Modeling ATM Automation Metering Conformance Benefits

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Air traffic controllers deviate flights from the user's preferred trajectory, to avert impending traffic conflicts and conform to flow-rate restrictions. The efficiency and effectiveness of such controller deviations directly affect controller workload and user costs (fuel and time). New Air Traffic Management (ATM) Decision Support Technologies have the potential to reduce unnecessary deviations and improve the efficiency with which necessary deviations are implemented. A model of ATM operations has been developed to evaluate the number and cost of en route ATM deviations due to separation assurance and metering conformance. The model evaluates the benefits of alternate decision support technologies based on their ability to accurately predict flight trajectories and support useful clearance decisions. This paper introduces a methodology for modeling arrival-metering conformance and discusses important linkages with a related methodology for modeling separation assurance. An example application is presented based on a traffic simulation of en route/transition airspace arrival delays. Input parameters of ATM delay absorption strategy, implementation accuracy of the chosen strategy, and time horizon are chosen to represent both current (Free Flight Phase 1) and future ATM automation (Center TRACON Automation System En route Descent Advisor) operations. The automation is shown to result in more fuel-efficient metering conformance ATM interruptions.

Air traffic controllers must occasionally interrupt flights (deviations from the user's preferred trajectory) to avert traffic conflicts and manage downstream airspace congestion. The large number of interruptions associated with current air traffic operations have led airspace users to strongly advocate for industry initiatives such as Free Flight [1-2]. Strong international efforts are underway to develop and deploy new Air Traffic Management (ATM) Decision Support Tools (DSTs) to assist controllers in reducing the frequency and impact of ATM-based interruptions.

It is critical to consider flow-rate or metering restrictions as well as conflicts in aircraft separation. The benefits associated with a focus on separation alone are unrealistic in that many ATM interruptions are due to dynamic capacity overloads that result in flight delays independent of conflict occurrences. The benefit of reductions in conflict deviations and route restrictions for any one flight will be negated if downstream congestion forces the flight to be delayed anyway. A hybrid approach is needed to model the impact of, and interactions between, ATM interruptions for conflicts and flow-rate restrictions due to congestion

Such a methodology has been developed to quantify the benefits of reduced and more efficient ATM flight interruptions. Prior work documented the application of this methodology to the modeling of conflict deviations for separation assurance [3]. The focus of this paper is to introduce the application of this methodology to the modeling of controller conformance to metering restrictions due to downstream congestion. Important linkages between the integration of metering conformance and separation assurance functions are also discussed.

An example analysis is presented to illustrate the benefit potential of advanced en route DST capabilities for managing en route traffic in a high-density extended terminal area. Results are presented comparing metering conformance ATM interruption costs for a baseline and advanced DST case. The baseline loosely represents the operations associated with Free Flight Phase 1 (FFP1) conflict probe and arrival metering consisting of the User Request

Evaluation Tool Core Capabilities Limited Deployment (URET CCLD) [4], and the Center-TRACON Automation System (CTAS) Traffic Management Advisor (TMA) [5]. An advanced DST case represents future operations employing the CTAS En Route Descent Advisor (EDA) integrated with TMA [6].

The remainder of this paper discusses the metering conformance ATM interruptions modeling approach and illustrative example. Section 1 describes the overall ATM Interruptions Model methodology, including key model components. Section 2 presents the example application of the model to realistic ATM cases. Assumed input parameters, estimated ATM Interruptions savings, and extrapolation of single-day, single-airspace simulation results to annual benefits at candidate deployment regions, are discussed. Section 3 offers closing remarks.

ATM INTERRUPTIONS MODEL

The ATM Interruptions Model is shown conceptually in Figure 1.

The focus of this paper is on the metering conformance model components illustrated in Figure 1. Initially a set of air-traffic "demand" trajectories (including arrival, departure, and overflight traffic) are simulated for a typical day within a block of en route airspace. This airspace simulation generates a set of four-dimensional (4D) "undelayed" trajectories, representing what each flight would do if left alone to fly the user's preferred trajectory. These trajectories define the conflict and arrival congestion traffic scenario to be evaluated.

The Metering Conformance ATM Interruption model component begins by analyzing traffic to determine the natural sequence and level of congestion at the airport. Arrival-metering operations are modeled and Scheduled Times of Arrival (STAs) are assigned for each arrival flight. These scheduled crossing times resolve downstream airport congestion. A second set of arrival flight trajectories is then generated, incorporating delay maneuvers necessary to meet the STAs. The particular strategies used to absorb the delay depend on the ATM technology and procedures employed. The aircraft-specific strategies used and their associated interruption costs are tabulated.

