

ROUTE AVAILABILITY PLANNING TOOL EVALUATION VIZUALIZATIONS FOR THE NEW YORK AND CHICAGO DEPARTURE FLOWS[†]

Ngair Underhill¹
Richard DeLaura

Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA 02420

When operationally significant weather affects a region of the National Airspace System (NAS) a Severe Weather Avoidance Program (SWAP) is initiated for that region. Each SWAP event is a unique mix of demand, weather conditions, traffic flow management (TFM) initiatives and traffic movement. On the day following a SWAP, the SWAP events are reviewed by FAA and airline representatives as part of the daily planning teleconference, and the TFM initiatives used are evaluated to understand their impact on the traffic flows, benefits, and disadvantages. Due to the complexity of the situation various exploratory visualizations were designed in order to evaluate aspects of the aviation environment and the responsive actions of the NAS during outbreaks of convective weather as well as to gain insights on the interaction of weather and traffic operations. From these visualizations, analyses and metrics were developed that could be used to objectively evaluate the effectiveness of TMIs. This paper will present three visualizations that have directly resulted in the development of analyses for TMIs or lead to insights into air traffic operations.

I. Introduction

Throughout the months of April through September the National Airspace System (NAS) is interrupted by operationally significant weather, primarily convection (thunderstorms), which poses a threat to aircraft and disrupts the standard traffic flows by reducing the airspace available to accommodate flight demand. In response to these conditions a Severe Weather Avoidance Program (SWAP) is put into effect. A SWAP will implement and coordinate various Traffic Flow Management (TFM) initiatives in and around the weather impacted area to mitigate delay. As part of the FAAs (Federal Aviation Administration) ongoing improvement efforts, SWAPs undergo intensive post-evaluation the following morning to determine the effectiveness of the TFM initiatives as well as other decisions both tactical and strategic.

To analyze TFM effectiveness the FAA must take into account all aspects of the events in which the TFM initiative was conducted, including: weather conditions, traffic demand, airborne traffic conditions, route availability and other TFM initiatives currently in effect or expected. Visualizations therefore accurately convey this information to the FAA such that distinct elements of the SWAP conditions can be evaluated for successful and effective TFM impacts as well as being used to identify scenarios in which there is potential for increased delay mitigation.

As a response to this need, the RAPT Evaluation and Post-Event Analysis Tool (REPEAT), a web based next-day analysis resource was developed. REPEAT provides detailed vizualizations and metrics of weather conditions, air traffic and airport departures from data collected the day before and processed overnight to enable immediate review of SWAP conditions. REPEAT was initially deployed in 2009, focusing on the New York Metro area airports; in 2010 this was extended to include analyses for the Chicago area as well.

REPEAT also serves to evaluate the Route Availability Planning Tool (RAPT)[1], a departure management decision support prototype that forecasts the operational significance of expected weather on departure routes. RAPT predicts the impact of convective weather on major departure routes by assigning a departure status to future departures (out to 30 minutes) along the route. A RED status means that operationally significant weather is

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¹ Assistant Staff, Weather Sensing Group, 244 Wood Street, Room S1-616, Lexington, MA 02420

impacting the route for flights departing during those times; the RAPT RED CONOPS is to consider closing or severely restricting traffic on the route, and to plan to reroute pending departures onto other, less impacted routes (figure 1).

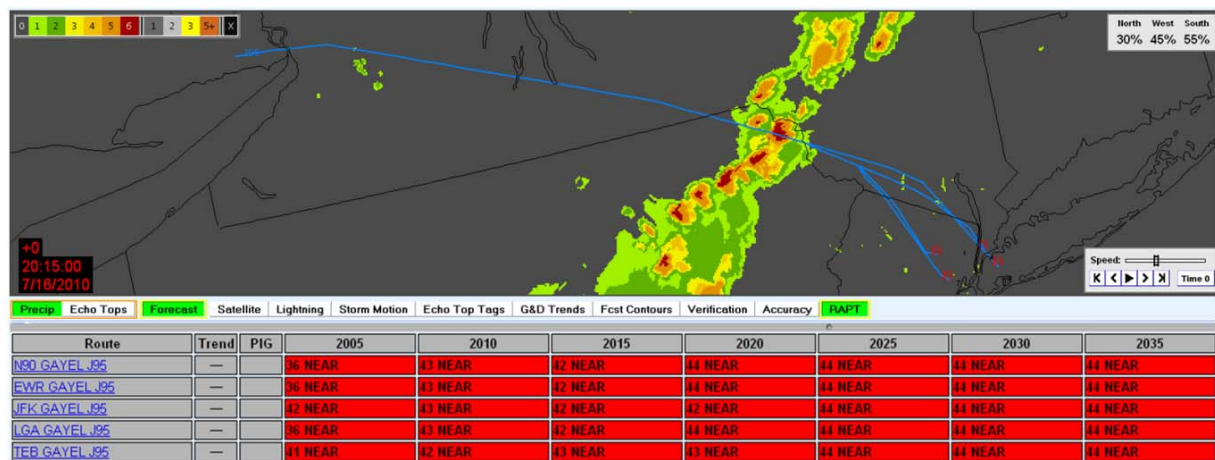


Figure 1. Convective weather impacting Jet Route J95 on the RAPT Display.

RAPT YELLOW status means that the departing flights are likely to experience some weather, and Air Traffic Controllers (ATC) should seek more information to determine whether the conditions are flyable; a RAPT YELLOW CONOPS prompts for closer investigation and leaves action (increase restrictions, decrease restrictions, no change) to the discretion of the ATC (figure 2).

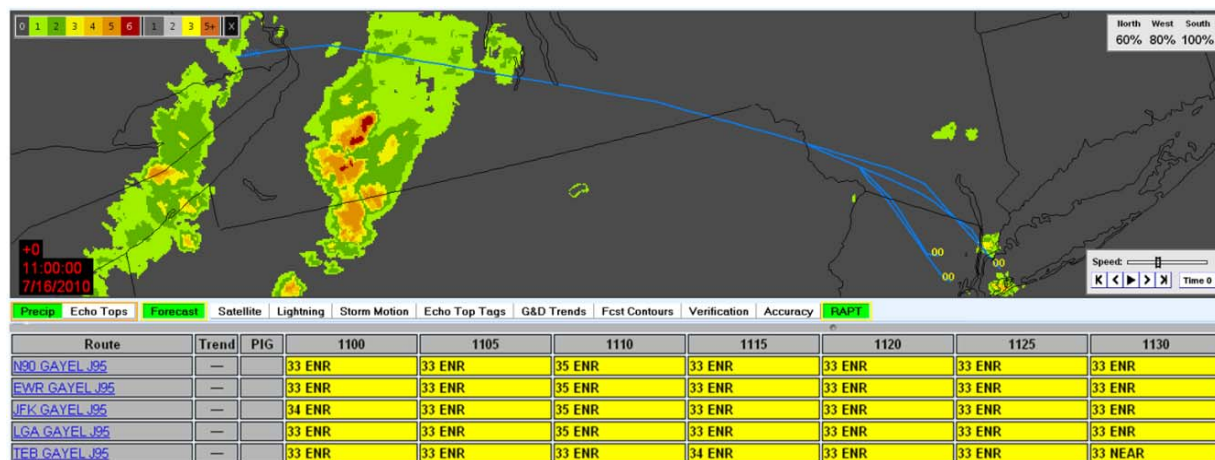


Figure 2. Weather impacting Jet Route J95 on the RAPT Display.

RAPT GREEN status means that no weather will impact flights along the route for the specific departure times, flights should be released for departure and routes should be opened for normal traffic flows (figure 3).

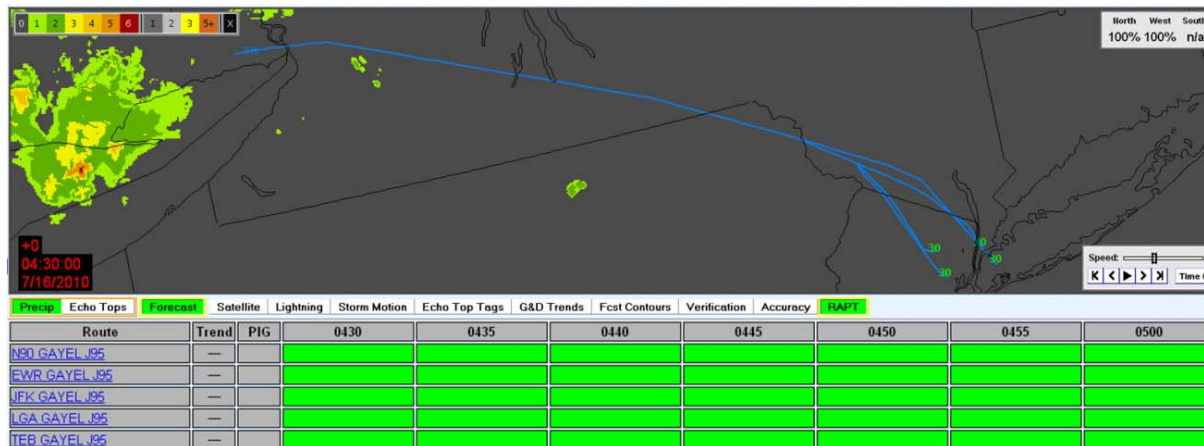


Figure 3. Jet Route J95 when clear of weather on the RAPT Display.

