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# Benefits Assessment Methodology for an Air Traffic Control Tower Advanced Automation System[*]

Tom G. Reynolds[†], Richard K. Jordan[‡], Mariya A. Ishutkina[‡], Robert M. Seater[‡] & James K. Kuchar[§]
*MIT Lincoln Laboratory, Lexington, MA 02420, USA*

**This paper presents a benefits assessment methodology for an air traffic control tower advanced automation system called the Tower Flight Data Manager (TFDM), which is being considered for development by the FAA to support NextGen operations. The standard FAA benefits analysis methodology is described, together with how it has been tailored to the TFDM application to help inform the development process and the business case for system deployment. Parts of the methodology are illustrated through data analysis and modeling, and insights are presented to help prioritize TFDM capability development.**

## I. Introduction

AN air traffic control tower advanced automation system known as the Tower Flight Data Manager (TFDM) is being considered for development by the Federal Aviation Administration (FAA)[1]. It is designed to replace the numerous standalone systems within current towers with an integrated technology suite comprising an advanced surveillance display system, an electronic flight strip/data manager system and a set of decision support tools (DSTs), as shown in Figure 1. The TFDM system is designed to provide the automation environment necessary to support future flexible airport and terminal airspace operations for Next Generation Air Transportation System (NextGen) towers[2]. The capabilities provided by the TFDM system should enable multiple system benefits, such as better performance during severe weather and other off-nominal conditions; reduced surface delay, taxi time and fuel burn (with associated improved operational and environmental performance); and enhanced safety.

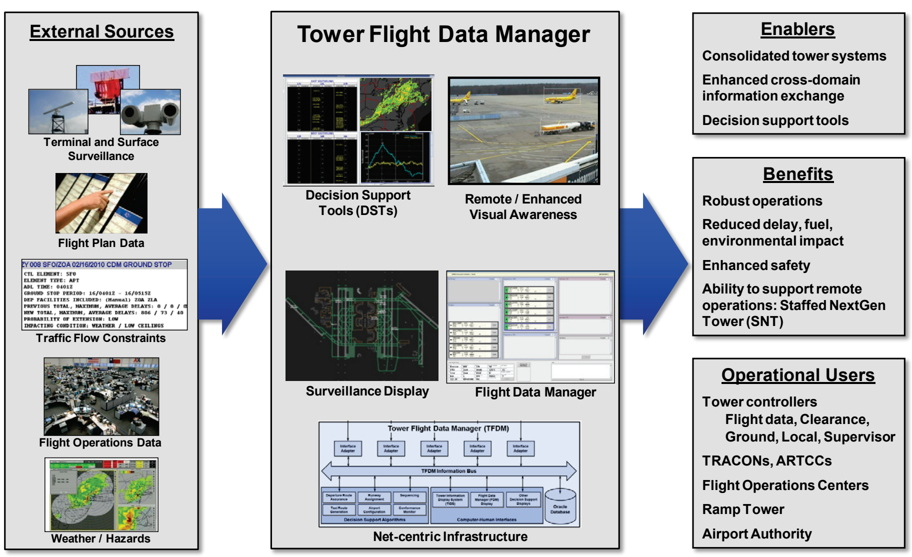


**Figure 1. Tower Flight Data Manager (TFDM) System Overview**

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[†] Technical Staff, Weather Sensing Group, MIT 33-115, 77 Mass. Av, Cambridge, MA 02139. AIAA Member.
[‡] Technical Staff, Weather Sensing Group, 244 Wood Street.
[§] Group Leader, Weather Sensing Group, 244 Wood Street. Associate Fellow AIAA.

Assessing these benefits is an important part of the TFDM investment analysis process. It demonstrates how well the new system performs over its lifetime relative to the baseline scenario in which the system is not deployed. Figure 2 illustrates the benefits assessment concept showing how a generic performance metric evolves with different systems as demand increases into the future. The performance of the baseline system declines as it is less able to handle increasing demand given its capabilities. By contrast, if a new system is designed with capabilities that enable it to better handle increasing demand, overall system performance can be maintained or even improved over time. The difference between the two curves at any point in time represents the performance benefits gained by deploying the new system relative to the baseline system. If these benefits can be quantified and converted into economic metrics (i.e. "monetized"), they can be compared to costs and, hence, make the business case for deployment and/or continued development of the new system.

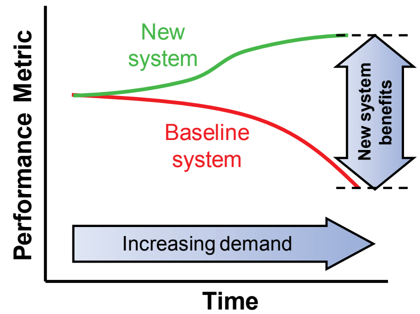


**Figure 2. Benefits Assessment Concept (adapted from Ref 3)**

In addition to its important role for investment analysis, benefits assessment can also help guide development of the new system itself. The process by which benefits are identified for the new system necessarily requires an understanding of the inefficiencies present in the current baseline system. Understanding the causality of these inefficiencies can help identify what capabilities the new system should possess in order to address them, and therefore, helps guide priorities for system development.

This paper describes the benefits assessment methodology being employed for TFDM and the insights that can be gained from its use. Section II describes the standard FAA benefits assessment methodology and how it is being tailored to the TFDM application. Section III presents preliminary data analysis, consistent with key parts of the methodology. Section IV then describes how the insights gained can be used to inform TFDM system development.