The separation assurance ATM interruption modeling components initially identify and record conflicts and near-conflicts from the metered (delayed) traffic scenario (output from the metering conformance model) in a conflict-incident database. Near-conflicts are included to allow the analysis of false alerts. These incidents are then filtered through an ATM perception model to identify whether ATM would perceive the incident as a conflict requiring interruption. This perception model reflects the level of conflict probe technology in terms of trajectory prediction accuracy, time horizon, and separation criteria. As such, it can account for various combinations of DST capabilities, supporting technologies (e.g., data exchange, FMS), and controller procedures. A resolution is identified for each separation assurance ATM interruption including tabulation of daily resolution fuel costs.

Daily fuel savings of both metering conformance and separation assurance ATM interruptions are then extrapolated to annual and NAS-wide benefits.

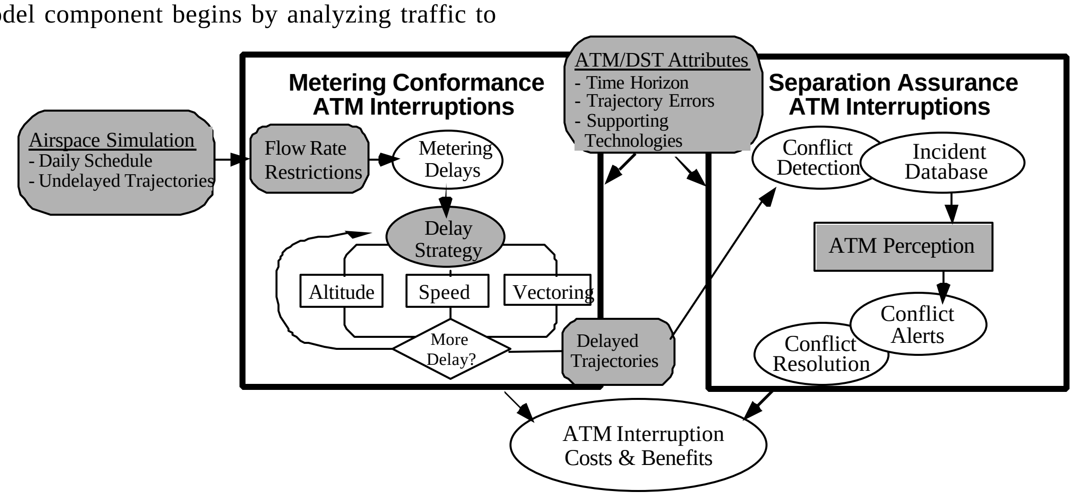


Figure 1. ATM Interruptions Model Approach

The functions of key model components are discussed below.

Airspace Simulation

In this study the Fort Worth Air Route Traffic Control Center (ZFW) airspace was analyzed, including arrival, departure, and overflight traffic operations between 40 and 250 nautical miles (nm), at or above 10,000 ft from Dallas-Fort Worth International Airport (DFW). Enhanced Traffic Management System (ETMS)-based flight trajectories for a typical day (Friday, June 14, 1996) were used to generate nominal trajectories for approximately 2,500 DFW arrivals and departures [7]. Sample-day arrival, departure and overflight operations are illustrated in profile view in Figure 2.

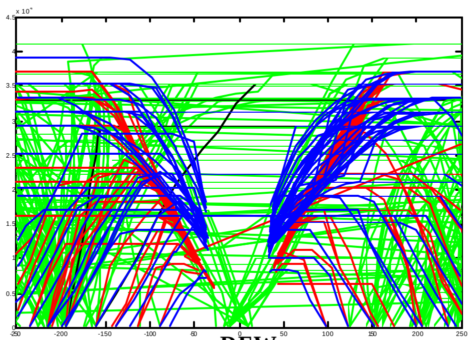


Figure 2. Profile View of DFW Study Day Operations

Standard departure and arrival routes, commonly known as Standard Instrument Departure (SID) and Standard Terminal Arrival Routes (STAR), are published procedures to aid in the coordination and routing of air traffic between Center and TRACON airspace. Aircraft typically follow SIDs and STARs to/from major airports. These routes are characterized by specific waypoints, headings, speeds, and other parameters. The modeled undelayed ZFW trajectories followed DFW SID and STAR routings, as shown in Figure 3.

