

2.3A MAKING DEPARTURE MANAGEMENT WEATHER IMPACT MODELS AIRSPACE-ADAPTABLE: ADAPTING THE NEW YORK ROUTE AVAILABILITY PLANNING TOOL (RAPT) TO CHICAGO DEPARTURE AIRSPACE *

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1. INTRODUCTION

The Route Availability Planning Tool (RAPT) operational prototype was deployed to Chicago in the summer of 2010, the first RAPT deployment outside of the New York departure airspace for which it was originally developed. In addition to the routine aspects of site adaptation (e.g., defining site-specific algorithm inputs such as departure route trajectories), the deployment offered an opportunity to test several more fundamental elements of RAPT: weather impact estimation algorithms, models for departure operations, and concept of operations. Since Chicago airspace, departure management practices, and prevailing convective weather patterns differ markedly from those in New York, the Chicago RAPT deployment provided an opportunity to evaluate the adaptability of RAPT's departure management and weather impact models to different terminal areas throughout the NAS.

This report presents the results of a summer-long evaluation of the Chicago RAPT operational prototype. The evaluation included observations made by researchers simultaneously stationed at O'Hare terminal (ORD), the Chicago TRACON (C90), and the Chicago Air Route Traffic Control Center (ZAU) during several days of convective weather impact. Air traffic data from the Enhanced Traffic Management System (ETMS) were analyzed and compared to RAPT blockage status forecasts to determine the suitability of RAPT guidance to Chicago departure operations. Forecast RAPT route status was compared to 'true' RAPT route status (blockage based on actual, not forecast weather) to determine the accuracy of the RAPT blockage forecast. RAPT performance in Chicago was analyzed to identify issues in the weather forecast inputs, the RAPT blockage and operational models, and the concept of operations that must be addressed in order to ensure that RAPT can provide consistent and effective

departure management guidance in a wide variety of terminal areas. Finally, a summary of observed operational RAPT use is presented.

The evaluation is presented in five sections: description of the evaluation methodology, description of departure management in Chicago, evaluation of the performance of RAPT algorithms, discussion of the adaptation of the RAPT concept of operations and observed operational use of RAPT during the evaluation, and conclusions and future work. Where applicable, comparisons are made to New York operations and RAPT use.

2. RAPT EVALUATION METHODOLOGY

The RAPT evaluation included field observations of traffic management operations during SWAP events and qualitative post-event data analysis. Observers were placed at ORD tower, C90 TRACON, and ZAU TMU for three different SWAP events (Table 1). The events included a wide range of weather impact severity, duration, and locations (Figure 1).

3. DEPARTURE MANAGEMENT DURING CONVECTIVE WEATHER SEVERE WEATHER AVOIDANCE PROGRAMS (SWAP)

The Chicago terminal area is cornerpost airspace, and operations are dominated by O'Hare International Airport (ORD) traffic. Key departure fixes and routes – referred to as 'tracks' in Chicago operations – are illustrated in figure 2. Departure demand is greatest out the east and south gates, and departure demand peaks in the morning and late afternoon / early evening. Figure 3 illustrates typical, fair weather terminal area traffic flows, and contrasts them to operations in New York.

Most departure management decisions during SWAP are made at the en route center (ZAU). In response to convective weather impacts, traffic managers in ZAU may apply a combination of three different strategies: route closure, mile-in-trail (MIT) restrictions on individual routes, and 'gate management', where several departure tracks out a

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Table 1 Chicago RAPT field evaluation days.

Date	Start (Z)	Finish (Z)	Facilities
06 July	1100	0100	C90, ZAU
07 July	1130	0100	C90, ZAU
28 July	1400	0100	C90, ZAU
01 Sept	1100	2300	ORD, C90, ZAU
02 Sept	1130	2300 (1600 in ZAU)	ORD, C90, ZAU

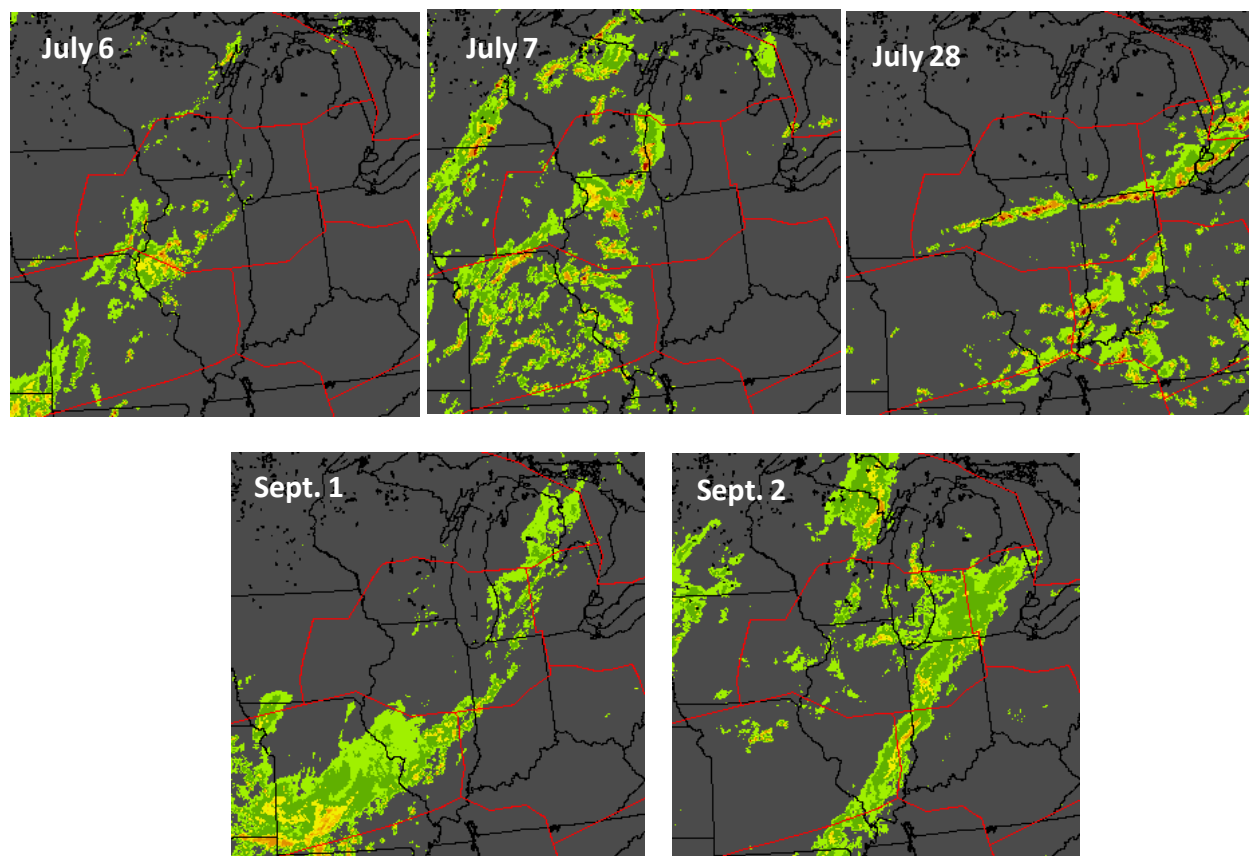


Figure 1 RAPT field evaluation case days.

