CHANGES IN ROLES/RESPONSIBILITIES OF AIR TRAFFIC CONTROL UNDER PRECISION TAXIING

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Abstract

In support of the NASA-Ames implementation of the NGATS(Next Generation Air Transportation System) ATM (Air Traffic Management) Airportal Program, a real-time simulation study investigated the changes in roles and responsibilities for tower controllers brought about by the introduction of new technology to achieve precision taxiing. The prototype tool that the controller interacted with was GoSAFE (Ground Operation, Situation Awareness and Efficiency Flow), which is part of a future surface concept. This future surface concept envisages that future surface operations will involve taxi clearances containing precisely timed taxi routes. The study was done in two parts: (1) the first phase was used to identify new areas of responsibilities for the tower controllers, and (2) the second phase was used to test those responsibilities. Four retired controllers participated in a Human-in-the-Loop study and the test bed used was DFW airport (East side only). The controllers interacted with the tool under two conditions – one using datalink and another using voice to issue and deliver clearances to the pilots. Phase-1 data analysis results showed a significant difference in the average workload reported at different controller positions, with the local east (LE1) controller being particularly busy. Phase-2 data analysis results indicated a more balanced re-distribution of workload and communications among the controller positions. Comparison of the two phases has been described in the results section, which includes an analysis of the dependent measures of workload, situation awareness, and nature of communications.

Introduction

Airports and surface congestion are the biggest bottlenecks in the current national airspace system (NAS) [8] [9]. In response, technological capabilities are being developed to improve the movement of surface traffic. New decision aids are required to integrate other extant technologies in the tower and present it to the users, particularly the tower controllers, in a coherent manner. The tower controllers in the current day rely heavily on the out-the-window (OTW) view for aircraft position, and on printed flight strips for flight details. The introduction of new technology to tower controllers is based on the presumption that the same size controller team will be able to manage double the traffic [4].

Activities are currently underway at NASA Ames Research Center to implement key elements of the NGATS ATM-Airportal Program. In response, the current study supports selected NGATS ATM-Airportal focus areas, including surface traffic optimization and the management of dynamic airport configuration.

In the current study, real time simulations were developed at NASA Ames Research Center to represent and study a future surface concept in a high fidelity airport tower environment. The aim of this effort was to explore the changes in the procedures, roles and responsibilities of the controllers when they interact with a prototype tool. The prototype tool chosen was GoSAFE (Ground Operation, Situation Awareness and Efficiency Flow), which is part of the SOAR concept (Surface Operation and Automation Research) [1].

The SOAR concept envisages that future surface operations will involve taxi clearances containing precisely timed taxi routes. This will be achieved through collaboration between tower control tools (e.g., GoSAFE) and advanced automation tools developed for the flight deck. GoSAFE is intended to plan efficient taxi operations [1] with the assumption that flight decks of the future can execute very precise taxi commands. Due to timing information embedded in the clearances, it was impractical for these clearances to be input by hand, and thus data link (electronic exchange of information) was required for the procedure.

A number of studies have examined tower controllers and their interactions with new tools or procedures. For instance, one study conducted at NASA Ames Research Center explored options for reducing runway incursions at LAX (Los Angeles International Airport) [5]. One option involved a procedural change in the tower, in which two controllers operated one runway each, instead of having one controller manage the two active runways. The study demonstrated that mixed runway operations and runway crossings required significant coordination between the two controllers. The required level of coordination increased the possibility of operational errors that could lead to runway incursions. To minimize such errors, a single controller was assigned to a set of parallel runways. In the current research effort, an attempt has been made to divide the responsibility for the two parallel runways without increasing communication and coordination.

Another study conducted at NASA Ames Research Center supported the Chicago O'Hare Airport Modernization Program. This study involved a human-in-the-loop simulation of the full build-out Airport Layout Plan (ALP) [2]. During the simulation, it was determined that one of the two controllers responsible for arrival traffic had a significantly higher workload than the other. Reorienting the areas of responsibility from an east-west to a north-south orientation mitigated the workload imbalance between the two positions.

This paper examines the changes in controller roles and responsibilities associated with the introduction of (1) the GoSAFE automation technology and (2) changes in controller surface area jurisdiction. GoSAFE was previously introduced in an earlier study (phase-1), and based on the phase-1 results, areas of controller responsibility were modified and implemented in the current study (phase-2). Phase-1 and phase-2 results are discussed and compared.

Summary of Phase-1 Results

Phase-1, which tested workload with the prototype tool, GoSAFE, found that controller workload was significantly different (i.e., unbalanced) across the four controller positions ($F= 130.47$, $df=3,130$, $p<0.001$). The Local East#1 (LE1) controller was significantly busier and experienced higher workload on the Workload Assessment Keypad (WAK) scale [10] ($M=4.1$, $SD=1.38$) than the Local East#2 (LE2) ($M=1.84$, $SD=1.13$), Ground East#1 (GE1) ($M=2.3$, $SD=0.86$) and Ground East#2 (GE2) ($M=1.13$, $SD=0.34$). The LE1 controller at DFW receives traffic from all directions, requiring management of traffic crossings through active runways for aircraft departing 17C and 13L, and for arrivals going to the terminals. Under phase-1, responsibilities of the GE2 controller had been substantially changed due to the introduction of GoSAFE [6] since this automation tool allowed LE1 to clear the aircraft crossing the active runways on DFW east 17R and 17C all the way to the gate, thereby reducing GE2’s level of responsibility. Thus GE2’s tasks were reduced to monitoring the arrivals, while actively managing departures. The jurisdiction change to split the active runways in the north–south direction rather than east-west was found to reduce the need for communication and coordination [6].

