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What is This?

A Field Demonstration of the Air Traffic Control
Tower Flight Data Manager Prototype*

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The development and evaluation process of the Tower Flight Data Manager prototype at Dallas Ft. Worth airport is described. Key results from the first field evaluation are presented, including lessons learned about making electronic flight information acceptable to controllers. Iteration of the field evaluation methods are discussed for practitioner benefit.

INTRODUCTION

Integrating airport surface information into the air traffic management system has been prioritized by the Federal Aviation Administration (FAA) to enable goals of the Next Generation Air Transportation System (NextGen). Improved surface information would enable more efficient arrivals/departures at high density airports, increased flexibility in the terminal environment, and improved collaborative air traffic management, which are all critical to meet increasing demand for air travel (FAA, 2010). To address this issue, the FAA is considering investment in a Tower Flight Data Manager (TFDM) to improve detection, tracking, and presentation of surface operations and initiate an unprecedented level of electronic information exchange.

TFDM is an integrated technology suite of advanced surveillance, electronic flight data, and decision support information to realize the FAA's vision of a NextGen Air Traffic Control Tower (ATCT). In the current ATCT environment, there exist multiple individual displays and information systems to support the operation. TFDM seeks to combine many of these systems into a single platform. This not only reduces maintenance costs and information disparity, but also enables the systems to inform one another providing information (and possibly decision support) beyond that of merely combining the systems. In addition, by transitioning to exclusively electronic information about all the flight plans (unlike today's paper flight strips), this information could be shared more easily between multi-tower airports and benefit other air traffic control facilities needing knowledge of the surface operations.

This paper introduces the TFDM prototype and the initial field demonstration conducted in the summer (2010) to validate and refine the TFDM functional requirements for the production system that is planned to be deployed later in the decade. In performing the field evaluation, the methodology for assessing human-system interactions is evolving to ensure that TFDM meets controller needs both in today's environment and in the future. The first evolution of the human-system interaction methodology and the results yielded are discussed here.

TOWER FLIGHT DATA MANAGER (TFDM) PROTOTYPE

A prototype of the TFDM system has been developed by MIT Lincoln Laboratory (MITLL) to identify and validate functional requirements for the deployed TFDM system and to investigate the feasibility of integrating a subset of the key ATCT systems. Enabling the Tower controllers and managers to interact with the TFDM system are the surveillance display (Tower Information Display System, TIDS), the electronic Flight Data Manager (FDM), and the Supervisor Display. More detailed information about the HMIs is provided below.
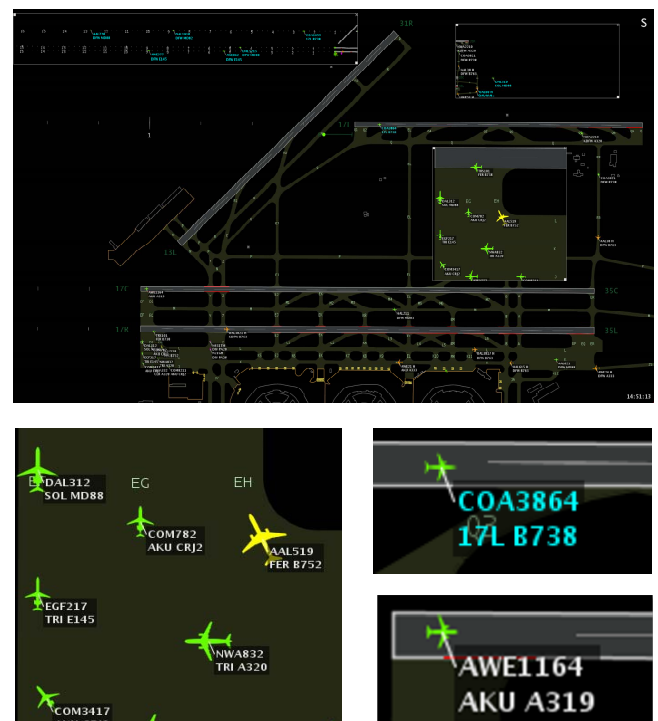

Figure 1: Tower Information Display System (TIDS).