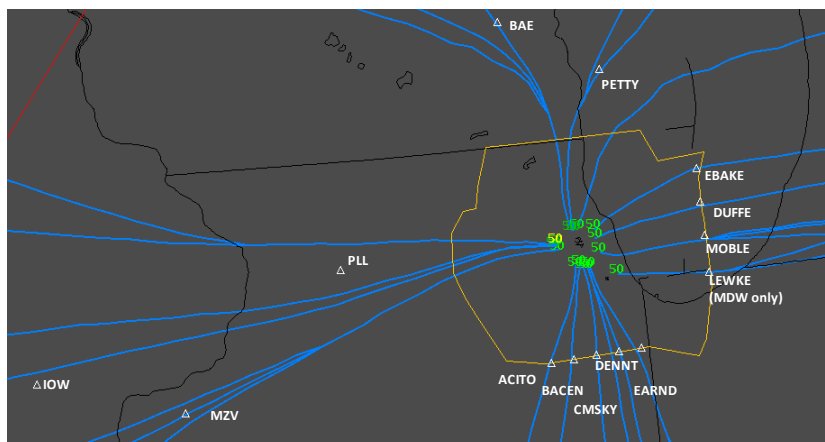


Figure 2 Major Chicago tracks and fixes.

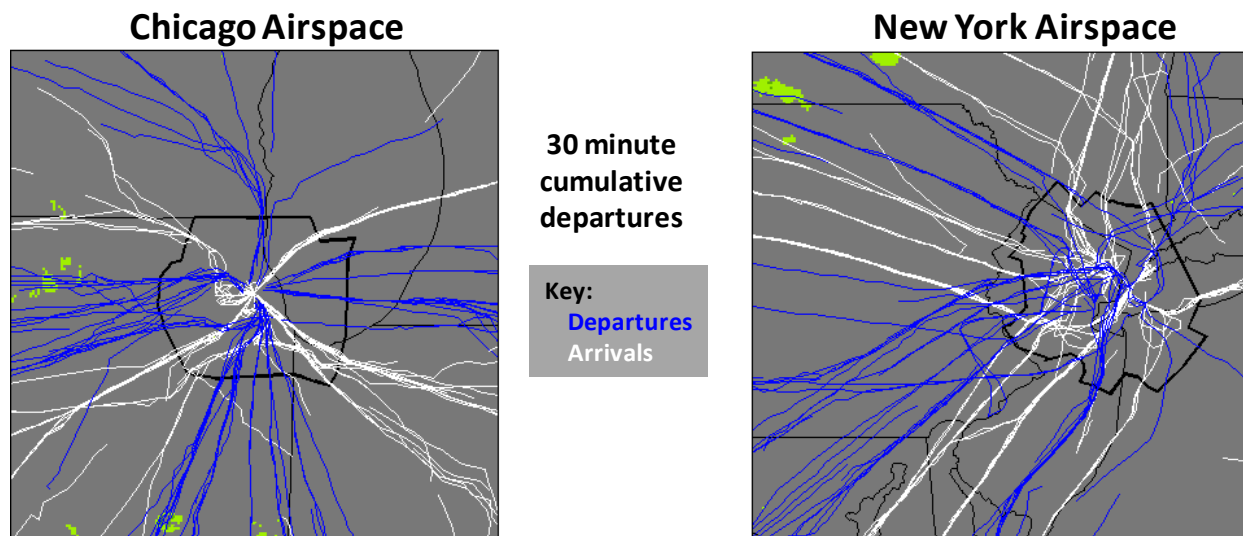


Figure 3 Fair weather traffic in Chicago and New York.

particular gate may be merged into one or two departure streams that are vectored around weather and then split back onto the original filed routes. For instance, departures through the five south gate fixes may be merged into two streams, each with 10 MIT restrictions (south gate '2x10'), to avoid convective weather impacts, and then split back onto their normal routing after the impacts have been passed (Figure 4). Individual route closures also occur, particularly when the impacted route is directly adjacent to an arrival stream and traffic managers are concerned that departures will deviate into arrival airspace to avoid weather, or when weather impacts are relatively limited

in scope (Figure 5). Gate management and traffic merging is more common in Chicago than in New York, because it is better suited to the cornerpost structure. As a result of the use of gate management strategies, Chicago departure gates are rarely completely closed. It is almost always possible to maintain a single departure stream, albeit with severe restrictions – in effect, the departure gate is constantly probed by pathfinders. By comparison, in New York's more complex, highly constrained airspace, individual route management strategies (closure, restriction, and / or vectoring to avoid weather) are more common.

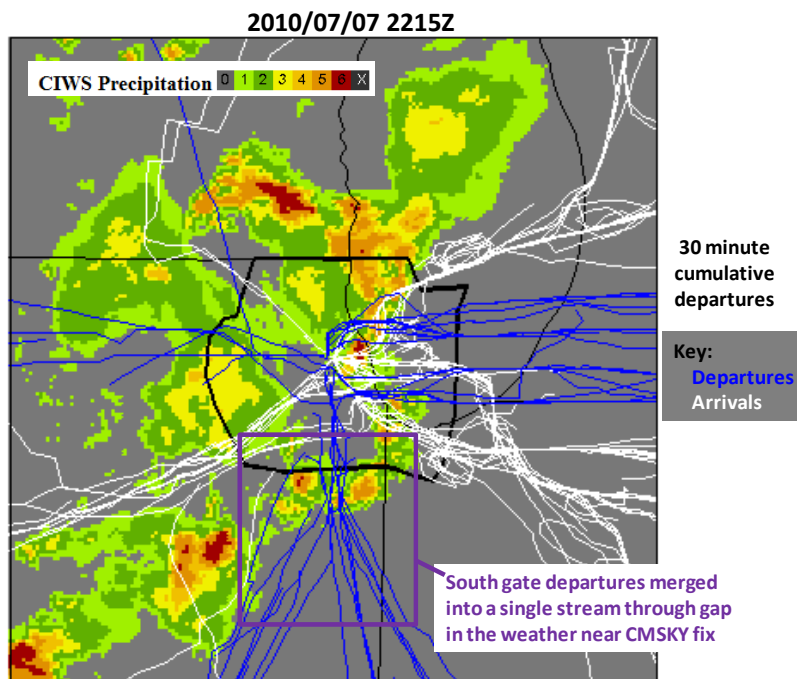


Figure 4 'Gate management' departure merging and splitting.