Arrival Delays

During peak periods controllers meter DFW arrival flights to meet airport capacity restrictions. A simplified model of TMA metering was developed to estimate metering delays for each ZFW arrival. Meter-fix scheduled times of arrival (STAs) at the TRACON boundary, and associated delays, were based on maximum TRACON entry rates and minimum inter-arrival fix separations, as shown in Table 1.

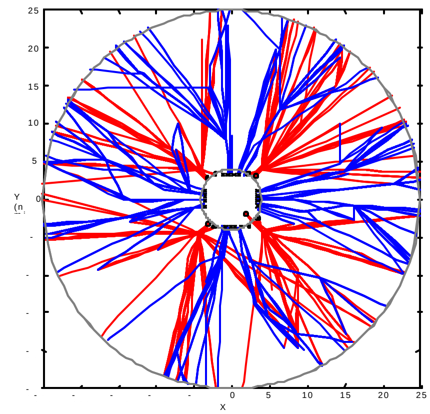


Figure 3. DFW Study Day STAR Arrival and SID Departure Operations

Table 1 DFW Scheduling Criteria

Scheduling Criteria	Assumed Value
Arrival Meter-Fix Separation	5.50 nm
TRACON Arrival Rate (4	150 ac/hr

Figure 4 shows a distribution of the arrival delays required to meet the Table 1 constraints over the course of the sample day. For reference, Figure 4 also shows overall DFW arrival throughput.

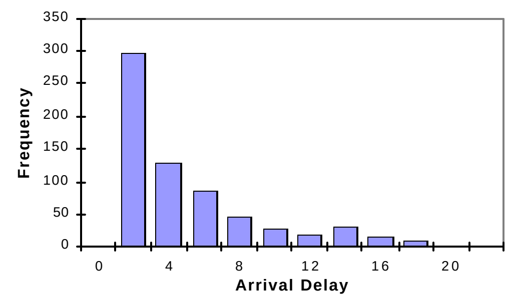
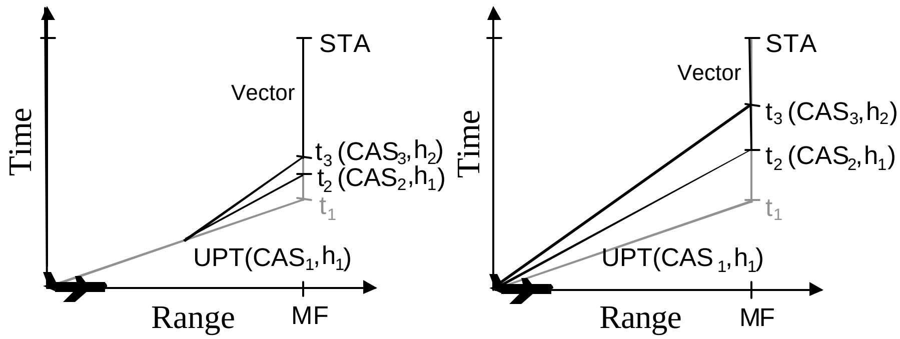


Figure 4. DFW Study Day Arrival Delays

Metering Delay Absorption

The absorption of arrival metering delay is essentially the resolution of intra-stream or metering conformance conflicts produced by traffic intending to converge on the same meter fix. Arrival metering delay was absorbed by altering the initial arrival trajectory with a combination of changes to the speed profile (cruise and descent), cruise altitude, and routing (vector/path-stretching).

Figure 5 illustrates the general methodology employed to clear an aircraft to meet an arrival fix Scheduled Time of Arrival (STA). The figure employs a strategy ordering of speed, altitude, vectoring, where the maximum amount of delay is absorbed by each method before moving onto the following method.



t_1 = User Preferred Trajectory (UPT) = Undelayed Metering Fix (MF) crossing time (CAS_1, h_1)
t_2 = Crossing time if cleared to minimum speed (CAS_2)
t_3 = Crossing time if cleared to minimum speed at a lower altitude (h_2)
t_4 = STA = crossing time if cleared to minimum speed, lower altitude, and vectored

Figure 5 En Route Arrival Delay Absorption for Different Time Horizons

Thus, the STA of Figure 5 is met by delaying the flight with a change in cruise speed (CAS_1 to CAS_2), a reduction in cruise altitude (h_1 at CAS_2 to h_2 at CAS_3), and the remaining delay absorbed with vectoring.

The effectiveness of the delay absorption model will depend on the amount of delay to be absorbed by any one flight, the time available to absorb the delay (i.e., effective time horizon), and the delay absorption strategy. For this analysis, the traffic scenario defines the flight delay (i.e., each arriving flight is subject to the same delay in the baseline and EDA cases). Differences in the delay-absorption performance of the baseline and EDA are modeled through differences in the effective time horizon and employed delay strategy.

