IMPROVEMENT OF TERMINAL AREA CAPACITY IN THE NEW YORK AIRSPACE

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This report is based on the S.M. Thesis of Alexander Donaldson submitted to the Department of Aeronautics and Astronautics in partial fulfillment of the requirements for the degree of Master of Science in Aeronautics and Astronautics at the Massachusetts Institute of Technology.

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Improvement of Terminal Area Capacity in the New York Airspace

by

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Abstract

The New York airspace is the most congested in the U.S. air transportation network. Increasing capacity in this area is critical to ensure the balanced growth of traffic across the U.S. This study compares the total measured runway capacity at the New York airports with the achieved throughput of the New York airspace. The comparison is performed for six airspace configurations representing operations under different wind conditions, visibility and relative arrival and departure demand. The comparison shows that in all cases the capacity of the system of airports is lower than the total capacity of the airports considered individually by approximately 20%. This finding suggests that air traffic throughput in the New York area is constrained by shared airspace resources. If these constraints could be removed, these funding suggest that capacity could be increased approximately 20% without any airport infrastructure or procedure changes.

An examination of procedures close to the airports is performed to identify fixed constraints. The impact of these constraints is not captured by the empirical analysis because these constraints are always present. This analysis identifies cases where new navigation technologies could be used to reduce the interactions between airports. The greatest potential for improvement is found to be in the lower performing configurations. Therefore procedural changes close to the airports may provide more benefit in reducing the variability of capacity between different configurations, rather than providing large increases in maximum capacity.

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Acronyms

ADS-B Automatic Dependent Surveillance-Broadcast

ARTCC Air Route Traffic Control Center

ATC Air Traffic Control

ASPM Aviation System Performance Metrics

CRDA Converging Runway Display Aid

CSPA Closely Spaced Parallel Approach

CSPR Closely Spaced Parallel Runway

ETMS Enhanced Traffic Management System

EWR Newark Liberty International Airport

FAA Federal Aviation Administration

FAF Final Approach Fix

GA General Aviation

IFR Instrument Flight Rules

ILS Instrument Landing System

IMC Instrument Meteorological Conditions

JFK New York John F. Kennedy International Airport

LGA New York LaGuardia Airport

LAHSO Land and Hold Short Operations

MIT Miles in Trail

MTOW Maximum Takeoff Weight

NAS National Airspace System

NextGen the Next Generation Air Transportation System

PDARS Performance Data Analysis and Reporting System

RNP Required Navigational Performance

ROT Runway Occupancy Time

TEB Teterboro Airport

TRACON Terminal Radar Approach Control

VFR Visual Flight Rules

VMC Visual Meteorological Conditions

Chapter 1

Introduction

The airspace around New York City handles the highest number of arriving and departing operations of any region in the United States National Airspace System (NAS). The three major New York airports, Newark Liberty International Airport (EWR), New York John F. Kennedy International Airport (JFK) and New York LaGuardia Airport (LGA) are situated in close proximity (within 15 miles) of each other. This high level of traffic and close proximity results in interaction between operations from adjacent airports preventing each airport from reaching the capacity that it could independently achieve.

The Federal Aviation Administration (FAA) is currently in the process of developing and implementing a range of technological and procedural changes known as the Next Generation Air Transportation System (NextGen). These changes may allow the decoupling of operations between the New York airports. This study will quantify both the amount of extra capacity available through decoupling current procedures, as well as the potential capacity benefits that may be obtained with improved procedures.

The closely located airports that will be examined in this analysis are the 3 major airports: EWR to the west, JFK to the southeast and LGA to the northeast of New York City, as shown in Figure 1-1. As well as, Teterboro Airport (TEB) to the north which is a busy General Aviation (GA) airport that serves some of the large demand for business and charter flights to and from New York City.

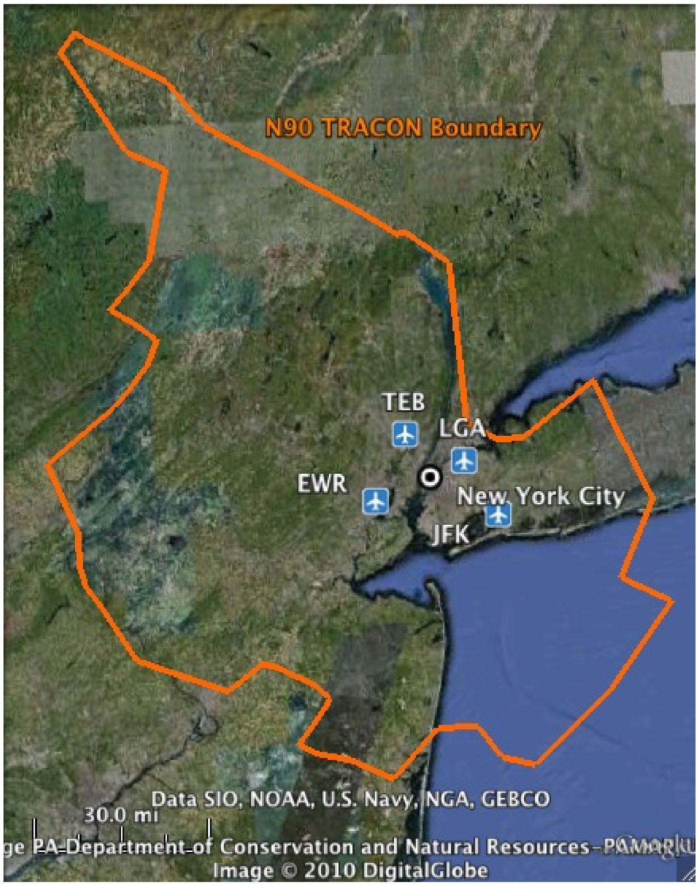

N90 TRACON Boundary
TEB
LGA
EWR
New York City
JFK
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
30.0 mi
ge PA-Department of Conservation and Natural Resources–PAMAGI
Image © 2010 DigitalGlobe

Figure 1-1: The four New York airports included in this study as well as the N90 TRACON boundary (shown in orange)

These airports depend on the airspace immediately surrounding them to both supply arriving aircraft and accept departing aircraft. Responsibility for control of this airspace is given to the New York TRACON, known by the designation "N90." The TRACON provides the interface between the individual New York airports and the en route airspace by controlling all arriving and departing air traffic within the area shown in Figure 1-1. Beyond the TRACON, aircraft are controlled by Air Route Traffic Control Centers (ARTCCs) such as New York Center (ZNY) or Boston Center (ZBW).

Ideally, the TRACON and ARTCC airspace that connects the selected airports to the wider air route network would be able to do so without placing any limits on the flow of traffic. However, as this study will show, this is not possible under current procedures due to the high density of the traffic in the New York area. These limitations mean that compromises have to be made in order to give each airport an equitable share of the available airspace capacity. These compromises mean that some New York airports are unable to attain the capacities that would be expected if they operated with their own dedicated airspace.

With demand for air travel in the United States expected to continue growing over the coming decades [1], increased capacity to the New York area will be necessary. Operating the airspace at close to capacity also has the secondary impact of increasing the magnitude and volatility of delays both at New York airports and also across the entire national airspace. Due to the highly interconnected nature of the air transportation system these delays that start in congested airspace can then rapidly propagate across the entire network.

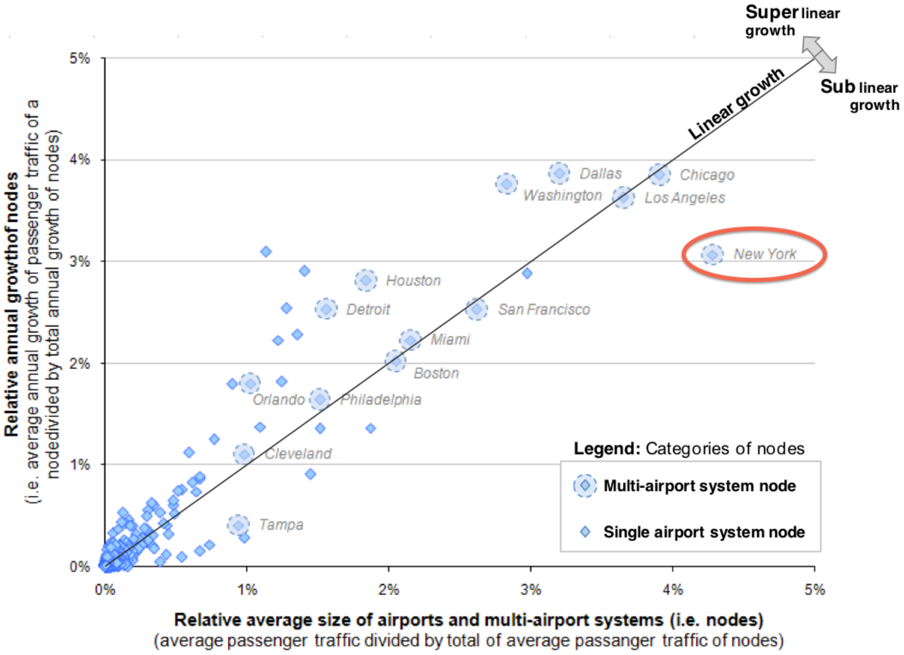


Figure 1-2: Relative annual growth versus relative size of airports and multi-airport systems in the United States from 1976 to 2005 [Reprinted from [2]]

Figure 1-2 shows that the New York airport system has a relative annual growth in traffic that is substantially lower than its traffic share. Scale free network theory predicts that the growth rate at nodes in a scale free network would increase linearly with traffic share. This prediction holds for most other nodes in the air transportation network [2]. The lower than expected growth rate shown for New York in Figure 1-2 suggests that the entire New York airport system is reaching its maximum capacity under current operational rules. Therefore growth of traffic at New York is likely to require increasing the capacity of the airspace feeding traffic to the New York airports.

This bottleneck at New York has implications for the growth of the entire U.S. air transportation network, since its airports serve a large origin/destination market and are also important hubs for several airlines both domestically and internationally.

The objective of this study is to quantify how much additional capacity is available at the New York airports if the current constraints imposed by the airspace could be removed. NextGen may provide the opportunity to both increase the capacity of current procedures as well as enable the design of new, higher capacity procedures. Identification of which specific procedures are limiting capacity is crucial in highlighting which NextGen technologies are likely to have the largest impact on capacity around New York.

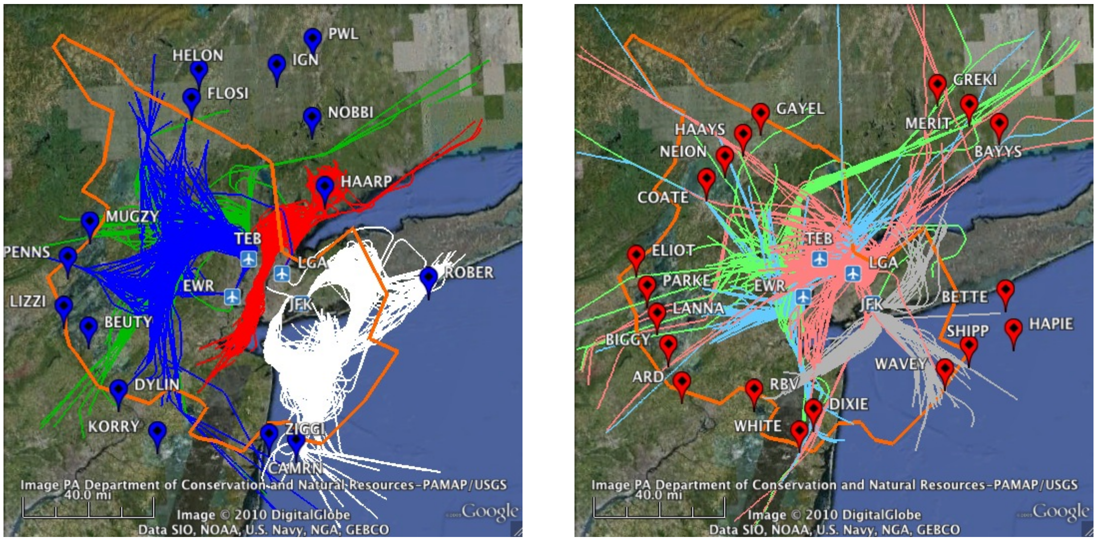
Chapter 2

Characterization of New York Traffic

The capacity of the New York airspace varies substantially depending on the particular set of runways and arrival and departure procedures in use at a given time. In order to investigate the potential for capacity gains across the spectrum of different operating conditions, this study will examine several representative configurations of the airspace. It is expected that some of these configurations will have higher potential capacity gains than others. In order to perform this analysis for different operating conditions, the alternate modes of operation of the New York airspace must be defined and configurations of interest identified.

2.1 Airspace Configurations

At a high-level, the arrival and departure procedures can be thought of as the routes that connect the runways at each airport to the en-route airspace of the national air transportation network. The points at which procedures in the New York airspace interface with the en-route airspace are fixed under all conditions. These fixed points are the arrival and departure "fixes" at the boundary of the N90 TRACON and are


PWL
HELON
IGN
FLOSI
NOBBI
HAARP
MUGZY
TEB
PENNS
LGA
ROBER
EWR
LIZZI
JFK
BEUTY
DYLIN
KORRY
ZIGGI
CAMRN
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google
GREKI
GAYEL
HAAYS
MERIT
NEION
BAYYS
COATE
TEB
ELIOT
LGA
PARKE
EWR
LANNA
JFK
BETTE
BIGGY
SHIPP
HAPIE
WAVEY
ARD
RBV
DIXIE
WHITE
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Google

(a) Arrival flight tracks and fixes

(b) Departure flight tracks and fixes

Figure 2-1: Location of arrival and departure fixes at the boundary of the New York airspace and representative arrival and departure flight tracks (PDARS data)

shown, along with representative flight tracks, in Figure 2-1[1]. However, the airport end of the arrival and departure procedures changes to connect with the particular runways in use at a given time. This variability means that the particular configuration of routes through the airspace is entirely dependent on the runways in use at a given time. A particular configuration of routes through the New York airspace will be referred to as an "Airspace Configuration." Due to the different procedures in use, each airspace configuration is expected to have a different potential capacity.

Arrival fixes are not normally shared between airports, with each airport having several fixes to accommodate traffic from different directions. However, departure fixes are typically shared between the New York airports. The these shared fixes require departure traffic from different airports to be merged within the TRACON airspace, as shown in Figure 2-1b. JFK is exceptional because it operates independently from the other airports for westbound and transatlantic departures, using dedicated fixes RBV (westbound), BETTE and HAPIE (transatlantic).

It is important to note that the procedures which comprise an airspace config-

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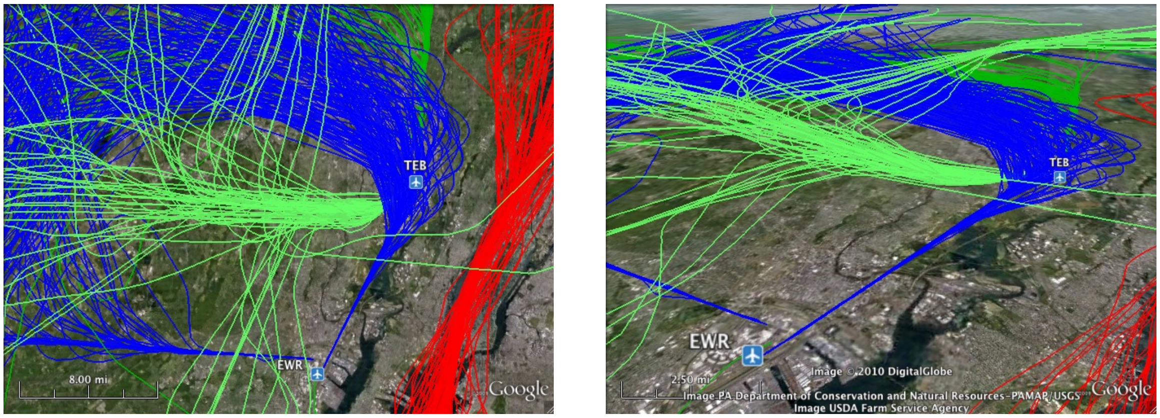
[1] In this and all subsequent diagrams the flight tracks are color coded according to the airport which they are associated: blue-EWR, white/grey-JFK, red-LGA, and green-TEB.


TEB
EWR
8.00 mi
Google
2.50 mi
Image © 2010 DigitalGlobe
Image PA Department of Conservation and Natural Resources-PAMAP/USGS
Image USDA Farm Service Agency

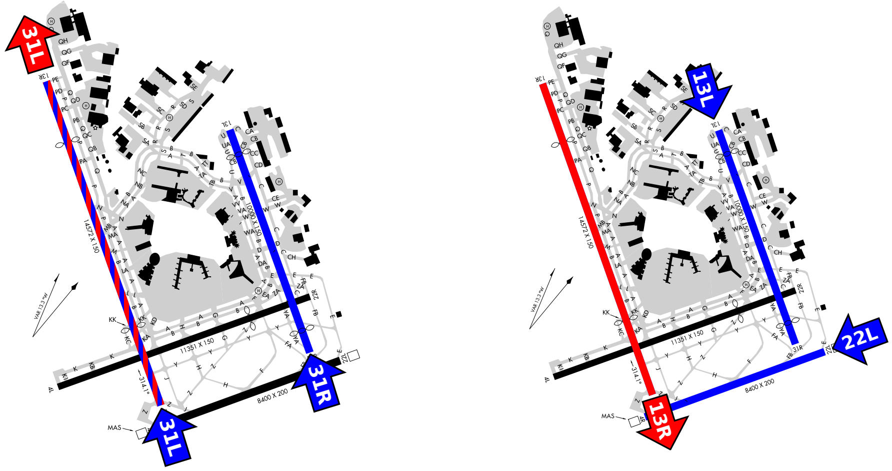
(a) Top-down view (b) Perspective view

Figure 2-2: An example of the use of vertical separation between tightly space procedures (arrivals to EWR 22L (blue) and departures from TEB 24 (light green)).

uration are inherently three-dimensional in nature. Vertical separation instead of horizontal separation may be used between procedures. An example of tightly vertically separated procedures are the approach to EWR runway 22L and the departure from TEB runway 24 as shown in Figure 2-2. The runway 24 departures from TEB are initially held at 1500 ft until they are adequately separated from the EWR 22L arrivals. At this point the TEB departures climb until they are sufficiently high above the EWR arrivals and then cross the arrival stream again en route to the appropriate departure fix.

2.2 Airport Configurations

Given that the airspace configuration is dictated by the runways in use at a given time, understanding airspace configurations requires an understanding of the factors that influence runway configuration selection. The capacity of a single airport is strongly tied to both the runways available for arrival and departure operations, as well as the physical layout of those runways. The arrangement of the runways is important because it often determines the degree of interaction between operations on the different runways at an airport. A higher level of dependency between operations on different runways generally leads to a lower capacity, since extra time is required to ensure that operations are correctly sequenced to avoid conflicts. Alternatively, if runways are able to operate independently, arrivals and departures generally occur as soon as each aircraft is ready.



(a) Arrivals: 31L & 31R, Departures: 31L

(b) Arrivals: 13L & 22L, Departures: 13R

Figure 2-3: Two example runway configurations at JFK

Figure 2-3 shows an example of two different runway configurations at JFK with two different types of interaction. In Figure 2-3a the interaction occurs because both arrivals and departures are sharing runway 31L. This means that a departing aircraft on 31L cannot begin its takeoff roll until the preceding arrival is clear of the runway. However, in Figure 2-3b the interaction is due to the departure flight path from 13R crossing the arrival runway 22L. This is a slightly higher capacity configuration because the departing aircraft can now begin its takeoff roll as soon as the 22L arrival touches down (i.e. the departure does not have to wait for the dependent arrival to slow-down and exit the runway before beginning its takeoff).

The performance of a particular runway configuration under a range of different traffic conditions can be illustrated using a Pareto capacity envelope [3] such as the one shown in Figure 2-4[2]. A capacity envelope defines the limit of the possible operating points of a runway configuration, and can either be derived based on observed

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[2] The Pareto capacity envelope is drawn through all "non-dominated" points. A non-dominated point is defined as being any point where an increase in departure (or arrival) rate cannot be achieved without reducing arrival (or departure) rate.

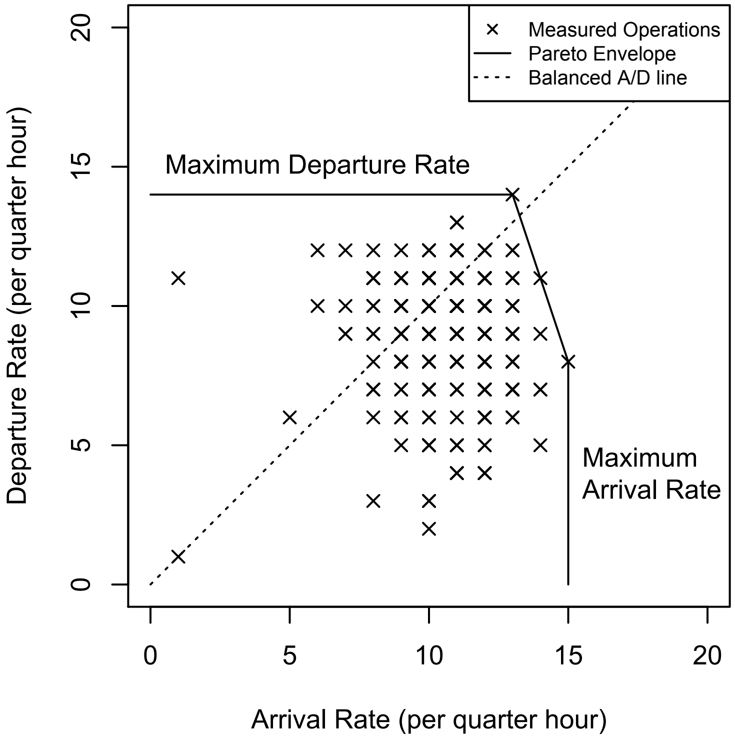

Figure 2-4: An example Pareto capacity envelope for EWR

airport capacities or estimated theoretically. Figure 2-4 shows that for most levels of arrival demand in this example (up to 13 aircraft per quarter hour), the maximum departure rate can be achieved independently of arrival capacity. Above 13 arrivals per quarter-hour, departures must be reduced below the maximum level in order to attain the maximum possible arrival rate. This interaction is most significant for configurations with shared use or crossing runways. However, it can also be observed even in configurations with completely independent runway operations due to congestion of the other shared airport resources such as taxiways or gates.

2.3 Factors influencing the choice of airspace configuration

Due to the close coupling between the runway selection at each airport and the routing of aircraft through the airspace, the same factors that influence runway selection also dictate the airspace configuration in use at a particular time. The runways in use at an airport are generally chosen as a result of the weather, as well as traffic conditions.

2.3.1 Wind Speed and Direction

Wind direction and speed are important factors because, for safety reasons, airports are required to minimize the ground-speed of aircraft landing and taking-off by conducting operations into the wind. Figure 2-5 shows that the winds from 240° are the prevailing winds at EWR with winds from 40° also being common. These prevailing winds are the reason the primary runways at EWR are aligned in the 4/22[3] direction, thereby allowing operations into the wind as frequently as possible. The runways in use dictate which arrival and departure procedures will be used at each airport. Wind direction is therefore one of the most important factors in determining the routing of traffic through the terminal airspace.

The local weather at each of the New York airports is not always consistent, the wind direction at each airport can be different. However, in many cases the airports will use similarly aligned runway configurations in order to keep traffic flowing through the TRACON in a similar direction. This alignment of the traffic flows makes the traffic flows easier to manage by keeping aircraft from different airports moving in similar directions.

