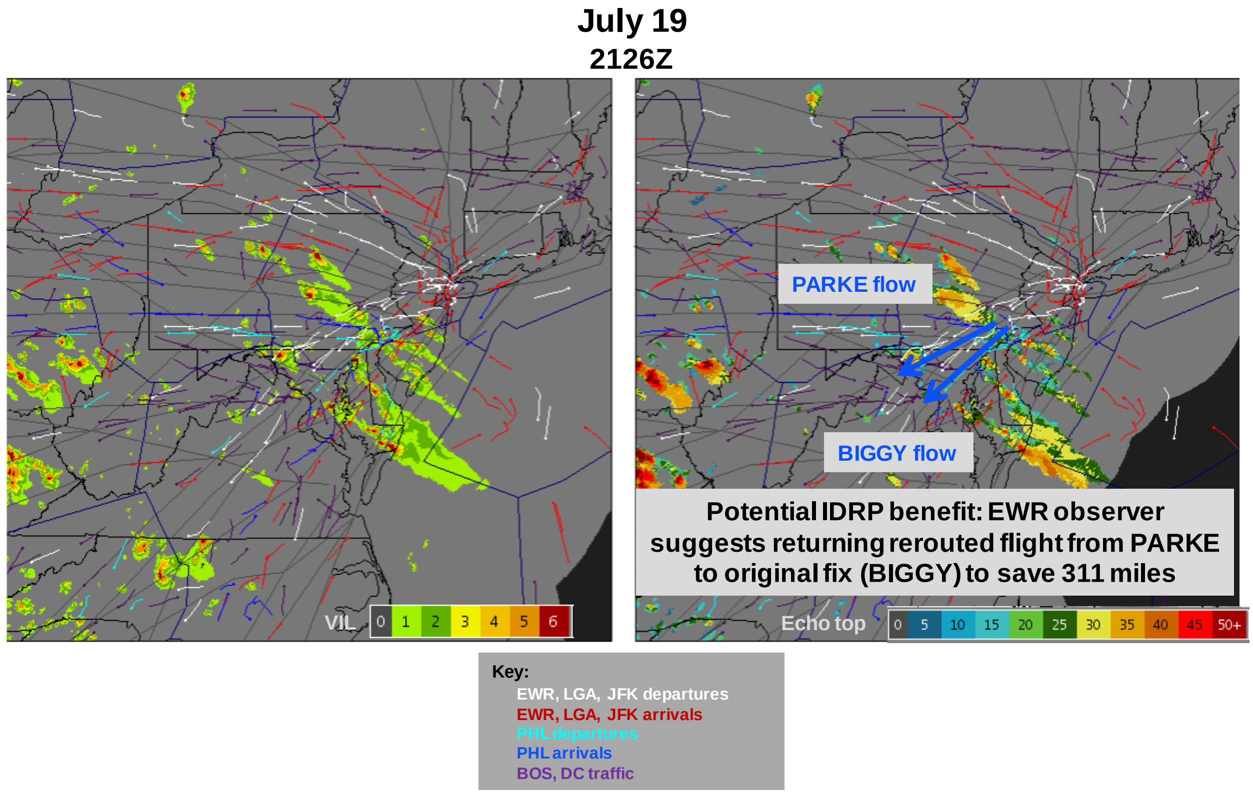
Potential IDRP benefit: N90 STMC uses IDRP to identify possible offloads from heavily used ELIOT to lightly used PARKE (both YELLOW)

Figure 37. Potential IDRP benefit opportunity, observed on June 17.

One more potentially beneficial use, also assisted by the MITRE observer, was observed in N90 at 1616Z on July 19. Five pending southbound departures were observed from White Plains (HPN) and Stewart International (SWF) airports. The load was deemed manageable, but the supervisor on duty did consider potential reroutes to improve departure spacing. No reroute action was taken, and no adverse effect was reported on southbound traffic. The observer noted that in all instances involving the TRC position, there may have been some hesitance to implement reroutes since the procedures for TRC-initiated and implemented reroutes was so new; as TRC procedures become more commonplace, IDRP use at the TRC position may become more aggressive.

Three observations from EWR provide some insight into potential uses and pitfalls in reroute planning. On June 17 at 2000Z, the observer assisted the Traffic Management Coordinator (TMC) and STMC in finding a route for a Charlotte-bound departure. The action seemed curious, since the preferred route, over LANNA, appeared open, with RAPT GREEN, a 15-minute post-impact GREEN (PIG) timer, and a recent successful departure along the route. However, a spinning arrival nearby may have rendered LANNA temporarily unavailable. The observer showed the TMC the reroute options in the IDRP flight list. The TMC hesitated, since the suggested reroutes required coordination. Using a folder containing a print-out of Coded Departure Route (CDR) alternatives, (the CDR “orange book”), he suggested a reroute through PARKE, which added only 18 miles to the trip. The STMC chose to coordinate the flight as a pathfinder over BIGGY, which reduced the travel distance by 116 miles. The choice appeared curious, as BIGGY was solid RED in RAPT and PARKE YELLOW going to GREEN; PARKE traffic was relatively light. The flight was released over BIGGY, but BIGGY remained closed as weather impacts continued to be heavy.

