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FINAL REPORT

The Dimensions of Information Requests:

What information is needed in the air traffic control tower?

Francis T. Durso, Jacob T. Fleming,

Georgia Institute of Technology

Brian R. Johnson,

Texas Tech University

and

Jerry M. Crutchfield,

Federal Aviation Administration

Abstract

In an effort to determine the information needs of tower air traffic controllers, six instructor controllers from the Academy in Oklahoma City were asked to control traffic in a high-fidelity simulator. Information requests were made apparent by eliminating access to standard tower information sources with the exception of out the window views. Controllers were required to ask for precisely the information they needed during the scenarios. The information requests were classified using an elaboration of Zwaan and Radvansky's (1998) situation dimensions. Despite allowing for more dynamic and cognitive classifications, the vast majority of requests were classified as requests about three of Zwaan and Radvansky's dimensions originally developed for reading comprehension: the protagonist, intentionality, and space. The information requests were also classified into 28 operational categories (e.g., aircraft identification, destination). From these results, the data were summarized, not just statistically, but by the creation of displays that mirrored the information needs. Position specific displays for ground and local were discussed. However, similarities in the information needs of the two positions led to the creation of a common display in which some information is presented in a steady-state format and some information is time shared. When off-nominal events were considered, runway closures caused an increase in requests for aircraft identification, and aircraft malfunctions seemed to cause an increase in the need for aircraft type. The display already provided those pieces information that was especially needed during these off-nominal events. Interestingly, the theoretical situation dimensions mapped neatly onto the operational dimensions and onto the structure of the display.

The Dimensions of Information Requests:

What information is needed in the air traffic control tower?

A number of disciplines have been concerned with information needs and how individuals seek information in order to satisfy those needs (Case, 2007). Information needs can be thought of as caused by a gap or uncertainty in knowledge (Belkin, 2005), understanding, or sense-making (Dervin, Foreman-Wernet, & Lauterbach, 2003) as related to some topic or goal, putting the operator in, what Belkin would call, “an anomalous state of knowledge.” . The outward behavioral manifestation of information needs, information seeking, is presumably conducted to reduce the information needs, that is to supply missing information needed to achieve the operator’s goals.

The study of information seeking behavior has obvious importance for the development of search engines, library infrastructures, and any task that presents an operator with more information than can be consumed at once, which is virtually every modern industrial task we ask operators to perform. Depending on the situation, information seeking can take many forms. On the internet, a user may use clues from a search, the “information scent” (e.g., Pirolli, 2007), to forage for the sought-for-information. In a library, the user may negotiate with a librarian, modifying the request interactively (Case, 2007). In everyday tasks, such as seeking the current time, it might involve glancing at a display on your wrist or asking the person next to you.

Even as we read a narrative, we monitor different kinds of information to satisfy the information needs established in us by a skillful writer. Reading researchers (Zwaan & Radvansky, 1998) have identified five dimensions that they believe characterize the information that readers track when encoding narratives, specifically: information about the protagonists, intentionality, space, time, and causality; the who, why, where, when, and how of the story.

According to the indexing model, when an incoming sentence changes one of these five dimensions, the reader updates the appropriate index. Zwaan, Radvansky, Hilliard, and Curiel (1998) showed that reading latencies increase when a sentence should lead to an update.

The protagonist dimension refers to traits of the character and is central to the story. Intentionality comprises the protagonist's goals, reasons, plans, and motivations and is thought to be critical in linking events. Causality comprises predictive inferences, as well as causal ones. Of course, space and time refer to locative and temporal dimensions. There is substantial support for monitoring these dimensions in reading (see Zwaan & Radvansky, 1998; Zwaan, Magliano, & Graesser, 1995). For example, researchers have shown that dimensional information is quite memorable (e.g., Zwaan, Langston, & Graesser, 1995), can proceed implicitly (e.g., Rinck, Hahnel, and Becker, 2001), and can cost processing resources when an inconsistency must be resolved (e.g., Dutke & Rinck, 2006).

In the current work, we are interested in drawing an analogy from the reading comprehension literature to information search in dynamic environments. Of interest is how information sought in dynamic environments can be classified and whether it is classified into the same information types found in the reading comprehension literature. There is some reason to believe that they may be: Some researchers have gone beyond text to apply the narrative dimensions to other media, such as film. (e.g., Magliano, Dijkstra, & Zwaan, 1996; Magliano, Miller, & Zwaan, 2001; Magliano, Taylor, & Kim, 2005) and virtual reality (e.g., Radvansky & Copeland, 2006).

