ESTIMATION OF NEW YORK DEPARTURE FIX CAPACITIES IN FAIR AND CONVECTIVE WEATHER*

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Abstract

When convective weather impacts the New York Metro airspace, traffic managers may employ several tactics to mitigate weather impacts and maintain manageable and efficient flow of traffic to and from the airports. These tactics, which include maneuvering individual flights through weather, merging and redirecting traffic flows to avoid storms, and rerouting traffic from blocked routes onto unimpacted or less-impacted routes, all affect the capacity of airspace resources (departure fixes, routes, or gates). Furthermore, the location of the weather impacts can have a great influence on the amount of leeway that traffic managers have in applying these tactics. In New York, departure fixes, the gateways to en route airspace where departure traffic from several metroplex airports are merged onto en route airways, are particularly critical. When congestion (volume of traffic in excess of capacity) occurs near departure fixes as a result of weather impacts, traffic managers must resort to airborne holding or unplanned departure stops to quickly reduce traffic over the fix to manageable levels. Nonetheless, when convective weather impacts densely packed and busy metroplex airspace, it is inevitable that traffic will need to use impacted departure fixes and routes to keep delays in check. For this reason, predictions of the weather-impacted capacity of critical airspace resources like departure fixes that are based in the reality of commonly used impact mitigation tactics, are needed to help traffic managers anticipate and avoid disruptive congestion at weather-impacted departure fixes.

The Route Availability Planning Tool (RAPT) DeLaura (2008), is a departure management decision support tool that has been used in the New York operations since 2003. It predicts the weather impact on departure fixes and routes based on departure times. RAPT assigns a blockage status (RED, YELLOW, or GREEN) to individual departure routes based on the departure time, the predicted severity of the convective weather that will impact the route, the likelihood that a pilot will deviate to avoid the weather along the route, the operational sensitivity to deviations in the departure airspace that the route traverses, and the location of the primary weather impacts on the route. These blockage forecasts assist traffic managers in prompt reopening of routes closed by convective weather impacts, provides warning of impending weather impacts, and provides an objective and operationally relevant measure of the severity of convective weather impacts on departure operations.

This paper presents an analysis of observed fair weather and convective weather impacted throughput on New York departure fixes. RAPT departure status and impact location are used to characterize the severity of departure fix weather impacts, and weather-impacted fix capacity ranges are estimated as a function of RAPT impacts.

1. DEPARTURE MANAGEMENT TACTICS IN THE NEW YORK AIRSPACE

The New York airspace is a complex maze of invisible pathways, with specific protocols and choreographed paths for each

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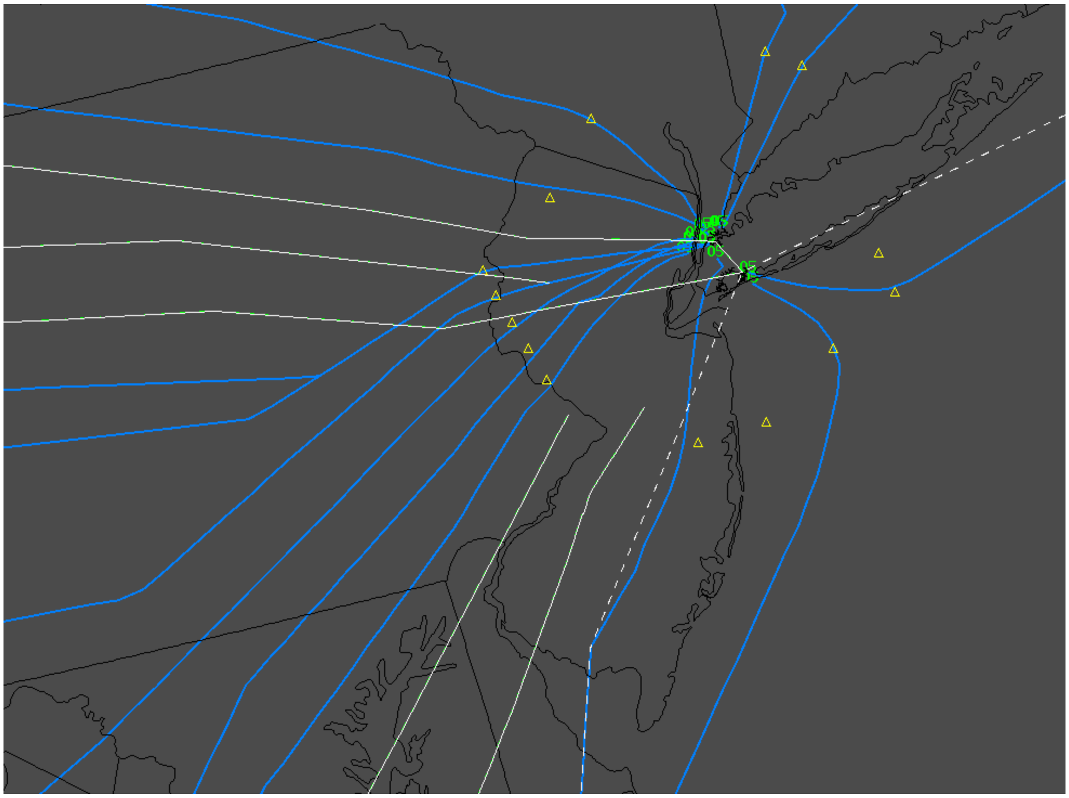


Figure 1. The primary New York departure routes (blue lines), arrival routes (white lines) and departure fixes (yellow triangles). The departure fixes are where flights transition from terminal radar approach control (TRACON) to en route traffic control.

flight. Like dancers in a performance, flights are traversing the space in different directions following these invisible protocols and paths but each maintains separation from the others.

Figure 1 shows these pathways in the New York airspace. The blue lines are departure paths, and the white lines are arrival routes. At the convergence of these routes is the densely packed New York Metro area where Newark Liberty International, John F. Kennedy International, LaGuardia, and Teterboro Airports are located in close proximity to one another. Together these four airports managed approximately 1.4 million arrivals and departures in 2011, approximately 77% of New York Metro operations FAA (2012). The airspace is complex and highly structured, with closely spaced arrival and departure flows, and departure fixes and routes that are shared by several airports. This complex traffic flow structure becomes more complicated when weather impacts this airspace and flows must be dynamically managed.

When convective weather impacts in New York Airspace result in the initiation of a Severe Weather Avoidance Program (SWAP), Traffic Flow Managers (TFM) use a variety of tactics to maximize efficiency and safety given the weather conditions and traffic demands. As the situation requires, different restrictions may be applied to control airspace, specific aircraft, traffic flows, or airports. The location of the impact, the airspace structure in the area, and the nature of the demand that uses the impacted areas are key considerations in selecting the mix of restrictions appropriate to best manage traffic. (DeLaura 2011b).

Traffic rate restrictions on routes or fixes, implemented as required miles-in-trail (MIT) or minutes in trail (MINIT) separations enable traffic managers to leave traffic on its original route and accommodate decreased capacity or increased uncertainty by reducing the traffic rate. In-trail restrictions increase the required space between the aircraft, providing greater flexibility to the air traffic controller to accommodate pilot deviations to avoid storms.