Figure 1 depicts the TIDS surveillance display. TIDS is an enhancement of the ASDE-X surveillance display (McAnulty, Doros, & Poston, 2001) that was developed over a decade ago and is used in several of the busier ATCTs today. Advanced surveillance systems have been investigated by other groups in the past (e.g., Hannon, 2010), however this is the first time a system linking surveillance and flight data has been tested with current air traffic controllers in an airport tower. Besides

correcting state errors of the ASDE-X (e.g., spinning icons of stationary aircraft), TIDS also expands the types of icons used to represent surface traffic through color, size, and shape coding. This allows controllers to easily identify point-out characteristics to other flights and increase their situational awareness of aircraft characteristics that may affect separation requirements, even when visibility out the window is reduced. TIDS displays a visual datablock color change (white to cyan) when an aircraft becomes airborne, a significant flight state change to a Tower controller. One key and unique enhancement of this prototype's TIDS display is its linkage to the FDM display. For example, by left clicking a TIDS target, both it and the corresponding electronic flight strip on the FDM are highlighted.

The FDM, shown in Figure 2, is an electronic touchscreen replacement for the paper flight progress strips (FPSs). To ease transition to electronic flight data, a similar information layout was used for the Flight Data Entry (FDE), the electronic version of the FPS. The primary difference from the FPS is that the FDE has the ability to update based on new information and expand, displaying additional flight information. Interaction with the FDM can occur interchangeably by touch or by mouse. Entry of information into the FDM can be made through a physical keyboard or through a virtual keyboard that appears when editing.
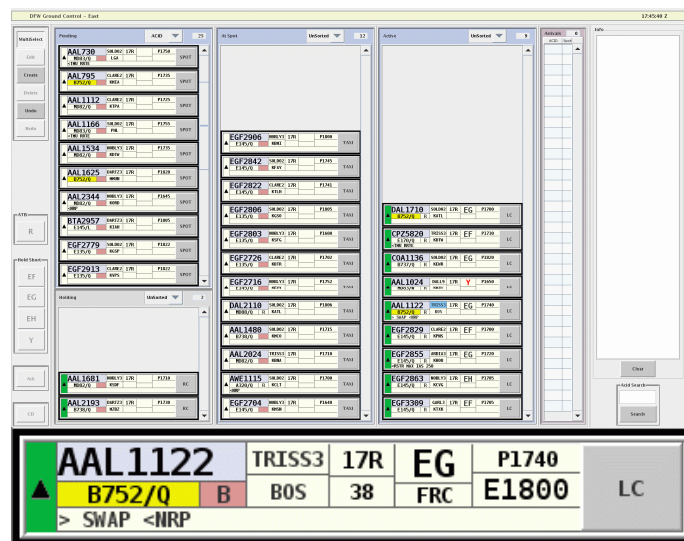

Figure 2: Flight Data Manager (FDM) and example Flight Data Entry (FDE) for AAL 1122.

Concerns have been presented about failing to account for the function of FPS positioning (e.g., "cocking" a flight strip as a visual memory aid) in electronic flight data (Durso, et al., 2008; Durso & Manning, 2003), thus efforts have been made to identify the functions these actions serve and to identify electronic substitutes. One example is that the status icon (on the left of the FDE) can be manually changed for any reason to indicate that the flight requires attention. Today, some controllers flip over a paper strip to ensure that the flight will not be cleared for takeoff accidentally. This action has a counterpart in the FDM allowing the FDE for that flight to be electronically "flipped" to hide the flight's data until it is "unflipped."

The previously mentioned linkage with the surveillance display also enables targets to be easily identified when FDEs are selected. Surveillance also allows the FDM to be automatically updated in some circumstances to reduce the "housekeeping" costs of maintaining electronic information. One example is that surveillance-based FDE movement automatically moves FDEs to the "Ready to Taxi" queue when an aircraft arrives at the entry point to the movement area, demonstrating readiness to receive taxi clearance. This reduces the requirement of the controller to search for this flight from amongst many FDEs, and also gives the controller a clear idea of the expected demand. More detailed descriptions of the Supervisor Display and the decision support tools (DSTs) will be deferred due to the fact that these functions were not demonstrated in the initial field demonstration, but descriptions can be found in Mehta, et al. (2010).

In addition to the new displays for tower air traffic controllers, the prototype encompasses a TFDM information bus (TIB), interfaces between TFDM and external data, and DSTs. The TIB is a net-centric data bus within which all TFDM information resides. The external data interfaces include connections to the surveillance systems (e.g., Airport Surface Detection Equipment (ASDE-X)), Flight Data Input/Output (FDIO) system, Traffic Flow Management System (TFMS), and airline data from the Flight Operations Centers (FOCs). The DSTs contain basic decision support functions including airport configuration, runway assignment, taxi routing, sequencing & scheduling, and departure routing. Initial versions of key interfaces and DSTs were tested at DFW in the spring of this year (2011) and analysis of those results is in progress. This paper will not discuss the DSTs, which were not included as a part of the DFW-1 prototype tested in 2010.

