A Preliminary Investigation of Tower Flight Data Manager Safety Benefits[*]

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ABSTRACT

Improvements to current air traffic management technologies and techniques are required to move toward the next generation air transportation system (NextGen). The Tower Flight Data Manager (TFDM) is a prototype air traffic control system consisting of the: (1) Flight Data Manager (FDM) facilitating interaction with electronic flight data, (2) Tower Information Display System (TIDS) providing enhanced surveillance information, and (3) Supervisor Display providing a means for front line managers and traffic management coordinators to interact with strategic and tactical planning and decision support tools. Given that TFDM aims to enable safe and efficient operations under NextGen, it is critical to analyze potential safety impacts and determine what types of real-world safety issues can be prevented or mitigated by TFDM. With this goal in mind, we reviewed 560 National Transportation Safety Board (NTSB) and Aviation Safety Reporting System (ASRS) reports focusing on commercial air carrier operations over a five-year period. Over 100 reports were deemed relevant to TFDM and further analyzed to determine the likelihood that these safety-related events could have been mitigated or prevented by the key TFDM capabilities outlined above. A systematic method for generating probabilistic estimates of benefits for a technology not yet deployed was utilized to produce effectiveness ratings for the various TFDM

components.

1   INTRODUCTION

Improvements to current air traffic management technologies and techniques are required to move toward the next generation air transportation system (NextGen). Over the next several decades, the Federal Aviation Administration (FAA) projects a significant increase in air traffic in the National Airspace System (NAS). Existing air traffic control towers will need to manage this growth while meeting NextGen targets for safe and efficient surface operations. The Tower Flight Data Manager (TFDM) is a prototype air traffic control system designed to help address these needs. TFDM's consolidated display system consists of the:

(1) Flight Data Manager (FDM) facilitating interaction with electronic flight data (Figure 1a). Most towered airports will receive the FDM to support the electronic distribution and tracking of flight data and clearances, supporting situation awareness and reducing workload associated with maintaining an accurate picture of the traffic situation in increasingly complex circumstances.
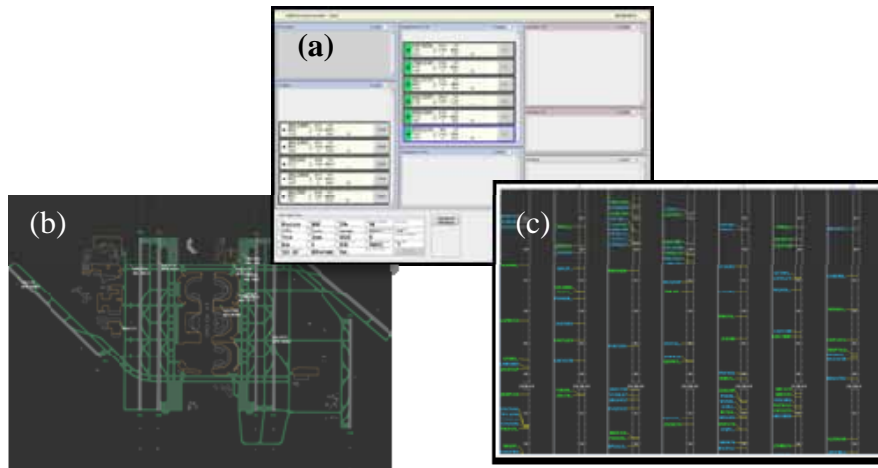

Figure 1 (a) Flight Data Manager (FDM); (b) Tower Information Display System (TIDS); and (c) Supervisor Display.

(2) Tower Information Display System (TIDS) providing enhanced surveillance information (Figure 1b). Airports with surface surveillance capabilities (i.e., Airport Surface Detection Equipment, Model X (ASDE-X)) will also

receive the TIDS and therefore benefit from enhanced processing of surveillance data, enabling both intent and state-based conflict detection.

(3) Supervisor Display providing a means for front line managers and traffic management coordinators to interact with strategic and tactical planning and decision support tools (Figure 1c). These tools (e.g., taxi conformance monitoring) will be introduced at key airports to allow controllers to monitor and manage traffic more effectively and to provide advance notice of hazardous situations.