REPEAT includes automated visualizations of departure operations during periods of weather impacts that provides REPEAT a basis on which to measure RAPT performance as well as allows fine tuning of RAPT's determination of operationally significant weather impact levels.

In order to gain insights into the utility and operational accuracy of RAPT guidance exploratory visualizations were developed using RAPT and traffic patterns. The first visualization shown is used to determine the speed and traffic rates with which departure routes, previously closed by weather impacts (RAPT RED), are reopened once the weather impacts are cleared (RAPT GREEN). These circumstances are referred to as 'Post-impact GREENs', or PIGs. The second visualization provides a basis for confirming the application of traffic restrictions and weather avoiding reroutes when departure routes are significantly impacted by convective weather (RAPT REDs and YELLOWs) through depiction of traffic on routes with similar trajectories. While restrictions and reroutes are sometimes recorded in the National Traffic Management Logs will sometimes contain records of route reopening, restrictions, and reroutes, the logging of these actions is infrequent. This visualization enables analysis of successful traffic flow rerouting since it would show rates similar to those of expected departures for a set of routes despite one or more of the routes being impacted. Opportunities where rerouting would have helped alleviate traffic would appear as potential capacity on clear routes adjacent to impacted routes with reduced rates.

In addition to the visualizations used for evaluation of these weather impact mitigation techniques another visualization was developed that gives insights into understanding the airport's inherent delay accumulation due to overscheduling or unanticipated capacity constraints. Throughout the day airports experience fluxes in traffic flows of both departures and arrivals but airports have a finite limitations on the number of operations that their available runways and terminal and nearby en route airspaces can accommodate. Towards understanding this delay accumulation, delay on the ground was depicted to determine underlying causes to delay under both nominal and constrained conditions. This visualization shows that even under clear weather conditions ground delay accumulates.

This paper presents these three visualizations, the associated insights gained through their evaluation, and the analysis that they are now used for: first, the RAPT Route Departure visualization and the post-impact GREEN analysis, followed by the Route Groupings Visualization and traffic flow movement analysis, and finally the Taxi Delay Visualization and the ground delay analysis.

II. Post Impact Green Analysis

In order to reduce delays caused by convective weather, the RAPT Concept of Operations (CONOPS) focuses on the timely reopening of routes closed due to convective weather impacts. A route is typically closed due to pilots deviating from their planned trajectories to avoid thunderstorms, an event which adversely affects adjacent departure or arrival traffic. Under these conditions, the air traffic controller workload increases significantly as the controller tries to maintain separation and guide planes through the airspace. During a SWAP, when traffic managers must constantly adapt to rapidly changing weather and air traffic demand, the clearing of weather on closed routes may be overlooked. Furthermore, without objective forecasts of convective weather impacts, traffic managers may be unwilling to reopen routes until weather is completely clear from the route and they have had the opportunity to probe the route with a pathfinder flight. The result is lost capacity and increased delay, as departures are not staged proactively in anticipation of forecasted weather clearance.

The availability of a route to take more departures, particularly after routes have been impacted by severe weather, are critical periods in a SWAP where the opportunity to accommodate built up departure demand reduces delays and decreases airport surface congestion. These periods are referred to as Post-Impact-GREENs (PIGs), where route availability has returned (RAPT status has turned GREEN) following convective weather impacts (RAPT RED status). Through comparative analysis of forecasted weather conditions on a route from RAPT and detailed track information on the flights that match those trajectories we can individually assess the extent to which the newly available capacity is used. Evaluation of potential improvements and successful exploitation of these periods provides a comparative measurement of SWAP PIG performance.

In retrospect, the importance of the PIG seems obvious. However, the significant opportunity for delay reduction by rapid identification and reopening of PIG routes was identified only after two cycles of RAPT field evaluation and data analysis. An evaluation of RAPT performance in New York during the summer of 2007 identified a flaw in the RAPT route status forecast algorithms (oversensitivity to small changes in the underlying weather forecast) that reduced the reliability of the RAPT guidance and eroded the confidence of users [2]. The flaw was fixed in the 2008 revision of RAPT, and a second field evaluation was carried out. Despite the improvements in the algorithm, the reduction of departure delay due to RAPT use in 2008, compared to 2007, was estimated to be only 10% [3]. This disappointing result led to an analysis of departure operations in 2008, in an effort to ascertain the reasons for the poor improvement in RAPT use. One goal of the visualizations was to understand the relationship between RAPT impact forecasts and traffic flows. Since no operational metric for departure efficiency as a function of weather impacts had been defined, the relationship between RAPT guidance and observed departure rates could not be calculated via some algorithm or formula. Instead several exploratory visualizations were developed using variables that were deemed relevant in order to look for potential correlations and generate insights and understanding of the dynamics of departure operations.

The highlight of these visualization was the RAPT Route Departure visualization which incorporated the full range of forecasted weather information as well as traffic on the route to provide insights both from the planning perspective as well as post-analysis effectiveness measurement.

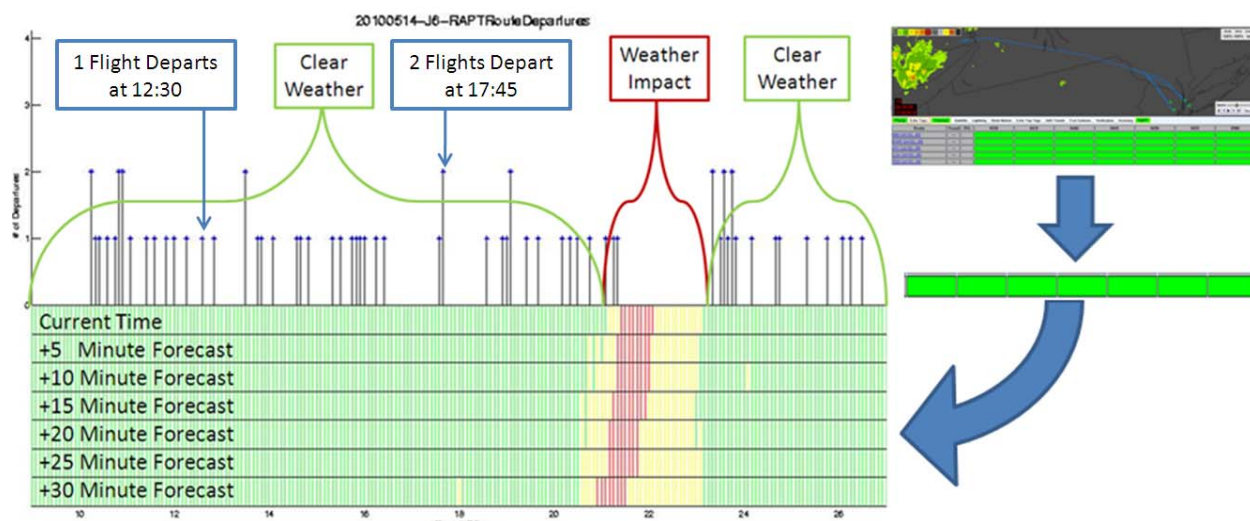


Figure 4. RAPT Route Departures visualization components.

Figure 4 depicts the elements of the RAPT Route Departures visualization. In this visualization the lower portion is comprised of RAPT route blockages statuses. The most recent forecast status is located along the top row, and forecasts for future departures displayed in descending rows. Essentially every series of forecasts displayed on the RAPT system is rotated 90 degrees and depicted adjacent to the previous and following forecasts. This representation of weather data shows exact starting and ending points of a weather impact on the route.

The upper portion of a RAPT Route Departure visualization (Figure 4) shows the traffic on the route by their departure time. The weather directly below any flight then is the expected impact that those flights were forecasted to encounter along the route.

After multiple SWAP days were viewed, it became clear that after weather impacts cleared, routes were late and/or slow in starting up. These missed opportunities highlighted a potential opportunity for decreasing delays [4]. In order to measure the potential amount of departures that could have been accommodated during these periods the visualizations were evaluated to determine operational efficiency through the calculation of two metrics (Figure 5).

The first metric was to determine the ability of ATC to identify a PIG, and initiate the flow of traffic on the route. For this the amount of time that passed between the weather clearing and the release of the first departure on the route was measured. This Time of First Departure metric, marked in blue in Figure 5 is an indication of the proactive initiative for exploiting these periods of clear weather.

