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# EVALUATION OF A FLIGHT DECK-BASED MERGING AND SPACING CONCEPT ON EN-ROUTE AIR TRAFFIC CONTROL OPERATIONS

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## Abstract

In an effort to reduce aircraft maneuvering, noise, fuel burn, and controller workload, the Federal Aviation Administration (FAA) is developing, and UPS plans to implement, an Automatic Dependent Surveillance-Broadcast (ADS-B) concept termed Merging and Spacing (M&S). M&S has two phases: a strategic set-up by a ground operator followed by tactical Flight Deck-Based Merging and Spacing (FDMS). This paper focuses on FDMS and presents the subjective and objective results of a MITRE human-in-the-loop simulation that examined FDMS from an air traffic controller perspective. The simulation is part of a development and maturation process that is underway for FDMS. The simulation was designed to examine the impact of FDMS on the following en route controller topics: traffic efficiency, voice communications load, safety, workload, and situation awareness. The simulation has been termed FDMS 1 and was conducted in May and June of 2006. Results indicated general acceptability and improvements over current-day operations under normal and non-normal conditions. In comparison to current-day operations, FDMS showed a reduction in: the number of controller-issued maneuvers, the number of communications, and workload. A reduction of situation awareness was not observed. These results will be used to further refine the concept and to focus future simulations as the application moves toward operational approval.

## Background

Aircraft arriving at an airport typically originate from numerous departure points and traverse different routes prior to merging into an arrival stream. This convergence is often necessary for an orderly delivery to the arrival and approach, and is accomplished through merging at downstream en route or terminal area waypoints. In order for the merge to be successful, aircraft on the routes to be joined must be synchronized in time and have sufficient spacing to allow for other aircraft to fit into the overall flow while maintaining, at least, the minimum required separation between aircraft.

Air Traffic Control (ATC) must merge the flows and maintain the separation standards while maneuvering the aircraft to meet restrictions from downstream sectors. Miles-in-trail (MIT) or metering restrictions (meter fix times) are often put in place to absorb delays when the downstream sector or an airport is predicted to be or is currently congested due to conditions such as weather or the volume of traffic [1]. MIT restrictions can also be put in place to meet spacing requirements for procedures such as Continuous Descent Arrivals (CDAs) that require a minimum spacing between aircraft pairs prior to flying the arrival.

Traditionally, spacing is not achieved during the en route phase of flight prior to top of descent. Controllers do not currently have the appropriate tools to efficiently plan the flow into the terminal area across multiple centers. If spacing cannot be achieved early on in the flight and MIT restrictions are in place, vectors are typically used to adjust in-trail spacing or to avoid conflicts since speed changes are often inadequate to effect the spacing within the sector [2]. Instead of being able to direct an aircraft to maintain a specific in-trail spacing interval, controllers must provide specific instructions, or instruction sequences, in order to achieve their goal. This process can be workload intensive for controllers and pilots and can also increase fuel consumption and flight time.

In the United States (US), the FAA is developing, UPS plans to implement, and Aviation Communication & Surveillance Systems (ACSS) is building equipment to support an Automatic Dependent Surveillance-Broadcast (ADS-B) concept termed Merging and Spacing (M&S). M&S is intended to allow flight crews, ATC, and airlines to efficiently achieve and maintain a desired spacing between aircraft pairs from the en route phase of flight down to the runway threshold. The goal of the initial implementation is to avoid downstream vectoring and speed changes by having the Airline Operations Center (AOC) set up spacing among a chain of aircraft pairs early on in the flight, and then to give flight crews the ability to maintain their spacing using on-board equipment



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through the arrival and approach in a manner consistent with today's Instrument Flight Rules (IFR) procedures and criteria.

The initial UPS planned implementation of M&S will occur in a low density, late night environment and comprises two phases: a strategic ground setup phase and a tactical flight deck phase. The first phase is termed Airline Based En-Route Sequencing and Spacing (ABESS). It consists of the AOC using a new tool to determine the desired sequence and spacing at a common merge fix for its arrival flow. Once the sequence and spacing intervals are determined, the AOC sends speed commands to company aircraft via the Aircraft Communications Addressing and Reporting System (ACARS) that flight crews will follow to achieve the desired goal. As the flight crew approaches the merge fix, the AOC will uplink an advisory that includes, at minimum, the Traffic To Follow (TTF) flight identification, the spacing interval in seconds, and the common merge waypoint for the aircraft pair. After the flight crew inputs this information into the on-board systems, the operation can transition to the second phase, designated as Flight Deck-Based Merging and Spacing (FDMS).