In particular we hope to explore this analogy in a supervisory control paradigm (Sheridan, 1992), such as air traffic control (ATC) as it is conducted in airport control towers. Supervisory control is complex: In supervisory control, the operator must not only maintain parallel task goals but the task goals change over time as does the information needed to accomplish them (Sundstrom, 1993). For example, in the ATC supervisory control paradigm the environment continuously changes regardless of the actions of the operator (that is, the environment is dynamic) and is one in which the operator delegates tasks to other agents (in this case pilots), and issues control actions causing changes in the dynamic, often uncertain, environment.

Extending the narrative dimensions research to supervisory control can have value in several regards. First, it would be of interest simply to confirm or disconfirm that the five dimensions that seem to characterize cognitive processing of textual narratives also characterize supervisory control tasks. It may be that these five abstract dimensions could characterize a broad range of real world tasks. On the other hand, other dimensions might emerge as an atomic component not reducible to the five dimensions of Zwaan and Radvansky (1998). Second, it is not clear which of the five dimensions would tend to dominate a task such as air traffic control. For example, the space dimension, which has an unclear status in updating narratives, might dominate monitoring of the ATC task. Third, in our study, the dimensions will be used to characterize information seeking, rather than the information monitoring tasks inherent in reading. Information seeking is usually seen as an active and purposive behavior. The purposive seeking done through a cacophony of environmental stimuli might differ substantially from passively indexing dimensions presented neatly one sentence at a time. Fourth, extending the dimensions to supervisory control may add insight into the process of designing displays. With this in mind, we flesh out a display design and look at its relationship to the five narrative dimensions. Fifth, and finally, the extension of the dimensions to air traffic control can help address specific FAA questions about the information requirements of the ATC tower. The FAA is engaged in NEXTGEN, an effort to revamp the National Airspace System to accommodate the expected increase in traffic expected by 2025. Understanding the information needs of controllers will be necessary to make this transition.

Of course other work exists in ATC directed at information requirements. Much of this work applies to other control environments, but a few studies have focused on tower control. In addition to the extensive task analysis of Ammerman et al. (1987) performed years ago, a handful of more recent studies bear on information requirements.

Booz-Allen-Hamilton (2006) observed controllers at seven towers in order to identify the type of information used by air traffic controllers. To facilitate data collection, task flow diagrams were created that described tasks performed by ground and local controllers. These diagrams were used to record the type of information that was needed to perform a task as well as the order in which information was used. In addition, sequential scan data collection forms were created to record the order in which equipment was used by controllers to gather information while performing a task that was outlined on the flow diagram. Durso, Sethumadhavan, & Crutchfield (2008; Durso, Sethumadhavan, Crutchfield, & Morris, under review) calculated the relevance of information used in air traffic control towers by considering measures of frequency and criticality gleaned from the Ammerman task analysis. Durso, Dattel, et al. (2008) studied the flight strip marks that were made in 10 control towers. Although, at best, an indirect measure of information requirements, strip markings are clearly related to the types of information being considered by the controller. Another area of research that lends insight to information requirements is the work on position relief briefings, the communication between controllers at the point of a personnel change at a position (e.g., Durso, Crutchfield, & Harvey, 2007; Sethumadhavan & Durso, in press).

In the current study, we asked professional air traffic controllers to direct simulated air traffic in a number of airport tower scenarios. To gain access to an understanding of the controllers' information needs, we eliminated direct access to all of the information normally made available in the tower cab, except information that could be processed by looking out the window or by communicating with the aircraft. Thus, all of the equipment normally used by a tower controller was eliminated and controllers were required to ask explicitly for any information they needed to work the scenario successfully. This allowed us to determine what information controllers needed and when they needed it.

In addition to investigating the dimensions of situation models, we continue by investigating the operational details of the information requests. Such details essentially supply the real-time, in situ foundation for information requirements. Such information has obvious practical value. In fact, we take the tack of summarizing the resultant information requests by developing an information display for ATC tower personnel. Although a skilled designer could do better in creating an implementable display, we found that display design was a valuable aid—more valuable than simple descriptive statistics-- in summarizing the resultant data in our discussions of this project. We pass along that approach as an aid to the reader in summarizing the data presented in this article.