Two IDRP uses were recorded at EWR, both on July 19, with an assist from the Lincoln observer. At 1329Z, the STMC used IDRP flight list options to try to identify reroutes for flights filed over PARKE, which was closed due to impacts in ZDC beyond the RAPT domain. A second observation was recorded at 2129Z. The observer noted a flight that had been previously rerouted from BIGGY to PARKE that could now be rerouted back to BIGGY, as weather impacts on BIGGY had subsided somewhat and traffic was once again flowing on BIGGY (Figure 38). Both BIGGY and PARKE showed RAPT YELLOW impacts; the BIGGY route would have saved 311 miles. The TMC rejected the idea, due to concerns about potential fix congestion and surface management impacts. The difficulty in restoring pre-departure reroutes back to their originally filed routes has been observed both in New York and Chicago during RAPT evaluations, and raises a concern that proactive, pre-departure reroutes, implemented beyond the horizon of forecast certainty, can impose a cost on the system when the reroute ultimately could have been avoided.



Potential IDRP benefit: EWR observer suggests returning rerouted flight from PARKE to original fix (BIGGY) to save 311 miles

Figure 38. Potential IDRP benefit opportunity, observed on July 19.

Only two references to IDRP were recorded from Delta airlines. One reference was a comparison to Harmony and Aerobahn, commercial systems used by Delta dispatch to manage their surface and departure route planning; several mismatches between IDRP flight lists and the in house systems were noted. In the other reference, a dispatcher noted the possibility of moving a flight to a lower demand fix.

4.2 USER FEEDBACK, POTENTIAL IMPROVEMENTS AND IMPEDIMENTS TO INCREASED USE

Several EWR users commented that they would not use IDRP to reroute flights pro-actively, without restrictions being present on the originally filed flight. They noted that “airlines file a flight plan for a reason,” and that they should not override the airline’s expressed preference without a clear reason to do so. Considering the observations, during this evaluation and others, that rerouted departures are rarely rerouted back to their originally filed flight plan if it becomes available, this approach reduces the number of unnecessary reroutes and their associated costs. IDRP must recognize the potential impacts of uncertainty on efficiency, and take into account the limits of impact forecast certainty when suggesting viable planning horizons for proactive rerouting.

Users at both EWR and ZNY noted that the IDRP alternative route list was a significant improvement over DSP, which displays only a single reroute option at a time. The additional mileage feature was particularly well-received. IDRP clearly can improve the implementation of reroutes once the reroute strategy has been put in place (e.g., the set of restricted routes and acceptable alternatives are known). Outside of the TRC position at N90, however, IDRP was not considered for use in planning reroute strategies. No observed uses of IDRP to plan reroutes were recorded at ZNY over the course of the evaluation.

The impediments to IDRP use to plan and execute reroutes in ZNY are a result of a concept of operations and tool design that does not yet match the ZNY's operational need for "strategic" planning and execution of reroutes (in this sense, "strategic" refers to the need to plan and manage several flights or traffic flows, and not to an extended time horizon). The traffic management task in ZNY includes resource management and allocation (fix and route opening, restriction, and closure), development of plans to balance demand and capacity on available resources in the tactical (approximately 0–30 minutes) time frame, and implementation of the reroutes for the three major New York airports (EWR, JFK, and LGA).

The tasks of coordinating airspace use among several facilities (major NY towers, N90, neighboring en route centers, and the Air Traffic Control Systems Command Center) and the high volume of flights that may need to be rerouted during periods of severe weather impacts necessitate a division of labor between resource management and coordination (done by the STMC and departure director) and reroute implementation (done by the Pit, which may be staffed by up to 3 TMCs during SWAP). The IDRP TRC use case, where a single user plans and implements reroutes of individual flights from the flight list, is poorly suited to the higher volume of flights and the resource coordination workload encountered at ZNY. The satellite airports managed by the TRC position account for approximately 30% of New York area departures; even during periods of intensive IDRP use observed in the TRACON, the number of flights under management was fairly small, and observed periods of use did not exceed 20 minutes.

By contrast, the Pit often needs to reroute a large number of flights over a prolonged period of time during typical SWAP impacts. For instance, during a period of moderate weather impacts on June 17, the observer recorded 132 reroutes implemented in the Pit over a 5.5 hour period (1521Z to 2057Z), a rate of 24 reroutes per hour. Several enhancements should be considered to increase the usability of IDRP for the planning and implementation of reroutes at ZNY:

1. Deployment to the Pit. The potential value of IDRP to improve reroute implementation was obvious from the field evaluation.