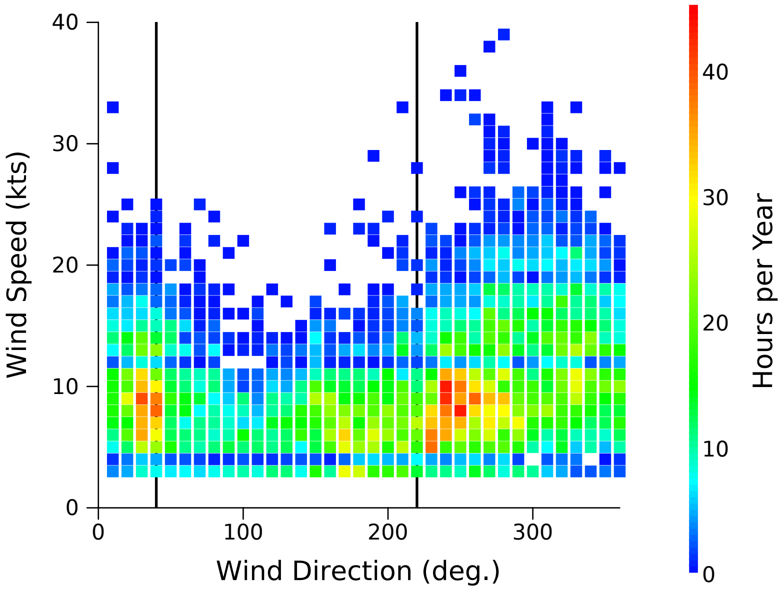

Figure 2-5: Surface wind speed and direction data measured at EWR during the period 2007-2008 from the ASPM database

2.3.2 Visibility Conditions

Visibility also plays a role in runway selection, with certain approach procedures only being available if minimum visibility requirements are satisfied. Visibility is particularly important in the New York area because the flexibility of "visual" approaches is frequently used to avoid inter-airport interactions that would occur with long and straight Instrument Landing System (ILS) approaches. An example of the impact of visibility conditions on airspace configuration is shown in Figure 2-6. In this example, the choice of approach (Canarsie visual or ILS) to JFK runway 13 dictates which climb procedures are available from LGA runway 13 (Whitestone or Flushing). Airspace configurations under visual conditions are therefore different (and will be considered as such) from those under instrument conditions even if the runways in use are exactly the same.

Visibility conditions also dictate when the more stringent IFR separations must be applied between subsequent approaching aircraft. These rules are imposed to ensure

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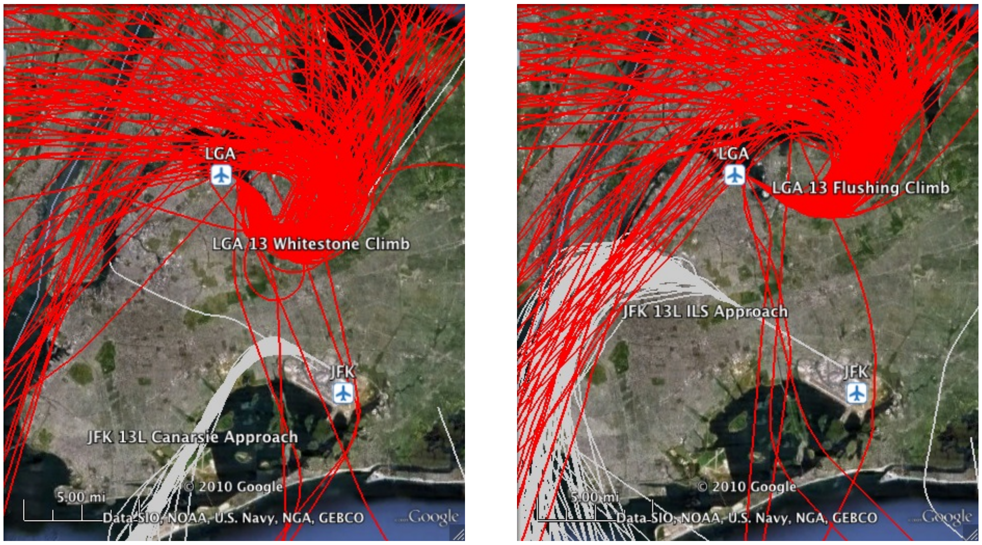
[3] Runway headings are given as the magnetic heading of the runway in tens of degrees. For example runway 22L at EWR has a magnetic heading of 219°, the "L" designates that it is the left of the two parallel runways in this direction.


LGA
LGA 13 Whitestone Climb
JFK
JFK 13L Canarsie Approach
© 2010 Google
5.00 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google
LGA
LGA 13 Flushing Climb
JFK 13L ILS Approach
JFK
© 2010 Google
5.00 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google

(a) Canarsie visual approach to JFK runway 13L

(b) ILS approach to JFK runway 13L

Figure 2-6: Representative flight tracks showing the difference between instrument and visual approach procedures to runway 13 at JFK and the coupling of this change with the LGA 13 departure procedure

Table 2.1: Required separation under IFR between pairs of arriving aircraft in the United States (nautical miles)[4]

		Following				
		Super	H	B757	M	L
Leading	Super	6	6	8	8	10
	H	2.5	4	5	5	6
	B757	2.5	4	4	4	5
	M	2.5	2.5	2.5	2.5	4
	L	2.5	2.5	2.5	2.5	2.5

arriving aircraft are safely separated from the wake of preceding aircraft. These separation rules are applicable to all Instrument Meteorological Conditions (IMC) airspace configurations and are listed in Table 2.1. Under visual conditions separation responsibility can be delegated to the pilot, who can then use visual separation to safely position his aircraft relative to the aircraft ahead. When separation responsibility is delegated in this manner, Table 2.1 does not apply. For departures, IFR and Visual Flight Rules (VFR) separation requirements are the same, with two minutes spacing required behind Heavy and Boeing 757 aircraft. All other departures are separated to meet the terminal area in-trail separation requirements. In the New York area the required in-trail separation is 2.5 nautical miles which typically corresponds to approximately one minute required separation between departures at the runway. At the boundary of the TRACON airspace, aircraft must be separated by the higher en route separation requirement which is typically at least 5 n.m.

2.3.3 Daily Traffic Patterns

In addition to the weather effects, the mix of different types of traffic also affects runway selection at an airport and determines which airports receive priority in use of shared airspace. The balance of arriving and departing traffic is important because interaction effects between runways can lead to some configurations having higher arrival or higher departure capacity. The proportion of heavier aircraft types may also be important due to their detrimental impact on both arrival and departure rates which often leads to the use of an additional runway (where possible).

The distribution of arrival and departure traffic throughout the day varies substantially between the four airports in this study. The hourly demand profile at an airport can be influenced by a variety of factors, such as the markets served by the airport, the type of traffic at the airport, the proportion of connecting flights, the dominance of one airline at an airport or slot control restrictions. Figure 2-7 shows the distribution of hourly Arrival and Departure traffic into the four study airports.

EWR has a small influx of arrivals early in the morning followed by three hours of high departure traffic levels. This traffic pattern is caused by the large demand for flights at the start of the business day. In the afternoon there is a sharp rise in arrival traffic at approximately three o'clock corresponding to the influx of transatlantic arrivals which departed from their origin airports in the early morning. The variability in the demand profile at EWR is not extreme due to a decision by Continental airlines (the dominant carrier at EWR) to reduce banking at this hub [5].

JFK exhibits a demand profile with very strong peaks in the morning and early afternoon and substantially lower demand outside these times. As with EWR, the af-

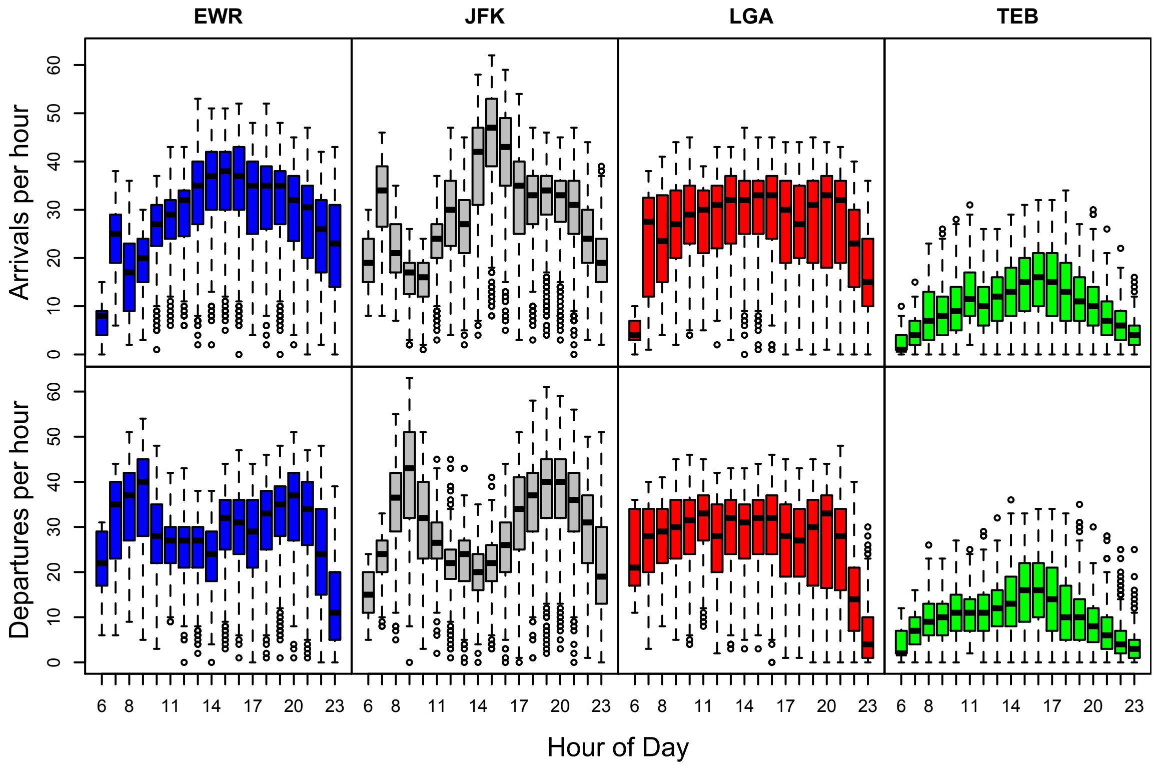


Figure 2-7: Box-plots showing the hourly distribution of arrival and departure traffic at each airport, based on 2007-2008 ASPM traffic data

ternoon arrival peak corresponds to the preferred time for transatlantic arrivals into the airport. These arrivals are then followed by a departure peak corresponding to the demand at the end of the business day as well as demand from connecting passengers from the preceding international arrivals. The traffic at JFK is split amongst many airlines both domestic and international, with no incentive to coordinate flight schedules. This lack of coordination leads to the more volatile traffic pattern at JFK compared to EWR.

LGA has the simplest demand profile, operating at a relatively constant level during the day and handling few operations during the night. This consistency is due to the use of “slot controls” at the airport, whereby the number of flights allowed each hour is limited to 68 [6]. The proximity of LaGuardia to New York City, combined with the limited aircraft size able to operate from its 7000 ft runways, ensures there is sufficient demand to fill the available slot capacity.

TEB does not have any scheduled flight service, its operations consist entirely of GA and charter flights. This lack of scheduled service gives rise to relatively high variability in the demand at the airport for its lower level of traffic (compared to EWR, JFK and LGA).

In order to provide insight into a broad range of different airspace configurations, scenarios for different values of all these variables will be considered. This means including configurations for both Visual Meteorological Conditions (VMC) and IMC conditions, traffic flows in both the north and south directions, and configurations used under high arrival and high departure demand at JFK and EWR.

Chapter 3

Configuration Analysis

The volume and composition of the traffic in the New York airspace changes throughout the day. Due to these changes, particular airspace configurations are favored at different times of the day in order to match the capacity of the airspace to the varying demand for arriving and departing traffic at each airport. Several configurations were used in the detailed analysis in order to provide insight into the airspace capacity constraints under a variety of operating conditions. Airspace configurations were chosen to explore the impact of the different factors influencing configuration selection that were identified in section 2.3.

During periods of low demand, capacity is often deliberately sacrificed in order to reduce the noise impact of aircraft operations or to allow runways to be closed for maintenance. Such low demand configurations will not be examined because the objective of this study is to quantify the potential for capacity gains beyond the levels currently achieved. Figure 3-1[1] shows the hourly distribution of arrival and departure traffic as well as the sum of both.

Configurations used when demand is high were selected by first isolating the hours of the day associated with the peak demand for arrivals and peak demand for depar-

---

[1] This figure is a boxplot, a type of graph that shows the distribution of a dataset. The colored boxes extend from the first to third quartiles (the inter-quartile range (IQR)) and therefore contain half of the data points. The solid black line within the box is drawn at the median of the data set. The dashed lines extending beyond this box encompass the entire range of the data excluding outliers. Outliers are shown using circles and are defined as any points below or above the first and third quartiles respectively by more than 1.5 times the IQR.

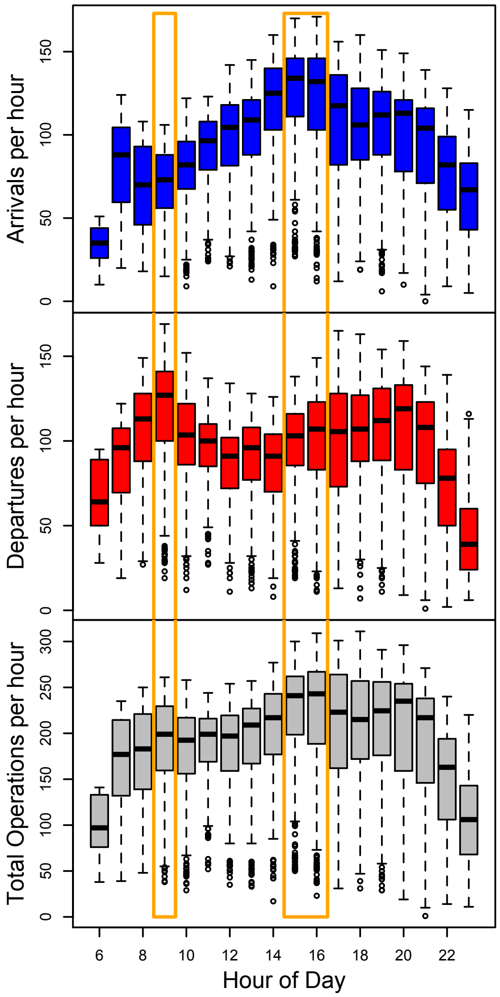
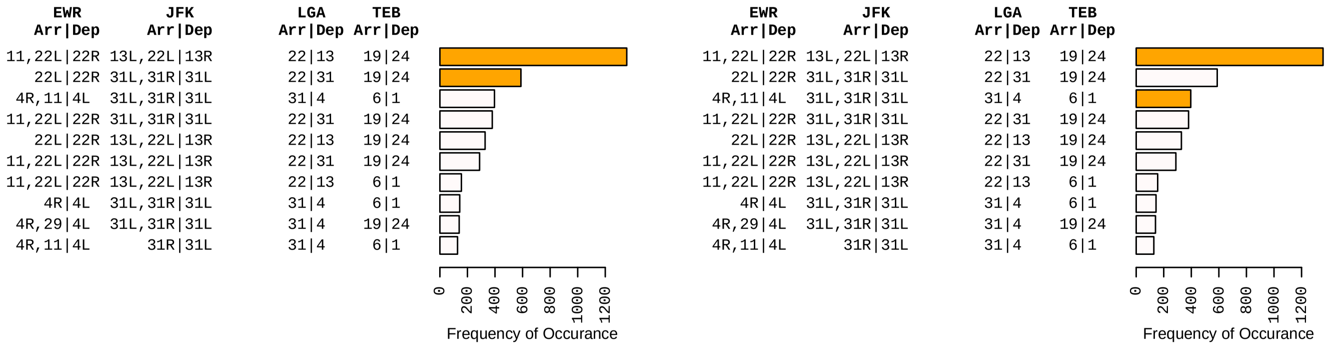


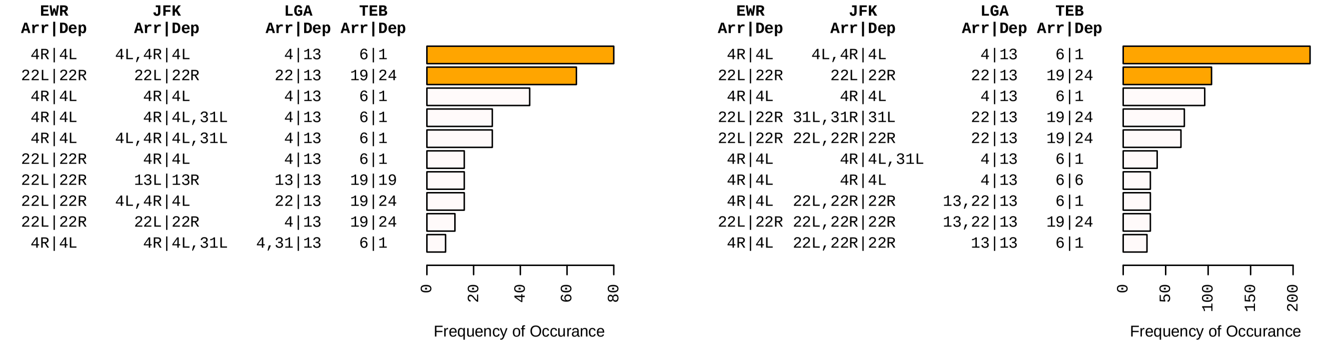
Figure 3-1: Aggregate airspace operations with peak arrival and departure hours selected for detailed analysis

tures as shown in Figure 3-1. The volume of departing traffic is highest during the morning hour of 9-10 a.m., corresponding to the many travelers wishing to travel at the start of the business day. The peak arrival traffic into the New York area generally occurs from 3-5 p.m. which is due to a combination of demand for travel at the end of the business day as well as the arrival of many international flights to EWR and JFK. Having isolated hours of the day where throughput is likely to be the highest priority for selecting an airspace configuration, configurations that represent the different wind and visibility conditions were chosen from within these hours.



(a) Peak Departure Hour (9-10 a.m.) under VMC

(b) Peak Arrival hours (3-5 p.m.) under VMC



(c) Peak Departure hour (9-10 a.m.) under IMC

(d) Peak Arrival hours (3-5 p.m.) under IMC

Figure 3-2: Traffic box-plot for the top 10 most frequently used configurations under both VMC and IMC, highlighted configurations will be analyzed in greater detail

The most common configurations in each flow direction under both VMC and IMC during the morning departure peak and afternoon arrivals peak periods were selected for analysis in this study as shown in Figure 3-2. In the case of the VMC configurations, this selection produced four distinct airspace configurations. However, for the IMC configurations, the selection only produced two configurations since the same two configurations proved to be the most common during both the departure and the arrival peaks. The runways used in the selected configurations are shown in Table 3.1 and will be explained in more detail in the following sections.

The prevailing wind conditions shown previously in Figure 2-5 are evident in the configurations listed in Figure 3-2. The use of the 22 direction at EWR frequently corresponds to the use of the 22 or 13 runways at JFK. This configuration caters to the southerly prevailing wind conditions. Use of the 4 direction at EWR corresponds to the use of the 4 and 31 direction at JFK which would be used for northerly winds.

Table 3.1: Selected airspace configurations for each scenario

	Airport									
	EWR		JFK			LGA		TEB		
	Arr	Dep	Arr	Dep	Mixed	Arr	Dep	Arr	Dep	Mixed
N-VMC-DP	4R	4L	4R	4L, 31L		31	4			1
S-VMC-DP	22L	22R	22L	22R, 31L		22	31	19	24	
N-VMC-AP	4R, 11	4L	31R		31L	31	4	6	1	
S-VMC-AP	11,22L	22R	13L, 22L	13R		22	13	19	24	
N-IMC	4R	4L	4R		4L	4	13	6	1	
S-IMC	22L	22R	22L		22R[a]	22	13	19	24	

[a] 22R is listed as a departures only runway for this configuration in ASPM, however the observed arrival throughputs suggest that the runway is in fact used for both arrivals and departures

3.1 VMC Configurations

When the visibility at an airport exceeds 3 statute miles, then the airport can operate under VFR. These rules allow flexibility in the separation required between arriving aircraft and also allow increased utilization of parallel and intersecting runways compared to the more restrictive IFR. The availability of particular visual approach procedures is also dictated by minimum visibility and ceiling requirements typically close to the 3 mile IFR visibility threshold.