FDMS allows for more active flight crew participation in achieving the desired spacing interval of an AOC and ATC. The main objective is to achieve consistent, low variance spacing between aircraft pairs during arrival operations through flight deck-originated speed adjustments. It uses on-board equipment to calculate and display information that allows a flight crew to manage their speed to achieve a desired spacing interval at and beyond a merge fix. Speed changes are exclusively used to achieve the desired spacing; use of vectoring or heading changes via flight deck equipment is not part of this initial FDMS implementation. Pairs of FDMS aircraft can be formed into linked chains by allowing a trailing aircraft in one pair to be a TTF for its following aircraft, provided that all aircraft in the chain are appropriately equipped.

M&S is expected to provide several benefits for airline operators, air traffic managers, and controllers. When an airline can use minor speed adjustments to ensure consistent and predictable spacing, controllers should be able to reduce the number of interventions they need to make with the traffic. Reduced maneuvering saves the airlines time and fuel, and should also reduce controller workload. Fewer necessary controller interventions should also result in fewer calls to aircraft, which lessens the load on the communications frequencies. If M&S helps controllers handle the current traffic streams more efficiently, they may be able to handle additional aircraft in their sector and airspace capacity could potentially be increased.

To take advantage of these benefits, UPS plans to implement M&S at its main hub at Louisville International Airport – Standiford Field (SDF). UPS currently has its Boeing 757 / 767 fleet equipped with ADS-B and Cockpit Display of Traffic Information (CDTIs) for traffic awareness [3]. FDMS builds on this current equipage and allows for more efficient and consistent CDA operations.

M&S is being matured in a FAA-sponsored development group that is supported by organizations such as the FAA, UPS, ACSS, Boeing, Honeywell, National Aeronautics and Space Administration (NASA), Eurocontrol and MITRE. MITRE is executing a series of human-in-the-loop simulations to evaluate this initial implementation from the perspectives of pilots and controllers, in both the en-route and terminal domains. This paper presents the results of the first HITL simulation of FDMS as defined by [4]. The simulation was intended to provide an initial evaluation of the impact on en-route controller operations under both normal and non-normal conditions.

# FDMS Operational Concept

To establish a hierarchy for applications fielding and to help define the tasks and responsibilities of pilots and ATC, a joint US and European group [5] developed four categories for Airborne Surveillance Applications (ASA): Airborne Traffic Situation Awareness, Airborne Spacing, Airborne Separation, and Airborne Self-Separation. FDMS has been developed as an Airborne Spacing application, which requires flight crews to "achieve and maintain a given spacing with designated aircraft…Although the flight crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged" [5]. This differs from Situation Awareness applications where pilots are simply using the CDTI to enhance their understanding of the traffic picture. It also differs from Separation applications where separation responsibility is transferred from ATC to the flight deck. Later implementations of FDMS may involve such a transfer, but Spacing applications are expected to be more appropriate initial implementations.

FDMS builds on similar concepts being explored and developed in other research facilities such as Eurocontrol (as CoSpace [6]), NASA Langley (as Airborne Merging and Spacing for Terminal Arrivals (Airborne Merging and Spacing for Terminal Arrivals (AMSTAR) [7]), and NASA Ames (as Trajectory-Oriented Operations with Limited Delegation (TOOWiLD) [8]). These



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concepts have a more active ATC role, but are very similar to FDMS. The international Requirements Focus Group (RFG) is also defining a similar concept termed Enhanced Sequencing and Merging [9].

### *Conduct*

FDMS begins when aircraft are merging at a common fix in the en-route environment, having been previously sequenced and spaced by the ABESS setup phase. Prior to the merge fix, the AOC delivers the FDMS initialization advisory via ACARS. The AOC can initially be the entity providing this information, since the test environment is late night / low density, and consists mainly of UPS aircraft. Later implementations in higher density environments will require ATC to deliver this information.

Once received, the flight crew inputs this information into their on-board systems, engages FDMS, and then receives the first FDMS speed command (CMD) via a CDTI or other display. Flight crews follow the CMDs to achieve the desired spacing interval at the merge fix and then maintain that interval until the final approach fix. At this point, CMDs are no longer provided and the flight crew configures normally and slows to their final approach speed.

