MODELING THE OPERATIONAL IMPACT OF AIR TRAFFIC CONTROL AUTOMATION TOOLS:

A Case Study of Traffic Management Advisor

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Abstract— **Traffic Management Advisor (TMA) is a decision support tool developed to assist Traffic Management Units (TMU) in metering and sequencing arrival traffic. This study examines the use and impact of TMA during its early stages of deployment at Chicago Center (ZAU). Determining impacts of use presents a methodological challenge because usage may depend on weather and traffic conditions, possibly leading to spurious results if simple with/without comparisons are made. In an effort to isolate the impact of TMA, this study therefore employs an alternate method. A preliminary understanding of TMA use is established through summary statistics. This enables the development and use of detailed statistical models to isolate the impact of TMA at ZAU. We find evidence through these detailed models that TMA use increased capacity in specific conditions and capacity variability was reduced in all scenarios. A simulation of these results on delay at Chicago O'Hare International Airport (ORD) showed that TMA use can decrease delay by 33%.**

Keywords: Air Traffic Management, Capacity, Traffic Management Advisor

I. INTRODUCTION

The Federal Aviation Administration (FAA) developed the Free Flight Phase 1 (FFP1) program with the goal of automating certain functions of air traffic control to improve performance of the National Airspace System (NAS). The FFP1 program established metrics used to evaluate system deployments, which assisted the FAA in performing tests and evaluations before undertaking widespread deployment of the tools. Tools analyzed in recent years include User Request Evaluation Tool (URET) and Traffic Management Advisor (TMA), which is the focus of this paper. TMA is part of a suite of tools that was planned to increase the efficiency of flight operations in all five domains of the NAS [1].

As discussed by Hansen [2], air traffic control system evaluations present a unique challenge. Because the NAS is affected by many diverse factors, such as weather and demand, isolating the impact of a specific air traffic control enhancement is complicated. The challenge is even more difficult during early stages of deployment when the tool is used only in selected time periods, which may be different from non-use periods in some systematic ways. In this study, to isolate the impact of TMA on airport operational capacity, we extend an econometric modeling method developed in [3] that considers capacity as a random variable. Our work contributes to the development of consistent and credible evaluation methods for automation tools, which will become increasingly important as NAS modernization proceeds.

Section II of this paper provides background on TMA, describes its functionality, and discusses previous benefit studies. Section III introduces summary statistics to aid in understanding how TMA is used, and describes the data used in the analysis. Section IV defines an econometric model used to determine the impacts of TMA implementation and presents estimation results. Section V isolates the capacity and variance of capacity effects of TMA to determine a change in delay from TMA use. Section VI concludes the research with discussion and recommendations.

II. TMA BACKGROUND

The role of TMA is to coordinate the transition between center and control airspace for arrivals. TMA was designed for decision support for the metering position of the Traffic Management Coordinators (TMC). However, as discussed by Bolic [4], the adaptation, or actual use instead of intended use, of systems developed for air traffic controllers (ATC) and traffic management coordinators (TMC) often diverges from the intended purpose. For example, at Los Angeles center, TMA was initially used to display traffic in a larger area than was previously available [2]. This increased "shared situational awareness" generated considerable operational benefit even when the decision support functionality was not in use.

TMA began initial daily use (IDU) at ZAU in June 2005. Adaptation also took place at ZAU, as TMA was used exclusively to facilitate the release of internal departures – those bound for an airport within the same Air Route Traffic Control Center (ARTCC) airspace. The TMA display screen is well suited to this function because of a detailed arrival

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schedule for the major airports in the Chicago TRACON—ORD and Chicago Midway.

Implementation at ZAU followed the successful implementation of TMA at eight ARTCCs, with the first implementation in 1996 at Fort Worth. Later implementations were supported by studies finding benefits from TMA implementations at Fort Worth and other centers. These benefit studies relied on before and after analysis, including summary statistics and regression modeling. Two examples of such studies are below.