The second metric focused on determining the successful exploitation of the clear weather period; in essence how much of the available capacity was utilized in order to offload traffic. To measure this the first three hours of a PIG, the period critical to alleviating pent up demand and cumulating delays, were analyzed. In Figure 5 this time period is shown by the Red Marking, extending from the Start of the Pig (marked in green) to three hours after. The first hour during this period is where the most benefit is present since this is the offloading opportunity, similarly the second hour offers still more capacity for waiting demand, by the third hour this push is expected to taper off. However with a belated start these traffic patterns can instead take place in the 2nd and 3rd hour instead of promptly so the first three hours are used as a measure.

The RAPT forecast for departure times, up to 30 minutes in advance is an important consideration for these metrics since more volatile weather may not give significant warning. Here (Figure 6) J6 goes from having a full YELLOW to a full GREEN in 10 minutes, then the first departure occurs during the 3rd period of full GREEN. Although this is 15 minutes after the weather fully cleared, this is still considered a prompt departure; it is assumed that at least 15 minutes would be required to coordinate the route reopening, and stage and execute the first departure, which suggests that the route reopening decision was made promptly at the time of RAPT clearing (or even in anticipation of it). The PIG criteria is also rather conservative in order to eliminate cases where there may be significant forecast volatility that would erode confidence in RAPT guidance. A PIG is identified through use of a strict clear weather threshold of 12 sets of forecasts (a full hour), where clear weather is currently in effect as well as predicted for the next half hour.

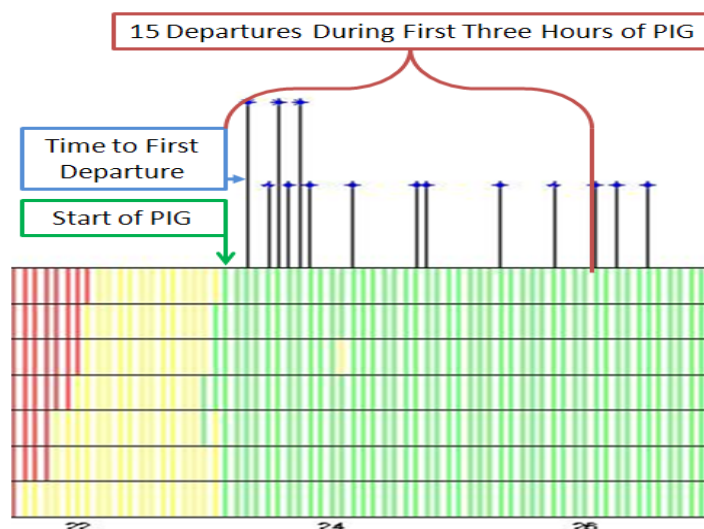


Figure 5. Visual depiction of Post Impact GREEN (PIG) metrics

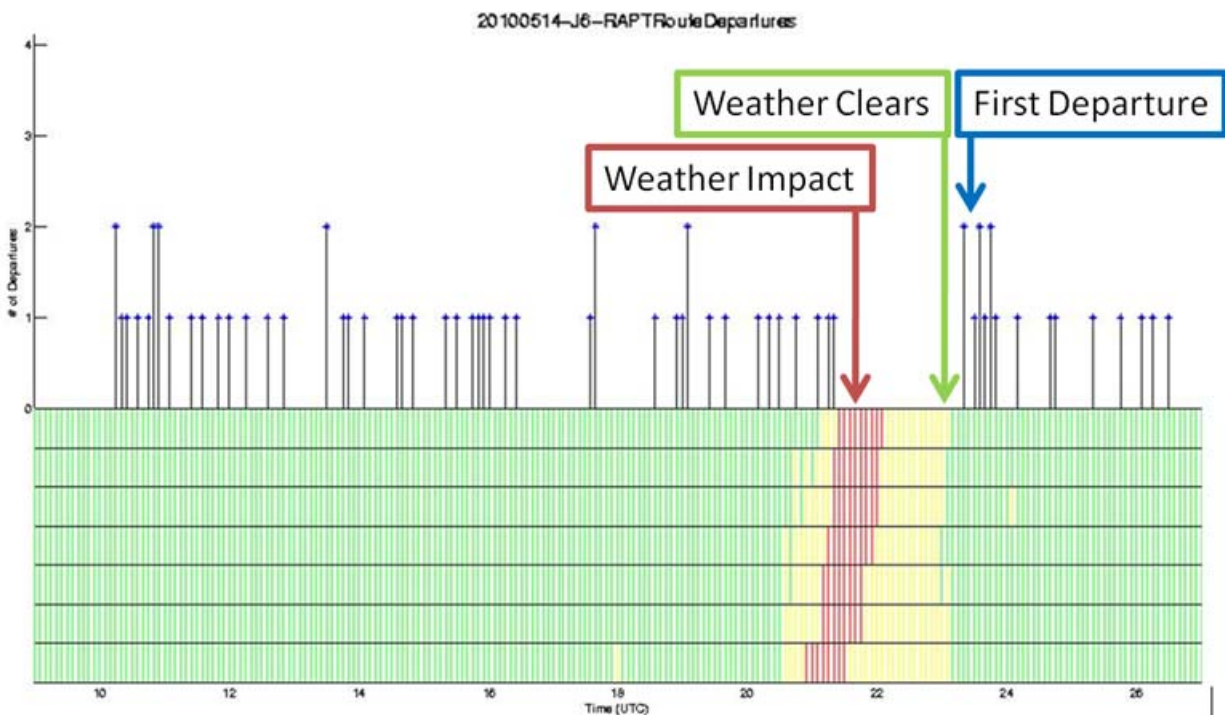


Figure 6. Rapt Route Departure visualization for route J6 on May 14, 2010.

The relationship between weather impacts and departures is made clear in the visualization (figure 6). The vertical depiction of forecasts (bottom row) enables visual heuristic checks for the onset and clearing of weather impacts, as well as sudden forecast changes. The departure counts, in 5 minute bins (upper row), visually correlates the use of the departure route with the weather impact state forecast by RAPT.

All convective weather days in 2008 were evaluated using these metrics. From these evaluations three main types of PIG events emerged. The first and worst case scenario was where a PIG started but traffic was both delayed in resuming and the rate of traffic didn't fully utilize the available capacity of the route.

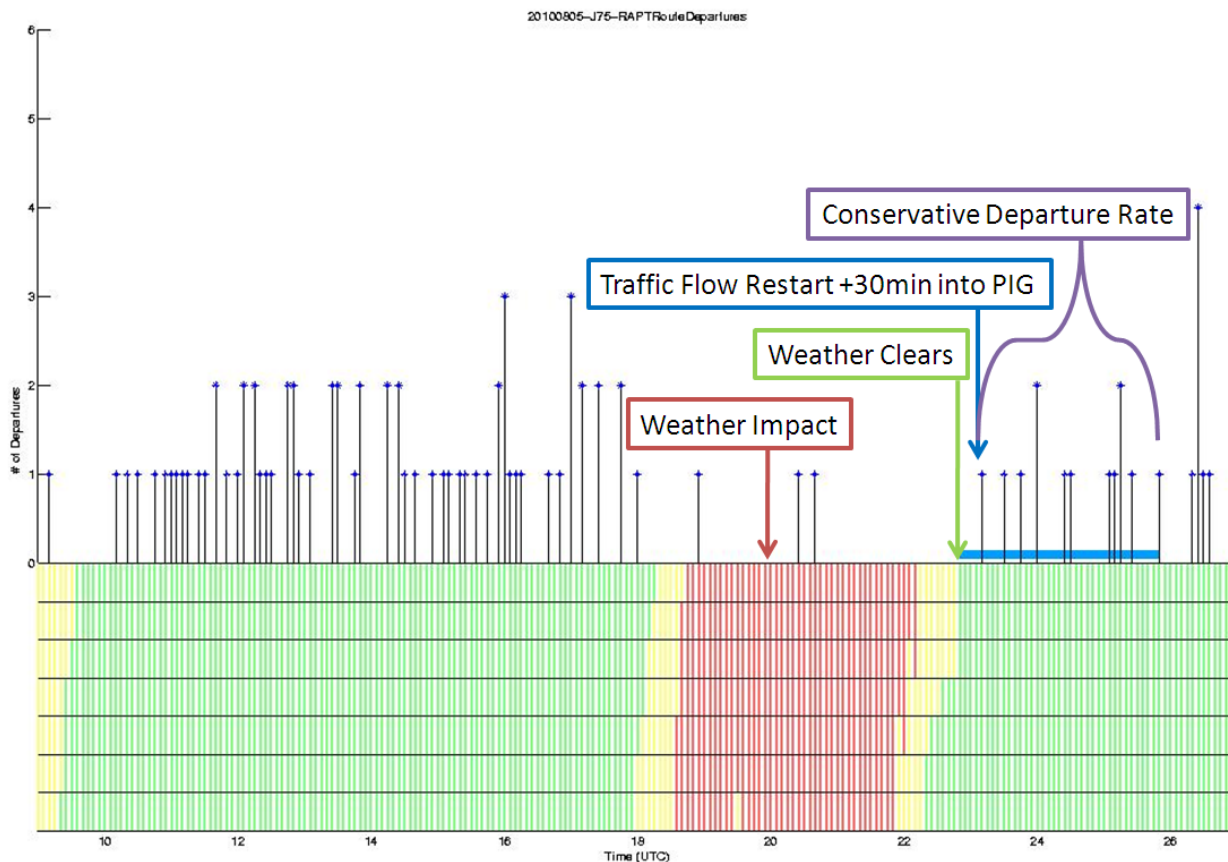


Figure 7. Rapt Route Departure visualization for route J75 on August 5, 2010.