### *ATC Responsibilities and Procedures*

The initial FDMS implementation is designed to be as transparent as possible to ATC. Controllers will be informed when FDMS is being conducted, but are not expected to need to know details such as specific aircraft pairings and target spacing intervals. As noted in [10], they should not require any new tools to facilitate the operation.

The controller's responsibility for separation does not change when FDMS is being conducted. ATC will monitor and maintain separation for all aircraft at all times. As they do normally, they will receive and, if appropriate, clear the flight crews for any heading or speed requests. ATC will not give specific clearances for FDMS but will for the routing and arrival procedures.

The spacing interval targeted by FDMS aircraft should approximate the interval desired by the controller prior to handoff to a downstream sector as well as that needed in the terminal area and upon landing. If the ATC-required spacing is different from that being provided by FDMS, controllers will intervene as they do today to achieve their desired spacing. ATC-initiated speed or heading instructions essentially stops FDMS for those aircraft. If the aircraft is able to resume its speed or rejoin the routing of other FDMS aircraft, FDMS could be re-initiated. The specific conditions and procedures for this case are still under development.

ATC will be expected to prevent non-participating aircraft from interfering with FDMS operations to the extent possible. For example, if a controller desires to resolve a situation between two aircraft and does not have a clear preference for which aircraft path to modify, the controller would be expected to intervene with the non-FDMS aircraft. ATC is also expected to avoid instructions contradictory to FDMS operations, unless necessary. For example, ATC would not be expected to offer routing that conflicts with the FDMS routing, e.g., ATC should not offer direct routing to shorten the defined arrival procedure. In order for ATC to fulfill these desired outcomes, it will need to have an understanding of the goals and desires for FDMS operations.

## Simulation

In order to help mature FDMS prior to implementation, MITRE developed and executed an en-route ATC simulation that involved merging traffic streams of FDMS aircraft under normal and non-normal situations. The simulation was also designed to provide an early examination of some of the potential benefits of FDMS and address operational issues as the concept moves through the operational approval processes. In particular, the simulation addressed ATC acceptance as well as the impact on operations, workload, situation awareness, and communications. FDMS is expected to have the following impact:

- Reduction in controller workload based on aircraft self-delivering a spacing interval (as with [6])
- Reduction in the number of controller interventions based on aircraft self-delivering a spacing interval (as with [11])
- No impact on controller situation awareness even though the aircraft are self spacing without controller instructions
- Reduction in the amount of monitoring required (as with [6])
- Reduction in the number of communications due to reduced ATC interventions (as with [12])
- No impact on the safety of current operations (as with [10 and 12])

### *Method*

Simulation Environment: The simulation was hosted at the MITRE Air Traffic Management (ATM) laboratory. The main simulation functions included en-route controller workstations and a



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traffic generator. The workstations included current ATC equipment: a Display System Replacement (DSR) with keyboard, trackball, and Display Interface Keypad (DIK), as well as a second display that hosted the User Request Evaluation Tool (URET). Two controller workstations were activated: one for the participant, and one for a MITRE confederate controller that assisted in the simulation. No new controller tools were implemented for the evaluation.

A second station hosted the pseudopilot and a software program that allowed for the entry of instructions from ATC. Pseudopilot inputs modified the behavior of aircraft that otherwise were following generated flight plans. A MITRE individual acted as the pseudopilot that "flew" all the aircraft. A custom interface was written that allowed the FDMS traffic to generate and follow speed commands to perform FDMS. The controller and pseudopilot stations were located in separate areas and communications were provided via headsets. For more details on the MITRE CAASD ATM simulation facility, see [13].

Traffic and Airspace: The UPS FDMS flights departed from various western-US cities and arrived at SDF. Each aircraft had a unique flight plan until the leg that ended at the merge fix of Centralia (ENL) in Kansas City Center (ZKC). The participants worked the ZKC sector just upstream of the sector containing the merge fix, and all of the scripted anomalous events were designed to occur within this sector. In case any cross-sector coordination was needed with the surrounding areas, the bordering sectors were combined and controlled by a MITRE confederate controller.

An arrival stream of thirteen UPS Boeing 757 / 767 aircraft arranged in four clusters of two to five aircraft performed FDMS. The FDMS arrival streams assumed an adequate ABESS ground setup, with minor errors in the spacing. Three non-FDMS UPS aircraft, and fourteen non-UPS, non-FDMS aircraft also passed through the participant's sector in each scenario. Since only high-altitude sectors were being simulated, all aircraft that were visible to the controller were between flight level (FL) 300 and FL400.

