Traffic Management Advisor Flow Programs:
an Atlanta Case Study

Shon Grabbe[*] and Banavar Sridhar[†]
NASA Ames Research Center, Moffett Field, CA, 94035-1000

Avijit Mukherjee[‡] and Alexander Morando[§]
University of California Santa Cruz, Moffett Field, CA, 94035-1000

Starting in 2010, the FAA began using new traffic flow management initiatives called Traffic Management Advisor Flow Programs to control flights destined for capacity-limited airports. This study explores through fast-time simulations the impact of these new traffic management initiatives on Hartsfield-Jackson Atlanta International Airport arrival operations. The emphasis of this study is on examining the distribution of delays for flights included and exempted from this new initiative. Of the 476 flights included in the Traffic Management Advisor Flow Programs, the results showed that when Atlanta was operating near maximum capacity, the mean total delay assigned to these flights was 31.6 minutes. However, the mean total delay increased to over 49.3 minutes when the airport capacity was reduced by 25%. In contrast, for the 408 arrivals that were exempt from the Traffic Management Advisor Flow Program the mean delay assigned to these flights by the Traffic Management Advisor was found to increase from 6.5 minutes when the airport was operating near maximum capacity to 24.8 minutes when the capacity was reduced by 25%. The experiments clearly illustrated the potential for imbalance in the distribution of delays assigned to the flights included within and exempt from the Traffic Management Advisor Flow Program. The mean total delay experienced by the included flights was between 85% and 99% higher than the delays experienced by the exempt flights. To alleviate this imbalance, a simulation-based approach is presented for selecting the "best" flow rate to reduce this imbalance, when developing a Traffic Management Advisor Flow Program. This approach depends on the arrival demand, airport configuration, and acceptance rate.

Nomenclature

ADL	Aggregate Demand List	FCA	Flow Constrained Area
ASDI	Aircraft Situation Display to Industry	FSM	Flight Schedule Monitor
ATL	Hartsfield-Jackson Atlanta International Airport	RBS	Ration By Schedule
CTA	Controlled Time of Arrival	STA	Scheduled Time of Arrival
CTA	Controlled Time of Departure	TFMS	Traffic Flow Management System
EDT	Eastern Daylight Time	TFP	TMA Flow Program
ETA	Estimated Time of Arrival	TMA	Traffic Management Advisor

I. Introduction

WHEN the demand at an airport significantly exceeds the available capacity, the Traffic Management Advisor[1] assigns delays to arriving flights to moderate the demand to current or anticipated capacity levels. For

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[*] Research Scientist, Systems Modeling & Optimization Branch, Mail Stop 210-15, shon.grabbe@nasa.gov, Associate Fellow AIAA.
[†] Senior Scientist, Aviation Systems Division, Mail Stop 210-10, Fellow AIAA.
[‡] Associate Project Scientist, University of California Santa Cruz, Mail Stop 210-8.
[§] Senior Software Engineer, University of California Santa Cruz, Mail Stop 210-8.

reference, the Traffic Management Advisor is a decision support tool deployed throughout the United States for efficiently sequencing and scheduling aircraft to arrival meter fixes, final approach fixes and to the runway threshold, while taking into account the airport configuration, the winds aloft, aircraft types and separation and/or flow rates constraints. These delays can lead to inefficiencies and significantly increase the complexity associated with managing the traffic flows in the en route environment. When this occurs, additional traffic management initiatives such as Ground Delay Programs have historically been implemented. One major downside associated with controlling flights with both a Ground Delay Program and the Traffic Management Advisor is that flights departing from within the same Center in which they later land can be "double delayed" (i.e., flights can receive multiple uncoordinated pre-departure delays from the two systems).[2,3]

To mitigate this "double penalization" problem, the FAA recently introduced a new traffic flow management initiative called a Traffic Management Advisor Flow Program. Briefly, this new initiative is used to reduce the demand of flights destined for a capacity limited airport by assigning pre-departure delays to these flights. Here the flights controlled by the Traffic Management Advisor Flow Program depart from outside of the TMA scheduling horizon, which typically extends about 200 nmi from the airport. This new initiative allows traffic flow managers to exempt internal departures from the Traffic Management Advisor Flow Program, which alleviates the double penalization problem. Because the Traffic Management Advisor Flow Program is relatively new (i.e., the first one was implemented at Newark Liberty International Airport in April of 2010), there have been few published studies that have examined the effectiveness of these new initiatives. To the best of the authors' knowledge, the only published study that investigates the effectiveness of Traffic Management Advisor Flow Programs appears in Ref. 2. However, there is a considerable body of literature that describes the development and testing of the Traffic Management Advisor (see for example, Refs. 1, 4-5) and a fair number of publications (see for example, Refs. 6-7) related to Airspace Flow Programs, which are similar to Traffic Management Advisor Flow Programs. Additional research studies that are designed to investigate Traffic Management Advisor Flow Programs would greatly improve the operational utility and effectiveness of these new initiatives.

To address this research gap, an integrated fast-time simulation system that consists of NASA's Future ATM Concepts Evaluation Tool[8], the FAA's Flight Schedule Monitor[9] and the Traffic Management Advisor[1] has been developed. Within this integrated system, the Future ATM Concepts Evaluation Tool was used to model the flow of traffic in the National Airspace System; the Flight Schedule Monitor was used to implement the Traffic Management Advisor Flow Program and the Traffic Management Advisor sequenced and scheduled the arrivals within about 200 nmi of the destination airport. Using this system, operationally derived scenarios were developed to investigate the impact that Traffic Management Advisor Flow Programs can have on one of the world's busiest airports, Hartsfield-Jackson Atlanta International Airport. For reference, the use of Traffic Management Advisor Flow Programs has been proposed by the FAA in order to manage arrival demand at Atlanta during periods of proposed taxiway construction, which can significantly reduce the capacity of the airport. Results are presented in terms of the distribution of delays imposed by the Traffic Management Advisor Flow Program and the Traffic Management Advisor.

