SEVERE WEATHER AVOIDANCE PROGRAM PERFORMANCE METRICS FOR NEW YORK DEPARTURE OPERATIONS*

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1. INTRODUCTION

When operationally significant weather affects the National Airspace System (NAS) a Severe Weather Avoidance Program (SWAP) is initiated. Each SWAP event is a unique mix of demand, weather conditions, traffic flow management (TFM) initiatives and traffic movement. Following a SWAP, the day's events are reviewed and the TFM initiatives used are evaluated to understand their impact on the traffic flows, benefits, and disadvantages. These analyses require an accurate representation of the conditions during SWAP and objective, data-driven metrics to determine the effectiveness of the implemented TFM initiatives, and to identify opportunities for improved decision making in future events.

As part of the ongoing development and evaluation of the Route Availability Planning Tool (RAPT) [1], a departure management decision support prototype currently deployed in New York, several detailed metrics were developed to streamline these analyses. This paper focuses on metrics that address the most significant concern regarding departure flows from New York airports: the timely reopening of departure routes that have been closed due to convective weather impacts. These metrics are derived from two datasets: flight tracks from the Enhanced Traffic Management System (ETMS) to monitor the flight traffic, and route blockage from the Route Availability Planning Tool (RAPT) to determine the impact of weather on routes.

RAPT automatically identifies Post-Impact-GREENs (PIGs) - the period of time when routes are clear ('GREEN') after being blocked by convective weather. Identifying PIGs early is a key element of the RAPT concept of operations, which enables traffic managers to restart traffic flow sooner along these routes, alleviating backed up ground conditions and reducing delay times for waiting flights [2]. An automated system, that correlates PIGs identified by RAPT with departure traffic flows, calculates both the time from the appearance of each PIG until the first departure along the PIG route, and the departure rate on the route during the PIG period. Short times to first departure and high departure rates during PIGs indicate efficient departure management during SWAP. These can sometimes be misleading, however, due to other factors negatively impacting the departures coming out of the New York Metro. Despite clearing weather, the traffic patterns of arriving aircraft can limit or stop departure operations, particularly in cases of deviating arrival planes, and surges in arrival rates.

Arrival aircraft deviating into departure airspace are often managed by closing nearby departure routes until the danger from incurring flights has passed. Arrival incursions are sometimes recorded in the National Traffic Management Log (NTML), but the extent to which the deviations occur is unmeasured. Lack of details regarding deviations limits evaluation of implemented responses and alternative actions. New algorithms comparing clear weather vs. SWAP traffic flows enables the locations and durations of incursions to be identified. Exact figures detailing incursions allows for thorough review as well as recognition of areas of frequent incursions and the potential for developing a targeted response for like situations.

Full flight tracks of arriving and departing flights provide significant insight into the status of the NAS. During SWAP when the airspace capacity is decreased and airport operation rates are limited, airborne aircraft by protocol receive priority. Arrival numbers can completely dominate operations at these times both in the air and on the ground, draining the resources available for departures in particular flows or for an entire region. To convey cases where departure infrequency results from these conditions, arrival and departure counts grouped according to

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direction of travel are calculated on an hourly basis.

Results from the automated analysis are made available on the RAPT Evaluation and Post Event Analysis Tool (REPEAT) website by 7AM ET for the FAA Northeast tactical review teleconferences, and are being tracked over the convective season for further analysis of operational performance. This paper will present the techniques used in the automated system and initial results from the analysis of operational data.

In the US, no air traffic route is unsusceptible to weather. Even with hours of advance warning and precautionary measures, sudden and unexpected events will likely occur in the form of anything from deviating planes to unpredicted weather patterns. To attain scheduled departure and arrival rates, various Traffic Flow Management (TFM) initiatives are utilized to mitigate these factors and ensure steady traffic flows to and from the airports. The ability of these TFM initiatives to achieve required flow rates, while accommodating weather and other factors, can be significantly improved if Air Traffic Managers (ATM) have the information they need to plan best-fit TFM programs at the onset of operationally significant conditions.

In order to improve traffic flow management during SWAP, post event analysis is conducted on a next-day basis following every severe weather event. Departure throughput is evaluated in terms of its effectiveness, its contributions, and its costs in terms of operations. These evaluations require detailed study of departure and arrival flows as well as other impacting factors that were present throughout the SWAP in order to accurately assess the influences of implemented TFM initiatives and effectiveness of departure management tactics on air traffic throughput.

As part of an ongoing evaluation of RAPT, multiple performance metrics were developed in order to study departure management efficiency during SWAP. These metrics focus on the timely reopening of major departure routes from the New York Metro airports after weather impacts (figure 1). These metrics produce data-driven analyses for evaluating flight traffic throughout the SWAP event as well as pinpointing particular instances of post weather route reopening that occurred throughout the day. These automated processes enable specific investigative analyses to be performed faster and in an objective manner throughout the SWAP season making possible accurate self-assessment that invariably results in better decision-making during SWAP events, increased traffic flows, and reduced operational delays.