## II. TFDM Benefits Assessment Methodology

The FAA defines a standard benefits analysis methodology that provides general guidelines for preparing benefit estimates for FAA decision-makers[4], but it needs to be tailored to each application. For TFDM, the guidelines were distilled into a seven-step process and a flow diagram representation was created to show the relationship between each step, as illustrated in Figure 3. The numbers in each box correspond to the steps described next.

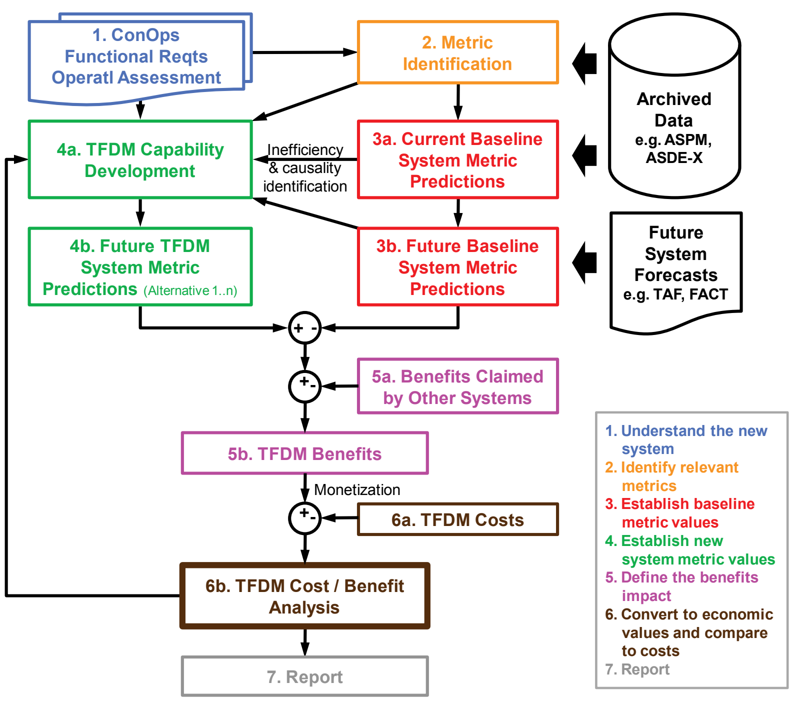


**Figure 3. TFDM Benefits Assessment Methodology**

1. **Understand the New System:** Develop and document a good understanding of the proposed new program, including the baseline case (the "do nothing" alternative) and the set of alternative approaches ("do something" alternatives) to be evaluated. For TFDM, understanding the new system is achieved via a number of means, including the Concept of Operations document (i.e. ConOps, describing the current system, justification for and nature of changes, sample operational scenarios and a summary of possible impacts); the Functional Requirements document (outlining the specific functions the system has to perform); the NextGen Surface Trajectory-Based Operations (STBO) recommendations and the Operational Assessment processes.

2. **Identify Relevant Metrics:** Identify and select metrics that are expected to improve as a result of the new program or investment. Normally, the metrics should be the same ones that have been selected to evaluate the FAA as a performance-based organization. Appropriate metrics depend on the type of system being developed, but major ones identified in the general guidelines include: Capacity increases (e.g. demand-to-capacity reduction); Safety (e.g. accident rate, severity of accidents); Efficiency (e.g. passenger delays, operational delays); Environment (e.g. fuel burn and emissions reduction); Productivity (e.g. number of aircraft handled, avoided staffing costs); and, Security (e.g. number of intrusions, hijackings). For TFDM, the understanding from Step 1 and the available archived data provides pointers to the performance metrics that are likely to be affected by its deployment: Efficiency, Capacity, Environment, and other International Civil Aviation Organization (ICAO) key performance areas of Safety and Productivity[5].

3. **Establish Baseline Metric Values:** Establish the baseline case behavior in terms of the chosen metrics for current and future operations. For the TFDM program, the current baseline system metrics (Step 3a) are assessed by analyzing archived operational data (such as from FAA Aviation System Performance Metrics (ASPM)[6] and Airport Surface Detection Equipment-Version X (ASDE-X)), from which current system inefficiencies can be identified. The baseline system metrics also need to be projected into the future (Step 3b). Archived operational data can be used to develop performance estimation models as a function of key system variables. For example, the delay at an airport is dependent on arrival and departure demand relative to capacity, so projections of the number of operations at an airport into the future, can be used to predict future system delay.

4. **Establish New System Metric Values:** Establish the new system's behavior in terms of the chosen metrics for current and future operations. The nature and magnitude of the observed inefficiencies in the current and future baseline system can provide insight into the specific capabilities that need to be developed by TFDM in order to decrease them and, hence, provide benefit (Step 4a). Determining the causality of the observed inefficiencies can be a challenge, but is often possible through a combination of operational data analysis, stakeholder input, field observations and domain expertise on the part of the analysts. Determining how the system metrics will evolve with different alternatives of TFDM capabilities (Step 4b) can build upon the system performance models developed for the baseline system assessment. For example, if TFDM capabilities are used to increase capacity of the system, these new capacities can be used with the same demand levels as in the baseline system assessment to predict likely delays under TFDM. Alternatively, new system performance models may be needed to fully capture the effects of new capabilities enabled through TFDM (e.g. absorbing delay at the gate instead of during taxi). In the investment analysis, several viable alternatives are identified that satisfy the TFDM operational requirements but with differing levels of capability, and hence deliver different benefits at different costs. During the investment analysis, each alternative is analyzed to explore the cost/benefit trade-off.