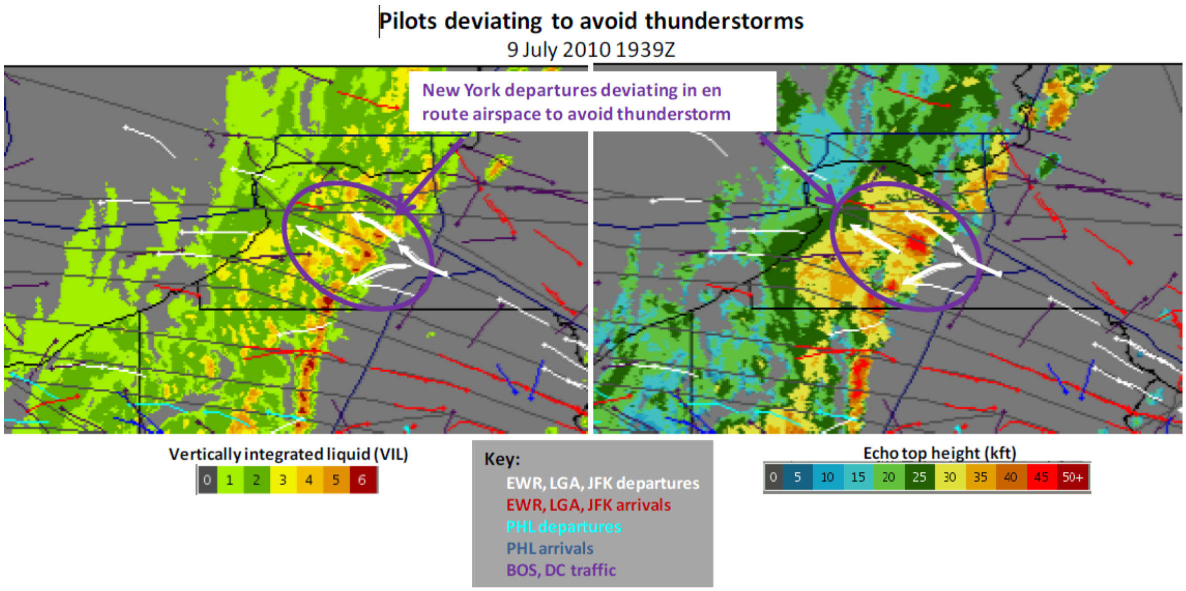


Figure 2. Pilots maneuvering to avoid convective weather.

In-trail restrictions can be easily adjusted up or down as conditions change.

As impacts become more severe or widespread, two or more traffic flows may be merged into a single, weather avoiding traffic flow. If the impact occurs at a fix, a similar maneuver can be used to direct all the traffic over an unimpacted fix before the flights return to their original routes. This flexibility supports higher rates of departure throughput while enabling traffic to bypass impacts. Flights shift only a minimal distance to avoid the weather before easily transitioning back to their original routes. These smooth transitions mean merging is easily implemented on adjacent routes and prevents local weather impacts from propagating to other unimpacted fixes. Merged traffic flows can be dynamically adjusted when weather impacts are rapidly evolving and difficult to predict, and often require coordination only among traffic controllers in a single en route control center.

If an impact makes a route fully unusable, traffic can be rerouted to avoid the impacted area entirely. Rerouting is a significant flight path change and will be implemented through altering the aircraft's flight plan. ATC controlling areas on the flight's new path will know to expect the flight and react

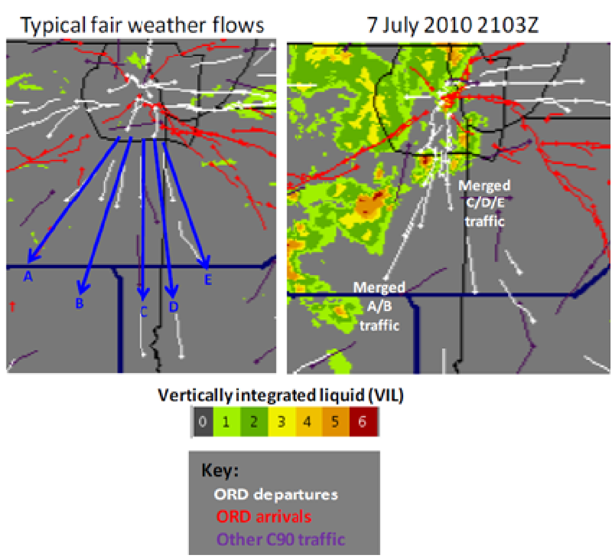


Figure 3. Pilots merging to avoid convective weather.

accordingly. When a fix/route is closed (zero capacity) the flights assigned to that fix will be rerouted. Rerouting usually requires coordination between two or more en route control centers.

2. QUANTIFYING CONVECTIVE WEATHER IMPACTS USING THE ROUTE AVAILABILITY PLANNING TOOL (RAPT)

The Route Availability Planning Tool (RAPT) is a decision support tool that provides forecasts of convective weather impact on specific departure routes by departure time (Robinson 2009). RAPT assigns a departure blockage status of RED, YELLOW, or GREEN based on the predicted location and severity of weather impacts and the flexibility to avoid the weather within the boundaries of the route. These blockage statuses enable air traffic managers to make informed decisions when to reopen routes post-impact, and provide advance notice to close routes that will become severely impacted.

A RAPT RED blockage status (figure 4) indicates that there is operationally significant weather impacting the route that is unavoidable without deviating outside of route boundaries that account for typical weather-avoiding deviations. The RED CONOPS advises closing the route and beginning to plan reroutes or severely restricting traffic flows. A YELLOW blockage status (figure 5) indicates that some weather impact will be unavoidable and / or there is considerable uncertainty about the degree of impacts, and that traffic managers should consider additional information in determining the best course of action. The RAPT GREEN blockage (figure 6) indicates that no significant weather is predicted to impact the route, and flights whose departure status is GREEN should be released for departure. Routes that were closed or restricted that have a GREEN status should have their restrictions relaxed or removed altogether (figure 6).

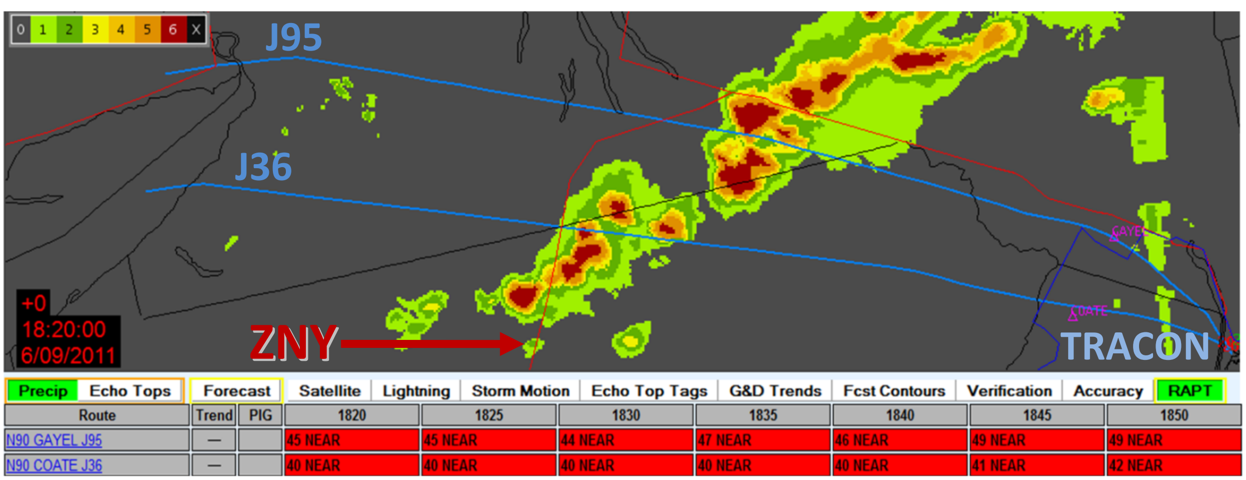


Figure 4. Convective weather results in a RAPT RED impact on jet routes J95 and J36 (blue lines). The ARTCC boundaries are red; the TRACON boundary is dark blue.