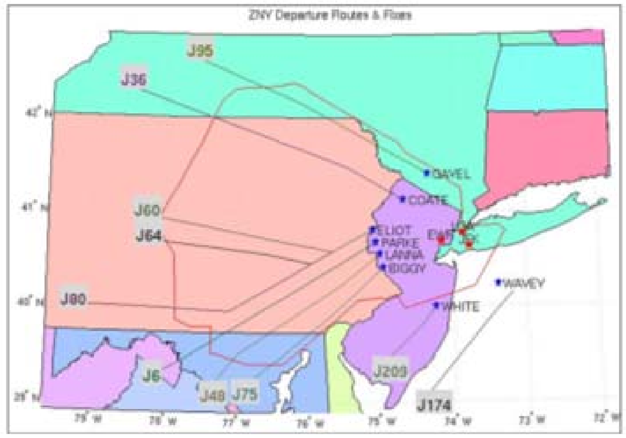

Figure 1: Major NY Metro departure fixes and departure jet routes.

2. POST IMPACT GREEN ROUTE REOPENING

In high traffic areas of the National Airspace System (NAS), airspace is a valuable resource, and convective weather reduces usable airspace that Air Traffic Controllers (ATC) need to maintain plane separation. When airspace is restricted by weather conditions, the number of aircraft that ATC can support in an area decreases. This in turn reduces the number of aircraft that ATC can accept into their airspace, which generates delays for waiting flights that could not be supported on schedule due to the limited airspace capacity. When controllers fear that they can no longer maintain safe separation between aircraft or ensure safe passage of aircraft on a particular route, that route may be closed to traffic until the weather clears. With accumulated delays due to impacted and closed routes, efficient operations are critical to prevent further backup and to alleviate conditions safely and quickly. To that end, recognizing and exploiting periods of clear weather during a SWAP can curb the rate of growing delays and jump start operations to resume their normal rates. As time is the key factor here, the speed with which clearing weather is recognized and proactively prepared for directly affects the time at which the NAS returns to its optimal state. During SWAP, even small advances in the timeliness of route reopening and rate increase can amount to significant delay reduction [3].

The REPEAT website provides a number of playback movies and analyses that show the weather's progression across time with the status of aircraft traveling through the area and the RAPT status associated with the displayed weather as well. Analyses range from detailed accounts of departure traffic on specific routes to overall summaries of traffic volume for all of the ARTCC arrival and departure gates. Calculations for these various analyses begin at Midnight following the arrival of the last of the day's Enhanced Traffic Management System (ETMS) and RAPT data. Analyses are automatically uploaded onto the REPEAT website prior to 7AM Eastern Time the following morning. Comments based on analysts' reviews of the automated results may be added to the web site during the following day, where appropriate.

A key focus is the Post Impact Green (PIG) analysis. PIGs occur when the weather clears after operationally significant weather impacts result in a route closure. These periods are key indicators of the efficiency of NAS operations due to the opportunity for route reopenings during them.

We define PIGs from the RAPT blockage status (RED, YELLOW, DARK GREEN, GREEN), which automatically identifies the weather impact on specific routes by departure times. RAPT RED and GREEN status have been shown to correlate well with route departure rates and operational impacts of convective weather [2]. The RAPT display shows seven consecutive blockage forecasts for a particular route-fix combination as a row of bars, with the leftmost bar being the departure blockage for the current five minute period and the rightmost bar the blockage status for a departure thirty minutes in the future.

By RAPT blockage definitions, PIGs occur when there is an 'impact' in which, of the seven forecast bars, at least three of the bars are **RED** or there is one **RED** bar with three **RED** and/or **YELLOW** bars…

followed by **clearing weather…**

followed by at least one hour of **GREEN** or **DARK GREEN**.

The PIG definitions of impact and weather clearing reflect a conservative assessment of what may be achieved in departure management during convective weather impacts. For a PIG to qualify there has to be severe enough weather that there is a realistically high chance that traffic along a route would be stopped, as well as a long enough period of undisturbed clear weather after the impact to provide opportunity for full route reopening. If there is insufficient convection there is no PIG because the route is not 'impacted' enough to warrant a route closure and a subsequent reopening. Similarly if there is not a long enough clear weather period following the impact, ATM may not have sufficient time to plan and execute the route reopening. These criteria ensure that automatically identified PIGs follow severe impacts and that the PIG time period is sufficiently long and clear for ATM to take action.

The REPEAT PIG analyses enable the quick identification of viable PIGs and the means to start an in depth study of the operations and situation that particular PIGs occur, as well as highlighting what actions if any could have improved the usefulness of the PIG. The PIG analyses focus specifically on modeling and analyzing two aspects of operations during PIGs that directly affect departure delay accumulations: reopening delay and route rates following a route reopening.

On routes that typically experience high traffic rates even small delays in reopening can result in the loss of departure opportunities for flights. In terms of operations, the delay for reopening is multiplied by the number of planes on the ground waiting to use that route. Once a PIG is identified from the RAPT status, the PIG analysis finds the first departure flight along the route after the PIG appeared. ETMS latitude and longitude coordinates for each flight are calculated against route coordinates and each flight is designated with the departure route that has the closest geographical proximity to its observed trajectory.

Departure rates on PIG routes are evaluated using departure counts for three sequential hours after the weather clears. Through examination of these results we can tell how quickly a weather impacted route was reopened, and how efficiently the route's traffic was able to start up and return to normal levels. Ideally the reopening would happen immediately within 5-10 minutes of the weather clearing, and then a departure flow equal to if not greater than normal traffic flows would commence and remain constant to quickly relieve pent-up departure demand.

The REPEAT web site presents the PIG analyses in two ways: the 'departure route summary' and the PIG summary table.