Figure 7 depicts route J36 on August 5th, 2010. This route consistently handles a fairly high level of departure traffic, the traffic in the first half of Figure 7 shows the route's typical rate of departures.

- At 18z weather impacts the route reducing traffic to a few stray aircraft while the severe weather continues for almost 5 hours.
- At 23z Figure 7 is marked with a green arrow to show where the route clears of weather.
- 30 minutes after the weather clears the first aircraft takes off.
- Over the next three hours traffic on the route gradually increases never gets back to typical traffic rates.

Here the slow restart of traffic on the route was not as significant as the decreased level of traffic, given the initial rates starting at the beginning of the PIG may have resulted in only one or two more flights getting off. However if the route had handled traffic similar to its earlier performance in the day during these three hours double the number of departures could have gotten out. After five hours of impact a significant amount of departures would have been delayed and this opportunity could have significantly helped reduce building delays.

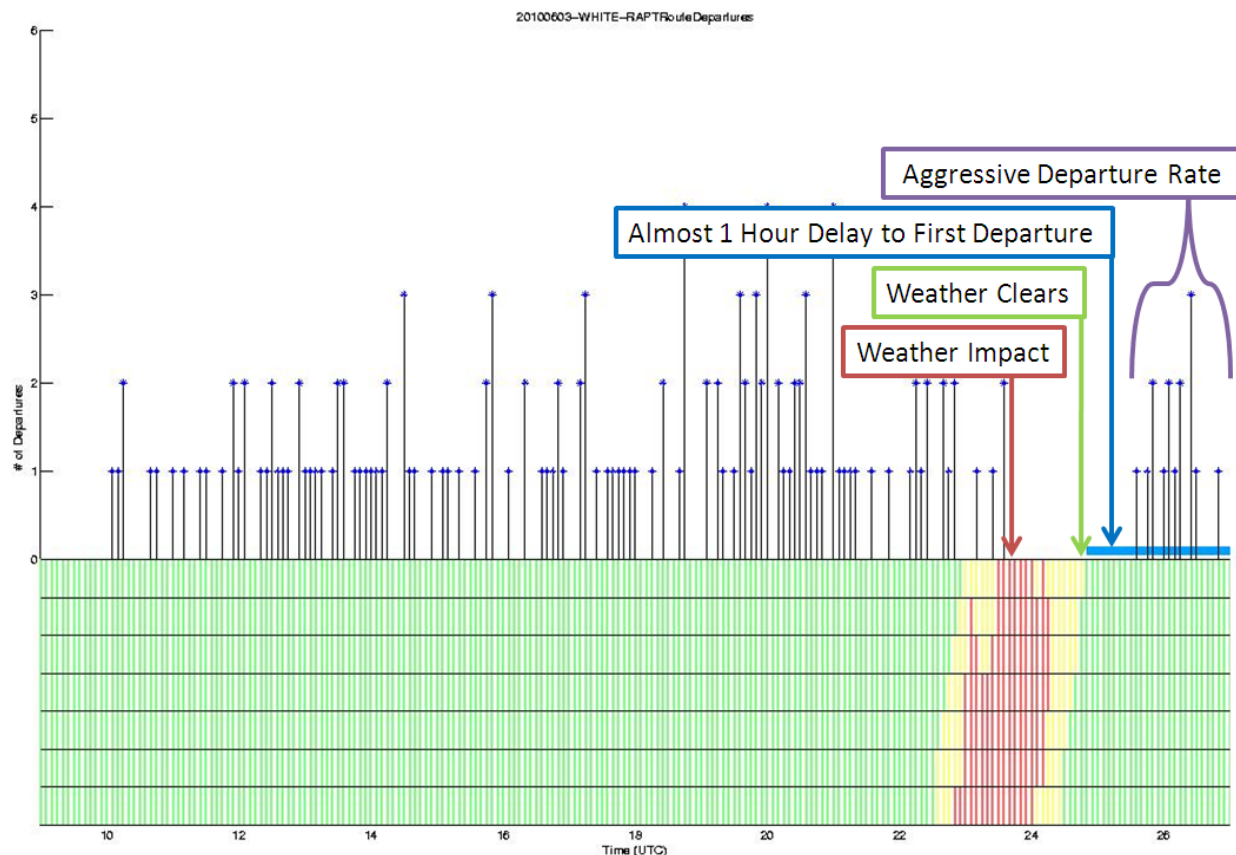


Figure 8. Rapt Route Departure visualization for RAPT route WHITE on June 3, 2010.

In Figure 8, the restart of traffic is again somewhat late but here an aggressive traffic movement is implemented. The route shown here, WHITE route has an even greater load of traffic than the previous route.

- The weather impact on the route is much shorter, only 2 hours long.
- Just before 25z the weather clears.
- Almost an hour after the weather has cleared the route the first plane departs.
- This first departure is shortly followed by almost nominal traffic rates.

Due to the high traffic volume of the route even the small impact would have impacted many flights and at the rates that this route handles the hour of route capacity could have handled many waiting departures.

From these two situations it was easy to determine that successful exploitation of PIGs relied on two key actions.

1. To alleviate built up demand, and curb building delays traffic flows should restart at high rates in order to accommodate as many aircraft as is manageable.
2. Traffic on the route should resume as soon as possible on a PIG to utilize the clear weather capacity and address the backup of waiting flights promptly.

In conjunction these two actions could result in a very different manifestation of PIGs.

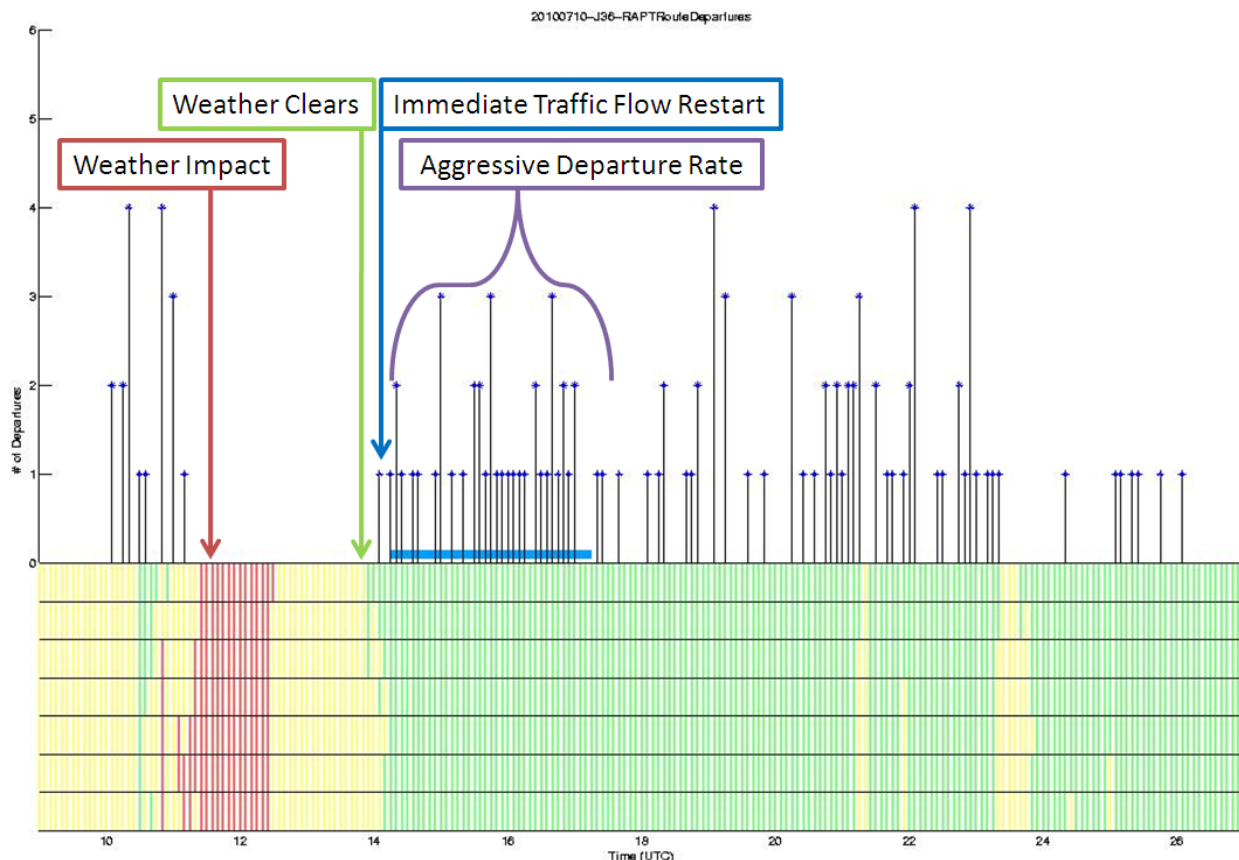


Figure 9. Rapt Route Departure visualization for route J36 on July 10, 2010.