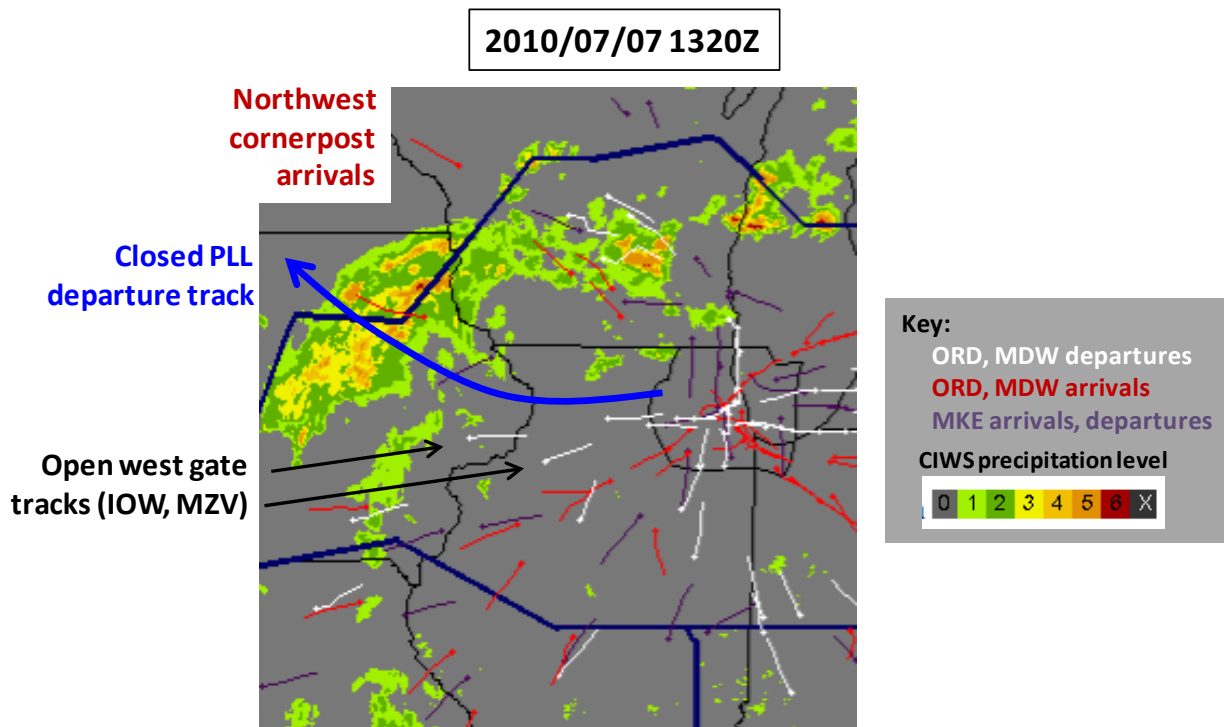


Figure 5 Managing individual route impacts near arrival airspace.

SWAP reroutes are rarely applied to move a flight from its filed route onto another departure track within a gate; they are generally used only when a departure gate is completely closed or severely restricted, and flights must be rerouted out a different departure gate. Several TMU personnel suggested that early (1-2 hours in advance) airline filing of proactive reroutes to avoid weather impacts is often counter-productive. The weather and ATC response is very dynamic, and more often than not, premature proactive rerouting results in additional reroutes to undo the original reroute – only now, with aircraft that may have additional fuel unnecessarily loaded.

4. RAPT ALGORITHM PERFORMANCE

Overall, RAPT performance was very good. REDs and GREENs on individual routes were generally in agreement with observed operations (Figure 6). RAPT YELLOWs routes were usually open, with some restriction (Figure 7). RAPT typically matched operations when merging strategies were employed with multiple YELLOW / RED, all YELLOW, or YELLOW / GREEN route timeline combinations (Figure 8). The most significant RAPT status problem observed was

over-warning when weather impacts were inside the TRACON, particularly as weather passed over the airport (Figure 9). The problem appears to be more common in Chicago than in New York, where storms that impact the TRACON often dissipate quickly as they move toward the nearby ocean. TRACON impacts in Chicago can linger for a long time as the storm moves from one departure gate to the next (Figure 10), and, as a result, RAPT errors in the Chicago TRACON may be more consequential than in New York. The observed over-warning may be due to a combination of factors: a tendency of the CIWS echo top forecast to decay echo tops too slowly, errors in the convective weather avoidance model (CWAM) for departure airspace near the airport, and / or route widths in the TRACON that do not reflect operations accurately, particularly when the gate management tactics described in the previous section are in use. Nonetheless, on several occasions when RAPT showed gate impacts that were 'dead RED' (all tracks departing out the gate were RED), the gate was either completely closed or severely restricted (a single departure stream with at least 10 MIT) (Figure 11).

2010/07/28

RAPT, 30 minute forecast at 1645Z

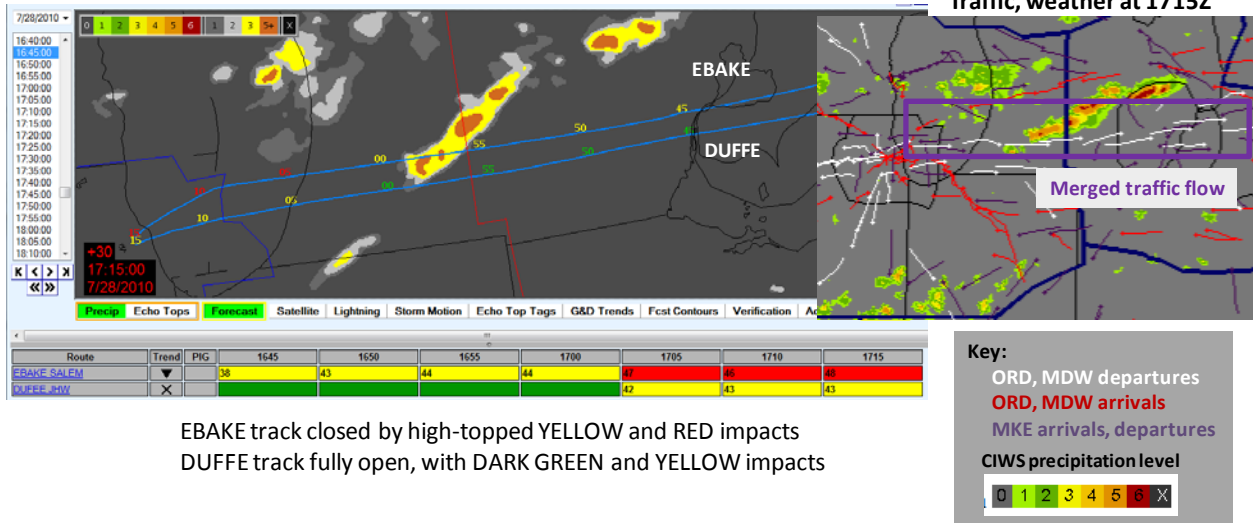
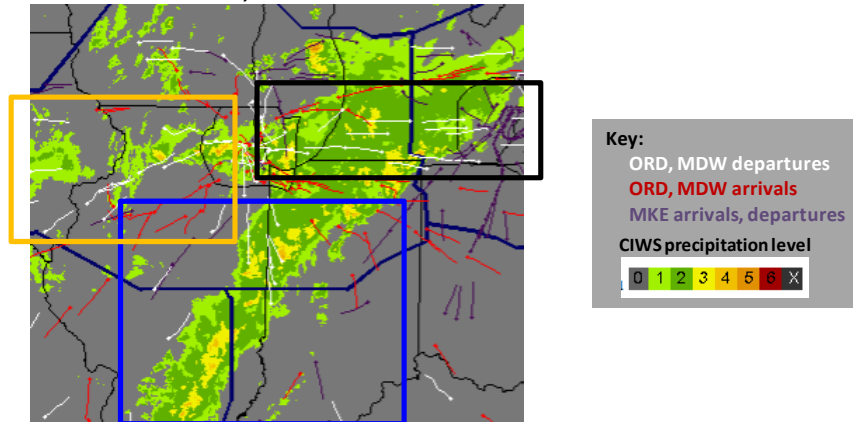