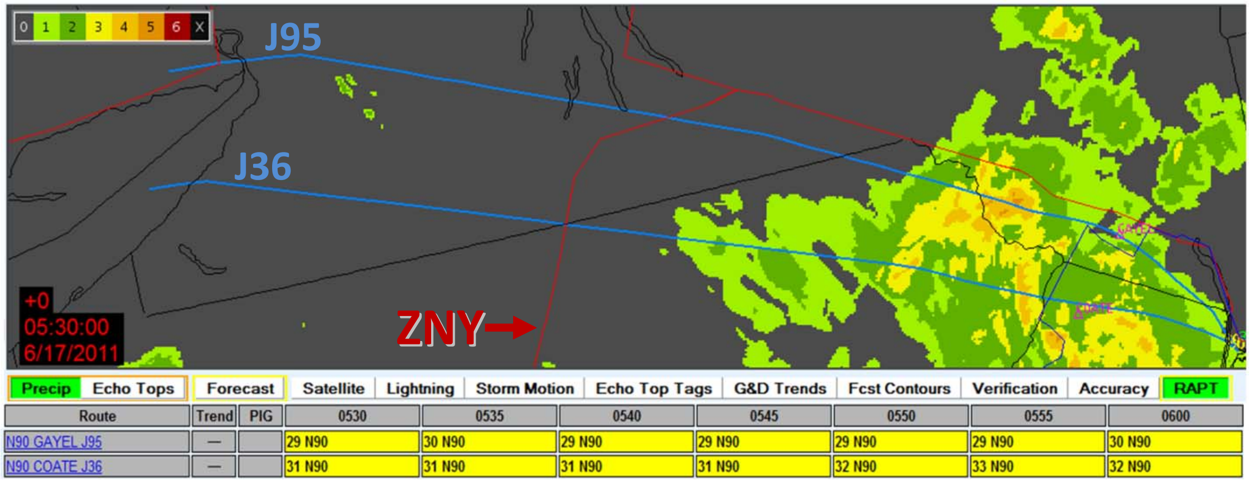


Figure 5. RAPT YELLOW status on routes J95 and J36 due to storms in TRACON (N90) and New York en route control (ZNY) airspace. ZNY ARTCC boundaries are red; the TRACON boundary is dark blue.

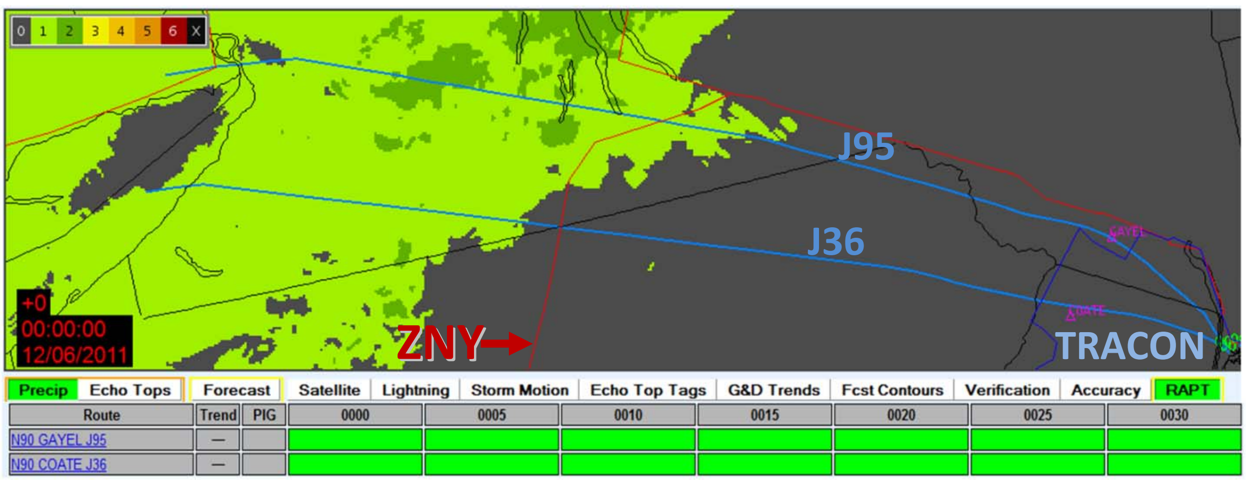


Figure 6. Precipitation far en route on J95 and J36 is present but not operationally significant. The ARTCC boundaries are red; the TRACON boundary is dark blue.

In addition to the blockage color, RAPT provides information about the location along the departure route where impacts are first identified. Impact locations are defined as N90 (TRACON airspace), NEAR (en route airspace adjacent to the TRACON and departure fix) and ENR (far en route airspace, beyond the adjacent en route airspace). Figure 7, 8 and 9 below show blockages in these different locations.

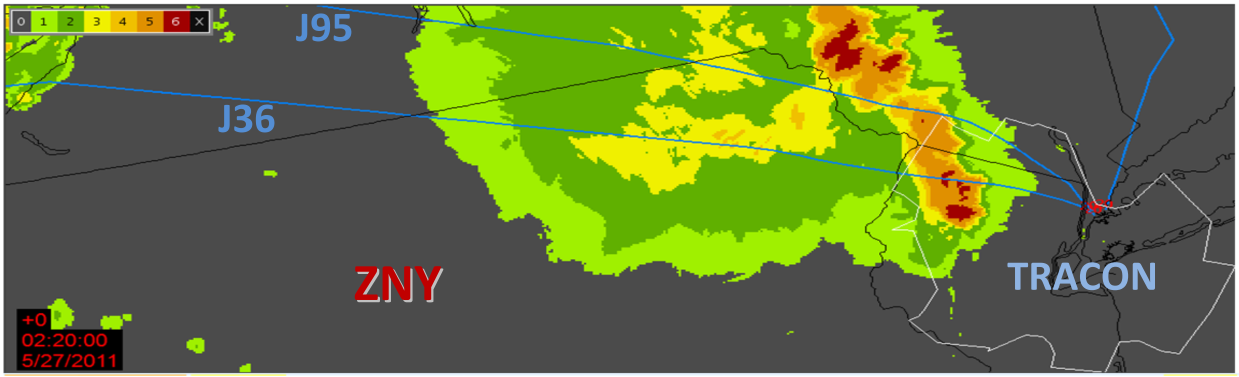


Figure 7. J95 and J36 are impacted by convective weather impacts in the TRACON (RAPT N90 location).

