



# Benefit Assessment for Metroplex Tactical Runway Configuration Management (mTRCM) in a Simulated Environment

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## Acronyms

AAR	=	Airport Acceptance Rate
ADR	=	Airport Departure Rate
ASPM	=	Aviation System Performance Metrics
EWR	=	Newark Liberty International airport
FAA	=	Federal Aviation Administration
JFK	=	John F. Kennedy International airport
JPDO	=	Joint Planning and Development Office
LGA	=	LaGuardia airport
MILP	=	Mixed Integer Linear Programming
MSE	=	Metroplex Simulation Environment
mTRCM	=	Metroplex Tactical Runway Configuration Management
N90	=	New York Terminal Radar Approach Control, or TRACON
NAS	=	National Airspace System
NextGen	=	Next Generation Air Transportation System
SD	=	Standard deviation
SME	=	Subject matter expert
SORM	=	System-Oriented Runway Management
TE	=	Throughput efficiency
TEB	=	Teterboro airport
TRCM	=	Tactical Runway Configuration Management

## 1. Introduction

The System-Oriented Runway Management (SORM) concept is a collection of capabilities focused on ensuring efficient use of runways while considering all of the factors that affect runway use. Examples of these factors are: surface wind velocity, meteorological conditions, traffic demand, adjacent airport traffic flows, severe weather activity, environmental factors, intersecting arrival/departure runways, distance between runways, etc. This myriad of factors requires consideration in arriving at runway configurations that collectively best serve the system as a whole. Tactical Runway Configuration Management (TRCM), is one of the SORM capabilities; a software tool to carry out this function was developed by Mosaic ATM (contract number NNL09AA02B), and has two separate and distinct algorithms. One is specifically tailored to a single airport environment, where there is no inter-relationship between the studied airport and other proximate airports; this single-airport TRCM tool was used in a previous study, to assess the benefits at selected airports [Refs. 1, 2]. The other TRCM algorithm was developed for a metroplex environment<sup>1</sup>. The metroplex environment poses considerable challenges to TRCM. The selection of runway configurations across airports within a given metroplex area requires consideration of the role of each airport in the grander context of National Airspace System (NAS) efficiency, as well as user preferences where possible. The focus of this report is limited to the metroplex environment and will be referred to as Metroplex TRCM or mTRCM.

A preliminary evaluation of the mTRCM algorithms was conducted for the New York metroplex (N90) environment, using two six-hour traffic scenarios in August 2011 [Ref. 3)]. There were four airports considered as part of the N90 (New York Terminal Radar Approach Control, or TRACON) metroplex: John F. Kennedy International Airport (JFK), LaGuardia Airport (LGA), Newark Liberty International Airport (EWR), and Teterboro Airport (TEB). The initial results documented benefits on *transit time* and *total delay* using mTRCM at this metroplex.

This report focuses on a benefit assessment of *total delay*, *transit time*, and *throughput efficiency* benefits using the metroplex TRCM algorithm at representative volumes for today's traffic at the New York metroplex. The New York metroplex was selected for the complexity in both airport configuration decisions and runway assignment and sequencing decisions. Any insight on potential algorithm improvement from this assessment will be recommended for future research. The paper is organized as follows: Section 2 gives a description of SORM and the metroplex TRCM algorithms. Following this description of the algorithms, method of test is presented in section 3. Section 4 provides the results of this assessment. Conclusions and proposed future research are detailed in section 5.

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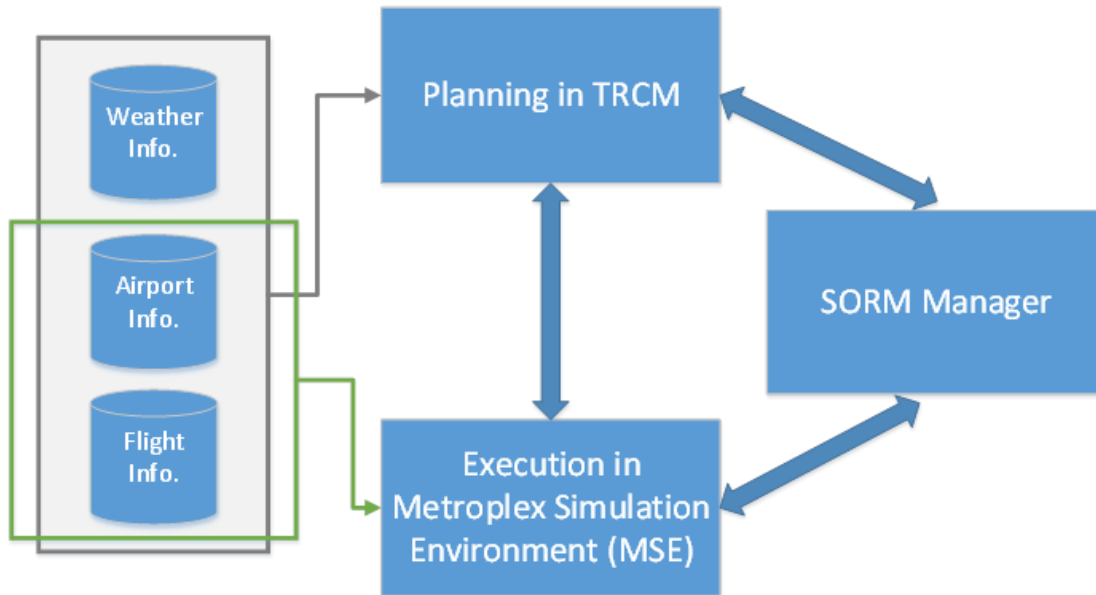
<sup>1</sup> The JPDO defines a metroplex as “a group of two or more adjacent airports whose arrival and departure operations are highly interdependent.” [Ref. 12]

## 2. Description of SORM and the metroplex TRCM algorithm

A thorough description of the SORM software can be found in Mosaic ATM [Ref. 4]. Figure 1 gives an overview of how the SORM software operates. The current software requires three types of inputs, which are weather information, airport information, and flight plans. Weather information includes wind speed and wind direction. Airport information includes layout of terminals, spots<sup>2</sup>, runways, arrival fixes, departure fixes, and their associated latitude and longitude coordinates, available runways, and runway policy (dedicated arrivals/departures or mixed-use operation). Flight information includes flight ID, origin and destination airports, aircraft type, assigned arrival or departure fix, assigned spot, scheduled arrival time at fix (arrivals), and scheduled gate departure time (departures).

The *SORM Manager* (Figure 1) alternates the control between planning and execution cycles. During the planning cycle (labeled as *Planning in TRCM* in the figure), it uses the metroplex TRCM algorithm (detailed in sections 2.1 and 2.2) for the next 90-minute simulation time segment. In the current algorithm implementation, a runway configuration change is not allowed during the freeze interval (the first 45-minute interval). The metroplex TRCM algorithm produces a plan listing recommended runway configurations and their associated change schedules during the planning interval (the second 45-minute interval). If the algorithm cannot find a better configuration than the current configuration, then the plan will be an empty list.

After each iteration of the planning cycle, the SORM software then operates in the execution cycle (*Execution in Metroplex Simulation Environment (MSE)*) simulating the airborne and taxi routes for individual aircraft using a medium-high fidelity simulation environment, called the MSE. It uses the airport information and flight information along with the runway configuration determined in the most recent planning cycle as inputs to simulate the arrival and departure operations. The MSE includes sufficient level of detail for airport surface operations using node-link<sup>3</sup> connections replicating the actual airport surface layout. It also incorporates aircraft-specific<sup>4</sup> airborne-speed and taxi-speed profiles. The MSE records several flights' status, including all simulated flight routes and their time stamps at all predetermined surface nodes. It provides the latest status to the planning cycle for its next iteration. These alternating cycles continue until all flights under study are simulated. Any performance metrics can be post-processed and computed from the MSE flight records.



**Figure 1. Overview of the SORM software.**

<sup>2</sup> Spot is the position where hand-off responsibility transfers between non-movement area (or ramp) and movement area controllers.

<sup>3</sup> Node-link connections represent a system of interconnected small surface segments along which an aircraft can travel. For modeling purpose, stopping and holding are allowed at nodes (endpoints of segments). Continuous movement is only allowed on links.

<sup>4</sup> Aircraft-specific refers to different aircraft make and model (e.g., A318, B747, DC8, etc.)

## 2.1. Metroplex TRCM algorithm delivered by Mosaic ATM (mTRCM-A)

The metroplex TRCM algorithm provided by Mosaic ATM uses Mixed Integer Linear Programming (MILP) to solve each airport independently for the airport-specific optimal runway configurations. Because each airport is solved independently, there is no constraint on interrelated metroplex conflicts captured in the current algorithm. Within each airport, the MILP requires a pre-processing step for flight input. All flights during the planning period are first sequenced according to a first-in-first-out (FIFO) rule. Next, appropriate runway separation rules between (pairwise) consecutive arrivals and departures are enforced, generating the list of flights ordered by their earliest time at runways under all possible runway assignments and routing policies. The MILP only considers flights from runway to fix (departures) or from fix to runway (arrivals), and does not capture any surface operations. Constraints of the MILP generally include (1) allocation of exactly one active runway configuration at any given time; (2) runway assignment of each flight exactly once to the active configuration; (3) enforcement of the FIFO rule on each active runway; and (4) no more than one configuration change during the planning period. The objective function to be minimized by the MILP includes (1) the cost of changes (in unit of time) from one active configuration to another; and (2) the cost of using runways (in time) for all flights. Wind speed and direction are captured in the objective function as a higher cost of using affected runways by affected flights. Currently this algorithm allows each airport within the metroplex to have different change times (i.e., relaxing the necessary coordination). Change times are only allowed in increments of 15 minutes. The first change time allowed is at 45 minutes from the start time because of the freeze time horizon (thus changes could take place at time 45 minutes, 60, 90, etc., from the start time).

## 2.2. Metroplex TRCM algorithm developed by LaRC (mTRCM-B)

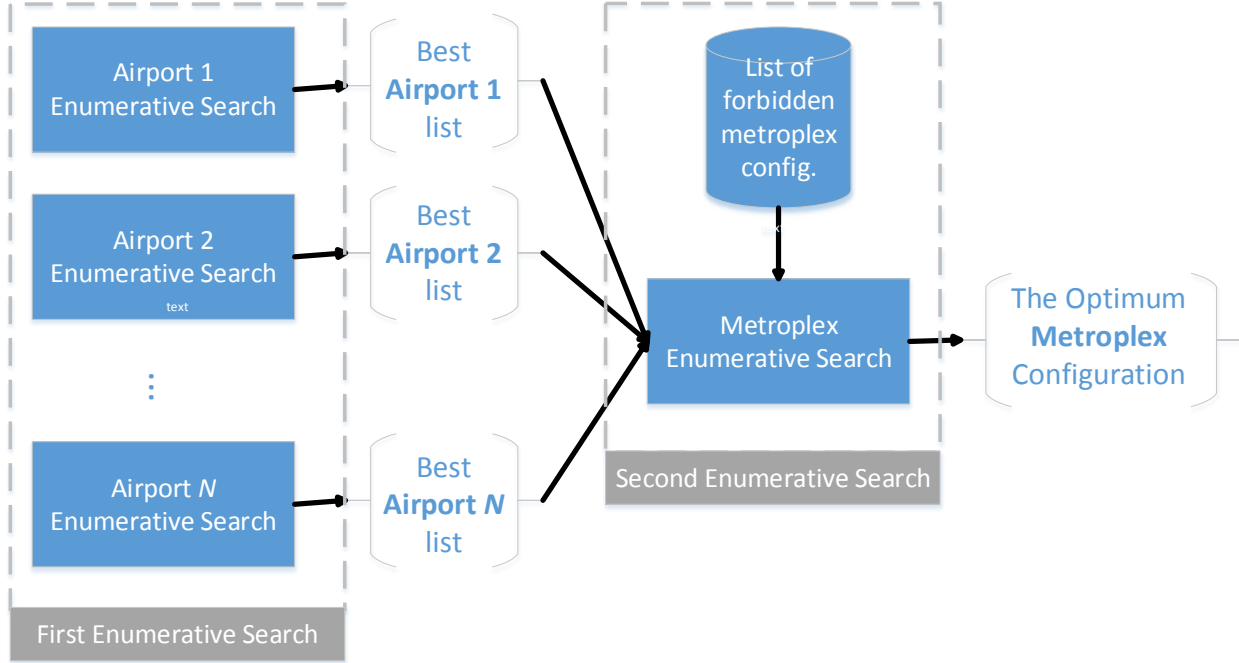
The metroplex TRCM algorithm developed by LaRC (mTRCM-B) uses two sequential enumerative searches. Figure 2 shows the conceptual depiction of the algorithm. The first search is performed for all airports within the metroplex and is equivalent to Mosaic's single airport TRCM. During the first enumerative search, the low fidelity simulation environment is used to calculate the total transit time<sup>5</sup> (the objective value) of all flights at each airport independently. The search trades off the airborne, taxi, and queue (departing aircraft only) time durations for the minimum total time. The low fidelity simulation computes transit time durations using the great circle distances for all airborne and taxi routes, along with their corresponding speeds. Wind speed and direction are taken into account to penalize runway configurations that should not be used during unfavorable wind conditions. This is accomplished by adding a penalty to the total transit time. At the end of this first enumerative search, airport-specific lists (one list for each airport) detailing the optimum change times and objective values of all available configurations are given as inputs to the second enumerative search. The airport-specific lists are shown in figure 2 as "Best **Airport 1** list", ..., "Best **Airport N** list".