5. **Define the Benefits Impact:** Compare the metric values between the baseline and new systems into the future. Many benefits can be assessed quantitatively (e.g. impacts on delay, throughput, fuel burn), while others may not (e.g. improvement in quality of life). To the extent possible, all of the benefits should be captured and described, even if they cannot be easily measured. For those benefits that will be quantified, it is necessary to estimate benefits for each year of the project life cycle. For TFDM, the difference between the predicted metric values for the baseline and TFDM scenarios provides a measure of the benefits gained by the deployment of the new system. These benefits are often in terms of physical measures, such as capacity increases allowing greater aircraft movements, increased efficiency in the form of the reduction in delay or fuel burn, and environmental benefits through the reduction in greenhouse gas/air quality emissions or noise contour area. A challenge exists when the benefits are shared between multiple dependent programs, and then unique benefits of each (Steps 5a and b), as well as their integrated benefit, must be distinguished.

6. **Convert to Economic Values and Compare to Costs:** As many of the identified benefits as possible should be converted to economic values to enable comparisons in the same economic terms as costs (i.e. dollars). For TFDM, converting the physical metrics to economic values can be achieved through considerations of impacts on Aircraft Direct Operating Costs (ADOC), Passenger Value of Time (PVT)[7], and newly-emerging environmental impact monetization techniques for quantifying climate damage costs, air quality health costs and noise-induced property value loss[8]. These monetized benefits can then be compared to the TFDM acquisition, deployment and maintenance costs (Step 6a) needed to undertake a full cost/benefit analysis (Step 6b). Some benefits may not be easy to monetize (e.g. increased situational awareness, user preference, or reduced workload), but they should still be identified. The insights gained by following this methodology throughout the system design lifecycle help to prioritize the various TFDM capability areas and focus the development process accordingly. This process is illustrated by the feedback arrow from Steps 6 to 4a in Figure 3, a process which is described in more detail in Section IV.

7. **Report:** The assumptions, models, inputs and results from the steps outlined above must be documented to form part of the investment analysis deliverables, for example in the TFDM Shortfall Report as part of the Investment Analysis Readiness Decision (IARD), the Initial Investment Decision (IID) and the Final Investment Decision (FID).

The next section discusses sample analysis to illustrate how the TFDM benefits methodology can be applied.

## III. Data Analysis of Current and Future Baseline Systems

One of the primary objectives of the TFDM system is to improve the efficiency of air transportation system operations on the surface and in the terminal area. In order to estimate how much benefit may be achievable with the new system, it is necessary to first understand the magnitude of the current (and possible future) inefficiencies in terms of key system performance metrics. Only then can an assessment be made of the extent to which these inefficiencies may be reduced through deployment of advanced systems such as TFDM. The metrics used in the sample analysis are taxi-out delay (which dominates over taxi-in delay at many airports) and fuel burn. The following subsections describe analysis of the taxi-out delay time and fuel burn in the current system[**] (Step 3a from Figure 3) and into the future (Step 3b from Figure 3). The analysis and models are continually being refined, but these discussions provide an example of how the methodology can be applied.

### A. Current Baseline Taxi-out Delay Time/Fuel Burn Analysis

Firstly, FAA ASPM data was used to explore aggregate performance at 43 airports identified in Figure 4 needed for the TFDM benefits analysis[††]. Secondly, a much more detailed analysis was conducted using ASDE-X surveillance data at Dallas-Fort Worth Airport (DFW), both to compare with the ASPM data analysis and to provide additional insights into the sources of the observed inefficiencies.

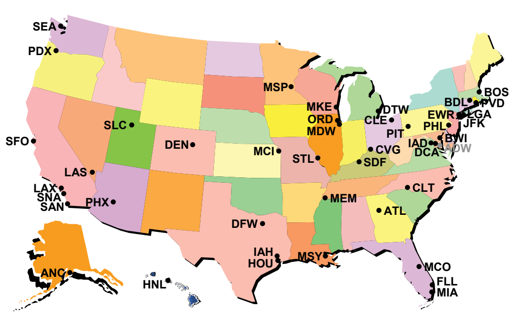


**Figure 4. TFDM Analysis Airports**

#### 1. *ASPM Analysis*

Taxi-out (push-back to wheels-off) statistics were extracted from ASPM, which provided per flight average and 10th percentile taxi times over the course of the year. The latter was assumed to be an approximation of the unimpeded taxi time (10% of the actual taxi times were below this value, so it is actually an over-estimate of the unimpeded time, but it is considered to be a better estimate than the ASPM-reported unimpeded time). The difference between the average and 10th percentile data provided an estimate of average daily taxi-out delay at each airport in 2008. These delays were then converted to fuel burn estimates by multiplying the taxi-out delay times by the taxi fuel flow rates weighted to account for the fleet mix at

[**] 2008 was used as the base year due to data availability

[††] There is a 44th airport (Andrews Air Force Base (ADW) identified in grey in Figure 4) which has very few scheduled operations, so is neglected in the analysis.

each airport as reported in ASPM. The ICAO engine emissions databank was used for fuel flow rates of specific aircraft in the fleet mix. All the observed taxi-out delay was assumed to be incurred with the aircraft engines operating at idle thrust (which may not be the case if some delay is absorbed with engines off or only a subset of engines on). Resulting daily total taxi-out delay time and fuel burn are presented for each of the 43 airports in Figure 5 below.