Section II describes the modeling methodology and the software architecture of the integrated decision support capability. A discussion of the Traffic Management Advisor Flow Program scenario, the simulation inputs, and the Traffic Management Advisor settings is presented in Section III. The experimental results of fast-time simulations used to explore the uncoordinated impacts of the Traffic Management Advisor Flow Program and the Traffic Management Advisor on arrivals into Hartsfield-Jackson Atlanta International Airport are presented in Section IV. Additionally, this section also contains the results of the simulations that were designed to determine the "best" flow rate to select when developing a Traffic Management Advisor Flow Program. Finally, concluding remarks are presented in Section V.

II.   Modeling Methodology

The major components of the integrated software system that was developed to explore interactions between the Traffic Management Advisor (TMA) and the TMA Flow Program (TFP) are illustrated in Fig. 1. On the left side of this figure are the system inputs, which consist of user schedules and flight plans and airspace adaptation data. The user schedules were extracted from historical Aircraft Situation Display to Industry (ASDI) data archives that will be described in Section III. The adaptation data for the "Primary Simulation" system was extracted from the FAA's Traffic Flow Management System (TFMS).[9]
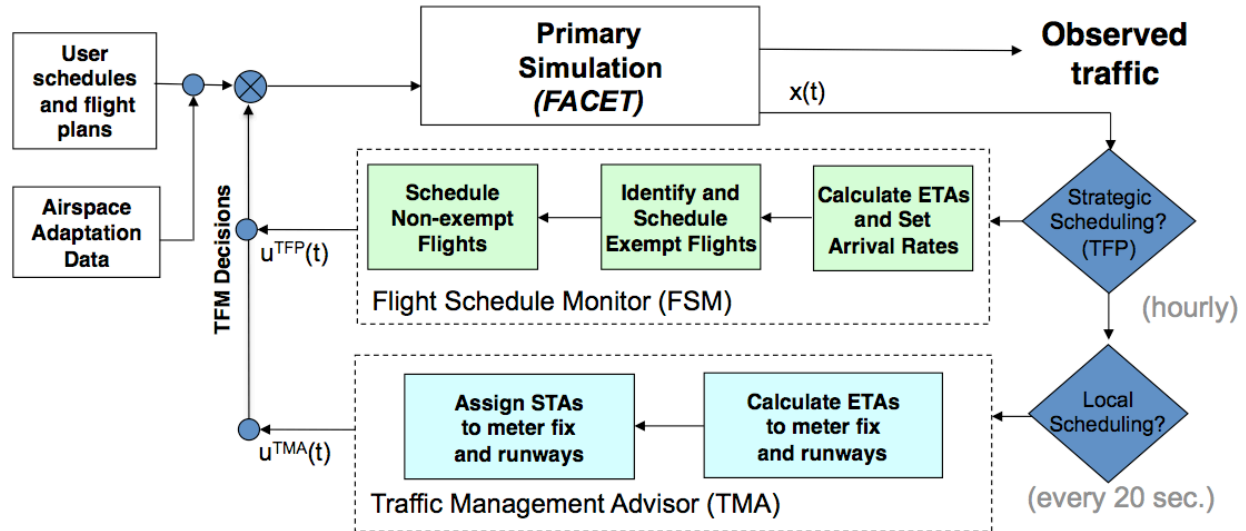
These system inputs were processed directly by the "Primary Simulation" system, NASA's Future ATM Concepts Evaluation Tool (FACET).[8] Every twenty seconds of simulation time, the "Primary Simulation" provides

updated state information, x(t), (e.g., latitude, longitude, speed, altitude, and heading) for all aircraft in the simulation via an Application Programming Interface (API) that has been described in previous studies.[10]

For this initial study, the interactions between FACET and the Flight Schedule Monitor (FSM) were accomplished via file transfer. Prior to conducting the fast-time simulation experiments, the TFP was planned in FSM and the resulting flight controls, which consisted of a set of Controlled Times of Departure (CTDs) for all flights include in the TFP, were logged to a file. For reference, this set of flights will be described in detail in Section III.A. This file was subsequently read by a Java-based application that communicated with FACET via the FACET API in order to implement the TFP controls, $u^{TFP}(t)$.

The three boxes that are collectively labeled as the "Flight Schedule Monitor" in Fig. 1 illustrate the high-level steps associated with planning a TFP in FSM. The first step in planning the TFP consists of calculating Estimated Times of Arrival (ETAs) for all flights to the boundary of the Flow Constrained Area (FCA) associated with the TFP. The definition of the FCA for the Hartsfield-Jackson Atlanta International Airport (ATL) scenario will be described in Section III.

Operationally, and for this study, the ETAs are calculated by the TFMS and transferred via an Aggregate Demand List (ADL) file to FSM. A human operator subsequently sets the FCA arrival rate via the FSM interface. In the box labeled "Identify and Schedule Exempt Flights", all flights exempt from the TFP are specified via the FSM interface, and the Controlled Times of Arrival (CTAs) associated with these flights are set to the ETAs. The list of flights exempt from the ATL scenario is described in Section III. Lastly, the Ration-by-Schedule (RBS) algorithm resident in FSM is used to calculate CTAs and CTDs for all non-exempt flights in the box labeled "Schedule Non-Exempt Flights" in order to satisfy the flow rate constraints at the FCA boundary. These controls are subsequently logged to an auxiliary file that is read by FACET.

Figure 1. Integrated system architecture.

The actual merging and spacing of the traffic flows to ensure efficient usage of the airport runways is accomplished via the collection of boxes labeled "Traffic Management Advisor" in Fig. 1. For the current study, the TMA performs the activities associated with these boxes once every twenty seconds. It is worth noting that operationally, TMA receives real-time position updates every twelve seconds, which coincides with the Center radar update rate. The slower update rate was selected for the fast-time simulations to improve computational performance. Using the trajectory prediction capabilities of TMA, ETAs to the meter fixes and all active runways for all aircraft are first calculated. This step is highlighted in the box labeled "Calculate ETAs to meter fix and runways" in Fig. 1. After calculating the ETAs, the flights are subsequently scheduled[11] subject to the airport, meter fix, and runway constraints using the time-based TMA scheduling algorithm, which is a derivative of a first-come-first-served algorithm. The outcomes of this scheduling are scheduled times of arrival (STAs) to the meter fixes and

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active runways for all flights. These steps are captured in the box labeled, "Assign STAs to meter fix and runways" in Fig. 1. The controls assigned by TMA at time t are labeled $u^{TMA}(t)$ in Fig. 1 and consist of a set of airborne delays for the arriving flights. For simplicity these are implemented as airborne holding in the "Primary Simulation" system.