2. Enhancements to support Pit use. A separate flight list interface, without the CIWS/RAPT display, is probably more appropriate to the Pit. The ability to copy IDRP route strings and paste them into the reroute terminal may also be necessary; this capability is widely used in DSP, and without it, IDRP may prove too cumbersome for frequent Pit use.

3. Improved flight list filtering. Flight list filtering options need to be better coupled to common reroute strategies. For instance, a Pit position assigned to implement reroutes for JFK ought to be able to display only flights with JFK origins, and should have the option to display only the currently affected fixes (i.e., those whose flights must be rerouted). “High confidence” planning horizons should also be identified, to reduce the likelihood and cost of unnecessary reroutes.

4. Better summary information to support planning. The only summary information that IDRP currently provides are aggregate counts of forecast demand over fixes or routes. Any finer-grained summary information that may be useful to ZNY flight planners requires sorting the flight list and manually inspecting the results (counting flights, identifying forecast departure spacing, etc.). These capabilities provide poor support for traffic managers trying to answer simple, operationally relevant questions like “How many Chicago metro departures are filed over COATE in the next 20 minutes? What fraction of the COATE demand do they represent?”

Delegation of reroute implementation directly to the major towers could possibly result in higher reroute efficiency. However, users currently lack tools that enable reliable and clear communication of system status and reroute strategies, and procedures that ensure the proper coordination of tower-implemented reroutes with the TRACON and ARTCC. In order for IDRP to support effective delegation of reroute implementation, such tools and procedures need to be in place.

Finally, observers noted that approximately 50% of departures on the flight lists were not associated with RAPT status. It is not clear how much of an impediment to use these unmatched flights pose, nor is it clear how precise match-defining criteria should be, given the considerable uncertainty in forecast of weather impact and pilot behavior.

5. CONCLUSIONS AND RECOMMENDATIONS

The assessment of decision making and decision support in departure management, particularly during convective weather SWAP, is difficult and complex. Metrics that characterize weather impacts, predictability, and quality of decisions such as reroute necessity and feasibility, are difficult to define and correlate to outcomes, which themselves are not easily defined. Nonetheless, in developing the metrics and studying how they relate to overall performance, one can gain valuable insights into the most important problems and the impediments to solving them.

The goal of more proactive planning is noble. However, proactive planning must take into account the considerable uncertainty present in departure operations during convective weather:

1. Weather and weather impact forecast
2. Pilot response to weather
3. Controller response to the workload of managing deviating pilots
4. The myriad of details that result in uncertainty in the wheels-off forecast
5. The current state of airspace restrictions

Arguably, the primary task of traffic management is the management of uncertainty – maintaining consistent and predictable traffic flows while at the same time maintaining flexibility and contingency plans that enable traffic management to respond to weather and humans that may act in unpredictable ways. Concepts and tools for proactive planning must be developed in harmony with this reality – which leads to the fundamental conclusion of this evaluation:

In a highly uncertain world, forecasts, decision support tools, and/or concepts of operations do not define feasible planning horizons; Mother Nature does. Automated decision support must be sufficiently "self-aware" to guide users to the limits of its utility in different circumstances. Otherwise it will result in poor decisions that compound problems when the world (both natural and human) does not behave as predicted.

Specific recommendations for IDRP enhancements and refinements build upon this finding.

1. **Realistic guidance for the limits of the planning horizon.** Forecasts of the likelihood of long-lived and/or widespread weather impacts are necessary if one wishes to extend the reroute planning horizon beyond 30 minutes with any hope of success. An ancillary RAPT forecast of departure gate impacts and a warning that impacts are likely to extend beyond an hour are be valuable planning tools that would enable airline operators to make better

fueling decisions and traffic managers to begin planning for the possibility of significant reroutes.

2. **Development of "extrapolation certainty" guidance.** A forecast that tells traffic managers "Conditions are likely to remain similar to current conditions for the next xxx minutes" provides extremely valuable guidance, enabling managers to extrapolate the most certain information they have – what is going on now – to realistic horizon limits.

3. **Improved RAPT RED accuracy.** The considerable volume of traffic observed occasionally on RAPT RED routes suggests that the criteria for RAPT RED need to be refined, to increase the certainty that RAPT RED fixes are not feasible, without greatly increasing the likelihood that pilots on RAPT YELLOW routes will refuse them.

4. **Refinement of IDRP capabilities and Concept of Operations to account for the observed situational capacity and tactics in the use of RAPT RED and YELLOW routes.** The current IDRP concept of proactive rerouting away from RAPT REDs to YELLOWs or GREENs takes no account of the considerable creativity displayed by traffic managers and controllers in moving traffic through impacted airspace. This evaluation identified nearly 700 departures that were released on RED fixes over 10 SWAP days, often using tactics such as flow merging (two or three routes merged into a single stream to avoid the weather) and managed deviations that are not well modeled in either RAPT impact or IDRP demand forecasts, that would have required reroutes according to the current IDRP concept of operations. These tactics enable traffic managers to hedge uncertainty while making use of capacity in impacted airspace when it is most needed. A better understanding of when and how they are used, and the information needed to improve the likelihood of their success, is critical to defining a comprehensive and viable concept of operations for IDRP. Concepts for estimating, forecasting, and presenting blockage and capacity for merged routes and full departure gates should be explored.