Requiring participants to request information whose access is controlled by the experimenter has been a useful methodology to help understand decision behavior, consumer choice, and so on (e.g., Payne, 1976; Staelin & Payne, 1976) including ATC. For example, Niessen, Eyferth, and Bierwagen (1999) asked German en route controllers to contol traffic while parts of the radar and flight strips were masked. Mousing over the mask revealed the needed information. Of course, Neissen et al. involved en route rather than tower controllers, but it also had the methodological limitation of that the mouse-over procedure allowed only a few components to be studied. In the current work, all information could be eliminated until the controlled asked for it. Although this removed the computerized access to hidden information that Niessen et al.'s participants enjoyed, it did allow us to investigate a wider range of information. Finally, Bisseret (1971) used a variety of techniques in his effort to identify the mental processes that air traffic controllers must perform in order to identify future conflicts between aircraft pairs. One method was to provide air traffic controllers with a scenario that contained limited information which required that the controllers ask for the information that they needed.

A final methodological detail goes to a concern about compromised need. When requesting information, individuals will make a request based on a compromised need—one that takes into account what the information source could deliver (Taylor, 1968). We explicitly directed this issue of compromise by instructing the controllers that they were free to ask for any information they needed even if they could not normally get that information in today's environment. Relatedly, we recognized that industrial operators in general will tend to request information in a form familiar to them For example, in pre-experimental interviews with consultant controllers, it was often the case that the information they claimed to need was conveyed by giving the name of the display—"I would need the D-BRITE" or "I'd need the ASDE-X in that situation." This familiarity bias makes it difficult to determine from experts the extent to which new approaches would be beneficial. For example, Cross (1992) asks us to imagine consumers in the early part of the last century who were asked how to make their iceboxes better. "More ice, more often" would be the likely reply, rather than chemical refrigeration. In order to circumvent this bias, we required that controllers tell us specifically what information they needed; for example, “I need the distance between the Continental and the King Air,” or “I want to see a display of my inbounds.”

Thus, we report data from professional controllers who were required to request explicitly various pieces of information while controlling simulated air traffic. The resulting data will be discussed both in terms of the narrative dimensions (e.g., protagonist) that characterize the requests and in the more specific ATC operational level (e.g., Aircraft Identification). We summarize the data from the requests with traditional statistics but more interestingly also by presenting a display design that maximizes access to the information typically requested.

Method

Participants

Six male air traffic controllers (mean age = 58.5) who served as tower cab instructors at the FAA Academy in Oklahoma City volunteered. They had an average of 25.50 years of experience controlling traffic (range: 21 to 31 years) and on average had controlled traffic in the field within the past 3.5 years (range: 1 to 9 years).

Design

All participants controlled traffic as both a ground and a local controller in each of the five scenarios; thus the design was a 2 (position: local, ground) x 5 (scenario) within subjects design. Participants’ initial staffing position was randomly assigned, with participants performing the remaining five scenarios in that staffing position before switching positions and performing the scenarios as the other position. Order of scenarios was counterbalanced.

Scenarios

Scenarios were developed in consultation with a subject matter expert. Details of the scenarios are presented in Table 1. Scenarios were designed to capture both routine and off-nominal aspects of controlling traffic in a tower cab environment. Because it is difficult to collect data for off-nominal events in field studies, the inclusion of such events in the scenarios provided a much-needed opportunity to determine the information needs during these rare events. Scenarios lasted between 34 and 41 minutes.

Insert Table 1 Here

Apparatus

This experiment was conducted using the FAA Academy's high fidelity air traffic control simulator in Oklahoma City. The simulator provided an out-the-window view of a fictional control tower environment, Academy Airport (see Figure 1), the environment in which U.S. controllers are trained. The view was portrayed on a set of screens providing a 3.5' x 25.0' panorama of the airport. Academy Airport had three runways, 11 taxiways, three helipads, and other special use areas and facilities (see Figure 2). The airport could accommodate heavy commercial aircraft and simultaneous approaches to a set of parallel runways.

Insert Figures 1 and 2 Here

Radio communications from aircraft were simulated. Through a combination of automated communication and the interactions of a pseudo-pilot, communication between pilot and controller mimicked field operations. For example, an arriving aircraft would call the tower and request a runway. The participant would then issue a clearance to land, and a readback would be generated.