Current (Phase-2) Methodology

The current study used the phase-1 results to configure, and later test, new areas of responsibilities for the controllers with GoSAFE. In order to compensate for the uneven distribution of phase-1 workload, changes in the areas of responsibilities for the LE1 and GE2 controllers were introduced under phase-2. The changes in jurisdiction are shown in Figures 1 and 2. The most prominent change involved reducing the area of responsibility for the LE1 controller. Specifically, phase-1 LE1 responsibilities of controlling aircraft crossing the south end of the active runways 17R and 17C, on taxiway ER, were transferred to GE2 under phase-2. Thus, the jurisdiction over the active runways was split in the north-south direction, where the north was controlled by LE1 and the south end of the runways was controlled by GE2.

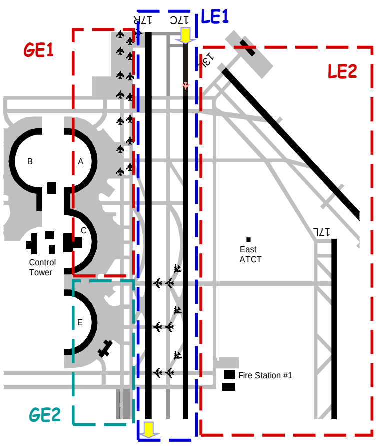

Figure 1. Phase-1 Area of responsibility

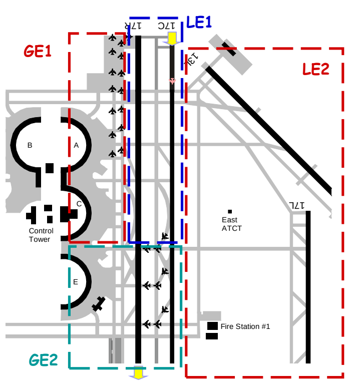

Figure 2. Phase-2 Area of responsibility

Experimental Conditions

Both phase-1 and phase-2 of the study used GoSAFE under two experimental conditions: (1) Mixed Communications and (2) Full Datalink, with three scenarios that were randomly distributed among the runs. The Mixed condition used GoSAFE to deliver the entire taxiway instruction (pre-clearance) via datalink, whereas all routine taxi clearances were issued in segments to the pilots using voice. In the Full Datalink condition, the complete taxi instruction (pre-clearance) and the routine taxi instructions were issued via datalink.

Hypotheses

The dependent measures of interest included Workload, Situation Awareness, and Communications. The hypotheses have been categorized under two categories – one that compared phase 1 and 2, and the other that focused on phase-2 only. It was hypothesized that (1) workload among controller positions would become more equally distributed under phase-2, as compared to phase-1, as a result of changes in the DFW jurisdiction, (2) situation awareness would remain the same regardless of phase (phase-2 vs. phase-1), and condition (mixed communications vs. full datalink), (3) voice communication loads would be more equally distributed among controllers under phase-2 as compared to phase-1, in terms of number of transmissions and percentage of voice channel occupancy, (4) under phase-2 jurisdiction, the controllers would experience higher workload in the mixed communications condition than in the full datalink condition, and (5) under phase-2 jurisdiction, the mixed datalink condition would have more voice communication than the full datalink condition.

Participants

The participants in the study were four retired controllers (two local and two ground controllers) who participated in both phase-1 and phase-2 of the study. Only one participant had DFW experience, but all participants were experienced tower controllers. On average, the participants had over 21 years of controller experience, and were retired for approximately six and a half years. In the current study, the participants staffed four tower positions, consisting of two local controller and two ground controller positions. The controllers rotated through each of the positions, changing after each study run, to randomize individual effects as much as possible.

Facilities and Simulators used

The traffic in the simulations was created using the Airspace Traffic Generator (ATG), a ground and airborne target generator customized for advanced ATC research. The ATG parsed and executed the 4-D taxi commands and emulated the flight deck automation required to operate the concept. The ATG was integrated with GoSAFE using High Level Architecture (HLA). The arrivals were monitored by the local controllers using a JBRITE display, which is an emulation of the FAA's DBRITE. In the current study, all the controllers used the GoSAFE displays to manage traffic. Time synchronization, data collection and data management details were implemented over the HLA network. Additional details on the software architecture and modules are documented elsewhere [7].