III. Experimental Setup

This section describes the TFP scenario, system inputs and the TMA settings used for testing the integrated TFM approach proposed in Section II.

A. TFP Scenario

Traffic flow managers at the FAA's Air Traffic Control System Command Center developed the proposed TFP scenario used in this study. The intent of the TFP was to control arrivals destined for ATL prior to the flight entering the TMA freeze horizon when the arrival demand was forecasted to significantly exceed the arrival capacity during periods of taxiway construction. Taxiway construction at ATL began in September of 2010 and was expected to last throughout the fall. Without the use of a TFP under these circumstances, the TMA, which is in operational use at ATL, could begin assigning significant airborne delays to flights in the en route environment and pre-departure delays to flights departing from within Atlanta Center. This can lead to significant inefficiencies and complexities in Atlanta Center's airspace, as controllers attempt to meet the schedules produced by TMA.

The FCA associated with the proposed TFP is illustrated in Fig. 2 by the red circle. This FCA consists of a 390 nmi circle centered around ATL. This radius was selected so that departures from airports, such as Orlando International Airport (MCO) and Indianapolis International Airport (IND), would be exempt (i.e., these flights would not be assigned any delays by the TFP) from the TFP. Referring to Fig. 2, all flights within the red circle were exempt from the TFP, while flights outside the circle were included in the TFP and assigned CTAs (at the boundary of the FCA) and CTDs by FSM to accomplish a user-specified flow rate across the FCA boundary. Additionally, all flights originating from Canada were also exempt from the TFP. For modeling purposes, the TFP was assumed to begin at 11:00 am Eastern Daylight Time (EDT) and extend through 8:59 pm EDT, and the baseline flow rate across the TFP, as prescribed by traffic flow managers within the FAA, was assumed to be 54 aircraft per hour. As discussed in Section IV.D, this flow rate was subsequently increased to 100 aircraft per hour in order to determine the most appropriate flow rate to use for a given ATL airport configuration.
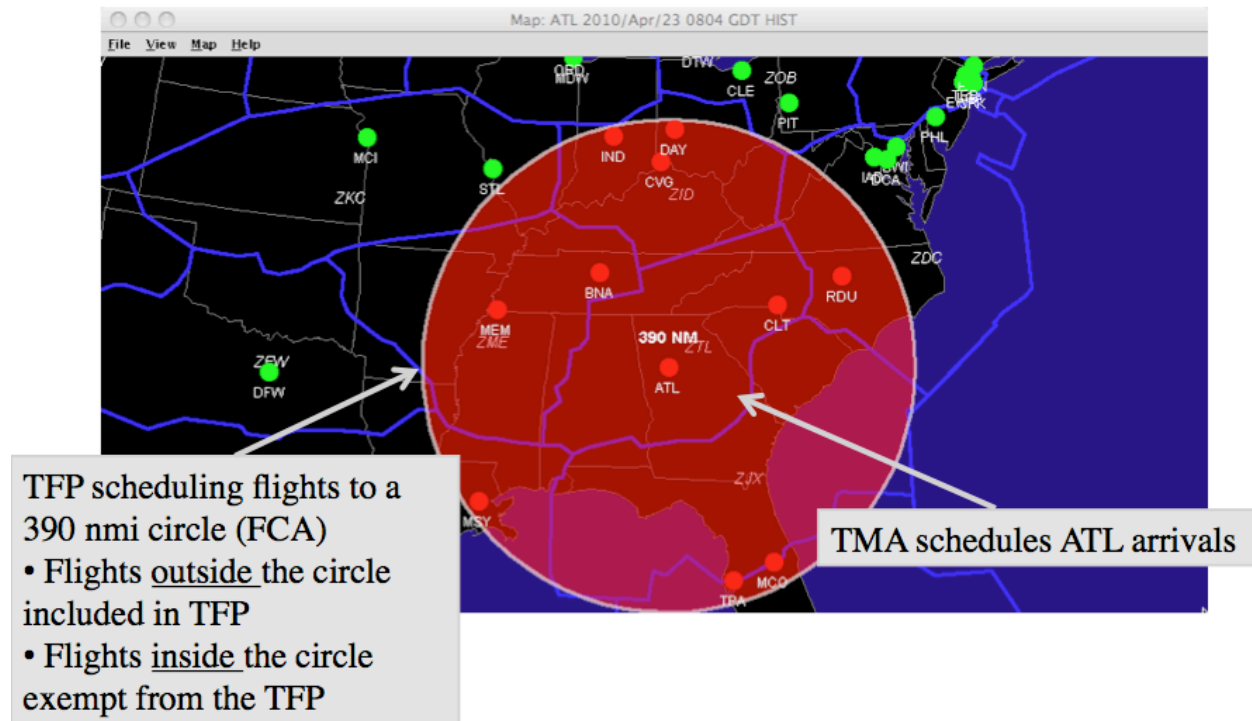

Figure 2. Proposed ATL Traffic Management Advisor Flow Program.

B. System Inputs

The TFMS ADL file from June 29, 2010 was used in part to develop the nine hour and 59 minute scenario considered in this study. This file consisted of 571 ATL arrivals, 95 of which would have been exempt had the TFP been operationally implemented. It is worth noting that this list of flights only included arrivals that departed outside of the FCA (red circle) depicted in Fig. 2. The schedule for flights departing from within the FCA depicted in Fig. 2 was developed using historical ASDI data archives from the June 29 and 30, 2010 ASDI data set. This data set was selected to coincide with the date of the ADL file that was used in planning the TFP that was previously described.