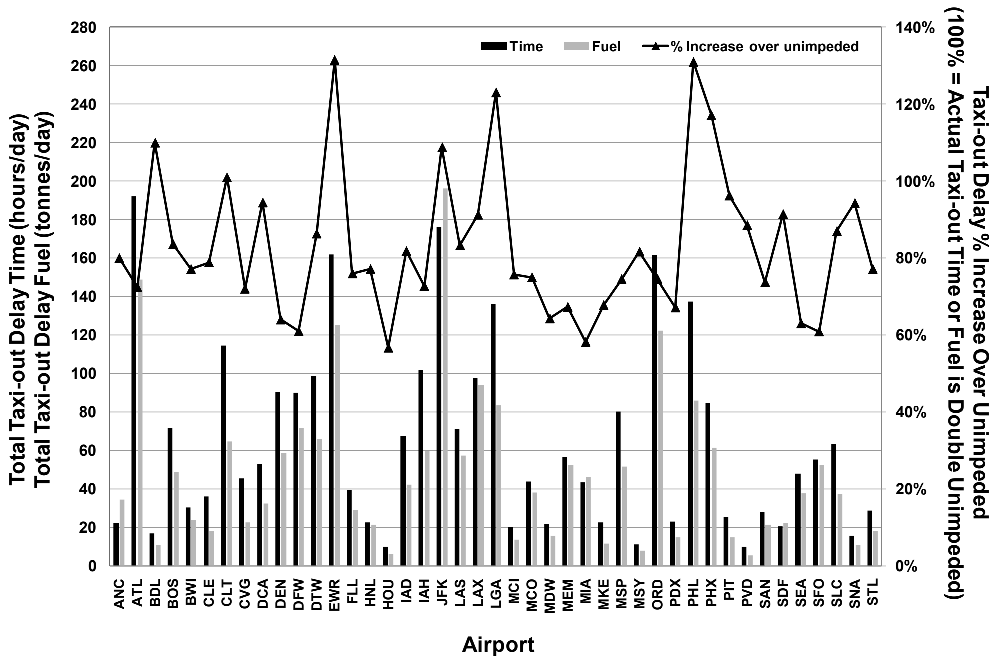


**Figure 5. 2008 Average Taxi-out Delay Time and Fuel (Note: 1 tonne=1000 kg)**

Above the bars are percentages showing the relative % increase over unimpeded, i.e. a value of 100% would indicate the observed taxi time or fuel burn were double the unimpeded values. These results provide insights into the airports in the current system with the greatest taxi-out and fuel burn inefficiencies. For example, it is apparent that there is significant delay time and excess fuel usage at ATL, EWR, JFK, LGA, ORD and PHL. The relative increases over the unimpeded are 73% for ATL and greater than 100% for JFK and PHL (i.e. taxi time and fuel use is more than double what it would be in the unimpeded case). The reason is that the total delay and fuel burn are spread over many more flights at ATL than at JFK and PHL. The importance of fleet mix is also apparent in the data: a given amount of average delay leads to a larger fuel burn impact for airports with a greater proportion of large, wide-body aircraft than smaller, narrow-body and regional jets. For example, ANC and MCI have similar total taxi-out delay times, but very different total taxi delay fuel consumption because ANC has a fleet mix dominated by large, wide-body (freighter) aircraft while MCI has mostly regional jets.

Summing over the 43 airports, the average total taxi-out delay time was 2533 hours/day (equivalent to 925,000 hours/year) and total taxi-out delay fuel was 1874 tonnes/day (684,000 tonnes/year). If all aircraft in the system were able to taxi-out unimpeded, these levels of savings would have been realized in 2008. In reality, a considerable portion of this apparent inefficiency is unavoidable (for example due to traffic separation requirements), the consequence of which is discussed in the next section.

*2. ASDE-X Analysis*

The ASPM analysis described in the previous section enables aggregate push-back to wheels-off taxi-out times to be assessed. This was supplemented with a more detailed analysis of one airport (DFW) using ASDE-X surveillance data, which allowed delays between the gate, spot, queue and runway to be analyzed (additional points such as the departure fix and overhead stream may need to be considered for the full TFDM benefits analysis in the future). It is useful to perform this more detailed analysis because, at these locations, inefficiencies can be observed and control mechanisms of advanced air traffic management systems may be applied to mitigate them in the future. Figure 6 shows notional cumulative time traces between these points for an "ideal" aircraft in the unimpeded system and an actual aircraft in the baseline system.