Traffic and Scenario

Future levels of traffic were simulated for DFW. The east side of DFW with a south flow using runways 17R, 17C, 17L, and 13L under clear day conditions were simulated. In general, the traffic count for a 45 minute scenario was 140-160. This is approximately 1.5 times current level of traffic for the east side only. The three scenarios included an arrival rush, an even flow of arrivals and departures, and a departure rush that morphed into an arrival rush.

Results

The tools used to collect data included the Workload Assessment Keypad (WAK) [10] and Task Load Index (TLX) [3] scales for measuring workload, and the Situation Awareness Rating Scale (SART) [11] for measuring situation awareness. To assess WAK workload, the participants pressed a key on their workload pad every 5 minutes during the simulation run. This WAK key press represented the participant's assessment of current workload experienced, which ranged from 1 (low workload) to 7 (high workload). In addition, TLX and SART questionnaires were administered to each participant after every simulation run. The researchers also made observation notes and led group discussions with the controllers. All data analysis results from these sources are described in this section.

Workload (TLX and WAK)

Table 1 presents summary statistics of the overall data distribution of workload, as measured on the TLX scale, with comparisons between phase-1 of the experiment (initial controller responsibility/ jurisdiction) and phase-2 of the experiment (new responsibility/ jurisdiction).

	Phase1 mean	**Phase1 SD**	**Phase2 mean**	**Phase2 SD**
Mental demand	3.2	1.5	3.1	1.1
Physical Demand	2.9	1.9	2.7	1.2
Temporal Demand	2.8	1.4	2.5	1.2
Performance	5.2	1.1	5.3	0.9
Effort	3.0	1.3	3.1	1.2
Frustration	2.5	1.1	2.1	1.1

Table 1. TLX Workload by the Phase

As shown in Table 1, the change in controller jurisdiction had a beneficial effect on most of the controller workload variables, with less mental demand, physical demand, temporal demand and frustration, along with increased performance. However, none of these observed differences were large enough to reach statistical significance.

Figure 3 shows a comparison of TLX workload ratings as a function of experiment phase (phase-1: initial jurisdiction, phase-2: new jurisdiction) and condition (mixed, full).

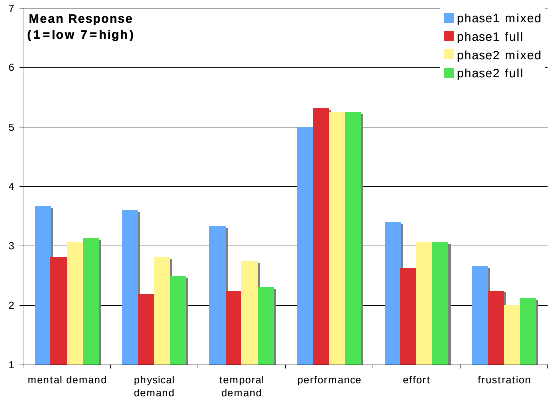

Figure 3. Workload by Phase & Condition

Figure 3 shows relatively large differences between phase-1 mixed vs. full conditions, whereas smaller differences are indicated between phase-2 mixed vs. full conditions. Under the phase-1 jurisdiction, statistically significant differences between the mixed and full conditions on the dependent measures of physical demand (F=4.87, df=1,29, p<= 0.05) and temporal demand (F=5.45, df=1,20, p<= 0.05) were realized. Conversely, no statistically significant differences were indicated between mixed and full conditions under phase-2 jurisdiction. Hence, it seems likely that the change in jurisdiction between the two experiment phases had the overall effect of balancing the workload across the mixed and full conditions on the specific variables measured by the TLX scale (i.e., minimized any possible mixed/full effect). This workload effect between the conditions may have occurred due to a decrease or re-distribution of traffic managed by the local controllers. During group discussion, the controllers mentioned that LE1, under phase-2, experienced increased spare mental capacity. This allowed LE1 controllers to issue commands in a timely fashion to the mixed condition pilots, due to the workload re-distribution under phase-2. Table 2 presents the differences of the means (absolute value) between the mixed/full conditions for each of the two phases of the experiment, for each of the TLX workload measures:

	Phase1 means: | mixed – full |	Phase2 means: | mixed – full |
Mental demand	0.9	0.1
Physical demand	1.4 *	0.3
Temporal demand	1.1 *	0.4
Performance	0.3	0.0
Effort	0.8	0.0
Frustration	0.4	0.1

Table 2. Workload for Condition & Phase
(*statistically significant at p < 0.5)

Similar results were found with WAK workload, showing a significant interaction effect of phase and condition (F=25.58, df=1,1 , p<= 0.05), where the phase-1 mixed/full workload difference of nearly 1 full scale point was virtually eliminated under phase-2. Figures 4 and 5 illustrate this effect graphically:

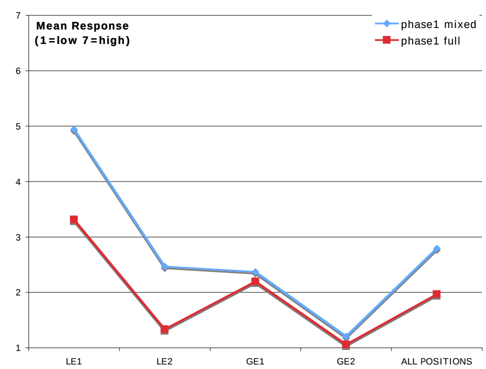

Figure 4. Phase-1 WAK Workload by Condition

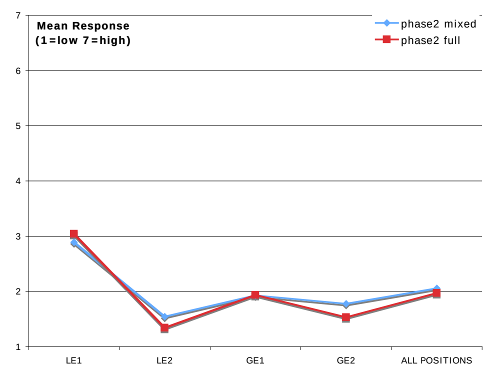

Figure 5. Phase-2 WAK Workload by Condition

Table 3 shows the range of TLX workload means across the 4 controller positions (LE1, LE2, GE1, and GE2) for each of the two experiment phases. Here, range is defined as the difference between the highest mean workload and the smallest mean workload among the four controllers.

TLX measure	**Phase-1 Range**	**Phase-2 Range**
Mental Demand	3.3	1.6
Physical Demand	3.4	0.8
Temporal Demand	2.9	1.6
Performance	1.5	1.0
Effort	2.6	0.5
Frustration	1.8	1.0

Table 3. Workload Range Across All Positions

The range provides a measure of variability of workload across the controller positions. The range values in Table 3 clearly show an overall re-balancing of TLX workload, as a result of the implementation of the new controller jurisdiction in phase-2 of the experiment (i.e., the phase-2 range of means is considerably less than the phase-1 range of means in TLX workload measures).

Figures 6 and 7 illustrate the effects of controller position and experiment phase on the TLX workload ratings. Only those means corresponding to the LE1 and GE2 positions are presented, since there was insufficient phase-1 vs. phase-2 workload variability for the other two positions. This would make sense, since LE1 and GE2 are the only two controller positions directly impacted by the jurisdiction change implemented in phase-2.

Figure 6 shows the phase-1 and phase-2 mean responses on each of the TLX workload measures, for position LE1 only. For the most part, responses on all of the workload measures show improvement under the new jurisdiction implemented in phase-2, as compared to the workload responses under the old jurisdiction in phase-1. There was less mental demand, physical demand, temporal demand, effort and frustration, with a slight improvement in performance.

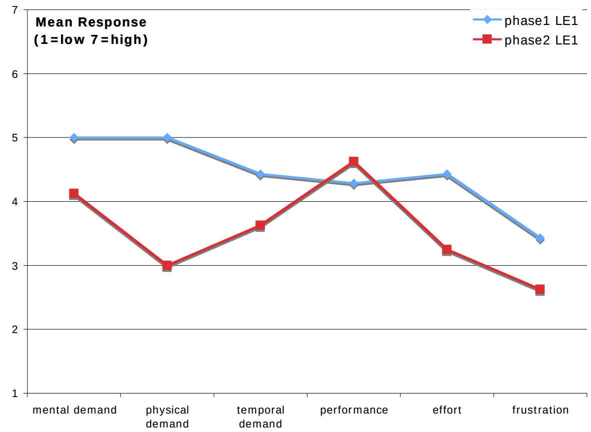

Figure 6. Workload by Phase (LE1)

Conversely, Figure 7 mostly illustrates just the opposite pattern of mean responses for the GE2 position, showing more phase-2 mental demand, physical demand, temporal demand, effort and frustration.

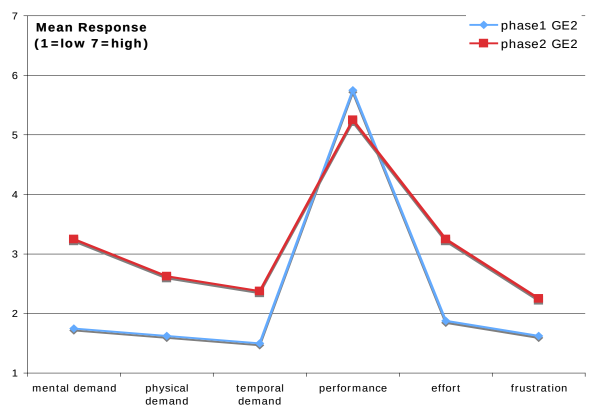

Figure 7. TLX Workload by Phase (GE2)

It would appear that the implementation of the new controller jurisdiction in phase-2 had the effect of re-distributing workload across the LE1 and GE2 positions. Hence, the workload was spread out more evenly across both positions, with one position experiencing an increase and the other position experiencing a decrease in workload. Figures 6 and 7 clearly show that the phase-2 distribution of means are much more similar to each other than the phase-1 distribution of means across the LE1 and

GE2 positions, providing further evidence of the observed workload re-distribution.