All utterances made by participants, experimenters, tower simulator support staff, the confederate, and the simulator were recorded (wireless microphones for the humans; digital connections for the simulator). In addition, a video recording was made of the monitor that was used by tower simulator support staff.

Procedure

Setup. Figure 3 shows a diagram of the experimental setup. The participant occupied either the local position (left) or the ground position (right); the confederate occupied the other position. Academy staff acted as ghost pilots and the information center. Call signs were managed by an experimenter near the information center. Call signs on slips of paper were projected on the wall and the participant could adjust the positions of the strips by informing the strip manager. Finally, another experimenter controlled the overall operation including calling for pauses, starting and stopping the scenario, and so on.

Insert Figure 3 Here

Procedure. Participants were told that we were interested in the information they typically needed when controlling air traffic. They were told that we were more interested in their information requests than in seeing how efficient they were at controlling traffic without their equipment. They were told that they would have access to the out-the-window view and that once a plane was contacted they would have access to the call sign of the aircraft. They could ask that the callsign tags be manipulated, but they were not allowed any writing utensils, so they could not annotate the tags nor make any other notes. They were told all equipment normally available in the tower cab could only be accessed by querying information central. They were asked to utter “Information” and then to request any information they desired (e.g., “Information. Where is the Cessna?”). They were also informed that they could have graphical representations of information by asking for the specific information that they needed. A two-dimensional graphic would then be drawn with the information requested.

Participants were also told that any information normally available or any information they would like to have, even if not normally available, could be obtained by querying the information position. Thus, they were told to feel free to ask that the scenario be paused if they desired and that regardless of their decision, the experimenter would insure that the scenario would pause every 5 minutes. Experimenter-initiated pauses were also incorporated to reinforce the notion that information seeking was more important than performance and to give the participants regularly scheduled opportunities to ask questions.

Participants initially watched a scenario modeled after the ground control position, followed by a practice scenario in which the participants acted as local control. Participants then completed 10 scenarios: each of the five scenarios twice, once as a ground controller and once as a local controller. During each session, participants worked with a confederate, who assumed the tower position not held by the participant. One confederate served in all scenarios for all participants.

At the beginning of each scenario, participants received a position relief briefing from the confederate controller. These briefings provided a variety of information including ATIS, wind (direction and speed), temperature, dew point, visibility, and approach ILS. In addition, briefings contained specific information regarding each scenario. Finally, participants received some notification regarding a unique scripted event that may occur. For example, when performing the runway closure scenario, participants received a warning that a runway would temporarily close. Participants were notified because the purpose of the scripted events was not to surprise participants but to determine if the events influenced the information requests.

A scenario ended when either the scenario time reached 30 min or when the total time (including pause time) reached 45 min. After the end of scenarios, participants gave a position relief briefing in which they described the status of the aircraft that they were controlling..

Results and Discussion

Transcriptions

Each transcription contained the communication that occurred during the scenario, including interactions between controllers (i.e., participant and confederate), controllers and pilots (i.e., participant and simulator), and between the participant and tower simulator support staff (i.e., participant and “information.”) The transcriptions were then coded. Broadly, the coding scheme consisted of two types of codes: contextual codes and information codes.

Both types of codes consisted of a function and parameters. The functions captured the primary purpose of the communication and the parameters were the additional details that happened to be conveyed as part of that primary purpose. Roughly, the function was the “verb” of the utterance. For example, the statement “Falcon three two two Delta Alpha taxi to Runway two eight Right” was coded as TAXI(TACID, RW), with TAXI being the function and TACID (type and aircraft identification) and RW being the parameters. There were 104 functions. Functions could take between zero and six parameters.

Contextual Codes

Contextual codes were used to code communications between participants and the confederate as well as communication between participants and the pilots (i.e., simulator). We will use contextual codes only when necessary to help better understand the information requests.

To understand contextual coding, consider a typical brief exchange between the pilot and the controller presented in Table 2. Typically, an aircraft issues a request, the controller issues an instruction, and the pilot reads back the instruction. In the example in Table 2, a pilot wants to depart, the controller issues an instruction to taxi to the runway, and the pilot reads back the instruction to taxi.