Figure 9 shows a case where following a weather impact there is a near perfectly executed resumption of traffic flows following a weather impact.

- The route is beset with weather from the beginning of the day and for a significant length of time.
- The weather clears the route just after 14z.
- After only ten minutes of RAPT GREEN, ATCs have the first aircraft in the air.
- This is followed by an aggressive departure push where the route handles a surge of departure traffic for three hours before traffic rates decrease to a steady rate.

This PIG period was fully utilized by ATC at its onset to handle the cumulated demand from the weather impact.

For the 2008 season, 113 PIG events from 11 SWAP days were analyzed in terms of efficient reopening and the untapped potential available [3]. The study showed that 35% of all PIGs had been missed opportunities (defined as occasions where the time to first departure after the appearance of a PIG was greater than 15 minutes) for timely route reopening.

PIGs pose a significant opportunity for traffic alleviation and a shift back towards standard traffic flow patterns. In an effort to decrease these missed opportunities, the RAPT concept of operations for 2009 pushed: 'GREEN means GO'; prompting Air Traffic Management (ATM) to open routes with RAPT GREEN forecasts. RAPT was also given a PIG Timer which would start counting when a route had cleared of weather post a weather impact. The PIG timer would draw the attention of ATCs to newly cleared routes so as to prompt route-reopening or a decrease of restrictions on the route to capitalize on the increased capacity.

Following this new strategy, the 2009 convective season was also evaluated. 2009 not only had an overall 48% decrease in time until the first departure but also showed further proactive management by ATMs.

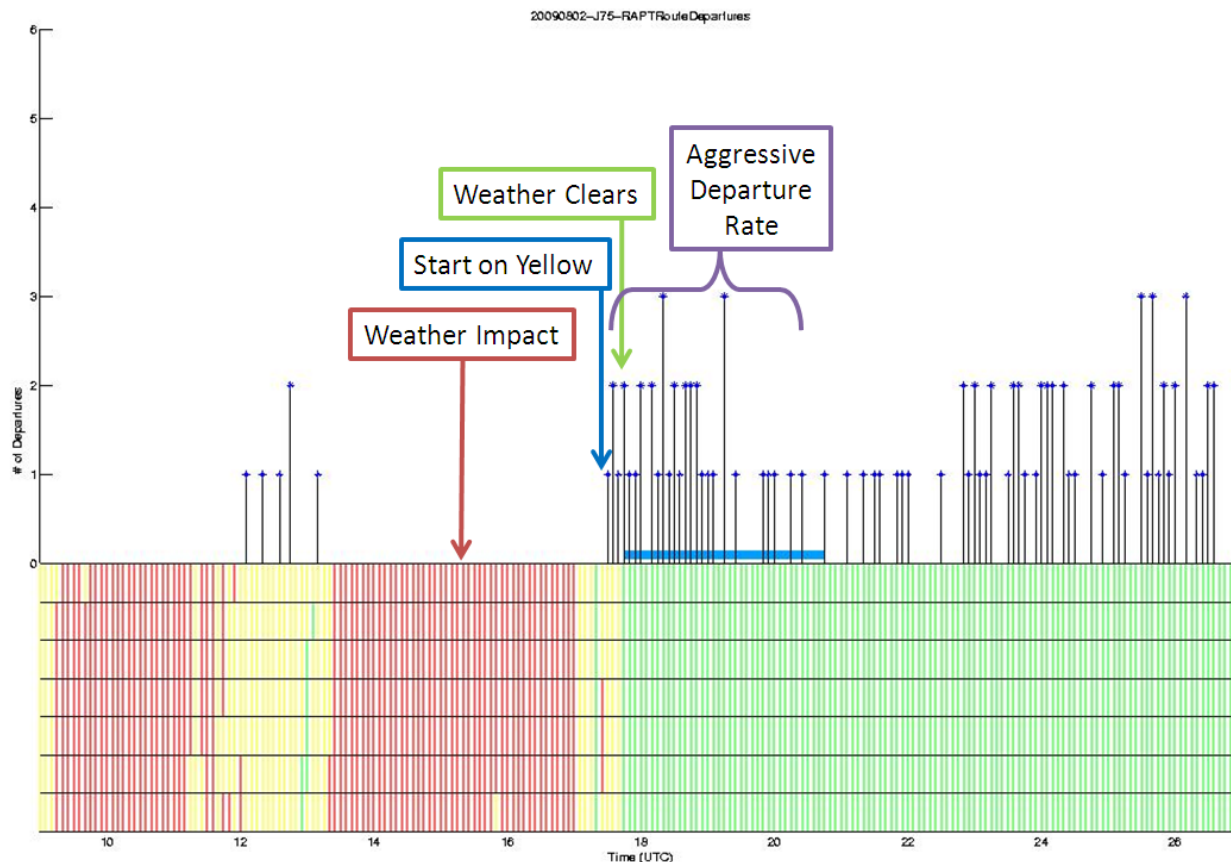


Figure 10. Rapt Route Departure visualization for route J75 on August 2, 2010.

For the event depicted in Figure 10 ATM carried out a proactive initiation of traffic on a route clearing of weather.

- Weather impacts were strong for the first half of the day only giving a small opportunity for a handful of departures around 12z.
- Just after 17z however the RAPT forecast indicates clearing weather. Anticipating the route availability, ATM proactively reopened the route before the route fully cleared.
- In addition to this ATM restarted the route with an aggressive rate.
- The weather fully cleared just before 18z.

Despite this case being an instance where forewarning of GREEN wasn't present, ATM recognized and exploited the improving conditions; by the start of the PIG, route traffic was already flowing at a high rate. This decision resulted in only two hours of heavy traffic flows; an hour and a half into the clear weather and traffic rates on the route had already decreased to a more relaxed rate. These instances show great proactive management from ATC that result in more efficient use of available departure resources when they are most needed. A metric – percentage of PIG departures on YELLOW – can be derived from this analysis and provides an objective measure of 'proactiveness'.

Despite these improvements however, some potential benefits still remain unexploited. Another TMI available to ATM during clearing weather conditions are pathfinders.

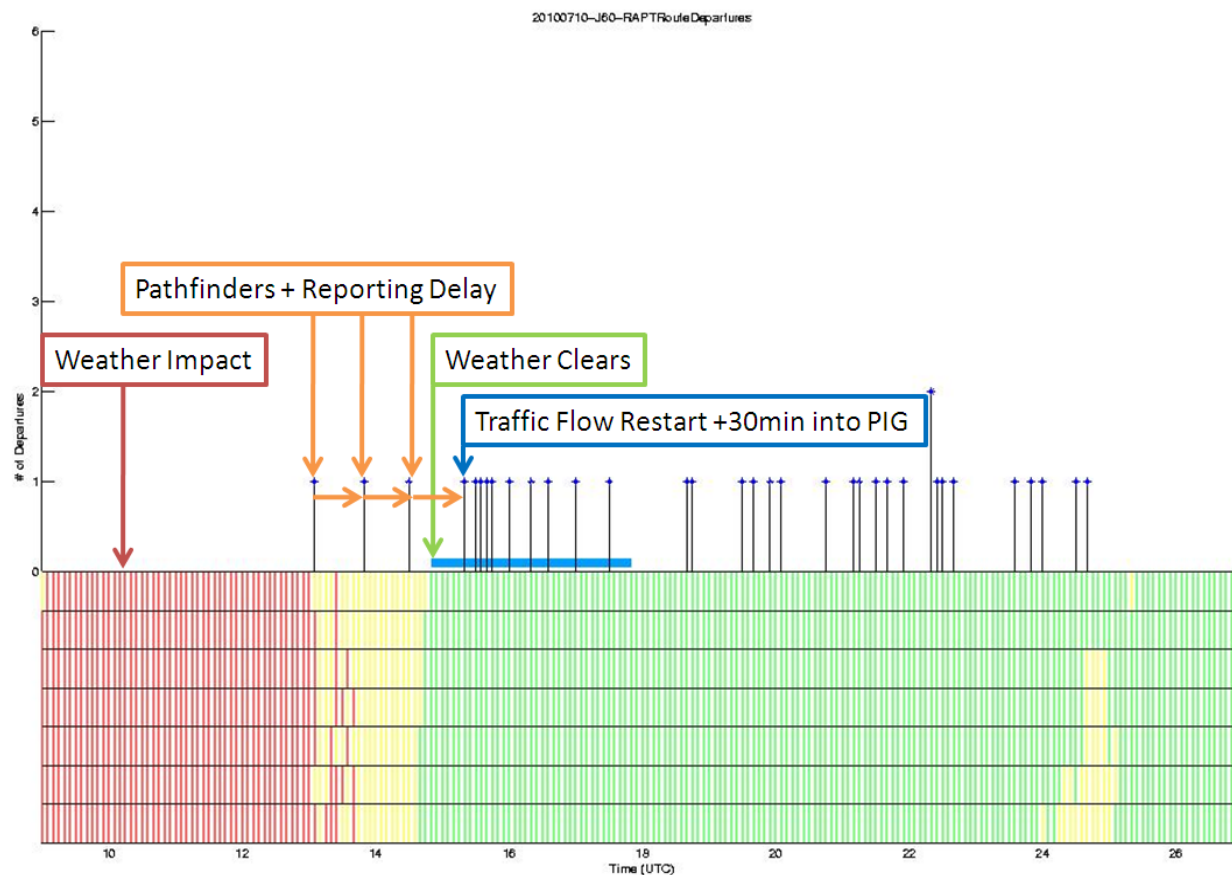


Figure 11. Rapt Route Departure visualization for route J60 on July 10, 2010.