A. TMA at Minneapolis Center (ZMP)

Through a comparative analysis of airport acceptance rates (AAR) before and after TMA deployment, the FFP1 program office determined that TMA increased AAR at ZMP. A regression analysis was then performed to isolate the impact of TMA. By defining AAR as a function of TMA, metrological condition, and runway interaction, it was found that the increase in the AAR mean was not statistically significant. This regression treated TMA as a dummy variable which was set to 1 to signify a time period after TMA was deployed.

A similar study was performed regarding the total operations rate, or the sum of the airport acceptance and airport departure rates. This analysis found a statistically significant increase in the operations rate after TMA was deployed. It was concluded that optimized arrivals flows under TMA allowed the controllers to release more aircraft [5].

B. TMA at Los Angeles Center (ZLA)

The impact of TMA on internal release departures to LAX from other airports within ZLA was examined after the June 2001 TMA implementation. Similar to ZAU, TMA allowed the Traffic Management Unit (TMU) at ZLA to optimize the release of these departures by fitting them in to the arrival stream without causing delays. By calculating the mean delay before and after the deployment of TMA, it was found that both gate and airborne delay decreased after TMA deployment. It was concluded that because other airports experienced increases in gate and airborne delay for the same time period, TMA was able to reduce delay at LAX [6]. This study did not include a regression analysis and did not consider other factors which could have contributed to a decrease in delay, such as changes in demand.

III. EXPLORATORY TMA ANALYSIS

For the purpose of modeling the impact of TMA on airport runway capacity, the operational impact at Chicago O'Hare International Airport (ORD) was chosen for case study. Data were collected for the study period of July 2005, immediately after IDU of TMA, to mid-March 2006.[1] Data were gathered from the FAA's Aviation System Performance Metrics (ASPM) database. The "Airport Efficiency" portion of this database provides variables on quarterly-hour arrival and departure count and "demand" at ORD, which will be explored in greater detail in Section IV. Each entry includes corresponding information about the meteorological condition (MC), other weather related information, and runway configuration.

[1] The period from December 19 to 25 was excluded, because schedules and operations are substantially changed by large volumes of holiday travel.

A TMA usage log was collected from ZAU to match the periods in ASPM with the periods when TMA was explicitly being used by the TMCs. During the study period, TMA was powered on and available for use from 6AM to 8PM daily. However, TMA was referred to sporadically by the TMCs; the times when TMA was assisting TMCs was recorded in a usage log [7]. To combine these data with ASPM data, time stamps on each of the data sets were matched.

A. TMA Use at ZAU

The following summarizes TMA usage data with the goal of gaining a general understanding of the factors affecting use of TMA during the study period. Discussions with TMCs, managers, and consultants supporting TMA implementation at ZAU revealed the policies and procedures affecting TMA use was sporadic; therefore, this study will focus on TMA usage periods rather than before and after TMA deployment periods. To determine the best model formulation, correlations between TMA use, meteorological conditions, and runway configuration are explored.

1) Meteorological Conditions

Table I summarizes TMA use in terms of visibility conditions at ORD. The three meteorological conditions classified are visual meteorological conditions (VMC), marginal visual meteorological conditions (MVMC), and instrumental meteorological conditions (IMC) [8]. Each quarter-hour data entry in ASPM is identified as either VMC or IMC. We further subdivided VMC into MVMC and "full" VMC, based on visibility criteria defined in [8].

TABLE I. CEILING AND VISIBILITY AVERAGES, BY METEOROLOGICAL CONDITIONS AND TMA USE

	IMC		MVMC		VMC	
	OFF	ON	OFF	ON	OFF	ON
Celiling (100's Ft)	8.95	16.02	19.96	27.64	12.92	13.2
Visibility (statute mi)	3.14	2.06	7.93	7.94	9.57	9.71
no of obs. with TMA	54		165		1254	
total no of obs.	1694		2445		19362	

From Table I it can be seen that during the study period there were very few observations of TMA use under IMC. Out of the 1473 periods that TMA was used, only 3.67% (54 periods) were during IMC. For those few periods when TMA was used during IMC, it was typically during high ceiling conditions. The average ceiling condition under IMC and TMA use was almost double that of the average ceiling condition under IMC with no TMA use. Conditions under MVMC and VMC when TMA was and was not in use are more similar, although under MVMC the ceiling is considerably higher when TMA is in use.