5. **Continued refinement of the objective criteria for reroute success, and further analysis to correlate forecast accuracy to rates of reroute success, and to related reroute success metrics to overall departure throughput.**

6. **Focus on the use of the IDRP flight list and reroutes alternatives to improve implementation of reroutes.** A flight list only IDRP interface should be deployed to the Pit for use in reroute implementation. However, in order to be successful, both the wheels-off prediction errors and forecast volatility must be improved considerably. Furthermore, the impacts of wheels-off error on flight demand lists and fix demand predictions must be determined, and the accuracy of both must be validated.

7. **Improved support for returning rerouted flights to their originally filed plans when possible.**

8. **Meaningful integration with surface systems to reduce uncertainty in forecast departure demand and sequencing.** IDRP should not be modeling what can be controlled and provided by surface systems.
9. **Improved dissemination of information about the current state of airspace restrictions and operational plans.**

APPENDIX A
DETAILED REROUTE ANALYSIS FOR CASE STUDIES

The following plots illustrate the characteristics of each observed reroute: true RAPT (symbol color) and observed traffic counts (y-axis) at wheels-off time on the originally filed and reroute target departure fixes. Circles indicate originally filed flight plans (true RAPT status and traffic count); diamonds indicate the same for reroute targets. The fix congestion limits for each RAPT color are identified on the plots by lines parallel to the x-axis, and the black line indicates fix closure. Two plots per day are shown. The first shows the characteristics of each reroute, grouped along the x-axis in order of necessity/feasibility (from left to right): necessary/feasible, necessary/not feasible, not necessary/feasible, and not necessary/not feasible. The second plot shows the same set of characteristics, only in these plots, the x-axis indicates time of day, enabling correlation of observed reroute necessity/feasibility with operational conditions at the time of implementation.

August 1

Figure A1 shows that a high percentage of reroutes on August 1 were necessary; more than half of those were characterized as infeasible. Nearly all reroutes were off closed RED or YELLOW fixes; infeasibility was due to high traffic counts on GREEN, YELLOW, and even RED reroute targets. The high percentage of infeasible reroutes is indicative of the widespread impacts; few unimpacted fixes were available for reroute traffic. The time of day plot (Figure A2) shows a small cluster of unnecessary reroutes around 23Z.

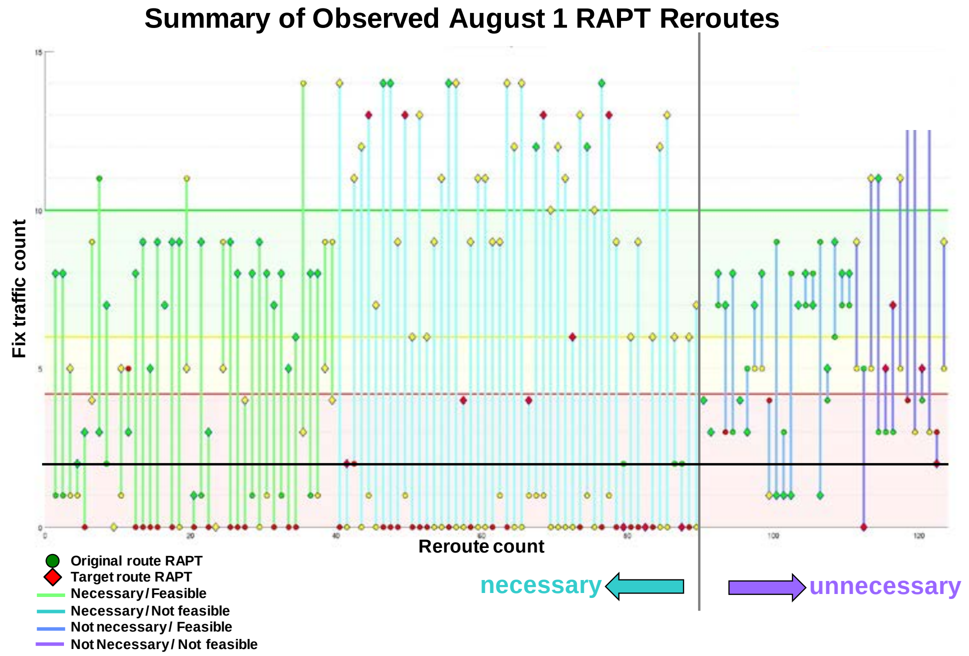


Figure A1. Summary of RAPT reroutes on August 1.