3.1.1 North-VMC-DP

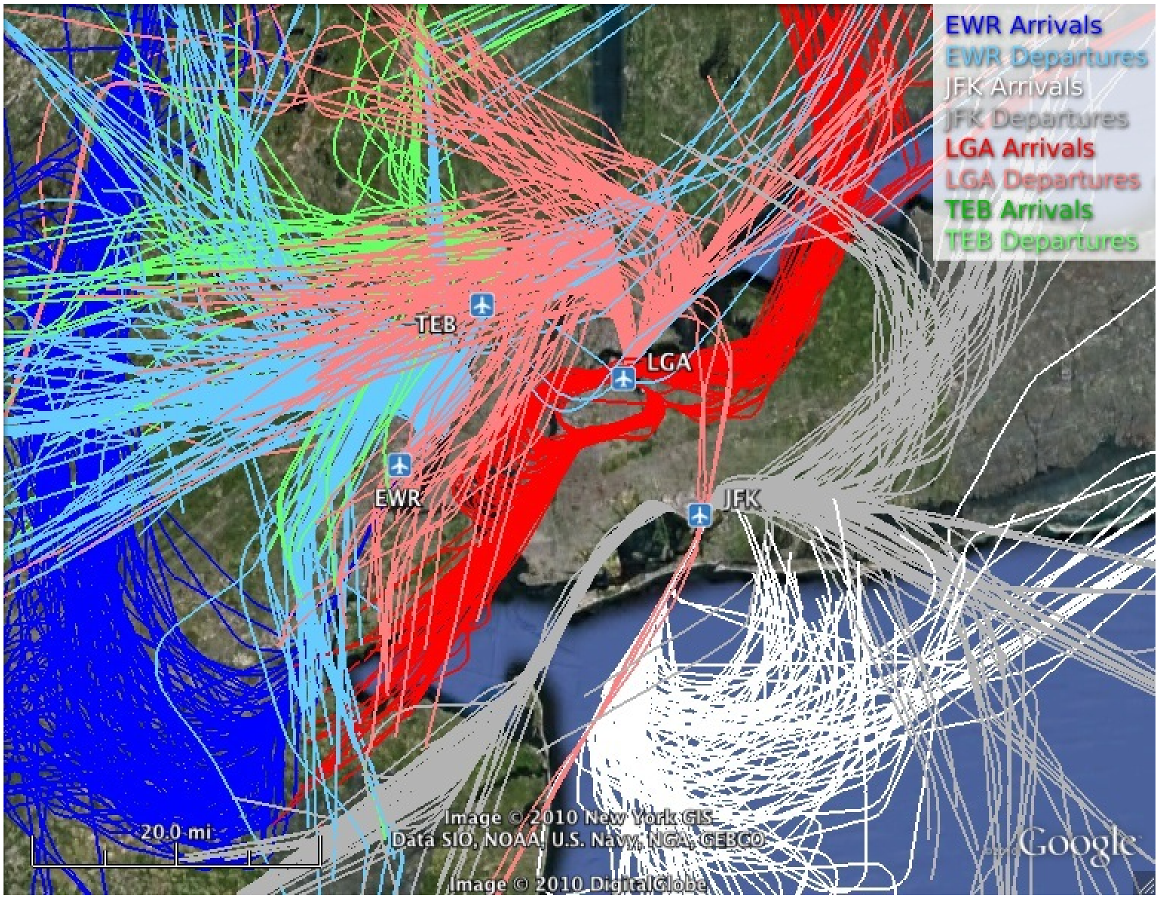
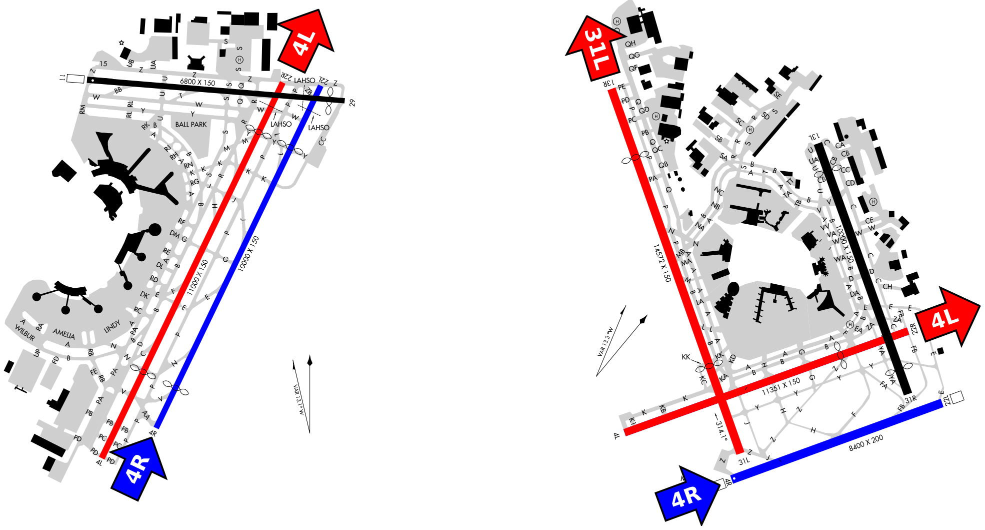
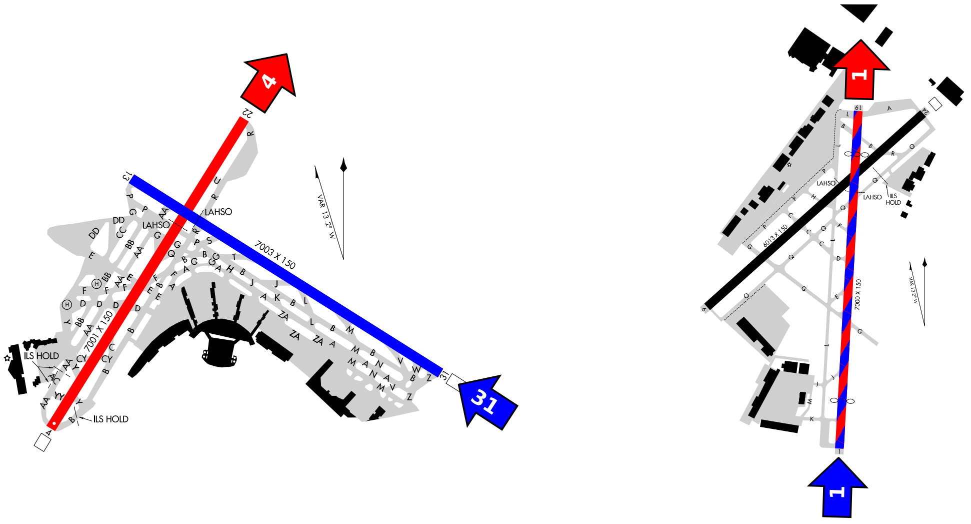

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
Google

Figure 3-3: Representative PDARS flight tracks for the north flow, VMC, departure priority configuration

This configuration has a high departure capacity and is used under VMC for northerly wind directions, flight racks for this configuration are shown in Figure 3-3 and the runway configurations at each airport are shown in Figure 3-4. At EWR, departures on 4L are independent from arrivals on 4R. This allows EWR to utilize efficiently all the departure capacity available from runway 4L. The departure airspace to the north is limited by departures from TEB runway 1 and to the east by some arrivals to LGA that follow the Hudson River, as shown in Figure 3-5. These constraints prevent the use of multiple departure headings close to the runway. However, the distance before the turn to the west shortly after departure can be adjusted to provide the required terminal area separation (2.5 miles) between subsequent departures.


4L
4R
6800 X 150
11000 X 150
10000 X 150
BALL PARK
LAHSO
31L
4L
4R
14572 X 150
11351 X 150
8400 X 200
10000 X 150

(a) EWR—Arr: 4R; Dep: 4L (b) JFK—Arr: 4R; Dep: 4L & 31L


4
31
7003 X 150
7001 X 150
LAHSO
ILS HOLD
VAR 13.2°W
1
1
LAHSO
7000 X 150

(c) LGA—Arr: 31; Dep: 4 (d) TEB—Arr: 1; Dep: 1

Figure 3-4: Arrival and departure runways used in the North-VMC-DP configuration

In contrast to the tight departure airspace at EWR, LGA has flexibility in separating departures from runway 4. Two climb procedures are available (as can be seen in Figure 3-3) which enables controllers to segregate faster traffic from slower traffic shortly after takeoff, allowing a more consistent departure rate.

LGA also operates separate arrival and departure runways. However, unlike EWR, the runways intersect requiring dependency between arrival and departure operations. The highest total capacity of this configuration is to insert a departure after each ar-

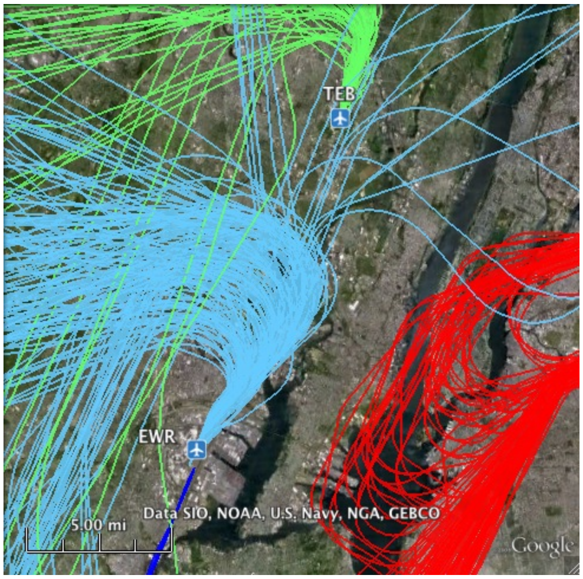


Figure 3-5: PDARS flight tracks showing the constraints to EWR 4L departures by operations at LGA and TEB

rival while operating the arrival runway at maximum capacity. If additional departure capacity is needed, then gaps can be added into the arrival flow to allow for extra departures. The spacing between arrivals is determined by the TRACON. Consequently adjustments of the arrival rate to accommodate extra departures require coordination between the LGA tower and N90 TRACON. The complexity of this coordination leads to a strong preference towards balanced arrival and departure throughputs during high demand periods at LGA.

This particular crossing configuration at LGA is also theoretically the least efficient because the intersection of the two runways is furthest from both runway thresholds. This means departures have to wait for a preceding arrival to land, decelerate and exit the arrival runway before being cleared to take-off. Whereas in the case of runways operations on runways 22 and 13 the departure can initiate takeoff as soon as the arrival clears the short distance to the runway intersection.

JFK operates independent arrival and departure operations with arrivals on 4R and departures on runways 4L and 31L. While departures on 31L and 4L are appear interdependent, they suffer little or no capacity reduction due to the crossing runways. Most departures on runway 31L will begin take-off after the intersection with runway

4L making the two runways completely independent.

3.1.2 South-VMC-DP

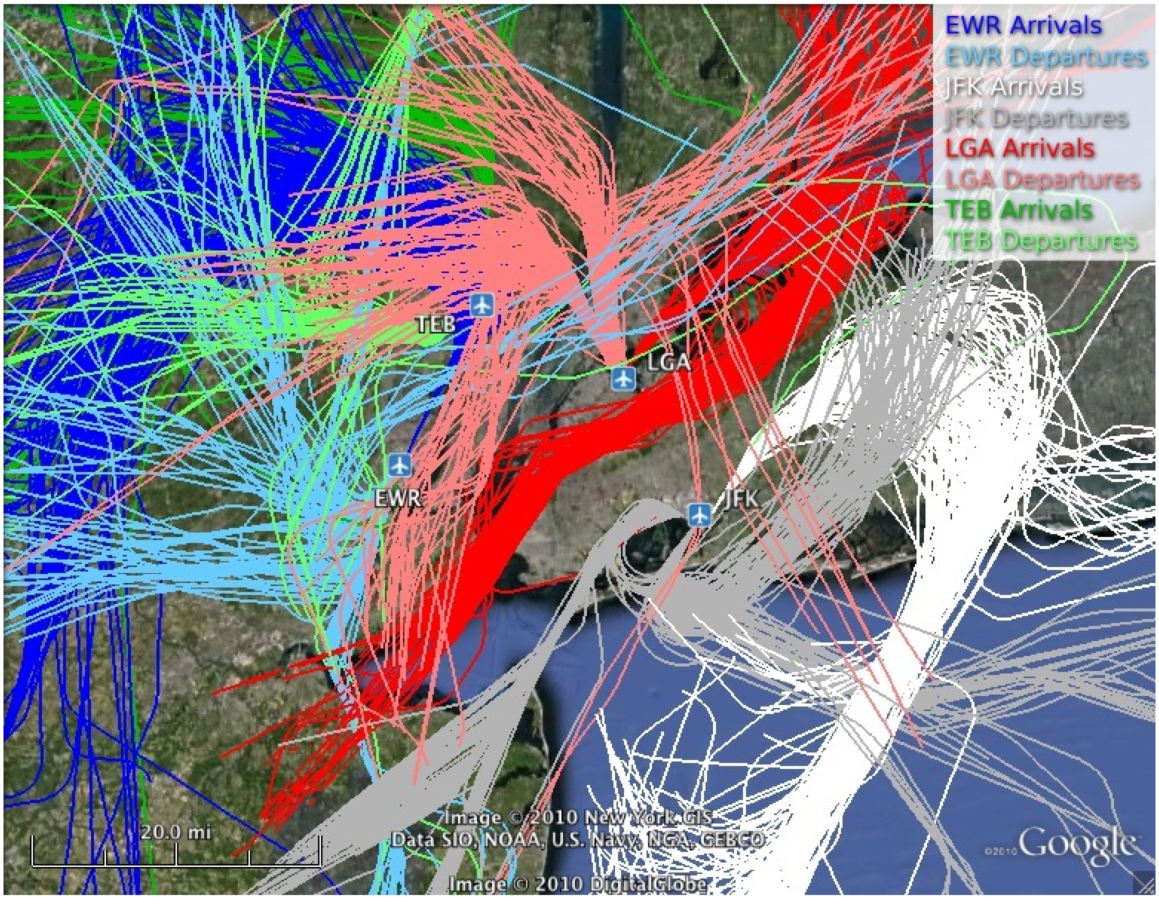
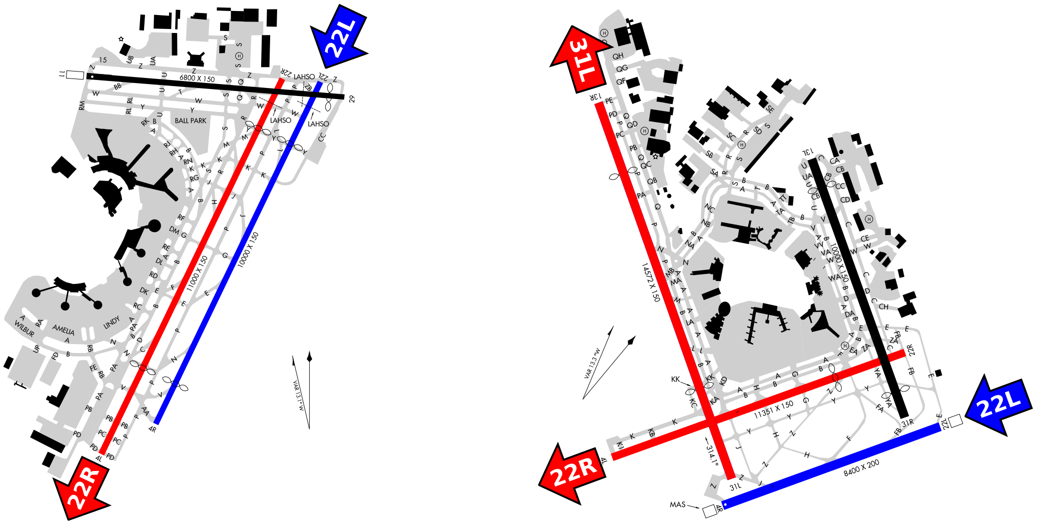

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
©2010 Google

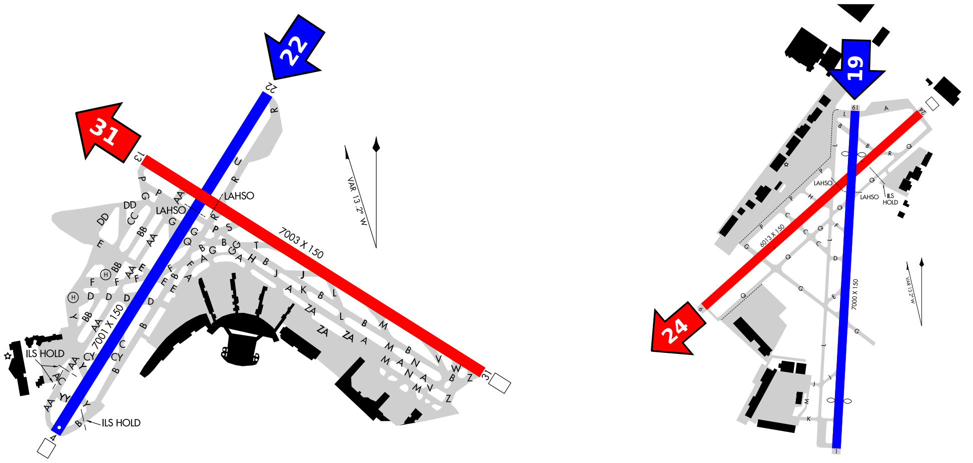
Figure 3-6: Representative PDARS flight tracks for the south flow, VMC, departure priority configuration

Flight tracks for the south flow, VMC departure priority configuration (South-VMC-DP) are shown in Figure 3-6 and the runway configurations are shown in Figure 3-7. This configuration shares many of the key features of the North-VMC-DP configuration. EWR again operates independent arrivals and departures on the main parallel runways. However, in this case, the airspace to the south is less restricted than to the north allowing aircraft to be turned to two different "dispersal" departure headings (215° and 239°) immediately after takeoff as shown in Figure 3-8. This procedure means the inter-departure spacing requirement is reduced to 6000ft or when the leading departure becomes airborne (but not if the leader is a Heavy or B757). Without multiple departure headings, subsequent departures must be given sufficient


22L
22R
6800 X 150
11000 X 150
10000 X 150
LAHSO
BALL PARK
AMELIA
LINDY
WILBUR
31L
22L
22R
14572 X 150
11351 X 150
8400 X 200
MAS

(a) EWR—Arr: 22L ; Dep: 22R

(b) JFK—Arr: 22L; Dep: 22R & 31L


22
31
7003 X 150
7001 X 150
LAHSO
ILS HOLD
VAR 13.2°W
19
24
6013 X 150
7000 X 150
LAHSO
ILS HOLD

(c) LGA—Arr: 22; Dep: 31

(d) TEB—Arr: 19; Dep: 24

Figure 3-7: Arrival and departure runways used in the South-VMC-DP configuration

spacing to ensure that the 2.5 mile terminal radar separation can be maintained between subsequent departures. Typically, these dispersal departure headings are only used during the morning when the traffic mix is predominantly smaller aircraft types, since these aircraft are better able to follow the required turns and the 6000 ft separation can be almost universally applied. Ideal use of dispersal departure headings would allow the runway capacity to be limited only by the time it takes a departure to move 6000 ft down the runway. Increasing runway capacity beyond this limit would require further reductions to the minimum allowed separation between departures.

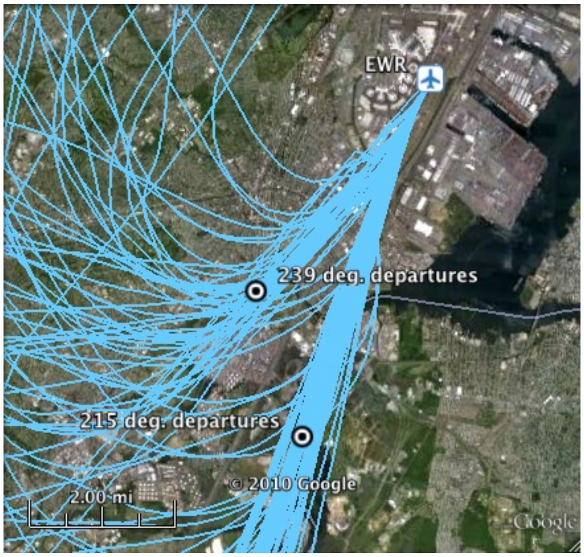


Figure 3-8: Representative flight tracks for the two dispersal departure headings from EWR 22R

The use of the crossing runways at LGA places the crossing point closer to the runway threshold for the arriving runway, theoretically making this configuration slightly more efficient than the one used in the North-VMC-DP airspace configuration. As with the North-VMC-DP configuration there is sufficient airspace available to the northwest of LGA to use two departure procedures, which allows the efficient spacing of departing traffic.

JFK has identical features to the North flow case, with two dependent departure runways and an independent arrival runway. In this configuration, the intersection for the crossing departure runways is further from the threshold of runway 22R than it was for runway 4L. This change may lead to a very slight drop in departure capacity compared to the north flow case. However, this is mitigated by starting the takeoff roll for departures on 31L after the intersection with 22R, thereby allowing independent operations on both runways.

3.1.3 North-VMC-AP

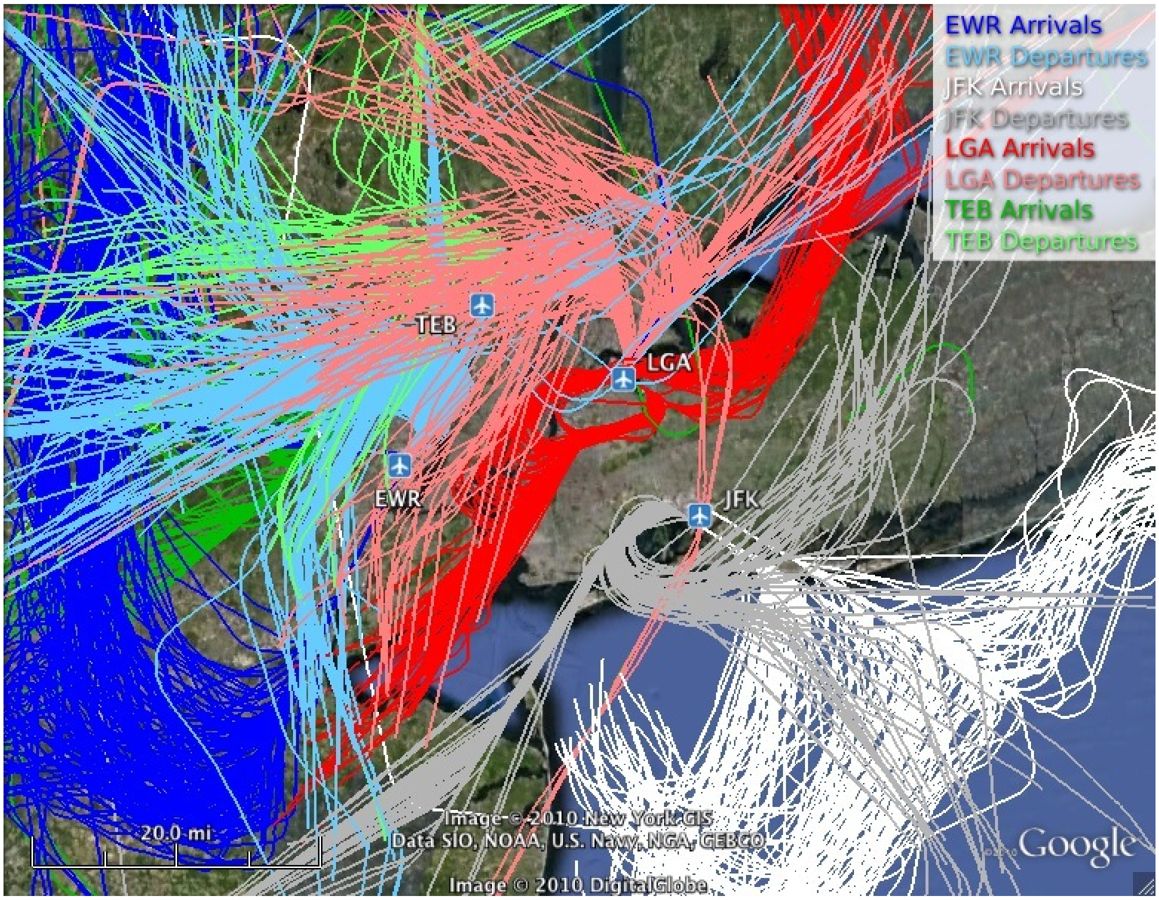
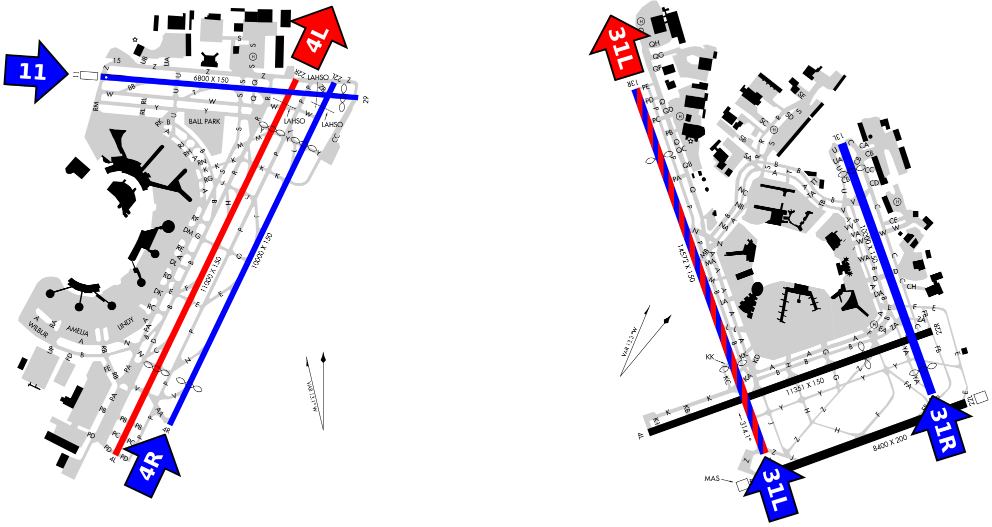
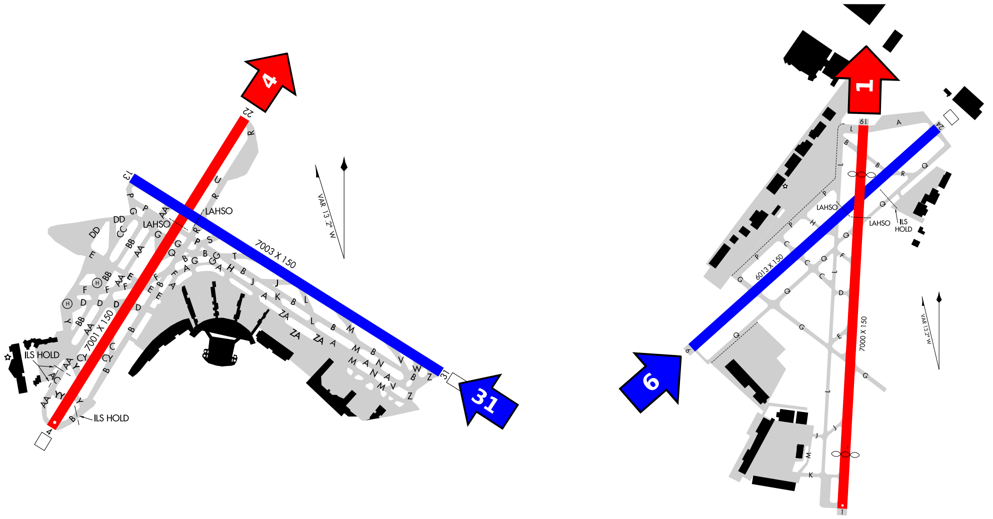

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
Google

Figure 3-9: Representative PDARS flight tracks for the north flow, VMC, arrival priority configuration

Figure 3-9 shows example flight tracks for the north flow, VMC configuration used when arrival demand is high at EWR and JFK. As explained in subsection 2.3.3 this high arrival demand corresponds to the afternoon surge in demand for international flights during the afternoon at EWR and JFK. The corresponding runway configurations are shown in Figure 3-10. During the afternoon arrival peak at EWR, the capacity of the main arrival runway (4R) must be supplemented by the addition of the crossing runway 11. Runway 11 has several restrictions on its use due to its short length (6800 ft) and restricted approach geometry: typically use is limited to Boeing 737-700 and smaller aircraft and a 15 miles spacing is required between successive


11
4L
4R
6800 X 150
11000 X 150
10000 X 150
LAHSO
BALL PARK
31L
31R
14572 X 150
11351 X 150
8400 X 200
MAS

(a) EWR—Arr: 4R & 11; Dep: 4L (b) JFK—Arr: 31L & 31R; Dep: 31L


4
31
7003 X 150
7001 X 150
LAHSO
ILS HOLD
1
6
6013 X 150
7000 X 150
LAHSO
ILS HOLD

(c) LGA—Arr: 31; Dep: 4 (d) TEB—Arr: 6; Dep: 1

Figure 3-10: Arrival and departure runways used in the North-VMC-AP configuration

arrivals (known as a Miles in Trail (MIT) restriction[2]). When certain wind conditions are met, arrivals on runway 11 can be conducted independently from arrivals on 4R through the use of Land and Hold Short Operations (LAHSO). Under LAHSO arrivals on both runways 11 and 4R are required to come to a stop before reaching the runway intersection. Not all arrivals are allowed to accept LAHSO clearances (e.g. no international airlines can use LAHSO), which adds further complexity to the sequencing of arrival traffic for this configuration.