The unscheduled hourly ATL arrival demand between 11:00 am EDT and 8:59pm EDT are shown in Fig. 3. The unfilled bars in Fig. 3a correspond to the demand associated with the flights impacted by the TFP. It is worth noting that the number of TFP impacted flights is nearly zero in the first time bin (i.e., 11:00 am to 11:59 am), since it takes a flight roughly one hour to travel from the circumference of the FCA illustrated in Fig. 2 to ATL. The hashed bars in Fig. 3a correspond to the unscheduled demand associated with the flights exempt from the TFP. The total unscheduled demand is shown in Fig. 3b. For reference, the nominal airport arrival rates under the "2_WEST_VMC" and "3_WEST_VMC", which will be described in the next section, are also shown in Fig. 3b as a solid line and a dashed line, respectively.

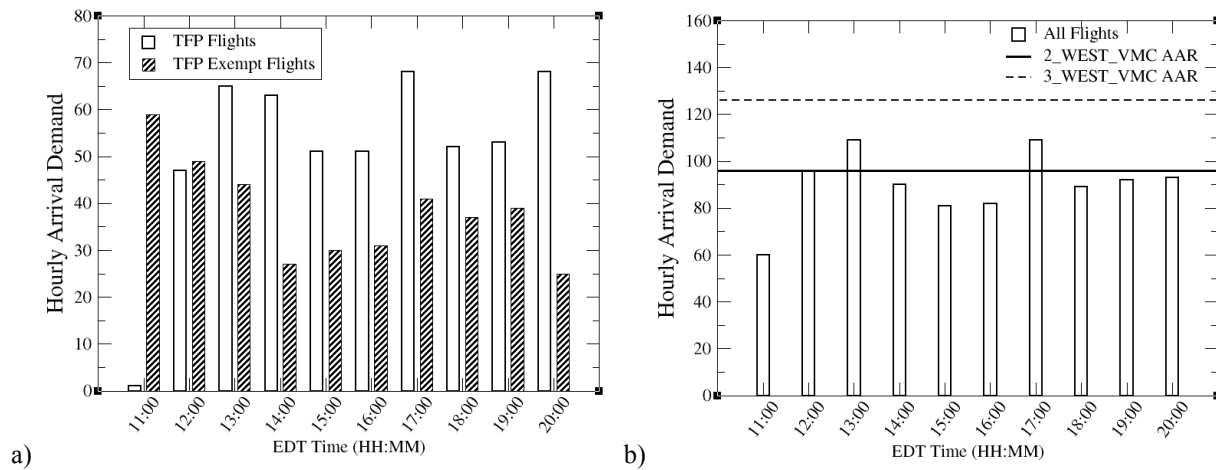a)   b)

Figure 3. a) Hourly unscheduled arrival demand for the TFP flights (white bars) and the flights exempt from the TFP (dashed bars) ATL arrival demand and b) total unscheduled arrival demand between 11:00 and 20:59 EDT.

C. TMA Configuration

The TMA was operated in a total of six west-flow visual meteorological condition (VMC) configurations, which are shown in Table 1. For reference, the five runways at ATL are labeled in Fig. 4. For our experiments, 26R, 27L and 28 were used for arrivals and 26L and 27R were used for departures under the west-flow airport configurations. No east-flow configurations were considered, but when the airport is in this configuration, runways 8L, 8R, 9L, 9R and 10 are used. For each of the fast time simulation experiments, the airport was allowed to operate in one of the configurations listed in Table 1 for the duration of the experiment. When configuring the TMA, the acceptance rate at the airport, including all runways and gates, was set to be "unrestricted", which is consistent with the way in which TMA is typically configured at ATL. "Unrestricted" in this case implies that only the minimum wake vortex separation requirements at the runways (see Table 2) were being enforced. Additionally, a five nautical miles (nmi) inter-aircraft spacing constraint was imposed at all meter fixes. For a given combination of runways, variations in the airport arrival rate (see column 3 in Table 1) were achieved by imposing additional restrictions on runway 28. This was accomplished by increasing the wake vortex separation buffer using the values specified in column 4 of Table 1. This is consistent with guidance used by traffic flow management specialists working at Atlanta Center.

Table 1. TMA west-flow visual meteorological condition configurations.

Configuration	Runways	AAR (aircraft/hr)	Runway 28 Separation Buffer (nmi)
3_WEST_VMC	26R/27L/28	126	0.1
3_WEST_VMC	26R/27L/28	118	3.0
3_WEST_VMC	26R/27L/28	112	3.7
3_WEST_VMC	26R/27L/28	104	4.9
3_WEST_VMC	26R/27L/28	100	6.0
2_WEST_VMC	26R/27L	96	-

Figure 4. Airport Diagram for Atlanta/Hartsfield International Airport.

The default wake vortex separation matrix used for the active runways (i.e., 26L, 27R and 28) is shown in Table 2. The data in this table shows the minimum separation in nautical miles between aircraft as they land in order for the trailing aircraft to avoid the wake vortex of the leading aircraft. The leading aircraft type is specified in the first column of the table, while the trailing aircraft type appears in the subsequent columns. For example, the minimum spacing at the runway when a small turboprop follows a heavy jet is six nautical miles. This separation varies depending on the engine type and weight class of the two aircraft that are being separated.

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Table 2.   Default TMA wake vortex separation matrix (in nmi) with the first column indicating the leading aircraft type and subsequent columns indicating the trailing aircraft type.

	Heavy Jet	Large Jet	Large Turboprop	Small Turboprop	Small Piston	Boeing 757
Heavy Jet	4.0	5.0	5.0	6.0	6.0	5.0
Large Jet	2.5	2.5	2.5	4.0	4.0	2.5
Large Turboprop	2.5	2.5	2.5	4.0	4.0	2.5
Small Turboprop	2.5	2.5	2.5	2.5	2.5	2.5
Small Piston	2.5	2.5	2.5	2.5	2.5	2.5
Boeing 757	4.0	4.0	4.0	5.0	5.0	4.0

IV.   Results

This section contains the results of sixteen, 10-hr, fast-time simulation experiments that were designed to explore the impact of TFPs on ATL arrival operations. A summary of these experiments is presented in Fig. 5. As shown by this figure, six fast-time experiments were conducted in which the flow rate associated with the TFP was set to a constant value of 54 aircraft/hr. Flight-level delay distributions for these six experiments are presented in Section IV.A.   Subsequently, aggregate delay statistics for these six experiments are presented in Section IV.B. Additionally, a model for estimating the TMA delay assigned to the flights included in the TFP for these six experiments is presented in Section IV.C. Lastly, results for the twelve fast-time experiments that were conducted while varying the flow rate associated with the TFP from 54 aircraft/hr to 100 aircraft/hr under the 2_WEST_VMC and "3_WEST_VMC, 0.1 nmi Buffer" TMA configurations are presented in Section IV.D.