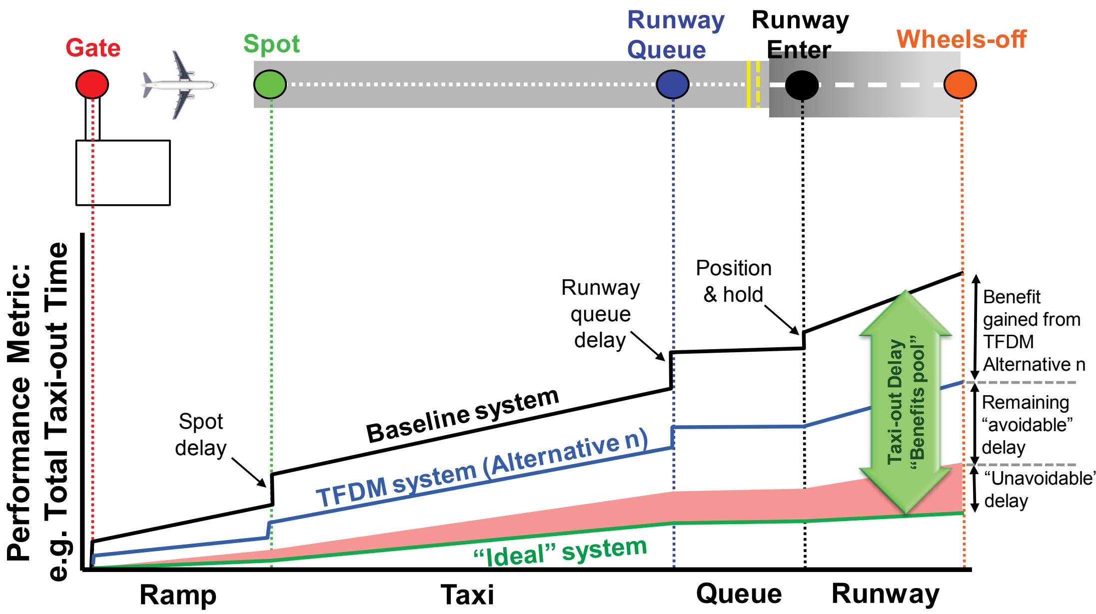


**Figure 6. Benefits Pool Representation**

Delay is represented by the difference between the actual time in the baseline system and what it would have been in the unimpeded system between the different control points. The taxi-out "benefits pool" is represented by the difference between the cumulative time from gate to wheels-off for the baseline and ideal systems. The benefits pool includes a combination of potentially reducible delays (e.g. through more efficient air traffic management) and "unavoidable" delays that cannot be eliminated. The TFDM system is expected to deliver benefits over the baseline system as a result of reductions in avoidable delay. Hence, the traces for different evolutions of the TFDM system design would be expected to lie somewhere between the two traces shown in Figure 6. The nearer the TFDM trace is to the ideal trace, the greater the benefits that are being accrued relative to the total benefits pool.

The availability of ASDE-X surveillance data for DFW enabled these traces to be developed for that airport. Data from five National Airspace System (NAS) fair weather Visual Meteorological Conditions (VMC) days in 2008 were analyzed to minimize the likelihood that observed inefficiencies were due to downstream system constraints (e.g. traffic management initiatives). Gate-to-spot times were calculated by comparing the pushback time for a given aircraft (from ASPM) and the time at which the aircraft was observed to arrive at the spot (from ASDE-X). The mean gate-to-spot time was calculated by weighting over all gate/spot pairs observed in the data, with the weights given by the relative frequencies of observed gate/spot pairings. Similarly, the unimpeded gate-to-spot transition time was calculated as the weighted average, with the same frequencies, over all gate/spot pairs of the minimum observed gate-to-spot transition times. Spot waiting times were measured from ASDE-X data as the time spent within a small box representing the spot location. The unimpeded time corresponded to the minimum observed time to traverse that box. Mean and unimpeded spot-to-runway (taxi) times were also calculated from the ASDE-X data using weightings for different spot/runway pairs in a similar fashion as the gate-to-spot times. Runway queue time was measured using observed time spent in an appropriate departure queue box relative to the minimum observed box traverse time. The overall mean runway queuing time was given by the weighted average of the individual runway queuing delays, with the weights determined by the relative frequencies of runway usage. Finally, runway occupancy time was determined by the difference between an aircraft's wheels-off time and the time it left the runway queue based on the ASDE-X tracks. As with the runway queue waiting time analysis, weighted averages with respect to runway use frequency were used to define the unimpeded and average runway occupancy times. The results of this VMC analysis are summarized in Figure 7, and compared to a similar analysis for a sample of Instrument Meteorological Conditions (IMC) days from 2008. Note that these results only present the taxi-out delay from push-back to wheels-off. Aircraft may incur additional delay at the gate (i.e. push-back relative to scheduled departure time). The average of these times was 6.4 minutes for the VMC days and 16.1 minutes for IMC, but these results can be deceptive owing to the large percentage of flights with zero or negative gate delay (70% in VMC, 41% in IMC). In addition, much of this gate delay is due to factors outside the influence of air traffic control, so will not be considered further in this paper.

Across the more than 3000 VMC flights analyzed, the average total taxi-out time of 13.6 minutes compares favorably with the ASPM VMC average taxi-out time at DFW in 2008 of 13.3 minutes per flight. The average taxi-out delay relative to the minimum observed in the data was 6.1 minutes per flight, while the 4.1 minutes per flight delay relative to the 10th percentile also compares favorably to the 4.3 minutes observed from the ASPM data. These strong correlations between the ASDE-X and ASPM total taxi out time and delay results provide confidence that the breakdown of delay between control points is also generally representative for DFW.