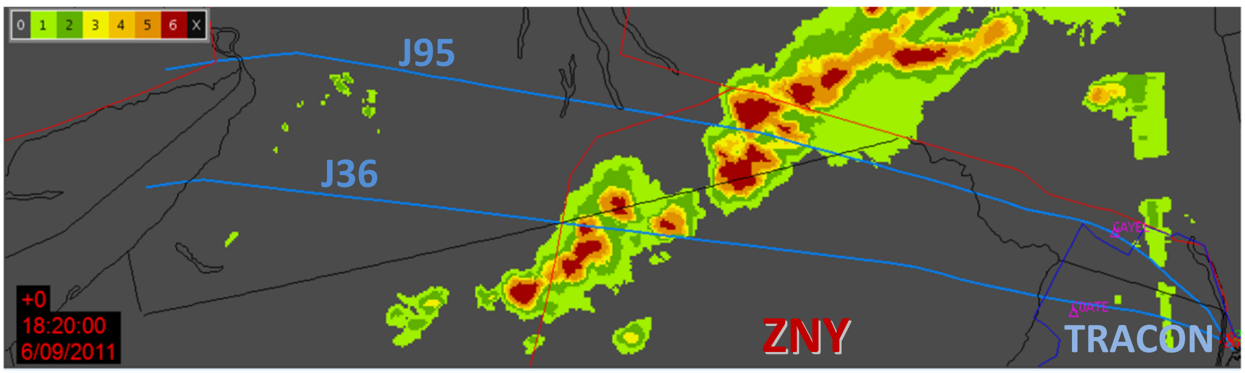
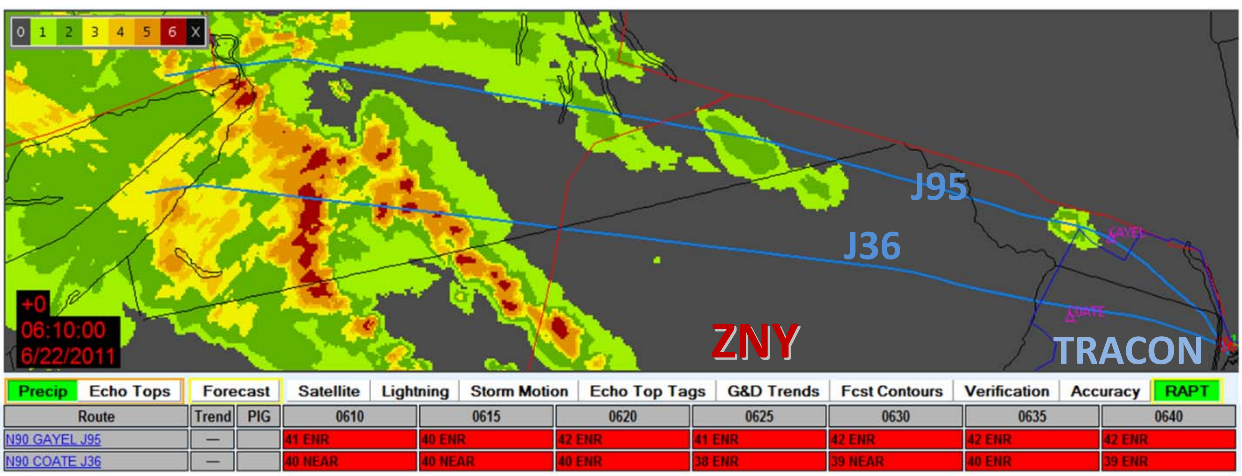


Figure 8. J95 and J36 are impacted by convective weather impacts in ZNY (RAPT NEAR location).



Route	Trend	PIG	0610	0615	0620	0625	0630	0635	0640
N90 GAYEL J95	—		41 ENR	40 ENR	42 ENR	41 ENR	42 ENR	42 ENR	42 ENR
N90 COATE J36	—		40 NEAR	40 NEAR	40 ENR	38 ENR	39 NEAR	40 ENR	39 ENR

Figure 9. J95 and J36 are impacted by convective weather in more distant en route airspace (RAPT ENR location).

2.1 *OBSERVED DEPARTURE FIX USAGE*

To establish the relationship between convective weather impacts and resource capacity, observed traffic counts were correlated to RAPT forecasts. To determine traffic counts over the fix, flights were identified from Enhanced Traffic Management System (ETMS) data. Flights that departed from the four major airports in the New York metroplex for which RAPT blockages are forecast (Newark Liberty International, John F. Kennedy International, LaGuardia, and Teterboro Airports) were identified. The observed flight trajectories were compared to the locations of the major departure fixes. Flights were assigned to the fix that they passed closest to, but were removed from the data set if this distance exceeded one sixth of a degree. Traffic counts were calculated for successive 30 minute analysis bins from 10Z to 2Z for the following day (6AM to 10PM local) on each of 74 analysis days in 2011.

The RAPT forecast of route blockage (RED, YELLOW, GREEN) was used as the measure of convective weather impact. RAPT status for the 30 minute analysis bins for each departure fix was defined as the majority RAPT forecast value for all RAPT departure routes passing through the fix during the time period defined by the bin This method mimicked observed TFM's decision making based on assessing the RAPT status. For 9 of the 11 fixes analyzed, the majority of departure traffic using the fix followed a single jet route in en route airspace to the boundary of the RAPT domain (approximately 45 minutes flight time); only two fixes (ELIOT and RBV) distributed traffic to multiple jet routes; for these fixes, RAPT impacts on multiple routes had to be combined into the 30-minute RAPT status for the fix.

Figure 10 shows the distribution of 30 minute departure fix traffic counts partitioned by RAPT color. The distribution of departure rates' 25th and 75th percentiles and the median has been plotted in gray behind the histograms. While these distributions show the general decrease in fix traffic as impacts increase, fix use within individual blockage colors varies considerably. The achievable (and optimal) fix use for impacted fixes (RAPT RED and YELLOW) is related to several situational factors beyond the local weather impacts that RAPT forecasts. The decision to make heavy use of impacted airspace – instances in the fairly long tails of the YELLOW and RED distributions - requires considerable judgment on the part of the air traffic manager. Several factors may enter into the decision, including the degree of volatility, extent and severity, geographical distribution and location of weather impacts DeLaura (2011a).

For widespread extended impacts which affect a number of routes, heavy use of YELLOW or even RED fixes may be required to maintain throughput and reduce the likelihood of crippling delays and surface gridlock. Figure 11 shows the relationship between blockage extent and departure resource use for 74 days from 2011. It plots the percentage of departures on fixes with a given impact (RED, YELLOW, or GREEN) vs. the percentage of time that level of impact occurred. Each day is represented by a triplet of dots (RED, YELLOW, GREEN): green dots give the percentage of departures during periods of RAPT GREEN vs. the percentage of time that departure fixes were GREEN, and likewise for YELLOW and RED. If all fixes were used equally, regardless of weather impacts, dots of all colors would fall on the diagonal.