Figure 5. Experiment matrix showing the sixteen experiments (shaded boxes) conducted by varying the TFP flow rates (columns) and the TMA configurations (rows).

A. Flight-level Delay Distributions

Flight-level TFP and TMA delays are presented in Fig. 6 for the 884 flights (each dot in the figure represents the delay assigned to one of these flights) that arrived at ATL between 11:00 am EDT and 8:59 pm EDT. These results were generated when the TFP flow rate was set to 54 aircraft/hr and the TMA was operated in a 3_WEST_VMC configuration with a separation buffer of 0.1 nmi (Fig. 6a) and a 2_WEST_VMC configuration (Fig. 6b). In Fig. 6a, ATL was operated in the 3_WEST_VMC configuration with an airport arrival rate of 126 aircraft/hr, which corresponds to ATL's unconstrained arrival rate. The mean TMA delay in this configuration was 3.2 min with a standard deviation of 5.6 min, while the mean TFP delay was 19.4 min with a standard deviation of 22.2 minutes. As expected, the TMA delays in Fig. 5a are relatively low, because as indicated in Fig. 3b, the uncontrolled arrival demand is well below the airport capacity for the entire 10-hr period. Overall, 34% of the flights received both TFP and TMA delays under this configuration.

In contrast to the results presented in Fig. 6a, Fig. 6b shows the TFP and TMA delays for the 884 arrivals when ATL is operating under the 2_WEST_VMC configuration with an airport arrival rate of 96 aircraft/hr. Under this configuration, the mean TMA delay is 21.1 min with a standard deviation of 18.2 min, and the TFP delay is 19.4 min with a standard deviation of 22.2 minutes. From Fig. 3b, this significant increase in the TMA delays is expected since the uncontrolled airport arrival demand is very near, or above, 96 aircraft per hour for seven of the ten hourly periods. As expected, the TFP delay does not vary as the airport configuration changes. Under this scenario, 47% of all flights receive both a delay from the TFP, and an uncoordinated delay from the TMA. In some cases these delays were observed to be very large (e.g., in excess of 30 minutes).

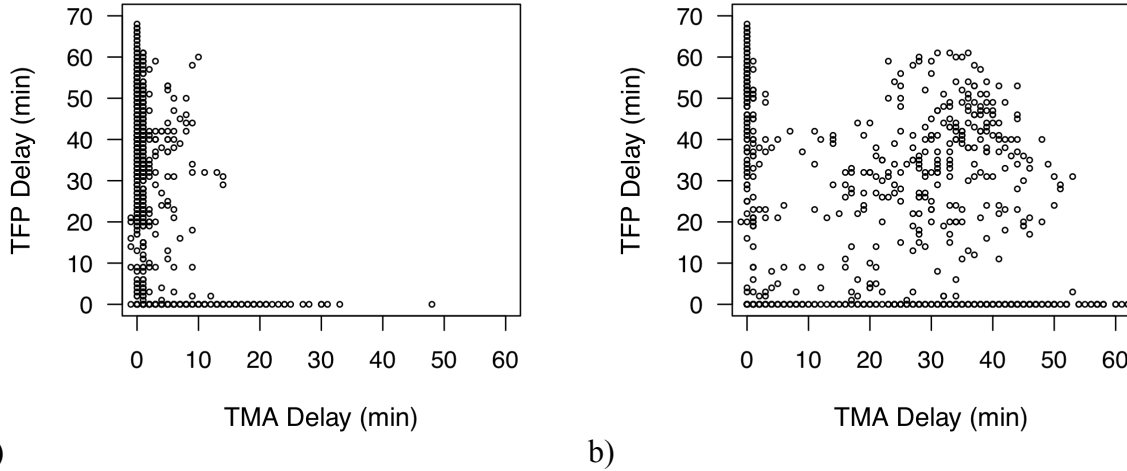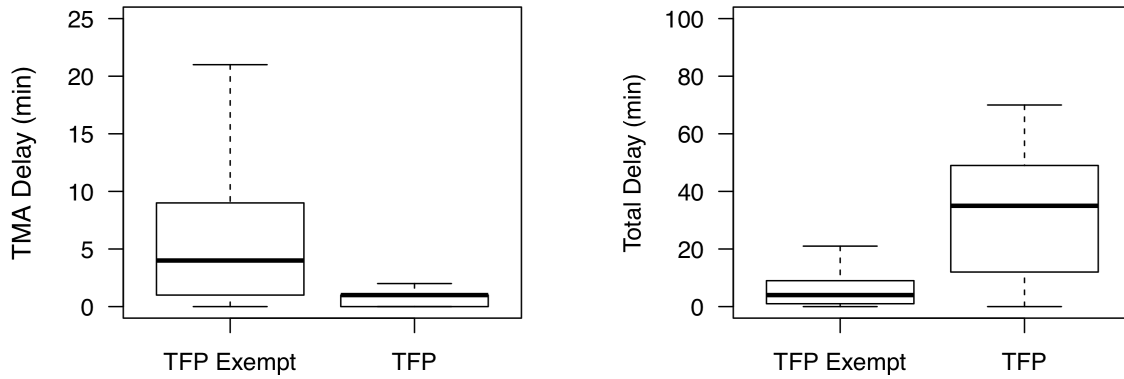a)   b)