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2) Runway Configurations

Chicago O'Hare International Airport has 6 active runways in 3 pairs of parallel runways. There are a number of possible runway configurations at ORD for arrivals and departures that can be used at any given time. The five most frequently used runway configurations for arrivals and departures are shown Table II, along with the proportion of time each is used and proportion of TMA use. The configuration 4R, 9L, 9R | 4L, 9L, 32L, 32R is known as the default configuration for VMC and MVMC.

TABLE II. FIVE MOST COMMON RUNWAY CONFIGURATIONS AT ORD

Configuration	% of Periods Configuration Used	% of periods TMA Used
22R, 27L, 27R | 22L, 32L, 32R	40.19	6.64
4R, 9L, 9R | 4L, 9L, 32L, 32R	36.22	6.95
22R, 27L | 22L, 32L, 32R	6.96	10.49
14R, 22L, 22R | 9L, 22L, 27L	13.07	3.39
9R, 14L, 14R | 4L, 9L, 22L	3.56	1.61

During the study period, TMA was "certified" on two runway configurations: 22R, 27L, 27R | 22L, 32L, 32R and 4R, 9L, 9R | 4L, 9L, 32L, 32R (referred to as configuration 1 and 2, respectively). This means that for these configurations TMA predicts the time when flights reach ORD entry fixes with sufficient accuracy. TMA was most likely used for these configurations and for 22R, 27L | 22L, 32L, 32R. This two arrival runway configuration was favored for two possible reasons. First it is very similar to the certified configuration 1. Second, TMCs noted that TMA did not "recognize" the third runway in configuration 22R, 27L, 27R | 22L, 32L, 32R when scheduling internal departures, a problem that did not arise when just two arrival runways were in use.

IV. ECONOMETRIC MODELING OF CAPACITY UNDER TMA

The following section introduces the econometric modeling technique used to model and determine the impact of TMA on operational capacity at ORD. This technique is based on the model developed by Hansen [3] to determine the capacity impact of new runway development.

A. Count and Demand Data Analysis

To accurately determine the capacity impact of TMA, the operations rate (operation count per unit time) is compared with operation demand per unit time. The data are divided into two groups based on TMA use; data for periods when TMA was in use are separated from data collected when TMA was not in use.

Data from ASPM were used for this analysis. The variable arrival (departure) count in the ASPM database indicates the number of arrivals (departures) in a time period (defined as a 15 minute interval). The variable arrival (departure) demand represents the number of aircraft scheduled to arrive (depart) in a specific time period. While demand for an operation often leads to that operation occurring, scenarios exist where the arrival (departure) demand exceeds the arrival (departure) capacity, or the maximum number of aircraft that can perform the operation in a given period. In this case, some aircraft will be queued. Aircraft counting toward the demand in a given period that do not actually arrive (depart) in that period are counted toward demand in the subsequent period. Thus the difference between count and demand in a given period is essentially the size of the queue at the end of that period.

To measure demand, ASPM determines the expected arrival time of an aircraft by adding the en-route time to the wheels-off time. An arrival in a time period before the calculated time is counted towards the demand in the earlier period in which it arrives; an arrival at the calculated time is counted toward the demand for that period; and an arrival after the calculated time is counted toward the demand in all time periods between the calculated arrival and the actual arrival time. Departure demand is calculated similarly, based on the actual pushback time plus an airport-specific unimpeded taxi time, or when a flight is subject to a ground delay program (GDP), the estimated time when the flight will be cleared for departure under the GDP.

The model developed for this study will use the data to determine the change in capacity for arrivals only due to TMA use. A model is constructed which treats capacity as a random variable, by calculating capacity as a function whose distribution depends on weather, runway configuration, demand, and TMA use. This methodology uses statistical procedures that estimate the relationship between these factors and capacity.