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[2] Miles in Trail (MIT) restrictions prescribe a minimum spacing (in nautical miles) between subsequent flights on a particular route. These restrictions are typically used to manage the traffic level at resources down stream of the restriction. In the New York area MIT restrictions are typically imposed at the departure fixes. These restrictions are then translated into a minimum spacing between departures to the same fix from each airport.

Although the two arrival runways at EWR can be operated independently, departures on runway 4L must always be sequenced in between arrivals on runway 11 because these runways cross unavoidably. This dependency has only limited impact on departure capacity due to the large spacing currently required between successive arrivals to runway 11.

In this north flow configuration, JFK uses only the two 31 parallel runways which have a greater separation, are longer, and also have superior taxi routes (i.e. no runway crossing required) compared to the alternative northerly runways, 4L and 4R. The use of a independent crossing arrival runway is not possible in the north flow case because the crossing of the flightpaths to 31L and 31R with runways 4L and 4R cannot be avoided. Placing departures on 4L or 4R would also be impractical with arrivals on both 31 runways given that they would have to occur in a simultaneous gap in both (independent) arrival flows. The use of runway 31L for departures is not ideal because LGA airspace to the north means that northbound departures from JFK must first turn south immediately after departure before continuing north (this can be seen by examining some of the gray (JFK departure) flight tracks in Figure 3-9).

The LGA configuration is identical to the one used in the morning period for northerly traffic flow. This is unsurprising given the limited choice of configurations available at LGA and the consistency of the traffic throughout the day.

3.1.4 South-VMC-AP

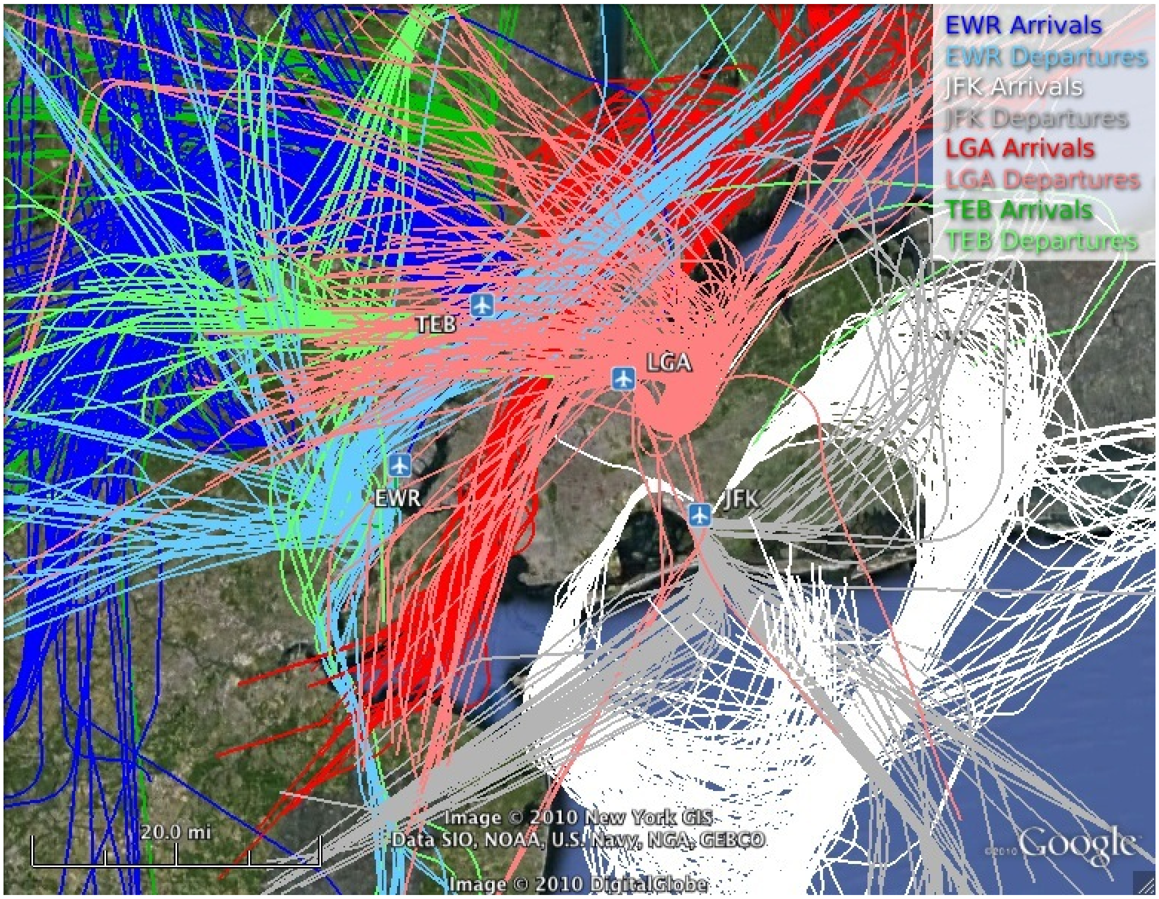
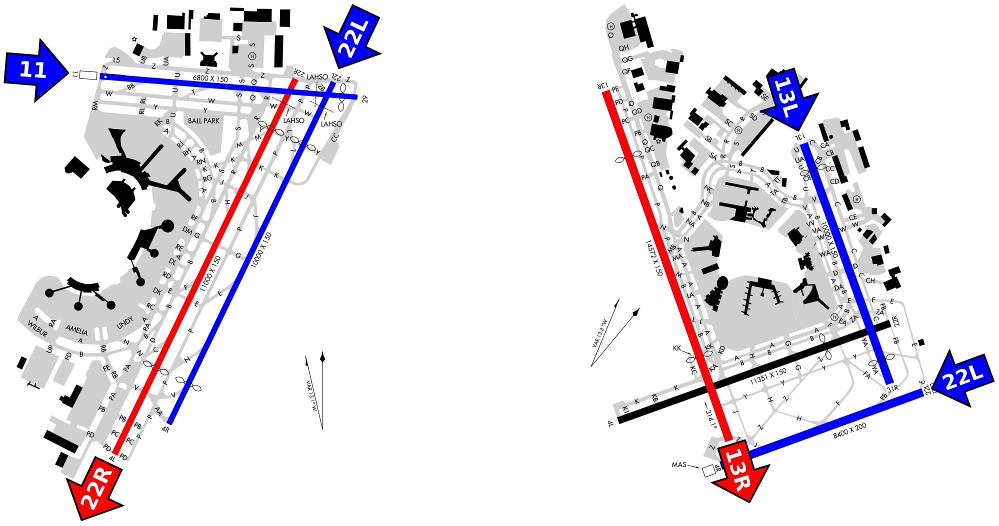
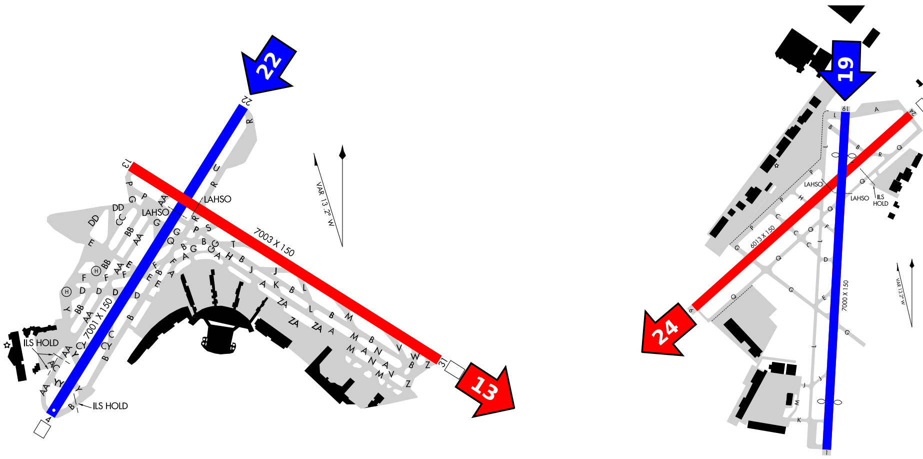

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
©2010 Google

Figure 3-11: Representative PDARS flight tracks for the south flow, VMC, arrival priority configuration

Flight tracks for the south flow, VMC arrival priority configuration (South-VMC-AP) are shown in Figure 3-11 and the runway configurations are shown in Figure 3-12. In order to provide sufficient arrival capacity during the afternoon arrival peak (discussed in subsection 2.3.3, EWR is again forced to use the crossing runway (11). Unusually, the use of runway 11 is often with a slight tailwind component given that the southerly prevailing winds are from 210°–270° (as shown in Figure 2-5). Above a certain threshold, this tailwind component can lead to an increase in the MIT restriction from 15 to 20 miles between arrivals to runway 11. The use of runway 11 rather than runway 29 is due to the close proximity of the LGA arrivals. This airspace constraint means that the only available approach to EWR 29 is a tight visual "circling


11
22L
22R
6800 X 150
11000 X 150
10000 X 150
BALL PARK
LAHSO
AMELIA
LINDY
WILBUR
13L
22L
13R
14572 X 150
11351 X 150
8400 X 200
MAS

(a) EWR—Arr: 11 & 22L; Dep: 22R (b) JFK—Arr: 13L & 22L; Dep: 13R

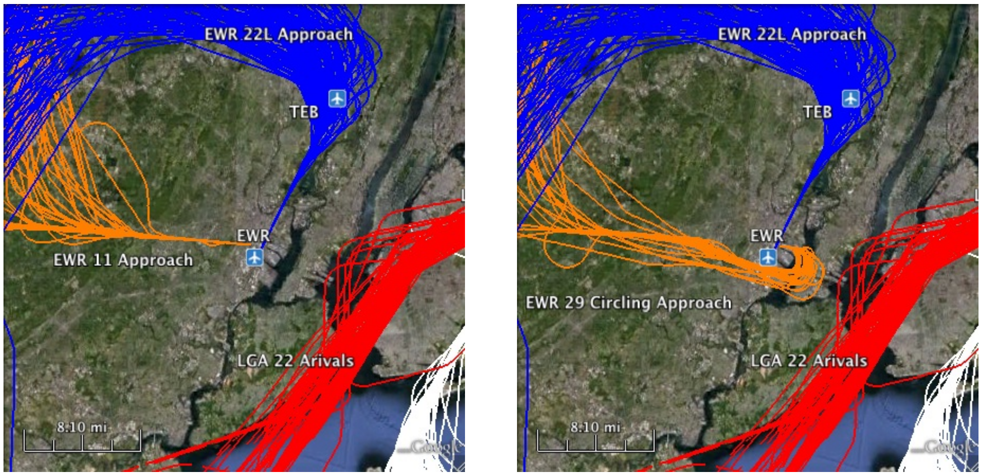

22
13
7003 X 150
7001 X 150
LAHSO
ILS HOLD
19
24
6013 X 150
7000 X 150
LAHSO
ILS HOLD

(c) LGA—Arr: 22; Dep: 13 (d) TEB—Arr: 19; Dep: 24

Figure 3-12: Arrival and departure runways used in the South-VMC-AP configuration

procedure." This circling procedure is shown in Figure 3-13b, where aircraft approach the airfield using the runway 11 approach before turing 180° just prior to landing. The complexity of the circling approach geometry requires a large reduction in arrival rate at the airport to ensure that arrivals to the two intersecting runways (22L and 29) do not conflict.

In configurations where the wind conditions require the use of runway 29 for arrivals, this runway will be the primary arrival runway. Heavy jet arrivals requesting



(a) EWR 11 approach

(b) EWR 29 circling approach

Figure 3-13: Representative flight tracks showing the difference between the commonly used runway 11 approach and the rarely used runway 29 approach at EWR

a longer runway may be placed on 22L. The Converging Runway Display Aid (CRDA) is a tool used by controllers to help safely and efficiently sequence arrivals to crossing runways. However, the geometry of the circling approach to runway 29 prevents the use of the CRDA to this runway which means that large separations are required in the arrival stream to runway 29 for aircraft requesting runway 22L. The capacity reduction caused by the use of runway 29 is large enough to warrant operating runway 11 for arrivals whenever possible, even in the presence of tailwinds. In contrast to the north flow configuration, departures on 22R can be operated independently from the two arrival runways if takeoffs are started south of the intersection with runway 11.

The runway configuration at LGA is the most favorable arrangement, with the crossing point close to the start of both runways. However, use of both runways 13L and 22L at JFK place limits on the available departure procedures at LGA. Under this configuration of JFK (specifically when runway 13L is used for visual arrivals), LGA is forced to use only the “Whitestone” climb procedure. Use of a single climb procedure means that controllers cannot use different routes to separate slower moving departures (e.g. propellor aircraft) from faster moving aircraft. Faster aircraft therefore require extra spacing after a slow departure to ensure they do not catch up with the slower aircraft. This effect may be small at LGA due to the fact that the departure rate is already reduced by the requirement to depart between pairs of arriving aircraft.

At JFK, the high arrival demand leads to a high arrival capacity configuration. Runways 13L and 22L are able to operate simultaneous independent arrival operations. The departure flightpath from runway 13R overflying 22L requires that departures are sequenced between arrivals to 22L, which limits the available departure capacity. This interaction between arrivals and departures is slightly less restrictive than the sharing of 31L found in the north flow case because departing aircraft can be in position on runway 13R and ready to depart whereas in the shared-use case they would be forced to wait off the runway.

3.2 IMC Configurations

Capacity under IFR is inherently lower than that achievable under VFR. In addition to the general changes to approach separation requirements described in subsection 2.3.2, specific procedures at each airport also change under IMC and these will be discussed where appropriate in the following sections.

3.2.1 North-IMC

Figure 3-14 shows typical flight tracks for the north flow configuration under IMC (N-IMC) with the corresponding runway configurations shown in Figure 3-15. While the north flow configuration at EWR appears to be the same under the IMC as the departure priority configuration under VMC, the actual operation of the runways is different. The centerlines of the parallel runways at EWR are separated by only 940 ft which places them in the most restrictive category of rules governing operations to Closely Spaced Parallel Runway (CSPR) under IMC. Under IFR, runways separated by less than 1500 ft are not permitted to operate both runways for departures or both for arrivals. Runways can be operated for segregated arrivals and departures. To do so, departures on one runway must be inserted between arriving aircraft on the other, with a departing aircraft only able to begin takeoff once the preceding arrival

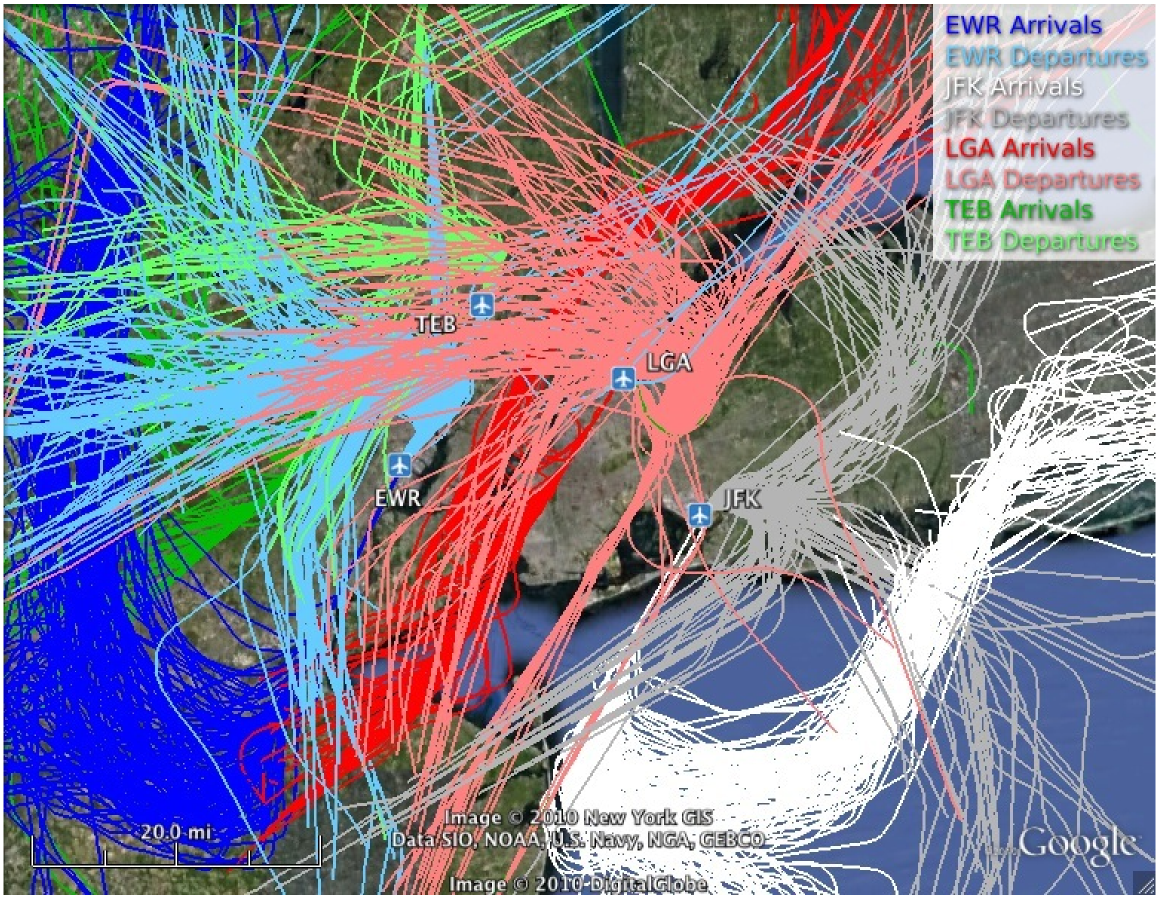
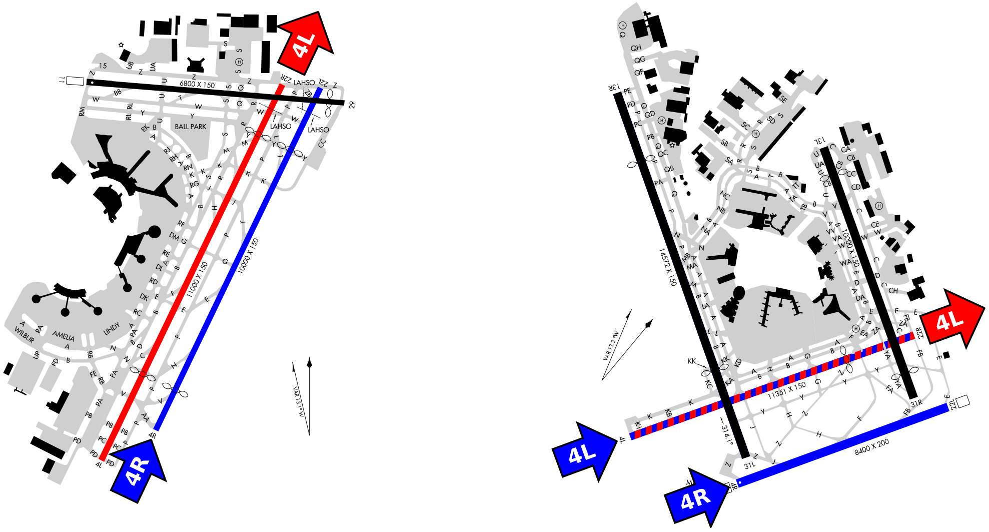

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
Google

Figure 3-14: Representative PDARS flight tracks for the north flow, IMC configuration

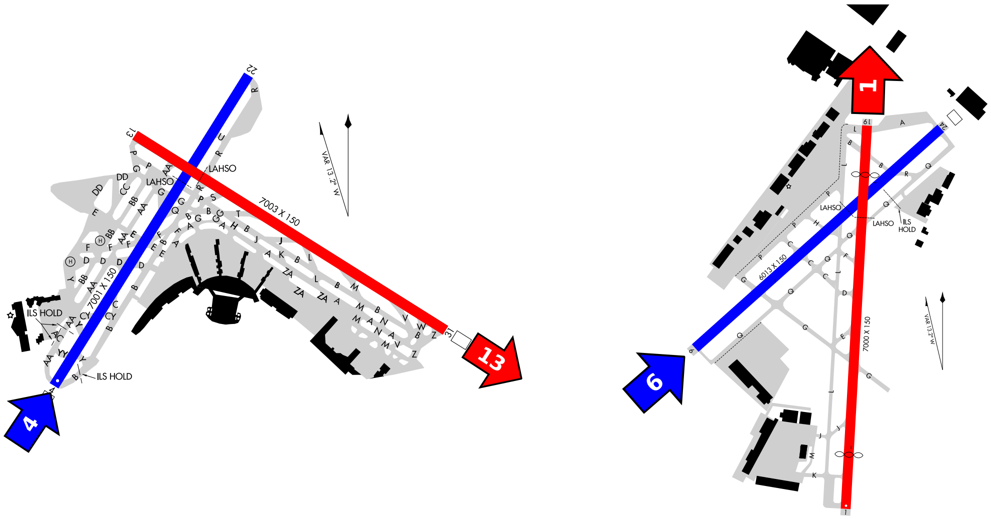
has touched down and as long as the subsequent arrival is more than 2 miles from the runway threshold. This requirement limits the departure capacity to the arrival capacity on the adjacent parallel, in a similar way to crossing runways.