Figure 6 Illustration of RAPT individual RED and GREEN route guidance that matches well with operations.

2010/09/02

Traffic, weather at 1445Z



RAPT east, south, west track forecasts at 1410Z

Route	Transit	1410	1415	1420	1425	1430	1435	1440
SEASH. SALFM	—							
DUFFE. JMW	—				27	25	27	27
MOBILE CSR	—	28	28	29	28	28	28	29
MOBILE DMR	—	28	29	29	28	28	29	29
MOBILE AIR	—	27	27	28	28	28	29	30
LEVINE. GUCRL	—	28	28	29	29	30	29	30
SEASH. GULF. BSL	—	28	29	29	29	29	29	29
SOTO. JBL	—							
BACEN. FAM	▲							
BACEN. ENL	▲							
CHESKY. PIV	—	29	29	29				
DEINT. DOWR	—	30	30	30	29			
DEINT. DUMR	—	30	29	30				
SASNO. RJ	—	30	30	30	29			
SASNO. PUM	—	30	30	30	29			
BSL. MWL	—							
BSL. FOD	—							
SOV. J19	—							
SOV. J89	▼							
MOJ. LMR	—							
MOJ. J19	—							
MOJ. ENL	—							

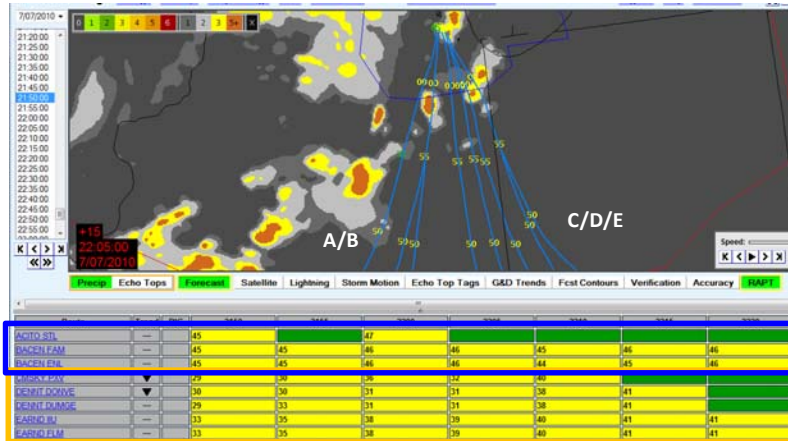
East gate tracks, no restrictions:
GREEN, YELLOW (tops < 30 kft)

South gate tracks all open, with 10 MIT:
GREEN, YELLOW (tops < 30 kft)

West gate tracks, no restrictions

Figure 7 Illustration of restrictions in place on RAPT YELLOW routes.

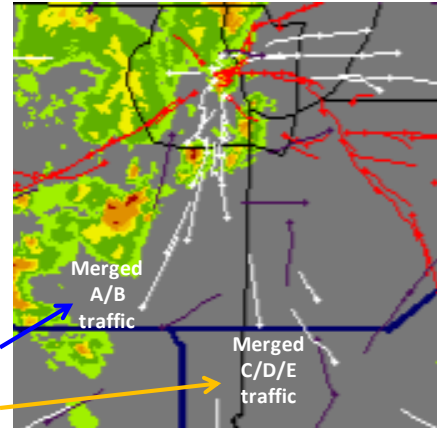
2010/07/07

RAPT, 15 minute forecast at 2150Z

A / B merged, 10 MIT
C / D / E merged, 10 MIT


RAPT mixture of YELLOW, GREEN with tops ranging from 29 – 47 kft
matches operational strategy

Traffic, weather at 2103Z



Key:

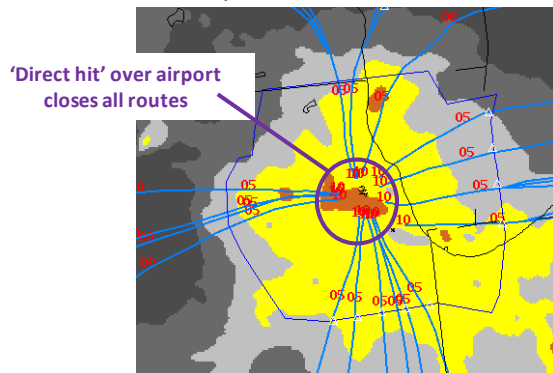
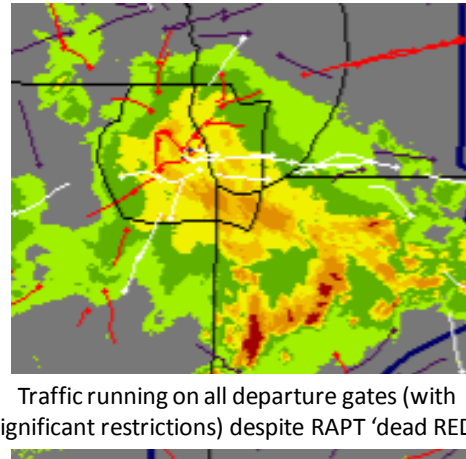
- ORD, MDW departures
- ORD, MDW arrivals
- MKE arrivals, departures
- CIWS precipitation level



0 1 2 3 4 5 6 X

Figure 8 Illustration of RAPT gate guidance that matches well with operations.