To isolate the impact of TMA, the capacity function includes a dummy variable which is set to 1 if TMA is in use in time period t, and it is set to zero otherwise. The parameter of primary importance is the coefficient on the dummy variable representing TMA use. This parameter is the contribution to capacity of TMA. If the coefficient is negative, it can be concluded that TMA reduces capacity; if it is positive, it can be concluded that TMA increases capacity. This coefficient for operation type *O* (where *O*= arrivals only for this study) will be termed β_0.

The example in Fig. 1 depicts β_0. The solid curve is a sample probability distribution of runway capacity. The second dashed curve is a sample probability distribution for runway capacity when TMA is in use, but when other conditions (weather, etc.) are similar. The difference in the mean values of these curves, represented by the curve peaks, is β_0. Fig. 1 depicts a case when TMA use affects only the mean of the capacity distribution. TMA use may also affect the variance of the capacity distribution by consistently feeding traffic to the airport at a more consistent rate. Both effects are considered below in section B.

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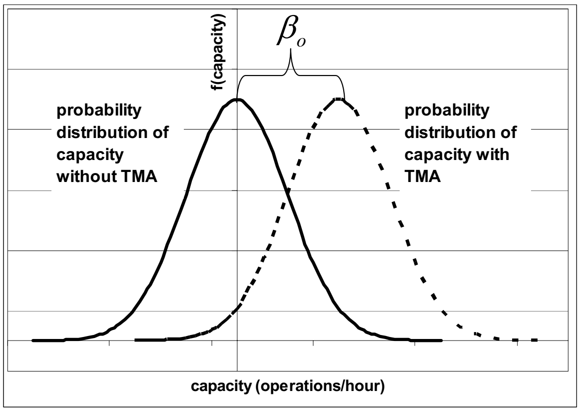

Figure 1. Depiction of β_0, the contribution of TMA to capacity.

B. Operational Impact: Censored Regression Model

The model to be used in this section is a censored regression, or tobit, model, which measures the difference in capacity due to TMA use. A censored regression model is appropriate because it is impossible for a count value to exceed a demand value. Throughput, or runway operations per unit time, is therefore censored by demand.

The tobit model formulation is below. The model will calculate the capacity based on the known operation demand and the known operation count. To isolate the impact of runway configuration and meteorological condition, there are separate models for each configuration and condition. We estimated the model for 4 different data sets. Models were estimated for VMC and MVMC and for runway configurations 1 (22R, 27L, 27R | 22L, 32L, 32R) and 2 (4R, 9L, 9R | 4L, 9L, 32L, 32R). Each model considers capacity as a function of demand, windspeed, and TMA use. Each model also captures the variance of capacity, and analyzes the impact of TMA on this variance.

The model specification is below.

$$\begin{aligned} Q_o(t) &= \min(D_o(t), C_o(t)) \\ C_o(t) &= \alpha_o + \beta_o A(t) + \gamma_o W(t) + \tau_o D_o(t) + \varepsilon_o \end{aligned} \tag{1}$$

Where:

$Q_o(t)$	is the count for operation of type o (either arrivals or departures) in 15-minute time period t;
$D_o(t)$	is the demand for operations of type o in time period t;
$C_o(t)$	is the ORD capacity for operations of type o in time period t;
$A(t)$	is equal to 1 if TMA is in use in time period t and 0 otherwise;
$W(t)$	is the windspeed in time period t;
ε_o	is a stochastic error term, assumed to be IID normal with mean 0 and variance $\sigma_o^2 + \rho_o A(t)$;
$\alpha_o, \beta_o, \gamma_o, \tau_o, \sigma_0^2, \rho_o$	are parameters to be estimated.

The model is estimated using a maximum likelihood method, which will find the parameters that best fit the data. Mainly, we are interested in β_0 and ρ_0, the effects of TMA on the mean and the variance of the capacity distribution. The detailed model estimation technique is discussed in great depth by Hansen [3].

1) Illustration of Censored Regression Model Results

For illustrative purposes, the full model results for one data set will be described in detail. We chose the model for VMC conditions and runway configuration 1 for this illustration. Estimation results appear in Table III.