Participants and Procedure: The simulation period lasted eight days, with a different participant controller per day. Five former radar (R)-position controllers with recent experience and three current ZKC controllers with career experience in the simulated sectors participated in the simulation. All were males with a mean ATC experience level of 28 years.

Each eight-hour day was the same for each participant and began with an introductory briefing and training session that covered the concept, the workstation, the airspace, and the traffic. Controllers were instructed to ensure spacing and separation, minimize disruptions to the FDMS stream, and intervene if they projected a significant deviation below the two minute interval at the merge. They were also instructed to accommodate any course of action requested by the pseudopilot, unless it was believed to compromise safety. After the brief, controllers were given time to familiarize themselves with the equipment and work a practice traffic flow that did not include aircraft conducting FDMS.

The remainder of the day included running each of the simulation scenarios and completing a questionnaire after each run. Each scenario started with the first two FDMS arrival aircraft in the participant's sector and ended when the last FDMS aircraft was handed off to the downstream controller. Following the scenario runs, controllers were asked to complete a final questionnaire and participated in a semi-formal debrief.

## *Scenarios*

Each participant experienced five scenarios:

Baseline / Current Conditions: Under the baseline, no FDMS operations were simulated and controllers and flight crews conducted operations under current procedures. Controllers were asked to deliver aircraft to the next sector such that a two minute interval between aircraft pairs could be achieved over ENL.

FDMS Normal Operations: This scenario simulated FDMS operations under normal conditions. Controllers were asked to ensure that aircraft would be delivered to the next sector such that a two minute interval between aircraft pairs could be achieved over ENL; however, the FDMS equipment made it unnecessary for the controllers to have to provide instructions to achieve the spacing. The controller did, however, have to resolve the occasional conflict between FDMS and non-FDMS traffic.

FDMS Overtake: All aircraft were successfully performing FDMS in this scenario except for one pair. After several minutes of normal operations, a trail aircraft suddenly sped up without notification to ATC and started to overtake its TTF (by 50 knots of groundspeed). This additional closure would cause the trail aircraft to be delivered too closely at the sector boundary. This could represent an equipment failure in the trail aircraft. ATC was required to detect the situation, determine which aircraft had the problem, and decide how to ultimately resolve the situation.

FDMS Suspension: This scenario also started with all aircraft successfully performing FDMS.



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However, it contained two events where different trail aircraft initiate, then suspend FDMS. In the first event, one trail aircraft requested to stop FDMS and remain direct to the merge fix. If the request was accepted, its spacing had to be actively maintained by the controller while it was in the midst of a stream of self-spacing traffic.

The second event had another trail aircraft request a re-route to an alternate merge fix. If granted, this aircraft later asked to return direct to the original merge fix without restarting FDMS. It was the controller's discretion whether or not to accept the request and work the aircraft back into the arrival stream.

<u>FDMS Termination</u>: The final scenario also started with all aircraft successfully performing FDMS. However, a situation was introduced that required all aircraft to stop FDMS and return to current day conditions. The controller was forced to actively space traffic that he was previously only monitoring for spacing.

### *Data Collection*

Numerous subjective and objective data metrics were collected during the experimental runs. Objective data included aircraft trajectory and positional history, simpilot maneuver input history, frequency and source of speed changes, counts and durations of voice communications, and frequency of separation violations.

Subjective data was gathered via the post-run and post-simulation questionnaires and during the debrief. Most questions were on a five or seven point scale while other questions were yes / no or open ended. Controllers were encouraged to add detail in the open text fields to justify or clarify their answers.

## Results

The following paragraphs present high-level results of the subjective and objective data analysis. See [14] for complete results and analysis.

### *Concept Acceptability*

Controllers reported that with appropriate training, they would conduct FDMS. On average, controllers found it "somewhat acceptable" to be responsible for separation during FDMS, except for one who answered "unacceptable." During the debrief, this participant explained that he did not feel it was fair for controllers to have separation responsibility without more information about when aircraft might be making speed changes. Controllers found the amount of information provided to make traffic management decisions to be "acceptable." They were also "confident" that the handed-off aircraft would be accepted at handoff with minimal problems.