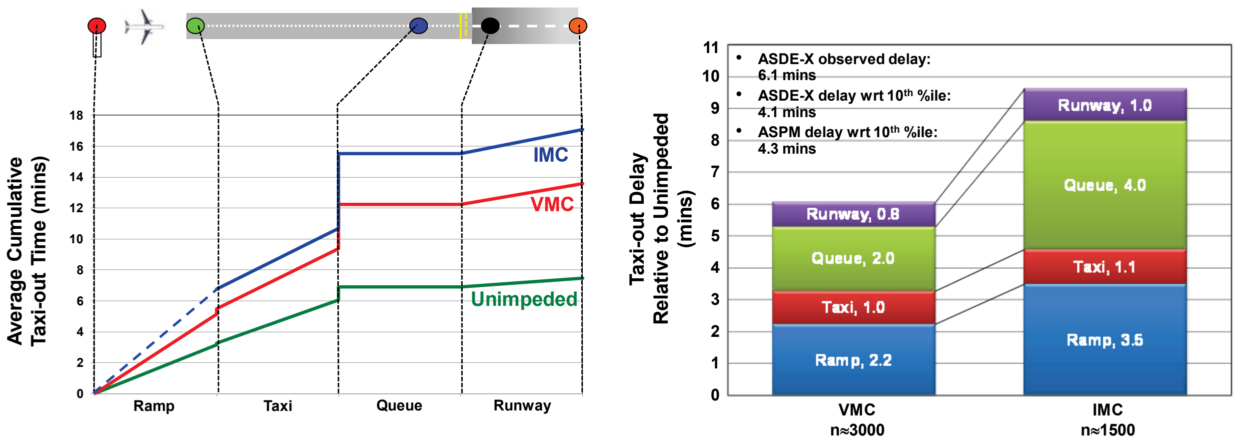


**Figure 7. DFW ASDE-X Analysis Results**

For these five NAS fair weather days at DFW, the majority of delay is seen in the ramp area and at the runway queues, with each contributing approximately 33% to the total overall delay. Taxi (spot-to-queue) and runway occupancy delay are non-negligible, accounting for 17% and 13% of the total delay respectively under VMC. Figure 7 also provides the same data for two representative IMC days at DFW. The total taxi-out delay for these days was seen to be higher than under VMC (9.6 minutes compared to 6.1 minutes). The taxi (spot-to-runway queue) and runway occupancy times were seen to be largely unchanged, while the majority of the additional delay was incurred in the ramp area and at the runway queues.

## B. Future Baseline Taxi-out Delay/Fuel Burn Analysis

The previous section presented analysis of the current baseline system consistent with Step 3a from Figure 3. This section discusses future system predictions consistent with Step 3b from Figure 3.

The TFDM Investment Analysis is required to be conducted at the 43 airports previously identified over an assumed 20 year lifecycle from 2015-2035. A standard queuing model was developed to project estimates of the average aircraft runway queueing delay and fuel burn out to the year 2035 for a subset of the airports considered in the 2008 analysis. Note that it is common for runways to be considered the dominant resource constraint at an airport[9], and hence the results presented in this section are in terms of runway queueing delay (which may manifest in the "queue" location described above, or propagate elsewhere on the surface). The airport runway system was modeled in a standard way, i.e. as a single server queue with time-dependent Poisson demand and exponentially distributed service times[9]. The queuing model inputs consisted of hourly demand profiles (based on FAA forecasts of future traffic demand[10]) and airport throughputs (based on FAA forecasts of airport capacity[11]). The results from this model exhibited unrealistically excessive delays in the future, for example more than 60 minutes per flight average runway queuing delay at some airports. At these levels of delay, schedules become so unreliable that typical hub-and-spoke networks become unsustainable. Instead of allowing these levels to accumulate, the system will have to adapt to better match capacity and demand at acceptable levels of performance (e.g. demand reduction through pricing methods or capacity increases). This highlights one of the major challenges in benefits assessment activities: even predicting future *baseline* system performance metrics requires significant assumptions which affect the baseline against which TFDM system performance is compared. Indeed, even the FAA forecasts of demand and capacity only extend to 2030 and 2025 respectively, and hence assumptions on their behavior to the full investment period of 2035 are required to arrive at full inputs for demand modeling, and this is in addition to the modeling assumptions themselves.

Various input and modeling assumptions are being developed in collaboration with the TFDM Investment Analysis team and they will continue to be refined, but in order to continue the discussion here, sample baseline system runway queueing delay estimates are shown in Figure 8 which utilize the following assumptions:

- Hourly demand profiles for each airport were obtained from 2008 ASPM data. It was assumed that the profiles will have the same shape in the future.
- For each airport, the demand profiles were scaled using the FAA demand forecasts[10]. Because demand is only forecast through 2030, the conservative assumption was made that the demand would not change between 2030 and 2035.
- The FAA capacity forecasts[11] were assumed to be theoretical optimal capacities. In the absence of data beyond 2025, it was assumed there would be no capacity changes between 2025 and 2035.
- ASPM data were used to obtain actually-achieved maximal throughputs (or saturation throughputs) for 2008 and it was assumed the ratio of saturation throughputs to the forecast capacities remained constant for each airport in the future. In reality, the proportion of saturation throughput to optimum capacity may increase in the future at some airports where the pressure to do so is high (e.g. as delay at those airports increase in the future).
- VMC and IMC delays were modeled separately and weighted according to VMC/IMC frequency to yield the total delay. It was assumed the ratio of VMC to IMC days does not change in the future.
- Average delays were capped at 15 minutes in VMC and 45 minutes in IMC. For the small number of airports where the model results indicated delays were greater than these numbers, capacities were increased sufficiently so as to limit future delay to these values (in the spirit of the system evolving to maintain delay at an acceptable level). While the IMC threshold number may seem high, close examination of ASPM data reveals average taxi-out delays during IMC approaching 30 minutes in 2008 at some of the airports in question.