TABLE III. CENSORED REGRESSION MODEL RESULTS

Parameter	Symbol	Estimate (Standard Error) T-Statistic
Intercept	α_o	**26.164** **(0.333)** **78.517**
Effect of TMA on capacity	β_o	**1.720** **(0.412)** **4.17214**
Effect of Windspeed	γ_o	**-0.201** **(0.026)** **-7.797**
Effect of Demand	τ_o	0.000 (0.000) -0.055
Variance	σ_0^2	**5.994** **(0.101)** **59.338**
Effect of TMA on Capacity Variance	ρ_o	**-1.267** **(0.310)** **-4.089**

The model results show that the baseline quarter-hour capacity for arrivals at ORD is 26.164 arrivals, which is the equivalent of 104.656 arrivals per hour. This is very close to the benchmarked 100 arrivals per hour determined by the FAA [9]. The results also show that when TMA is being used by the TMCs, arrival capacity is increased by 1.720 arrivals per quarter hour, or 6.880 arrivals per hour. This is equivalent to a 6.6% capacity increase. The results show that windspeed decreases arrival capacity by -.201 arrivals per quarter hour, and that demand has no impact on capacity. The estimated variance is 5.994 arrivals per quarter hour squared, which is decreased by -1.267 when TMA is in use. All parameters except demand are significant at the 0.05 level (denoted by the boldface type).

2) Model Results for the Impact of TMA on Arrival Capacity and Variance of Capacity

The impact of TMA on the capacity mean, measured by β_0, and capacity variance, ρ_0, for the four sets of MC and runway configuration are shown in Table IV.

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TABLE IV. THE EFFECT OF TMA ON CAPACITY MEAN AND CAPACITY VARIANCE

MC & RW Configuration	β_o Values (Standard Error) T-Statistic	ρ_o Values (Standard Error) T-Statistic
VMC, RW 1	**1.720** **(0.412)** **4.172**	**-1.267** **(0.310)** **-2.976**
VMC, RW 2	.302 (.357) .846	**-1.892** **(.345)** **-5.479**
MVMC, RW 1	.822 (.914) .899	**-1.554** **(.642)** **-2.420**
MVMC, RW 2	-1.318 (.961) -1.372	**-1.784** **(.718)** **-2.485**

The β_0 values are not significant in three of four meteorological conditions and runway configuration cases. Under VMC and runway configuration 1, capacity mean is significantly higher due to TMA. There is a possible "self-selection" bias in this case because it represents favorable conditions, which could encourage TMA use.

The ρ_0 values indicate the estimated change in capacity variance when TMA is in use. The results suggest that arrival capacity variance did decline when TMA was in use. We also note that these results are consistent with the FFP1 LAX study [6], which found less dispersion between arrival counts and throughput after TMA was implemented.

If TMA usage at ZAU did in fact reduce arrival capacity variance, this would have an important benefit. It would reduce delay, because a negative capacity deviation is more likely to have an adverse effect than is positive deviation to have a beneficial effect. In many cases, positive deviations cannot be fully exploited because there is insufficient demand. While a negative deviation can also be inconsequential, it is more likely to contribute to a queue going into the next period.

The following section explores how the use of TMA can affect delay due to its capacity and variance impacts.

V. DELAY IMPACT ESTIMATION

To illustrate the potential of TMA use to save minutes of flight delay, a simulation was employed. The operational count if TMA was in use 100% of the time was simulated and compared with operational count if TMA had never been in use during the study period. To further isolate the capacity and variance effects of TMA, two potential operational count scenarios were calculated: one with the capacity effect of TMA calculated alone (ρ_0=0), and another with both the capacity and capacity variance effect. Operational demand was kept constant over all scenarios to fully illustrate the delay changes due to TMA.

A. Delay Calcuation without TMA

Using demand and count data for all quarter hour periods at ORD collected for January 2006, a cumulative count curve was constructed. A cumulative curve in this case is a plot of cumulative operational count on the y-axis and time on the x-axis. In the first period, cumulative operational count (n_1) is equal to the count of operations in period one (n_1'). In the second period, cumulative operational count (n_2) is the count in period two (n_2'), plus the count in period one (n_1'). Therefore the cumulative operational count in period two is n_2=n_1+n_2'. The count in period three is n_3=n_2+ n_3', and so on for all remaining periods. Cumulative demand is determined similarly.