The departure route summary provides a detailed layout of each departure route with the route's specific weather and traffic patterns for a single day (Figure 2):

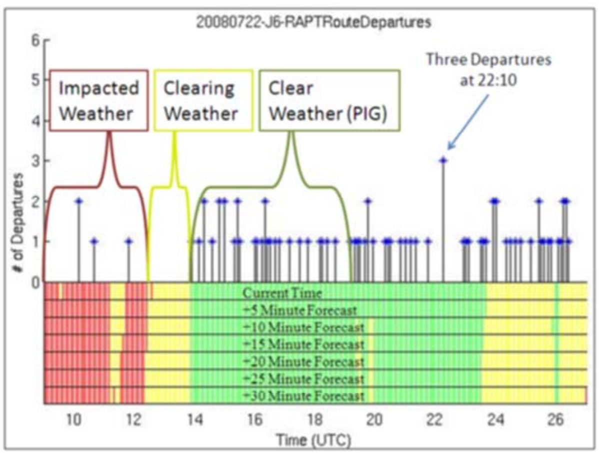

Figure 2: The departure route summary table for J6 on July 22, 2008.

RAPT: At the bottom of the analyses are the RAPT blockage timelines. Each vertical column is the RAPT display for that departure route at the time on the x-axis with the topmost block being the blockage for the current 5 minute departure bin, the 2nd to the top being the blockage for a departure 5 minutes into the future and the bottommost block the blockage forecast for a departure 30 minutes in the future.

DEPARTURES: On top of the RAPT blockage timelines are vertical star-capped lines which denote the number of aircraft that departed during that particular 5 minute bin on the x-axis. The number of departures during a particular 5 minute bin determines the height of the line. The scale on the left hand side of the table denotes the number of departures in the vertical departure lines.

From the departure route summary, we can quickly see the progression of RAPT timelines throughout the day, and the exact sequence of departing flights that flew that route. These detailed analyses give us specific indications of the severity and duration of weather impacts, the length of PIG periods, the time of post-impact route reopenings, and the departure throughput during each of these periods.

The PIG summary table is illustrated in Figure 3.

Route 20090728	PIG Start (UTC)	PIG End (UTC)	PIG Period (Min)	PIG TFD (Min) **=No Departure	Total Departures 0-1 Hour PIG	1-2 Hour PIG	2-3 Hour PIG	Total PIG Period
J95	2225	2525	180	5	5	8	7	20
J36	2225	2525	180	0	15	11	7	33
WHITE								
WAVEY								
J60								
J64								
J80								
J6	2205	2340	95	10	4	6	n/a	10
J48	2205	2340	95	15	2	2	n/a	4
J75								
RBV-J60	2225	2525	180	100	0	2	1	3
RBV-J64	2225	2525	180	15	2	2	2	6
RBV-J80	2225	2525	180	5	4	4	3	11
RBV-J6	2225	2525	180	0	2	4	5	11
RBV-J48	2225	2525	180	150	0	0	1	1
RBV-J75	2225	2415	110	0	1	3	n/a	4

Figure 3: The PIG summary table for July 28, 2009.

Route: the jet route that the particular weather blocked and the traffic that used it.

PIG Start (UTC): time when the weather cleared to a GREEN status on RAPT (rounded to 5 minute intervals).

PIG END (UTC): the start of the five minute interval during which the route was again affected by operationally significant weather or three hours after the weather cleared (no weather impact).

PIG Period (Min): The duration of the clear weather (GREEN) period, up to three hours.

PIG TFD (MIN): The PIG Time of First Departure - the difference in minutes between the weather clearing the route and the first flight departing on that route.

**=No Departure: if there were no flights within the duration of the PIG a double asterisk is used to indicate a complete lack of flights.

Total Departures: For each hourly interval following the clearing of the weather, the number of flights that departed using that route, and the total number of flights that departed for that route during the entire duration of the PIG

These charts work as an at-a-glance summary of the performance during the day through evaluation of PIGs along the major departure routes supported by RAPT. Key information provided for each PIG includes the start time, end time, duration, the time difference between the weather clearing and the first departure, and the departure counts at hourly intervals as well as the total number of departures that took off for the duration of the PIG up to three hours.

From this chart (Figure 4) we can tell:

Route 20090728	PIG Start (UTC)	PIG End (UTC)	PIG Period (Min)	PIG TFD (Min) **=No Departure	Total Departures 0-1 Hour PIG	1-2 Hour PIG	2-3 Hour PIG	Total PIG Period
J95	2225	2525	180	5	5	8	7	20
J36	2225	2525	180	0	15	11	7	33
WHITE								
WAVEY								
J60								
J64								
J80								
J6	2205	2340	95	10	4	6	n/a	10
J48	2205	2340	95	15	2	2	n/a	4
J75								
RBV-J60	2225	2525	180	100	0	2	1	3
RBV-J64	2225	2525	180	15	2	2	2	6
RBV-80	2225	2525	180	5	4	4	3	11
RBV-J6	2225	2525	180	0	2	4	5	11
RBV-J48	2225	2525	180	150	0	0	1	1
RBV-J75	2225	2415	110	0	1	3	n/a	4

Figure 4: The PIG summary table for July 28, 2009.

Route J36

- A flight departed within the same five minute interval during which the weather cleared
- An aggressive departure rate was maintained for two hours after the weather cleared
- The departure rate slowed slightly during the third hour of clear weather

Route RBV-J48

- Was clear for 150 minutes before a single plane took off.