Figure 8 shows the future year results normalized to 2008 levels. Across the 43 airports in the analysis set, the total runway queueing delay is estimated to increase by a factor of approximately 1.5 over 2008 levels in 2015, a 4.2 times increase by 2025 and a 6.5 times increase by 2030 (and the same in 2035 given the assumption of constant demand and capacity from 2030 to 2035 due to the lack of official forecast data to this final out year). Note that there are forecast to be many more aircraft in the system in the future and hence the average delay *per aircraft* is increasing at a slower rate than these numbers. Summing the delay estimates over the investment analysis period of 2015-2035 suggests the cumulative taxi-out delay over those 20 years is approximately 92 times greater than the delay in 2008. If it is assumed that the forecast delay will be absorbed with aircraft engines on, the fuel burn forecasts would increase at these same levels. If some proportion of the delay is absorbed with engines off (e.g. at the gate), then the fuel burn growth in the future will be less than shown in Figure 8 by that proportion.

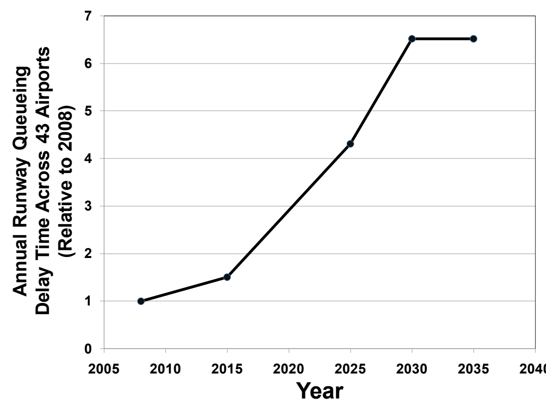


**Figure 8. Sample Baseline Runway Queueing Delay Predictions**

Figure 9 shows the level of cumulative runway queueing delay predicted by the model described in the previous section. Given some of this is unavoidable, and some is claimed by other systems (both of which need to be estimated during the investment analysis process), the proportion of the delay which is available for reduction through deployment of TFDM is shown in a notional way. TFDM capabilities should be designed to deliver benefits against this remaining portion of the estimated delay, with different amounts likely to be delivered by different TFDM

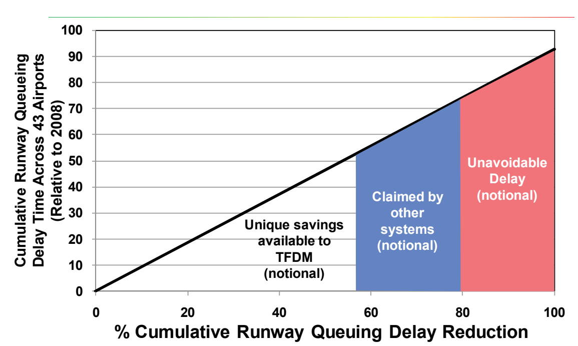


**Figure 9. Notional Runway Queue Reduction Breakdown**

alternatives previously described. As discussed earlier, monetizing the benefits from any delay reduction can be achieved by multiplying by appropriate factors to account for ADOC and PVT[7]. Care is needed to determine what monetization factors apply to specific benefits. For example, if TFDM capabilities allow more delay to be absorbed at the gate with engines off, then a different ADOC value should be used for delay accrued at the gate compared to during taxi, and although total passenger delay may not change significantly regardless of where the delay is absorbed, a lower PVT value may apply for delay incurred at the gate if passengers are free to access the airport terminals. Similarly, establishing the location of the delay absorption (e.g. at the gate with engines on or off) is highly relevant if environmental impacts are being monetized.

## IV. Informing TFDM System Development Priorities

The magnitudes of system inefficiencies identified by the aforementioned analyses can be used to prioritize development of capabilities for TFDM, illustrated in Figure 3 by the arrow from Step 3a/3b to Step 4a (and supplemented by the results from the cost/benefit analysis shown by the arrow from Step 6b to 4a). Because the first field demo for TFDM will be at DFW, the ASDE-X analysis of DFW is especially useful for guiding early development. Naturally, future analysis will focus on other major airports to ensure that TFDM does not become over-specialized to a single facility.

Together with field observations and input from subject matter experts, the ASDE-X analysis helps identify causes of the delay. Table 1 identifies some of the possible causes and classifies them by type of TFDM opportunity. In some cases, TFDM can offer direct improvements to efficiency (e.g. through decision support tool algorithms and displays), while in others it can primarily improve situational awareness (e.g. through enhanced surveillance displays, flight data management and communications).

For example, one cause for delay in the ramp is that the aircraft is not ready at the spot when it would be best for it to begin taxiing. While this issue is beyond the control of the air traffic control tower at DFW (where ramps are under airline control), TFDM could improve situational awareness through better ramp-tower communication, thereby allowing controllers to work around the problem. From the point of view of designing algorithms and decision support tools, addressing this issue may be a low priority. In contrast, consider one of the causes for delay in the queue: runway capacity limit. If too many aircraft are sent to a runway during a given period of time, the queue will lengthen and aircraft will incur avoidable delay. This is an area where TFDM can directly improve efficiency, by helping controllers to determine when aircraft should start taxiing to the runway.