The second search generates all feasible combinations of the airport-specific lists, which is referred to as all feasible metroplex configurations. The search loops through these metroplex configurations while ensuring each configuration is not on the excluded metroplex configuration list. This list, provided by the user, contains combinations of configurations that exhibit interrelated metroplex conflicts that are not operationally allowed. The search at any given time only keeps track of two configurations, the best found and the contender. If the first configuration is not on the excluded list, it will become the best found. The next configuration on the list becomes the contender. If the contender is on the excluded list, it is rejected and the next configuration on the feasible list becomes the contender. At any time during the search, if the contender outperforms the best found (in terms of the total metroplex transit time of all flights), then the search will replace the best found with the contender. The evaluation repeats until all feasible metroplex configurations are considered. At the end of the search, the best found is the optimum metroplex configuration. The optimum metroplex configuration provides the optimum runway configurations at all airports along with their optimum configuration change times (shown in figure 2 as "The Optimum **Metroplex** Configuration"). Currently this algorithm allows each airport within the metroplex to have different change times (i.e., relaxing the necessary coordination). Change times are allowed in increments of 5 minutes (e.g., at time 45 minutes, 50, 55, etc., from the start time.)

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<sup>5</sup> Transit time is defined as the travel time from arrival fix to spot (for arriving aircraft), or from spot to departure fix (for departing aircraft).





**Figure 2. Overview of the metroplex TRCM algorithm by the LaRC researchers.**

### 2.3. Comparative assessments of the metroplex TRCM algorithms

Table 1 compares the two metroplex TRCM algorithms described in sections 2.1 and 2.2. The different algorithms are used only in the *Planning in TRCM* process segment. The same simulation (MSE) is used in both algorithms for the *Execution in MSE*.

**Table 1. The metroplex TRCM algorithm comparison.**

Features		Metroplex TRCM provided by Mosaic ATM (mTRCM-A)	Metroplex TRCM developed at LaRC (mTRCM-B)
Algorithm elements	<i>Planning in TRCM</i>	MILP solver capturing travel duration between runways and fixes, or in other words only airborne duration	Two sequential enumerative searches for the optimum combined airborne and surface durations (between spots and fixes) using low fidelity fast-time simulation
	<i>Execution in MSE</i>	MSE	

The two metroplex TRCM (mTRCM) algorithms (mTRCM-A and mTRCM-B) were evaluated based on transit time [Ref. 5]. Using two six-hour test days in August 2011, the mTRCM-A provided transit time savings between 43 and 114 seconds per arrival for the metroplex; and a penalty of 79 seconds and a saving of 71 seconds per departure for the metroplex. In comparison, the mTRCM-B provided transit time savings between 16 and 104 seconds per arrival for the metroplex, and a saving between 16 and 95 seconds per departure for the metroplex.

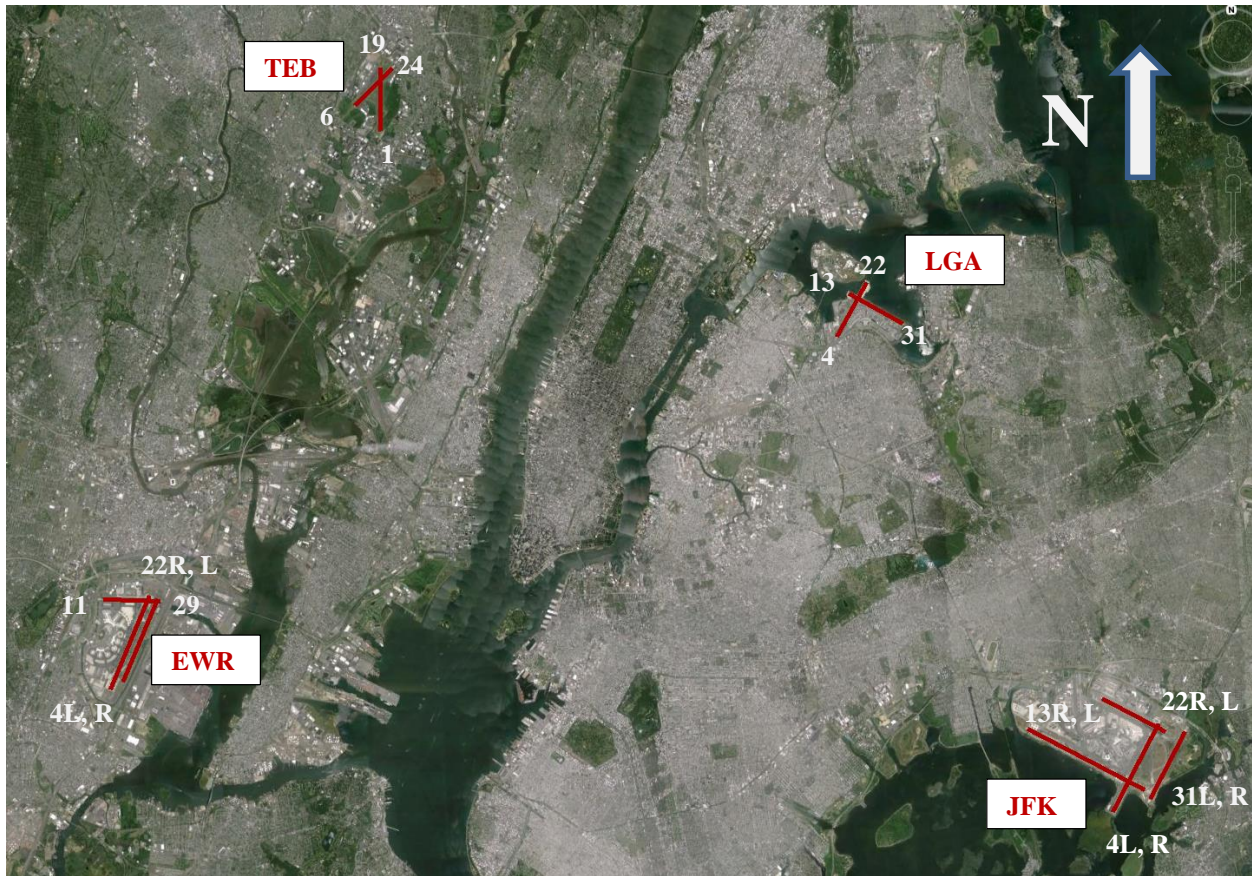
Overall, the mTRCM-B algorithm gives consistently better average transit time savings per flight over all airports within the metroplex than the mTRCM-A. Also, because the mTRCM-B implementation allows the exclusion of configuration combinations that are known to be infeasible in normal metroplex operations, it is more realistic. In addition, the mTRCM-B algorithm uses the single-airport TRCM that was previously evaluated at JFK and two additional airports outside the N90 metroplex [Refs. 1, 2], so the evaluation team was very familiar with its operation. Since the team did not have as much confidence in the results obtained from the mTRCM-A algorithm, it was decided that this algorithm would not be used for the benefits assessments. Since only the mTRCM-B algorithm will be used, for the remainder of this analysis and will be referred to as the mTRCM algorithm.

### 3. Method of test

#### 3.1. Test cases

For this assessment, a set of historical data that covers a period from late 2009 to 2010 was used. The selected days for testing are a set of twelve days identified by the Federal Aviation Administration (FAA) and the Joint Planning and Development Office (JPDO) for NextGen research. These days were identified by the FAA as capturing seasonal trends in the National Airspace System (NAS) for that year, using an optimization based method to minimize differences in predicted and actual levels of desired performance metrics at the daily level [Ref. 6]. The New York metroplex (N90) was used for this assessment of the mTRCM algorithm because it has been identified (along with another 6 metroplex sites) as a prioritized metroplex site for FAA's implementation of key NextGen operational improvement areas through 2018 [Ref. 7]. The four airports considered in this metroplex are JFK, LGA, EWR, and TEB.

Figure 3 shows relative airport locations for the four N90 airports. JFK has two sets of perpendicular parallel runways. One is in a southeast/northwest orientation (13R/31L and 13L/31R). The other is in a northeast/southwest orientation (4L/22R and 4R/22L). LGA has intersecting runways; one is in a southeast/northwest orientation (13/31) and the other is in a northeast/southwest orientation (4/22). EWR has a set of parallel runways in a northeast/southwest orientation (4L/22R and 4R/22L) intersecting with a runway in a southeast/northwest orientation (11/29). TEB has intersecting runways; one is in a north/south orientation (1/19) and the other is in a northeast/southwest orientation (6/24).



**Figure 3. Relative airport locations for JFK, LGA, EWR, and TEB, image courtesy of Google Earth.**

Runway configurations evaluated in this assessment are based on the most frequently used from the historical data. Table 2 gives a complete list of all evaluated configurations in this assessment. There were 14 runway configurations evaluated at JFK, 10 configurations at LGA, 10 configurations at EWR, and 6 configurations at TEB. A runway configuration in this report was defined as a set of unique active runways used for arrivals and departures. It did not

depend on traffic flow direction or on runway policy (dedicated arrivals/departures or mixed-use operation). At JFK, for example, configuration numbers 6 (A\_22L\_D\_22R) and 9 (A\_22L\_22R\_D\_22R) are two unique sets of active runways although they both operate in the same traffic flow direction with runway 22R operating as a dedicated departure in configuration number 6, and as a mixed-use runway in configuration number 9.

**Table 2. Runway configurations.**

(A\_rwy1\_D\_rwy2\_rwy3 = Arrivals primary on runway 1; Departures on runways 2 or 3)

Configuration Number	JFK	LGA	EWR	TEB
1	A_31R_31L_D_31L	A_31_D_4	A_22L_D_22R	A_19_D_24
2	A_22L_D_22R_31L	A_22_D_31	A_4R_D_4L	A_6_D_1
3	A_13L_22L_D_13R	A_22_D_13	A_22L_11_D_22R	A_1_D_1
4	A_31R_D_31L	A_4_D_13	A_4R_11_D_4L	A_19_D_19
5	A_4R_D_4L_31L	A_31_D_31	A_22L_D_22R_29	A_24_D_24
6	A_22L_D_22R	A_4_D_4	A_4R_4L_D_4L	A_6_D_6
7	A_13L_D_13R	A_13_D_13	A_4R_29_D_4L	
8	A_4R_D_4L	A_22_D_22	A_4L_D_4L	
9	A_22L_22R_D_22R	A_4_D_31	A_29_D_29	
10	A_4R_4L_D_4L_31L	A_13_D_4	A_11_D11	
11	A_4R_4L_D_4L			
12	A_22L_22R_D_22R_31L			
13	A_13L_D_13R_13L			
14	A_22L_22R_D_31L			

As an example of several interrelated N90 metroplex conflicts, departures from runway 22 at LGA are likely to interfere with traffic to and from other airports (see figure 3). As such, this departure runway configuration should be avoided. If runway 13/31 is closed or winds requires the use of runway 22, then runway 22 will be used for both arrivals and departures (i.e., A\_22\_D\_22 in table 2). Other examples of interrelated N90 conflicts can be found in Ref. 11. In the current algorithm, a list of excluded metroplex configurations has been captured. Table 3 gives details of this list. The first column is the operational constraints, which have been modeled in the algorithm according to the last two columns.

**Table 3. List of excluded metroplex configurations implemented in the mTRCM algorithm.**

Operational constraints	Modeling constraints	
	When LGA is in	JFK is not allowed to be in
When LGA lands on Runway 4, and JFK is on ILS to Runways 22L 22R <sup>6</sup> , LGA cannot depart on Runway 13.	A_4_D_13 (Conf #4)	A_22L_D_22R_31L (Conf #2) A_13L_22L_D_13R (Conf #3) A_22L_D_22R (Conf #6) A_22L_22R_D_22R (Conf #9) A_22L_22R_D_22R_31L (Conf #12) A_22L_22R_D_31L (Conf #14)
Instrument approaches (LOC) to LGA 31 must fly a loop which uses JFK airspace areas, requiring JFK to use a 31L 31R for arrival configuration.	A_31_D_4 (Conf #1)	A_22L_D_22R_31L (Conf #2) A_13L_22L_D_13R (Conf #3) A_4R_D_4L_31L (Conf #5) A_22L_D_22R (Conf #6) A_13L_D_13R (Conf #7) A_4R_D_4L (Conf #8) A_22L_22R_D_22R (Conf #9) A_4R_4L_D_4L_31L (Conf #10) A_4R_4L_D_4L (Conf #11) A_22L_22R_D_22R_31L (Conf #12) A_13L_D_13R_13L (Conf #13) A_22L_22R_D_31L (Conf #14)
	A_31_D_31 (Conf #5)	A_22L_D_22R_31L (Conf #2) A_13L_22L_D_13R (Conf #3) A_4R_D_4L_31L (Conf #5) A_22L_D_22R (Conf #6) A_13L_D_13R (Conf #7) A_4R_D_4L (Conf #8) A_22L_22R_D_22R (Conf #9) A_4R_4L_D_4L_31L (Conf #10) A_4R_4L_D_4L (Conf #11) A_22L_22R_D_22R_31L (Conf #12) A_13L_D_13R_13L (Conf #13) A_22L_22R_D_31L (Conf #14)

Table 4 provides details of the twelve days used for analysis. These days are representative of the 2009-2010 time period and cover a range of weather conditions and traffic volumes. The traffic volumes did not include military flights. There were 4 weekend days. JFK, LGA, and EWR had approximately the same traffic volumes (~500 arrivals and 500 departures per day) for weekdays. Weekend and weekday volumes did not significantly differ at JFK and EWR. However, the weekend volumes at LGA differed significantly from the weekday volumes. The majority of TEB traffic was general aviation, and rather constant across all test days in this assessment.