JFK (JFK's routes consisting of the RBV routes, J95, J36 and WAVEY)

- All of JFK's routes excepting WAVEY cleared of weather at 2225

Despite RBV-J48's long TFD, all six RBV routes, and all of JFK's available routes but one cleared simultaneously, indicating that the lack of flights might be caused from reaching maximum operational limits at either the fix or the airport. With convective weather clearing there would likely be a surge of arrivals to the airport as well, increasing the possibility that the departure rate achieved by J48 was a result of operationally monopolizing rates of traffic elsewhere.

These analyses are done for every major RAPT jet route exiting the New York Metro area to provide a perspective of NY departure operations. The full set of these analyses together provides an overview of operationally significant weather impacts and the efficiency of departure management operations throughout the day.

3. USE OF PIG ANALYSIS IN EVALUATION OF DEPARTURE OPERATIONS

The following three examples illustrate how the PIG analysis is used to evaluate departure operations on a single departure route over the course of a SWAP day.

PIG Case #1: Efficient route reopening

The PIG summary table row illustrated in figure 5 shows a 3 hour PIG on departure route J6, starting at 1350 UTC. Looking at this first analysis reveals that traffic starts up quickly (within five minutes of the appearance of the PIG), and departures continue at a high rate throughout the duration of the PIG. This is ideal for a route reopening since the quick startup of traffic, and the maintained high departure rate provide quickly service pent up departure demand.

Route 20080722	PIG Start (UTC)	PIG End (UTC)	PIG Period (Min)	PIG TFD (Min) **=No Departure	Total Departures 0-1 Hour PIG	1-2 Hour PIG	2-3 Hour PIG	Total PIG Period
J6	1350	1650	180	5	5	8	8	21

Figure 5: The PIG summary table row for J6 on July 22, 2009.

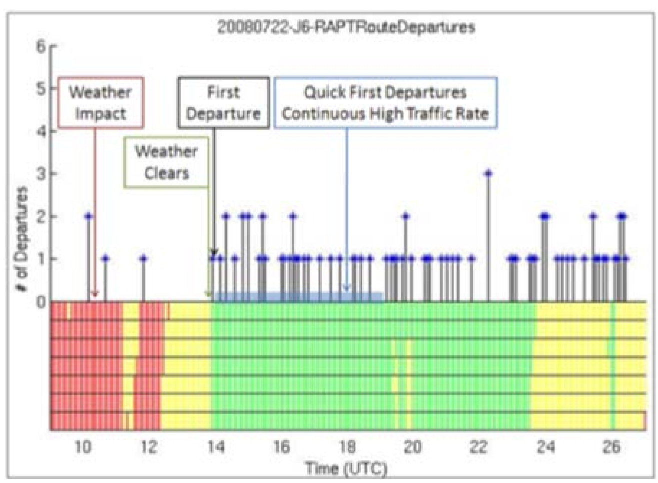

Figure 6: The departure route summary table for J6 on July 22, 2008.

From figure 6, the departure route summary, we get a sense of the weather impact influencing the event. The weather on this route and date was severe for a few hours before it diminished and then cleared at 13:50. During that five hour period, only four planes departed on the route. Around 23:45, less significant weather impacts the route (YELLOW), but doesn't have as much influence on the traffic flow as the first (RED) impact.

In this example the initial onset of weather early in the day may have motivated the quick route reopening due to awareness of increasing delay. The PIG was quickly recognized, and ATM efficiently organized and sent off a steady stream of departures using the newly available route. This PIG was used well, in terms of accommodating departure traffic when the weather cleared the route.

PIG Case #2: Slow response

Route 20080723	PIG Start (UTC)	PIG End (UTC)	PIG Period (Min)	PIG TFD (Min) **=No Departure	Total Departures			
					0-1 Hour PIG	1-2 Hour PIG	2-3 Hour PIG	Total PIG Period
WAVEY	1500	1800	180	30	2	3	3	8

Figure 7: PIG summary table row for WAVEY on July 23, 2008

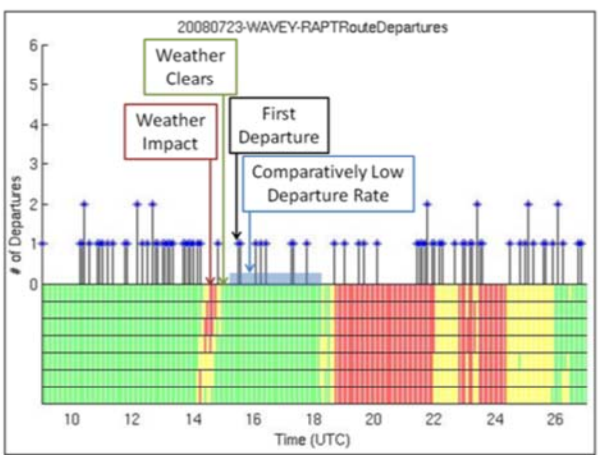

Figure 8: The departure route summary table for WAVEY on July 23, 2008.

In this PIG (illustrated in figures 7 and 8), the weather impact preceding the PIG is relatively short but the clear weather rate of traffic seems to be much heavier. Due to the heavier traffic rate, we could expect a little bit of buildup in regards to departure traffic – since during the short amount of time that weather was impacting the route a number of planes could have –and likely were scheduled to-take off. In this case, TFM may have been slow to recover route capacity after weather cleared.