Figure 6. TMA versus TFP flight delays when the configuration of ATL is a) 3_West_VMC with an airport acceptance rate of 126 aircraft/hr and b) 2_WEST_VMC with an airport acceptance rate of 96 aircraft/hr.
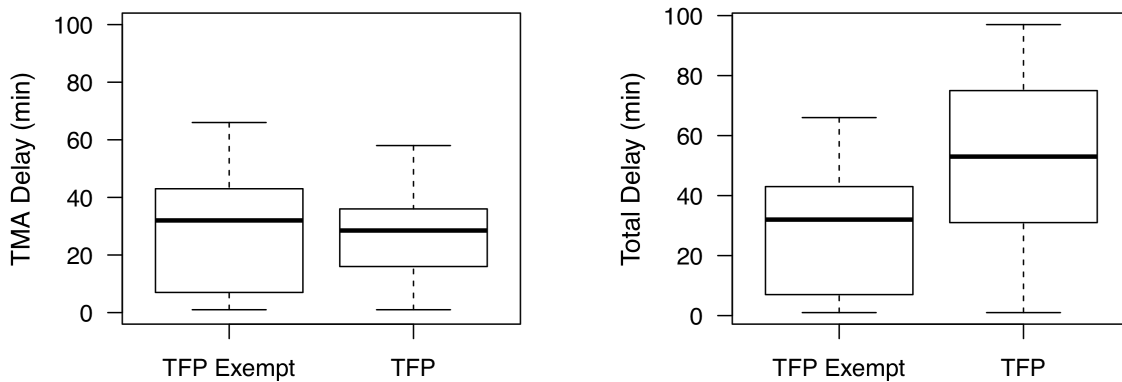
B. Aggregate Delay Distribution for flights included and exempt from the TFP

This section presents the aggregate total delays and the TMA delays assigned to the 884 flights that arrived at ATL between 11:00 am EDT and 8:59 pm EDT. For comparison purposes, the delays for the flights included and exempt from the TFP are presented separately. Ideally, the flights included and exempt from the TFP should be assigned roughly equivalent levels of delay, but as illustrated by the results in this section this seldom occurs. The imbalance in the delay distribution is especially pronounced when ATL is operating at or near its maximum capacity (i.e., 126 aircraft/hr) as illustrated in Fig. 7 and Tables 3 and 4. As illustrated by Fig. 7a, the median TMA delay for flights exempt from the TFP is 300% higher than the median for TFP flights. However, the median of the total delay (see Fig. 7b) for the TFP flights is 775% higher than the median for the flights exempt from the TFP, while the mean total delay is 386% higher for the TFP flights as compared to the flights exempt from the TFP as shown in Tables 3 and 4. Note that for the flights exempt from the TFP, the TMA delay is the total delay experienced by these flights.

a)   b)

Figure 7. a) TMA delay in minutes and b) total delay in minutes for the TFP flights and the flights exempt from the TFP for the 3 West VMC ATL configuration with an airport acceptance rate of 126 aircraft/hr.

When ATL is operating under a two-runway, VMC configuration with an AAR of 96 aircraft per hour, the median TMA delay for the flights exempt from the TFP is 33% higher than the delay for TFP flights (see Fig. 8a), and the mean TMA delay for the flights exempt from the TFP is 30% higher than the delay for TFP flights (see row labeled "2 West, 96 ac/hr" in Table 3). In contrast, the median total delay for TFP flights is 85% higher than the median total delay for flights exempt from the TFP (see Fig. 8b), and the mean total delay for TFP flights is 99% higher than the mean delay for the flights exempt from the TFP (see Tables 3 and 4). Figures 7 and 8 clearly illustrate that as the capacity of ATL decreases, the distribution of delays between the TFP flights and the flights exempt from the TFP becomes more balanced.

a)   b)

Figure 8. a) TMA delay in minutes and b) total delay in minutes for the TFP and TFP exempt flights for the 2 West VMC ATL configuration with an airport acceptance rate of 96 aircraft/hr.

Table 3. TMA delays assigned to TFP and TFP exempt flights for alternate airport configurations.

Airport Configuration	Mean TMA Delay for TFP Flights (min)	Standard Deviation for TFP Flights (min)	Mean TMA Delay for TFP Exempt Flights (min)	Standard Deviation for TFP Exempt Flights (min)
3 West, 126 ac/hr	1.2	2.2	6.5	7.7
3 West, 112 ac/hr	1.3	2.2	6.6	7.7
2 West, 96 ac/hr	19.1	16.8	24.8	19.9

Table 4. Total delays assigned to TFP impacted flights for alternate airport configurations.

Airport Configuration	Mean Total Delay for TFP Flights (min)	Standard Deviation for TFP Exempt Flights (min)
3 West, 126 ac/hr	31.6	21.2
3 West, 112 ac/hr	31.6	21.1
2 West, 96 ac/hr	49.3	25.6

C. Delay Estimation

The actual time that a TFP impacted flight will arrive at the destination airport may deviate significantly from the original estimated time of arrival because of the TFP delays that these flights may incur and to a lesser extent because of the TMA delays that are assigned to the flights. These large deviations can lead to significant schedule disruptions for airline operators. Once a TFP-impacted flight has departed, the airline operator may be interested in calculating a revised estimate of a flight's arrival time for planning purposes. To accomplish this, the operator will require an estimate of the en route travel time, which can be readily calculated using modern flight planning software, and an estimate of the amount of delay that the flight will incur because of the TMA.

Major factors that can influence the amount of TMA delay that a TFP-impacted flight will incur include, but are not limited to, the following:

- The configuration of the airport (e.g., west flow or south flow, three active runways or two active runways)
- The airport acceptance rate
- The demand at the airport at the time that the TFP impacted flight arrives at the airport
- The weight class distribution of the arrivals (e.g., are all arrivals in a 15-min interval heavy jets, or is there a mix of heavy jets and turboprops)

In Fig. 9, the average TMA delay assigned to TFP-impacted flights in a 15-min interval is plotted as a function of the arrival demand divided by the airport capacity in a 15-min interval. Data for 120, 15-min intervals are shown in this figure for the 10-hr fast time simulation experiments that were conducted when ATL was operating in a VMC "Trips West" configuration with airport acceptance rates of 126, 112 and 100 aircraft per hour and a TFP flow rate of 54 aircraft per hour. Some interesting trends that are evident from this figure are that the average TMA delays assigned to TFP-impacted flights are zero when the airport is operating at below 50% of available capacity. Additionally, the delays are observed to increase dramatically when the airport begins operating above capacity, as would be expected.