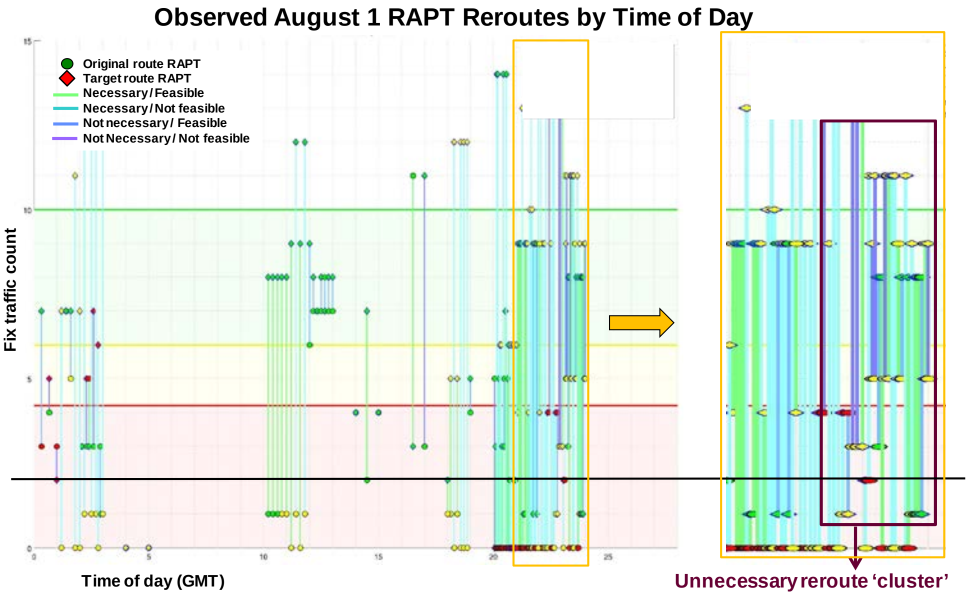


Figure A2. Time series of RAPT reroutes on August 1.

September 7

Figure A3 shows the summary of September 7 reroutes. A very high percentage were considered necessary, taking traffic from closed RED and, in some cases, YELLOW fixes. A high percentage of reroutes were considered infeasible, as reroute targets carried very heavy traffic, well beyond the nominal congestion limits. As on August 1, there were few unimpacted options, so heavy traffic was a necessity on open fixes. However, the more stable and less severe weather impacts enabled steady and efficient use of those impacted fixes. The relatively small number of unnecessary reroutes were grouped during two periods (14–15Z and 22–00Z) when weather impacts were less severe (Figure A4).