Insert Table 2 Here

Specifically, an aircraft (Challenger 903PQ) calls in requesting to depart to Peachtree DeKalb. The contextual code for this request was CALLINDEPARTURE. The code in parentheses after CALLINDEPARTURE describes all of the additional information provided in the pilot's statement. In this instance TACID = type and aircraft identification ("Challenger 903PQ"), LOC = location ("at Spartan Aviation"), FR = flight rules ("IFR"), ATIS = Automatic Terminal Information Service ("information papa"), and DESTINATION = destination ("Peachtree DeKalb"). This was followed by an instruction to taxi. The contextual code was TAXI followed by additional information that included TACID = aircraft's type and aircraft identification (Challenger 9PQ) and RW = which runway to take (RW 28R). Finally, the pilot reads back the instruction to taxi. The contextual code was READBACK. In this case, the additional information in parenthesis provides what is being read back. In this example the pilot is reading back the instruction to taxi.

Information Codes

The communications of particular importance were requests for information. Information codes were used to code every type of information request posed by participants. Initially, there were 50 codes to describe information requests. After consulting with a subject matter expert, the number of codes was reduced to 28. The 28 codes along with example information requests are presented in Table 3.

Insert Table 3 Here

Inter-rater reliability

In all, 31,847 lines of code were required to transcribe each statement. The average scenario contained 531.78 lines of code (range = 306 – 940). Three experimenters independently coded the transcripts. Percent agreement was based on six scenarios, one from each participant. Mean percent agreement was 84 percent. Percent agreement ranged from 73 to 95 percent, depending on the rater-pair and the sampled scenario.

Scenarios

The scenarios differed in time to complete (including pause times, Table 4), $F(4, 20) = 5.65$, $p = .003$, $\eta^2 = .531$, number of statements (Table 5), $F(4, 20) = 3.81$, $p = .02$, $\eta^2 = .43$, and these scenario effects interacted with position for time to complete, $F(4, 20) = 11.49$, $p < .001$, $\eta^2 = .70$, number of statements, $F(4, 20) = 16.2$, $p < .001$, $\eta^2 = .76$., and number of pauses (Table 6), $F(4, 20) = 4.40$, $p = .01$, $\eta^2 = .47$. The aircraft malfunction scenario proved more intricate for the local compared with the ground controller, taking reliably longer, $t(5) = 3.46$, $p = .018$, more statements, $t(5) = 4.37$, $p = .007$, and more pauses, $t(5)$ 5.00, $p = .004$. It was the fog scenario that proved intricate for the ground controllers, taking longer, $t(5) = 5.29$, $p = .003$, and involving more statements, $t(5) = 3.51$, $p = .02$. For the other scenarios, some measures marginally suggested more complexity for local in runway closure and expect departure clearance time (EDCT.) The night scenario showed no indications of position differences.

Insert Tables 4, 5, 6, here

The number of information requests varied with position *F*(1, 5) = 8.25, *p* = .04, η^2 = .62, and scenario, *F*(4, 20) = 3.55, *p* = .024, η^2 = .42, were significant. As indicated in Table 7, ground controllers (*M* = 19.20) made fewer requests than local controllers (*M* = 35.57) in all scenarios. The interaction between position and scenario was marginally significant, *F*(4, 20) = 2.81, *p* = .053, reflecting the fact that local sometimes made as many as 22.50 more requests than ground (EDCT scenario) to as few as 4.16 more requests (FOG scenario).

Insert Table 7 here

Situation Models

In their article on situation models, Zwaan and Radvansky (1998) discussed five dimensions of situations. Those dimensions were: causality, intentionality, protagonist, space, and time. We added to these five dimensions five additional dimensions as well as an "unclassified" category. The characteristics of the dynamic ATC task encouraged us to add *motion*, *rules*, and *environment*. In addition, we added two dimensions that acknowledged the fact that the controllers themselves were protagonists. Thus, Controller Intent and Controller Memory were included.

Thus, each of 1663 information requests were assigned to the 11 situation dimensions, the five situation model dimensions of Zwaan and Radvansky (1998), three dynamic ATC dimensions, two operator dimensions, and unclassified. Of course, as in the reading literature, all traffic information requests were related to the protagonist, i.e., the aircraft, in some way. As such, information requests that identified the aircraft were not sufficient to classify an information request as protagonist. Only information requests about inherent characteristics of the aircraft were classified as protagonist (e.g, “Information, is 80Y IFR or VFR?”). Requests about where the aircraft was located were classified as space (e.g., “Information, where is 40DQ at?”) and requests about anything involving time, including the current time in the scenario, were classified as time (e.g, ”What time is it?”). Requests about what the aircraft was planning to do were classified as intentionality (e.g., ” What was the departure routing on 41C?”). If there was a causal component, but not intention, the information was classified as causality (e.g., “What is the wind?”).