### *Controller Interventions*

The simulation tracked the number and types of controller instructions made as aircraft traversed the sector on their way to the merge. The maneuver types in the analysis included: heading changes, altitude changes, speed changes (controller commanded), and reroutes. As some controllers may have preferred to resolve situations with different types of maneuvers (for example, instructing a speed change instead of giving a vector), the counts for each instruction type were totaled and analyzed. It should also be noted that the analysis is for instructions given to *all* aircraft in the sector; it is not limited to FDMS aircraft only. See Table 1 for a summary of intervention counts by scenario and type.

**Table 1. Number of Controller Interventions by Scenario and Type**

| | Heading Instructions | Altitude Instructions | Re-routes to PXV | Speed Instructions (Controller) | Total Controller Instructions |
|---|---|---|---|---|---|
| Baseline Mean | 8 | 2 | 0.25 | 5.875 | 16.125 |
| Standard Deviation | 8.960 | 1.512 | 0.463 | 3.271 | 8.741 |
| Observations | 8 | 8 | 8 | 8 | 8 |
| FDMS Normal Mean | 0 | 1.375 | 0.25 | 0.25 | 1.875 |
| Standard Deviation | 0.000 | 1.408 | 0.707 | 0.707 | 1.885 |
| Observations | 8 | 8 | 8 | 8 | 8 |
| FDMS Overtake Mean | 0.25 | 1.375 | 0.5 | 1.5 | 3.625 |
| Standard Deviation | 0.463 | 1.996 | 0.926 | 0.423 | 3.462 |
| Observations | 8 | 8 | 8 | 8 | 8 |
| FDMS Suspension Mean | 1.625 | 1.875 | 1.25 | 1.25 | 6 |
| Standard Deviation | 1.996 | 1.642 | 0.463 | 1.389 | 3.295 |
| Observations | 8 | 8 | 8 | 8 | 8 |
| FDMS Termination Mean | 1.5 | 1.25 | 0.625 | 1.875 | 5.25 |
| Standard Deviation | 3.505 | 2.053 | 0.518 | 2.850 | 4.713 |
| Observations | 8 | 8 | 8 | 8 | 8 |

Although counterbalancing was employed among the "problem" scenarios (overtake, suspension, and termination), the baseline scenario was always presented first and the normal operations scenario was always presented second. This was done to obtain an initial baseline reading before controllers were exposed to FDMS operations, and so that controllers would have a chance to view nominal FDMS operations before being asked to deal with problems. Although it is possible that practice effects may have impacted the results for comparisons between baseline and normal, any effects should be minimal due to differences in the way the traffic flows progressed. Still, it is possible that the significance of some results may be somewhat magnified due to potential learning effects. An additional analysis of the problem scenarios showed no significant order effects.

In order to ensure that the FDMS operations did not minimize one type of controller intervention only to increase another type, the effect of the FDMS procedure on total controller interventions by scenario was examined first. The total controller instruction counts in the last column of Table 1



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were produced by summing the counts across intervention type. A univariate analysis of variance and paired *t*-tests analysis found significantly more total instructions given by the controller in the baseline scenario than in the other scenarios ($p \leq 0.01$ for all). This suggests that FDMS operations required significantly fewer interventions from the controller – even when spacing disruptions or other problems were introduced. The means and standard error bars for total interventions are presented graphically in Figure 1.

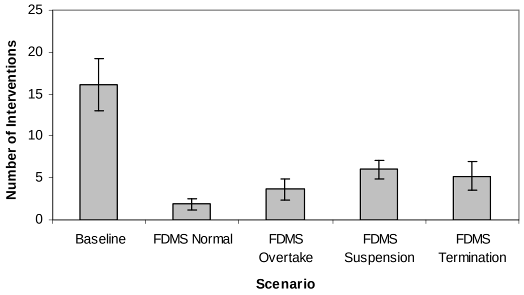


**Figure 1. Total Number of Controller Interventions by Scenario (Vertical bars denote 95% standard error confidence intervals)**

The difference in total interventions resulted primarily from a significantly greater number of heading and speed instructions given in the baseline scenario. The paired *t*-tests found significantly more heading instructions were given in the baseline than in both the FDMS normal ($p = 0.040$) and overtake ($p = 0.043$) scenarios. The controllers also gave significantly more speed instructions in the baseline scenario than in each of the other scenarios ($p = 0.014$ for suspension; $p < 0.01$ for others). This result is consistent with the FDMS concept of operation, since the algorithm supplanted the controller in providing speed guidance for the FDMS traffic. There were no significant differences in the number of altitude changes and re-routes. Figure 2 presents differences in heading and speed interventions across scenario.