The configuration at JFK also uses only the two parallel runways in the 4 direction but unlike EWR, these runways are separated by 3000 ft which allows increased flexibility in their use. In particular, mixed arrival and departure operations are permitted. Runway 4L is shared between arriving and departing traffic and 4R is used exclusively for arrivals. While the runways are permitted to be used for simultaneous approaches, a minimum of 1.5 n.m. diagonal spacing must be provided between arrivals to adjacent runways. Approaches to the 31 parallel runways could have been conducted independently given the 6700 ft separation between them. The use of the 4 parallel runways is more common than the use of the 32 parallel runways under IMC


4L
4R
6800 X 150
11000 X 150
10000 X 150
4L
4R
14572 X 150
11351 X 150
8400 X 200

(a) EWR—Arr: 4R; Dep: 4L

(b) JFK—Arr: 4L & 4R; Dep: 4L


13
4
7003 X 150
7001 X 150
LAHSO
ILS HOLD
1
6
6013 X 150
7000 X 150

(c) LGA—Arr: 4; Dep: 13

(d) TEB—Arr: 6; Dep: 1

Figure 3-15: Arrival and departure runways used in the North-IMC configuration

because the wind is more frequently aligned with 4L and 4R.

LGA is able to use both the Whitestone (northerly) and Coney (southerly) departure procedures (pink flight tracks in Figure 3-14, allowing efficient routing of departure traffic. This flexibility is because JFK does not use the 13/31 runways thereby allowing LGA to use the shared airspace between LGA and JFK. The departure rate at LGA remains tied to the arrivals rate due to the use of intersecting runways. This dependency, combined with the increased separation required between instrument arrivals, leads to a lower departure rate under IMC despite the favorable climb procedures.

3.2.2 South-IMC

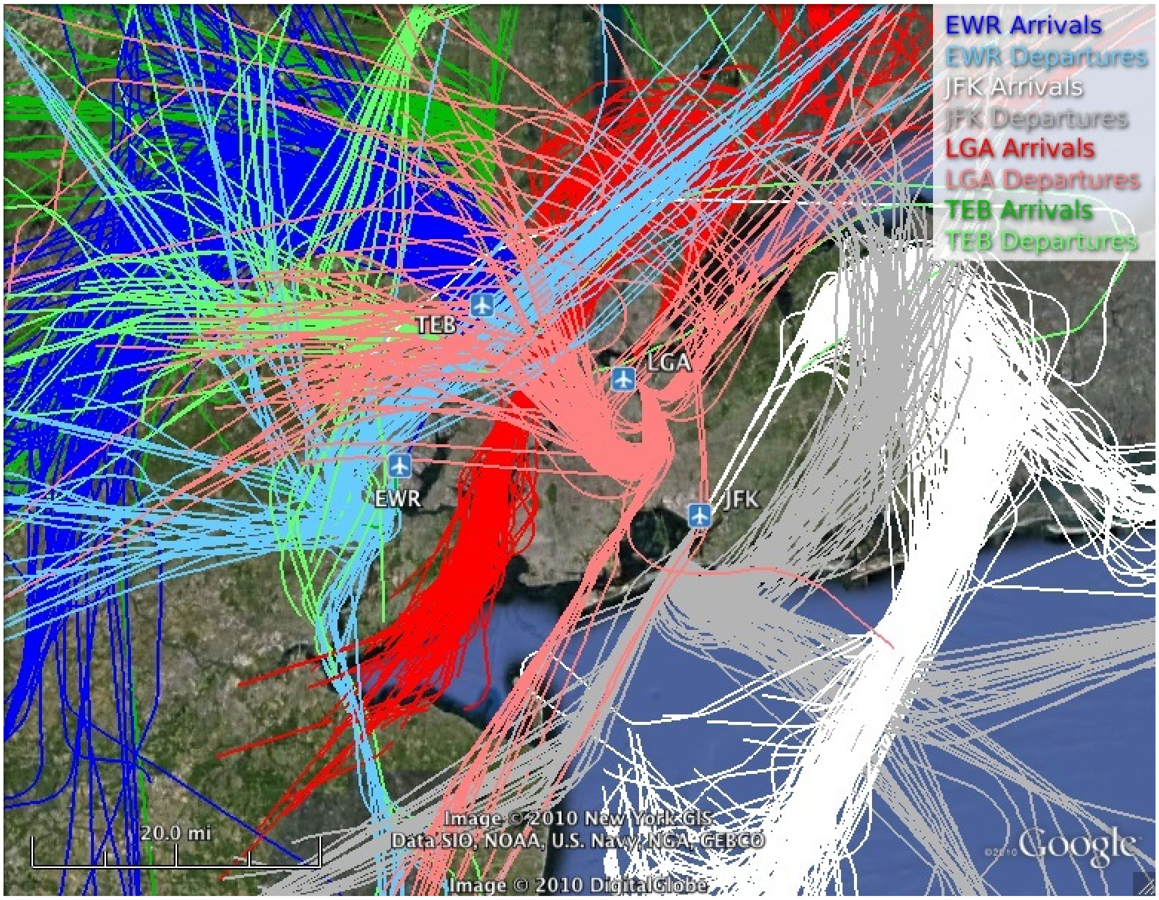
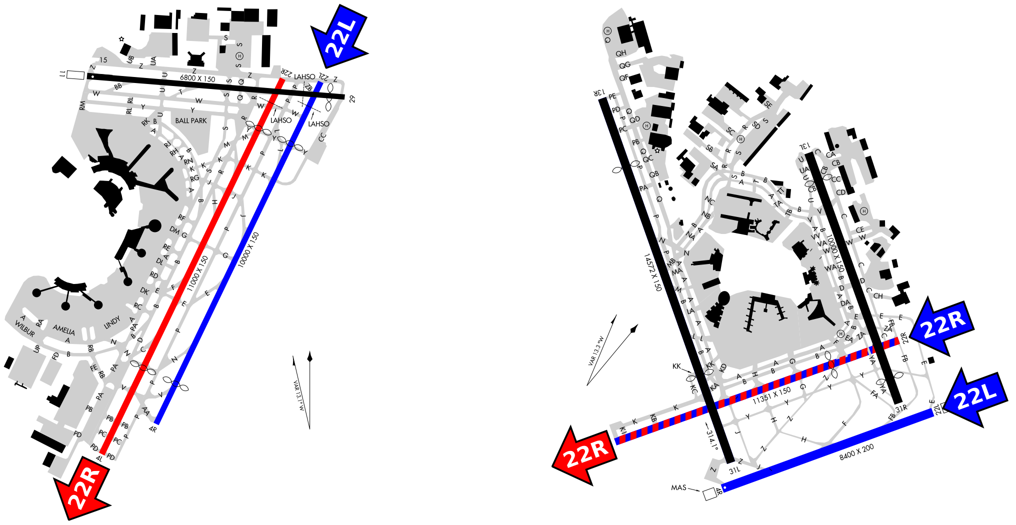

EWR Arrivals
EWR Departures
JFK Arrivals
JFK Departures
LGA Arrivals
LGA Departures
TEB Arrivals
TEB Departures
TEB
LGA
EWR
JFK
20.0 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
©2010 Google

Figure 3-16: Representative PDARS flight tracks for the south flow, IMC configuration

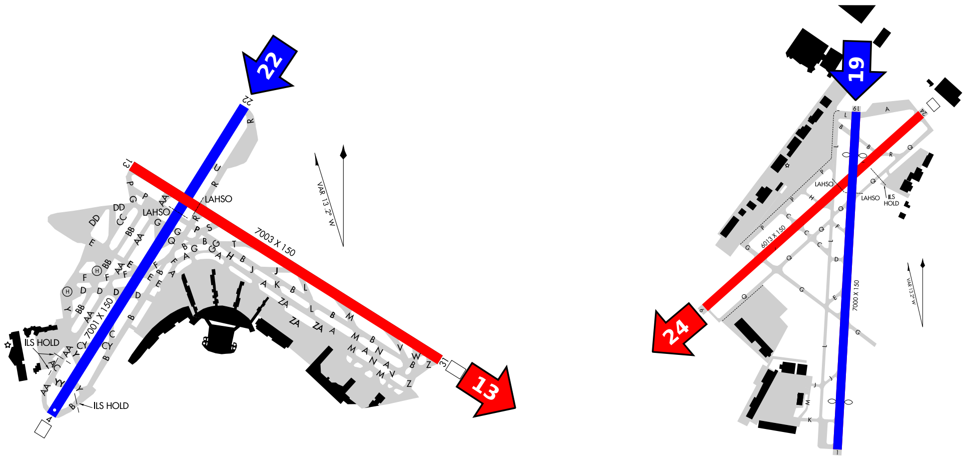
The arrival and departure procedures (Figure 3-16) and runway configurations (Figure 3-17) used in the south flow IMC (S-IMC) case present almost identical capacity constraints to the north flow IMC scenario. JFK and EWR operate the same runways as the north flow case but in the opposite direction, leading to identical parallel runway separation rules as the north flow case. LGA benefits from the more advantageous arrivals 22 and departures 13 runway configuration, with the crossing point close to the threshold of both runways.

The S-IMC case does however add an additional airspace constraint compared to the north flow case. Under certain conditions, both departures from LGA and arrivals to JFK would ideally use the same airspace known as the “Belmont Extension


22L
22R
6800 X 150
11000 X 150
10000 X 150
22R
22L
14572 X 150
11351 X 150
8400 X 200

(a) EWR—Arr: 22L; Dep: 22R

(b) JFK—Arr: 22L & 22R; Dep: 22R

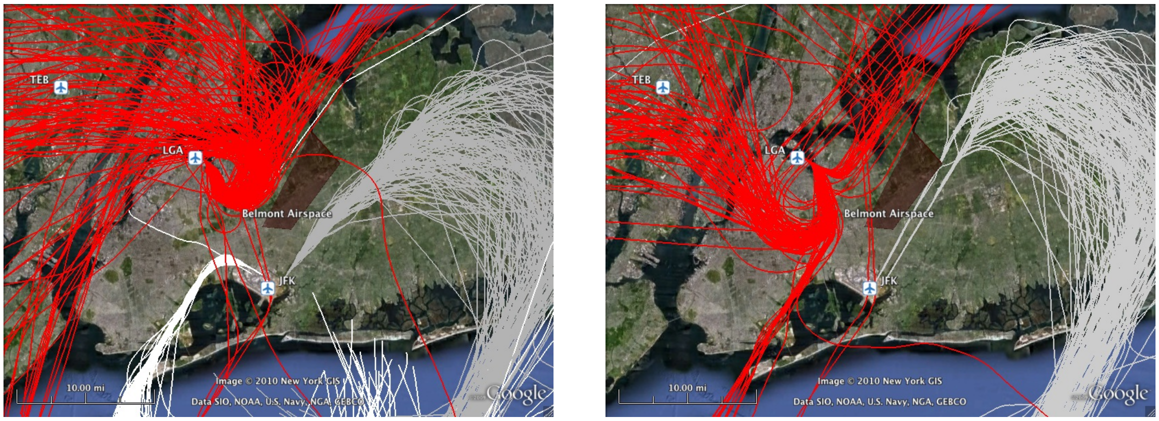

22
13
7003 X 150
7001 X 150
LAHSO
ILS HOLD
19
24
6013 X 150
7000 X 150

(c) LGA—Arr: 22; Dep: 13

(d) TEB—Arr: 19; Dep: 24

Figure 3-17: Arrival and departure runways used in the South-IMC configuration

Airspace." Under most flow conditions, this airspace is used by LGA to enable multiple departure routes from runway 13, as shown in Figure 3-18a. However, control of this airspace is ceded to JFK under a specific set of conditions that occur in the afternoon for the selected south IMC configuration. [7] This transfer of control allows the use of 22L and 22R ILS procedures at JFK for arrivals, as shown in Figure 3-18b. Without the Belmont airspace, LGA is prevented from using the Whitestone departure procedure which turns to the north shortly after take-off (shown in red in


TEB
LGA
Belmont Airspace
JFK
10.00 mi
Image © 2010 New York GIS
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google

(a) LGA control of the Belmont Airspace (b) JFK control of the Belmont Airspace

Figure 3-18: Example flight tracks for two different uses of the Belmont Extension Airspace

Figure 3-18a). Without the Whitestone climb, the routing of LGA departure traffic is less efficient causing increased spacing to be required between subsequent departures.

Chapter 4

Empirical Analysis of Potential Capacity

The following analysis compares the Pareto capacity envelopes measured at each airport individually with the aggregate Pareto capacity envelope of the system of airports. This comparison quantifies the degree to which airport runway capacity is left un-utilized over the two year measurement period. This unused airport capacity is hypothesized to be due in part to interactions between the New York airports, causing the system of airports to have a lower capacity than the airports considered individually.

4.1 Data Sources

The source data for the following capacity analyses is the ASPM database compiled by the FAA. The ASPM database is a compilation of a variety of data sources such as flight track and flight plan data from Enhanced Traffic Management System (ETMS), weather data and airport configuration records from Air Traffic Control (ATC). Several fields from the ASPM data were used to conduct the airport and airspace capacity analysis. Capacity calculations for each airport were categorized by the airport runway configuration and the meteorological conditions at the airports (IMC or VMC). Therefore both runway configuration and weather data were extracted from ASPM.

The 15 minute arrival and departure counts were used as the basis for measuring the throughput at each airport.

4.1.1 Outlier Removal

This study concentrates on analyzing the steady-state constraints to New York airspace capacity. While the reduced capacity associated with switching airspace configurations is an interesting temporary capacity restriction, the ASPM database does not provide sufficient resolution in its configuration data to measure these effects. The ASPM data provides 15 minute resolution on the arrival and departure count data. However, the configuration at each airport is only updated on an hourly basis. Given this low update frequency, the two hour period surrounding any change in configuration was removed from the data in order to exclude these transient effects.

The airport runway capacity envelopes used in the following empirical capacity analysis are sensitive to the highest throughput points for each airport runway configuration. This sensitivity makes the analysis closely dependent on the criteria used to remove outliers. The measurements used in this study were therefore filtered by excluding any combination of arrival and departure rates (per 15 minutes) observed only once for a given runway configuration at an airport[1]. This filtering meant that for any specific operating point to be included in the analysis, it must have been observed twice for a given runway configuration at an airport. The filtering ensures that the points used to define the potential capacity are repeatable observations and are less likely to be due to unique traffic situations or data recording errors.

4.2 Estimation of Potential Capacity

An estimate of the total potential capacity available at any given time in the New York region is calculated in two steps. First the potential capacity is calculated for each airport individually and then at an aggregate airspace level. For a single airport operating in isolation, the potential capacity would be close or equal to the observed throughput for high demand periods with favorable traffic conditions. However, the aggregate potential capacity of a system of airports may never be reached if, as is hypothesized for New York, interactions in the airspace limit capacity.

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[1] This filtering is performed independently for each airport. Therefore within the data for each airspace configuration single data points are permitted

4.2.1 Single Airport Capacity Potential

For every capacity measurement at a single airport, the potential additional capacity available is simply the distance of the observation from the Pareto capacity envelope. An entire spectrum of potential capacities is possible from every operating point and depends on the relative number of arriving and departing aircraft added in the additional capacity. In this analysis, arrivals and departures will be added in the same ratio as at the observed operating point. This assumption will mean that the potential capacity is rarely the true optimal capacity of the airport that would be achieved if arrivals and departures were both maximized together. However, this method does reflect current operations in New York where arrival and departure demand are rarely optimally balanced.

Figure 4-1 shows how the potential capacity can be calculated for an example throughput measurement at one airport. Variability in capacity due to runway configuration and visibility is controlled by conducting the calculation for individual runway configurations. The sample size is assumed to be sufficiently large such that the Pareto capacity envelope for each runway configuration captures some points where capacity as opposed to demand is limiting the observations that define the envelope. If this assumption were not true then the potential maximum capacity measurement would be conservative. The analysis also assumes that the Pareto envelopes for each individual airport are defined by throughput measurements for which the airport is not constrained by coupling between airports. If the assumption is not correct, then the estimated potential capacity for the airport would again be conservative.

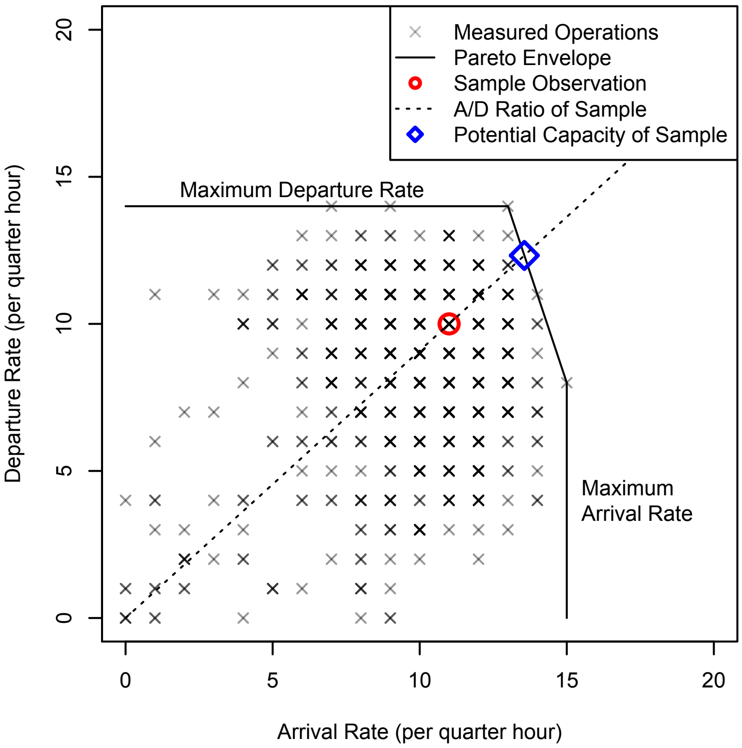


Figure 4-1: An example capacity envelope for the EWR configuration with arrivals on 22L and departures on 22R showing the potential capacity for one sample measurement. The density of the points is proportional to the number of times that operating point was observed

4.2.2 Potential Decoupled Capacity for the System of Airports

The potential capacities for each of the four airports were summed for every throughput observation, as shown in Figure 4-2. This summation measures how much runway capacity would be available in the airport system if every airport were to operate at its potential capacity. In contrast to the airport potential capacity calculation, this aggregate potential capacity value is not necessarily the Pareto envelope of the airspace capacity observations. This difference is because interaction between the airports may prevent each airport simultaneously operating the Pareto envelope.

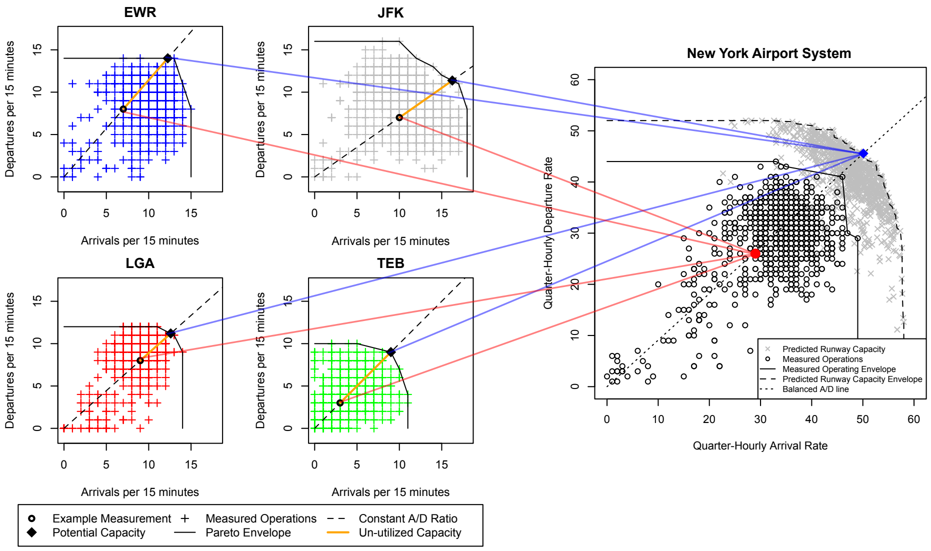


Figure 4-2: Summation of observed throughput and potential capacities to give aggregate values for an example 15 minute observation

Each measurement period has a unique combination of different arrival to departure ratios across the four airports. This leads to an envelope of different airspace potential capacities for a single airspace configuration, with some traffic mixes allowing significantly better runway utilization than others. A Pareto front can then be drawn around this envelope of maximum predicted capacities to find the best achievable airspace capacity if each airport were operating under ideal traffic conditions (the dashed line in Figure 4-2).

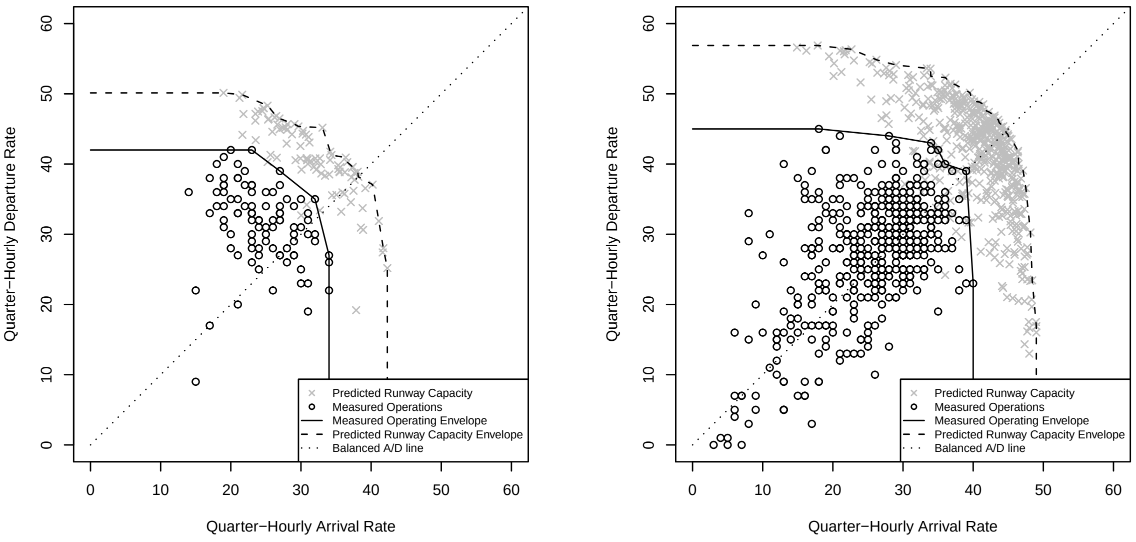
4.3 Results

This section will compare the measured throughput and potential runway capacity for the north and south flow conditions for the departure priority, arrival priority, and IMC configurations. Demand, which is primarily dictated by airline schedules, is assumed to be constant between the two different flow directions within each of these three situations. This is because these schedules are independent of the wind conditions, which is the main factor in determining the flow direction (as explained in subsection 2.3.1). This constant demand means that any differences observed between the north and south flow within each case is due to constraints imposed by either the runways or the airspace.