<sup>6</sup> Arrival | Departure

**Table 4. Test cases.**  
(A = Arrival Operations, D = Departure Operations)

Test #	Date (Day of the week)	N90		JFK		LGA		EWR		TEB	
		#A	#D	#A	#D	#A	#D	#A	#D	#A	#D
1	20091006 (Tue)	1,567	1,610	428	479	502	506	524	530	113	95
2	20091017 (Sat)	1,237	1,297	449	501	269	269	406	433	113	94
3	20091120 (Fri)	1,787	1,769	527	544	564	560	582	570	115	95
4	20100110 (Sun)	1,574	1,546	507	520	455	447	498	485	115	94
5	20100309 (Tue)	1,754	1,731	503	515	553	544	580	577	118	95
6	20100325 (Thu)	1,792	1,819	526	555	567	564	584	604	115	96
7	20100506 (Thu)	1,763	1,794	491	536	582	582	574	583	116	93
8	20100518 (Tue)	1,706	1,739	484	515	564	564	544	562	114	98
9	20100605 (Sat)	1,306	1,368	480	528	288	290	426	455	113	95
10	20100703 (Sat)	1,407	1,436	524	561	305	300	467	481	112	94
11	20100713 (Tue)	1,541	1,532	494	519	426	403	508	515	114	95
12	20100722 (Thu)	1,835	1,863	565	592	565	567	592	608	114	96

### 3.2. Metrics definitions

The primary metrics for this assessment were average (per flight) *total delay* and *throughput*. Total delay is the sum of delays within metroplex airspace (airborne between fix and runway), delay on the ground (surface), and delay outside the arrival fix (arrival only). Delay is the difference between actual and ideal time durations. The ideal time duration is the un-delayed shortest time through the metroplex regardless of weather conditions if an aircraft is the only aircraft in the system at the time it is operated. Delay within metroplex airspace is the difference between actual flying (airborne) and ideal flying time durations. Delay on the ground is the difference between actual surface (taxi plus any departure queue times) and ideal surface time durations. The ideal surface time duration of any departure does not include any departure queue time duration because it is the only departure in the system, and therefore it does not need to be in the queue. Delay outside fix is for arrival only and is the difference between actual time stamp<sup>7</sup> and scheduled time stamp<sup>8</sup> at the arrival fix.

Theoretically, there is a relationship between throughput and transit time [Refs. 8, 9]. As throughput increases, transit time increases. As throughput approaches the system capacity, transit time increases exponentially, since aircraft will be subject to holding. For arrivals, transit time is defined as the travel time from arrival fix to spot. Specifically it was computed as the difference between the actual time stamp at spot and the actual time stamp at the arrival fix. For departures, it is from spot to departure fix. Specifically, it was computed as the difference between the actual time stamp at departure fix and the actual time stamp at spot. Throughput and transit time were directly related. That is, if the proposed system has a smaller transit time than the baseline, then it also has a better throughput than the baseline.

Another throughput metric in this analysis is throughput efficiency (TE). TE is the ratio of the actual to the optimum effective throughput, and is unit-less. The actual effective throughput is defined as the ratio of the number of aircraft that have transited through its exit system point to the total actual transit time of these aircraft, as defined in the previous paragraph. The optimum effective throughput is defined similarly, with the exception of using the total minimum times instead of the total actual times. The minimum transit times for all fix-spot pairs were determined first, and were then used to compute the total minimum times. Any system with TE closer to 1 is preferred. TE has been shown to be insensitive to traffic volume in Ref. 10, and, therefore, is appropriate for this assessment when traffic volume was the same in the baseline and the proposed systems. As a result, the system with a better throughput will be the system with a higher TE.

<sup>7</sup> The actual time stamp is the time stamp of an aircraft obtained from the MSE.

<sup>8</sup> The scheduled time stamp is the time stamp of an aircraft scheduled in the flight plan.

### 3.3. Data collection

To assess the mTRCM benefit, the metrics defined in Section 3.2 must be compared with the actual historical operations. Because the traffic volumes did not include military flights, which caused the traffic volumes to be lower than those in the FAA Aviation System Performance Metrics (ASPM) database, the metrics of interest were not available from the ASPM for a fair comparison. Also, comparing results from two sets of simulated runs (using historical vs. mTRCM configuration schedules) was considered to be better for benefits assessment than comparing simulated and actual data. This is because all of the operating conditions (e.g., actual flights, standard taxi routes, etc.) were controlled in the same way within the simulation environment for both the historical and the mTRCM configuration schedules. Therefore, the benefit quantification is considered fair and straight forward. In contrast, the benefit quantification by comparing the simulated and actual data becomes complex. The actual operating conditions may be different and usually random than those in the simulation environment. Therefore, the benefit could be either from them TRCM schedules solely or from the compounding effects of the mTRCM schedules and random operating conditions.

Each test case in Table 4 was run once using the SORM software with the historical runway configurations obtained from the ASPM database (i.e., the baseline), and once with the mTRCM-generated runway configuration schedule. Specifically, there were a total of 24 runs (12 days  $\times$  2 runway schedule cases). For the baseline case, the software bypasses the planning cycles (the *Planning in TRCM* in Figure 1) and only invokes the MSE (the *Execution in MSE*) to simulate the airborne and ground routes of all aircraft given the historical runway configuration schedule. The historical runway configuration schedules (the baseline) can be viewed as the schedules produced by subject matter experts. The differences between the baseline's and the mTRCM's total delay and transit time were computed on a flight-by-flight basis. The average (per flight) benefits were then computed for all twelve test cases. Positive values indicated there was a benefit of using the mTRCM over the baseline. Negative values indicated a penalty of using mTRCM over the baseline. In contrast, TE was computed for both the baseline and mTRCM cases on a system level basis (i.e., not for individual flights), and compared for this assessment. Throughput benefit of using the mTRCM occurs if its TE is higher than the baseline's TE, and vice versa.

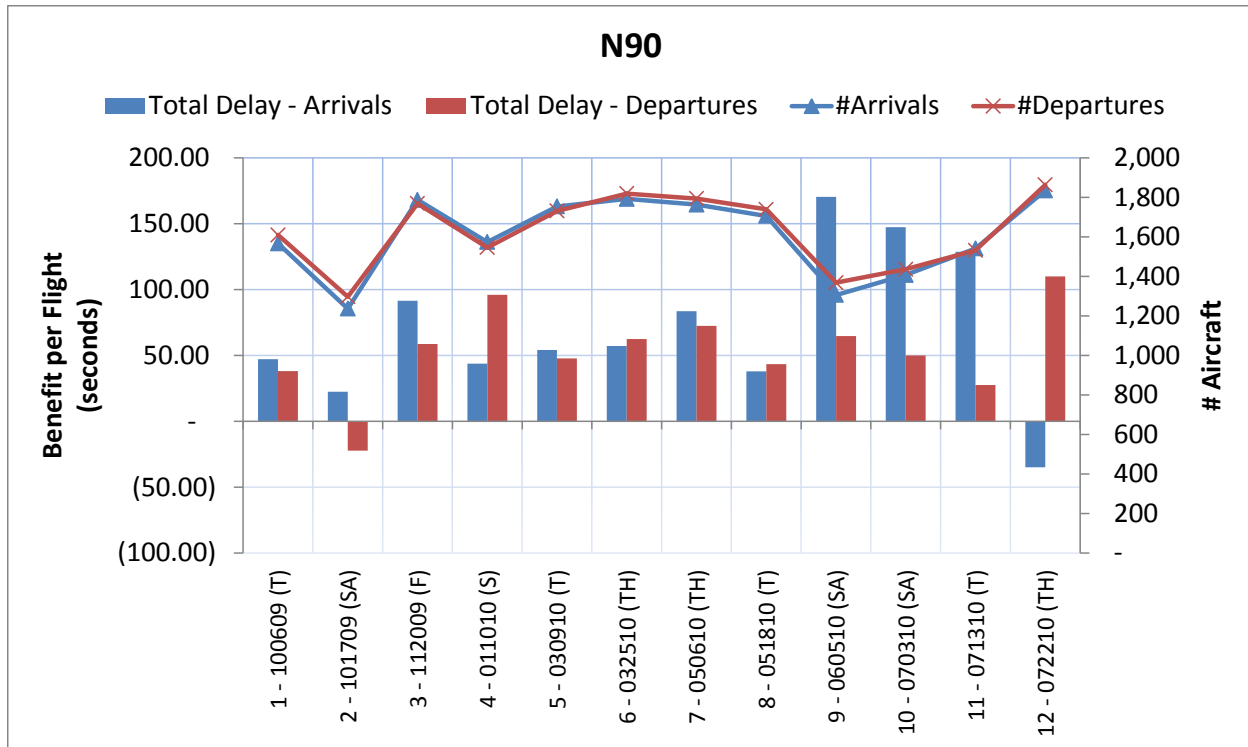
### 3.4. Analysis technique

To test if the mTRCM runway schedules outperform the baseline schedules, the well-known *t*-test is used [Ref. 13]. However, the *t*-test assumption is that both schedules produce Normal-distribution metrics. Deviation from this assumed distribution requires the use of an equivalent non-parametric *Mann-Whitney* test (or sometimes called the *Wilcoxon* rank sum test) [Ref. 13]. In this assessment, the Mann-Whitney test is used to determine if the medians, as opposed to the mean, of the mTRCM's metrics are better than the baseline's.

## 4. Analysis Results

### 4.1. Total delay

Figure 4 shows per flight average total delay benefits for arrivals and departures for all twelve days at the N90 metroplex. In the same figure, numbers of arrivals and departures were plotted to determine if any correlation existed between demand volume and magnitude of benefit. There was no strong correlation observed. This may be because the demand volume is not high enough to observe the strong correlation. Generally, weekend volumes were smaller than weekdays. Total delay benefit varied by day. The mTRCM usually provided total delay benefit over the baseline for arrivals and departures (ten out of twelve days). Eight out of twelve days total delay benefits for arrivals were higher than those for departures.



**Figure 4. Per flight average delay benefit (in seconds) for arrivals and departures for all days (in Day# - mmddyy (day) format) at N90 metroplex.**

It is important to note that, because the benefit is considered at the system level (i.e., for the metroplex and not for individual airports), some airports might sustain a greater penalty, if it results in a net benefit for the metroplex as a whole. Airports within the N90 metroplex were analyzed next. Similar to figure 4, figure 5 shows per flight average total delay benefit for arrivals and departures for all twelve days at JFK, LGA, EWR, and TEB. Similarly, there was no strong correlation between demand volume and magnitude of benefit observed. Generally, weekend volumes were smaller than weekday's especially at LGA. In contrast, JFK and TEB did not have this trend, while EWR had a slight trend.

For JFK, the mTRCM reduced total delay compared to the baseline for arrivals and departures. Half of the test days had greater total delay reductions for arrivals compared to those from departures, while the opposite was true for the other half of the test days.

For LGA, the mTRCM provided mixed results of total delay benefits as compared to the baseline. Arrivals had negative values (representing a penalty for using the mTRCM over the baseline), while departures had positive values. Eleven out of twelve days had total delay benefits for departures higher than those from arrivals.

For EWR, all twelve days the mTRCM provided the total delay benefits over the baseline for arrivals and departures. All test days showed total delay benefits for arrivals that were higher than those from departures.

For TEB, the mTRCM provided net total delay benefits over the baseline for arrivals and departures. All test days displayed total delay benefits for arrivals that were higher than those from departures.



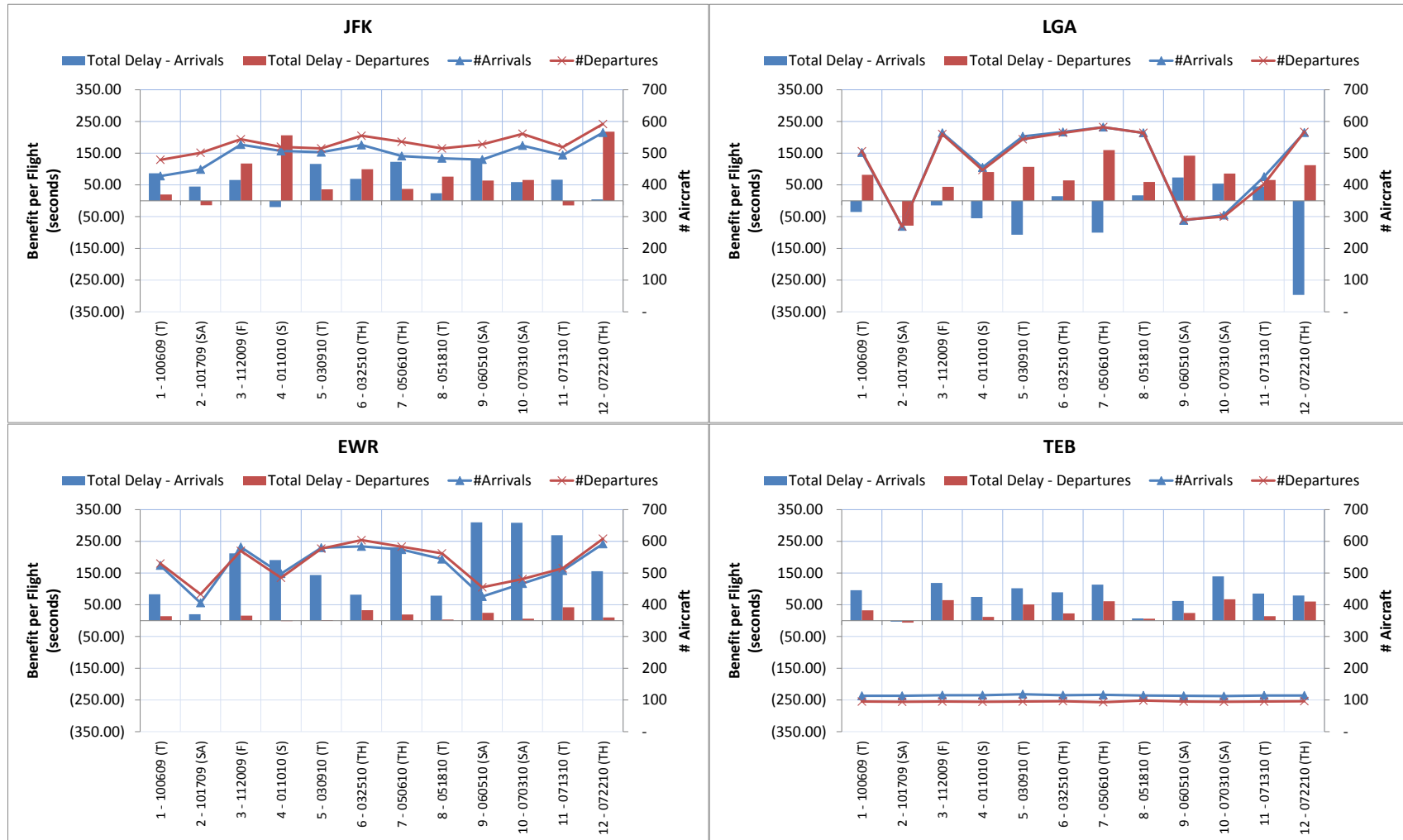
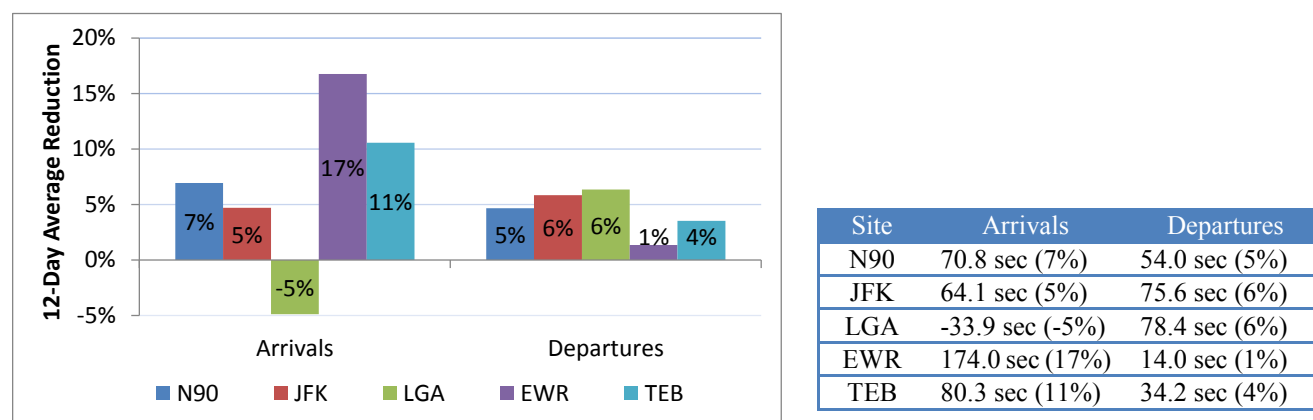