ANOVA statistics of controller position effects on workload for each phase are shown in Tables 4 and 5:

	F ratio	* p<0.5
Mental Demand	20.8	*
Physical Demand	8.1	*
Temporal Demand	15.0	*
Performance	1.7	
Effort	11.5	*
Frustration	5.6	*

Table 4. Position Effects on Workload (Phase-1)

	F ratio	* p<0.5
Mental Demand	10.8	*
Physical Demand	1.2	
Temporal Demand	3.3	
Performance	2.1	
Effort	0.3	
Frustration	1.4	

Table 5. Position Effects on Workload (Phase-2)

In general, the phase-1 analysis of position resulted in statistically significant differences on most of the TLX workload dependent measures (Table 4). Conversely, the phase-2 analysis of position on each of the workload measures resulted in only one statistically significant difference (Table 5). This would seem to provide further evidence of the workload re-distribution across positions, resulting from a change in controller jurisdiction. The controllers also mentioned that under phase-2, the GoSAFE technology assisted them with runway crossings, a task traditionally handled by the local controllers. It was further noted that in the absence of the surface technology provided by GoSAFE, this change in areas of responsibility would not have been operationally feasible due to the communication and coordination requirements under phase-2, especially with the increased level of traffic.

A position by phase interaction effect of WAK workload (Figure 8) was also realized (F=15.83, df=3,406, p<= 0.05), with a general reduction of workload under phase-2, and similar trends across the controller positions (e.g., LE1 and GE2 workload re-distribution under phase-2).

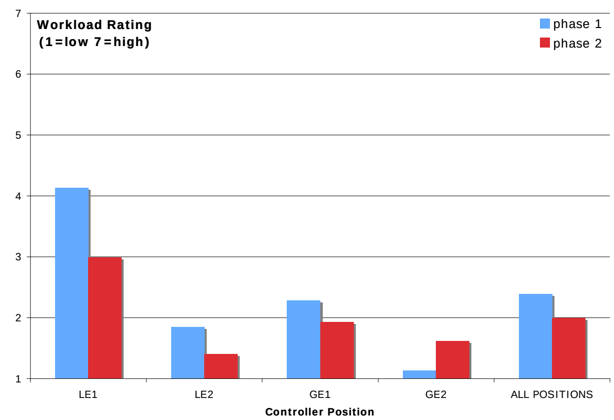

Figure 8. Workload by Phase and Position

Situation Awareness (SART)

The change in controller jurisdiction implemented in phase-2 had the effect of improving situation awareness on all of the 10 SART measures. As compared to the phase-1 mean responses, the phase-2 mean responses indicated less instability, variability, complexity and division of attention. The phase-2 mean responses also indicated more alertness, spare mental capacity, concentration, information quantity, and familiarity. Statistical significance was achieved on the instability, concentration and familiarity measures. SART means and ANOVA statistics are listed in Table 6:

	Phase-1 mean	Phase-2 mean	F-ratio	p< 0.05
Instability	3.1	2.4	4.4	*
Variability	3.6	3.2	1.8	
Complexity	2.9	2.6	0.7	
Alertness	4.8	5.2	1.9	
Spare mental capacity	5.6	5.8	0.3	
Concentration	4.7	5.4	7.1	*
Division of attention	3.6	3.3	0.8	
Information quantity	5.1	5.3	1.2	
Information quality	5.1	5.1	0.0	
Familiarity	5.4	5.9	6.3	*

Table 6. Situation Awareness: Phase Effects

Conversely, SART analysis results, broken down by experiment phase and mixed/full conditions, were less striking. While some marginal differences in the mixed/full condition were observed as a function of experiment phase, neither the main effect of the mixed/full condition, nor the interaction effect of phase by condition, for any of the SART measures, reached statistical significance.

Figures 9 and 10 illustrate the interaction of experiment phase by controller position on situation awareness. Only the means for those controller positions directly impacted by the change in jurisdiction (i.e., LE1, GE2) are illustrated. Results for positions LE2 and GE1 are not shown, since their phase-1 vs. phase-2 differences were relatively consistent, relative to the LE1 and GE2 differences which were much more striking.