2010/08/03

RAPT, 20 minute forecast at 1155Z**Traffic, weather at 1215Z**

Traffic running on all departure gates (with significant restrictions) despite RAPT 'dead RED'

Key:

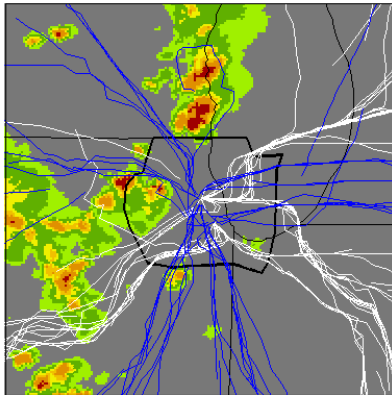
- ORD, MDW departures
- ORD, MDW arrivals
- MKE arrivals, departures
- CIWS precipitation level

0	1	2	3	4	5	6	X
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Figure 9 Illustration of RAPT over-warning in the TRACON as weather impacts pass over ORD.

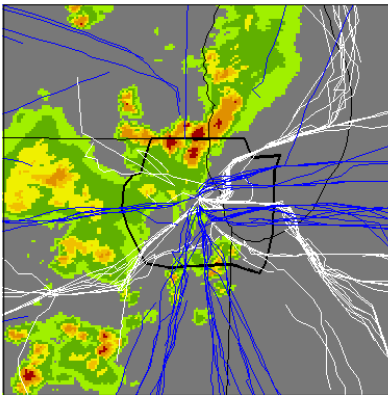
2010/07/07

2030Z



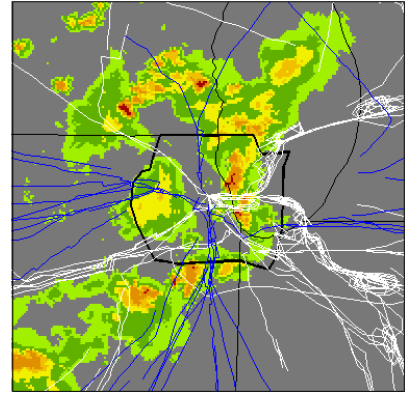
Storm impacts on and near western C90 boundary severely restrict west gate departures

2130Z



North gate departures shut down as storm moves to the NE

2245Z



East gate departures shut down as 'backside' storm growth impacts eastern C90 and arrivals are brought in through departure airspace

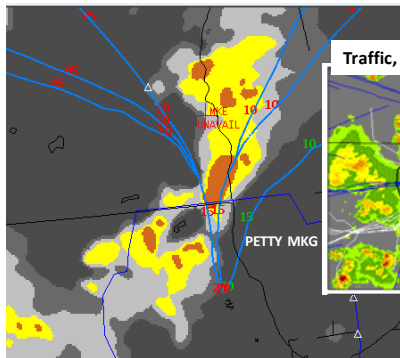
30 minute cumulative departures

Key:
Departures
Arrivals

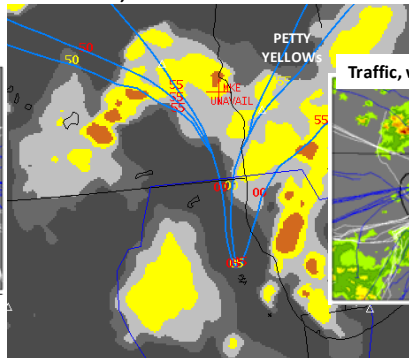
CIWS Precipitation 0 1 2 3 4 5 6 X

Figure 10 Long-lived weather impacts crossing the TRACON.

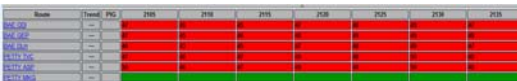
2010/07/07

RAPT, 20 minute forecast at 2105Z

Traffic, weather at 2130Z

RAPT, 20 minute forecast at 2250Z

Traffic, weather at 2215



North gate departures closed as storm crosses northern boundary of C90; RAPT shows RED on all but PETTY MKG (nearest to NE arrival cornerpost)



North gate reopened as 1 x 10, matching appearance of YELLOW impacts on PETTY tracks

30 minute cumulative departures

Key:
Departures
Arrivals

CIWS Precipitation 0 1 2 3 4 5 6 X

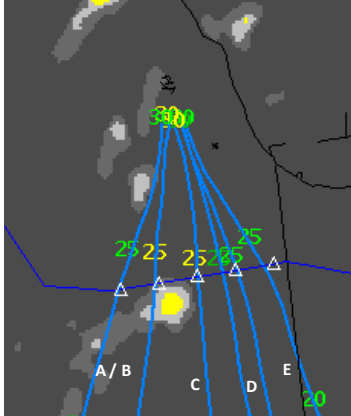
Figure 11 Perception of RAPT over-warning.

In the TRACON and near en route airspace, RAPT occasionally underestimated weather impacts. On occasion, deviations around low intensity (level 2), low-topped storms in the TRACON required closure of departure gates because TRACON could not thread traffic through the weather to the fix (Figure 12). Uncertainty in predicting pilot behavior, lack of sufficient information on low altitude storm structure, and the

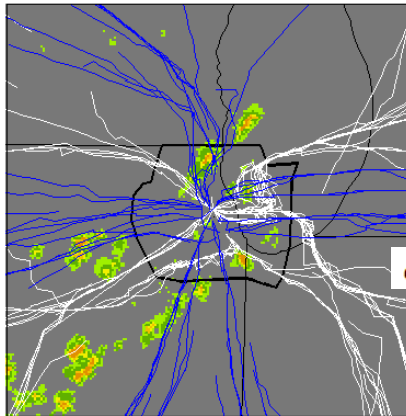
complexity of operational constraints on the ability of air traffic control to vector traffic around weather (e.g., the relationship between arrival / demand balance, runway configuration, and airspace availability for departure traffic) make cornerpost TRACON operations exceedingly difficult to model at the fine spatial scale required for accurate RAPT blockage calculation.

2010/07/06

RAPT, 15 minute forecast at 2015Z



Traffic, weather at 2030Z



30 minute cumulative departures

Key:
Departures
Arrivals

CIWS Precipitation 0 1 2 3 4 5 6 X

Route	Trend	PIG	2015	2020	2025	2030	2035	2040	2045
ACTO STL	▲	×							
BAKIN FAM	×	×			45	45			
BAKIN FAL	×	×			45	45			
CHSKY PAV	▼	×			45	45		45	45
DEMIT DOWNE	▼	×							45
DEMIT DUMGE	—	—							
EARNO ILL	—	—							
EARNO FLM	—	—							

South gate departures running under heavy restrictions (A/B 1x10, C,D,E 10 MIT), despite RAPT mix of GREEN and YELLOW

Figure 12 RAPT under-warning on TRACON weather impacts.