Half an hour after the weather was clear the first departure takes off, only one other aircraft departs during that first hour, and then during each of the following two hours only three flights depart. The analysis graph (see Fig. 8) shows that the rate is far less than the clear weather rate the route was maintaining before the weather impact. In this instance both the startup of traffic and the rate of traffic could have been better managed in an effort to increase NY departure capacity.

PIG Case #3: Underutilization of PIG capacity

Route 20080810	PIG Start (UTC)	PIG End (UTC)	PIG Period (Min)	PIG TFD (Min) **=No Departure	Total Departures			
					0-1 Hour PIG	1-2 Hour PIG	2-3 Hour PIG	Total PIG Period
J36	2105	2405	180	5	3	0	14	17

Figure 9: PIG summary table row for J36 on August 10, 2008.

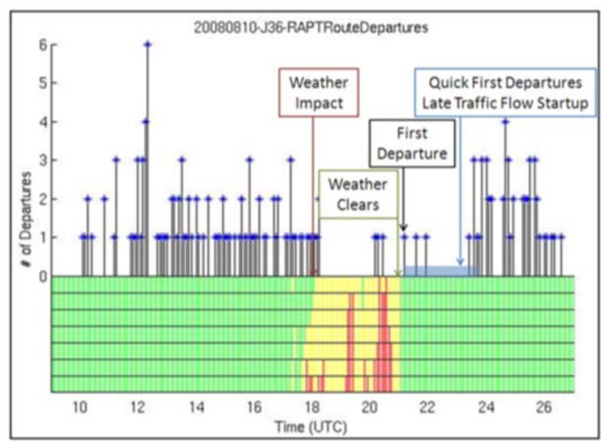

Figure 10: The departure route summary table for J36 on August 10, 2008.

In this case (figures 9 and 10), the route volume is quite high during the first half of the day, when the weather was clear. The weather impact extends for a period of three hours during which no departures took off. These two aspects indicate that a substantial amount of traffic would likely be waiting to depart by the end of the weather impact.

However, despite the prompt release of several flights soon after the weather clears the route, the open route is underutilized - with only three flights departing in the first hour of the PIG. No flights departed on the route during the second hour of clear weather. Traffic volume on the route only begins to climb back towards its rate capacity during the third hour of clear weather. The third hour helps put into perspective the lost potential of the first two hours through its departure count of 14 planes. This high rate indicates that significant pent-up demand could have taken advantage of PIG capacity in the first two hours of the PIG period.

PIG analyses also provide insights and potential evaluation of ATM procedures. One specific route reopening protocol, called a "pathfinder", requires a single flight to successfully fly a route without significant deviations before that route is to be declared clear for traffic. The downside of a pathfinder is that if the flight is successful then the time between the departure of the pathfinder and the flight's reported success could have been used for departures. The time it takes for the pathfinder to clear the weather and then for the next plane to get into the air is a significant lost opportunity for traffic [2].

The PIG analysis illustrated in figure 11 shows two instances of pathfinders used to probe the route. The first pathfinder departed during YELLOW blockage, just before the weather cleared and was unsuccessful. An hour after the first pathfinder departed another pathfinder was approved and departed, by now the route had shown clear weather for fifty minutes. This pathfinder, having taken off well after the weather cleared, was successful. The time however between this second pathfinder's departure and the subsequent opening of the route was over an hour. The clear weather departure times that the first pathfinder postponed by departing while the weather was still impacting the route were also lost opportunities for traffic which makes for a potential route opening time delay of almost two hours.

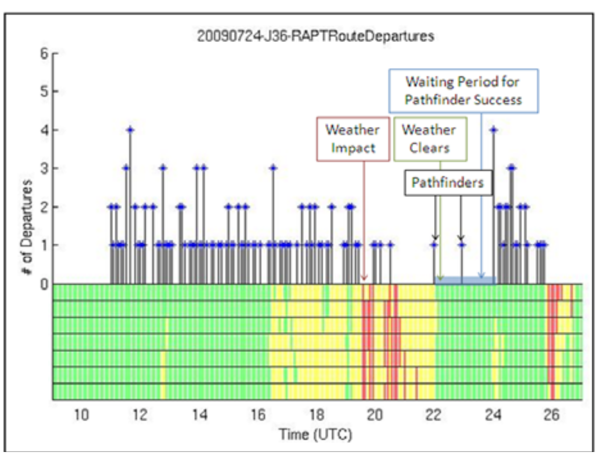

Figure 11: The departure route summary table for J36 on July 24, 2009.

Another study that these metrics are used for is to determine the improvement of TFM efficiency through the SWAP season [2]. The development of traffic coordination and situational awareness over the convective weather season as controllers become more adept at identifying and exploiting traffic opportunities is also assessable. As ATC become more comfortable with the convective weather season, they become more adept at recognizing and exploiting potential for departure flows, releasing departure flights more quickly than they may have earlier in the season. Through use of the route metrics, individual routes can be compared across the season to determine TFM improvements in utilizing PIG opportunities. Diminishing times between route clearings and resumption of standard traffic rates over a season would indicate acclimatization of controllers to the convective weather and an increase of their ability to assess and coordinate traffic in response to ongoing conditions.