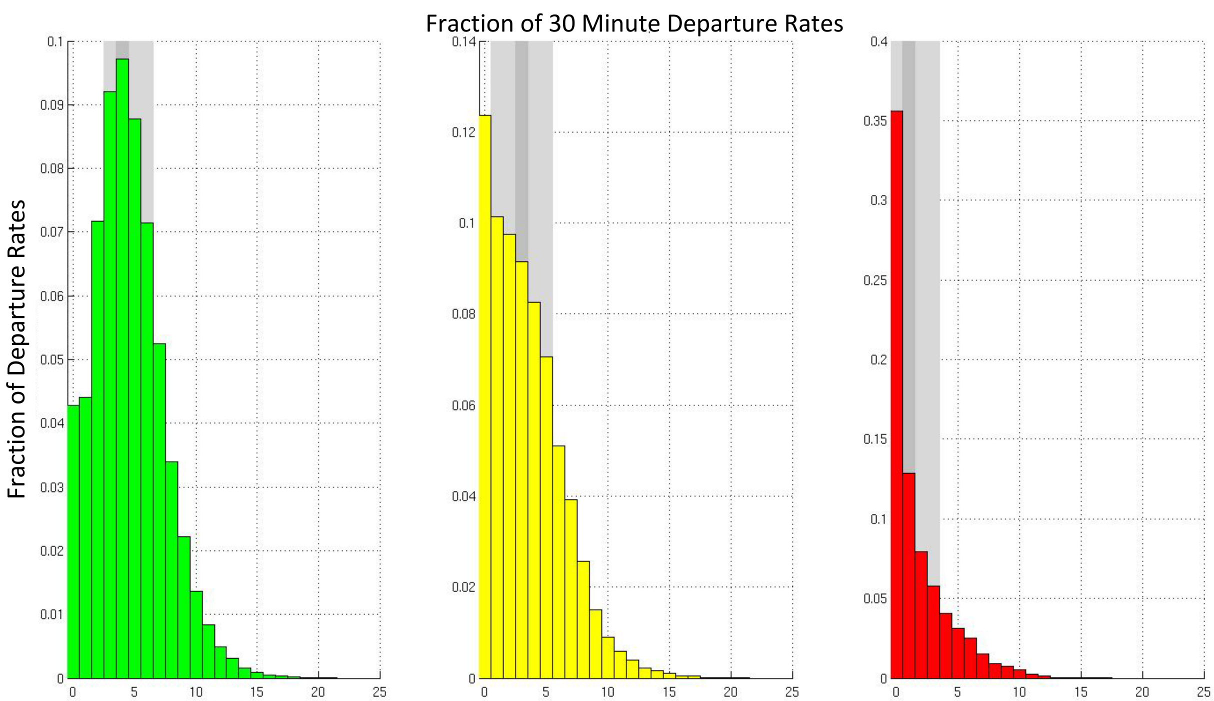


Figure 10. Distribution of traffic counts over 30 minute periods by blockage color.

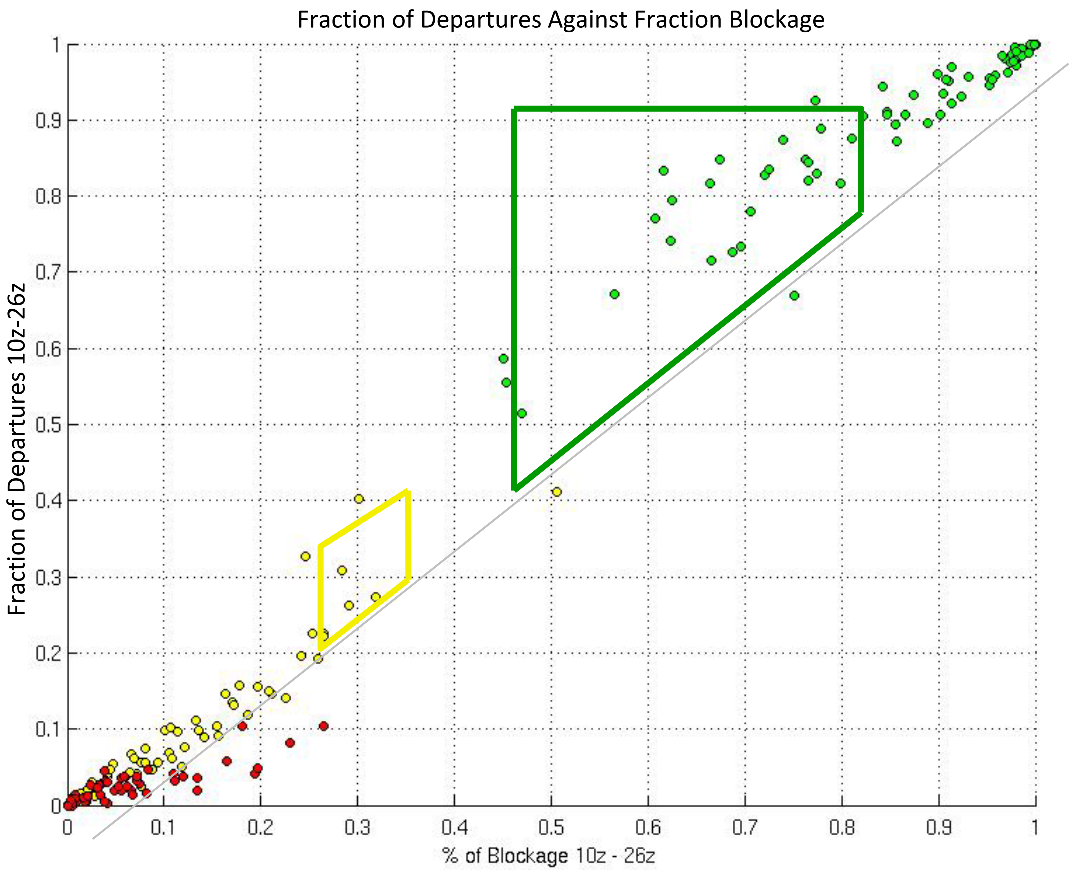


Figure 11. A visualization of the fraction of traffic handled by each blockage color by the fraction of the day with that blockage.

The cluster of GREEN dots in the top right corner represents fair-weather days, when fixes were GREEN the vast majority of the time, and nearly all departures were released on GREEN fixes. On days with weather impacts, GREEN use tends to fall above the diagonal, suggesting that GREEN routes carry a larger percentage of demand (green box on the plot). During periods of YELLOW and RED, departure rates were typically lower than during GREEN periods, so the percentage of the day taken up by a YELLOW or RED blockage typically does not handle an equal percentage of the day's traffic, and the dots typically fall below the diagonal. However, on several days with a high percentage of YELLOW, YELLOW fix use accounts for a higher share of traffic than normal (YELLOW box on plot). RED fix use also increases with increasing RED blockage (albeit more slowly than YELLOW), indicating that even heavily impacted fixes may carry considerable traffic as impacts become increasingly widespread.

Weather impact location strongly influences the available capacity of the fixes. Figure 12 shows the distribution of traffic counts over a 30 minute period for forecasts of RAPT RED by the location of the weather impact. Percentiles and medians for the distribution are plotted behind the histograms as in figure 10. RAPT RED blockages near the TRACON ('N90 REDs') often completely shut down fix traffic (thirty-minute traffic counts were 0 for approximately 65% of the N90 REDs, and 1 for another 15%). When the RAPT RED location was in the immediately adjacent en route control center airspace (RAPT 'NEAR' location), traffic is still heavily restricted (counts of 2 or less approximately 70% of the time). Impacts in the immediately adjacent NEAR airspace often result in traffic restrictions that are passed back to the fix and / or uncertainty about whether the en route center will be willing to accept an unrestricted stream of traffic result in a reduced fix use, even if the fix itself is not directly impacted.