The accuracy of RAPT route blockage forecasts, based on a comparison of route status color calculated from forecast weather (operational RAPT) with route status calculated from observed ('true') weather, was scored for 6 days of operations (8/12, 8/13, 8/14, 9/10, 9/18, and 9/21). Figure 13 shows the results of the comparison for RAPT 15 and 30 minute forecasts. RAPT 30 minute forecasts of GREEN were accurate

over 95% of the time, YELLOWs were accurate roughly 70% of the time, and RED forecasts were accurate approximately 60% of the time. RAPT forecasts showed a slight bias toward over-warning. The RAPT forecast accuracy observed in Chicago was nearly identical to that observed in New York (Hayward, et al., 2010).

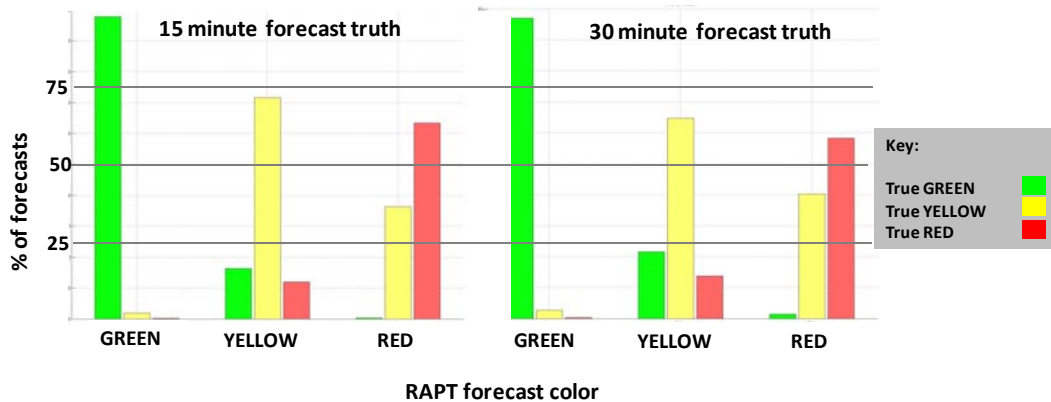


Figure 13 RAPT route status forecast accuracy.

5. RAPT CONCEPT OF OPERATIONS AND OBSERVED USE

The RAPT concept of operations, presented in (Robinson, et al., 2009), is illustrated in figure 14 and can be summarized as follows:

GREEN means GO! After weather impacts have cleared a route and the RAPT forecast timeline has turned all GREEN (or some combination of GREEN and DARK GREEN – known as a post-impact GREEN or PIG), reopen the route without restrictions (unless other concerns – for example, arrivals deviating into the departure airspace – merit further constraint).

RED means PLAN REROUTE. When the RAPT forecast timeline turns all RED or

substantially RED, plan to reroute departure traffic off the route.

YELLOW means use judgment to manage restrictions. YELLOW status indicates partial blockage, and / or uncertainty in the forecast. When routes are substantially YELLOW, traffic managers should consult additional information (the RAPT route trend box, echo top heights and trends, weather forecast animation) to decide whether restrictions should be increased, decreased, or maintained at the current level. For instance, experienced RAPT users in New York commonly reopen routes closed by RED impacts when RAPT routes begin to show post-impact YELLOW status with decreasing or stable echo tops. This practice has resulted in significant decreases in post-impact departure throughput.

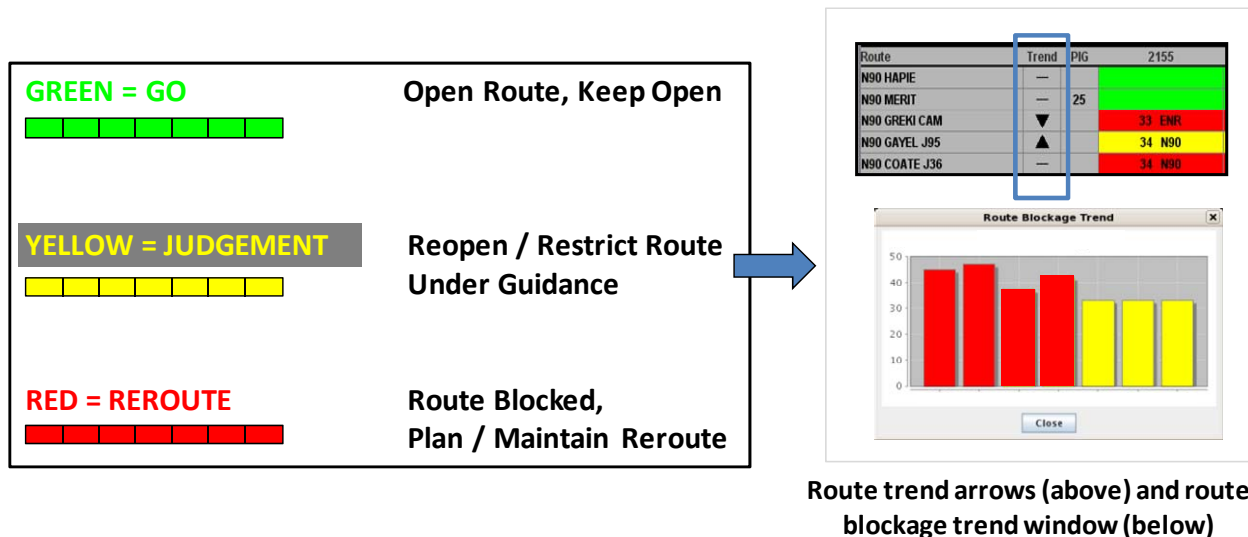


Figure 14 RAPT concept of operations.

The RAPT concept of operations was readily applied in circumstances where departure management was focused in individual route impacts. Several applications of RAPT to reopen closed routes or to

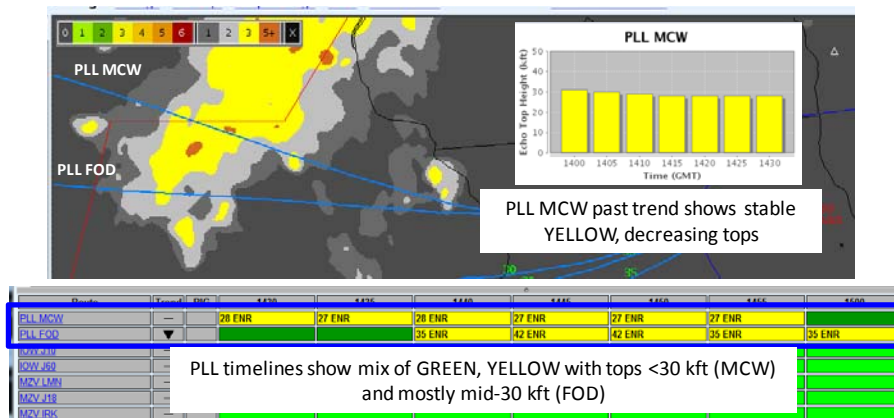
reduce restrictions on already open routes were observed. Table 2 and figures 15-18 present a list of observed RAPT applications, some of which were assisted by the observer.