Pathfinders are single flights that are released on routes that are not yet reopened in order to probe the airspace and report back on the feasibility of reopening the route. As figure 11 shows pathfinders typically take 45 minutes to clear a route sufficiently to report back if it was passable with confidence. However ill-timed pathfinders can delay traffic as well. A pathfinder taking off before full GREEN and meeting with significant impact will cause the route to be closed until ATC are absolutely sure that the route is experiencing sufficiently safe conditions. Also if the pathfinder takes off even so much as 20 minutes before the route goes green, ATC will sometimes wait to hear back from the pathfinder delaying flights while 25 minutes of clear conditions passed in order to get the confirmation back from the pathfinder that the route conditions are in fact flyable. Particularly since neither of these cases will positively affect the automatically calculated PIG statistics, having visualizations present with the information easily comparable enables detection and accommodation for these and like situations. Because of the many inefficiencies associated with the use of pathfinders, the RAPT concept of operations seeks to minimize their use and to replace it with a reliance on RAPT PIGs and YELLOWS to identify opportunities to reopen closed routes.

III. Traffic Flow Movement

When weather impacts become significant on particular departure routes, ATC may reduce traffic on the impacted route and reroute pending departures to nearby, less-impacted routes. This rerouting enables the flights to take off and start heading towards their destination airport without having to fly in their initially assigned route in sub nominal condition. The RAPT concept of operations includes this technique as a suggested action for when two adjacent routes have the forecast where one has YELLOW or RED conditions and one has GREEN conditions. The YELLOW/RED route would still have scheduled demand, but since there is an adjacent route with GREEN conditions, rather than holding these flights on the ground until their route's status improves there is the option to reassign the flights to the adjacent route which has a GREEN status.

The Route Groupings visualizations were developed to streamline evaluation of these particular techniques, as well as to raise the awareness of evaluators that they were in effect. Pictured in Figure 12, the Route Groupings

visualization clusters multiple adjacent routes that have a similar directional trajectory and monitors their individual and combined cumulative departures. These are compared against a blue backdrop of a fair weather cumulative total average for the same routes that serves as a comparison for their overall traffic totals. In addition to this, the day's weather conditions for each route are also depicted, associated with the departure counts vertically over time. These provide quick analysis of the status of the route in relation to their traffic.

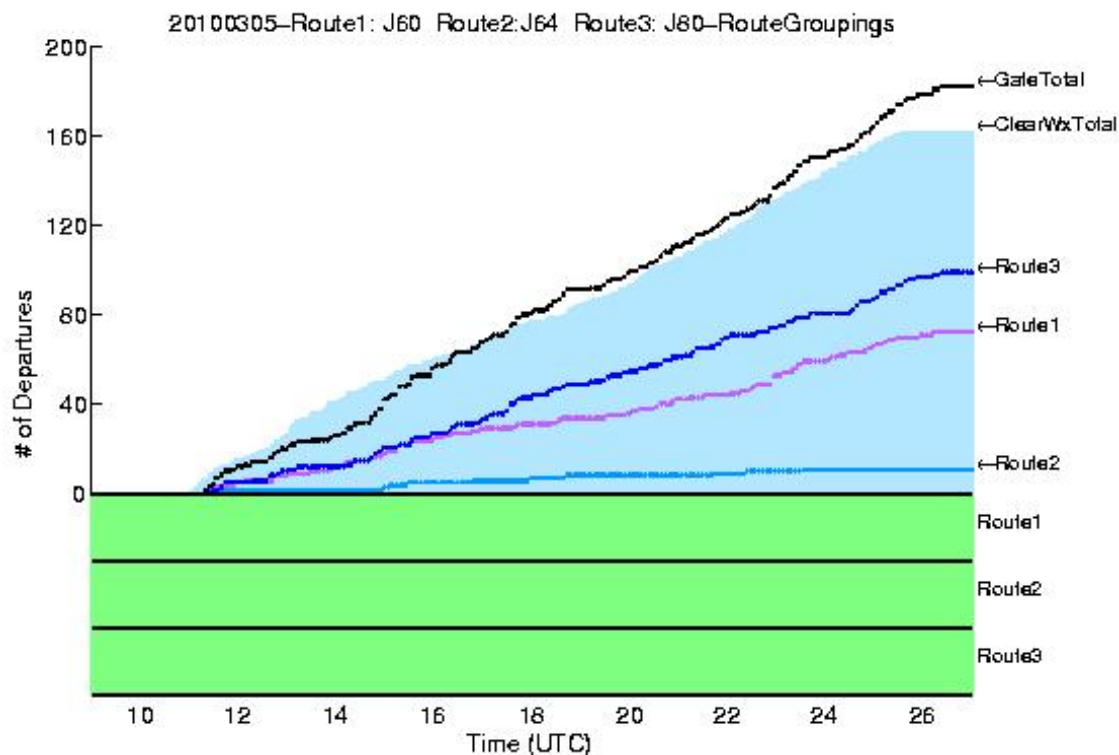


Figure 12. Route Groupings visualization for routes J60, J64 and J80 on March 5, 2010.

To give a foundation for expected traffic on the routes, Figure 12 shows a clear weather day from earlier in the year where traffic is unobstructed. J64 as mentioned still does not handle much traffic from the two airports, but J80 and J60 both handle a steady stream of departures throughout the day.

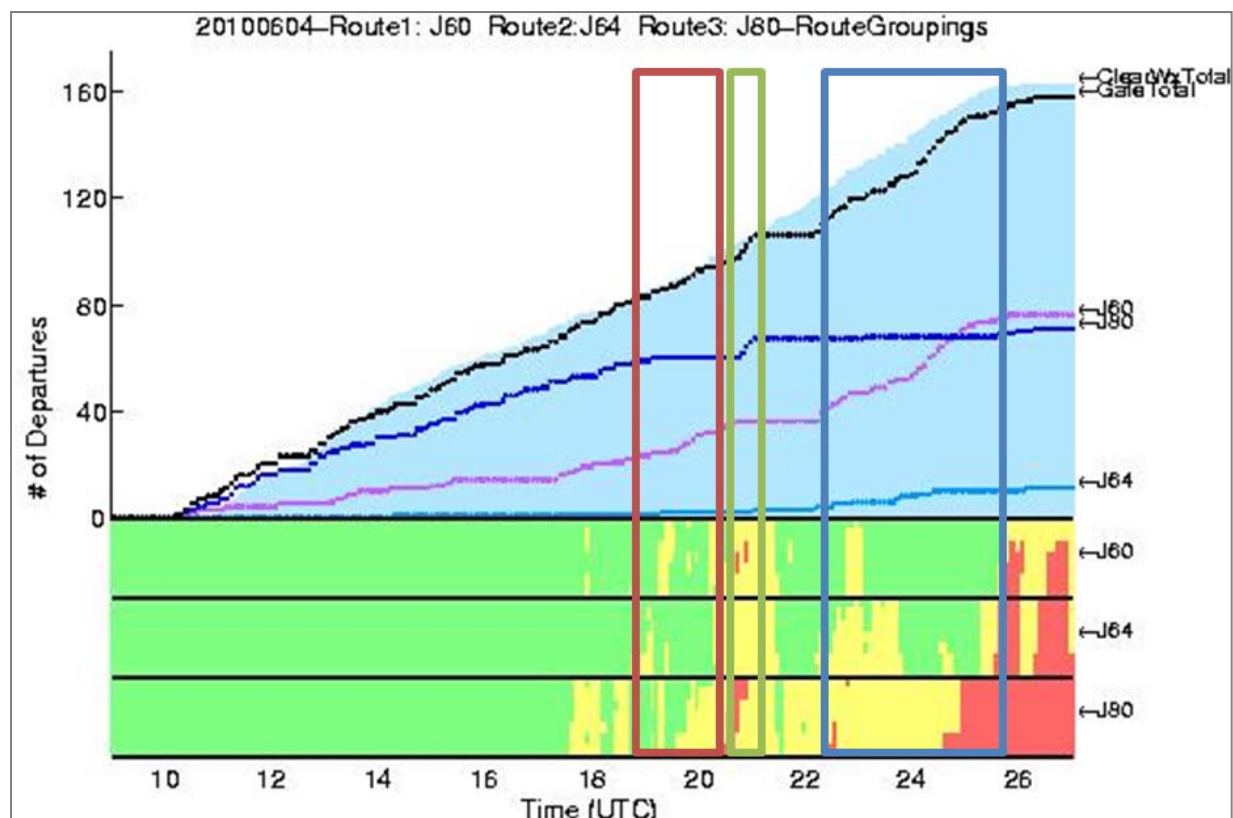


Figure 13. Route Groupings visualization for routes J60, J64 and J80 on June 4, 2010.