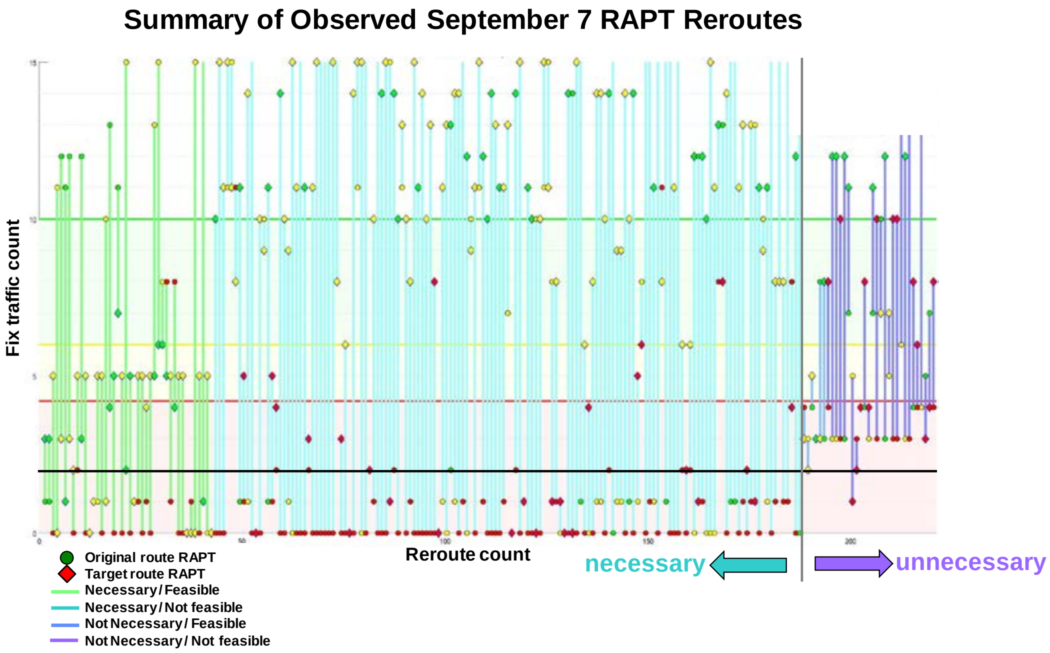
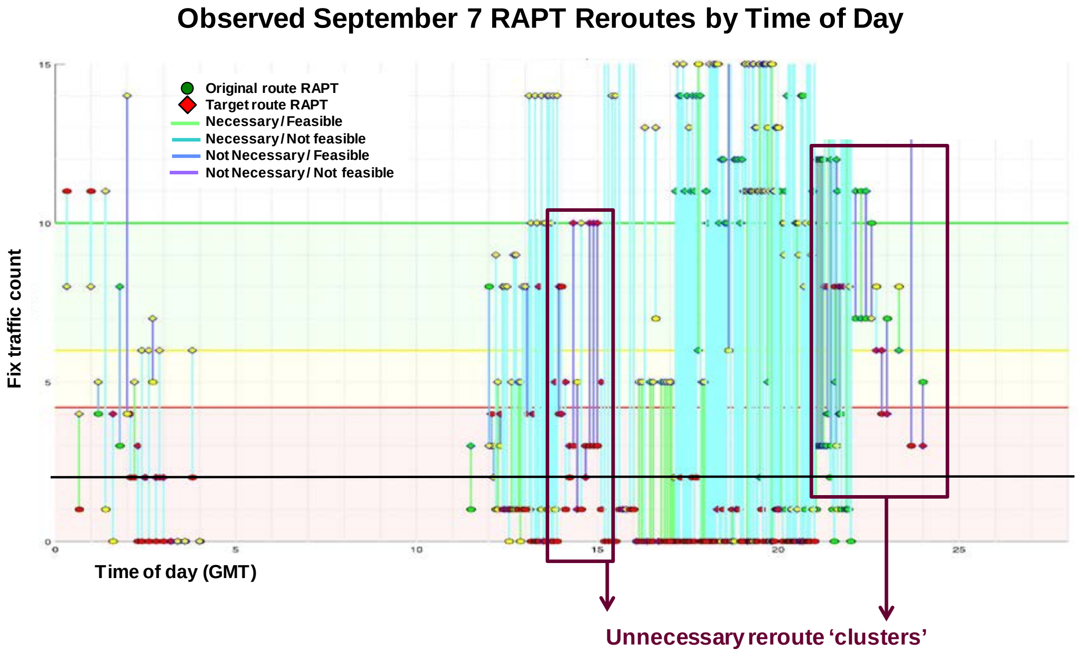


Figure A3. Summary of RAPT reroutes on September 7.



Unnecessary reroute 'clusters'

Figure A4. Summary of RAPT reroutes on September 7.

<u>June 17</u>

Necessary reroutes were primarily from RED or congested or closed YELLOWs (Figure A5); a few necessary reroutes were from closed GREENs, which may indicate missed opportunities to reopen closed routes, or GREEN routes that were deemed unusable due to other circumstances (e.g., deviating/holding arrivals, although few deviating or holding arrivals were observed on this day). The relatively high percentage of unnecessary reroutes took traffic from on uncongested GREEN fix to another. Figure A6 shows that the majority of unnecessary reroutes were late in the day (22–00Z).

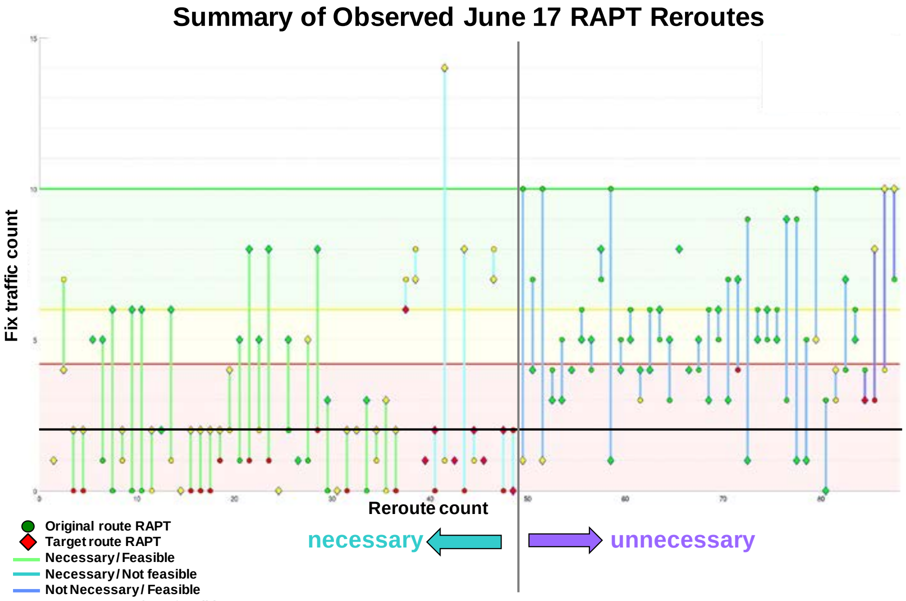


Figure A5. Summary of RAPT reroutes on June 17.