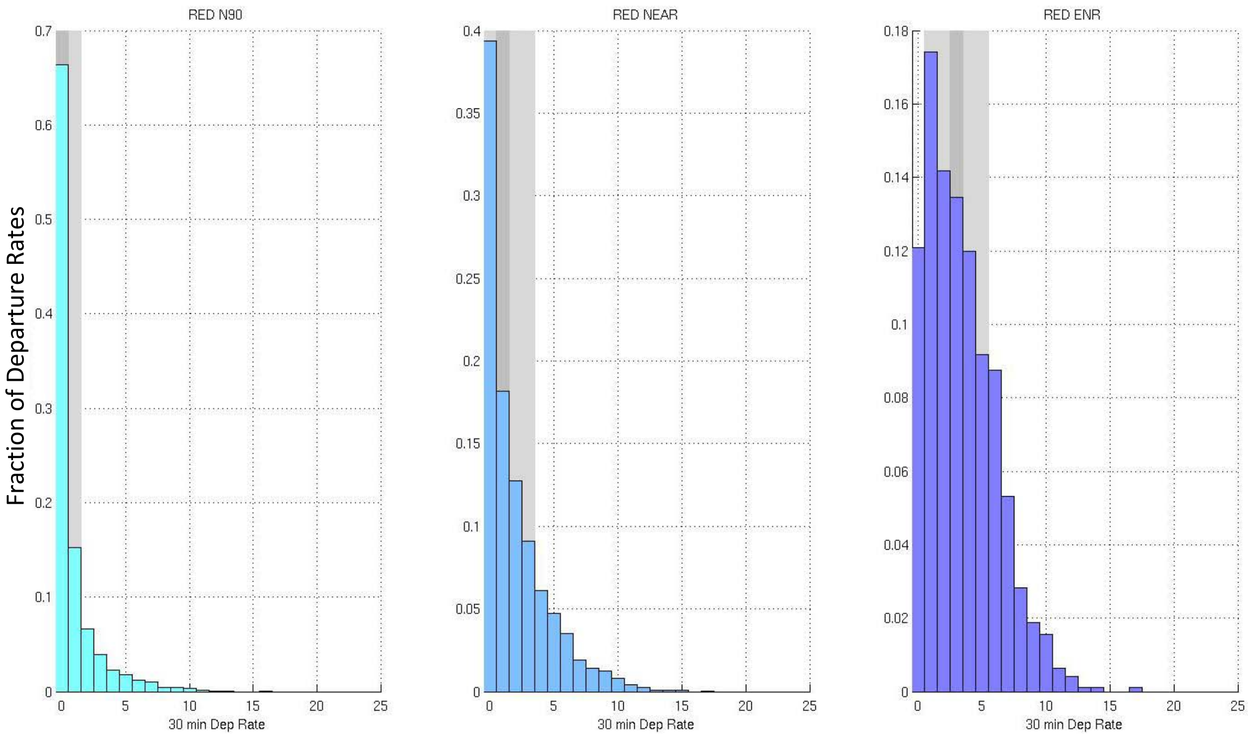


Figure 12. Distribution of traffic counts over 30 minute periods during RED blockage by RAPT blockage location.

However, when the blockage location is ENR, fixes with a RED forecast blockage support a much higher traffic rate – approaching the observed rates for YELLOW fixes. This is most likely due to the increased ability to manage weather avoiding deviations in less congested en route airspace, resulting in fewer passed back restrictions and more certainty that departure traffic will be accepted by en route controllers. These statistics highlight the network behavior of the National Airspace System (NAS), and provides empirical data that give insights into the propagation of traffic flow disruptions due to convective weather. A comparison of YELLOW fix use by blockage location shows a similar, although somewhat less-pronounced, behavior (figure 13). Although RAPT attempts to calibrate its blockage forecasts to account for the variation in operational sensitivity to weather impacts in different airspaces, the effect may be greater than RAPT currently estimates. These results also suggest that RAPT RED blockage calibration may need adjustment in en route airspace, and / or that RAPT departure trajectories should not probe so far into en route airspace.

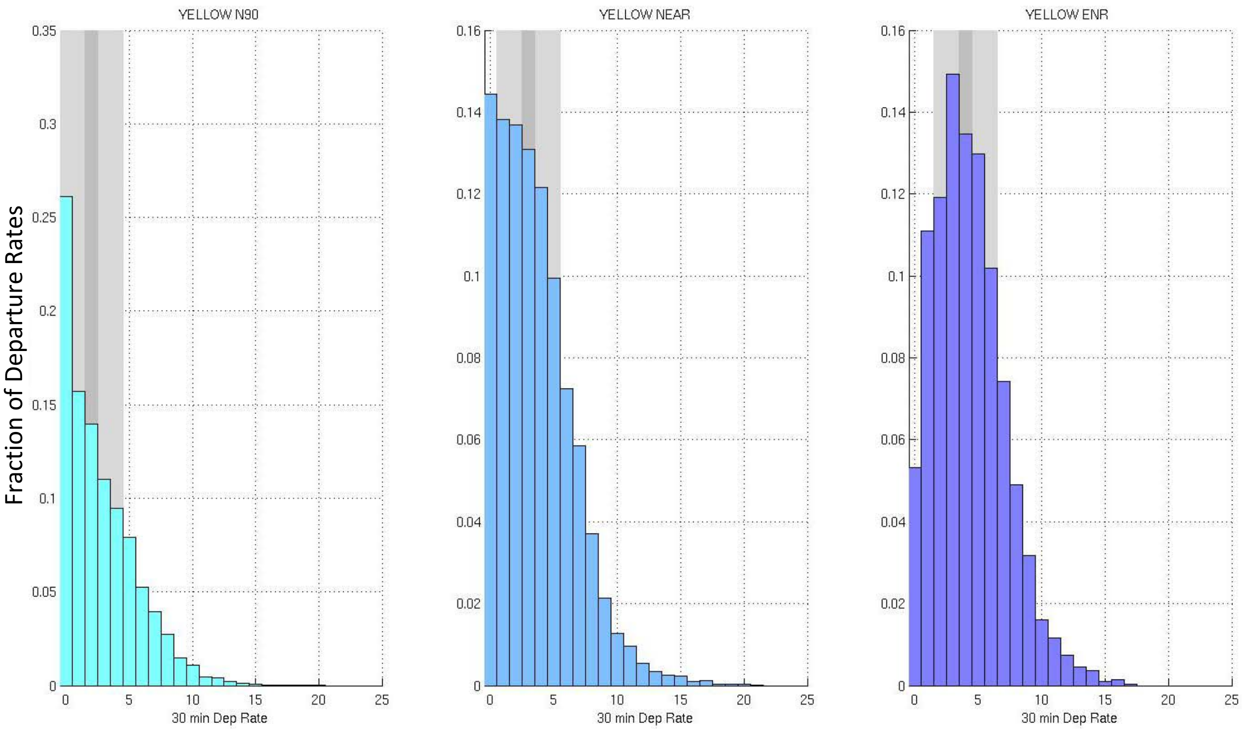


Figure 13. Distribution of traffic counts over 30 minute periods during YELLOW blockage by blockage location.