The affect of time horizon is illustrated in Figure 5. Note that at larger time horizons (right figure), speed and altitude changes can absorb more delay. As the effective time horizon decreases (left figure), the need for more expensive vectors (path stretching) increases since the speed and altitude changes cannot absorb as much delay.

<u>Metering Conformance Methods</u>

Four possible metering conformance methods are used to alter the trajectory of particular flights so that the proper amount of delay is absorbed. The four methods are summarized below and graphically illustrated in Figure 6 (profile view) and Figure 7 (plan view):

- **Speed Control** - Reduce aircraft cruise and descent CAS speed along the initial routing and altitude profile. Chosen speeds are limited by aircraft performance-based minimum speeds and subject to ATM controller rounding/ increment limitations. In this study, the descent speed is set to essentially "balance" cruise and descent CAS speeds. The higher of cruise/descent CAS is initially decremented until both speeds are equal. Then each speed is alternately decremented. Although actual controller techniques may not be so precise, this approach conservatively represents controller actions. Reduction in speed profile results in an earlier TOD location.

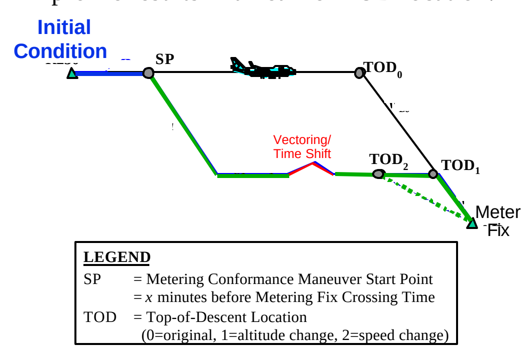


Figure 6 Metering Conformance ATM Interruption (Vertical Profile)

- **Altitude Change –** Descend and maintain a new cruise altitude (until final top of descent) down to floor of the high-altitude sector airspace (flight level (FL) 230/240). With future technology cases, speed may also be allowed to change at the new altitude, providing an optimal combined speed/altitude approach.

- **Vectoring–** Increase path length, using simple 1-sided vectors, at constant altitude and speed, up to a maximum heading change.[1] An error is imposed on the final turnback vector to reflect ATM clearance limitations that may lead to arrival fix STA deviations, as shown in Figure 7. A turnback error is modeled as a random sample from a distribution, with bounds reflecting ATM/DST accuracy.

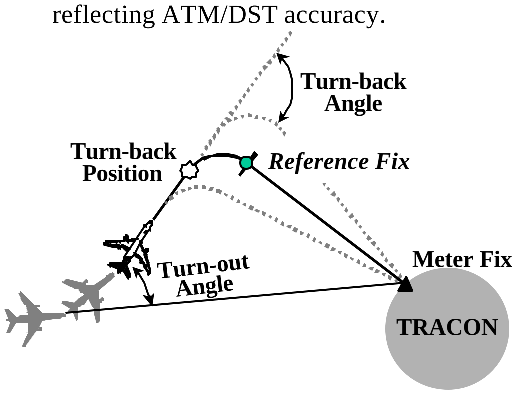


Figure 7 Modeled Vectoring Method

- **Time Shift Strategy** – A last resort method, assumes delay is absorbed in additional vectoring at cruise altitude/speed, essentially shifting metering fix crossing times to absorb any remaining delay.

A specific delay strategy is defined by the ordering of these methods in addition to time horizon and clearance accuracy parameters.

Metering Conformance Cost Model

Metering conformance ATM interruptions, which delay arrival aircraft to meet airport capacity constraints, result in both time and fuel penalties. Time costs were calculated directly from the TMA-required delay combined with FAA-based time cost rates [8]. Time costs include both crew and maintenance components which vary by aircraft type.

Fuel costs were calculated using Equation 1.

$$\text{FuelCost} = \text{Fuelburn Rate} \times \text{CruiseDist/CruiseSpeed} \quad (1)$$

Eq. (1) arrival fuelburn rates were based on high-fidelity simulations of a B737 aircraft under various conditions normalized to determine the fuelburn rate (lbs/min) at various altitudes and airspeeds [9]. Thus delay strategies that reduced speed or altitude, would employ different fuelburn rates. Vectoring or timeshift methods increased fuel costs by increasing the time (distance) spent at constant speed/altitude with its associated fuelburn rate. Additionally, the change in TOD location under modified cruise speed and the fuel impact of the vectoring turnback error were added to the delayed arrival trajectory fuel cost. The fuel impact of the new TOD location leads to additional fuel burned on the extended or reduction in fuel burned on the shortened cruise segment. Vectoring turnback error impacted fuel costs as increased vectoring distance (late turn), or on descent (early turn). The B737 simulation results were extrapolated to all aircraft classes by applying a scale factor derived from FAA-based airborne cost rate data [8]. A fuel cost of $0.10 per pound was assumed.