This example (Figure 13) depicts a convective day: June 4th, 2010 where the westward bound routes are impacted by weather in the later half of the day. The two main routes J60 and J80 are traditionally heavily used by the two airports whose traffic is monitored here: Newark Liberty International Airport (EWR) and LaGuardia International Airport (LGA). J64 typically handles very little EWR and LGA traffic as it is the main route for Philadelphia International Airport's departures to the west. By comparing the Gate Total, the total cumulative departures for the day, against the Clear Wx(weather) Total, the clear weather observed traffic rates, we can see the impact specific periods of traffic have on the overall departure totals. Periods when both routes stop all traffic between 21 and 22z causes the day's cumulative departures to fall away from the expected traffic counts.

- After 19z, J80 begins to experience sustained convective weather on the route, and the traffic using J80 ceases entirely. This lack of traffic does not mean that planes scheduled for J80 are automatically cancelled or wait on the ground however. Instead at about 19:30z we notice that J60, who is experiencing some but significantly less convective impact than J80 has a sudden surge in traffic, to the extent that it is accommodating expected demand for both routes.
- At 20:30z, we see the opposite reaction, where J60 also gets hit with weather and J80 offloads a higher rate of traffic in a very short period of time.
- Then at 22z, J80 traffic stops again and J60 traffic restarts, its departure rate exceeding the rates experienced during nominal operations. This significant amount of departures reduces the difference between the Clear Weather Total and the day's cumulative departures.

In addition to evaluations of TFM initiatives these visualizations also assist in providing situational awareness for the day. If a rerouting program is in effect and many other operations are requiring attention, ATC may choose to not return flights to their initial route if it becomes open, instead opting to not reroute any further flights enabling traffic to return to normal flows on their own. This frees up the ATC to attend to other more pressing concerns, but will also mean that a PIG evaluation may not show traffic on an opened route until well after it has cleared of

weather. This type of operational decision can be evaluated by monitoring the overall flights through a set of routes, if an adjacent route to the PIG route is handling more than its standard level of traffic the PIG traffic may not be accumulating delays, but is already being handled through this TFM initiative. On the other hand, this circumstance bears further scrutiny, since excessive reroutes may decrease overall departure efficiency and result in fewer flights being assigned their preferred routes.

IV. Taxi Delay Visualizations

Beyond visualizations made available on REPEAT, many other visualizations are being constructed to facilitate ongoing research into the minimization of overall departure delay. A visualization was created to provide insights into the buildup of ground delay for pending departures under various conditions. While airports would accumulate severe amounts of ground delay due to the closure of routes and convective weather, we also found that under clear weather conditions and optimal airport operations flights still experienced delays although not nearly as substantial.

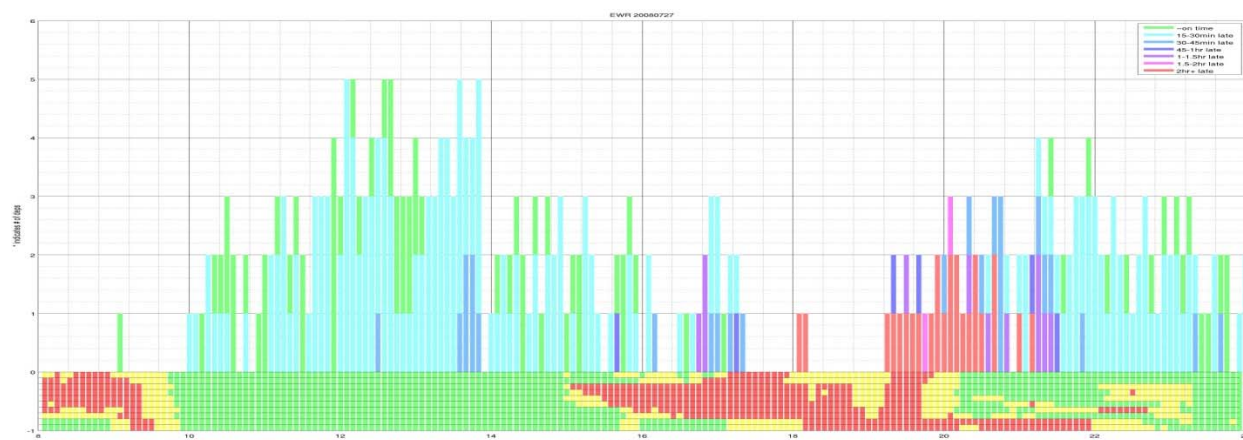


Figure 14. RAPT Taxi Delay visualization for EWR on July 27, 2008.

To evaluate one aspect of this, Taxi Delay visualizations (Figure 14) were developed. These graphs combine RAPT weather data with ASPM ground information times to provide a clearer insight into the workings of delay accumulation and the relationship between surface operations and departure releases during convective weather.

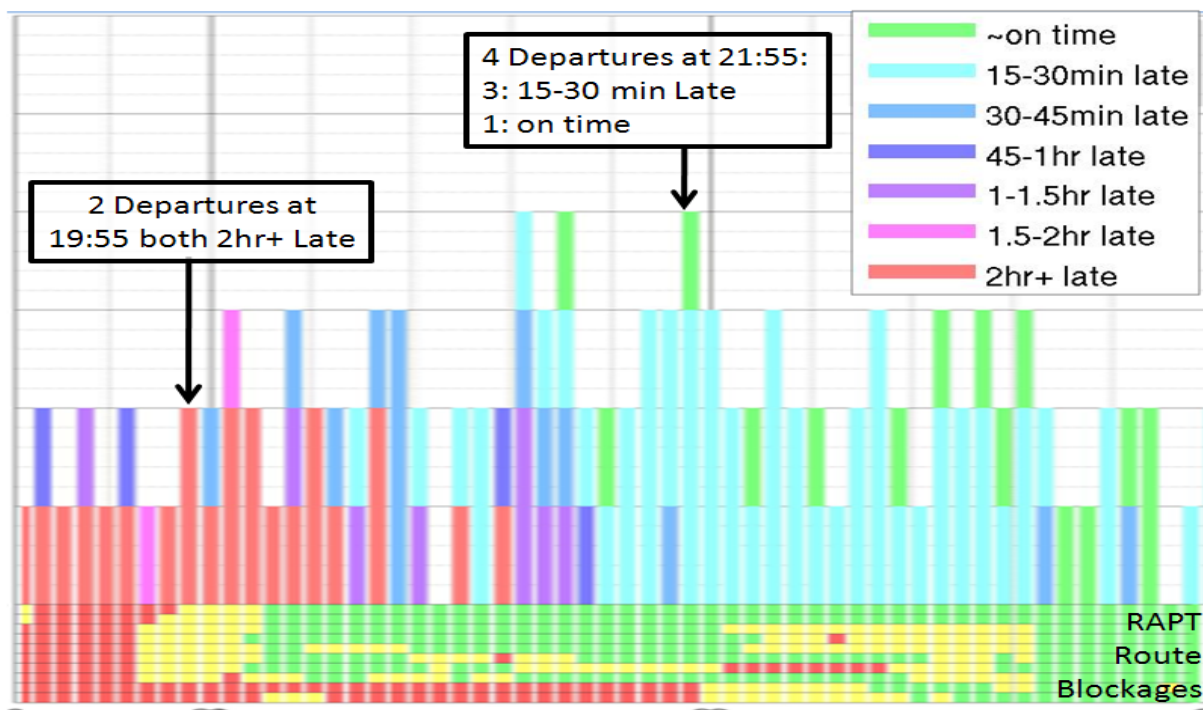


Figure 15. RAPT Taxi Delay visualization components.

RAPT Route Blockages: The lower aspect of the visualization displays the route blockages for the airport's main Jet Routes. Each route is represented by one row with the blockage colors for a flight departing at that time.

Flight Information: The flight information is represented by colored bars above the RAPT Route Blockages.