Table 2 Observed RAPT uses during the 2010 evaluation.

Date	Time (Z)	Facility	Use	Figure
6 July	2039	C90	Situational awareness: managing restrictions on W gate departures	--
6 July	2215-2235	C90	Situational awareness: managing restrictions on E gate departures	--
6 July	1910	ZAU	Situational awareness: confirmation of area request for restrictions on W gate departures in response to deviations	--
6 July	2020	ZAU	Situational awareness: RAPT blockage trends on W gate departures, S gate track A (westernmost of S gate departures)	--
7 July	1415	ZAU	Avoided restrictions: Assessment of area warning (also based on RAPT) that restrictions may be needed on N gates; SWAP TMC used RAPT GREEN forecasts to keep N gates running without restriction	--
7 July	1430	ZAU	Route reopening: SWAP TMC used RAPT to convince area to reopen W PLL tracks as 1x20	15
7 July	1903	ZAU	Proactive reroute: Planned weather avoiding reroutes of W gate departures (MZV) to S gate track A	16
28 July	2006-2038	C90	Situational awareness: plan restrictions as severe impacts hit the S gate; look to reopen W gate departures over MZV to relieve S gate demand	--
28 July	1929	ZAU	Situational awareness: plan to reduce restrictions on E gate (DUFFE, EBAKE)	--
28 July	2020	ZAU	Route reopening: reopen W gate (MZV) to westbound, rerouted southbound departures in 10 minutes (also a missed opportunity – could have been done sooner)	--
1 Sept	1120	ZAU	Route reopening: S gate tracks D, E reopened, restrictions on C reduced to 7 MIT	17
2 Sept	1952	ORD	Situational awareness: ‘push from the bottom’ as ORD calls ZAU to requested reduction of restrictions on E gate departures based on RAPT guidance	18

2010/07/07

RAPT, 15 minute forecast at 1430Z



Traffic, weather at 1533Z

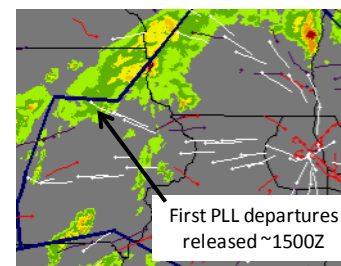
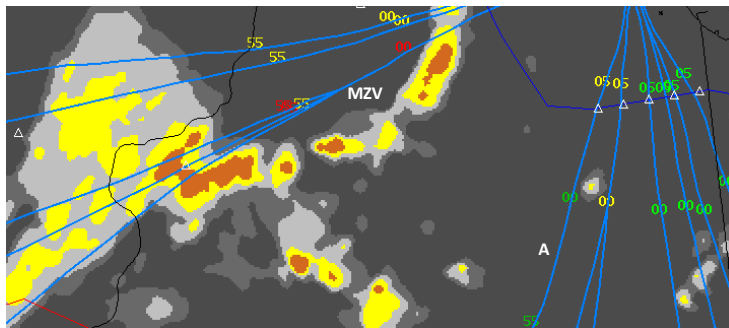
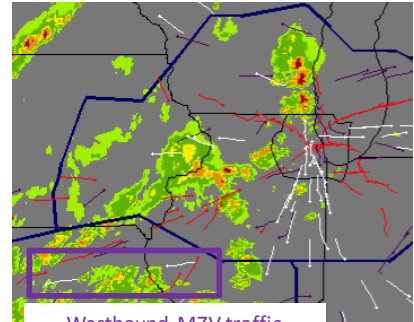


Figure 15 Use of RAPT on July 7, 2010 to reopen west gate (PLL tracks) departures.

2010/07/07

RAPT, 15 minute forecast at 1855Z**Traffic, weather at 1945Z**

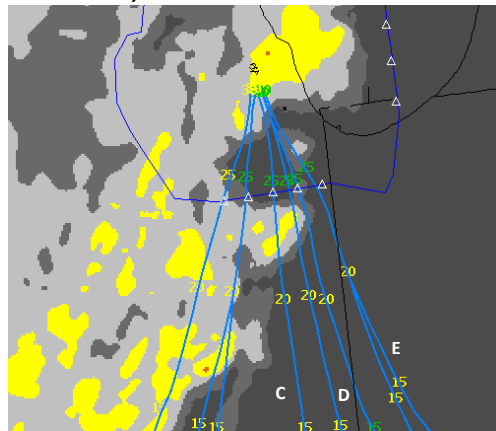
Westbound MZV traffic
rerouted onto south gate A
track (started ~1900Z)

[illegible]

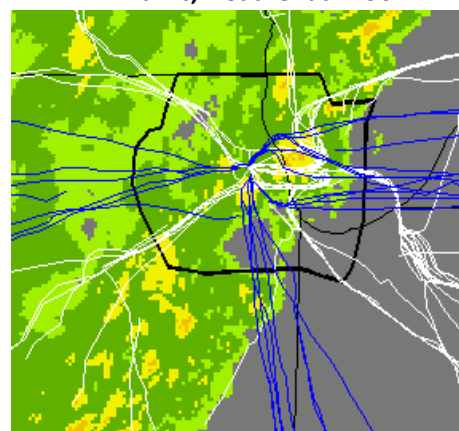
West gate departure tracks through MZV fix nearly 'dead RED'

Figure 16 Use of RAPT on July 7, 2010 to plan proactive weather-avoiding reroutes from west gate to south gate.

2010/09/01

RAPT, 15 minute forecast at 1115Z

Traffic, weather at 1130Z



C flow increased, D, E traffic resumed ~1120Z

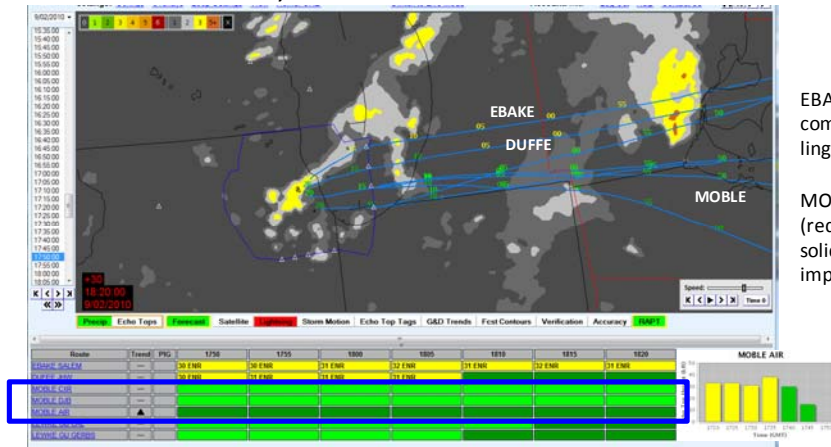
Route	Trend	PIG	1115	1120	1125	1130	1135	1140	1145
ACIO STL	—	38	34	34	32	34	32	32	
BAGEN FAM	—	28	28		29	30	31	31	
DEBENT DUMGE	—	29	29		29	29	31	31	
DEBENT DUMGE	▲	29	33						
DEBENT DUMGE	▲	29	29						
DEBENT DUMGE	▲	29	29						
EARNBU	▲	28	29						
EARNBU	▲	28	29						

C, D, E tracks all show improvement from low-topped YELLOW to GREEN

Figure 17 Use of RAPT on September 1, 2010 to reopen south gate departure tracks.