This approach was used to calculate the total fuel expended for each simulated delayed arrival trajectory. Metering Conformance ATM Interruption benefits are calculated as the difference between the total arrival delay costs of the various technology cases under study. This reflected the savings at the study airport/airspace over a single day.

Separation Assurance ATM Interruptions

Because the focus of the paper is on metering conformance ATM interruptions, the model's separation assurance ATM interruptions methodology is only briefly summarized here. However, it is important to note the need to consider the cumulative affect of decisions on a flight to produce accurate results from the modeling effort. Integrating functions (e.g., metering and conflict probe) captures important coupling interactions. One coupling involves the inefficiency of solutions that do not consider the entire problem domain. For example, accommodating a faster route/UPT just to reach a metering situation does not necessarily improve flight fuel efficiency. Second, not knowing the outcome of one DST function may limit the effectiveness of other functions. For example, lack of aircraft intent from not knowing metering conformance flight changes degrades trajectory prediction used by the conflict probe. As shown in Figure 8, this may lead to missed and false alerts.

[1] Although actual controller vectoring is more complex (e.g, S-turns), this approach captures the primary impact of vectoring for the purposes of this paper.

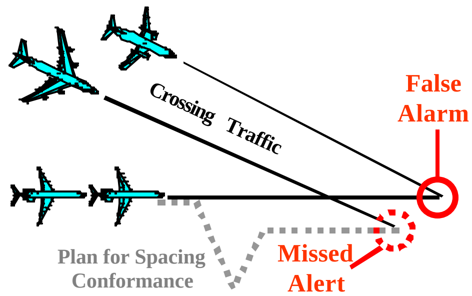


Figure 8 Improved Trajectory Intent with Integrated Metering and Conflict Probe

The separation assurance model component detects and resolves conflicts among the metered arrival, departure and overflight trajectories. Conflict detection models are employed to develop an incident database of potential conflicts. ATM is assumed to intervene and interrupt conflicting trajectories that are perceived to violate acceptable controller spacing. Integration with metered flight changes provides improved perception, leading to fewer false and missed conflict alerts. For each perceived conflict recorded in the incident database, the model uses conflict separation assurance resolution algorithms to tally the cost of resolution.

The separation assurance ATM interruptions model application and the resulting metrics of missed/false alert rates and conflict probe interruptions costs are discussed in detail in References [3] and [10].

<u>NAS Extrapolation</u>

Using the interruption rates and resolution costs found in the single airport daily simulation, the model employs a simple extrapolation, shown in Eq.(2), to estimate annual ATM interruptions benefits at candidate deployment regions. A similar extrapolation method would be applied to separation assurance ATM Interruptions, as discussed in References [3] and [10].

$$\text{Cost} = (\text{Ops}) \times (\text{Interrupt Rate}) \times (\text{Cost/ Interrupt}) \qquad (2)$$

where:

Ops	= Annual Airport Ops (00s)
Interrupt Rate	= No. interruptions per 100 operations
Cost/Interrupt	= Average cost per interruption ($/op)

The Metering Conformance ATM Interruption rates are also adjusted by airport to account for variations in congestion, based on historical delay statistics [11]. It is assumed that airports with fewer overall delays would require a disproportionately fewer metered arrivals. Airports are broken into four delay classes with 25-100% of DFW's portion of metered arrivals.

ILLUSTRATIVE EXAMPLE

Researchers at the NASA Ames Research Center are developing en route tools within the Center-TRACON Automation System (CTAS) to include the En Route Descent Advisor (EDA). The following illustrative example is used to show the potential benefits of CTAS EDA over a FFP1 baseline. Using the model, potential metering conformance ATM interruption costs were calculated for both technology cases using a detailed ZFW single-day traffic scenario. The resulting benefits were then extrapolated to annual NAS-wide candidate deployment regions.