As is evident from Fig. 9, there is a clear non-linear relationship between the average TMA delay assigned to a TFP impacted flight and the amount of congestion at the airport, as measured by the ratio of the demand divided by the capacity. The blue curve in Fig. 9 is a fit to the data using the following expression:

$$Delay = \beta_0 + \beta_1 \cdot \rho + \beta_2 \cdot \exp(\rho) \tag{1}$$

where ρ = airport demand / airport capacity and the parameter estimates are presented in Table 5.

The Prob > |T| values in Table 5 are used to determine whether a particular parameter (e.g., β_0, β_1, β_2) has statistically significant predictive capabilities. The low values of Prob > |T| indicate that all of the parameters (i.e., regression coefficients) are statistically significant.

The coefficient of determination, R^2, for this model is 0.522, which indicates that the model has reasonable predictive capabilities. For reference, $R^2=1$ if a model has perfect predictive predictability, while $R^2=0$ for a model with no predictive capability. Using the model in Eq. (1), an operator could estimate the average TMA delay that would be experience by the TFP-impacted flight from a forecast of the airport demand and capacity.
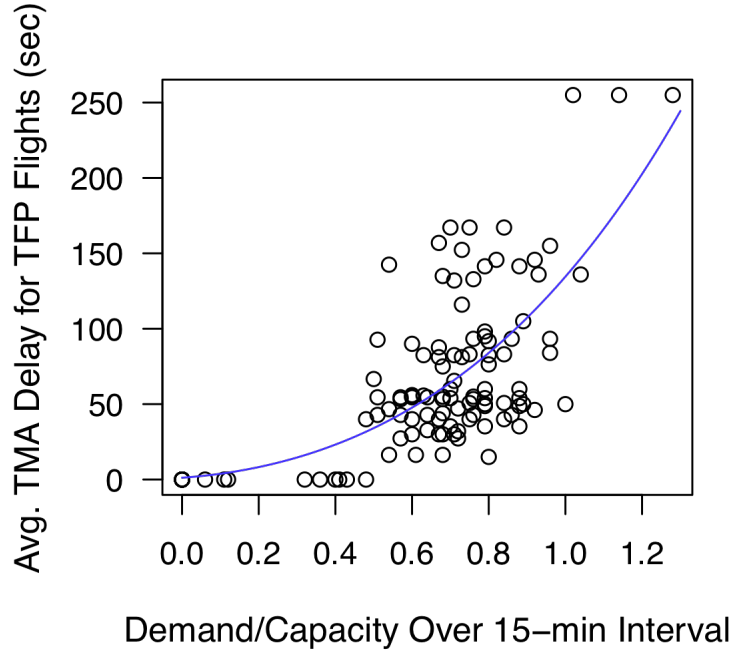

Figure 9. The average TMA delay assigned to a TFP-impacted flight in a 15-min interval versus the airport demand divided by the airport capacity for the simulated results (open circles) and the model estimated delays (solid blue curve).

Table 5. Parameter estimates for model designed to estimate the average TMA delay experienced by a TFP-impacted flight.

Parameter	Parameter Estimate	Standard Deviation	Prob > |T|
β_0	-159.2	35.3	< 0.001
β_1	-142.3	65.3	0.031
β_2	160.4	38.4	< 0.001

D. Delay Variations with TFP Flow Rate

Previous results in this section assumed a constant TFP flow rate of 54 aircraft per hour, which was the original flow rate prescribed by the FAA for this study. Unfortunately, the results in the previous sections clearly illustrate that with this flow rate the TFP impacted flights receive considerably more delay than the flights that were exempt from the TFP. To determine the "best" flow rate to use for a given airport configuration, the TFP was subsequently remodeled with flow rates of 56, 60, 64, 72, 80 and 100 aircraft per hour. Using the CTAs and CTDs associated with these six alternative flow rates, an additional ten, ten-hour fast time simulations were conducted with ATL operating in a 3_WEST_VMC configuration with an airport arrival rate of 126 aircraft per hour and in a

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2_WEST_VMC configuration with an airport arrival rate of 96 aircraft per hour. The results of these simulations are shown in Fig. 10.

In Fig. 10a, the mean flight delays are plotted as a function of the TFP flow rate for the TFP impacted flights (solid black line) and the flights exempt from the TFP (dashed green line). The mean delays for the flights exempt from the TFP, which are due entirely to the TMA, are shown to vary between 6.5 min and 10.4 min and they are only weakly correlated to the TFP flow rate. In contrast, the mean delays for the TFP impacted flights are strongly correlated with the TFP flow rates, and these delays are shown to decrease rapidly from 31.0 min per flight to 2.8 min per flight as the TFP flow rate is increased. Based on visual inspection of Fig. 10a, the "best" TFP flow rate to select when ATL is operating in the 3_WEST_VMC configuration with an airport arrival rate of 126 aircraft per hour is 60 aircraft per hour. Here the term "best" is used to indicate a TFP flow rate, which results in nearly equal mean flight delays for the flights impacted by the TFP and exempt from the TFP.

Variations in the mean flight delays with TFP flow rate when ATL is operating in a 2_WEST_VMC configuration with an airport acceptance rate of 96 aircraft per hour are presented in Fig. 10b. The general trends for this airport configuration are similar to those previously discussed in conjunction with Fig. 10a. The most notable differences between Figs. 10a and 10b pertain to the magnitude of the mean flight delays and the location of the "best" TFP flow rate. As illustrated in Fig. 10b, the "best" flow rate for the 2_WEST_VMC configuration increases slightly to approximately 70 aircraft per hour, which corresponds to the point at which the black (TFP flight delays) and dashed green (TFP exempt flight delays) curves intersect. These results indicate that TFP flow rates should be selected to coincide with the predicted airport configuration and capacity, since overly restrictive TFP flow rates (i.e., unnecessarily low TFP flow rates) can lead to significant levels of imbalance between the mean flight delays experienced by the flights included and exempt from the TFP.