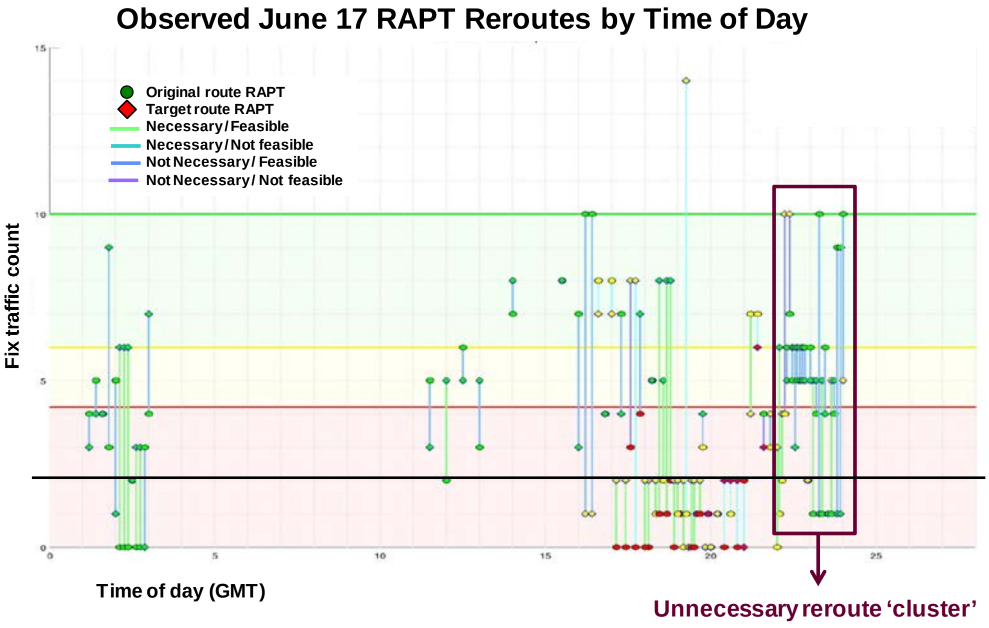


Figure A6. Time series of RAPT reroutes on June 17.

July19

On July 19, most reroutes took traffic from closed RED and YELLOW fixes (Figure A7). Approximately 1/3 of the reroutes characterized as unnecessary took traffic from RED fixes whose traffic count fell between the closure and RED congestion thresholds, suggesting that the thresholds and necessity criteria may have underestimated the percentage of necessary reroutes on this day. Figure A8 illustrates the “cluster” of unnecessary reroutes between 21Z and 00Z, a period of dynamic and difficult to predict storm evolution during the day.

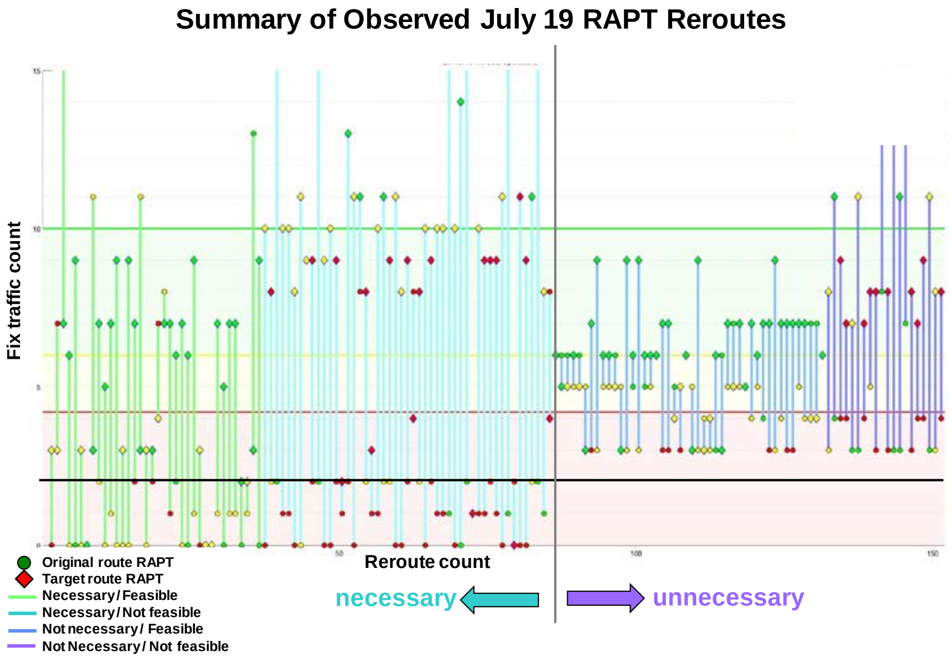
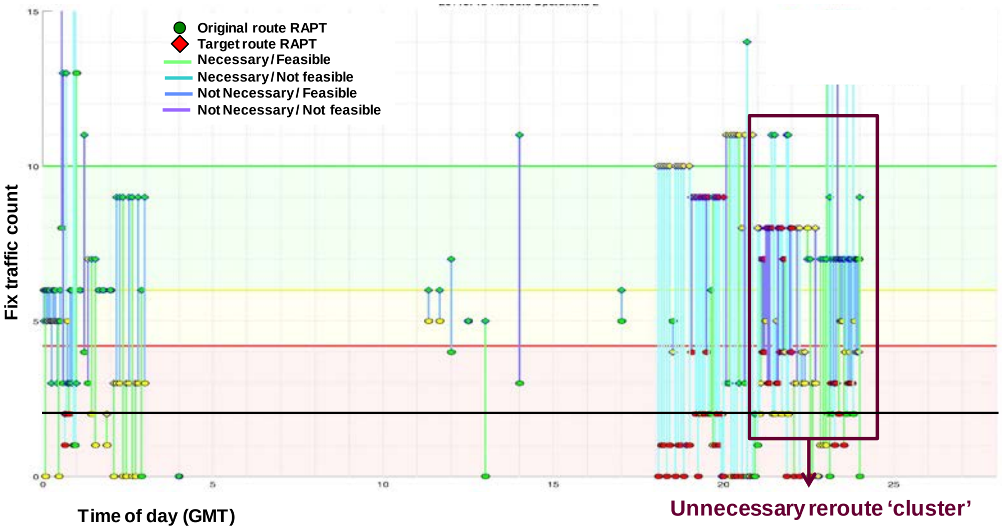