The purpose of MITLL's contribution to the TFDM program was to develop a functional prototype of the system and to validate an initial set of functional requirements for the production system. An initial requirements document was developed based on previously developed systems, the benefits case for expected decision support capabilities, and an investigation of the current tower information requirements. The prototype TFDM system was then built based upon the generated requirements. During development, a user group composed of nationwide ATCT managers aided the design team by evaluating design iterations, filling in appropriate design specifications, and suggesting potential new functional directions. The next stage of development involved validating the requirements by testing the prototype TFDM system in context of the ATCT operation. Examples of requirements that needed to be validated included the content of the FDE and that the FDM shall have a touchscreen capability.

The plan for TFDM prototype requirements validation includes both field demonstrations and human-in-the-loop (HITL) simulations. Field demonstrations allow validation of

the requirements with high construct validity using subject matter experts in their natural, real-time, environment. HITLs allow a experimentally controlled evaluation of the TFDM system using off-nominal scenarios and future traffic levels that are unlikely to occur in the field today.

Two field demonstrations of the TFDM prototype were recently completed at Dallas Ft. Worth (DFW) airport. The first demonstration (DFW-1) occurred in August and September of 2010. This demonstration succeeded in evaluation of the TFDM TIB, surveillance and flight data inputs, and the TIDS/FDM HMIs. The second demonstration (DFW-2) occurred in April and May of 2011. DFW-2 introduced basic DST capabilities, additional information inputs including weather, and the Supervisor Display. DFW-1 is the subject of this paper.

DFW-1 FIELD DEMONSTRATION

The purpose of DFW-1 was to evaluate TFDM performance using live traffic data, evaluate acceptability of the prototype functionality available at the time, evaluate usability and other human-system interactions, and identify potential TFDM benefits opportunities.

DFW-1 occurred in the Center Tower at DFW, which is normally used as an operational backup for the East and West Towers. Two control positions were supported in DFW-1: ground control (GC) and local control (LC). Figure 3 shows the TFDM setup for one of the positions in DFW-1. A third (non-touchscreen) FDM was setup on the other side of the Tower to allow a test team member (MITLL confederate) to perform the functions of the Tower's Flight Data position.
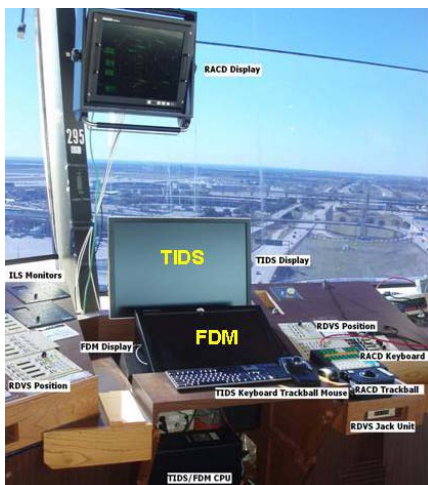

Figure 3: DFW Center Tower TFDM setup.

The demonstration itself took place 3 days per week for two weeks from 6:00a to 2:30p each day. Two DFW NATCA certified professional controllers participated in the evaluation and switched periodically between ground and local control positions. One DFW ATCT front line manager served as a demonstration observer and coordinator with the other DFW ATCTs. Each day of the demo, the MITLL test team

conducted a 30-minute training session to introduce the system to the participant controllers. Another 30 minutes was then spent familiarizing the controllers hands-on with the system, assisted by a test team member. Once comfortable, the evaluation portion of the demonstration began.

The main portion of the evaluation (approximately 5 hours) was conducted as a shadow operation of the DFW East Tower operation. Shadow operations required that the participant controllers issue verbal commands as if they were communicating with pilots, however these communications were never broadcast. Meanwhile, East Tower DFW controllers maintained control of the operation the entire time. Center Tower participants maintained the TFDM system, moving and notating FDEs as if they were maintaining separation without actually having separation responsibility.

Throughout the shadow operations, two observers were stationed at the ground and local control positions to answer controllers' questions about the system, to collect observation data and to issue awareness probes. Two observation logs were used. In one log, how the participants interacted with the FDM was recorded (touch, mouse, physical keyboard, virtual keyboard, input content) to evaluate whether the touchscreen capability was used and/or desired by controllers. In the other log, issues observed or participant comments made about the system were noted and coded (TIDS/FDM, problem/benefit, source of confusion/workload). Awareness probes were also issued in low-workload periods to test how useful the TFDM HMIs were in identifying task-relevant information. Throughout the shadow operation, observers asked the controllers to identify task-relevant information (e.g., to Local: "Where is AAL 101?" when the flight was on final approach to the runway) and recorded the information/display used, response accuracy and time to respond.