4.3.1 Departure Priority Configurations

Figure 4-3 shows the achieved throughput and maximum potential capacity envelopes for the departure priority configurations under VMC. In both flow directions the maximum potential capacity envelope is substantially larger than the measured throughput of the airport system. This difference implies that for both configurations, the airport infrastructure can support a higher number of operations than is ever observed.

The maximum potential departure rates (per quarter hour) for the two departure priority configurations are 57 in the south flow case and only 50 in the north flow case. However there is less variability between the maximum measured departure capacities with the south flow case achieving a maximum of 45 operations per quarter hour compared with 42 in the north flow case. These observations suggests that under high departure demand the departure capacity of the airspace is relatively insensitive to the available runway capacity. In particular 42-45 operations per quarter hour seems to represent an upper limit on the departure capacity of the airspace based on current operations. This limit is likely due to capacity constraints in the TRACON or ARTCC. The runways at each airport have demonstrated the potential for an additional 8-12 departures per quarter hour beyond this airspace capacity under ideal traffic conditions (a 19–26% increase).



(a) North Flow-Departure Configuration

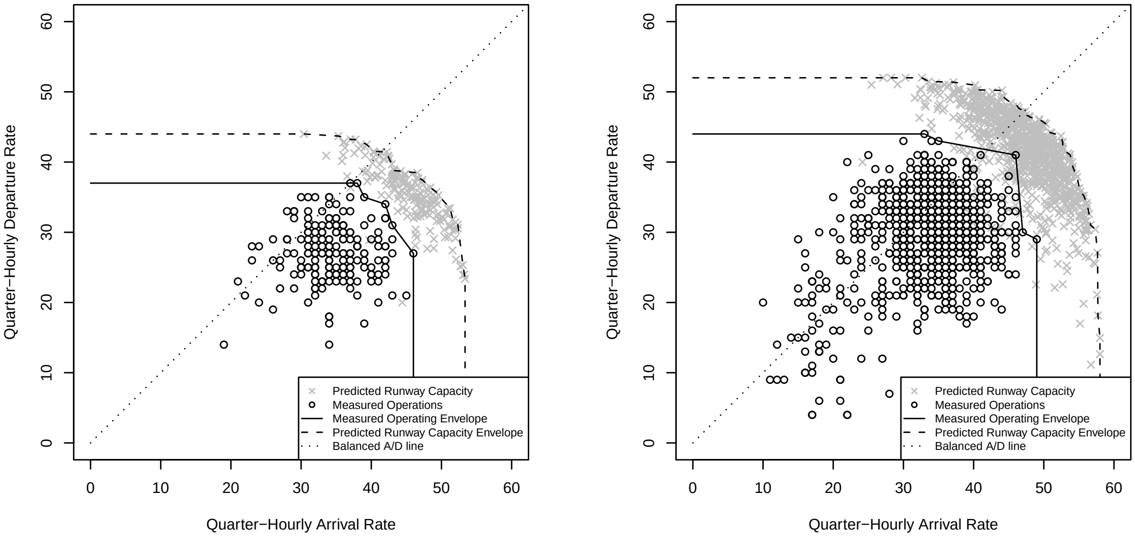
(b) South Flow-Departure Configuration

Figure 4-3: Comparison of measured airspace capacity and predicted total runway capacity for the departure priority configurations under VMC, 5 a.m. - 12 a.m.

The difference in the potential capacity envelopes between the north and south flow departure priority configurations is difficult to explain due to runway or airspace constraints. Subsections 3.1.1 and 3.1.2 highlighted the symmetry between the constraints on these two configurations. Therefore the difference between the two flow directions is likely due to the small number of throughput measurements for the north flow case compared to the south flow case. This imbalance is due to southerly winds being more common than northerly winds in the New York area. The difference could also be by air traffic controllers operating more efficiently in the south flow configuration, because it is the arrival configuration they experience most frequently.

4.3.2 Arrival Priority Configurations

The measured and potential capacity envelopes for the arrival priority configurations under VMC are shown in Figure 4-4. For these configurations the maximum observed arrival throughput is 46 operations per quarter hour in the north flow case and 49 operations per quarter hour in the south flow case. The maximum potential arrival capacity is 53 operations operations per hour for the north flow case and 58 for the south flow case. The potential runway capacity is again substantially higher than the achieved throughput of the airport system and the measured throughput is relatively consistent between the two flow directions.



(a) North Flow -Arrival Configuration (b) South Flow -Arrival Configuration

Figure 4-4: Comparison of measured airspace capacity and predicted total runway capacity for the arrival priority configurations under VMC, 5 a.m. - 12 a.m.

The results for the arrival priority configurations suggest that the maximum arrival capacity of the airspace is approximately 46-49 operations per quarter hour. While the potential runway capacity is 7-9 operations per quarter hour beyond this level. As with the departure priority case this suggests that restrictions in the TRACON or ARTCC are constraining both arrival and departure capacity.

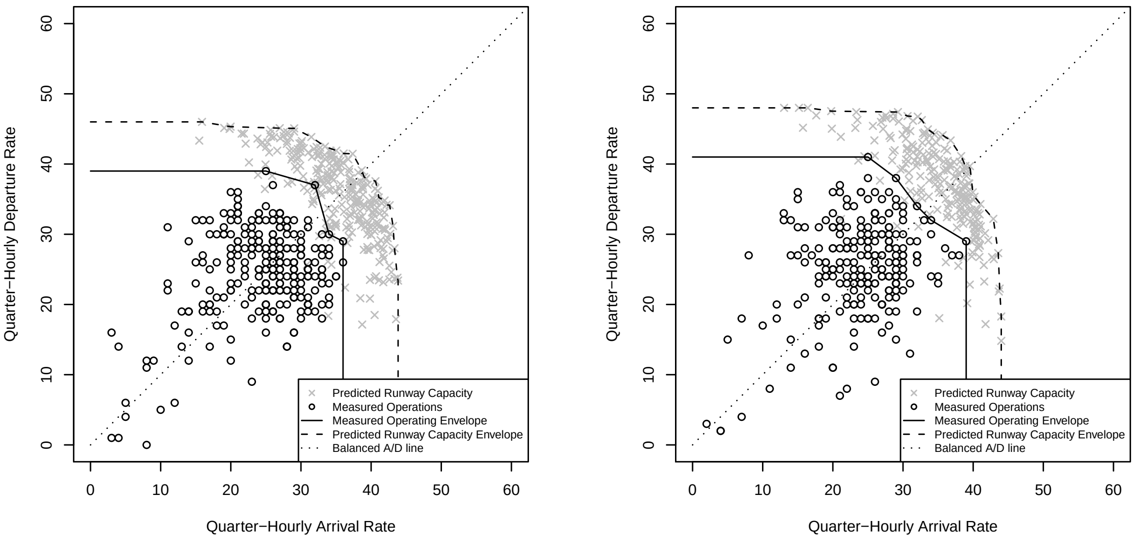
Comparison of the two configurations shows that while arrival throughput is consistent between the flow directions, for departures both the maximum measured throughput and the potential runway capacity show a drop of 7-8 operations per quarter hour. The drop in runway capacity is likely due to the shared use of the departure runway (31L) at JFK in the north flow case, whereas the south flow configuration utilizes a dedicated departure runway. This observation highlights the imbalance in capacity total capacity between the north and south flow conditions when arrivals are a priority.

4.3.3 IMC Configurations

The measured throughput and potential capacity envelopes for the IFR configurations are similar between north and south flow conditions. Both flow conditions have a maximum potential departure capacity of 44 operation per quarter hour and a maximum potential arrival capacities of 46 and 48 operations per hour for the north and south flow configurations respectively. This lower potential capacity compared to the VMC configurations is due to the larger arrival separation requirements under VMC as well as the lower capacity runway configurations used in these conditions (as explained in section 3.2).

The maximum observed departure throughput is eight operations per hour below the potential capacity in both for both IMC configurations. The difference between the measured maximum arrival throughput and the potential capacity is 8 operations per hour for the north flow case and 5 operations per hour for the south flow case. The observed throughputs are therefore lower for the IMC configurations than for the VMC configurations. This observation suggests that the airspace capacity is more constrained under IMC than under VMC. This result is not intuitive given that IMC only changes procedures close to the airports. However, subsection 4.4.1 will show that there are mechanisms by which increased congestion can reduce the efficiency of the airspace.

Figure 4-5b shows that some observations for the south flow arrival case come closer than any other configuration to the predicted capacity, particularly when arrival rates are high. This observation suggests that during periods of high arrival demand under IMC, the configuration is close to the maximum attainable runway capacity. This observation makes sense given that both EWR and JFK are limited to operations on only two closely spaced parallel runways for this configuration (as described in subsection 3.2.2).



(a) North Flow

(b) South Flow

Figure 4-5: Comparison of measured airspace capacity and predicted total runway capacity for two airspace configurations under IMC, 5 a.m. - 12 a.m.

4.4 Causes of the Throughput Constraints

Section 4.3 shows that for all of the examined airspace configurations the aggregate runway capacity is substantially higher than the achieved throughput of the system of airports. Physically, this means that the airspace prevents aircraft from achieving the minimum spacing required at the runway. To achieve the potential runway capacity each airport would have to be able to simultaneously operate at this ideal spacing.

4.4.1 Airspace Capacity Constraints

In order to achieve the maximum possible runway throughput, arriving and departing aircraft must be separated by the minimum allowed spacing (described in subsection 2.3.2). Any increase from the minimum allowed separation represents runway capacity that is being wasted.

For arrivals, the TRACON must deliver aircraft to the start of each final approach with the minimum required separation. Currently this separation is managed by "vectoring" the aircraft, whereby controllers individually guide each aircraft into position behind the preceding aircraft. The controllers manually adjust the path each aircraft uses, making it longer or shorter as required to achieve the minimum required spacing. While vectoring aircraft can yield high throughputs, it also places a substantial workload on controllers during high traffic periods. Under very high traffic levels, achieving this minimum spacing may simply place an excessive workload on the TRACON. At these times the total volume of traffic or the traffic flow rate into and out of the TRACON may be restricted to ensure the traffic remains at a manageable level.

The increased use of precise time-based navigation in NextGen may allow ATC to give tightly defined arrival time clearances to arriving aircraft, thereby leaving little or no additional separation management by the TRACON. Alternatively (or additionally), NextGen may allow separation responsibility to be delegated to pilots, even under IFR [8]. Aircraft would then be responsible for maintaining a given separation from the aircraft in front, using a technology such as Automatic Dependent Surveillance-Broadcast (ADS-B) to monitor the position of the lead aircraft. These procedures could reduce TRACON controller workload thereby allowing the alleviation of the arrival throughput constraints.

Arrival capacity may be constrained even further upstream than the TRACON in the en-route airspace controlled by the ARTCCs. Like the TRACON the centers can be limited by controller workload. Discussions with air traffic control personnel also suggest that some of the procedures used to manage traffic flow in the ARTCCs may lead to inefficient arrival spacing. In particular, for New York, it is the ARTCCs that are responsible for managing aircraft in holding patterns. ARTCCs procedures dictate that it is always the bottom aircraft in the holding stack that is released first. This strict procedure means that time is sometimes wasted waiting for the bottom aircraft to turn back to the correct heading before leaving the holding pattern. In contrast, if the TRACON was to manage the holding aircraft, they would be able to choose the aircraft that was best positioned to rapidly exit the holding pattern.

The inefficiencies associated with holding aircraft may explain why the maximum observed airspace capacity drops between the VMC and IMC cases. This is because holding is typically required more often under IMC in order to compensate for the reduced capacity at the airports under these conditions.

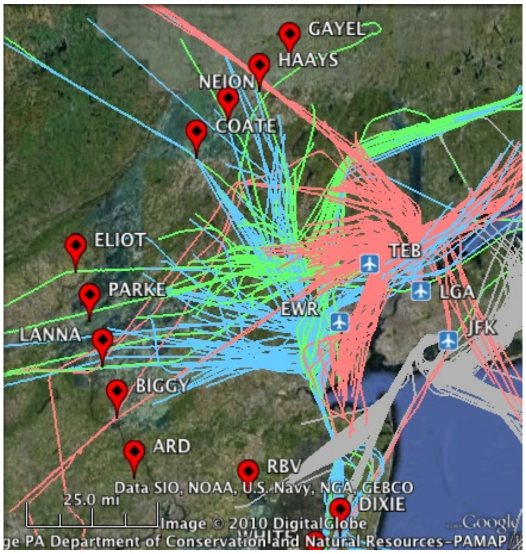

GAYEL
HAAYS
NEION
COATE
ELIOT
PARKE
LANNA
BIGGY
ARD
RBV
DIXIE
TEB
LGA
EWR
JFK
25.0 mi
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2010 DigitalGlobe
ge PA Department of Conservation and Natural Resources-PAMAP
Google

Figure 4-6: Example flight tracks showing the merging of departure traffic from different airports before reaching the departure gates (also shown) for the S-VMC-DP configuration.

The spacing between departing aircraft is managed by the air traffic control towers at each airport. Towers do not typically suffer from the same workload constraints as the TRACON or ARTCC. The interaction mechanism between departures must therefore be different from that for arrivals. A likely cause of inefficiency in departure sequencing is the merging of traffic flows from different airports before the departure fixes (shown in Figure 4-6). Each fix has a capacity of approximately 12 aircraft per quarter hour[2] which is slightly higher than a typical departure runway capacity (8-10 operations per quarter hour). There are also many more departure gates than departure runways, therefore total gate capacity is much higher than the total runway capacity. Despite this high capacity, conflicts can still occur between airports leading to some departures being slightly delayed in order to ensure safe separation of aircraft at the gate. Gate capacity is typically managed by assigning a MIT restriction between departures to the same gate from each airport. Departure gate capacity is also frequently lowered below the maximum allowed by separation requirements in order to manage the traffic flow through the ARTCCs.

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[2] this capacity was estimated assuming all aircraft are traveling at the terminal area speed limit of 250 knots and are separated at the minimum required spacing of 5 n.m.

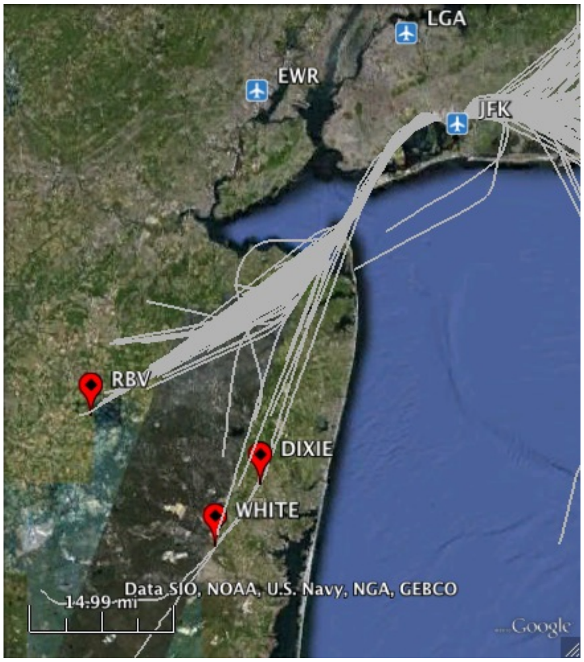

Figure 4-7: Departures from JFK runway 31L to the west over RBV

A simple example of departure gate capacity limiting departure throughput at an airport can be seen for departures from runway 31L at JFK. 31L is typically used for aircraft departing to the west over the RBV departure fix (which is exclusively used by JFK departures) as shown in Figure 4-7. In this situation a spacing restriction applied at RBV translates directly into a reduced departure rate from 31L at JFK. Similar situations occur at other airports and departure gates the situation is complicated by the fact that most departure gates are shared between airports and airports usually utilize multiple gates. This dependency leads to many different MIT restrictions being applied at each airport, which adds complexity to the departure sequencing.

Increasing departure capacity will require removing the interaction between departure procedures from adjacent airports. This could be achieved by either redesigning the departure gates such that each airport has its own gates. The level of coordination between airports could also be improved to reduce the number of conflicting departures. Procedural separation of departure flows from the New York airports would benefit from NextGen precision navigation technologies such as Required Navigational

Performance (RNP)[3]. RNP departure procedures would allow departure procedures from different airports to each climb efficiently towards their own departure gates while maintaining safe separation.

The solution to increased departure capacity out of the New York area may lie many miles away in the ARTCC airspace. NextGen concepts that increase the capacity of en route airspace would reduce or eliminate the need for MIT restrictions over the departure fixes (described in subsection 4.4.1). Removal of these constraints would increase the departure rate attainable at each airport.

4.4.2 Traffic Effects on Throughput

It is also important to note that while removing the airspace constraints would increase throughput, achieving the maximum possible throughput requires consideration of several other factors:

- The level of demand at each airport
- The arrival to departure ratio at each airport
- The mix of different aircraft types at each airport

Effect of Demand on Measured Airspace Capacity

The estimation of the potential airspace capacity implicitly assumes high demand at each of the four New York airports because it is constructed from Pareto maximal throughput measurements. However, this study has not sought to directly measure the total demand in the airspace for each throughput measurement. It is therefore possible that while the potential capacity of the airspace is constructed from high demand operating points at each airport, such demand conditions may never be observed simultaneously. In this case, some of the potential capacity improvement would be attainable through increased demand to some of the airports. This scenario seems unlikely given the high levels of traffic seen in all of the studied airports. The high frequency of long delays into and out of the New York area are also indicative of demand for traffic that often approaches the capacity of the region.

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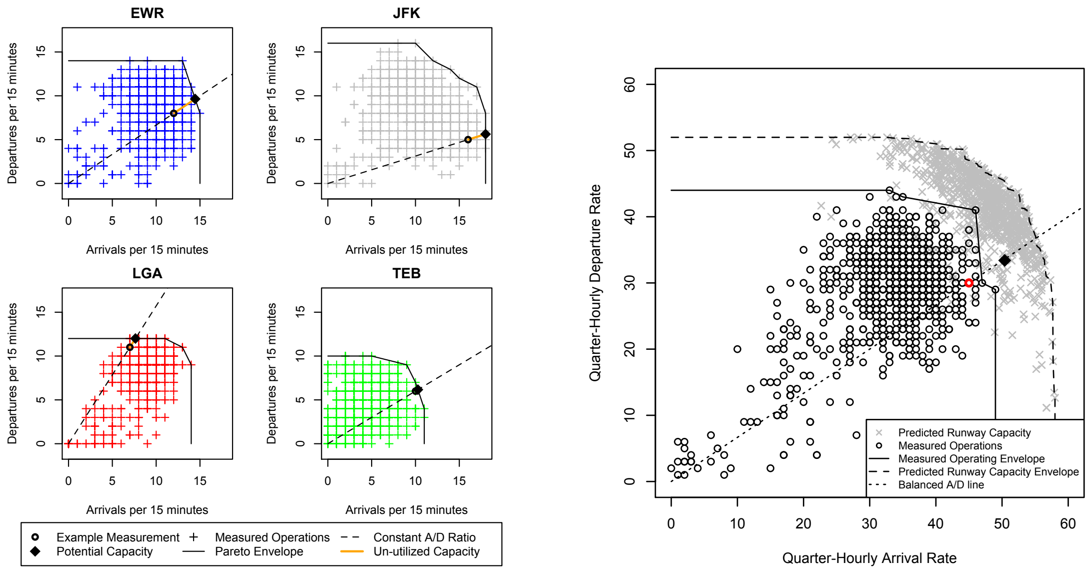
[3] Required Navigational Performance (RNP) procedures define complex three-dimensional trajectories that aircraft must follow to a pre-defined level of precision. For example an RNP0.3 approach procedure requires that an aircraft be within 0.3 n.m. of the procedure centerline at least 95% of the flight time.

Effect of Arrival to Departure Ratio

The ratio of arrivals to departures at an airport can have a strong influence on the total runway capacity available at that airport. For every arrival-to-departure ratio at the aggregate level, there is an optimal combination of individual airport arrival-to-departure ratios. Figure 4-2 shows an example operating point with a favorable balance of arrivals to departures at each airport, leading to a potential capacity lying on the Pareto envelope. Figure 4-8 shows another 15 minute period, but in this case the balance of traffic at each airport is sub-optimal. At both EWR and JFK there are a large number of arrivals and few departures, while at LGA the converse is true. This sub-optimal combination leads to a aggregate potential capacity well below the maximum potential capacity at this arrival-to-departure ratio.



(a) Individual airport throughput measurements

(b) Aggregate airspace throughput and potential capacity

Figure 4-8: An example throughput measurement with a low potential capacity

Removing the variability in maximum capacity due to the balance of arrival and departure demand may be difficult. This difficulty is primarily because the FAA has little control over airline schedules, with airlines generally able to schedule flights at their discretion. This lack of management of the demand for traffic can lead to inefficient use of the airport resources. In particular, arrival or departure peak periods that force airports to operate away from the more efficient operating points. Demand control could be performed in a variety of ways from economic disincentives to scheduling flights during peak traffic hours ("peak hour pricing") to the highly restrictive slot control schemes commonly found in Europe. Demand control in New York is made particularly difficult by the large variability in the runway capacity of the airport system. This variability is dependent on which airspace configuration is in use. Additionally, the optimum capacity at EWR and JFK is often not balanced between arrivals and departures because these airports often operate an odd number of runways with segregated operations e.g. two arrival runways and one departure runway or vice-versa. This imbalance between arrival and departure capacity leads to strong coupling between the relative demand for arrivals and departures and the airport capacity. Such coupling makes it difficult to devise a demand management scheme that treats all airline schedules fairly.

Effect of Traffic Mix on Airspace Capacity

The prediction of the potential airspace capacity used in this analysis uses the best observed throughputs measured at each individual airport. This method means that the potential capacities calculated are likely to be for favorable mixes of aircraft at each of the New York airports. These favorable traffic mixes are not necessarily present at the same time, therefore some of the gap between the observed throughputs and estimated potential capacity is likely to be due to sub-optimal traffic mixes at some airports.

These fleet mix effects will not reduce the estimated potential capacity of the airspace, however they may contribute to the lower achieved throughputs. The mix of different aircraft sizes operating at each airport is difficult to change given that airline fleets evolve over decades.

Even considering a fixed traffic mix, the sequencing of different aircraft types has a large impact on the maximum possible arrival runway capacity. Certain pairings of arriving aircraft are substantially more efficient than others. Where possible, ATC does attempt to utilize efficient arrival sequences. However, large changes to the arrival order are unfeasible given the tight airspace around New York. The sequencing of different aircraft types is an area that may be improved by NextGen technologies. Such changes would reduce the magnitude of the capacity loss due to sub-optimal variable traffic mixes.