The dependence of fix use on blockage location suggests some consequences for traffic management in response to rapid storm motion or evolution. Storms that move from en route airspace towards the airports (or vice-versa) create the need to reevaluate traffic flows regularly to respond to the changing capacity. These capacity changes can happen over 30 minutes or periods up to several hours, depending on the speed of storm motion and evolution. The storm's severity, predictability, and the demand on the impacted route also influence how closely the conditions need to be monitored to ensure sufficient reaction time to cuts in capacity. Highly organized, more predictable storms may permit longer range planning and less frequent plan updates than rapidly evolving and difficult to predict storms.

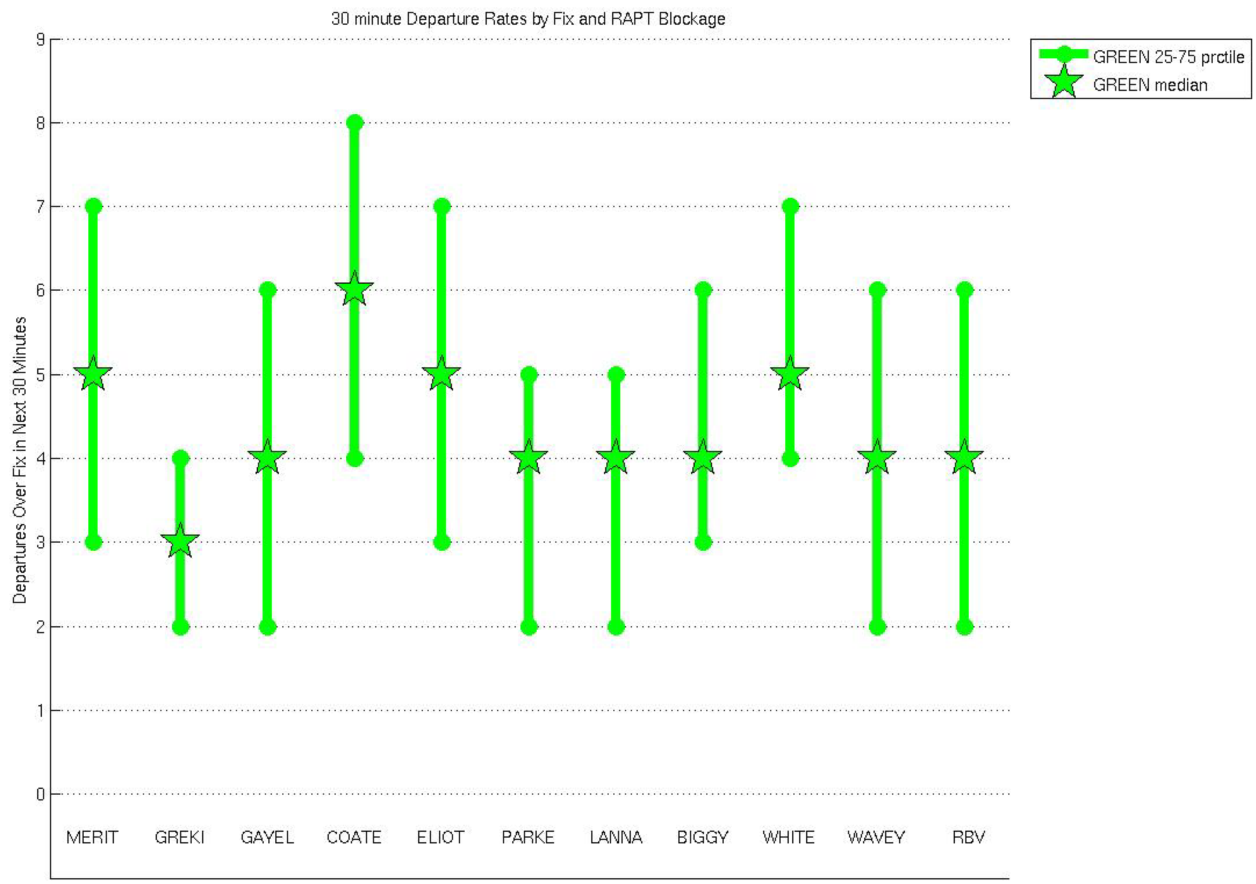


Figure 14. The ranges of traffic counts for individual departure fixes during GREEN conditions.

The geographical distribution and distribution of demand among fixes can also affect how fixes are used when convective weather impacts arise. Figure 14 shows the observed median, 25th and 74th percentile fix counts for the main New York Metro departure fixes during RAPT GREEN conditions. Fixes are arranged across the x-axis in counterclockwise geographic order, from the northeast-bound to southbound (WAVEY) departures. RBV, at the far right of the x-axis, handles westbound and southwest-bound departures from JFK airport only.

Fair weather fix counts reflect scheduled demand and the preferred routings between origin-destination pairs. COATE, for instance, is the preferred fix used for flights out of the New York area destined to Chicago O'Hare airport; over the course of a day the top three New York airports on average depart 67 flights to Chicago O'Hare FAA (2012). The observed heavy use of COATE is driven, in part, by the heavy New York – Chicago flight schedules. The fixes are grouped into the New York departure gates as follows:

- East: MERIT, GREKI
- North: GAYEL, COATE
- West: ELIOT, LANNA, PARKE, BIGGY, RBV (JFK traffic only)
- South: WHITE, WAVEY

Arrival flows are tightly sandwiched in between the departure gates. Nonetheless, within a particular departure gate, traffic managers have considerable flexibility to maneuver flights through one fix or another (without filing a reroute) to avoid weather. This is a tactic that is commonly employed in New York, particularly in the management of the north and west gate fixes. So, for instance, flights that are filed through PARKE onto the J6 jet route may be taken out the LANNA departure fix to avoid impacts near PARKE and then maneuvered back onto J6 downstream from PARKE. Furthermore, when it becomes necessary to

Figure 15. The ranges of traffic counts for individual departure fixes during YELLOW conditions.

reroute flights, traffic managers will try to reroute them to alternative fixes within the departure gate to minimize coordination and disruption of traffic flows. The distribution of fix traffic during RAPT YELLOW (figure 15) illustrates these tendencies. During YELLOW blockage conditions rates are lower than during GREEN blockage. However, within each departure gate, the median departure counts for each fix are very close, suggesting that departure traffic can be readily rearranged between fixes within a particular gate to avoid weather impacts. It is interesting to note that since RAPT YELLOW is RAPT's most broadly defined blockage color, covering the widest range of conditions and impact uncertainty, the overall spread of observed fix traffic is broader than during either GREEN or RED conditions.