Figure 5. Per flight average delay benefit (in seconds) for arrivals and departures for all days (in Day# - mmddyy (day) format) at all airports within N90 metroplex, all plots use a common scale.



Reductions in total delay (per flight) for all days were computed. These reductions were then averaged over twelve days and are shown in figure 6. Overall, the N90 metroplex showed 71 seconds per flight reduction of delay (or 7% with respect to the baseline) for arrivals, and 54 seconds per flight reduction (or 5%) for departures. JFK and LGA displayed higher percent reductions in departures than arrivals. In contrast, EWR and TEB provided higher percent reductions in arrivals than departures. It is noted that LGA had mixed results with a negative reduction (or, an equivalent to an increase) in total delay for arrivals and a positive reduction for departures. EWR showed a substantial total delay benefit for arrivals over departures (i.e., 174 vs. 14 seconds or 12 times higher). TEB provided about two times higher benefits for arrivals over departures.

Mann-Whitney tests show the mTRCM provided statistically significant smaller per flight total delay than the baseline for N90 arrivals (p-value = 0.0002) and departures (p-value = 0.0010). For JFK, EWR, and TEB, the mTRCM provided statistically significant smaller per flight total delay than the baseline for arrivals and departures (p-value < 0.05). For LGA, only for departures that the mTRCM provided statistically significant smaller per flight total delay than the baseline (p-value = 0.0010), while for arrivals there was no difference between the mTRCM and baseline (p-value = 0.2352).

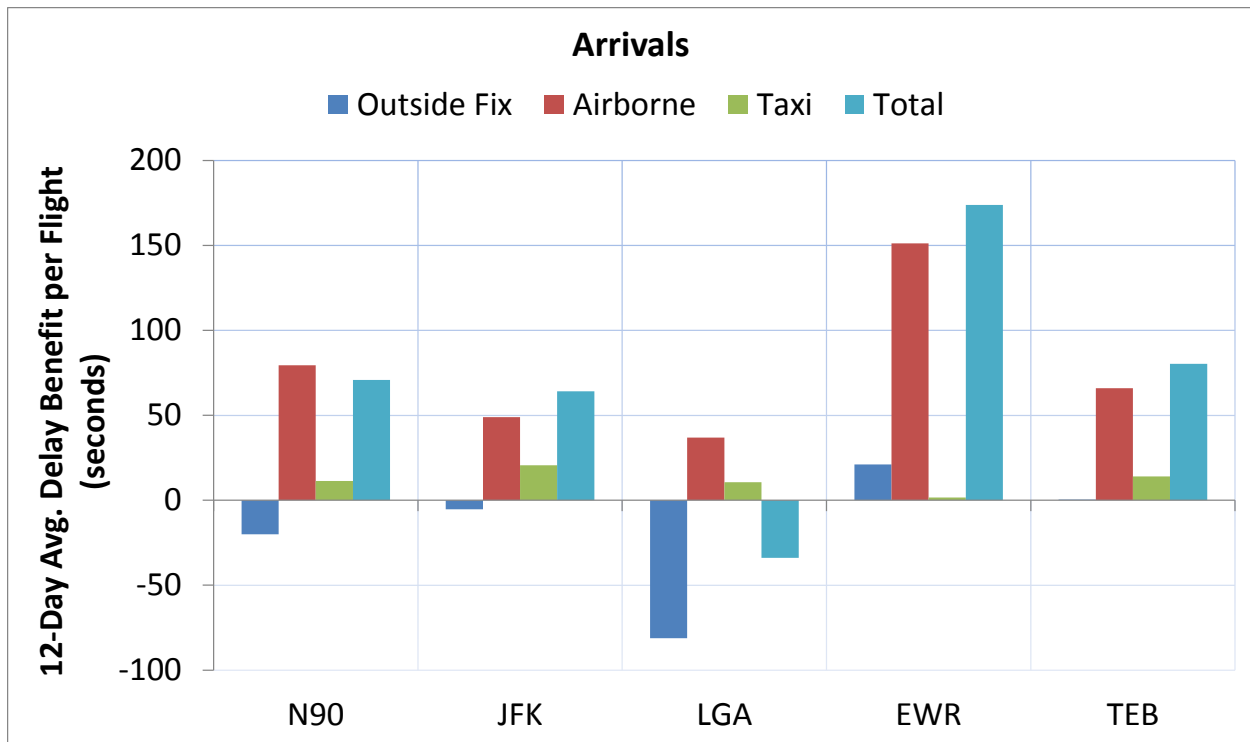


**Figure 6. Average (overall days) reduction in per flight total delay (baseline minus mTRCM).**

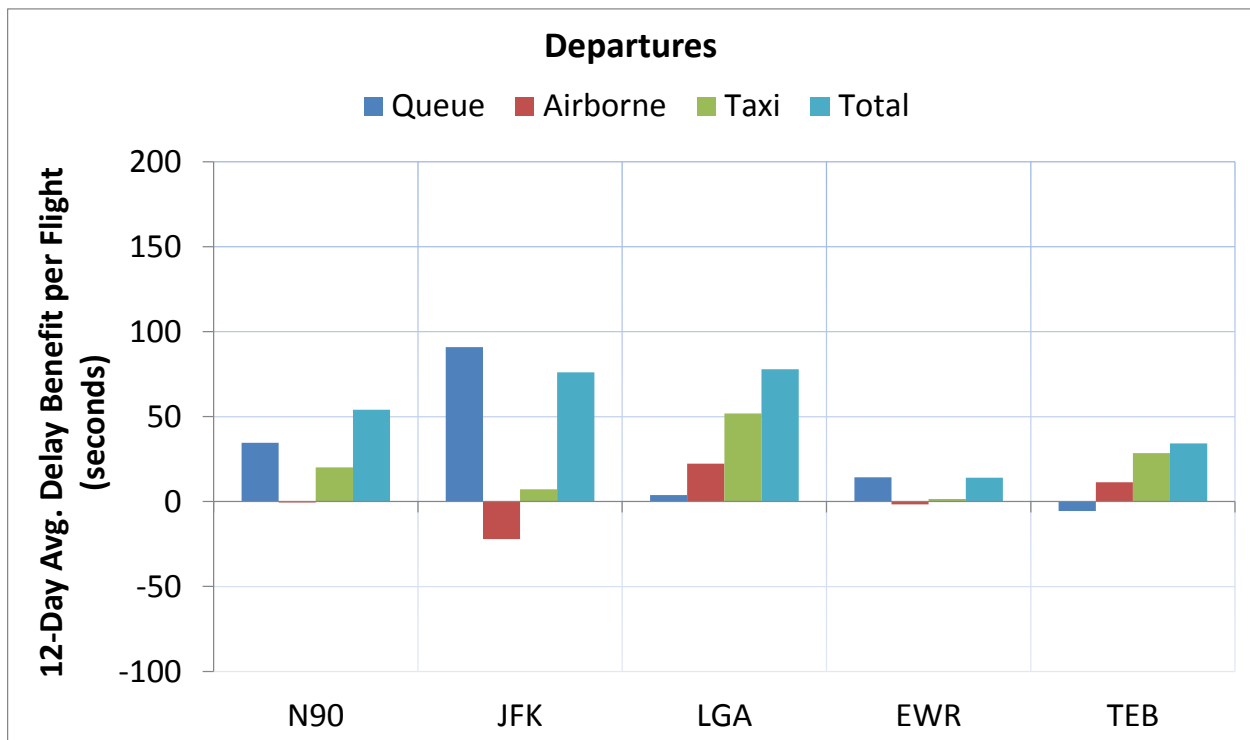
To better understand what contributed to the 12-day average total delay benefits, the total delays were further broken down into delay within metroplex airspace (or airborne), taxi delay, departure queue delay, and delay outside arrival fix. Figure 7 shows average (over 12 days) per flight delay broken down for arrivals and departures for all sites.

For arrivals (figure 7a), with the exception of LGA, the mTRCM provided total delay benefits over the baseline. For LGA, the main driver of negative total delays (penalty of using the mTRCM) was a substantial (negative) delay from outside arrival fix. Benefits from airborne delays were higher than those from surface (taxi) delays for all sites. Positive total delays were contributed by a positive benefit in airborne delay for all sites.

For departures (figure 7b), the mTRCM provided total delay benefits over the baseline. Benefits from surface (taxi plus departure queue) delays were higher than those from airborne delays for all sites. Positive total delays were largely the result of positive benefits in surface delay for all sites. The type of surface operations that contributed most to surface delays (i.e., taxi or departure queue) varied by sites. N90, JFK, and EWR showed departure queue as the driver, while LGA and TEB showed taxi as the driving influence.



(a) Arrivals

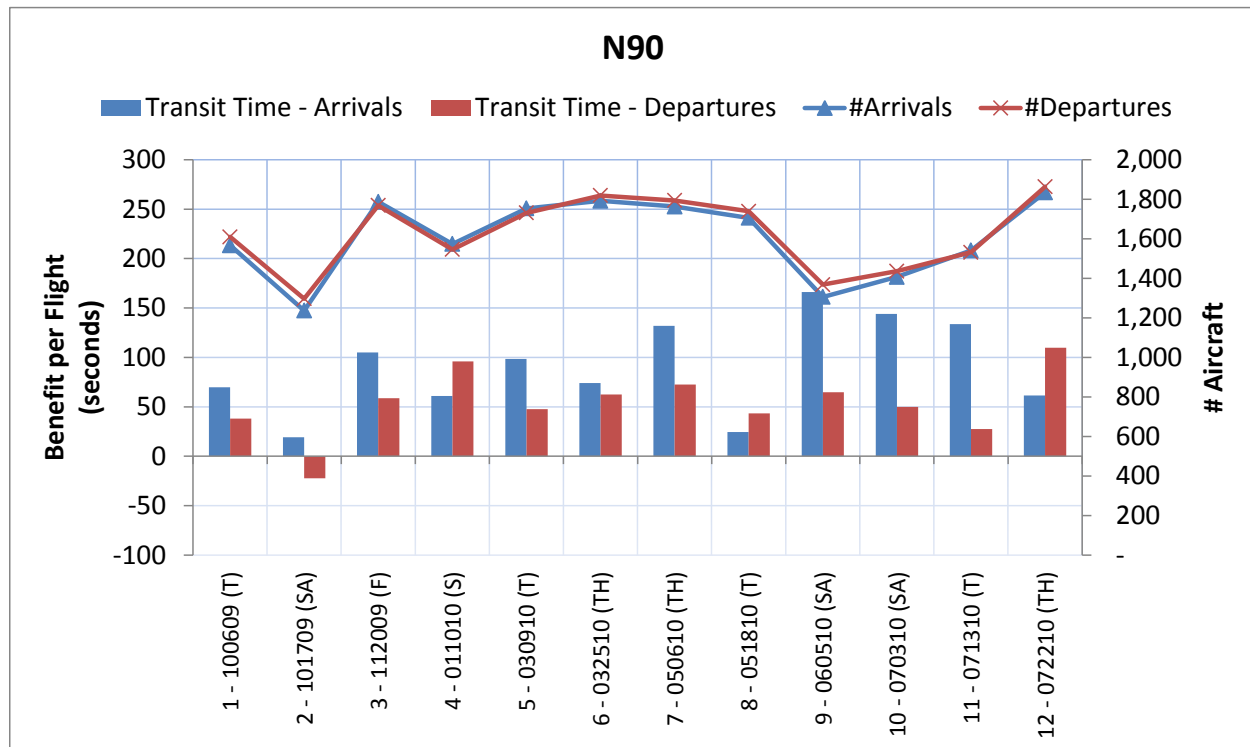


(b) Departures

Figure 7. Average (over 12 days) per flight delay breakdown (in seconds) for arrivals and departures at all sites.