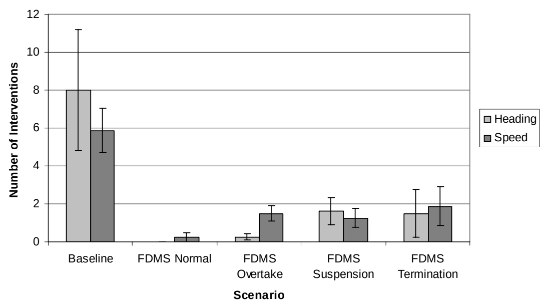


**Figure 2. Controller Heading and Speed Interventions by Scenario (Vertical bars denote 95% standard error confidence intervals)**

## *Workload*

Controllers were asked to rate their peak and average workload experienced during each scenario on the Bedford workload rating scale as shown in Figure 3 [15]. The baseline condition was rated as a higher workload condition with a rating of “fair / enough spare capacity for all desirable additional tasks.” FDMS normal and non-normal scenario average workload was rated as “easy / workload low” in the post-run questionnaires. When all aircraft had to terminate FDMS, the average rating increased to “fair / enough spare capacity for all desirable additional tasks.” This suggests a trend in which the more aircraft encounter difficulties or make requests, the more difficult the operation becomes for the controller. Overall, controllers reported that their workload during FDMS was “acceptable.”

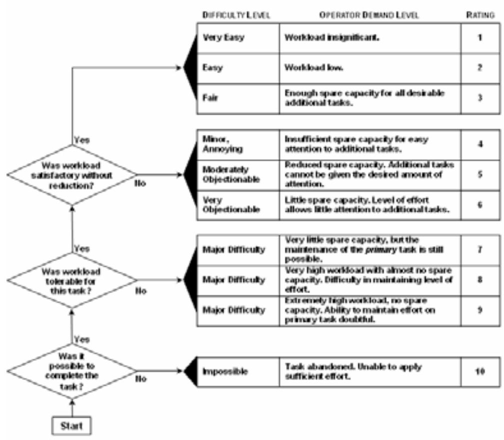


**Figure 3. Bedford Workload Rating Scale**

## *Situation Awareness and Monitoring*

On average, for the four FDMS scenarios, controllers reported that it was “easy” to remember which aircraft were conducting FDMS. Controllers reported that their level of traffic awareness during FDMS was “acceptable,” and that FDMS made it “somewhat easier” to monitor and maintain the sequence of aircraft.

Controllers reported that it was “somewhat easy” to detect conflicts, separation violations, or spacing issues; however, responses were variable about knowing when to intervene. When confronted with a developing situation, controllers needed time to determine if the situation would correct itself or whether they needed to intervene. None felt that this created a potential safety problem as they had “acceptable” amounts of time to detect and react to situations.

Controller responses were varied on FDMS having an effect on the monitoring of traffic. Some controllers reported an increase in monitoring and



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associated workload and noted that the complacency inherent in a monitoring task could slightly increase the time to detect developing situations. However, some participants also speculated that as controllers became comfortable with how the traffic performed, increased workload due to monitoring may dissipate, and abnormal situations could become even easier to detect than in today's operations. None of the controllers had difficulty shifting from monitoring FDMS aircraft to actively controlling spacing for those aircraft in the termination scenario. No separation violations occurred during any of the scenarios.

## *Communications*

Throughout the runs, the number of controller Push-To-Talk (PTT) keyings and the total duration of the controller's time on the frequency were tracked. PTT pairs included responding to aircraft check-ins, handoffs, as well as controller instructions and queries. In order to reduce the effect of accidental microphone keyings on the results, only the counts and durations for PTT keyings greater than 1 second were included in the analyses. See Table 2 for a summary of controller communications data.