<u>Case Definitions</u>

The following cases describe a system baseline, reflecting FFP1 capabilities, and an advanced system based on CTAS EDA capabilities. The EDA case is shown to lead to more efficient ATM interruptions by improving the metering conformance delay absorption clearances, per assistance from the EDA-calculated advisories and longer time horizon (facilitated by DST advisories).

Both cases are assumed to employ the CTAS TMA to schedule arriving aircraft. TMA creates an optimum time-based arrival schedule for an airport complex and establishes scheduled times of arrival (STAs) at TRACON-boundary meter fixes to control the flow into the TRACON airspace. The TMA schedule is continually updated from radar returns flight data from the ARTCC Host computer system in response to changing events, until an aircraft's metering-fix Estimated Time of Arrival (ETA) is within 19 minutes (the "freeze horizon"), at which point the aircraft's Scheduled Time of Arrival (STA) is frozen. TMA STAs are distributed to each en route sector managing arrival traffic. The STAs and TMA estimates of delay to be absorbed are displayed directly on the controller's Display System Replacement (DSR) in an alphanumeric meter list.

Other attributes of the two cases are discussed below:

Case 1 Free Flight Phase 1 Baseline

The modeled baseline reflects en route operations aided by FAA Free Flight Phase 1 arrival metering and conflict probe. CTAS Traffic Management Advisor (TMA) schedules and meters arrival flights, separately from a URET CCLD conflict probe and trial-planning tool. TMA sets an arrival aircraft metering fix crossing schedule at the Center/TRACON boundary and displays flight-specific delay advisories to the controller. The controller cognitively creates a strategy to absorb the specified delay to meet the TMA schedule. As each arrival progresses toward the terminal area, and is delayed by the controller, TMA updates the displayed delay estimate to provide feedback to the controller as to the effectiveness of the employed delay strategy.

The FFP1 baseline reflects current ZFW metering conformance methods, based on discussions with NASA ATM experts familiar with ZFW en route airspace [12]. A time horizon of 16 minutes (before the undelayed metering fix crossing time) is assumed, allowing a 3-minute lag after the TMA STAs and delay advisories are displayed to the controller.

The baseline delay strategy assumes controllers first employ altitude control by descending aircraft to the floor of the high-altitude airspace. Additional delay is absorbed using speed reductions, based on controller experience, down to a minimum speed applicable to most aircraft types. A speed error is added to the optimal case to represent cognitive limitations in developing the metering conformance clearance without automation assistance. Finally, vectoring is used to absorb any residual delay.[2] The vectoring turnback error reflects controller cognitive limitations in identifying the optimal vector turnback location/time.

Case 2 CTAS EDA

Case 2 future en route operations are defined by an ATM system with the integrated capabilities of both the CTAS TMA and En Route Descent Advisor (EDA) tools. This includes TMA arrival scheduling, as in the baseline case, and EDA high-fidelity trajectory modeling to predict future aircraft positions for conflict probe and metering conformance maneuver advisories. EDA's integration of automated metering-conformance advisories with conflict probe reduced conflict-probe false-alarm and missed-alert rates. The EDA maneuver advisories assist controllers in formulating and executing a traffic delay strategy to meet the TMA schedule, allowing the controller to quickly and accurately assess the impact of various delay strategies. As such, a longer 18-minute time horizon is assumed.

The EDA delay strategies [6] are modeled in the following way. With a longer time horizon speed control can be used more effectively and because of its fuel efficiency is attempted first. If speed control alone is not sufficient, a combination of altitude/speed adjustments are used instead. Here, EDA advises an optimal speed/altitude combination, difficult to calculate without EDA data and computational assistance. Vectoring, the least precise and least efficient strategy is reserved for large delays. EDA vectoring advisories are designed to bring the flight within speed-control range using precise "turn-back" advisories to reduce uncertainty [13].

Table 2 presents the parameters used to model the delay absorption strategies for both cases. Key attributes are the ordering of the strategy, the assumed time horizon, and various accuracy parameters assumed within each delay absorption method.