## 4.2. Transit time

Figure 8 shows per flight average transit time benefits for arrivals and departures for all twelve days at the N90 metroplex. No strong correlation was observed between demand volume and magnitude of benefit. This may be because the historical demand volume is not high enough to observe the strong correlation. It is anticipated that if the future increased demand were to be simulated, then a strong correlation would be observed. Transit time benefit varied by day. Generally, the mTRCM provided transit time benefit over the baseline for arrivals and departures. Nine out of twelve days transit time benefits for arrivals were higher than those for departures.



**Figure 8. Per flight average transit time benefit (in seconds) for arrivals and departures for all days (in Day# - mmddyy (day) format) at N90 metroplex.**

To understand transit time benefits at individual airports, per flight average transit time for arrivals and departures for all twelve days were broken down by airports (shown in figure 9). As for the overall metroplex, there was no strong correlation between demand volume and magnitude of benefit observed at each of the individual airports.

For JFK, the mTRCM provided transit time benefits over the baseline for arrivals and departures. Seven out of the twelve days the transit time benefits for arrivals were higher than those for departures.

For LGA, the mTRCM provided transit time benefits over the baseline for arrivals and departures. Nine out of the twelve days the transit time benefits for departures were higher than those for arrivals.

For EWR, all twelve days the mTRCM provided transit time benefits over the baseline for arrivals and departures. All twelve days the transit time benefits for arrivals were higher than those for departures.

For TEB, the mTRCM provided transit time benefits over the baseline for arrivals and departures. Eleven out of the twelve days the transit time benefits for arrivals were higher than those for departures.

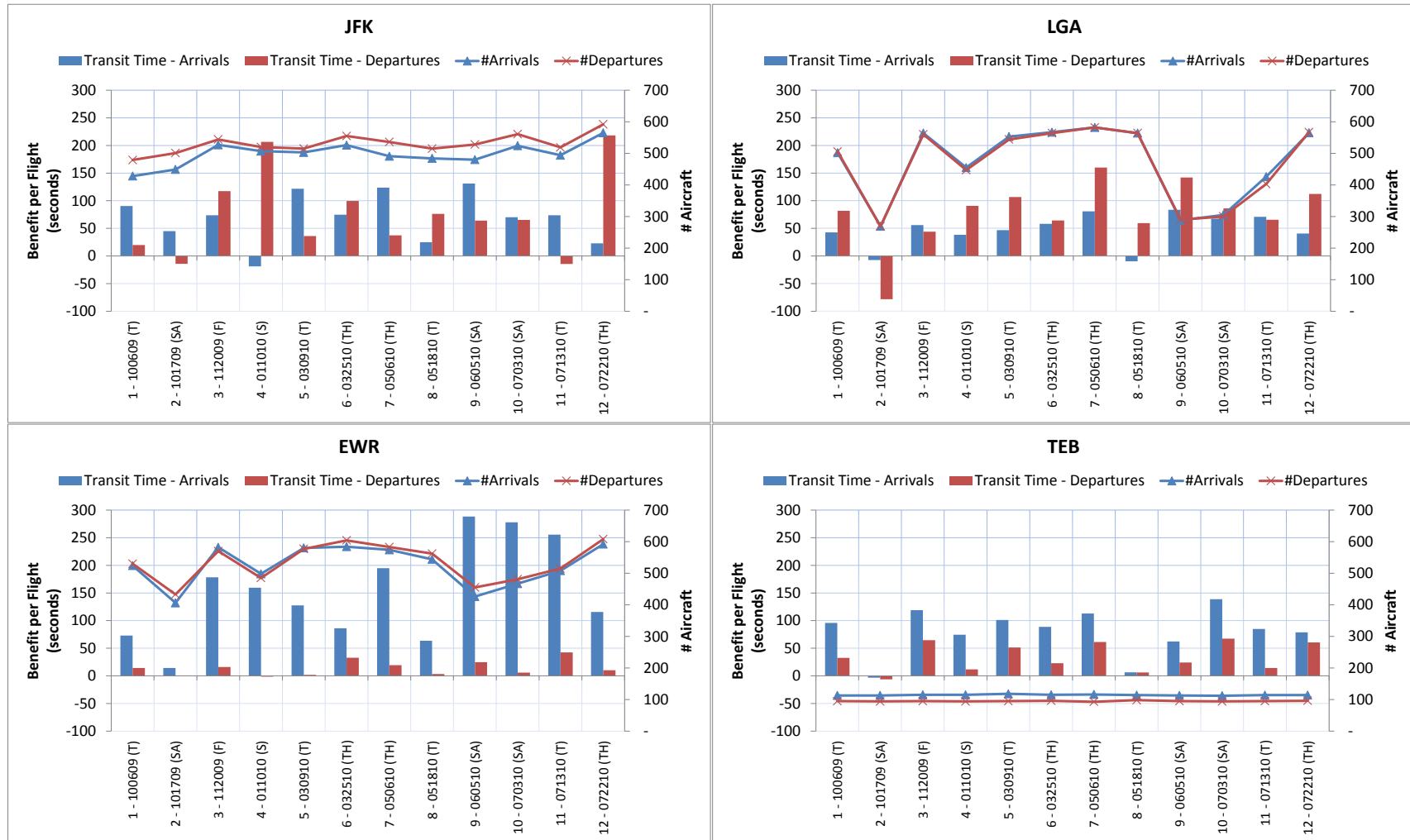
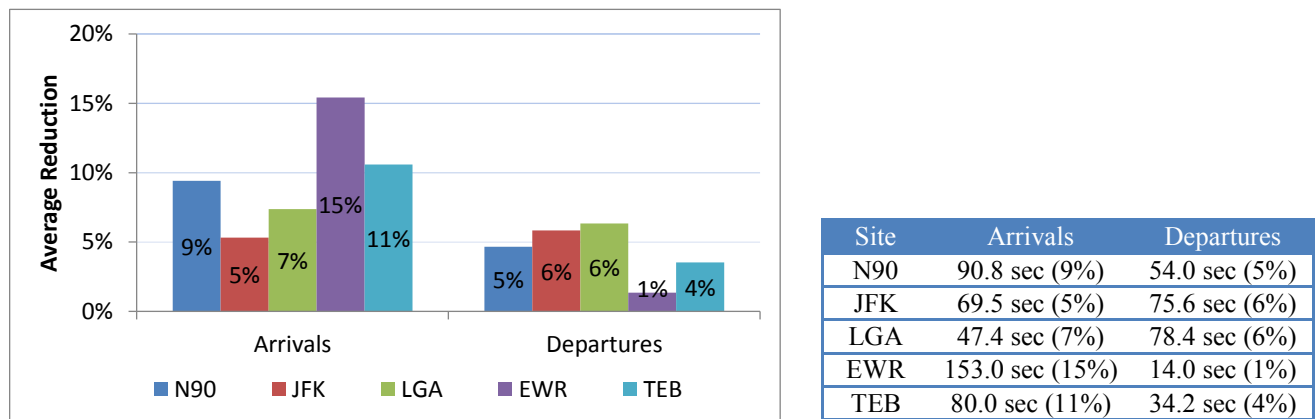


Figure 9. Per flight average transit time benefit (in seconds) for arrivals and departures for all days (in Day# - mmddyy (day) format) at all airports within N90 metroplex, all plots in a common scale.

Percent reductions in transit time per flight were averaged over all twelve days and are shown in figure 10. On average, the mTRCM provided higher percent reductions, with respect to the baseline, for arrivals (between 5% and 15% across all sites) than departures (between 1% and 6%). JFK showed a slightly higher percent reduction in departures than arrivals. In contrast, N90, LGA, EWR, and TEB showed higher percent reductions in arrivals than departures. EWR provided a substantial transit time benefit for arrivals over departures (i.e., 153 vs. 14 seconds or 11 times higher), while TEB gave about more than two times higher benefit for arrivals over departures. Overall, the N90 metroplex had 91 seconds per flight reduction (or 9%) in mean transit time for arrivals, and 54 seconds per flight reduction (or 5%) for departures.

Mann-Whitney tests show the mTRCM provided statistically significant smaller per flight transit time than the baseline for N90 arrivals (p-value = 0.0001) and departures (p-value = 0.0010). For JFK, LGA, EWR, and TEB, the mTRCM provided statistically significant smaller per flight transit time than the baseline for arrivals and departures (p-value < 0.05).



**Figure 10. Average (overall days) reduction in per flight transit time (baseline minus mTRCM).**

#### 4.3. Throughput efficiency (TE)

Scatter plots of demand versus throughput efficiency (TE) for all hours and all days were generated for arrivals and departures. These plots were useful for checking sensitivity of the TE to traffic volume. Figure 11 shows the scatter plots for arrivals and departures at JFK. There was no strong trend between demand and TE. In other words, TE was insensitive (or robust) to traffic volume. Baseline departures had the widest range of TE (from 0.4 to 1.0). Historical capacity during the period of 10/2009 to 09/2010 was retrieved from the ASPM database. Depending on many factors such as weather and runway configuration, the Airport Acceptance Rate (AAR) and Airport Departure Rate (ADR) capacities can vary from hour to hour. Therefore, they are considered as random variables with underlying distributions. The 95% coverage interval<sup>9</sup> of the historical capacity distribution was used to determine how close the traffic volume used in this study was to the capacity during the same time period. This interval is shown on the figure (green vertical lines). For arrivals, 95% of AARs were between 28 and 52 aircraft per hour. For departures, 95% of ADRs were between 22 and 52 aircraft per hour. It is observed that both arrival and departure processes had data points scattered within and beyond these ranges; therefore, JFK operated at its historical capacity. This implies that if increased traffic volume is expected in the future, an improvement in capacity (or equivalent to a TE improvement) at JFK is needed.

<sup>9</sup> 95% Coverage interval indicates that 95% of hourly throughputs fall within this interval.

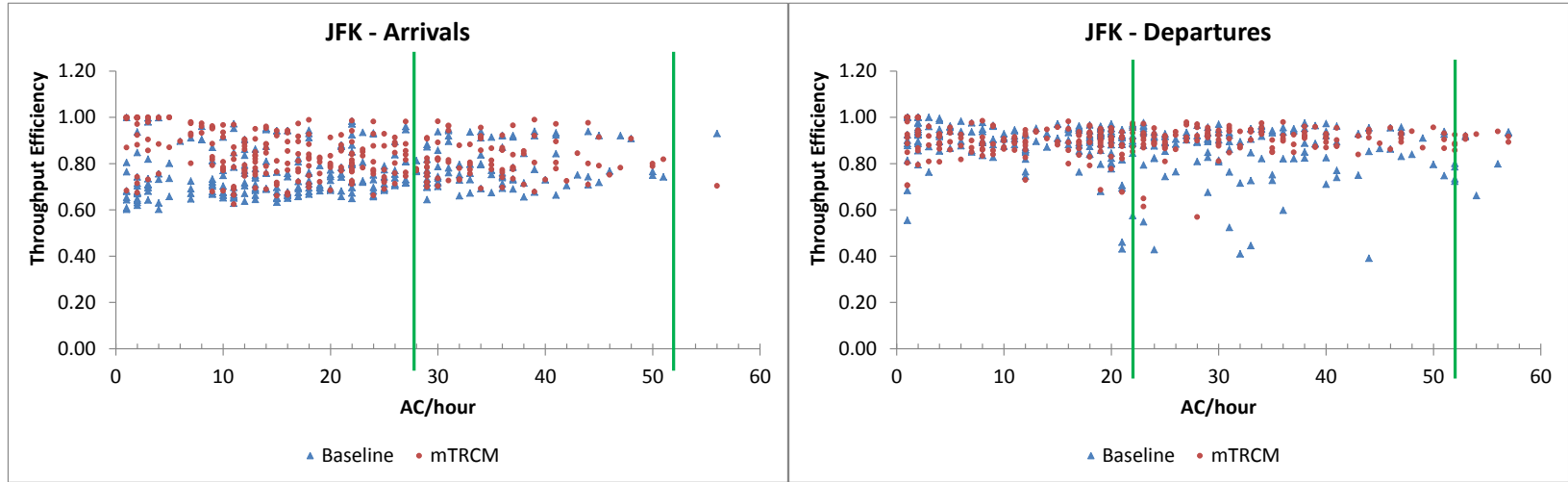


Figure 11. Scatter plots for all tested days at JFK with the 95% coverage intervals of historical Airport Acceptance Rate and Airport Departure Rate (green vertical lines).