Given that TFDM aims to enable safe and efficient operations under NextGen, it is critical to analyze potential safety impacts and determine what types of real-world safety issues can be prevented or mitigated by TFDM. With this goal in mind, we conducted a data-driven safety assessment involving a comprehensive review of aviation accident and incident databases to determine the likelihood that these safety-related events could have been mitigated or prevented by the key TFDM capabilities outlined above. Similar assessments have been conducted for other aviation systems such as Runway Status Lights (RWSL; Wilhelmsen, 1994). In this paper, we report the number of safety-related events deemed relevant to TFDM by controller position, weather conditions, flight phase and contributing factor (e.g., decision error, adverse mental state) to provide contextual information regarding the types of incidents that can be addressed by TFDM. A systematic method for generating probabilistic estimates of benefits for a technology not yet deployed was then utilized to produce quantitative effectiveness ratings for the phased TFDM components.

2   METHOD

We utilized archived accident and incident data maintained by the National Transportation Safety Board (NTSB) and Aviation Safety Reporting System (ASRS) to determine observed frequencies of safety events. NTSB reports represent thorough investigations of events associated with the operation of an aircraft where any person suffered death or serious injury or any aircraft received substantial damage. ASRS reports are subjective accounts about safety-related aviation events voluntarily submitted by pilots, air traffic controllers, and other aviation industry personnel. Although subject to limitations related to sampling and reporter bias (Chappell, 1994; Degani *et al.,* 1991), reported incidents provide valuable qualitative information regarding the types of hazards, accident precursors, and safety-related issues that could potentially be prevented or mitigated by TFDM.

We specifically reviewed Part 121 accidents/incidents that occurred over a five-year period between January 2005 and December 2009, focusing on Part 121 operations as they represent scheduled commercial air carriers generally operating out of controlled airports. Only completed NTSB investigations and ASRS reports submitted by tower air traffic controllers were utilized to ensure more accurate reporting of causal factors. These selection criteria produced a total event count of

560 (NTSB: 247; ASRS: 313).

   A coding spreadsheet was developed to collect relevant data (e.g., airport, tower position) from each of the selected reports. Contributing factors were inferred by the analyst given information provided in the individual reports, and were systematically categorized according to the Department of Defense (DoD) Human Factors Analysis and Classification System (HFACS; Wiegmann and Shappell, 2001, 2003; DoD, 2005), presented hierarchically in Figure 2.
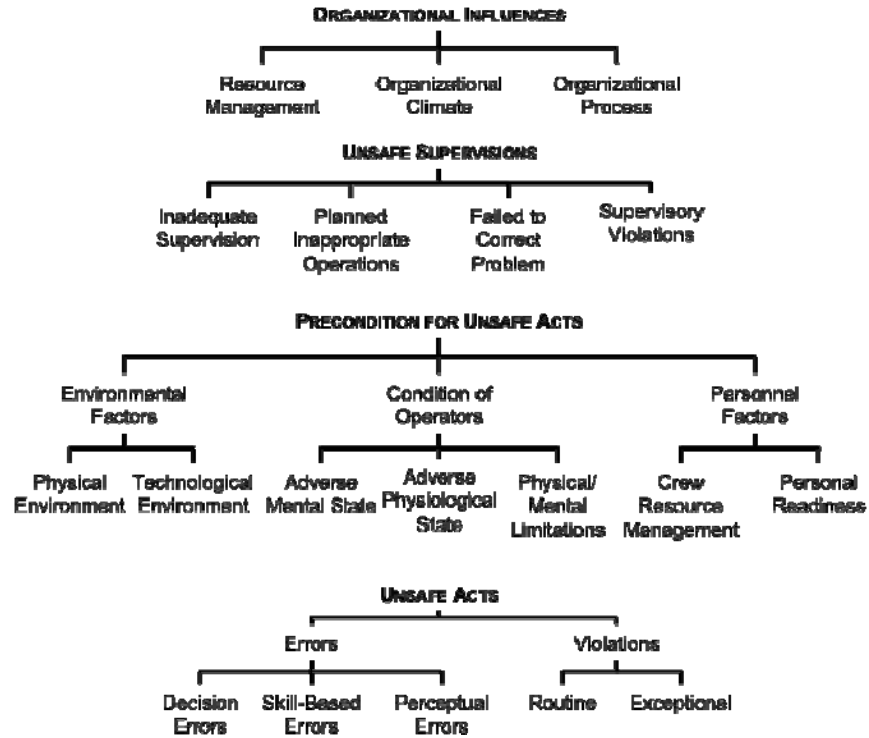

Figure 2 HFACS Codes (adapted from http://hfacs.com/about-hfacs-framework).