Bar color: This indicates the length of time the flight spent between pushing back from the gate, and taking off. This comprises of the amount of time spent on the ground between pushback and wheels off.

Bar Height: Each flight is represented by one colored bar, so for a particular time if four flights took off, then there will be four bars stacked vertically over that time.

Bar Times: The time that each flight (and the bar that represents it) took off is located directly vertical to the bar, so a flight that took off at 22z will be located directly over the RAPT blockage for 22z and will be in a vertical stack of other flights that took off at 22z.

Figure 15 shows the progression of traffic and delay through the day as the airport's routes are impacted and then clear of weather. This visualization shows the morning progression with gradually increasing departure rates and ground delays until about 14z where traffic decreases just before the weather impact. The impact starts at around 15z with the major western and then south-western routes quickly going RED. Traffic during this time holds to the rate for a short while before stopping. Just before the North routes become severely impacted one last wave of flights depart, multiple of these having significantly higher delay of over an hour. Over the next two hours of heavy weather impacts only two flights get out, both having already taken over 2 hours of delay on the ground.

At 19z, flights start departing again despite the weather impacts. Despite the airport restarting departures before the weather fully cleared, departure delay on the ground didn't return to normal levels until almost 2 hours after the routes cleared fully of weather.

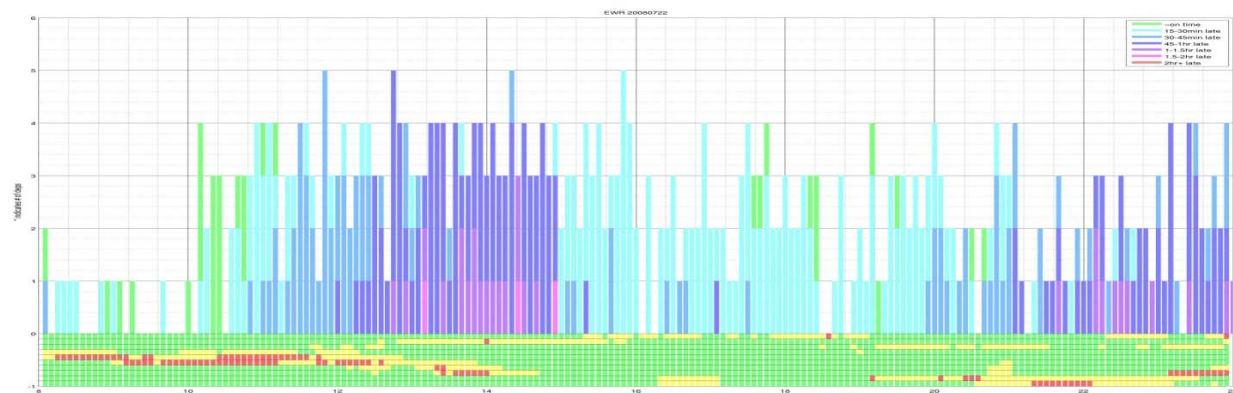


Figure 16. RAPT Taxi Delay visualization for EWR on July 22, 2008.

Figure 15 shows the complete halt of departures on the major jet routes due to all main routes being impacted; this resulted in severe delays for all flights that were to depart during this time period. However Figure 16 shows a day when only some routes were impacted at any one time and as traffic increases (10-11z), we see that their average delays also increase. After this period, traffic continues to operate at a high rate with decreasing delays as the number and severity of impacted routes decreases in the 15-16z period of the day.

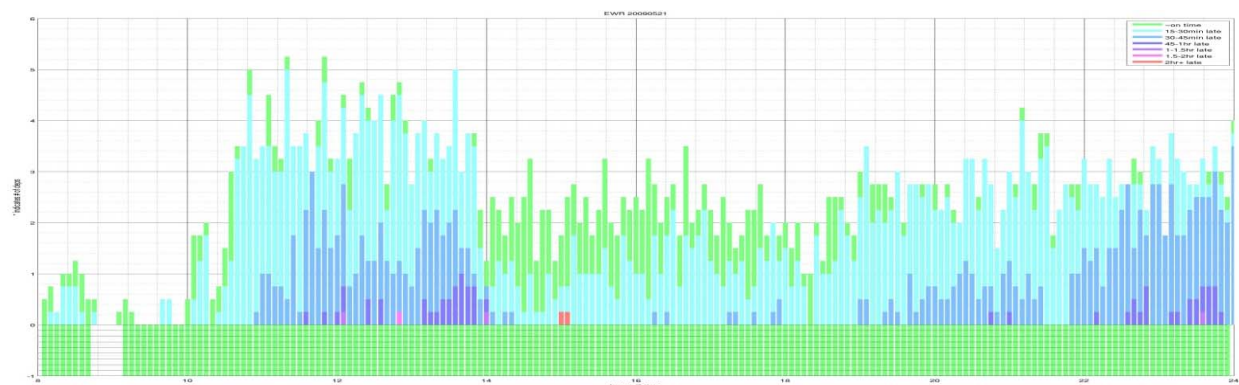


Figure 17. Average RAPT Taxi Delay visualization for EWR over 4 clear weather

Figure 17, however, brings another aspect to light: this shows the average observed flight delays from 4 days, all with clear weather conditions. Although there is no weather blockage or other disruptive conditions during the course of these days, the departures still experience delays. Surprisingly the number of flights that actually do depart on time, most prevalent during the middle of the day after higher departure rates in the morning and afternoon. This indicates that even though weather impacts clearly do cause significant amounts of delay, a certain baseline of delay is standard for nominal airport operations simply due to departure rates and/or flight scheduling.

Taking into account this base delay that airports operate with the delay in Figure 16 cannot be completely attributed to the weather. Although it's clear that the weather impacts did add some delay to operations, the operational delay can account for up to an hour of delay for some flights. We can see that the airport rates were not significantly below average for the day as well, so despite the weather impacts, traffic managers were able to maintain high departure rates. Another point that is highlighted by these visualizations is that several airports are already scheduled at, or even above, their true departure capacity for certain periods of the day, and any significant interruption of airport activity during those periods will result in a rapid increase in departure delays that may require several hours to recover.

These visualizations (figures 15-17) provide an overview of departure operations during fair weather and convective weather SWAP. By combining them with the route grouping and individual route departure visualizations, we are able to piece together a picture of when, where, how many, and under what conditions departures were released on any day of operations.

V. Conclusion

The Route Availability Planning Tool (RAPT) provides forecasts of departure route blockage due to convective weather impacts, that air traffic managers (ATM) can use to make operational decisions regarding route and traffic flow management. However the usefulness of RAPT is directly related to the objective tactical decisions that can be made based upon their information. To fully utilize RAPT's potential, traffic management initiatives (TMIs) as well as ATM procedures and actions have to be evaluated in conjunction with RAPT blockage in order to develop a well structured concept of operations that can take advantage of RAPT information to improve ATM efficiency.

As a means to this end, exploratory visualizations were developed utilizing ATM and RAPT data to provide insights into departure operations. These visualizations not only enabled the development of metrics that could be closely associated with departure operation management decisions, but could also highlight best strategies for traffic management as well as cases where there was lost potential for delay reduction. Ongoing evaluation of these visualizations and the metrics that logically link to traffic management decisions has resulted in the identification of areas for improvement. Strategies for greater efficiency have also developed from these evaluations, and due to the improved concepts of operations resulting improvement in operations have been observed.

Three visualizations used in these analyses were presented. The RAPT Route Departures graphs give a direct accounting of each route's use and condition throughout a day for close assessment of the route's individual performance. These can be used to measure the efficiency of instances of proactive management (in particular, reopening of routes closed by weather impacts after the impact have cleared) by providing a solid metric for the number of aircraft affected by decisions, as well as a critical analysis for when opportunities were missed that can be used for future planning and operations management.

Closely associated with the RAPT Route Departure graphs are the Route Grouping visualizations which provide flow information for the analysis of traffic constraints on weather-impacted routes, and the use of reroutes to nearby less-impacted routes to avoid those impacts. While the RAPT Route Departure graphs may show an individual route's performance, these graphs offer a big-picture overview of all traffic departing along similar trajectories to capture the use of major TFM initiatives. These can show that although a single route might be underutilized, other routes are accommodating more than their standard rates and the overall departures expected can be handled efficiently.

While both of these monitor traffic rates, a third graph, the Taxi Delay visualization, provides the ground delay for flights, visually correlated to the RAPT route blockage for their departure routes, over the course of the day. These visualizations can give exact measurements of how much accumulated delay has been observed on the ground by waiting departures, and provide insights into the relationship between route blockage and ground delay. This critical measure of actual delay experienced is an important driving factor behind prompt operations and can quantify the benefit of swift attention to departure opportunities. Together, these visualizations, used with a solid foundation of traffic flow management (TFM) operations provide detailed and specific evaluation of weather events, traffic movement, TFM initiatives and greater understanding their impacts on the National Airspace System.

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