In addition to shadowing normal DFW East Tower operations, a flight check aircraft was used to follow scripted scenarios created specifically to test the usefulness of the existing TFDM functionality. Scripted scenarios included the aircraft going around on an approach, side-stepping to a parallel runway for landing on approach, taxi non-conformance, and changing departure route during taxi. During these scenarios, participants were timed between when the scenario occurred and when they noticed the abnormality. The displays used to identify information were also noted. East Tower controllers were completely aware of the scenario script and the flight check aircraft, but participant controllers were not notified.

After completion of the shadow operations and scenarios, participants were asked to complete system evaluation questionnaires using a online survey on the TIDS, FDM, and the integrated TFDM system. Finally, a 30 minute joint discussion with both participants about the system was held with the field evaluation team and facilitated by the test director in order to collect impressions of the system, areas for improvement, and suggestions for future functionality.

FIELD DEMONSTRATION RESULTS

Extensive field results were obtained from the two-week demonstration. Although results about system performance and reliability were collected for the field demonstration, the focus here will remain on controller acceptance and controller performance with the prototype.

TFDM Performance Acceptability
In survey results, 90% of participants responded that they felt TFDM displayed information was mostly accurate, with over 50% responding that the information presented was completely accurate. The primary accuracy complaint was the delay in the airborne status indication on the flight's datablock, which did not occur until the flight reached approximately 200 ft in altitude because of limitations inherent to the beacon response from the aircraft transponder.

TFDM Functionality Acceptability
Using observations and discussion/survey feedback, information was also gathered about the functionality that was or should be exhibited by TFDM, shown in Table 1 below. The primary functionality suggestions made by the participants are noted in the table below with the number of controllers who suggested it (out of a total of 12 controllers). One overall TFDM suggestion included the need to further utilize information integration to improve decision support (e.g., once an arrival is within 1nm of threshold, indicate on the crossing flight's FDE that no clearance should be given to a flight preparing to cross the runway). There were also discussions involving their concerns about future functionality such as if weather overlay information would clutter the TIDS and potential acceptable mediations for it.

Example TFDM Functionality Recommendations	Controllers recommending (out of 12 total)
TIDS	
Recommended a touchscreen interface	4
Add airline updated "spot" destination to arrival datablocks	3
Integrate ARTS data into TIDS display (only ASDE-X for DFW-1)	2
FDM	
Provide means of drawing attention to particular fields on the FDE, automatically if possible (e.g., indicating an unusual runway assignment, low altitude)	10
Need ability to ideally manipulate (but at least view) Local Control's FDEs on Ground Control FDM	7
Provide means of drawing attention to particular FDEs (i.e., ability to "cock" the FDE)	7
Indicate on FDE when an action needs to be taken (e.g., EDCT near expiration)	4

Table 1: Example TFDM Functionality Recommendations

TFDM Human Machine Interfaces Acceptability
There were also a significant number of comments and suggestions for the TFDM computer-human interfaces specifically, examples of which are shown in Table 2. Both TIDS and FDM were rated 4.5 out of 5 as "beneficial to Tower operations" on average across the 12 participating

controllers. Controllers considered TIDS easy to learn, easy to use, and particularly appreciated the linkage with the FDM. The TIDS was considered a substantial improvement over the ASDE-X display. Participants positively viewed the touchscreen functionality of the FDM display. Logging of how participants interacted with the FDM revealed that touchscreen was used equally as often as mouse on ground control, and touchscreen was used even more often on local control. They also appreciated the surveillance-based FDE movement, which simplified their display maintenance tasks. Electronic transferring of flight data was also viewed positively. Examples of specific usability and display recommendations are listed in the table below.