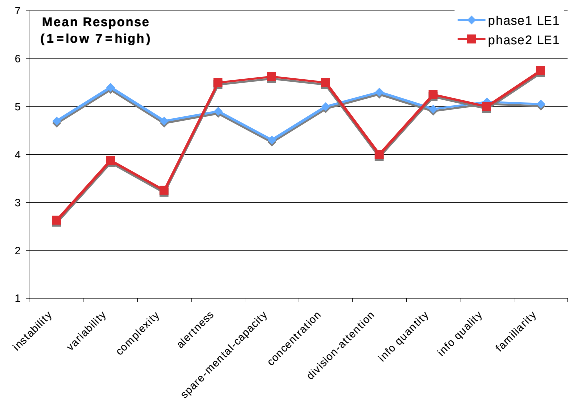

Figure 9. LE1 Situation Awareness By Phase

Under phase-2 (as compared to phase-1), the LE1 position experienced less instability, variability, complexity, and division of attention. Under phase-2 (as compared to phase-1), the LE1 position also experienced more alertness, spare mental capacity, concentration, information quantity and familiarity, with about the same level of information quality (Figure 9 and Table 7). In group discussion, the controllers also indicated that, under phase-2, they had more spare mental capacity, especially in the mixed condition. So, in general, there was consistent improvement in situation awareness experienced in phase-2 as compared to phase-1 for position LE1. Under the original jurisdiction, the LE1 controller scrolled up and down the map to handle the aircraft crossing both the north and south ends of the active runways. Under the new jurisdiction where LE1 is no longer responsible for the south end of active runways, the LE1 controller scrolled between North 17L and R, and taxiways EM, up to the boundary of the new LE1 jurisdiction area. Hence, it would make sense that LE1 had better situation awareness under phase-2, since there was less jurisdiction area to attend to. The hypothesis that situation awareness would remain the same between the two phases was not upheld for LE1, since situation awareness improved due to better stability, and spare mental capacity brought about by the changes in controller jurisdiction.

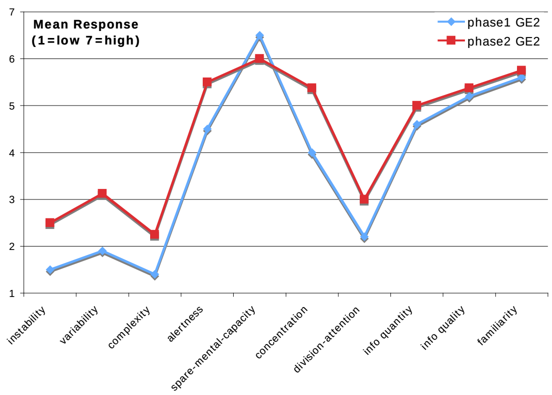

Figure 10. GE2 Situation Awareness by Phase

Under phase-2 (as compared to phase-1), the GE2 position experienced more instability, variability, complexity, alertness, concentration, division of attention and information quantity. Under phase-2 (as compared to phase-1), the GE2 position also experienced less spare mental capacity, with about the same level of information quality and familiarity (Figure 10 and Table 7). So, while there was some improvement in situation awareness on several of the SART measures, there was also some degradation or no improvement on most of the measures. This finding is consistent with researchers' observations of phase-2 runs, where GE2 would occasionally ask LE1 if there were more departures on 17R, since aircraft on taxiways ER could not cross 17R until the departure aircraft had left the airport. Therefore, in this instance, GE2 experienced less situation awareness, requiring controller coordination to develop a fuller awareness of surface traffic. However, it should be noted that while some degradation in situation awareness occurred, the level of degradation was usually less than one scale point, and situation awareness generally remained at a relatively high level.

While Figures 9 and 10 clearly show a general level of improvement in situation awareness for the LE1 position, and some degradation in situation awareness for the GE2 position, they also show these effects to be one of situation awareness re-distribution across both positions, i.e., the LE1 and GE2 phase-2 curves are much more similar to each other than the LE1 and GE2 phase-1 curves. Situation awareness improvement for LE1 is quite high for some of the SART measures (e.g., instability, variability, complexity) while GE2 situation awareness degradation, if indicated at all, is generally low in magnitude. For instance, spare mental capacity increased for LE1 by 1.3 scale points, whereas GE2's spare mental capacity decreased by only 0.5 scale points. Combined with the relative lack of variability observed from the other two positions, this would point to an overall increased level in situation awareness across all positions.

SART means and ANOVA statistics for the phase by position interaction effects are described in Table 7.

Phase by Position Interaction Effects	LE1 Phase-1	LE1 Phase-2	GE2 Phase-1	GE2 Phase-2	F-ratio	* p <= 0.05
Instbty	4.7	2.6	1.5	2.5	5.4	*
Variabty	5.4	3.9	1.9	3.1	7.0	*
Cmplx	4.7	3.3	1.4	2.3	3.4	*
Alert	4.9	5.5	4.5	5.5	0.8	
SpMC	4.3	5.6	6.5	6.0	2.7	*
Conctn	5.0	5.5	4.0	5.4	1.5	
DivAt	5.3	4.0	2.2	3.0	3.6	*
InfoQan	5.0	5.3	4.6	5.0	0.1	
InfoQal	5.1	5.0	5.2	5.4	0.2	
Familty	5.1	5.8	5.6	5.8	0.6	

Table 7. Situation Awareness: Phase by Position Interaction Effects

Again, only cell means for the LE1 and GE2 positions are presented since there is insufficient variability in the phase-1 vs. phase-2 curves for the other two positions to account for any possible significant interaction effect. This would make sense, since again, LE1 and GE2 were the only positions to be directly impacted by the jurisdiction change implemented in phase-2

Communication

Number of voice transmissions by position & phase

The mean number of controller issued voice clearances by position and experiment phase is shown in Figure 11:

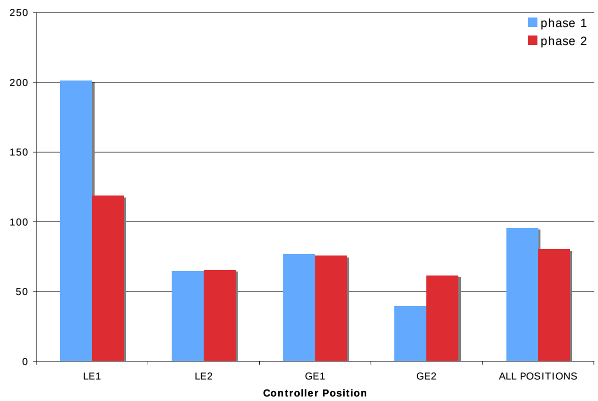

Figure 11. Mean Number of Voice Transmissions by Position and Phase

The change in jurisdiction between the two phases decreased the total number of voice clearances from 95.6 in phase-1 to 80.4 in phase-2 (all positions combined or overall effect of phase). However, this overall effect of phase was not statistically significant. ANOVA results did show an overall significant main effect for position (F=4.13, df=3,68, p<= 0.0094). When the position effect was broken down by phase, ANOVA results showed a significant phase-1 main effect (F=4.15, df=3,68, p <= 0.01), and a non-significant phase-2 effect. This would seem to indicate that the number of voice transmissions was more equally distributed across the positions under phase-2, as compared to phase-1. Figure 11 shows that LE1 experienced a large decrease in the number of voice clearances between the phases, from 201 to 118. Conversely, GE2 experienced a small increase in the number of voice clearances, from 40 to 62. Thus, the change in jurisdiction balanced the number of voice transmissions between the LE1 and GE2 positions, while decreasing the overall number of voice transmissions across the two positions. This would make sense, since during phase-2, the traffic handled by LE1 decreased, while that handled by GE2 increased, which would necessarily have an effect on their voice transmissions.

Number of voice clearances by condition and phase

Table 8 shows the mean number of voice transmissions broken down by condition (mixed/full) and phase (phase-1/phase-2). ANOVA results yielded a significant main effect of condition (F=112.11, df=1,72, p<0.001), while no significant differences were observed for the effect of phase.

	Experimental Condition	
	Mixed	Full
Phase-1	181.1	10.3
Phase-2	177.9	2.5

Table 8. Mean No. of Voice Transmissions by Condition and Phase

A number of factors may have contributed to the results indicated in Table 8 (i.e., a smaller number of voice clearances under phase-2 and full datalink conditions): (1) Under full datalink, the voice transmissions are limited to situations such as clarification on possible air traffic control error/oversight, or other unanticipated circumstances, and (2) Under phase-2, the LE1 controller was not required to monitor both the north and south sections of the active runways. Hence, the LE1 controller was able to direct full attention to a smaller jurisdiction area. However, under the old jurisdiction (phase-1), pilots called in for clearances because LE1 controllers would focus on the north side of the active runways and not always notice that there were aircraft waiting on the south side for a clearance (requiring more verbal communication). The spilt in jurisdiction under phase-2 in the north and south direction eliminated this problem. Finally, (3) Under phase-2 and full datalink conditions, controllers often used single mouse clicks to frequently go between different sections of the map, eliminating the need for pilots to verbally alert controllers on aircraft waiting for clearances.

It was also noted that sometimes there were issues with sending clearances to aircraft via datalink. Controllers often inadvertently cleared all taxi segments of the aircraft's preclearance, even those that were out of their jurisdiction. In such cases, these controllers would inform the other controllers about such clearances. It was interesting that this error occurred only in the datalink mode where there was a tendency for controllers to clear all segments. While this action occurred only occasionally, it would still have the effect of reducing the number of voice transmissions, therefore supporting our findings. As an interesting aside, controllers would occasionally clear aircraft for a segment and could not remember that they had done so in the datalink mode. This problem could be resolved if automation did not allow controllers to issue clearances outside their jurisdiction.

Voice channel occupancy by controller by phase

Voice channel occupancy is defined as the percentage of radio frequency occupied relative to the total duration of the simulation run. Figure 12 shows the overall distribution of voice channel occupancy by controller position and phase.

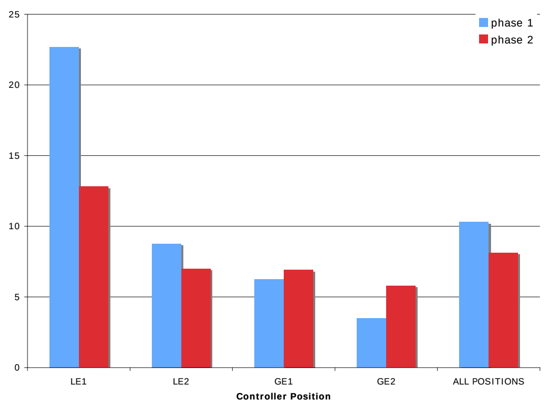

Figure 12. Mean Percentage of Voice Channel Occupancy by Position and Phase

ANOVA results yielded a significant main effect of controller position (F=4.82, df=3,68, p<=0.01). When the position effect was broken down by phase, ANOVA results showed a significant phase-1 main effect (F=4.42, df=3,68, p <=0.01), and a non significant phase-2 effect. This would seem to indicate that voice channel occupancy was more equally distributed across the positions under phase-2, as compared to phase-1. Further, the means in Table 9 clearly shows that LE1 experienced a large decrease, and GE2 experienced a small increase in voice channel occupancy, from phase-1 to phase-2. Thus, the change in jurisdiction balanced and lowered the level of communication and frequency congestion among the controller positions.