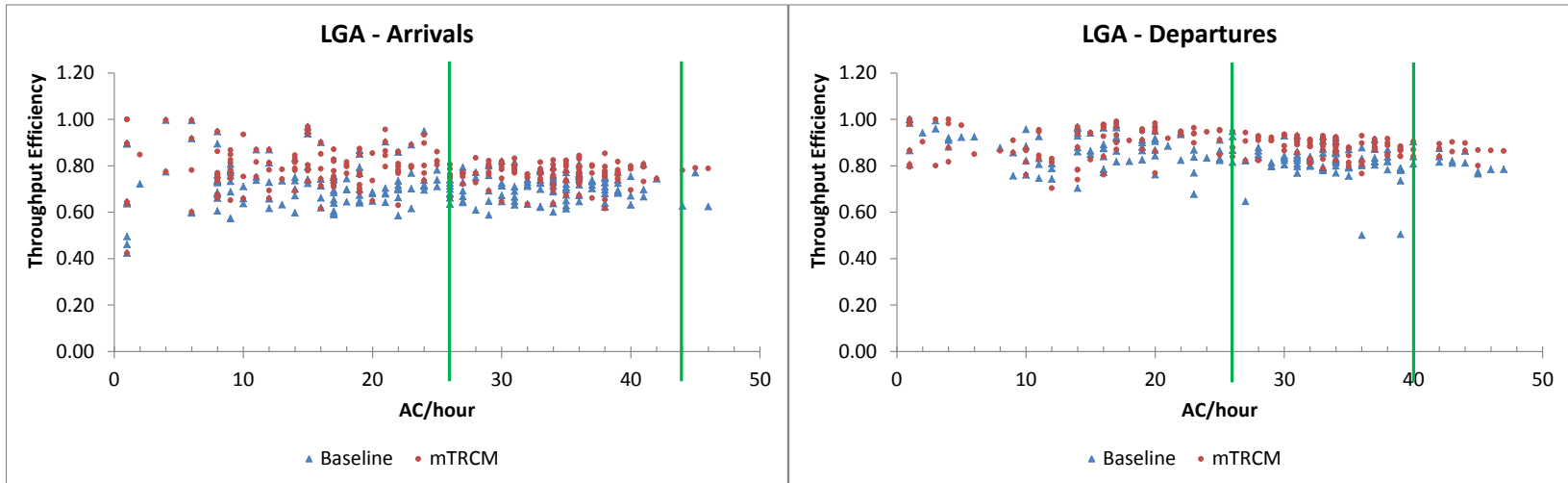
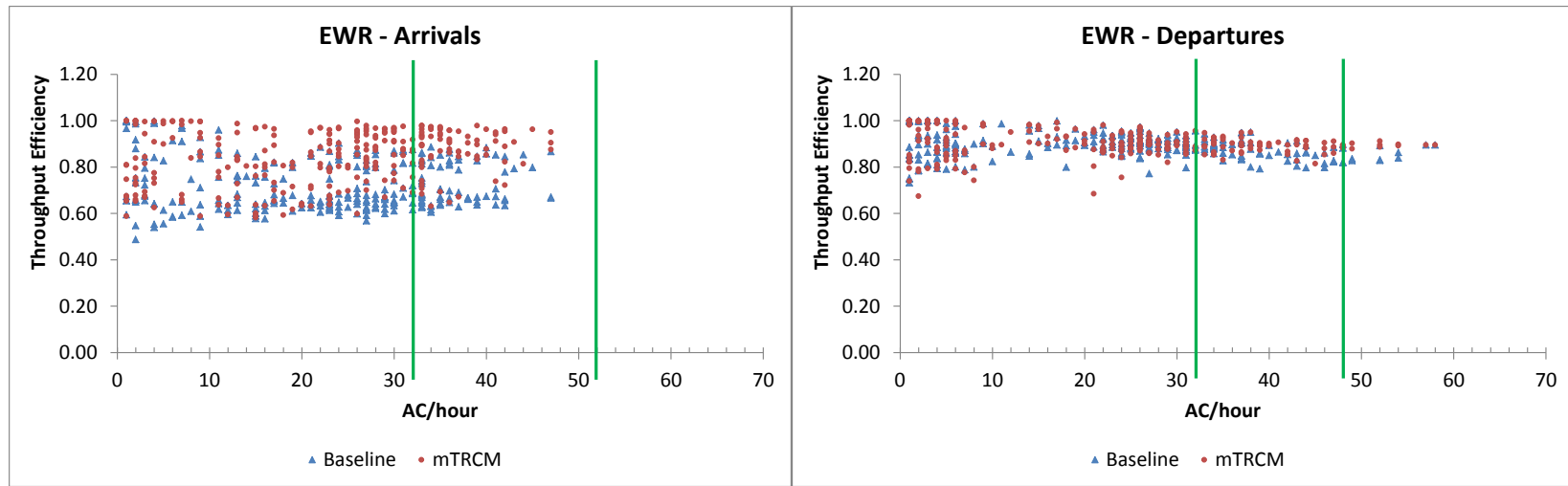
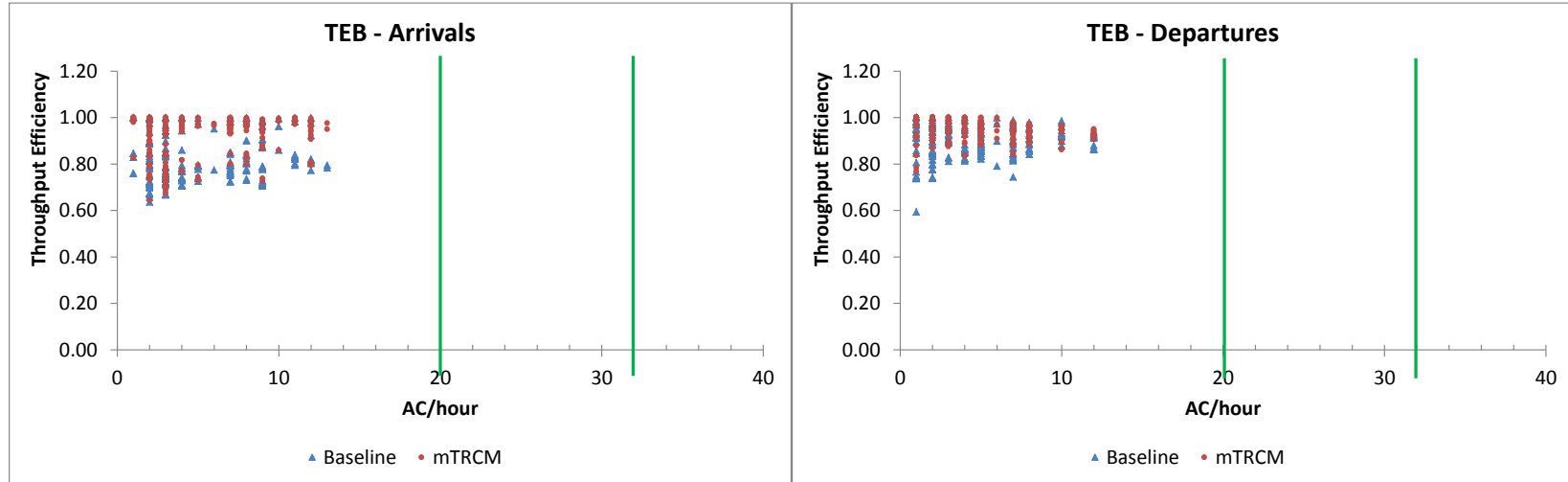


Figure 12. Scatter plots for all tested days at LGA with the 95% coverage intervals of historical Airport Acceptance Rate and Airport Departure Rate (green vertical lines).



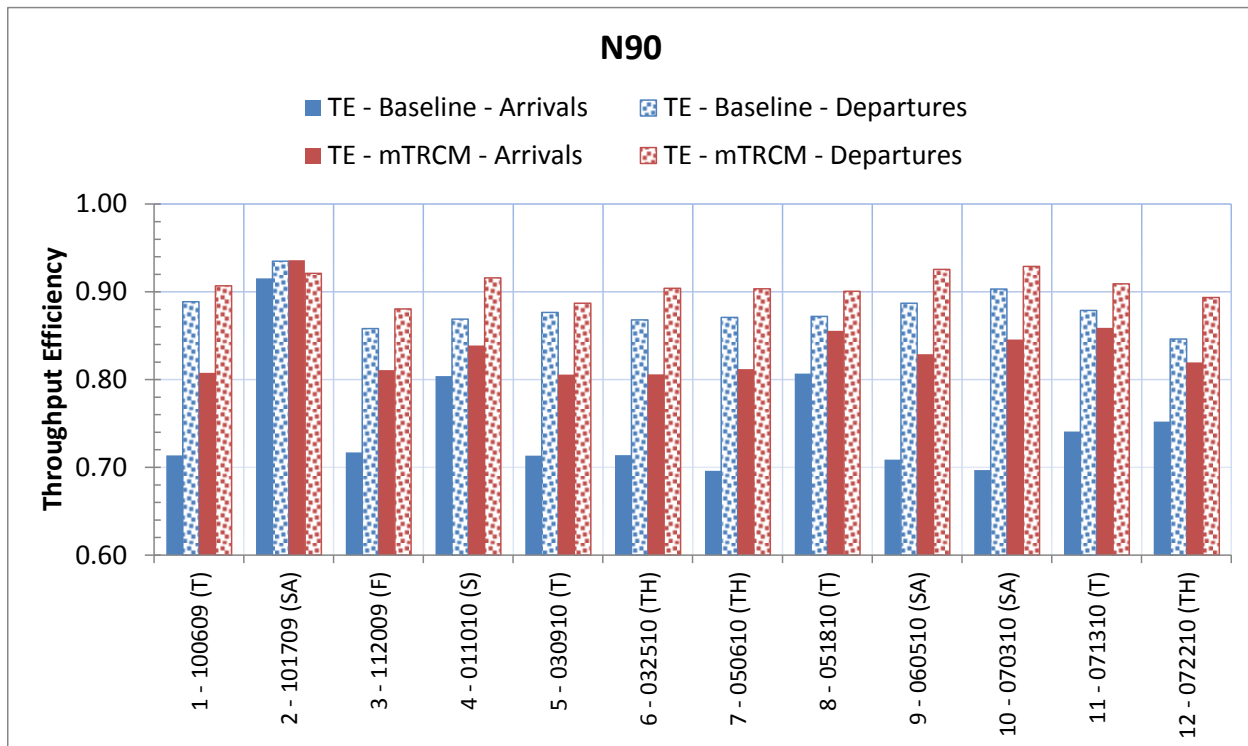
**Figure 13.** Scatter plots for all tested days at EWR with the 95% coverage intervals of historical Airport Acceptance Rate and Airport Departure Rate (green vertical lines).



**Figure 14.** Scatter plots for all tested days at TEB with the 95% coverage intervals of historical Airport Acceptance Rate and Airport Departure Rate (green vertical lines).

Figures 12 to 14 show similar plots for LGA, EWR, and TEB. There was no strong trend between demand and TE at these three airports. For LGA arrivals (figure 12), 95% of AARs were between 26 and 44 aircraft per hour. For departures, 95% of ADRs were between 26 and 40 aircraft per hour. Both arrival and departure processes were also at their historical capacities. For EWR arrivals (figure 13), 95% of AARs were between 32 and 52 aircraft per hour. For departures, 95% of ADRs were between 32 and 48 aircraft per hour. Both arrival and departure processes were also at their historical capacities. For TEB arrivals and departures (figure 14), 95% of AARs and ADRs were between 20 and 32 aircraft per hour. Both arrival and departure processes were far less than their historical capacities. This implies that TEB can generally absorb higher traffic volume without any capacity improvement to its current operation. In contrast, LGA and EWR were at their historical capacities, and were in need of any capacity improvement in order to absorb higher traffic volumes.

Figure 15 shows mean (over all hours) TEs for arrivals and departures for all twelve days at the N90 metroplex. TE varied by days, type of operation (arrival vs. departure), and runway configuration schedules (baseline vs. mTRCM). Upon inspection of the figure, TEs for arrivals were generally smaller than those for departures. Using the mTRCM schedule usually provided better TEs over the baseline schedule for arrivals and departures. In the baseline case, the TEs for arrivals varied in the range of 0.70 and 0.92; for the mTRCM case, TE for arrivals were in the range of 0.81 and 0.94. For departures, the baseline case resulted in TEs in the range of 0.85 and 0.93, while for the mTRCM case, they were in the range of 0.88 and 0.93. The mTRCM provided smaller TE variations (narrower ranges) than the baseline for both arrivals and departures. Comparing variations between arrivals and departures, departures showed smaller variations in TE than arrivals for both runway configuration schedules. This implies a more robust operation efficiency for departures than arrivals regardless of runway schedules.



**Figure 15. Mean (over all hours) throughput efficiencies (TE) at N90 metroplex for arrivals and departures for all days (in Day# - mmddyy (day) format).**

To understand TEs at individual airports, mean (over all hours) TEs for arrivals and departures for all twelve days were next broken down by airports (shown in figure 16). TE varied by days, type of operation (arrivals vs. departures), runway schedules (baseline vs. mTRCM), and airports. Similar to N90 observations, TEs for arrivals were smaller than those for departures at all airports. The mTRCM schedule provided better TEs over the baseline for arrivals and departures. Table 5 summarizes the TE ranges, standard deviation, and mean (over all days) by type of operation, runway configuration schedules, and airports. The mTRCM schedule produced smaller TE variations (smaller



standard deviation) than the baseline for arrivals and departures at all airports. Similar to N90 observations, departures showed smaller TE variations than arrivals for both runway schedules.

**Table 5. Throughput efficiency ranges (min, max), standard deviation (SD), and mean (over all hours and days) by type of operation (arrivals vs. departures), runway schedules (baseline vs. mTRCM), and airports.**

Airport	Type of Operation	Baseline Schedule			mTRCM Schedule		
		Range	SD	Mean	Range	SD	Mean
N90	Arrivals	0.70-0.92	0.06	0.75	0.81-0.94	0.04	0.84
	Departures	0.85-0.93	0.02	0.88	0.88-0.93	0.01	0.91
JFK	Arrivals	0.68-0.92	0.08	0.76	0.79-0.97	0.05	0.84
	Departures	0.84-0.93	0.03	0.88	0.88-0.92	0.02	0.91
LGA	Arrivals	0.66-0.90	0.07	0.72	0.73-0.89	0.04	0.78
	Departures	0.80-0.92	0.04	0.84	0.86-0.95	0.03	0.89
EWR	Arrivals	0.64-0.88	0.06	0.73	0.79-0.90	0.04	0.84
	Departures	0.87-0.96	0.03	0.89	0.86-0.96	0.02	0.90
TEB	Arrivals	0.79-0.99	0.07	0.84	0.87-0.98	0.04	0.93
	Departures	0.87-0.97	0.03	0.92	0.94-0.97	0.01	0.95

Improvements in the mean TEs are shown in figure 17 as percent improvement with respect to the baseline. On average, the mTRCM provided higher percent improvements for arrivals (between 9 and 16 percent across all sites) than departures (between 1 and 6 percent). Especially, EWR showed a substantial TE improvement for arrivals (16%). Overall, the N90 metroplex provided 12% TE improvement for arrivals, and 3% improvement for departures.