   It is often the case that accidents and incidents involve multiple failures lining up across various system layers due to failed or absent defenses. Within an air traffic control context, latent failures in the "organizational influences" layer may involve inappropriate processes or a climate conducive to complacency. While TFDM does not directly address organizational influences, this layer is critical in that it can impact performance at all other levels. The next layer refers to "unsafe supervision" and captures strategic issues such as planned inappropriate actions (e.g., maintaining or choosing an airport configuration not aligned with environmental constraints). Decision support tools provided through the TFDM Supervisor Display provide support for this layer. Moving to the next layer in the model, "preconditions for unsafe acts" includes both environmental (e.g., reduced visibility) and operator state (e.g., high workload, low situational awareness)

factors. TFDM provides defenses at this layer through improved surveillance and the consolidation of stove-piped systems, allowing easier access to information. The final opportunity for accident prevention is captured by the "unsafe acts" layer where errors or violations may take place. Decision errors (e.g., decision to issue takeoff clearance while another aircraft is landing) and perceptual errors (e.g., misjudging aircraft location) occur at this layer and are targeted by many aspects of TFDM. Electronic flight data, for example, tracks aircraft state and provides earlier alerting to potentially hazardous conditions (e.g., runway incursions). In addition, decision support tools provide tactical support for monitoring the airport surface and alerting the controller to situations in need of attention (e.g., taxi non-conformance).

A systematic method for generating probabilistic estimates of benefits for a technology not yet deployed (Barnett and Paull, 2004) was then utilized to produce effectiveness ratings for TFDM components. An aviation human factors expert with piloting experience rated the likelihood that individual safety-related events could have been mitigated or prevented by TFDM components. The TFDM components were considered incrementally according to planned implementation phasing; namely, consolidation and electronic flight data, improved surveillance and conflict detection, and decision support tools. Specifically, the rater considered three questions for each analyzed incident:

(1) Would the availability of consolidated/integrated systems and electronic flight data have prevented the event?
(2) Would the availability of consolidated/integrated systems and electronic flight data plus improved surveillance/conflict detection have prevented the event?
(3) Would the availability of consolidated/integrated systems and electronic flight data plus improved surveillance/conflict detection and decision support tools have prevented the event?

Responses to these questions were provided along a five-point scale ranging from "almost definitely no" to "almost definitely yes" with intermediate responses of "probably no," "50/50," and "probably yes." These responses were translated into probabilities as follows:

- Almost Definitely No   0%
- Probably No   25%
- 50/50   50%
- Probably Yes   75%
- Almost Definitely Yes   100%

This method allowed for calculations of incremental effectiveness per TFDM component as well as an aggregate effectiveness rating of the TFDM system as a whole.

3   RESULTS AND DISCUSSION

Following a thorough review of the 560 accident reports meeting the selection criteria defined previously, a subset of the reports were found to be relevant to the

TFDM safety analysis. 129 of the reports (25 from the NTSB database and 104 from ASRS) were considered relevant to TFDM. Fifty airports were represented in the reports deemed relevant to TFDM. The median number of analyzed events per airport was one, with a range of one to 14 (five ASRS reports did not indicate airport).

Table 1 presents the number of NTSB and ASRS accident and incident reports associated with various tower positions, weather conditions, and phases of flight. With respect to tower position, an overwhelming majority of analyzed events included a local controller (note that incidents may have involved more than one controller position). The local controller is responsible for the active runway surfaces, clearing aircraft for takeoff or landing and ensuring that prescribed runway separation exists at all times. Although the time spent taking off and landing represents a small portion (~6%) of the total time spent in flight, over half of all accidents occur during the takeoff and landing phases (Boeing, 2011). In looking at the breakdown of contributing factors specific to the local control position, the vast majority of cases involved adverse mental states (e.g., high workload; 47) and decision errors (e.g., inappropriate takeoff clearance; 39), reflecting the complexity involved with operations during the takeoff and landing phases. Other key contributing factors to analyzed incidents involving a local controller include the technological environment (e.g., system failures; 26), skill-based errors (e.g., visual scanning disruptions; 23), and the physical environment (e.g., inclement weather; 22).