2010/09/02

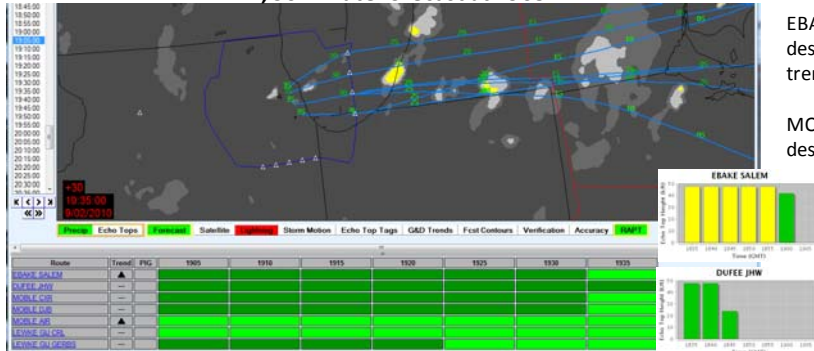
RAPT, 30 minute forecast at 1750Z



EBAKE / DUFFE running 1x7, matching RAPT combination of YELLOW and GREEN with lingering high tops

MOBLE running with a 15 MIT restriction (reduced to 10 MIT at 1827Z), excessive given solid RAPT GREEN on MOBLE routes and rapidly improving impact trend

RAPT, 30 minute forecast at 1905Z



EBAKE / DUFFE restriction remains in place, despite solid RAPT GREEN and rapidly improving trends on both routes

MOBLE still running with a 10 MIT restriction, despite solid RAPT GREEN

EBAKE, DUFFE, MOBLE restrictions finally reduced to 10 MIT on each at 1957Z

Figure 19 Missed opportunity to reduce restrictions and reopen departure routes on east gate.

The use of RAPT in making gate management decisions requires sufficient experience with RAPT to match timeline patterns to complex gate management operations that involve merging and vectoring traffic flows. While this is possible (traffic managers are masters of complex pattern recognition!) and has been observed among experienced users in New York, this mode of use makes significant cognitive demands on the user, particularly if one tries to consider trends in timeline patterns. These cognitive demands could be greatly reduced by the provision of 'gate blockage' forecast and trend information, based on a combination of automated trajectory identification algorithms (Krozel, et. al., 2004), adapted to the specific departure airspace and the RAPT route blockage algorithm (Martin, 2007).

Users regarded RAPT with a level of professional skepticism appropriate for the introduction of a brand new tool. Traffic managers generally took note of RAPT status (or were willing to do so when asked by observers) when decisions were being considered or made, occasionally made decisions based on RAPT guidance at the suggestion of the observer, and eventually used RAPT in a few decisions without

suggestion from the observer. No RAPT-based decisions were rescinded, perhaps an indication that users were applying RAPT in low risk situations, where there appeared to be a high probability of success (again, perfectly appropriate behavior often observed in New York field evaluations; see Robinson et. al., 2009). Users in C90 and ORD tower tended to view RAPT less as an active decision support tool and more as enhanced situational awareness; however, as ORD tower is already accustomed to making specific requests for reduced restrictions to ZAU, it is a reasonable expectation that ORD tower will use RAPT guidance to become more proactive in making their requests. Given the high degree of coordination among Chicago facilities, the ability to formulate and implement plans quickly, and the strong focus on ORD, the potential for proactive decision making and departure delay reduction using RAPT is great and can readily be realized if users are given the follow-up training needed to develop confidence and experience with RAPT. Finally, it is clear that traffic managers would benefit from follow on training that highlights observed and potential opportunities for RAPT use, and the positive outcomes that result from RAPT-based decisions.

6. CONCLUSIONS AND FUTURE WORK

A RAPT prototype was deployed to Chicago in the summer of 2010. A field study was carried out to evaluate the applicability of the RAPT concept of operations and the ability to site-adapt RAPT to a typical cornerpost airspace very different from the New York airspace for which RAPT was developed. Observers were deployed to ZAU, C90, and ORD tower for three SWAP events (over five days of operations), characterized by a wide variety of weather impacts. The study included an analysis of departure management operations, a qualitative analysis of the operational accuracy of RAPT guidance, forecasts and site adaptation, RAPT use, and the applicability of the RAPT concept of operations to Chicago departure management. Quantitative statistics such as departure rates as a function of RAPT color (as in Robinson, et. al., 2009) and post-PIG performance (Underhill, et. al., 2010) were not available for this analysis. Additional work is needed to adapt the analysis algorithms for the Chicago airspace.

The Chicago airspace differs markedly from New York's, and departure management operations reflect that difference. The majority of route management decisions are made in ZAU and focused primarily on the needs of ORD. The influence of a single dominant airport and the flexibility of the cornerpost structure enables a flexible departure 'gate management' strategy, in which departure flows out a single gate may be merged into one or more traffic streams that are vectored to avoid weather, and then returned to their planned routes once the weather is cleared. (Traffic flow merging is also employed in New York, but less frequently and on a smaller scale.) RAPT guidance can be readily adapted to this mode of use by experienced users, but the potential benefits from RAPT use in gate management operations could be increased significantly with the addition of a gate blockage forecast enhancement that is specifically focused on gate management decision making. This enhancement could be based on the adaptation of automated trajectory identification algorithms already developed to the Chicago airspace, combined with the existing RAPT blockage algorithm.

Individual route management, similar to that employed in New York, is also widely employed in Chicago departure management operations, and the RAPT concept of operation applies readily, with no further adaptation. The site adaptation and RAPT algorithm were well suited to operations and RAPT guidance should be as applicable to decision making in Chicago as it was in New York. The tendency of RAPT to over-warn during weather impacts in the TRACON should be addressed through training and adjustments to the site adaption. However, given difficulties observed in both New York and Chicago when weather impacts are primarily in the TRACON, further research is needed to improve RAPT models of TRACON operations.

7. REFERENCES

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