Figure A7. Summary of RAPT reroutes on July 19.

Observed July 19 RAPT Reroutes by Time of Day



Unnecessary reroute ‘cluster’

Figure A8. Time series of RAPT reroutes on July 19.

GLOSSARY

AAL	American Airlines
ACID	Aircraft Identification
ARTCC	Air Route Traffic Control Center, or Center
ASDE-X	Airport Surface Detection Equipment, Model X
ASPM	Aviation System Performance Metrics
ATM	Air Traffic Management
BOS	Boston Logan International Airport
CCFP	Collaborative Convective Forecast Product
CDR	Coded Departure Route
CIWS	Corridor Integrated Weather System
DAL	Delta Airlines
DSP	Departure Spacing Program
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FSM	Flight Schedule Monitor
HPN	Westchester County Airport
IDRP	Integrated Departure Route Planning
ITWS	Integrated Terminal Weather System
JFK	John F. Kennedy International Airport
LGA	La Guardia Airport
MIT	Miles-In-Trail
N90	New York Terminal Radar Approach Control
NAS	National Airspace System
NTML	National Traffic Management Log
NWA	Northwest Airlines
PHL	Philadelphia International Airport
PIG	Post-Impact GREEN
RAPT	Route Availability Planning Tool
STMC	Supervisory Traffic Management Coordinator
SWAP	Severe Weather Avoidance Plan
SWF	Stewart International Airport
TEB	Teterboro Airport
TMC	Traffic Management Coordinator
TRACON	Terminal Radar Approach Control
TRC	Tactical Reroute Coordinator
UAL	United Airlines
VIL	Vertically Integrated Liquid

ZBW	Boston Air Route Traffic Control Center
ZDC	Washington Air Route Traffic Control Center
ZOB	Cleveland Air Route Traffic Control Center

REFERENCES

1. “Route Availability Planning Tool (RAPT)” (briefing), Initial FAA RAPT Technical Interchange Meeting (TIM), MIT Lincoln Laboratory, May 16, 2007.

2. “Integrated Departure Route Planning: IDRP Upgrade Training” (briefing), MITRE CAASD, April 18, 2011.

3. Robinson, M., R.A. DeLaura, and N.K. Underhill, “The Route Availability Planning (RAPT): Evaluation of Departure Management Decision Support in New York during the 2008 Convective Weather Season,” Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009), Napa, CA, 2009.

4. Robinson, M., R.A. DeLaura, J.E. Evans, and S. McGettigan, “Operational Usage of the Route Availability Planning Tool (RAPT) During the 2007 Convective Weather Season,” MIT Lincoln Laboratory Project Report ATC-339, 6 October 2008.

5. DeLaura, R.A., D.L. Klingle-Wilson, M. Robinson, R.F. Ferris, N.K. Underhill, and Y.G. Rodriguez, “Making Departure Management Weather Impact Models Airspace-Adaptable: Adapting the New York Route Availability Planning Tool (RAPT) to Chicago Airspace,” MIT Lincoln Laboratory Project Report ATC-378, 26 May 2011.

6. Robinson, M., J.E. Evans, and T.R. Hancock, “Assessment of Air Traffic Control Productivity enhancements from the Corridor Integrated Weather System (CIWS),” MIT Lincoln Laboratory Project Report ATC-325, 30 June 2006.