**Table 2. Controller Audio Metrics**

| | PTT Keyings > 1 sec (count) | Total Time on Frequency for Keyings > 1 sec (sec) |
|---|---|---|
| Baseline Mean | 85.125 | 298.750 |
| Standard Deviation | 14.623 | 76.107 |
| Observations | 8 | 8 |
| FDMS Normal Mean | 64.875 | 221.125 |
| Standard Deviation | 14.237 | 44.636 |
| Observations | 8 | 8 |
| FDMS Overtake Mean | 65.375 | 223.500 |
| Standard Deviation | 3.688 | 16.858 |
| Observations | 8 | 8 |
| FDMS Suspension Mean | 72.125 | 252.875 |
| Standard Deviation | 4.249 | 19.578 |
| Observations | 8 | 8 |
| FDMS Termination Mean | 68.000 | 227.000 |
| Standard Deviation | 4.280 | 18.313 |
| Observations | 8 | 8 |

The average number of controller calls and responses to the traffic (PTT keyings) greater than one second in duration per scenario are presented graphically in Figure 4. A univariate analysis of variance and paired *t*-tests analysis found significantly more calls to aircraft in the baseline scenario than all of the FDMS scenarios ($p = 0.007$ for overtake; $p < 0.05$ for the others). This is generally consistent with the controller intervention results; the less the controllers needed to intervene with the traffic, the fewer calls to aircraft needed to be made.

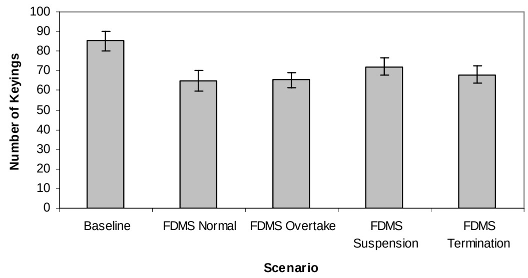


**Figure 4. Average Number of Push To Talk Keyings with Durations > 1 Sec by Scenario (Vertical bars denote 95% standard error confidence intervals)**

The average total time on frequency for controller calls and responses to the traffic greater than one second in duration per scenario is presented graphically in Figure 5. The analysis found that controllers spent significantly more time on frequency in the baseline scenario than all of the FDMS scenarios ($p < 0.01$ for normal, overtake, and termination; $p = 0.021$ for suspension).

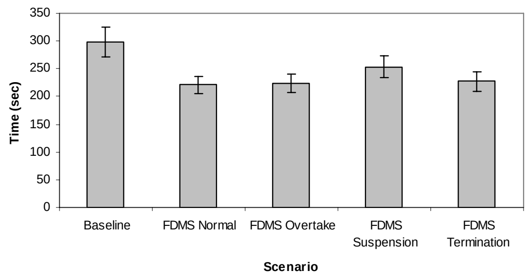


**Figure 5. Average Total Times on Frequency for Push To Talk Keyings with Durations > 1 Sec by Scenario (Vertical bars denote 95% standard error confidence intervals)**

The objective data is supported by the subjective data where participants reported that the impact on their communications with traffic was "somewhat less" during FDMS operations, as compared to controlling a similar number of aircraft under similar conditions without FDMS.

# Conclusion

This paper reviewed a simulation that examined a new Aircraft Surveillance Application (ASA) that is under development in the US. The concept is termed Flight Deck-Based Merging and Spacing (FDMS) and its main objective is to achieve consistent, low variance spacing between aircraft pairs during arrival operations through flight deck-originated speed adjustments. Overall operational efficiency was expected to be increased through the avoidance of costly, low-altitude maneuvering and reduced communications, without a negative impact on human performance issues. The impact of FDMS on the en-route controller's



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overall operation, workload, situation awareness, and safety were examined.

Controllers reported on average that FDMS during en-route operations: was acceptable, reduced workload over operations without FDMS, allowed for acceptable traffic awareness, and reduced communications. Many of these gains likely resulted from a significant reduction in the number of interventions needed to achieve and maintain in-trail spacing of an arrival flow – even when spacing disruptions or other problems were introduced. Controller responses were varied on issues related to monitoring and interventions, which will continue to be examined in future simulations.

Based on these results and those of past simulations [e.g., 6, 7, and 8], the concept will continue forward in the development process. The results will be used to further refine the concept as it moves toward operational approval.

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## Key Words

Air Route Traffic Control Center (ARTCC), Air Traffic Control (ATC), Airborne Surveillance Application, Airborne Separation Assistance Systems (ASAS), Automatic Dependent Surveillance-Broadcast (ADS-B), ATM lab, Cockpit Display of Traffic Information (CDTI), en route, flight deck-based merging and spacing (FDMS), human factors, Merging and Spacing (M&S), miles-in-trail, MITRE CAASD.

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