Table 2 Assumed Delay Strategy Parameters

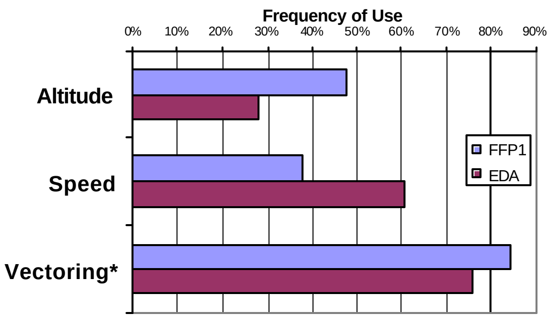
	FFP1	EDA
General		
Strategy Order	Altitude Speed Vectoring Time Shift	Speed Altitude/Speed Vectoring Time Shift
Time Horizon	16 min	18 min
Speed		
Speed Increments	10 kt	5 kt
Speed Error	+ 10 kt	None
Min Cruise Speed Min Descent Speed	BADA BADA	BADA - 10kts BADA - 20kts
Altitude (Jets only)		
Permitted Altitudes	Min Altitude ONLY	FAR Altitudes
Min Altitude	FL230/FL240	FL230/FL240
Vectoring		
Heading Increment	1°	1°
Max Vector Angle	60°	60°
Turnback Error	± 20 seconds	± 10 seconds

BADA = Eurocontrol Base of Aircraft Data (BADA) "low" cruise airspeed by aircraft type, assumed to approximate 10kts above best endurance speed [14]. FAR = Federal Aviation Regulations permitted altitudes: 2000' increments at/above FL290, 1000' increments below.

[2] Controllers typically employ holding patterns for vectoring delays in excess of 8 minutes. Although not modeled geometrically, the time-shift method adequately models the economic affects of such vectoring

ATM Metering Conformance Benefits

The resulting metering conformance ATM Interruptions and frequency of each delay method employed by case are shown in Figure 9. This figure shows the increased use of fuel efficient speed control methods and reduced reliance on the more expensive vectoring methods in meeting the TMA metered schedule.



* Vectoring includes Time Shift method.

Figure 9. Comparison of Employed Metered Arrival Delay Strategy

On average, the metered arrivals were delayed by 3-5 minutes. The range of delay absorbed with each method is shown in Table 3. The table compares the various delay absorption methods employed in both the baseline and EDA cases. The results show that EDA appears to replace the altitude method with the less intrusive and more cost-effective speed adjustment method. EDA did not significantly alter the use of vectoring; however, EDA appears to save vectoring for larger magnitude interruptions.

Table 3. Metered Arrival Delay Comparison

	Delay (min)					
	FFP1 Baseline			CTAS EDA**		
	Range	Ave	Total	Range	Ave	Total
Altitude	0-4.6	0.4	275	0-7.6	1.0	629
Speed	0-2.5	0.5	321			
Vectoring*	0-16.6	3.1	2,054	2.8-18.1	3.0	2,017
Total***	NA	4.0	2649	NA	4.0	2646

* Vectoring includes Time Shift method.
** CTAS EDA combines speed and altitude methods.
*** Case Totals differ due to rounding.

Table 4 compares the resulting fuel costs tied to the FFP1 baseline and EDA cases. The table points out the fuel efficiency of speed delays, where delays absorbed with speed control can actually reduce the overall flight cost.

Table 4. Metered Arrival Fuelburn Comparison

	Fuelburn ($)					
	FFP1 Baseline			CTAS EDA		
	Range	Ave	Total	Range	Ave	Total
Alt/Speed	$(30)-58	$3.59	$2375	$(52)-112	$(0.16)	$(108)
Vectoring*	$0-234	$21.87	$14476	$0-277	$21.34	$14130
Total	$(14)-292	$25.45	$16851	$(52)-349	$21.18	$14022

* Vectoring includes Time Shift method.

As both cases used the same traffic scenario, each flight was subject to the same time delays in the baseline FFP1 and EDA cases. As a result, EDA savings reflect improved fuel efficiency in absorbing the common TMA metering delay. Figure 10 graphically shows the distribution of per operation EDA metering conformance fuel savings.

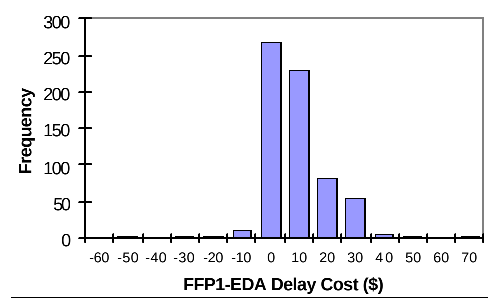


Figure 10. CTAS EDA Savings Per Operation

Annual/National Benefits Extrapolation

The simulated 1996 daily ATM cost savings at ZFW, due to more efficient metering conformance ATM interruptions, was extrapolated to an annual level and to other candidate regions using Eq.(2). The DFW metering conformance ATM interruption rates and costs per operation observed in the simulation are shown in Table 5.