In a similar manner Traffic Managers have used PIG analyses the morning following SWAP events to get an overview of the previous day's weather and traffic movement over the jet routes and to evaluate the impact of specific departure management tactics during that time. Data-driven metrics provide a statistical basis on which to appraise TFM and assess situations for potential improvements. Details of instances of proactive SWAP management are evaluated to determine and create better practices that can be incorporated into common use. Evidence of cases of missed opportunities are also studied and used as training material to improve TFM response in future situations. Besides TFM evaluation, these statistics are also used to validate RAPT operational forecasts by checking that RAPT forecast scores accurately depict the blockage based on the observed weather.

Finally, these metrics also enable deeper probing into the specific underlying factors of traffic flow and various departure management circumstances. Data analysis for events when multiple routes are impacted compared to events with a single impacted route can reveal whether multiple PIGs instigate timelier route reopenings and increased departure rates. The PIG analysis may also be used to determine if air traffic managers are more aggressive in responding to PIG opportunities during high demand periods (typically early morning or late afternoon).

4. ARRIVAL INCURSIONS

PIG metrics and the REPEAT visualizations reveal many different aspects of a SWAP by correlating weather impacts with observed departure traffic. However, other aspects of the NAS must also be taken into consideration to fully understand the situation since slow or delayed reopening of routes is sometimes the result of other circumstance that make the route unavailable or unsafe for flying. In order to determine the authenticity of PIGs, it is important to know if any other underlying factors are influencing traffic that would directly affect route usage. To ensure the validity of a PIG, additional operational factors must be considered to rule out other possible explanations for traffic behavior. One of the most severe of these influencing factors is when arriving aircraft deviate out of their airspace and into departure route airspace [2].

Arrival incursions can cause a departure route to be shut as soon as they are detected. While weather deviations can induce such programs as a “two-as-one” route usage or the implementation of miles in trail (MIT) restrictions, the danger of spacing issues between oncoming aircraft almost always translates into the closing of a route. Arrivals get priority because comparatively it is much easier to stop a departure flow by preventing takeoffs than trying to indefinitely coordinate arriving planes through holding or rerouting. Arrival flights also have nonnegotiable delay limits; they will land within the boundaries of their available fuel – available runway or not, whereas departing flights can be held back for any desired length of time, giving greater flexibility without the sacrifice of safety if the closure needs to be extended. Understanding where and when arrival incursions occur is important not only to validate PIG-based operational evaluations, but also to support research leading to the inclusion of arrival incursion prediction into integrated arrival / departure management decision support.

An automated algorithm was developed to identify arriving aircraft that deviated into departure airspace. Departing flight trajectories from four days without operationally significant weather were combined to make three-dimensional maps of nominal departure flows, broken down by latitude, longitude and altitude. After outliers were removed, the remaining trajectories were used to define the boundaries of standard departure flows (figure 12). The same process is carried out to map arrival airspace and the overlapping regions between the two maps are removed from the departure map in order to accommodate areas sometimes utilized by both arrivals and departures. What remains then is the three-dimensional airspace specific to departures only. When the trajectory of an arrival flight enters the departure airspace for a period of time, it is deemed to have ‘incurred’ into the departure airspace.

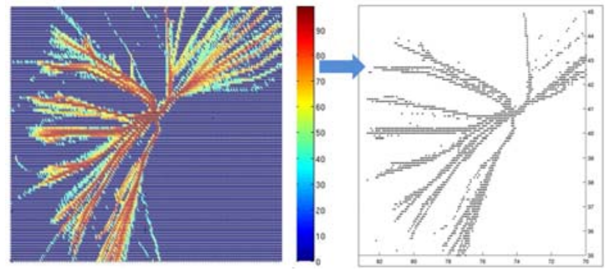

Figure 12: Main route boundary definitions extracted from departure flow trajectories.

Figures 13 and 14 illustrate two arrival incursions, overlaid on the New York departure airspace (black pixels). Green and red pixels indicate the trajectory of the arriving aircraft, with the red pixels indicating portions of the arrival trajectory that deviate into departure airspace. In this illustration, only a portion of the overlapping arrival trajectory represents an incursion; the green portion of the overlapping arrival trajectory traverses altitudes that are not part of the departure airspace.

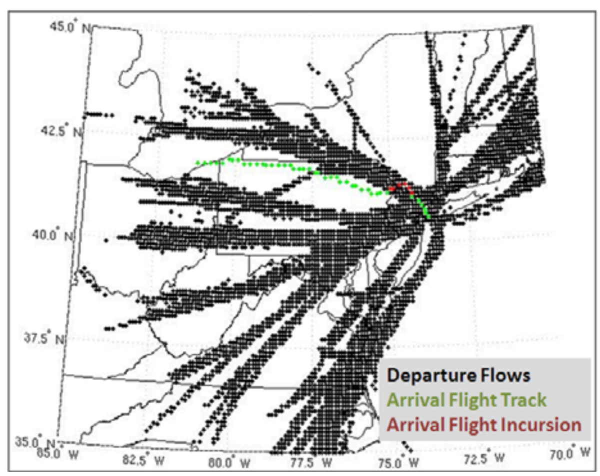

Figure 13: An arrival incursion visual showing flight track and incursion.