Example TFDM Human-Machine Interface Recommendations	Controllers recommending (out of 12 total)
TIDS	
Wake timer correction (needs ability to time for either 2 or 3 min)	8
Reduce difficulty in panning display	3
FDM	
Surveillance-based FDE movement needs improvement (capture traffic on taxiways Y, Z, B, & A and FedEx ramp area)	6
FDE information needs modification (add beacon code, add requested/final altitude)	6
Provide means of changing taxiway assignment on LC FDM	5
Reduce difficulty of scanning/scrolling Pending queue on GC FDM	4

Table 2: Example TFDM HMI Recommendations

Situation Awareness and Workload
The situation awareness probes enabled insight into the displays used to locate flights and if there were any display impediments to locating a flight. All flights except for one were accurately located by the participants. The response times ranged from less than 1 sec (1 response) to exceeding 15 sec (6 responses). The majority (51 responses) fell into the 1-5 sec time range, and ground control positions located flights more quickly (average 4.6 sec) than local control (average 5.9 sec). The excessive response times were explained by the participants: "I would have never had to communicate with that flight" or the flight had not yet entered Tower airspace. Controllers responded that the displays supported the scenarios sufficiently aside from the go-around (pilot normally alerts controller), aborted takeoff, taxi route deviation (taxi non-conformance prompt is planned for future prototypes), and incorrect beacon code (the issue could be recognized on the TIDS datablock, but beacon code was subsequently added to the FDE for DFW-2). Controllers rated that the FDM positively aided in recognizing a flight plan amendment (any changes to FDE fields changed the field blue until acknowledged).

Workload was assessed qualitatively for this field demonstration. An observational comparison was made between how quickly the participant completed tasks and responded to aircraft and how quickly the controlling East Tower controller performed these functions. In situations in

which there appeared to be higher workload, the shadow controllers would fall behind on pilot responses (or stop responding completely) and would fall behind on display maintenance tasks, such as updating ATIS reported on the FDE. Display interactions that were observed to lead to controller workload were noted by staff to address in future TFDM prototypes. Examples of interactions causing higher workload and the subsequent TFDM mediation are described in Table 3 below.

Workload-inducing interaction with HMI	TFDM requirements/specification modification
Too much time spent filtering West Tower flights (participants only controlling DFW East Tower traffic)	Improving filtering, adding means to transfer flight control to West side
Difficulty searching for a flight	• Capture traffic on taxiways A, B, X, Y and in Fed Ex ramp area in surveillance-based FDE movement • Search function should extend not only within one's own FDM, but throughout TFDM • Widening scroll bars for touch scrolling
Difficulties editing FDEs or typing information	• Capture traffic on taxiways A, B, X, Y and in Fed Ex ramp area in surveillance-based FDE movement • Search function should extend not only within one's own FDM, but throughout TFDM

Table 3: TFDM requirements/specification modifications based on workload observations.

DISCUSSION & LESSONS LEARNED

The goals of DFW-1 were accomplished in this first field demonstration. The TFDM prototype was found to be acceptable by controllers. However, they did have several suggested improvements to ensure that the prototype is operationally usable as it evolves into a production level HMI. A critical requirement for TFDM appears to be to find a balance of using the enabled linkages (e.g., surveillance with flight data) to minimize "housekeeping" workload present with the electronic information without crossing the boundaries into controllers' decisions and over-automating.

One example was a TFDM design decision to automate FDE movement of flights who were ready to receive taxi clearance, but NOT automating FDE movement of flights who were detected by surveillance as "line up and wait." "Line up and wait" is a clearance that is accompanied with certain privileges and it is not exclusively a physical position on the runway threshold, thus a controller decision should still be required to move the FDE. Similarly, using integrated information to provide additional safety functions or decision support to increase efficiency is also important to controllers. The key to acceptance of electronic flight information is to maximize the added benefit to ensure additional workload of maintaining information currency is outweighed. The controller suggestions from DFW-1 were used a basis for revising the TFDM functional requirements and design specifications. The key suggestions have already been incorporated into the next iteration of the TFDM prototype which was evaluated with

additional functionality of the DSTs and Supervisor Display during DFW-2.

In addition to the design changes identified in the field demonstration, several methodology issues for collecting controller interaction data with the system were identified. The TFDM prototype development team was fortunate to have extensive access to data collection in a field environment. One challenge resulting from this was to piece together separate screen shot movies from the TIDS & FDM, video of the controllers looking out the window and interacting with the displays, East Tower audio recording, as well as each individual observer's logs. During analysis it became difficult to recreate a complete picture of the context. In response, MITLL's human-system integration team has developed a system allowing an analyst to view data jointly to aid in quantification of performance data. The data playback system enables an analyst to identify a time of interest and then jump to that point in the data and playback the video and audio sources above simultaneously to capture the data of interest. This system has been prepared and used for DFW-2 data analysis.

One method that worked particularly well was the shadow observation itself. By having two similarly trained controllers performing the same task at the same time, workload issues due to prototype use became particularly evident to observers. Thus, during DFW-2 use of the data playback system will enable a more quantitative analysis of the system issues causing the participant controller to fall behind his or her East Tower counterpart.

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