Having identified some of the critical causes of delay that are addressable by TFDM, specific capabilities can be identified that TFDM could provide to help with each issue. Table 2 maps the efficiency improvement opportunities from Table 1 to the benefit mechanism by which TFDM might address the

**Table 1. Mapping of Delay Location to Causes that TFDM Capabilities Might Address**

| Location of Delay | Identified Causes | TFDM Opportunities |
|---|---|---|
| Ramp | Aircraft not ready | Situational awareness |
| | Ground crew not ready | Situational awareness |
| | Ramp blocked | Situational awareness |
| | Forgotten at spot | Efficiency improvement |
| | Back propagation of delay | Indirect impact |
| Taxi | Runway crossings required | Situational awareness |
| | Long taxi route | Efficiency improvement |
| | Taxiway capacity limit | Efficiency improvement |
| Queue | Runway crossings by others | Situational awareness |
| | No airborne route available | Efficiency improvement |
| | Runway capacity limit | Efficiency improvement |
| | Inefficient departure sequence | Efficiency improvement |
| Runway | Aircraft not ready | Situational awareness |
| | Runway crossings by others | Situational awareness |
| | Aircraft performance | Situational awareness |
| | No airborne route available | Efficiency improvement |

**Table 2. Mapping Delay Causality to TFDM Capabilities for Efficiency Improvement Opportunities**

| Identified Causes | Benefits Mechanism | Candidate TFDM Capability | Key Enabling Capabilities | Observations & Analysis |
|---|---|---|---|---|
| **Forgotten at spot** | Prevent waiting aircraft from being overlooked | Notify controllers when aircraft is at spot for long time | Predict normal spot wait time | Frequency of occurrence; Assess proper threshold |
| **Long taxi route** | Avoid long taxi routes if shorter alternatives exist | Assign efficient taxi routes, accounting for upcoming runway configuration changes | Predict upcoming RW configuration changes; Taxi time modeling | Presence of alternative routes; Taxi time model accuracy |
| **Taxiway/ runway capacity limit** | Manage demand on taxiway/runway to match capacity | Recommend spot release times to meter surface traffic | Surface queuing models to predict congestion | Frequency of occurrence and correlated conditions; Ideal queue length |
| **No airborne route available** | Get aircraft to runway (only) when route is available | Predict route blockage and manage spot release time to achieve needed runway time | Departure route availability analysis; Taxi time modeling | Frequency of occurrence; Reliability of route availability forecasts |
| **Inefficient departure sequence** | Increase dep. seq. efficiency | Manage spot release times to improve sequence | Predict dep. sequence; Sequence optimization | Comparison to optimal sequence |

cause. That mechanism, in turn, corresponds to a set of capabilities drawn from the requirements and concept of operation documents. Those capabilities cannot exist alone, so they must be matched to enabling capabilities, i.e. prerequisites for the capabilities that provide direct benefit. These may all be supported by observations and analysis identified in the final column.

The development of TFDM is still undergoing, so Tables 1 and 2 should not be taken to be exhaustive. Rather, they indicate how the benefits analysis described earlier in this paper can be brought to bear in a practical fashion to guide system and software development. For example, Table 1 identified "no airborne route available" as a cause for delay that is potentially addressable by TFDM. It would do so by ensuring aircraft only arrive at the runway when a route is available and absorbing any resulting delay in the most efficient manner possible, such as at the gate (the benefits mechanism). It would achieve this by predicting the status of departure routes (e.g. open or blocked), and then managing the gate or spot release times to ensure aircraft only arrive at the runway when its route is open (primary capability). This would require underlying models of route blockage and taxi time (enabling capabilities) at a level of accuracy appropriate to deliver a benefit[12]. To refine the algorithm and prioritization of these capabilities, field observations and analysis should focus on the frequency and conditions under which various blockage scenarios exist (observations & analysis).

Another cause identified in Table 1 was runway capacity limits. TFDM could better manage demand on the runway to match capacity (benefits mechanism). Specifically, it would predict when the runway could become congested and recommend that aircraft be held at the gate or spot (primary capability). In order to enact that capability, TFDM must have underlying queuing models of the airport surface to predict when congestion could occur (enabling capability). To refine the algorithm and prioritization of these capabilities, further field observations should focus on the frequency and conditions under which runway demand exceeds capacity, and further data analysis should focus on determining the ideal queue length that will properly balance incurred delay with the probability of missing a slot in the overhead stream (observations & analysis).

Once the causes have been mapped to capabilities, and tentative priorities have been assigned, the process should be iterated. That iteration may occur concurrently with prototype development or as a prior phase, depending on the development environment. Following up on those tasks will both help refine the algorithms underlying the capabilities, as well as inform their relative prioritization. Through this process, the critical TFDM capabilities and their enablers are identified and clearly mapped to measurable benefits. Often there are design choices to be made, for example between complexity, cost, and performance of the tool. Such tradeoffs can be explored using the general framework; Step 4b in Figure 3 is where the model of the future system allows these different trade-offs to be explored in the wider context of the benefits assessment activity.

## V. Summary

Benefits assessment is an important element in the investment analysis process of FAA air traffic control systems. This paper has described the methodology being used for benefits assessment of the TFDM air traffic control tower advanced automation system. The utility of the methodology has been illustrated using appropriate data analysis and discussion of the insights that can be gained from its application have been presented. Future work will build upon the concepts presented here to help guide the TFDM development process, and these will be presented in subsequent publications.

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