Table 1 Tower position, weather condition, and flight phase summary results by database.

	# of Reports		
	NTSB	**ASRS**	**Combined**
Tower Position			
Ground	10	17	27
Local	18	92	110
Local Assist	1	1	2
Supervisor	1	11	12
Weather Condition			
VMC	23	83	106
IMC	2	11	13
Marginal	0	4	4
Not Reported	0	6	6
Flight Phase			
Taxi	23	37	60
Takeoff	17	70	87
Climb	0	12	12
Approach	1	8	9
Landing	8	39	47

The majority of analyzed safety events occurred during visual meteorological conditions (VMC). In interpreting these findings, it is important to keep in mind the percentage of time spent in VMC versus instrument meteorological conditions (IMC) at any given airport. For example, the FAA reported that in 2004, Atlanta (ATL) spent 73% of the time in VMC, 16% of the time in marginal VMC, and 11% of the time in IMC (Kang et al., 2007). Assuming similar distributions at other airports, it would be expected that a larger number of safety-related events would occur under VMC than IMC simply due to the amount of time spent under these conditions. With respect to contributing factors, adverse mental states (49) and decision errors (41) account for the vast majority of safety-related events during VMC, while the physical environment (8) was the biggest contributing factor during IMC.

Analyzed incidents represent the full range of tower operations in terms of phase of flight. It is clear from Table 1 that the majority of safety events involved at least one aircraft that was taking off (note that events involving multiple aircraft may represent more than one phase of flight). As mentioned previously, over half of all accidents occur during the takeoff and landing phases. Interestingly, more safety-related events occurred during the taxi phase than during landing across our analyzed incidents. Adverse mental states (44) and decision errors (43) are the leading contributing factors during the takeoff phase, while adverse mental states are most implicated during the taxi (32) and landing (17) phases. There are no clear trends for contributing factors during the climb or approach phases of flight.

As discussed previously, contributing factors to analyzed incidents were classified according to HFACS codes, the results of which are shown in Figure 3. Nine of the 19 HFACS codes were identified as relevant to the TFDM safety assessment. All safety events were associated with at least one HFACS code, with a range from 1 to 4 HFACS codes per incident (mean = 1.8). There appear to be three natural groupings of contributing factors in terms of their frequencies in contributing to analyzed incidents. Decision errors and adverse mental states comprised the majority of coded safety-related events. Skill-based errors and both the physical and technological environments form the second grouping. Perceptual errors, adverse physiological states, crew resource management, and planned inappropriate operations form the final grouping. From a human factors perspective, the breakdowns across these contributing factors could be utilized to drive design requirements in future systems to ensure that proposed solutions (technological or otherwise) actually address existing safety threats. For example, the high frequency of decision errors contributing to safety-related events points to the need for improved decision support systems within the air traffic control tower.
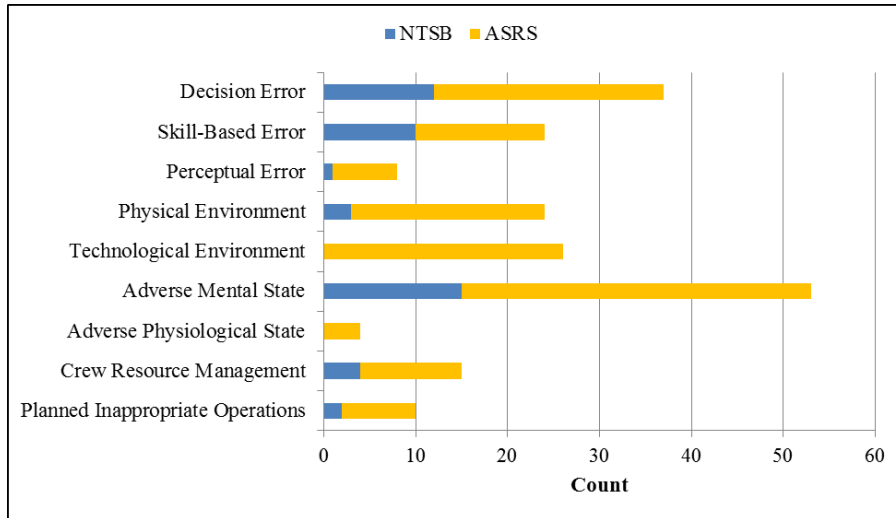
Figure 3 Contributing factors results by database.