Figure 16 shows the medians and ranges for fix traffic during RED blockage. There is an overall decrease from the YELLOW blockage traffic counts for both the percentile range, as well as across all fixes for their individual median fix traffic counts. When routes are impacted with RED conditions, fixes almost always have higher traffic demand than can be safely managed. The ranges and medians seen during RED conditions are attributed to various factors. COATE's persistent high rates are probably due to the common tactic to merge COATE and GAYEL traffic when these routes are impacted. LANNA is also likely achieving higher rates due to common merging techniques; PARKE, LANNA and BIGGY are typically merged to support southwest bound flights during impacted conditions. LANNA as the middle of these three geographically (and farthest from any arrival traffic streams) would be the target trajectory for a three-as-one merge of these routes since flights could return to the other routings more easily than if the merged route was located on one of the edge routes.

Many other factors likely influence fix use during convective weather impacts. For instance, traffic managers may be more sensitive to departure deviations near active arrival flows. Conversely, they may be more tolerant of deviation on fixes that are more distant from their neighboring fixes. The reliance of an airport on a particular fix may

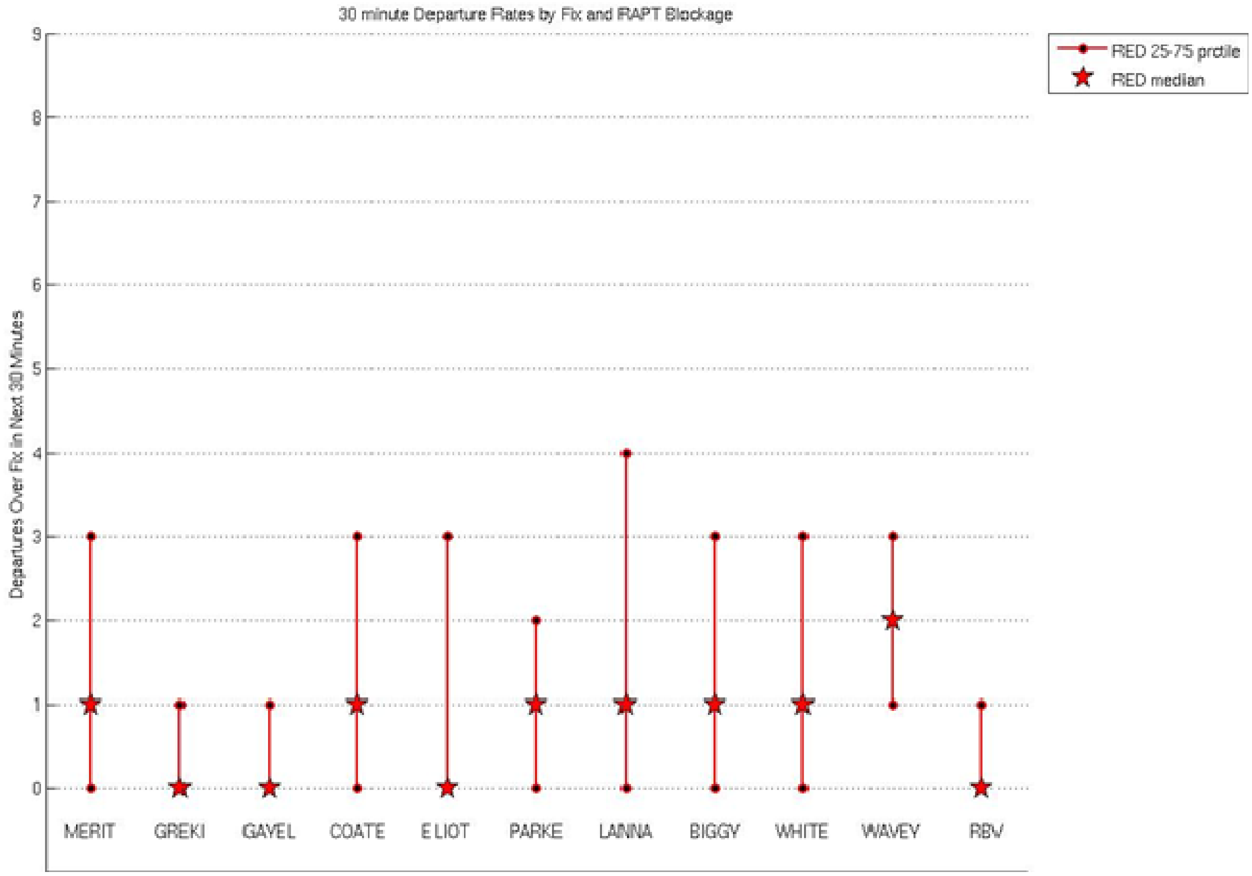


Figure 16. The ranges of traffic counts for individual departure fixes during RED conditions.

motivate high traffic flows even under RED conditions. For instance, each airport only has access to one of the southbound fixes (WHITE and WAVEY) and reroute options are difficult to coordinate, so there is great benefit if these routes can be kept open even during weather. The influence of these characteristics has yet to be measured, however, and the extent of their influence on decision making, is still unquantified.

3. CONCLUSION

During normal operations the target rates of traffic over New York's departure fixes is a balance between limiting factors such as weather, neighboring flows, and en route constraints, and motivating factors such as departure demand, and increasing surface congestion and delays. Traffic managers employ a variety of tactics to maintain efficient management of departures during convective weather impacts. Using the RAPT route blockage status as a measure of convective weather impacts on specific departure routes, this paper presented an analysis of departure fix use as a function of convective weather impact severity and location along the route. When there are widespread weather impacts and demand is significant, traffic flow managers must depart traffic in RAPT YELLOW and even RAPT RED conditions to support operations. Operational success and efficiency in restricted conditions depends on accurate estimates of manageable traffic rates over fixes to ensure throughput while preventing disruptive events such as congestion, volume stops or airborne holding.

This study shows that there are decreases in fix traffic rates with increases in RAPT blockage severity. However, the degree of reduction depends not only on the RAPT blockage color, but also on the location of blockage along the departure route. For both RED and YELLOW blockages, the observed fix traffic reduction was much greater when the weather impacts were either within the TRACON, or in downstream en route airspace immediately adjacent to on near the transition blockages occurred in en route airspace farther downstream, observed traffic reductions were less severe, possibly due to the fact that controllers in downstream en route airspace have greater flexibility to manage weather avoiding deviations. This finding suggests that it may be desirable to revise some of the RAPT parameters to better match operational capabilities. It also emphasizes the need for traffic managers and decision support systems to monitor changing impacts due to storm motion and evolution to anticipate when weather impacts will move into and out of regions where weather impacts may be magnified by operational constraints imposed by airspace structure. Finally, the study shows that traffic managers appear to distribute traffic flows among fixes within the same departure gate as needed to avoid weather impacts. This tactic has the advantage of requiring less coordination and disruption of flow structure than the implementation of reroutes, and may result in more efficient use of impacted airspace.

Models for departure operations during convective weather benefit greatly by having an objective measure of weather impact such as RAPT route blockage. However, the factors that determine achievable capacity and the desirable allocation of resources to meet demand during convective weather must take into account more than forecasts of local (i.e., fix or route) weather impacts and demand. This study identified several of those factors and provides initial quantitative measurements of their impacts on achievable capacity. Future work will expand and incorporate these factors into quantitative models that estimate achievable capacity and desirable allocation of resources under a variety of weather impact scenarios, while taking into account the considerable uncertainty present in operations (and manifest in the spread of capacity distributions). These models will enable the refinement of concepts and training for the use of existing decision support tools like RAPT, and inform the development of the next generation of decision support tools.

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