Mann-Whitney tests show that the mTRCM provided statistically significant higher TEs than the baseline for N90 arrivals (p-value = 0.0004) and departures (p-value = 0.0015). For JFK, LGA, and TEB, the mTRCM schedule provided statistically significant higher TEs than the baseline for arrivals and departures (p-value < 0.05). For EWR arrivals the mTRCM provided statistically significant higher TEs than the baseline (p-value = 0.0002), while for departures there was no TE difference between the mTRCM and baseline (p-value = 0.097).

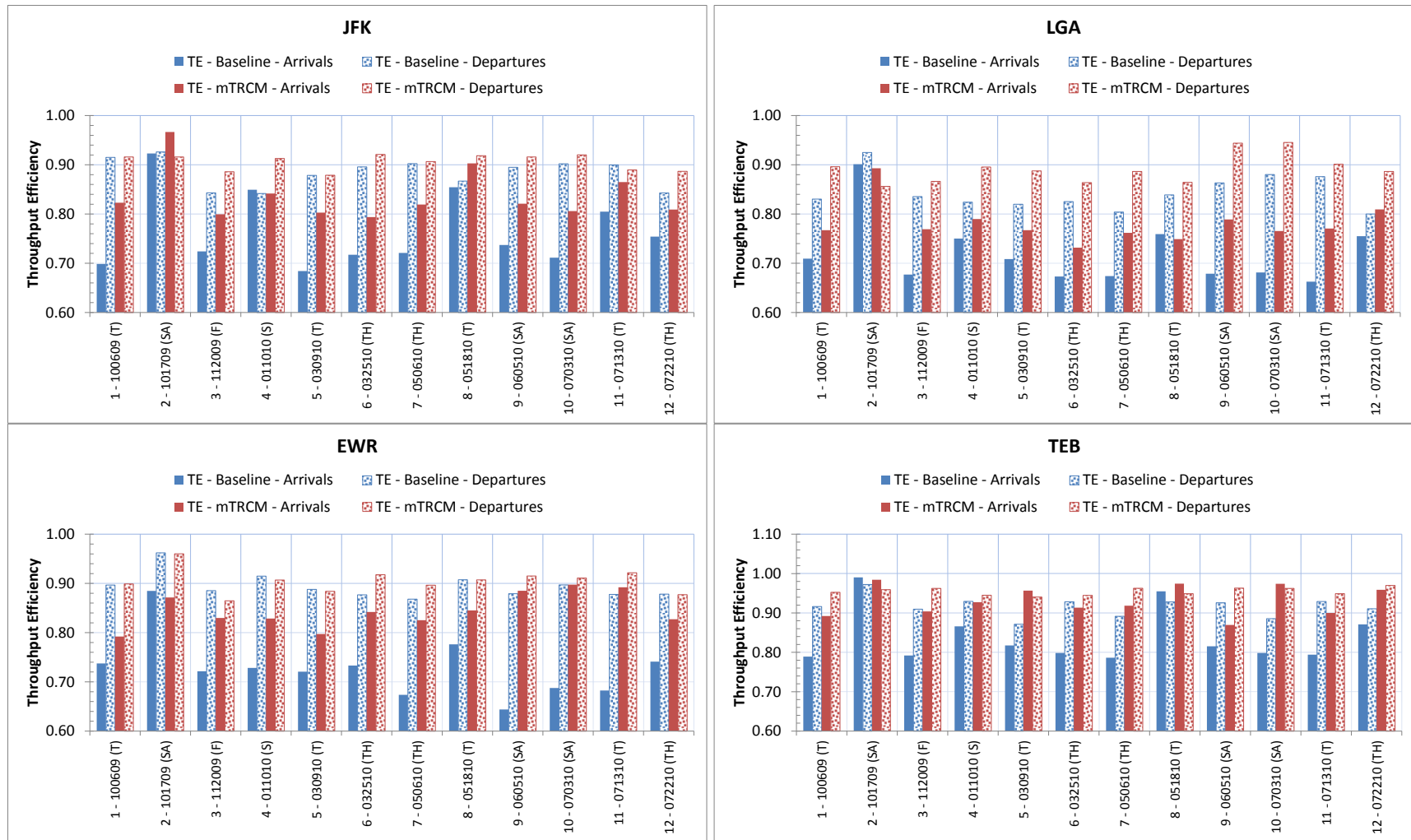
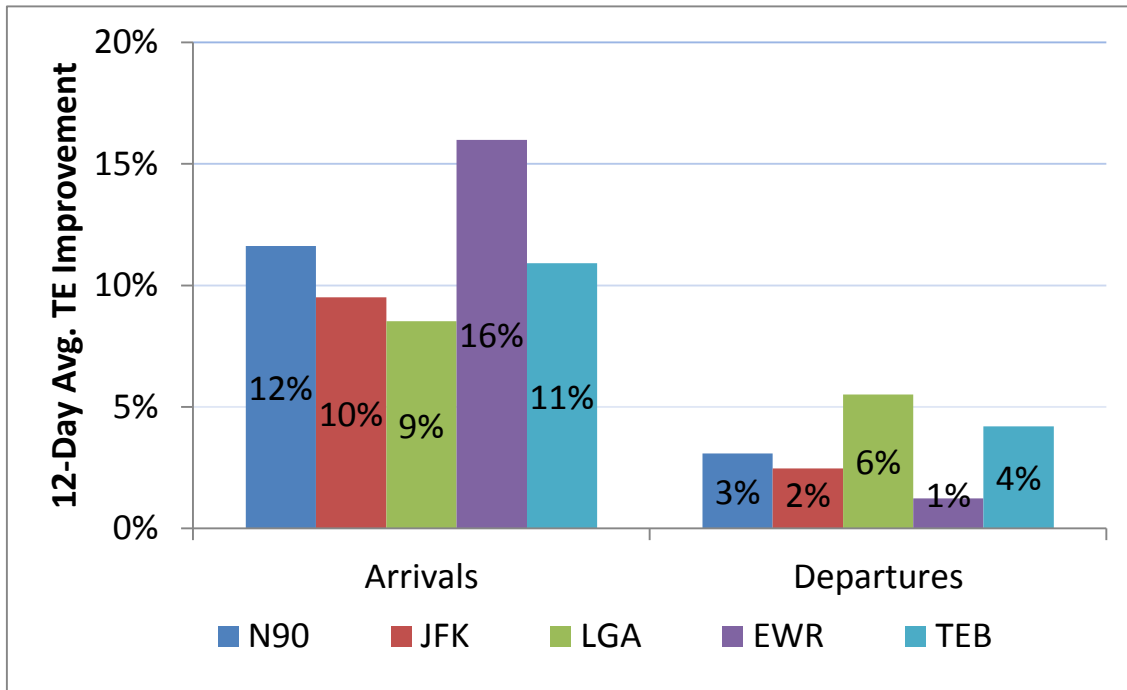


Figure 16. Mean (over all hours) throughput efficiencies (TE) for arrivals and departures for all days (in Day# - mmddyy (day) format) at JFK, LGA, EWR, and TEB.



**Figure 17. Average (over all days) improvement in throughput efficiency (ratio of mTRCM and baseline).**

#### 4.4. Runway configuration changes

Although runway configuration changes were not a designated metric for this study, the frequency of changes recommended by the mTRCM was evaluated for its operational feasibility. Typically, configuration changes can be categorized as: (1) a change in the primary direction of arrival and departure flows; and (2) a change in how runways are used within the same primary flow direction. Examples of the former category are a change in the southeast (13R/13L) to northwest (31L/31R) direction, or a change in the northeast (4L/4R) to southeast (13R/13L) direction. Examples of the latter category are a change in runway usage from an arrival (or departure) runway to a mixed-use runway for both arrivals and departures (i.e., from A\_31R/D\_31L to 31R, 31L/31L), or an additional runway to the existing primary flow direction (i.e., from 13L/13R to 13L, 22L/13R).

The first category, a change in the primary flow direction, affects arrivals more than departures. Because of the way arrivals are routed into terminal areas, there must be enough airspace to allow published routes to be flown through the TRACON airspace and proper airport traffic patterns to be flown, including any additional vectoring or path-stretching that might be needed for spacing considerations. A change in the primary flow direction must account for all of these, especially for any flights that would have to be re-routed in order to accommodate the new runway configuration. Because arrivals are affected more by changes in flow direction, the changes to flow direction that were counted for this study were those associated with a change in the primary arrival runways used. In contrast, the second category, a change in active runways within the same flow direction, requires less coordination among flights (especially for arrivals), airspace, and airport traffic pattern than the change in the flow direction.

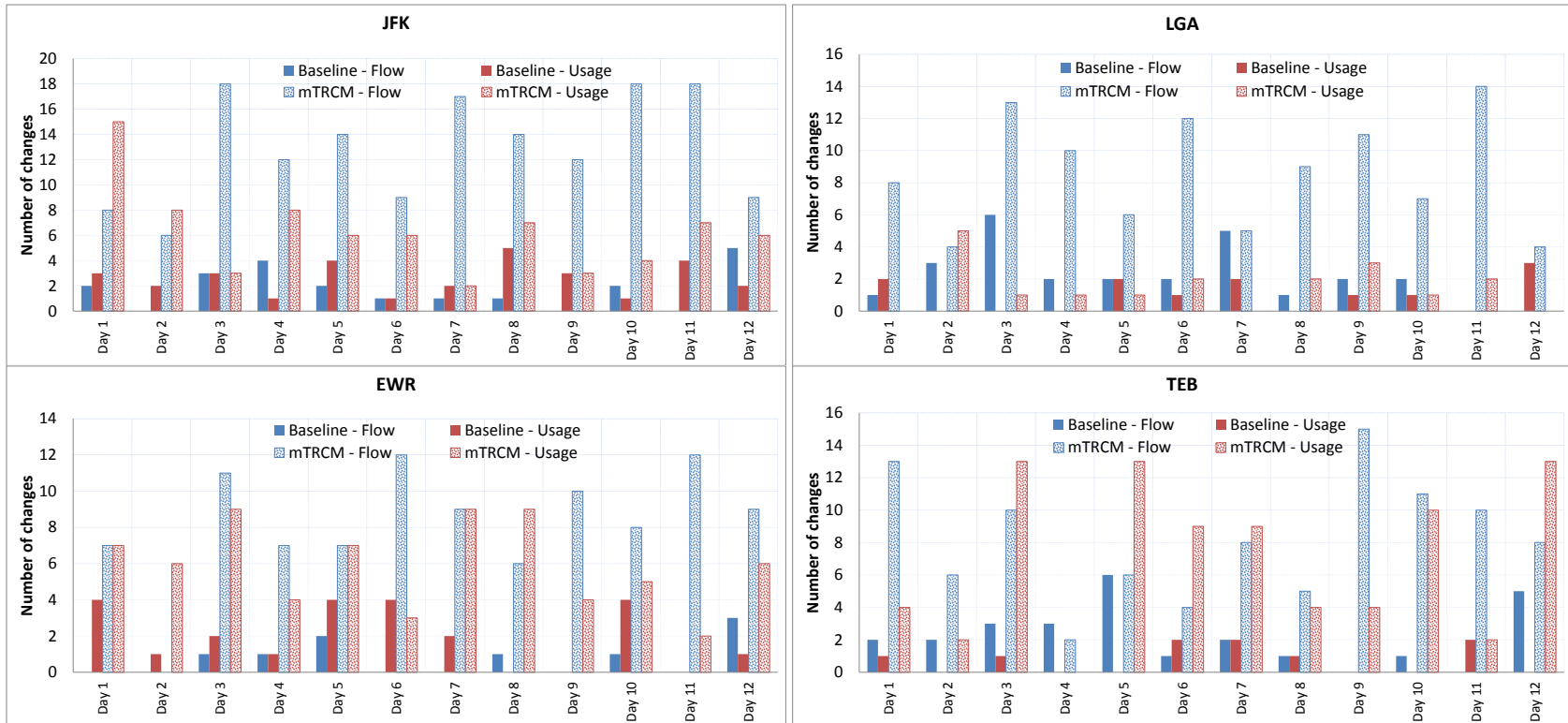


Figure 18. Number of configuration changes at JFK, LGA, EWR, and TEB for all tested days.

Figure 18 shows the number of configuration changes resulting from using the mTRCM schedule; changes in flow direction (the first category) are labelled as “Flow” and changes in runway usage within the same flow direction (the second category) are labelled as “Usage”. The corresponding historical number of changes (i.e., the baseline’s changes) that occurred on those days are also shown. The number of configuration changes varied by days, change categories (“Flow” vs. “Usage”), runway schedules (baseline vs. mTRCM), and airports. Table 6 summarizes the ranges, standard deviation, and mean (over all days) of the number of configuration changes by change categories, runway schedules, and airports. The mTRCM resulted in higher day-to-day variations (larger ranges and standard deviations) than the baseline case at all airports for both change categories. Additionally, the mTRCM had higher average number of changes per day than the baseline for both change categories. The higher average number per day recommended by the mTRCM is theoretically anticipated because the algorithm is able to take all flight, weather, and airport information into account while trading off the airborne, taxi, and queue (departing aircraft only) time durations for the minimum total time. This trade off calculation is usually complex and may be beyond operator’s capability without significantly increasing the workload. The right balance between the operator’s acceptable changes per day and the expected benefits needs to be further investigated so that the number of changes are not excessive.