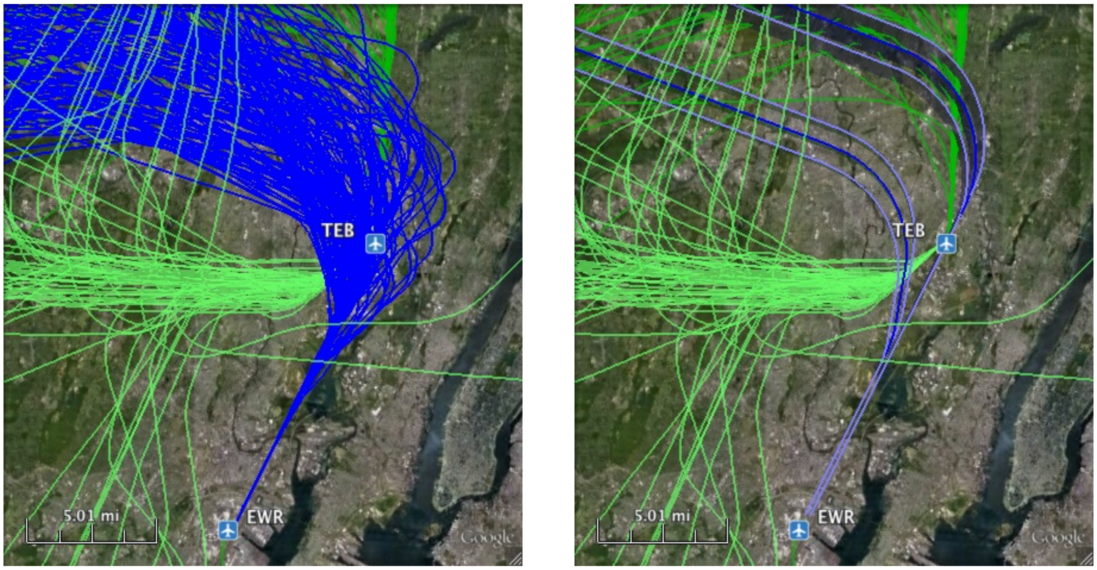
Chapter 5

Runway Capacity Improvements

The empirical potential capacity measurement explained in section 4.3 can only measure capacity that is available under current procedures. Some of the procedures at New York prevent airports from ever attaining the full capacity from their runways. Capacity attainable by removing these limits would not be estimated by the empirical approach in section 4.3. This section will show examples of where current procedures limit capacity and will also estimate the potential capacity gains from removing these limits. The runway capacity model detailed in Appendix B will be used to estimate the scale of the capacity improvements.

5.1 Potential improvements at EWR

One strategy for increasing arrival capacity in the southerly flow direction at EWR would be to enable the simultaneous use of both 22L and 22R for arrivals. Simultaneous parallel approach procedures are currently available under VMC to runways 4L and 4R, but are not permitted in the 22 direction due to airspace constraints to the north. The position of the TEB 24 departure procedure currently prevents the use of two approaches to the 22L and 22R parallel runways. Improved airspace utilization may be possible using NextGen precision navigation technologies such as RNP. Figure 5-1 shows how RNP procedures could be used to sub-divide the airspace currently used by the 22L approach to enable approaches to both 22L and 22R.



(a) Current 22L approach

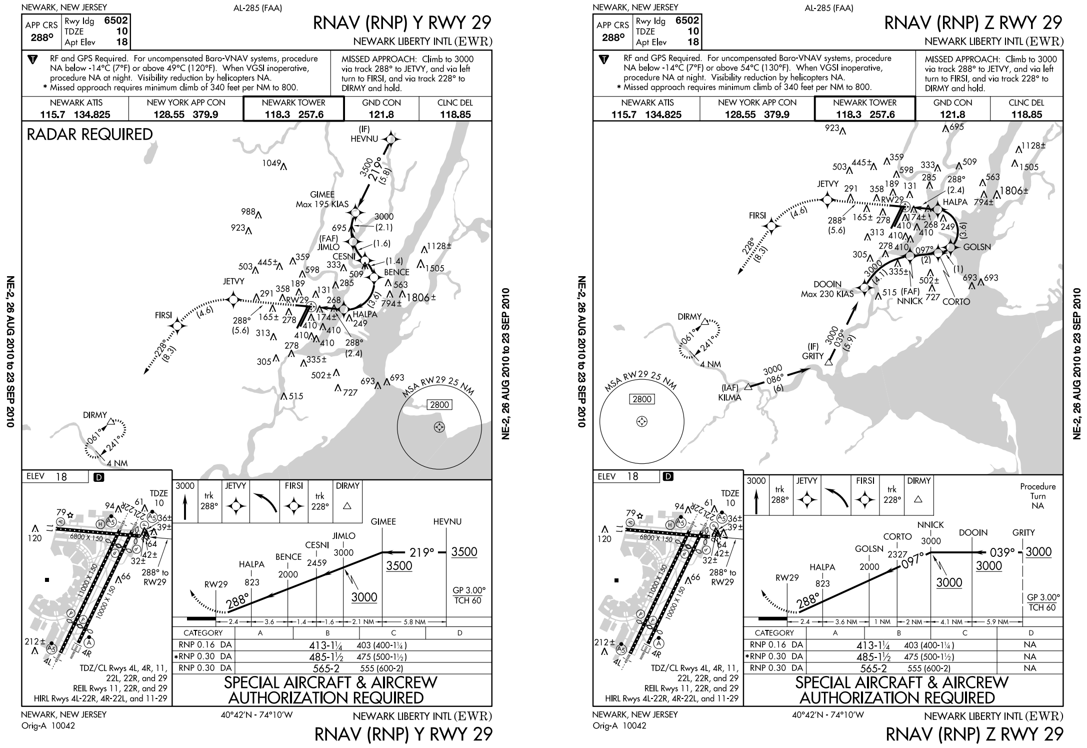
(b) Hypothetical RNP approaches to 22L and 22R (track centerline and RNP containment region)

Figure 5-1: Comparison of the currently flown approach to 22L with hypothetical RNP approaches to 22L and 22R

UnderVMC simultaneous approaches to 22L and 22R would provide EWR with increased flexibility in its arrival capacity. Simultaneous approaches to 22L and 22R would likely prohibit any operations on the crossing runway, which currently performs approximately eight arrivals per hour. Given that arrivals on 22R would reduce the departure throughput on this runway, simultaneous approaches to 22L and 22R will not increase the total capacity at EWR. However, this change would allow greater arrival capacity than is currently achievable, giving the airport greater flexibility to deal with surges in arrival demand.

Under IMC EWR is limited by the the separation requirements for operations on CSPR, as explained in section 3.2. At EWR allowing simultaneous use of both runways for arrivals would reduce the impact of IMC during periods of high arrival demand. This would allow the airport to sacrifice departure capacity in order to increase the arrival rate, a trade that is currently not possible. Improving access to CSPR is recognized as being a high priority goal for NextGen [9].

In the northerly direction a relaxation of the IFR CSPR operating restrictions could be applied without any other changes. In the south flow case these changes would have to be accompanied by a redesign of the airspace to the north of EWR in order to accommodate a 22R approach (as explained above).


NEWARK, NEW JERSEY
AL-285 (FAA)
RNAV (RNP) Y RWY 29
NEWARK LIBERTY INTL (EWR)
APP CRS 288°
Rwy ldg 6502
TDZE 10
Apt Elev 18
RF and GPS Required. For uncompensated Baro-VNAV systems, procedure NA below -14°C (7°F) or above 49°C (120°F). When VGSI inoperative, procedure NA at night. Visibility reduction by helicopters NA.
* Missed approach requires minimum climb of 340 feet per NM to 800.
MISSED APPROACH: Climb to 3000 via track 288° to JETVY, and via left turn to FIRSI, and via track 228° to DIRMY and hold.
NEWARK ATIS 115.7 134.825
NEW YORK APP CON 128.55 379.9
NEWARK TOWER 118.3 257.6
GND CON 121.8
CLNC DEL 118.85
RADAR REQUIRED
(IF) HEVNU
GIMEE Max 195 KIAS
(FAF) JIMLO
CESNI
BENCE
HALPA
JETVY
FIRSI
DIRMY
MSA RW 29 25 NM
2800
NE-2, 26 AUG 2010 to 23 SEP 2010
ELEV 18
TDZE 10
SPECIAL AIRCRAFT & AIRCREW AUTHORIZATION REQUIRED
CATEGORY A B C D
RNP 0.16 DA 413-1¼ 403 (400-1¼)
•RNP 0.30 DA 485-1½ 475 (500-1½)
RNP 0.30 DA 565-2 555 (600-2)
GP 3.00° TCH 60
TDZ/CL Rwys 4L, 4R, 11, 22L, 22R, and 29
REIL Rwys 11, 22R, and 29
HIRL Rwys 4L-22R, 4R-22L, and 11-29
NEWARK, NEW JERSEY
Orig-A 10042
40°42'N - 74°10'W
NEWARK LIBERTY INTL (EWR)
RNAV (RNP) Y RWY 29
NEWARK, NEW JERSEY
AL-285 (FAA)
RNAV (RNP) Z RWY 29
NEWARK LIBERTY INTL (EWR)
RF and GPS Required. For uncompensated Baro-VNAV systems, procedure NA below -14°C (7°F) or above 54°C (130°F). When VGSI inoperative, procedure NA at night. Visibility reduction by helicopters NA.
* Missed approach requires minimum climb of 340 feet per NM to 800.
MISSED APPROACH: Climb to 3000 via track 288° to JETVY, and via left turn to FIRSI, and via track 228° to DIRMY and hold.
DOOIN Max 230 KIAS
(FAF) NNICK
CORTO
GOLSN
(IF) GRITY
(IAF) KILMA
Procedure Turn NA
SPECIAL AIRCRAFT & AIRCREW AUTHORIZATION REQUIRED
NEWARK, NEW JERSEY
Orig-A 10042
40°42'N - 74°10'W
NEWARK LIBERTY INTL (EWR)
RNAV (RNP) Z RWY 29

(a) RNP Y procedure (from north)

(b) RNP Z procedure (from south)

Figure 5-2: Two new RNP procedures to runway 29 at EWR [10]

The restrictions placed on operations to arrivals to runway 29 at EWR described in subsection 3.1.4 are a major limitation to EWR arrival capacity. The FAA has already begun the process of improving the arrival capacity of runway 29 through the design and publication of several RNP approaches to the runway shown in Figure 5-2. The use of this precision navigation technology increases the consistency with which each aircraft executes the approach procedure by enabling controllers to use the CRDA. With improved predictability in the spacing between arrivals, more efficient sequencing of aircraft onto the two arrival runways will be possible. However, the close proximity of the thresholds of runways 22L and 29 makes tight sequencing of operations to these runways infeasible under all but the most ambitious NextGen proposals. Improved sequencing to runway 29 is therefore only likely to be useful when wind conditions dictate use of that runway and is unlikely to be a means of increasing maximum arrival capacity at EWR. For this improvement to be realized, every aircraft and aircrew using runway 29 must be equipped and trained to fly the RNP approach.

5.2 Potential improvements at JFK

JFK shares the Belmont airspace to the north as described in subsection 3.2.2. When the Belmont airspace is delegated to LGA arrivals are not allowed on runway 22R at JFK. Removing this restriction could be achieved by either using an RNP departure procedure from runway 13 at LGA or implementing curved RNP approaches to 22L and 22R at JFK. It is unlikely that this change would increase the capacity of the favorable S-VMC-AP configuration, however it would provide the airport with more flexibility under less ideal wind and visibility conditions.

JFK would also benefit from any technologies that could enable increased use of configurations with crossing runways. The North-VMC-AP configuration described in subsection 3.1.3 highlights the limits imposed on JFK capacity by the runway geometry in some configurations. In this case, the sequencing of simultaneous arrivals to either 22L or 22R (in addition to the currently used 31R) would allow 31L to be exclusively used for departures. This would provide a similar capacity to the equivalent south flow configuration (South-VMC-AP), thereby reducing some of the uncertainty in capacity due to weather. Tools such as the CRDA would aid controllers in safely and efficiently sequencing arrivals to these crossing runways.

At JFK the potential for increased capacity due to CSPR separation rules is smaller than for EWR because simultaneous operations are already allowed on all of its parallel runways. However enabling independent arrivals on the 4/22 runways would enable more efficient operation of the airports compared with the coordination required by the current 1.5 n.m. diagonal spacing requirement.

5.3 Potential improvements at LGA

In most cases the capacity at LGA is close to the maximum possible given its two crossing runways (as can be seen in Figure B-2c). There is therefore little opportunity for procedure redesign to create extra capacity at this airport. However, due to the location of the airport between the other New York airports it is likely that changes to procedures at LGA will be required in order to increase capacity at these other airports.

The loss of the Belmont extension airspace (described in subsection 3.2.2) is the only common procedural constraint on LGA runway capacity. This constraint causes the south IMC configuration to be the worst performing configuration of all those studied at LGA. Comparison with the throughput of the north flow IMC case suggests that the reduction may be as great as 8 operations per hour. RNP procedures for LGA runway 13 departures and JFK runway 22L and 22R arrivals could be designed to remove this constraint.

Chapter 6

Conclusions

This study has shown that the capacity of the New York airport system is below the total runway capacity of each of its constituent airports. The measured gap between airspace capacity and runway capacity of the system is likely due to congestion either in the TRACON or in the ARTCCs. Such congestion imposes spacing restrictions on both arriving and departing traffic as it enters and leaves the New York area.

The potential for capacity improvement was measured to be as great as 48 departures per hour in the S-VMC-DP configuration and 36 arrivals per hour in the S-VMC-AP configuration. These are large numbers of operations when compared to the capacity of 84-92 operations per hour [11] at EWR under optimum conditions. This analysis shows that even without increasing the runway capacity at each airport, substantial capacity improvements are available by improving the flow of traffic through the airspace.

While some of the constraints on the New York airports lie in the airspace, attaining the full runway capacity of the system will also require ideal traffic conditions. In particular demand for operations must be sufficient to fill the available capacity at each of the airports. That demand must also be in the correct ratio of arrivals to departures at each airport. The ideal level of demand and balance of arrivals and departures varies with each airspace configuration. This variability makes controlling demand a difficult balance between over-scheduling flights which would lead to delays and under-scheduling which would leave capacity un-utilized in some conditions. Some of the procedural changes presented in chapter 5 may allow a more uniform capacity between configurations thereby alleviating some of the uncertainty in determining how many flights should be scheduled.

The method used to estimate the potential runway capacity of the New York airports was inherently conservative. Only capacity that had been demonstrated at some point in the two year measurement period was included in the calculation. This method meant that the ever-present constraints imposed by procedural interaction close to each airport were not measured. Examination of the procedures at each airport showed that for the best configurations at each airport the procedural constraints due to other airports are not restrictive. However these interactions are often the reason that sub-optimal weather conditions lead to substantial capacity reductions.

With current runway separation requirements NextGen is unlikely to be able to make large increases in the capacity of the New York airport system beyond the maximum potential measured in this study. However, NextGen will provide the tools to alleviate some of the interactions that limit capacity in lower-performance configurations.

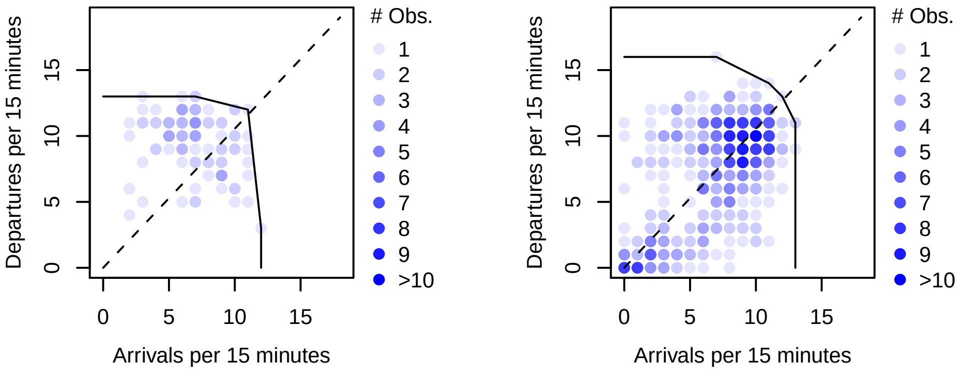
Appendix A

Capacity Envelopes

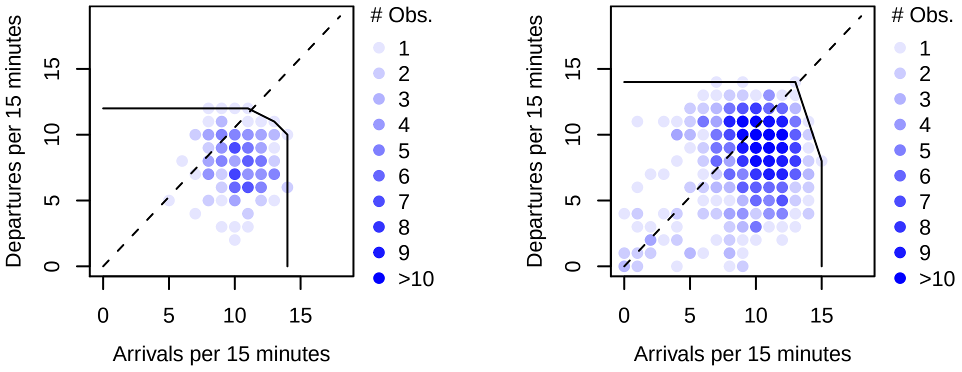
Figures A-1, A-2, A-3, and A-4 show the capacity envelopes at each airport for every airspace configuration analyzed. The density of each operating point is proportional to the frequency with which that combination of throughputs was observed for that airspace configuration.

A.1 EWR Capacity Envelopes

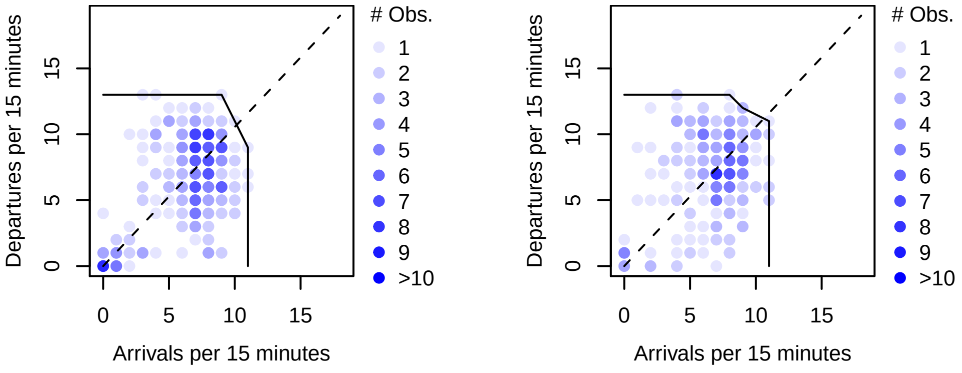
At EWR the departure priority configurations that utilize only the the two main parallels give capacity envelopes that are balanced between arrival and departure capacity. Use of the crossing runway in the arrival priority configuration allows a clearly observed increase in the arrival rate. The observed throughputs under IMC have a large amount of variability likely due to different IMC weather conditions imposing different levels of constraint on the airport operations. The capacity of the airport is similar between north and south flow conditions under IMC, as would be expected given the symmetry of these configurations (described in section 3.2).



(a) N-VMC-DP (b) S-VMC-DP



(c) N-VMC-AP (d) S-VMC-AP



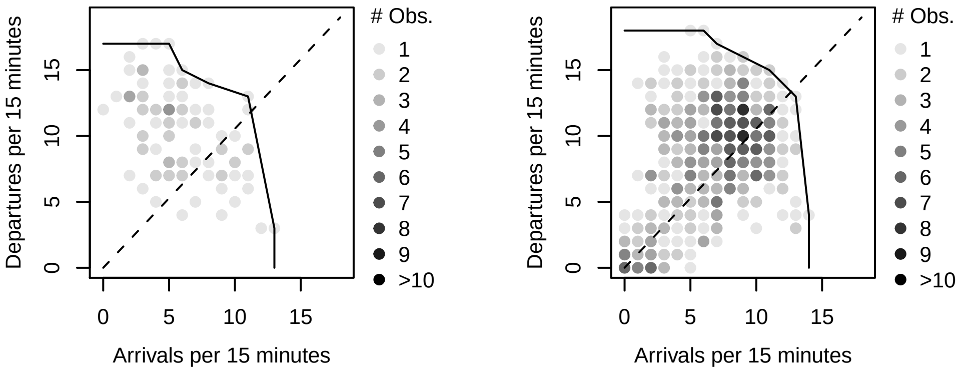
(e) N-IMC (f) S-IMC

Figure A-1: Runway envelopes at EWR for each configuration (6 a.m. – 12 a.m.).

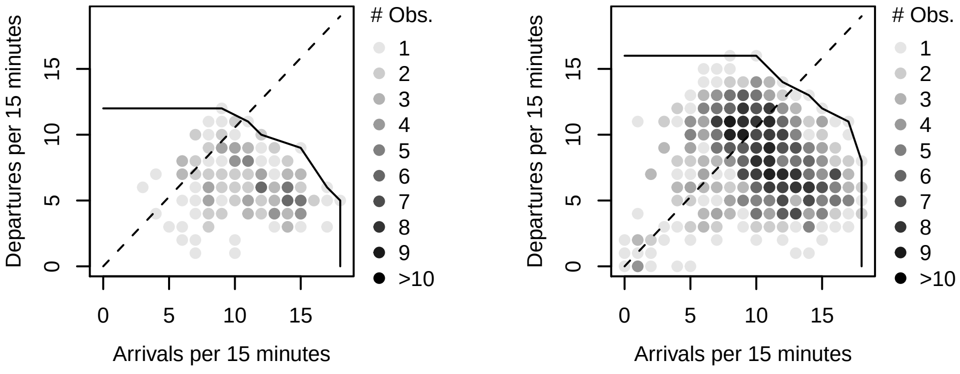
A.2 JFK Capacity Envelopes

At JFK the use of two departure runways leads to a high (17–18 operation per quarter hour) departure capacity in the departure priority configurations. However this available capacity is rarely fully utilized, as the low density of observations at high departure throughputs shows in Figure A-2a and Figure A-2b. In contrast the use of a second arrival runway in the south flow arrival priority configuration (Figure A-2d) does create heavily used extra arrival capacity. When only two runways are used during high arrival demand periods (the north flow arrival priority configuration), departure capacity is severely restricted in order to meet arrival demand. Comparing Figure A-2c and Figure A-2d shows the expense to departures of operating a shared runway (Figure A-2c) compared to segregated (Figure A-2d) operations.

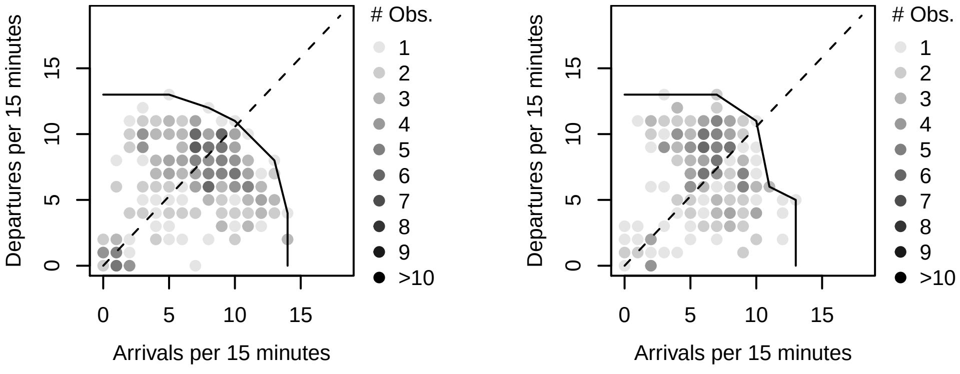
Under IMC JFK trades capacity between arrivals and departures, through use of a shared arrival and departure runway (4L/22R). The maximum arrival and departure capacity of the airport are substantially lower under IMC than many of the commonly observed VMC operating points. This observation shows that under IMC demand frequently exceeds airport capacity.