For the dimensions that we have added, motion was information about the movement of an aircraft (e.g., ”What's eagle flight's speed?”); environment was information about the airport or surrounding environment (e.g., “What's the altimeter?”); rules were information about predefined information that the controller should have known prior to the scenarios (there were no such queries).

For the two classifications that viewed the operator as a protagonist, controller memory was information about the past actions of the controller (e.g., “I can't recall what I told FedEx. I think I just… Did I tell him to hold short of charlie?”); controller intent was information regarding the actions that a controller plans to perform (there were no such queries).

Judges were permitted to assign a query to multiple categories. Information requests that fit multiple dimensions or no dimension were classified as unassigned, but we will look at these in more detail later. Most of the information requests that were unassigned were because they could fit into multiple dimensions, not because they failed to fit any dimension. For example, requests for hold short information (e.g., "ZW still holding, correct?") could provide space information or intentionality information. Space would be the position of the aircraft, whereas intentionality would indicate whether the aircraft was planning to continue or to hold short.

The classification was done independently by two judges. Reliability was 87.43% and disagreements were resolved by discussion. Pie charts comparing ground and local controllers along the 10 dimensions (and unclassified) appear in Figure 4.

First, note that the preponderance of the classifications involve the Zwaan and Radvansky (1998) dimensions, even though those were imported from an analogy to reading comprehension. With the exception of motion and controller memory, the added categories accounted for little or nothing. Even though motion and controller memory occurred at nontrivial levels, they were small in comparison to the original five dimensions.

Insert Figure 4 Here

Proportions (see Tables 8-14) were analyzed with a 2 X 5 (Position X Scenario) multivariate analysis. The dependent variable was the proportion of information requests based on each situation model dimension. This analysis revealed a significant Position main effect ($F(1, 5) = 9.56$, $p < .05$, *partial* $\eta 2 = .66$). The interaction and the Scenario main effect were not significant ($p > .05$). To investigate the significant Position main effect, follow-up 2 (Position:) x 5 (Scenario) univariate ANOVAs were performed for each situation model dimension.

Insert Tables 8-14 Here

Protagonist information was the most prominent situation model dimension, especially in the runway (M = .52), night (M = .59), and malfunction (M =.54) scenarios, ($F(4, 20) = 10.88$, $p < .05$, *partial* $\eta 2 = .68$). These requests came proportionally more from ground controllers ($M = .50$) than local controllers ($M = .43$), $F(1, 5) = 8.78$, $p < .05$, *partial* $\eta 2 = .64$, although the fog scenario showed a reversal.

On the other hand, local controllers usually showed a greater proportion of intentionality information (M = .20) than did ground controllers (M = .12), $F(1, 5) = 8.38$, $p < .05$, *partial* $\eta 2 = .63$, although the effect did depend on scenario, $F(4, 20) = 6.10$, $p < .05$, *partial* $\eta 2 = .55$, with runway, $t(5) = 4.41$, $p = .007$, and fog, $t(5) = 5.64$, $p = .002$, scenarios being significant and EDCT showing a reversal.

Space requests also implicated position only in some of the scenarios, as suggested by the position x scenario interaction, $F(4, 20) = 11.63$, $p < .05$, *partial* $\eta 2 = .70$). Specifically, space information tended to be comparable between the two positions with the exception of the EDCT scenario, $t(5) = -6.51$, $p = .001$, in which ground had proportionally fewer requests and a trend in the ground fog scenario, $t(5) = 3.18$, $p = .024$, which showed a marked reversal; the larger proportion of space requests by ground is expected given that out-the-window views of the airport were severely limited for the ground position in the fog scenario.

For time, a significant main effect of scenario was found, $F(4, 20) = 24.32$, $p < .05$, *partial* $\eta 2 = .83$. This effect was due to participants making significantly more time requests in the EDCT scenario than any other scenario. Given the expected departure clearance time event in the eponymous scenario, this increase in time requests is perhaps not surprising. The position x scenario interaction for time requests was marginally significant, $F(1.13, 5.64) = 5.38$, $p = .06$.