**Table 6. Ranges (min, max), standard deviation (SD), and mean (over all days) for number of configuration changes by change categories (flow vs. usage change), runway schedules (baseline vs. mTRCM), and airports.**

Change Category	Airport	Baseline Schedule			mTRCM Schedule		
		Range	SD	Mean	Range	SD	Mean
Flow Change	JFK	0 - 5	1.60	1.75	6 - 18	4.27	12.92
	LGA	0 - 6	1.80	2.17	4 - 14	3.48	8.58
	EWR	0 - 3	0.97	0.75	0 - 12	3.27	8.17
	TEB	0 - 6	1.85	2.17	2 - 15	3.81	8.17
Usage Change	JFK	1 - 5	1.31	2.58	2 - 15	3.41	6.25
	LGA	0 - 3	1.04	1.00	0 - 5	1.45	1.50
	EWR	0 - 4	1.68	1.92	2 - 9	2.39	5.92
	TEB	0 - 2	0.87	0.75	0 - 13	4.78	6.92

To better understand the airport-specific configuration changes, the frequency of changes by category across all days was plotted for historical (baseline) and the mTRCM recommended runway schedules (shown in figure 19). For JFK, the mTRCM generated schedules suggested 67% of total changes as changes in the flow direction and the other 33% as changes in runway usage. In contrast, JFK historically (i.e., the baseline schedules) executed more changes in runway usage (60% of total) than flow direction changes. At LGA, the mTRCM recommended more flow direction changes (85%) than runway usage changes. This was also true historically. That is, 68% of total historical (baseline) changes were changes in flow direction. In practice, JFK and LGA usually operate in the same flow direction. In addition, historically JFK had higher average traffic volume per day than LGA (from table 4). It is speculated that approach controllers at the N90 chose to change the flow direction at LGA to follow the flow direction at JFK, as observed by this statistics. This speculation will need further investigation.

EWR had more flow direction changes than runway usage changes recommended by the mTRCM (58%). In contrast, 72% of total historical changes at EWR were runway usage changes. TEB had more flow direction changes for both the historical schedule (74%) and the mTRCM schedule (54%) than changes in runway usage. In practice, TEB operations have a strong interaction with EWR operations. Given the traffic volume at TEB was much lower than that at EWR historically (table 4), it is suspected that traffic flow managers chose to change the flow direction at TEB to accommodate the operations at EWR. This speculation will, again, need to be investigated further.

Overall, the mTRCM preferred a change in “Flow” over a change in “Usage” categories, while historically the preference varied by airports. Ratios of the mean change frequencies per day between the mTRCM and the baseline at all airports are given in figure 20. The mTRCM recommended 7 times the historical flow direction changes at JFK; 4 times at LGA; 11 times at EWR; and 4 times at TEB. In comparison, the mTRCM recommended twice the historical changes in runway usage at JFK; twice at LGA; 3 times at EWR; and 9 times at TEB. These values were clearly excessive compared to what is normally found at these airports, especially for the flow direction change. The mTRCM currently does not take into account the costs associated with a flow direction change whereas air traffic personnel are keenly well aware of the costs. Further refinement in the algorithm will need to incorporate these costs.

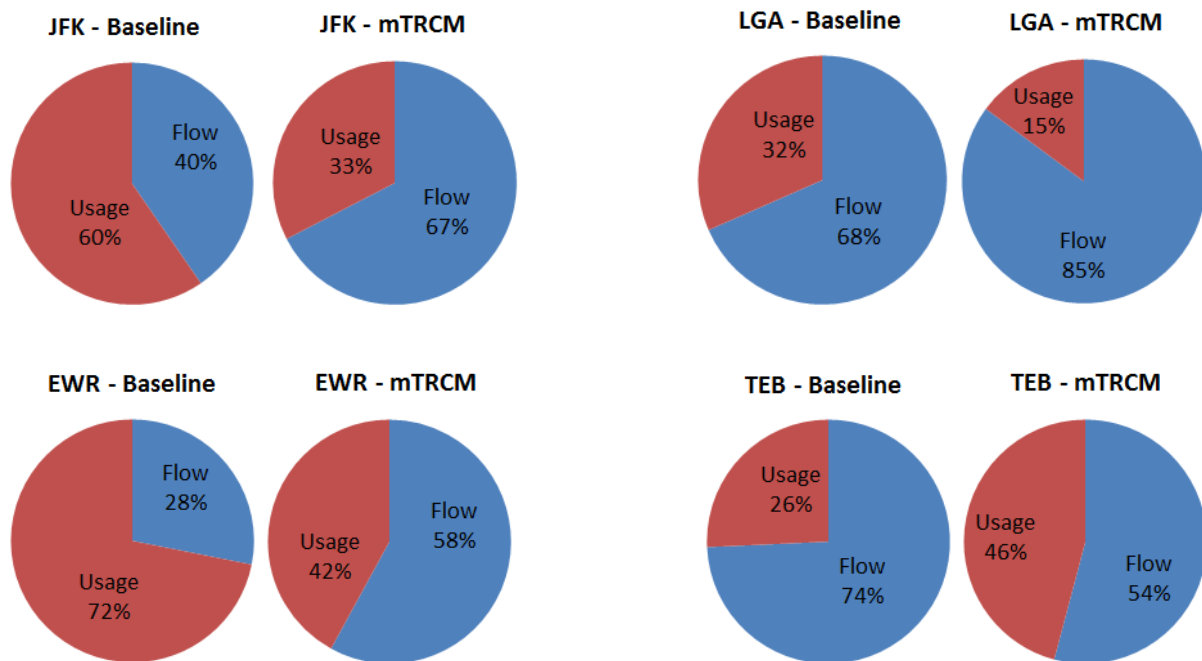


Figure 19. Breakdown of number of configuration changes by categories (flow vs. usage changes) at JFK, LGA, EWR, and TEB.

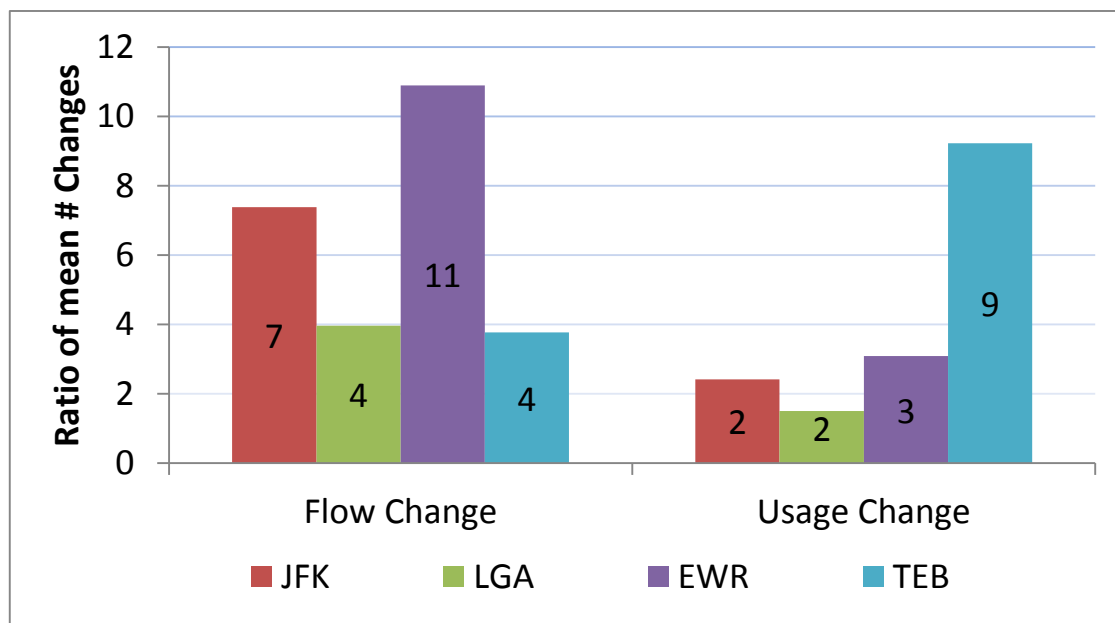


Figure 20. Ratio of the mean (per day) number of configuration changes between mTRCM and baseline.

## 5. Conclusions and future research

The System-Oriented Runway Management (SORM) concept is a collection of capabilities focused on a more efficient use of runways while considering all of the factors that affect runway use. Examples of these factors are: surface wind velocity, meteorological conditions, traffic demand, adjacent airport traffic flows, severe weather activity, environmental factors, intersecting arrival/departure runways, distance between arrival runways, etc. Tactical Runway Configuration Management (TRCM), one of the SORM capabilities, provides runway configuration and runway usage recommendations, and monitoring the active runway configuration for suitability given existing factors. This report focuses on the metroplex environment, with two or more proximate airports having arrival and departure operations that are highly interdependent. The myriad of factors that affect metroplex operations require consideration in arriving at runway configurations that collectively best serve the system as a whole. There are two metroplex TRCM (mTRCM) algorithms currently available; one was provided by Mosaic ATM under a contract to NASA (referred to as “mTRCM-A”), and the other has been developed by LaRC researchers (referred to as “mTRCM-B”). The mTRCM-A algorithm uses Mixed Integer Linear Programming (MILP) to solve each airport independently for the airport-specific optimal runway configurations. Because each airport is solved independently, this algorithm does not adequately capture interdependent metroplex conflicts. In comparison, the mTRCM-B captures these conflicts by referencing a list of excluded metroplex configuration combinations. The mTRCM-B uses this list during the second of two sequential enumerative searches. The first search is performed for all airports within the metroplex independently, resulting in airport-specific lists of all configurations with their associated best change times. These lists along with the excluded metroplex configuration list are then given as inputs to the second enumerative search, which generates the optimum metroplex configuration that is free of interdependent metroplex conflicts.

This study first compared the mTRCM-A and mTRCM-B algorithms using the same traffic datasets provided by Mosaic ATM for the New York metroplex (or N90). For this study, there are four airports considered as part of the N90 (New York Terminal Radar Approach Control, or TRACON) metroplex: John F. Kennedy International Airport (JFK), LaGuardia Airport (LGA), Newark Liberty International Airport (EWR), and Teterboro Airport (TEB). Based on this comparison, the mTRCM-B provided configuration change schedules generating consistently higher per flight transit time savings than the savings from the mTRCM-A. A benefit assessment of total delay, transit time, and throughput efficiency (TE) was performed using the mTRCM-B algorithm on twelve representative days during 2009-2010, using traffic volumes from N90. N90 was selected for its complexity in both airport configuration decisions and runway assignment and sequencing decisions. To assess the mTRCM-B benefit, the performance metrics must be compared with the actual historical operations.

To assess the mTRCM-B benefit, the performance metrics must be compared with the actual historical operations. The historical configuration schedules can be viewed as the schedules produced by subject matter experts (SMEs), and therefore are referred to as the SMEs’ schedules. These schedules were obtained from the FAA’s Aviation System Performance Metrics (ASPM) database; this is the most representative information regarding runway configuration selection by SMEs. All twelve traffic days were run once in the SORM software using the historical runway configurations, and once with the mTRCM-B-generated runway configuration schedule.

Total delay, transit time, and throughput efficiency (TE) benefits varied by days, by airports, and by type of operation (arrivals vs. departures). For total delay, the mTRCM-B’s runway configuration schedules statistically showed better results than those reflected in the SMEs’ schedules for departures at all airports. For arrivals, the mTRCM-B’s statistically showed better results than those reflected in the SMEs’ schedules at the New York metroplex (N90), JFK, EWR, and TEB. There was no statistical difference in total delay between both schedules for LGA arrivals. N90 observed an average (over all days) total delay benefit of 70.8 seconds (or 7% benefit) per arrival and of 54 seconds (or 5% benefit) per departure. For transit time, the mTRCM-B’s schedules statistically outperformed the SMEs’ schedules for all airports and all service types. N90 observed an average (over all days) transit time benefit of 90.8 seconds (or 9% benefit) per arrival and of 54 seconds (or 5% benefit) per departure. For TE improvement, the mTRCM-B’s schedules statistically outperformed the SMEs’ schedules for arrivals and departures at N90, JFK, LGA, and TEB. For EWR, the mTRCM-B’s schedule provided a statistically better TE than the SMEs’ only for arrivals; for departures there was no statistical difference in TE between both schedules. Over all days, the average improvement for N90 was 12% for arrivals and 3% for departures.

Although the number of runway configuration changes was not initially a metric for this assessment, it was evaluated to determine whether or not the number of changes recommended by the mTRCM-B was operationally feasible. Using the same scheme as in a previous study [Ref. 1], configuration changes were categorized as: (1) a change in the primary direction of arrival flows (referred to as “Flow”); and (2) a change in how runways are used

within the same primary flow direction (“Usage”). The frequency of configuration changes varied by days, change categories (“Flow” vs. “Usage”), runway schedules (historical SMEs’ vs. mTRCM-B’s), and airports. Overall, the mTRCM-B preferred a change in “Flow” over a change in “Usage” categories, while historically the preference varied by airports. In terms of change frequencies, the mTRCM-B recommended higher averages per day (as high as 11 times) than the SMEs. These change frequencies were clearly excessive compared to what is normally found at airports throughout the National Airspace System (NAS), especially for the flow direction change. It is recommended that, as part of future algorithm improvements, the mTRCM-B should be adjusted to limit the number of changes per day to what would be considered a more acceptable number. Additionally, because a list of interrelated metroplex conflicts has been captured in the current mTRCM-B algorithm, future improvement should also include airspace coordinations replicating more realistic metroplex operations.

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