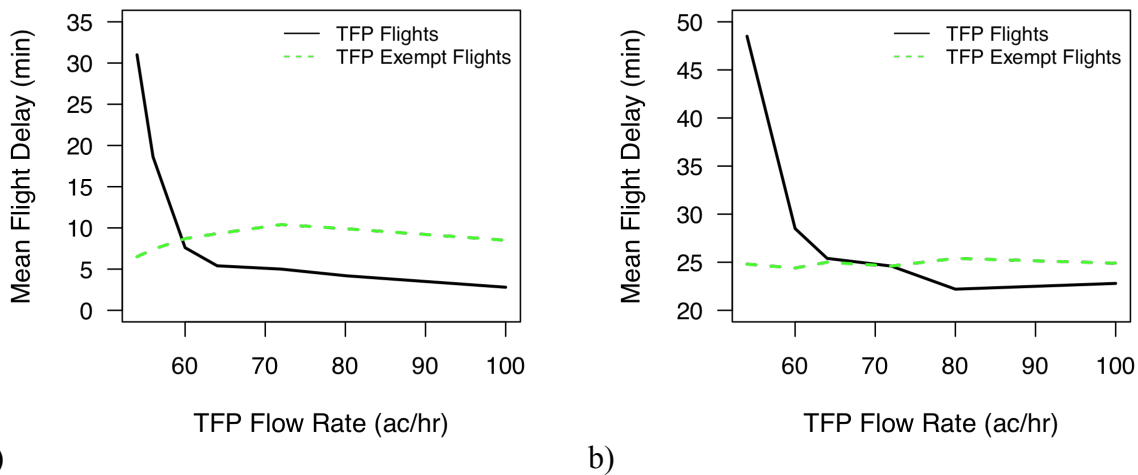a)   b)

Figure 10.   Mean flight delay in minutes versus the TFP flow rate in aircraft per hour when the configuration of ATL is a) 3_West_VMC with an airport acceptance rate of 126 aircraft/hr and b) 2_WEST_VMC with an airport acceptance rate of 96 aircraft/hr.

V.   Conclusions

Starting in 2010, the FAA began using a new traffic management initiative, which is referred to as a Traffic Management Advisor Flow Program, to reduce the demand of flights destined for a capacity limited airport by assigning pre-departure delays to these flights. Here the flights controlled by the Traffic Management Advisor Flow Program depart from outside of the Traffic Management Advisor scheduling horizon, which typically extends about 200 nmi from the airport. The final sequencing and scheduling of the arrivals within approximately 200 nmi of the airport is accomplished completely independently by the Traffic Management Advisor. This study is designed to explore through fast-time simulations the impact that Traffic Management Advisor Flow Programs have on arrival operations with an emphasis on identifying situations in which flights receive multiple uncoordinated delays, as a result of being controlled first by the Traffic Management Advisor Flow Program and subsequently by the Traffic

Management Advisor. Using an operationally proposed Traffic Management Advisor Flow Program scenario and historical flight schedules, sixteen scenarios were developed in which flights arriving into the Hartsfield-Jackson Atlanta International Airport were first assigned delays by the Traffic Management Advisor Flow Program and subsequently assigned delays subject to meter fix, runway, airport, gate, and wake vortex separation constraints by the Traffic Management Advisor.

For the scenarios considered, between 34% and 47% of the 884 arrival flights over a ten-hour planning horizon experienced both delays from the Traffic Management Advisor Flow Program and delays from the Traffic Management Advisor. When the airport was operating near maximum capacity (126 arrivals per hour), the mean total delay assigned to these "double delayed" flights was 31.6 minutes. However, the mean total delay for these flights increased to over 49.3 minutes when the airport capacity was reduced to 96 aircraft per hour. In contrast, for the 408 arrivals that were exempt from the Traffic Management Advisor Flow Program the mean Traffic Management Advisor delay was found to increase from 6.5 minutes when the airport was operating at an acceptance rate of 126 aircraft per hour to 24.8 minutes when the capacity reduced to 96 aircraft per hour. The experiments clearly illustrated an imbalance in the distribution of delays assigned to the flights included and exempt from the Traffic Management Advisor Flow Program.

A nonlinear model was developed to estimate the amount of Traffic Management Advisor delay that the Traffic Management Advisor Flow Program impacted flights would likely experience upon arriving at the airport. The model relates the Traffic Management Advisor delay to the congestion being experienced at the airport, as measured by the arrival demand to capacity ratio. The coefficient of determination, R^2, for this model was 0.52. The model captures the major delay trends that were observed in the simulations that were (1) the Traffic Management Advisor delays are nearly zero when the airport is operating below 50% of capacity and (2) the Traffic Management Advisor delays increase rapidly as the demand-to-capacity ratio exceeds one. This new model may be useful to airline operators as they calculate revised estimated times of arrival for flights impacted by Traffic Management Advisor Flow Program.

Lastly, in an effort to determine the "best" flow rate to use for a given airport configuration, the Traffic Management Advisor Flow Program was remodeled with flow rates of 56, 60, 64, 72, 80 and 100 aircraft per hour. Using the controlled times of arrival and departure associated with these six alternative flow rates, twelve, ten-hour fast time simulations were conducted with ATL operating in a three runways, west-flow configuration with an airport arrival rate of 126 aircraft per hour and in a two runway, west flow configuration with an airport arrival rate of 96 aircraft per hour. The "best" Traffic Management Advisor Flow Program flow rate was found to increase from 60 aircraft per hour to 70 aircraft per hour as the airport configuration changed from a three-runway to two-runway configuration. These results clearly illustrate the need to coordinate the parameters used in developing the Traffic Management Advisor Flow program with the Traffic Management Advisor, since overly restrictive Traffic Management Advisor Flow Programs can lead to significant levels of imbalance in the mean flight delays experienced by flights included and exempted from Traffic Management Advisor Flow Programs.

Acknowledgments

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