	LE1	LE2	GE1	GE2
Phase-1	22.7	8.8	6.3	3.5
Phase-2	12.8	7.0	6.9	5.8

Table 9. Mean Percentage of Voice Channel Occupancy by Position and Phase

Summary

This current research effort successfully implemented airport surface configuration changes, which directly impacted controller's roles and responsibilities without compromising their workload, or increasing frequency congestion. In fact, these changes had the effect of *decreasing* both workload and frequency congestion while increasing situation awareness, primarily for local controllers. Additionally, GE2 ground controllers experienced a relatively small increase in workload, which may have the beneficial effect of preventing tedium and vigilance decrement. Evidence of this was provided from the results of the current study, where the small increase in workload occurred concurrently with an increase in alertness and concentration (under phase-2, as compared to phase-1). All of these beneficial effects were possible due to the introduction of automation (GoSAFE), allowing controllers to effectively work with an increased volume of surface traffic (relative to those handled by present day airport operations). The aviation community generally recognizes that sharing the management and control of active runways has the effect of increasing coordination and communication among controllers, and may also compromise safety [6]. In the controllers' opinion the changes in areas of responsibility would not be acceptable to them in the current day operations due to the potential increases in communication load and a corresponding decrease in safety, but they felt that the surface automation tool, GoSAFE, alleviated some of these concerns.

The study also had some limitations. For example, due to practical and technical constraints, it was necessary to implement a randomized ANOVA, under circumstances where possible inter-correlations among the data points may have introduced some bias into the analysis. However, such bias was minimized by the experimental procedures which randomized possible individual effects. To increase the chance of further reducing such bias within the statistical analysis of data, further research with a larger sample size is recommended. Further research which examines other measures such as the controller's ability to deal with anomalies and off-nominal events is also needed to study the impact on safety. Finally, while we would expect that carefully implemented configuration changes to other airports would have similar effects as the current study, it is recommended that further research be conducted using test beds other than DFW, to gain a larger perspective on the generalizability of our findings.

In summary, the results clearly indicated that the change in jurisdiction (areas of controller responsibility) and the implementation of GoSAFE had a re-distribution effect for positions LE1 and GE2, and an overall positive impact on the dependent measures of workload, situation awareness and communication, with 1.5 times the current level of traffic. As the volume of air/ground traffic continues to rapidly expand in the milieu of real-world air and surface space, our results would most likely have special implications for projected future NAS operations, at 1.5 times (or more) air/ground traffic, relative to current capacity.

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References

[1] Cheng, V. (2004). Surface Operation Automation Research for Airport Tower and Flight Deck Automation. *IEEE Intelligent Systems (ITSC),* Washington, DC, October 3-5.

[2] Chicago OMP Ultimate-phase Real Time Simulation Evaluation (COURSE) Project report (2005).

[3] Hart, S**.** G. & Staveland, L. (1988). Development of the NASA Task Load ,Index (TLX): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (eds.), Human Mental Workload (pp. 139-183).

[4] Hunter, G., Ramamoorthy, K., Cobb, P., Huang, A., Blake, M., & Klein, A. Evaluation of Future National Airspace System Architectures. AIAA Modeling and Simulation Technologies Conference and Exhibit, San Francisco, California, Aug. 15-18, 2005.

[5] Los Angeles International Airport Runway Incursion Study. Phase II Alternative simulation (2001). Future Flight Central, FFC-LAXR002.

[6] Martin, L.; Verma, S.; Cheng, V. & Ballinger, D. (2007). Developing a decision support tool interface for surface domain controllers. HFES proceedings, October 2007, Baltimore.

[7] Northrop Grumman Information Technology (2005). Virtual Airspace Simulation Technology – Real-Time: VAST RT Data processing system requirements and specification. VASTRT DataProc-NASA-DID-P100, version 0.1

[8] Smeltink, J.W. ; Soomer, M.J. ; de Waal, P.R. & van der Mei, R.D. (2004). An Optimisation Model for Airport Taxi Scheduling. Technical Report, National Aerospace Laboratory NLR.

[9] Soomer, M.J., & Franx, G.J. (2007) Scheduling Aircraft Landings Using Airlines' Preferences. *European Journal of Operational Research*, In Press.

[10] Stein, E.S. (1985). Air traffic controller workload: An examination of workload probe. (Report No. DOT/FAA/CT-TN84/24). Atlantic City, NJ: Federal Aviation Administration Technical Center.

[11] Taylor, R.M. (1989). Situational Awareness Rating Technique (SART): the Development of a Tool for Aircrew Systems Design. In Proceedings of the AGARD AMP Symposium on Situational Awareness in Aerospace operations, CP478.

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