Requests for controller memory showed significant effects of both position, $F(1, 5) = 8.07$, $p < .05$, *partial* $\eta 2 = .62$, and scenario, $F(4, 20) = 3.98$, $p < .05$, *partial* $\eta 2 = .44$. Ground controllers ($M = .008$) made proportionally more memory requests than local controllers ($M = .002$). For the scenario main effect, although pairwise comparisons were not significant, the effect is most likely due to more memory requests being made in the fog scenario ($M = .014$) than the night and aircraft malfunction scenario in which no memory requests were made.

Neither motion nor environment reached significance. Interesting, only local made such requests. Motion requests were made in every scenario by local, although only at a rate of 1% or 2%, whereas environment requests were even rarer, and occurring only in the runway and EDCT scenarios.

Finally, consider the classifications that fell into more than one category. Table 15 presents these 39 (of 1663) in a co-occurrence table. As might be expected from the previous discussion, intentionality, space, and protagonist were involved in most of the dual coded utterances. In fact combinations of space-intentionality and protag-intentionality were 28% of the multiply classified utterances. A typical example of space-intentionality was a request which asked for intentionality information but within a specified area, such as “Info, any other aircraft on final to RW 28R outside Woody?” Thus, these requests represent a contextualized query based on space. Normally, the context for a query is the aircraft (the protagonist) (e.g., Is the Falcon holding short?). A typical example of protagonist-intentionality was a request that asked for two types of information, and thus were actually two information requests, such as “And is 6PP IFR and what’s his route?”

Insert Table 15 here

In summary, there were large proportions of protagonist, intention, and spatial requests. There were some time requests, while causality was not used as the sole category for any requests. Although there were few controller memory requests, these requests varied based on both position and scenario. Requests for motion and environment, on the other hand, did not proportionally change between scenarios. At the level of situation dimensions, the two positions, local and ground, differed somewhat in how they allocated their requests. A greater proportion of ground's requests were about protagonist and controller memory. Local's requests had proportionally more intentionality and space requests, but this depended on the scenario.

Operational analyses

We now turn to a detailed look at the specific information requests. The 1663 requests represented 28 different operational functions. As we investigate the specific information requests, we attempt to summarize the results by building a display that provides the controllers with a maximum of information and a minimum of display clutter. Thus, we hope to use the display as a method of abstraction of the data that more traditionally has taken place using descriptive statistics.

Proportions of information requests for each position and scenario can be seen in Figure 5. In this figure, the proportions for each information request are represented by the size of the pie slices in the graphs, while the frequencies of the requests are overlaid onto the graphs.

Insert Figure 5 Here

Primary requests of local and ground: Position specific displays

For ground, the most frequent information requests, summed across all participants and scenarios, was ACID (f = 181), followed by LOC (f = 154), TYPE (f = 58), DESTINATION (f =

44), and GRAPHIC-MULTIPLE (f = 31). These account for 79.73 % of the ground controller requests. These five requests can be conveyed to the ground controller with a simple display like that shown in Figure 6a.

Insert Figure 6 Here

For local, the most frequent information request, summed across all participants and scenarios was DEPROC (f = 180), followed by ACID (f = 169), LOC (f = 144), FR (f = 141), TYPE (f = 111). These five requests are 69.24 % of the requested information. These five requests can be conveyed to the local controller with a simple display like that shown in Figure 6b. Borrowing from the Remote ARTS Color Display System, the indication of flight rules can be restricted to noting VFR traffic. IFR traffic can be assumed if no information is provided.

Because the local and ground displays are spatial graphic displays, other information requests are also covered beside the five requests which gave rise to it. These include requests for AIRBORNES, DEPARTURES, INBOUNDS, all GRAPHICS, SEQUENCE, and DISTANCE. Thus, this simple local-specific display actually covers 93.12 % of the information requests made by local, while the ground-specific display actually covers 88.59 % by ground. Thus, in many ways, the displays provide a summary of the information requests made by the controllers.

Aligning ground and local: Common displays

In the Booz-Allen-Hamilton (2006) study mentioned earlier, there was considerable similarity in the type of information required by local and ground controllers (aircraft position, ACID, type, and runway) and in scan patterns (frequent scans out the window and at flight progress strips). Booz-Allen-Hamilton (2006) concluded that ground and local controllers rely on similar information, and they therefore recommended a standard tower cab design that would be shared by ground and local controllers.