NAS-wide benefits were calculated assuming en route/transition airspace deployment of the scenario technologies at 43 candidate airport sites. An airport's assumed share of delayed arrivals, relative to DFW, based on the 1996 Aviation Capacity Enhancement Plan delay data [15] follows:

100%	ATL, BOS, DFW EWR, JFK, LAX, LGA, ORD, PHL, SFO, STL
80%	CLT, CVG, DCA, DTW, IAD, IAH, MDW, MIA, MSP, PHX, PIT, SEA
50%	BDL, BNA, BWI, CLE, DEN, FLL, HOU, LAS, MCO, PDX, SAN, SLC
25%	COS, DAB, HPN, LGB, MEM, OAK, SDF, TEB

Table 5. DFW Metering Conformance Simulated Interruption Rates

Case	Rate	Ave Cost ($)
FFP1	30.4/100 ops	$103.86/op
CTAS EDA	36.5/100 ops	$99.59/op

Using 1996 annual arrival operations [16], annual savings by airport were calculated using Eq. (2). Annual savings reflect the difference between the annual ATM interruptions cost of the FFP1 baseline and CTAS EDA case. The total benefit at all 43 airports is $16.7M annually. The annual savings for various deployment airports are plotted graphically in Figure 11. The benefits vary significantly by airport due to different activity levels and extent of existing delays. The largest savings occur at the capacity-restricted hub airports of Atlanta (ATL), Dallas-Ft. Worth (DFW), Los Angeles (LAX), and Chicago (ORD).

CONCLUSIONS

This paper presented a new methodology for assessing the performance of en route DST technologies for reducing the frequency and impact of ATM-based deviations to the user's preferred trajectories. The methodology provides an approach to evaluating the trajectory costs of en route ATM interruptions by modeling specific controller metering and conflict resolution actions, aided by automated DST technology. The model is sensitive to the complex interactions of time horizon, controller delay strategy ordering and accuracy used to absorb arrival metering conformance delays. Additionally, the importance of integrating metering conformance and separation assurance (e.g., conflict probe) functions was discussed. Furthermore, a simple method was identified to extrapolate results from a single day's traffic simulation at ZFW to annual NAS-wide technology deployment benefits. This methodology was illustrated by a brief example of the CTAS EDA tool relative to FFP1 operations. The example revealed the methodology's value for use in the concept development and validation of ATM automation concepts in support of NAS free flight initiatives. Additionally, it estimated a benefit of EDA metering conformance benefits of $1.1M annually at DFW and over $16.7M if employed at 43 likely airport locations.

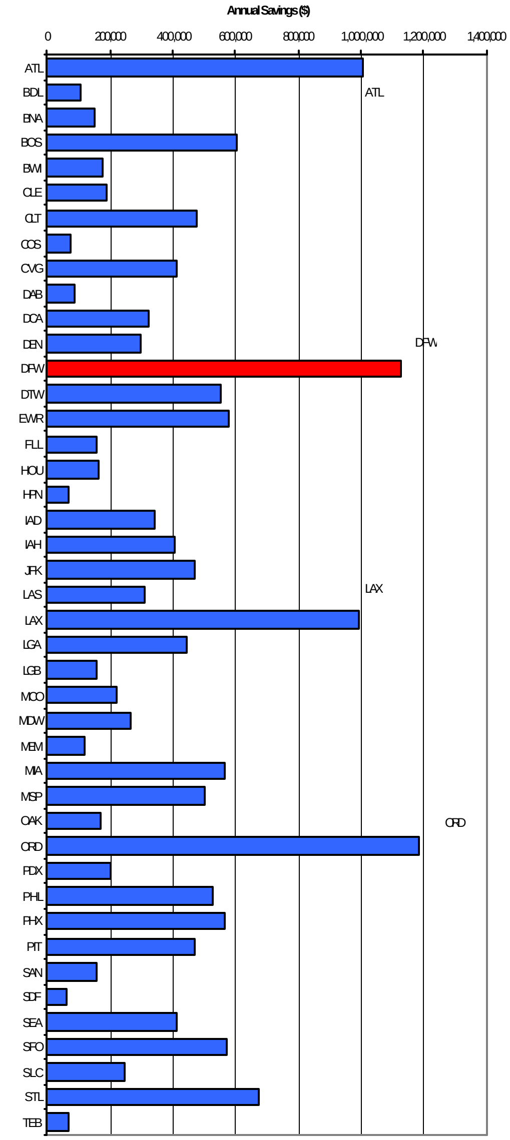


Figure 11. Annual NAS-wide EDA Metering Conformance Benefits

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