The horizontal distance between any two points on the curves is equal to the wait time in queue that an operation (arrival) was delayed. The area between the two curves is the delay in flight-minutes for the time period of study.

To illustrate how this method can be used to determine the delay savings potential of TMA, the study period of January 6, 2006 from 13:15-21:15 was chosen. The first step was to construct the curves of cumulative demand and cumulative count in the "without TMA" scenario for this period. These curves can be seen in Fig. 2.

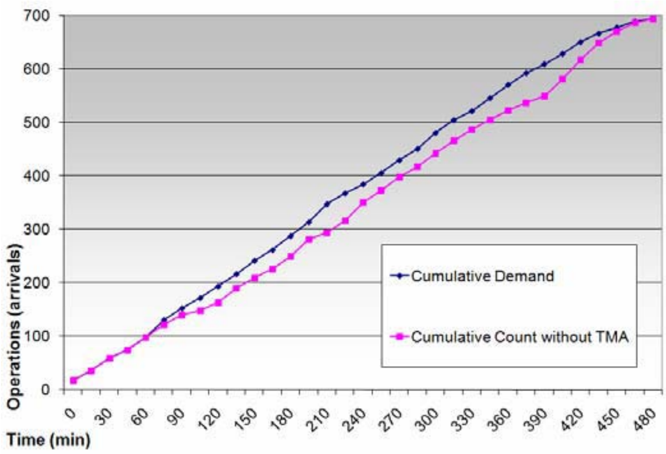

Figure 2. Cumulative Demand and Count: Without TMA Scenario

The area between the two curves, or the study period delay in flight-hours, is equal to 225.9 flight-hours.

B. Delay Calcuation with TMA

To simulate and isolate the capacity effect and the variance of capacity effect of TMA, cumulative curves were constructed for the two scenarios. The estimated parameters of the capacity function from (1) were used to calculate the new capacity. The parameters of the best fit models are in Table V.

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TABLE V. CAPACITY ESTIMATION EQUATION PARAMETERS

	Capacity Mean				Capacity Variance	
	α	β_0	γ	τ	σ^2	ρ_0
VMC, 1	26.164	1.720	-0.201	0.000	5.994	-1.267
VMC, 2	21.696	0.302	0.114	0.112	6.333	-1.892
MVMC, 1	28.151	0.822	-0.560	-0.021	6.028	-1.554
MVMC, 2	25.949	-1.318	-0.126	-0.054	5.740	-1.784

The following sections describe how the capacity effect and the variance of capacity effect were determined.

1) Simulation of TMA Capacity Effect

To isolate the effect on capacity of TMA, capacity was calculated as a function of the parameters in Table V depending on the MC and runway configuration. Capacity in each period was assumed to be normally distributed with mean

$$\mu_C = \alpha 0 + \beta_0 A(t) + \gamma_0 W(t) + \tau_0 D_0(t) \quad (2)$$

and variance $\sigma^2 + \rho_0$, where $\rho_0 = 0$. Capacities for each quarter hour period in the study period were then drawn from this distribution. Next, as in (1), the operational count was calculated as the minimum of the capacity and the operational demand. The unserved operations in any period were added to the operational demand of the next period.

The simulated cumulative operational count curve represents the operational count that would have been achieved if TMA was in use during the entire study period, but only the capacity effect of TMA was realized. The cumulative count of operations with the TMA capacity effect is shown below in Fig. 3, along with the cumulative count without TMA and the cumulative demand.