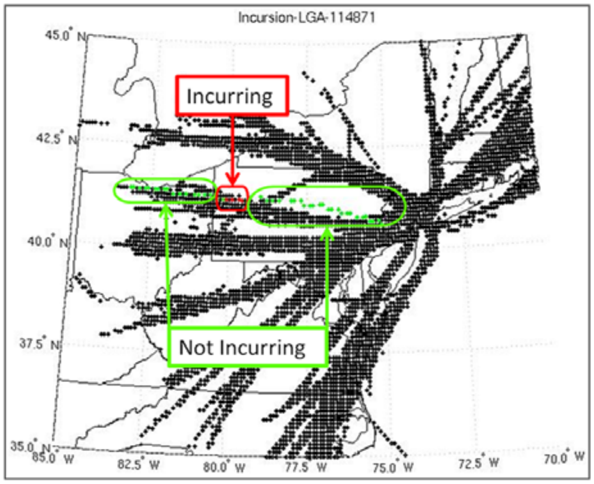

Figure 14: An arrival incursion visual showing flight track and incursion.

Automatically generated summaries of arrival incursions for each day identify the location, time, duration, and extent of arrival deviations into departure airspace (figure 15). Such information supports PIG validation, and can provide insight into the impacts of arrival incursions on departure management. Analysis of operational response to arrival incursions may identify airspace 'hot spots' where air traffic control is particularly sensitive to arrival incursions, or differentiate 'manageable' incursions from 'severe' incursions that necessitate the closure of neighboring departure airspace. Such insights are necessary to support advances in decision support.

20090613 Arr. Apt	ETMS Flight id.	Start tm	End tm	Total tm
JFK	567169	15.9667	16.1667	13
JFK	567173	16.06	16.2333	12
LGA	569668	18	18.1333	9
JFK	571324	17.8333	18.0333	13
LGA	572467	18.1333	18.2333	7
LGA	572537	18.2833	18.4333	10
EWR	572691	18.4833	18.55	5
LGA	575362	17.9333	18.0167	6
LGA	576452	18.7167	18.8	6
LGA	576691	18.5167	18.6	6
LGA	576916	19.0833	19.1667	6
LGA	578497	18.6333	18.75	8
LGA	580538	19.25	19.3167	5
LGA	584214	21.0333	21.1333	7
JFK	587026	21.1667	21.2333	5

Figure 15: An arrival incursion summary table for June 13, 2009.

5. AGGREGATE ARRIVAL AND DEPARTURE RATES

An accurate assessment of the efficiency of route openings and closings must be considered in the context of overall TRACON operations. For instance, surges in arrival demand can stifle departure rates, even if individual departure routes are open and departure demand exists, because the majority of total available operational capacity for the TRACON or airports is needed to service arrivals. During SWAP this precedence becomes even more pronounced when operational airspace is decreased and typical traffic rates are unsustainable causing standard rates of arrival to induce growing departure delays as departure availability is unable to accommodate demand. These cutbacks can happen at the airport level concerning runway availability or from the TRACON or Center because of diminished airspace capacity or workload capability

Recognition of periods where arrivals monopolize operations is important as they can be the main mitigating factor reducing departures and constraining conditions in circumstances which may be mistaken for missed opportunities to increase departure throughput. These are particularly significant during a PIG period, when clearing weather opens the jet ways for safe travel, since this may simultaneously provide an opportunity for waiting airborne arrival traffic to reach the airports. In these cases, the need to service pent-up arrival demand may make it impossible to resume departure operations until well into the PIG period. In these circumstances, the resulting late departures startup times on PIG routes could falsely imply inefficient route reopenings.

In order to capture possible capacity issues, an analysis was developed to assign observed arrivals and departures in terms of the New York flows (or gates, in the New York TRACON nomenclature) in the RAPT domain. RAPT departure gates are northbound (J95, J36), westbound (J60, J64, J80, J6) and southbound (J48, J75, J209, J174), and for arrivals the gates are eastbound (J70, J584, J146, J51) and northbound (J42, J191, J121). The Arrival and Departure Summary Chart (figure 16) on the REPEAT web site provides a summary of thirty minute arrival / departure counts by gate, along with RAPT weather impacts.

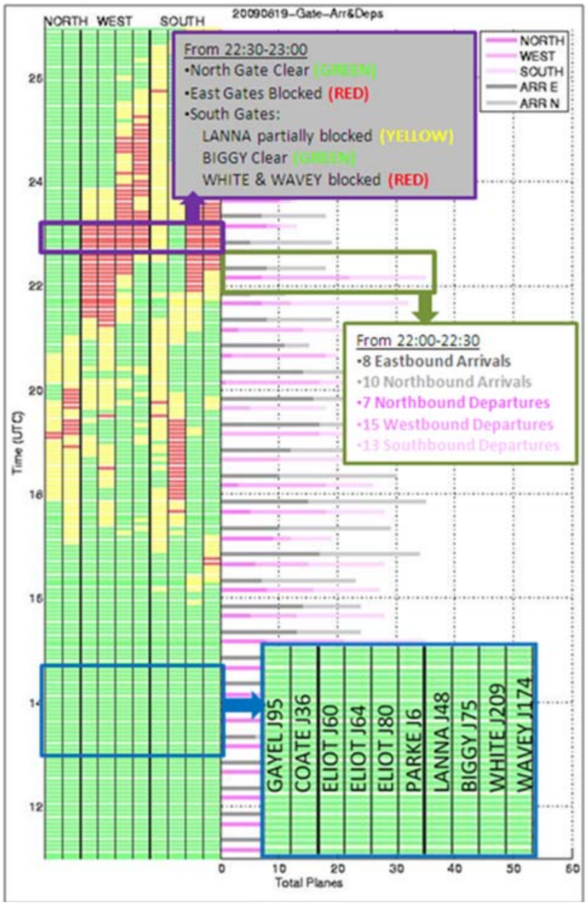

Figure 16: The Arrival and Departure summary chart of August 19, 2009 with detail breakdown.