(a) N-VMC-DP (b) S-VMC-DP



(c) N-VMC-AP (d) S-VMC-AP

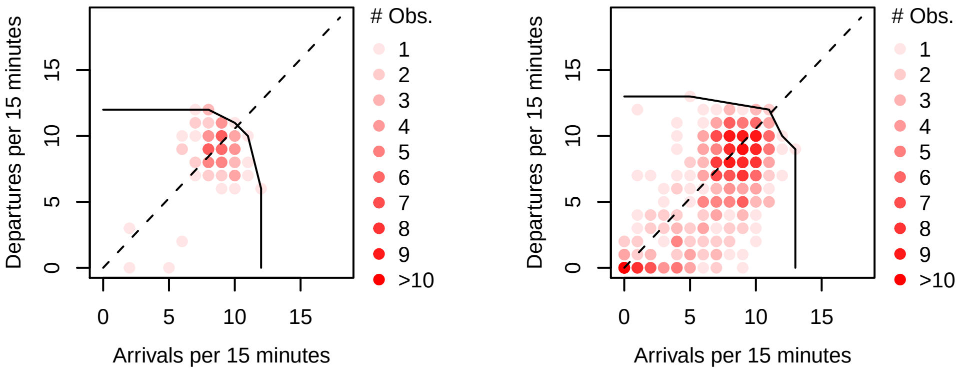


(e) N-IMC (f) S-IMC

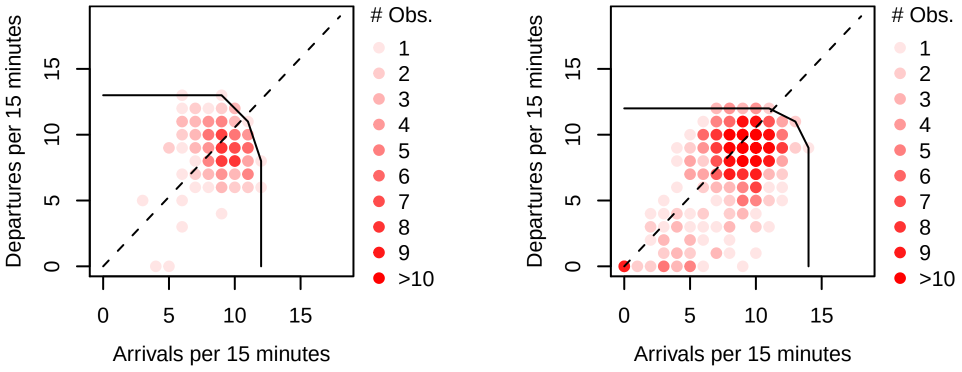
Figure A-2: Runway envelopes at JFK for each configuration (6 a.m. – 12 a.m.).

A.3 LGA Capacity Envelopes

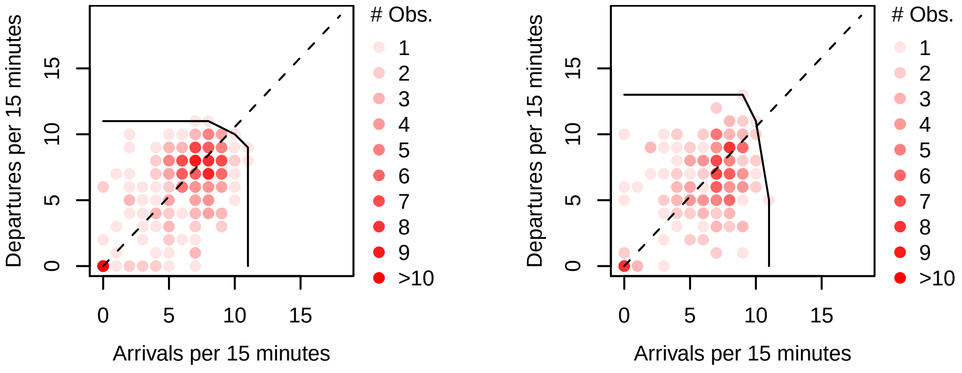
Figure A-4 shows that the crossing runway configuration at LGA leads to the airport frequently operating with approximately equal numbers of arrivals and departures. Under IMC traffic generally remains balanced however with lower achieved arrival and departure throughputs. The generally high demand at LGA leads to the measured throughputs being consistently close to the capacity envelope.



(a) N-VMC-DP (b) S-VMC-DP



(c) N-VMC-AP (d) S-VMC-AP

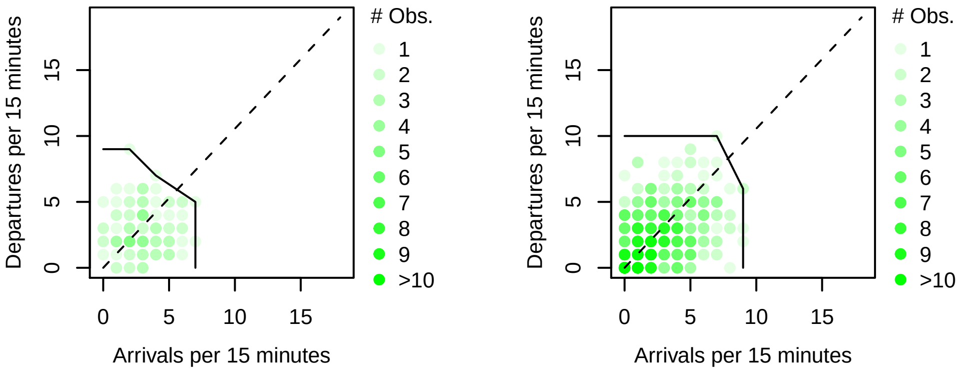


(e) N-IMC (f) S-IMC

Figure A-3: Runway envelopes at LGA for each configuration (6 a.m. – 12 a.m.).

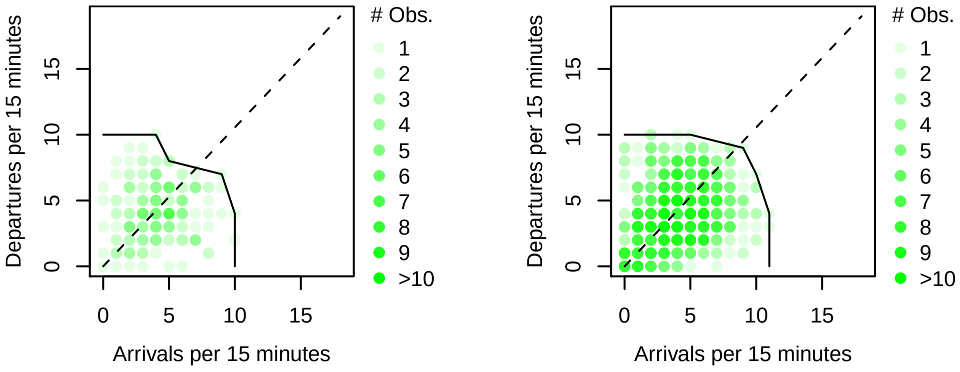
A.4 TEB Capacity Envelopes

The lack of scheduled service at TEB leads to a different distribution of observed throughputs compared to the other three airports. At TEB the the most frequently observed operating points are for low numbers of operations, while the data close to the capacity envelope is sparse. Comparison of the single runway configuration in Figure A-4a with the other two runway VMC configurations shows that the capacity for the single runway configuration is lower and requires sharing of arrival and departure capacity. The IMC configurations have lower capacities than the equivalent VMC configurations and relatively little trading between arrival and departure capacity, as would be expected given these configurations segregated arrival and departure runways.



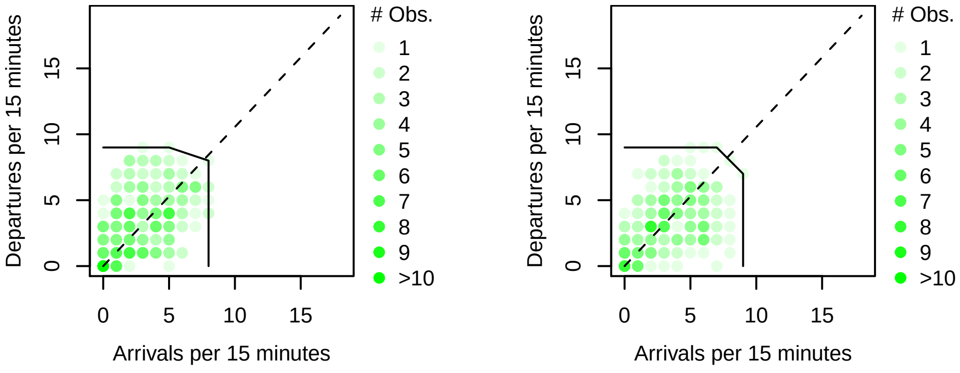
(a) N-VMC-DP

(b) S-VMC-DP



(c) N-VMC-AP

(d) S-VMC-AP



(e) N-IMC

(f) S-IMC

Figure A-4: Runway envelopes at TEB for each configuration (6 a.m. – 12 a.m.).

Appendix B

Theoretical Analysis of Airspace Capacity

The empirical analysis explained in chapter 4 can only measure capacity that is available under current procedures. Some of the procedures at New York prevent airports from ever attaining the full capacity from their runways. Capacity attainable by removing these limits would not be measured by the observation-based approach in chapter 4. In order to predict these potential gains, a theoretical capacity model is required. A comparison between the results of the theoretical and empirical analyses will help identify scenarios where demand may be limiting throughput.

Airport capacity modeling is the subject of continued research and capacity models can be made to consider many different variables affecting capacity. However, for the purposes of this study, a simple queuing model will provide sufficient results for a first-order comparison of theoretical and achieved capacity at each airport.

B.1 Theoretical Estimation of Runway Capacity

A queuing model for arriving and departing traffic was used as the basis for estimating runway capacity at each airport. This model was originally proposed for arrivals by Blumstein [12] and extended by Odoni and de Neufville [13] to include departures and mixed-use runways. The model has been adapted in this study to include the effects of VFR, dispersal departure headings and crossing runways, all of which are important features of the New York airspace.

The arrival and departure capacity was calculated at the three major airports (EWR, JFK and LGA) for each runway configuration considered in the empirical analysis.

B.1.1 Arrival Capacity

The basic runway capacity model assumes flights are being conducted under IFR, which means that the minimum spacing requirements between subsequent arrivals and departures are clearly defined. The minimum spacing requirements within a pair of aircraft are dependent on the relative weight categories of the two aircraft. For arriving aircraft, this dictates a minimum spacing that must be maintained over the length of the final approach. For departures, the separation is defined as a minimum time between successive operations. In the following calculations, i will be used to refer to the weight category of the lead aircraft and j to weight category of the trailing aircraft. The time required between a pair of arriving aircraft on an approach of length r is defined by both the required separation distance (s_{ij}) within the pair, as well as the approach velocity of the lead and trailing aircraft (v_i and vj) (as shown in Figure B-1). Under IFR, the FAA requires controllers to impose minimum separation rules between aircraft depending on their respective Maximum Takeoff Weights (MTOWs). These separation requirements (s_{ij}) are listed in Table B.1. The

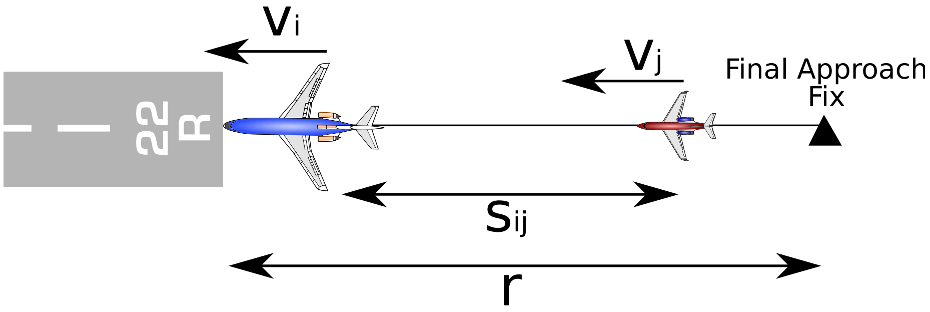


Figure B-1: A representation of the key parameters describing an arriving pair of aircraft as used in the runway capacity model calculation of the time required is dependent on whether the lead aircraft is faster or slower than the trailing aircraft and is shown in Equation B.1. In all cases, the separation must be at least the Runway Occupancy Time (ROT) of the leading aircraft in (o_i) order to ensure the runway is clear before the next arrival.

$$T_{ij}^{\text{IFR}} = \begin{cases} \max\left[\frac{r+s_{ij}}{v_j} - \frac{r}{v_i}, o_i\right] & \text{when } v_i > v_j \\ \max\left[\frac{s_{ij}}{v_j}, o_i\right] & \text{when } v_i \leq v_j \end{cases} \tag{B.1}$$

Table B.1: Required separation (s_{ij}^{Arr}) under IFR between pairs of arriving aircraft in the United States (nautical miles)[4]

		Following (j)				
		A380	H	B757	M	L
Leading (i)	A380	6	6	8	8	10
	H	2.5	4	5	5	6
	B757	2.5	4	4	4	5
	M	2.5	2.5	2.5	2.5	4
	L	2.5	2.5	2.5	2.5	2.5

The probability of encountering any given pairing of weight categories for the lead and following aircraft is found by multiplying the probabilities of encountering aircraft with weight categories i and j. These probabilities were generated using ETMS count data for 2007 and 2008, which lists the time of arrival (or departure) and aircraft type for each flight. These probabilities were calculated separately for peak arrival and peak departure periods of the day because at some airports (particularly EWR and JFK) the mix of aircraft types is significantly different between morning and afternoon periods.

Once both the probability and time required of an operation by aircraft weight i, followed by an aircraft of weight j, have been calculated the expected time taken by an arriving aircraft pair is given by Equation B.2. A buffer b of 10 seconds is added to account for the conservatism required to ensure no aircraft violates the separation criteria.

$$E[t_{ij}] = \sum_{i=1}^{4} \sum_{i=1}^{4} p_{ij} \cdot (T_{ij} + b) \tag{B.2}$$

The arrival capacity of the runway is then simply the inverse of the expected time per operation and is shown in Equation B.3.

$$\mu = \frac{1}{E[t_{ij}]} \tag{B.3}$$

B.1.2 Departure Capacity

Table B.2: Modeled separation between subsequent departures

		Following (j)				
		Super	H	B757	M	L
Leading (i)	Super	120	120	120	120	120
	H	120	120	120	120	120
	B757	120	120	120	120	120
	M	60	60	60	60	70
	L	60	60	60	60	70

For departing aircraft, separation is defined in terms of time rather then distance. This time is only specified for departures following Heavy or B757 classes of aircraft, in which cases two minutes separation is required. In all other cases, the separation time must be great enough to ensure that the preceding departure is clear of the runway and that subsequent departures maintain at least the 2.5 n.m. terminal area separation while climbing. Odoni and de Neufville [13] suggest that one minute is typically required to meet these separation requirements. This value was increased to 70 seconds for departures following a Light aircraft to account for their lower velocity during the climb. The complete departure separation table is shown in Table B.2. This inter-departure time is used in the same way as the inter-arrival time to calculate the expected time between departures using Equation B.2 and overall capacity using Equation B.2.

B.1.3 Extensions to the Model

The runway capacity model outlined above provides a good starting point for modeling of the capacity at the New York airports. However, it does not account for some important features of typical airport operations in the United States. Insight provided by discussion with New York air traffic managers was used to refine the model to more accurately reflect the way operations are actually performed.

Operations Under Visual Flight Rules

Under VFR, the separation requirement between arrivals can be relaxed and separation responsibility may be transferred to the pilot, in which case the separation distances in Table B.1 are no longer required. However, conversations with ATC personnel suggest that even under VFR the separation requirements in Table B.1 are still applied by TRACON during vectoring to final approach. This difference between IFR and VFR is captured in the model by always enforcing the required separation distance at the Final Approach Fix (FAF). However, under VFR aircraft are allowed to violate this separation requirement during the final approach whereas under IFR they are not (under all conditions separation must be greater than the ROT of the preceding aircraft).

This difference between IFR and VFR procedures is modeled by only enforcing the wake separation requirement at the start of the final approach, after which faster following aircraft are allowed to catch-up with the lead aircraft (but not to violate the ROT constraint). The VFR inter-arrival time is shown in Equation B.4.

$$T_{ij}^{\mathrm{VFR}} = \max\left[\frac{r + s_{ij}}{v_j} - \frac{r}{v_i}, o_i\right] \tag{B.4}$$

Dispersal Departure Headings

Where possible the New York airports will use multiple departure headings for departing aircraft. This allows departure capacity to be increased because it removes the requirement to apply terminal area radar separation between departures. With dispersal headings in use, subsequent departures are cleared for takeoff once the previous departure has travelled at least 6000 ft down the runway and is also airborne. A revised departure separation time matrix (not shown) was created for runways with dispersal headings where departure runway occupancy times reduced by ten seconds for medium and light aircraft categories. This modification was based on approximate take-off performance estimates. Separation behind Boeing 757 and Heavy aircraft remained unchanged because the two minute wake vortex separation always applies following these aircraft.

Crossing Runways

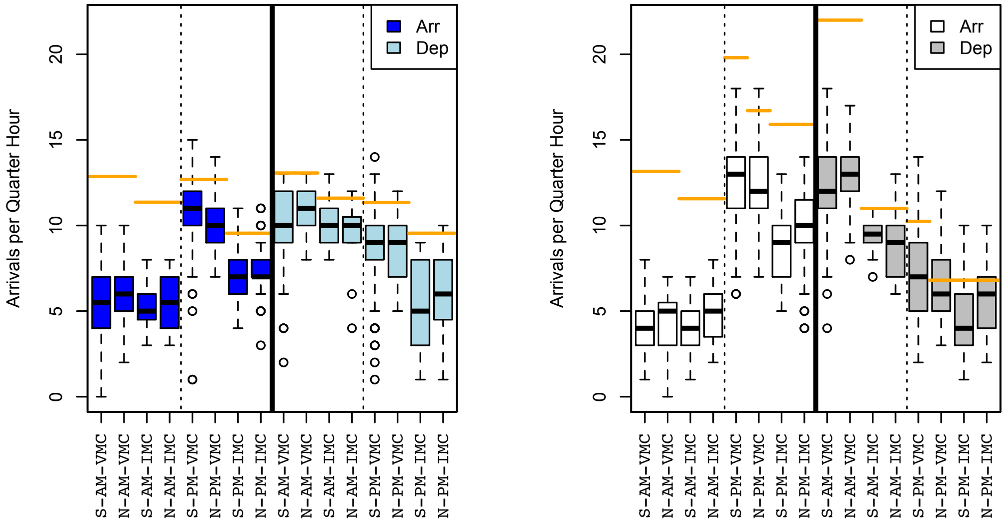
At airports with a pair of crossing runways, the capacity of the runway system was simply modeled as twice the lower capacity of the two runways. This is almost always twice the capacity of the arrival runway if arrivals and departures are segregated between the two runways, since the inter-arrival spacing is almost always greater than the inter-departure spacing. This scenario represents operation of the runways such that one departure is launched between each pair of arrivals. This mode of operation maximizes the total capacity of the crossing runway system.

Shared Runways

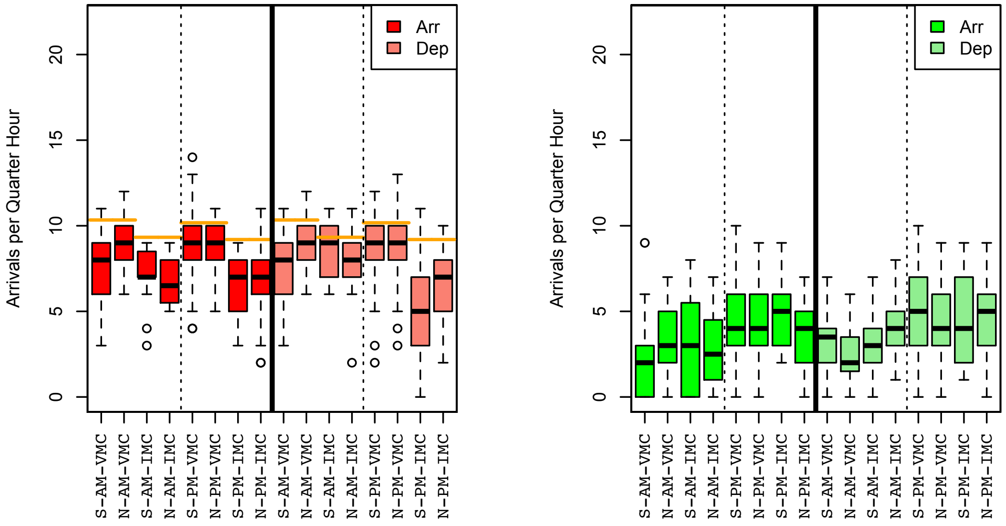
For configurations where a runway is shared by both arrivals and departures, the capacity of the runway is modeled at the balanced operating point. This assumes that the runway operates alternating arrival and departure operations. The balanced operating point yields the highest possible total runway capacity.

B.2 Results

Figure B-2 compares the observed arrival and departure traffic level at each airport for the example airspace configurations with the modeled runway capacity. In this analysis, the observations were limited to only the peak arrival or peak departure



(a) EWR (b) JFK



(c) LGA (d) TEB

Figure B-2: Measured capacity at each airport for each airspace configuration as well as the capacity predicted from the runway capacity model hours (as appropriate for each configuration) in order to restrict the analysis to higher demand periods.

Figure B-2a shows that traffic at EWR matches the capacity predicted by the model, with the exception of arrival throughput during the morning traffic peak. The low arrival throughput during the morning is, however, likely to be due to low demand rather than any airspace constraints. The departure rate under IFR is substantially lower than the VFR and modeled rate. This difference is probably due to the CSPR spacing requirements discussed in subsection 3.2.1.

Figure B-2b shows that at JFK, as at EWR, the morning arrival throughput is well below the theoretical runway capacity, because of low demand. Unlike EWR, the departure capacity in the morning under VMC is far lower than the theoretical runway capacity. The explanation for this un-utilized capacity may lie in the limited departure capacity available for the same period under IMC. With only a single runway for departures, IMC halves the departure capacity in the morning compared to VMC.

Under VMC, the south flow arrival priority configuration at JFK appears to perform slightly below the theoretical capacity while the north flow arrival priority configuration is often operating at capacity. In this case, the capacity of the north flow configuration is lower than the south flow configuration because two rather than three runways are in use, as shown in Figure 3-12 and Figure 3-10. The lower than possible south flow traffic is likely due to conservatism in the scheduling to offset the lower capacity of the north flow and IMC configurations. The theoretical arrival capacity at JFK under IMC is difficult to attain, due to the dependent approaches in use to the parallel runways (explained in subsection 3.2.1). Arrival throughput must also be sacrificed in order to allow departures on the shared runway.

The throughput at LGA matches the predicted runway throughput very closely for the selected configurations. The only large discrepancy between theoretical and measured capacity is for the south arrival priority configuration under IMC. In this case, the departure rate is substantially lower than expected. This discrepancy is likely due to the transfer of the Belmont extension airspace to JFK, described in subsection 3.2.2, which restricts the climb procedures available to LGA thereby limiting the departure rate. Comparison with the throughput of the north flow IMC case suggests that the reduction may be as great as 8 operations per hour.

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