Table 2 summarizes the aggregate effectiveness results (averaged over all NTSB and ASRS accidents/incidents considered) according to incremental benefits provided by a phased implementation of TFDM components. TFDM core implementation involving the consolidation of systems as well as the availability of electronic flight data has an estimated effectiveness of 25% in preventing or mitigating analyzed incidents. An example incident that could have been prevented or mitigated by electronic flight data is the Boston 2005 runway incursion (NTSB event ID 20050624X00863) in which two aircraft (EIN132, USA1170) were cleared for takeoff on intersecting runways within five seconds of one another; the FDM would have alerted the controller when the second aircraft (USA1170) was cleared for takeoff and the controller would have been able to immediately cancel the takeoff clearance.

Table 2 TFDM effectiveness ratings

TFDM Component	Estimated Effectiveness Rating
Consolidated/integrated systems and electronic flight data	25%
Plus improved surveillance/ conflict detection	42% increment
Plus decision support tools	15% increment
Total Effectiveness Rating	82%

Adding improved surveillance provides an average incremental effectiveness of 42%. Enhanced conflict detection enabled by this capability could have prevented or mitigated the San Francisco 2007 runway incursion (NTSB event ID

20070610X00701) in which the controller forgot about a landing aircraft (SKW5741) and cleared another aircraft (RPA4912) for takeoff on an intersecting runway. TFDM would have alerted the controller when RPA4912 was cleared for takeoff given surveilled information indicating that SKW5741 was crossing the landing threshold of the intersecting runway. Finally, adding decision support tools provides an average incremental effectiveness of 15%. An example incident that would have been prevented by a decision support tool is the Denver 2007 runway incursion (NTSB event ID 20070110X00037) in which an aircraft (LYM4216) missed its taxiway turn due to inclement weather and ended up turning onto an active runway on which another aircraft (FFT297) was attempting to land. Taxi conformance monitoring, specifically, would have alerted the controller to this situation when LYM4216 missed its intended taxiway. In total, full implementation of TFDM reveals an effectiveness of 82% in preventing or mitigating safety-related events across analyzed incidents.

4   CONCLUSIONS

This research involved analyzing a subset of NTSB and ASRS reports to determine the likelihood that these safety-related events could have been mitigated or prevented by any of three key TFDM capabilities: (1) consolidation/integration of systems and electronic flight data; (2) improved surveillance; and (3) decision support tools. The findings from this preliminary investigation of TFDM safety benefits indicate that while all three capabilities provide safety benefits in and of themselves, the largest impacts would be realized through the introduction of improved surveillance and enhanced conflict detection via the TIDS. In addition, the findings related to contributing factors, in particular, could be utilized to drive design requirements in future systems to ensure that proposed solutions (technological or otherwise) actually address existing safety threats. Next steps in this research could include expanding the sample size of accident/incident data by examining operational error data (i.e., FAA Operational Error/Deviation System), increasing the time period of interest, and looking at other aviation operations (e.g., Part 129 foreign air carriers, Part 135 air taxi and commuter, and Part 91 general aviation). Importantly, the safety benefits associated with TFDM capabilities are intrinsically linked to the nature of the accidents/incidents contained in the sample of analyzed reports. Expanding the sample size could greatly influence the incremental benefits associated with those capabilities.

The systematic approach used to estimate the effectiveness of TFDM components can be extended to other prospective NextGen systems, as well as to other domains (e.g., medical) in which archived safety-related data are available. To the extent that safety-related data can be represented as actual costs, efforts could be made to monetize safety benefits associated with the prevention of relevant accidents. Furthermore, effectiveness ratings and monetized values could be utilized in conjunction with extrapolation protocols to estimate potential safety benefits in

future years. We are currently in the process of monetizing safety benefits associated with the implementation of TFDM over its expected 2015-2035 lifetime.

ACKNOWLEDGMENTS

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