The increase and decrease of arrivals compared to departures and the effect of weather on overall traffic are easily identifiable over the course of the day through comparison of adjacent bars. For instance, one can see the diminishing of North gate departure traffic as weather impacts GAYEL J95 and COATE J36 at 18:00 UTC (figure 17). There are five northbound departures from the 17:30 period, then three at 18:00, and then for the next 1.5 hours (18:30 to 20:00) there are no departures while weather fully covers the two north routes.

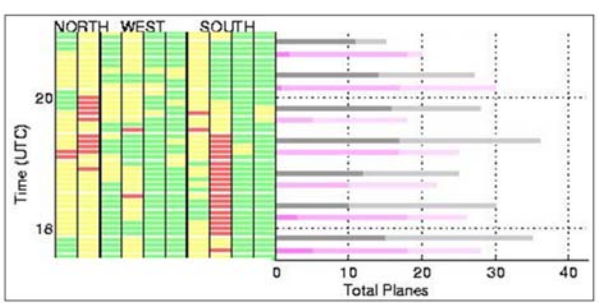

Figure 17: The Arrival and Departure Summary chart from 18:00 UTC to 21:00 on August 19, 2009.

Figure 18 illustrates the interaction between arrival demand and departure capacity. The main weather impact for ELIOT J60 and ELIOT J64 of the westbound departure routes clears just before 24:00 UTC time. However, this also indicates that the adjacent eastbound arrivals also have a clear path in regards to weather. A close look at the traffic for the 24:00 to 24:30 period immediately following the clearing weather shows that westbound departures increased from two to four aircraft, but eastbound arrivals increased from five to thirteen aircraft. The next thirty minutes showed that eight flights departed and eleven arrivals traversed the area - a much more balanced mix. This analysis indicates that, although departure throughput during the first hour of clearing weather appears low, air traffic management efficiently addressed the more pressing arrival demand first, and restarted departure flows as quickly as circumstances allowed. Such analysis of weather impacts and throughput on tightly-coupled, adjacent traffic flows can provide insights needed to model and predict weather-impacted capacity for integrated arrival / departure decision support.

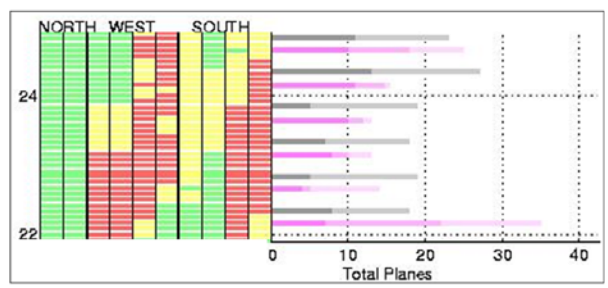

Figure 18: The Arrival and Departure Summary chart from 22:00 UTC on August 19, 2009 to 1:00 August 20, 2009

6. CONCLUSION

During convective weather SWAP events, when airspace is restricted by weather and routes cannot fully accommodate traffic demand, operational efficiency is critical to ensure safe and sustainable traffic patterns. To improve and expand upon current practices, objective metrics and data analysis are necessary in order to compare and contrast the relative success of traffic management tactics and procedures. These metrics may be used to evaluate the validity and effectiveness of specific decision support tools, and to analyze the efficiency of operations during SWAP. Instances of successful proactive management and lost potential can be identified, from which researchers, managers, and practitioners can determine 'best practices' and pinpoint areas for improvement. This paper presented metrics and data analyses developed to support the evaluation of the effectiveness of the Route Availability Planning Tool (RAPT) and the efficiency of departure operations in New York.

One specific measurement of efficiency is the recuperation of departure traffic flows following a route clearing of weather (i.e., a Post-Impact GREEN (PIG), when RAPT route status changes from RED to GREEN). The efficiency and situational awareness of the TFM can be measured by the time it takes to reopen closed departure routes after the appearance of a PIG, and by the number of departures on the route during the recovery period when pent-up departure demand can be released. This paper presented an automated analysis that identifies PIGs, calculates time to first departure and traffic counts during PIG periods, and presents PIG-related metrics on a post-event analysis web site (REPEAT) by 7 AM the following morning.

To accurately interpret these metrics, however, other aspects ongoing during the SWAP must also be taken into account due to their influence on departure operations. Arrival traffic is one of the greatest influencing factors on departure operations, both in regards to the priority to handle arriving aircraft at the expense of departure operations as well as halts or restricted rates to departures should arrivals incur into departure airspace. To account for arrival impacts, information about arrival incursions such as where and when they occur are recorded to complement the PIG analyses and account for decreases or stops in departure traffic. Arrival traffic counts are also monitored throughout the day to address situations where departure traffic takes second priority to arrival operations. Used in coordination, these three analyses provide broad situational awareness of SWAP events as well as objective statistic based metrics for situation evaluation, measurement of operational effectiveness and ongoing program analysis and improvement.

7. REFERENCES

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