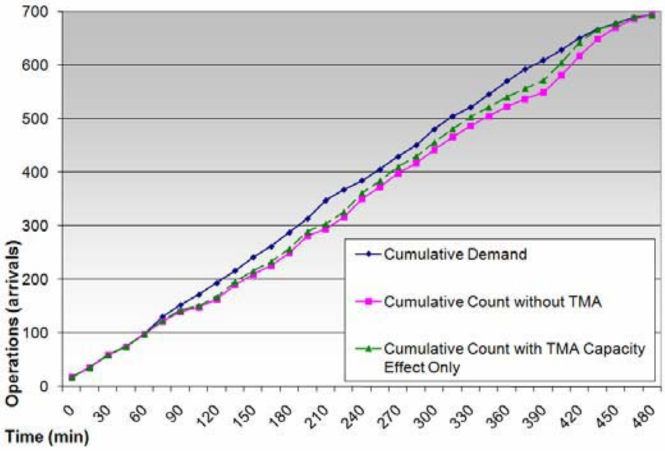

Figure 3. Cumulative Demand and Count: TMA Capacity Effect Only Scenario

The delay calculated for the TMA capacity effect only scenario was 147.7 flight-hours which is a delay savings of 78.1 flight-hours over the scenario when TMA is never in use.

2) Simulation of TMA Variance of Capacity Effect

To simulate the variance of capacity effect, the capacity effect along with the variance of capacity effect was calculated. The same method was used as for the TMA capacity effect only scenario. Capacity was assumed to be normally distributed with mean μ_C and variance $\sigma^2 + \rho_0$, where ρ_0 is the associated value for each MC and runway configuration from Table V. The cumulative operational count for the TMA capacity and capacity variance scenario can be seen in Fig. 4.

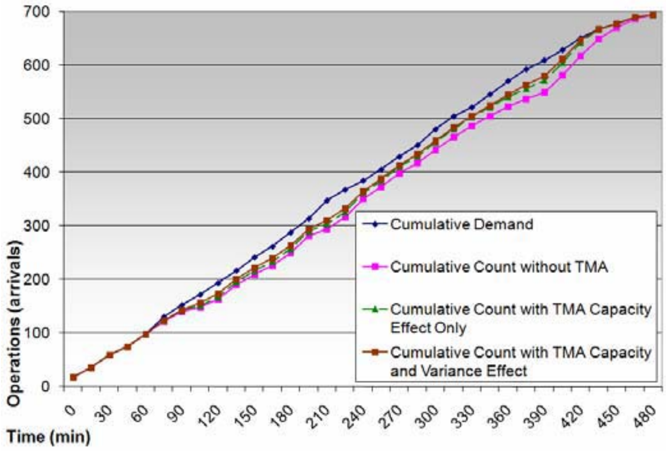

Figure 4. Cumulative Demand and Count: TMA Capacity Variance Effect

The delay for the TMA capacity and capacity variance effect was 121.0 flight-hours, which is a savings of 26.7 flight-hours as compared with the TMA capacity effect only scenario and an overall delay savings of 104.9 flight-hours.

Using the same method for the entire month of January 2006, if TMA had been in use 100% of the time, TMA would have saved 750 flight-hours of delay for arrivals compared to the "without TMA" scenario. Of these 750 flight-hours, 500 flight-hours of savings were due to capacity effect, and 250 flight-hours of savings were due to variance effect. This finding generalizes to a savings in delay of 9,000 flight-hours per year and about 10 seconds per flight.

VI. CONCLUSIONS

This study found that the use of TMA for releasing internal departures appears to have decreased capacity variance and in some cases increased capacity mean. Using the model results, it was found that increased use of TMA could lead to decreased delay of about 10 seconds per flight.

Additionally, we have furthered the use of censored regression applied to ASPM data as an evaluation method for ATM tools. In particular, we have shown how this method can be used to investigate the effect of new tools on the variance of capacity as well as its mean. In our particular case, we find that TMA use, even though it was restricted to releasing internal departures, had a measurable impact on arrival capacity variance at ORD.

Further study is necessary to assess the impact of TMA when it is used for time based metering. Time based metering went into effect in June 2007 at ZAU, and could decrease the variance in capacity by allowing controllers to effectively

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manage capacity especially during high traffic periods. Understanding the impact of TMA on capacity and capacity variance due to time based metering, and comparing these findings with those in this study, would provide insight into the benefits of TMA when it is employed for its full range of uses rather than used only for more limited, adapted purposed.

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