Comparing the two position specific displays in the current article also shows some points of alignment. Both have a position symbol connected to a datablock with ACID and TYPE. Both also have some information about the intention of the aircraft—either *Destination* for the Ground controller or *DEPROC* for the local controller. We can take advantage of these points of alignment to generate a common display.

The union display. One simple solution is to allow all the information from both specific displays to be on the common display. This would be the union of the two specific displays. This is only possible because the “Destination” needed by Ground was for arrivals only—that is the ultimate parking position of the incoming aircraft and the DEPROC needed by Local was for departures only. Thus, arrivals would display Parking-Destination and departures would display the exiting DEPROC.

Clearly, there are two staffing positions—local and ground—and two classes of aircraft—arrivals and departures. Thus, one would surmise, that there would be four clusters of information needs: the information local needs for arrivals, the information local needs for departures, the information ground needs for arrivals, and the information ground needs for arrivals. Our data indicate that 90% of the information requests made by the local controllers were for departing aircraft, and 90% of the information requests made by the ground controllers were for arriving aircraft. Virtually all of the requests made by a controller for the minority class of aircraft were identical to the requests they would have made from the other staffing position. For example, the local controller normally asks for destination information about departing aircraft, but on the rare occasions destination information is requested for an arrival it is the same request that a ground controller would make, namely parking position. Similarly, when a ground controller asks about the minority class of flights (i.e., the departures), the destination requests are about the final destination city. Thus, surprisingly, local and ground seem to deal with departures and arrivals respectively, and when they do query about the other type of flight they need the information that would normally be needed by their compatriot in the tower. In our discussion with SMEs, these kinds of requests likely reflect an effort of one controller position trying to help the other controller position. In any event, this makes it possible to combine the ground and local controller displays and to capture all of the information needs, not by staffing position, but by class of flight—arrival or departure.

The shared field display. Interestingly, the next most frequent information request is the local controllers' request for destination, which of course typically refers to a city or airport rather than a particular parking area. This additional alignment of the Destinations (arrival and departure) raises the possibility of a more intricate display.

Aligning datablocks using the different destinations requires both Destination and DEPROC on a common display, but this should be done in a way that has minimal impact on clutter, is logically consistent, and addresses additional information needs of the two controllers. We note that DEPROC is a near term intention of departing aircraft and DEST is a far term intention. In our study, DEST for ground controllers was usually Parking for arrival aircraft, but of course DEST can be a feature of either arriving or departing aircraft.

Thus, one way to have both DEPROC and DEST on the same display without adding clutter would be to time-share the near term intention of the AC with the far term intention. For a departing aircraft, DEPROC and DEST would time-share: Thus, the display might alternate between Academy One and DFW, showing a flight leaving on the Academy One departure headed to Dallas Fort-Worth. For an arriving aircraft, DEST would time-share with some near term intention. TAXI is a viable piece of information to time-share with DEST. Thus, an arrival might alternate between the C-B taxiway sequence and Spartan Aviation parking. Adding these features to a common display allows the common display to account for additional information requests. The common display adds DEPROC (f = 23), FR (f = 25), and Taxi (f =3) for Ground, and DEST (f =11) and TAXI (f = 0) for local. Notice that while adding Destination for local follows from the data, adding Taxi does not. Instead, it follows from the gap evident when aligning Ground and Local. More specifically, Destination (local) : DEPROC (local) :: Destination (ground) : ______. If Destination (local) is viewed as a far term intention and DEPROC (local) as a near term intention, then one answer that completes the analogy with Destination (ground) is TAXI, which is a near term intention of the taxi routes of arriving aircraft. Thus, this common display, which can be represented as in Figure 7, is largely evidence based, but also has some information that is logically consistent but not necessarily needed often according to the data. (The few taxi information requests apparent in the data were *not* requests about particular taxiways, but rather reflected a memory failure about whether or not the participant controller issued a taxi instruction.)

Insert Figure 7 Here

Inspection of Figure 7 shows the ACID or callsign in the first line of the datablock along with an indication of the flight rules; VFR traffic is indicated by a V, and instrument traffic is indicated by an absence of a flight rule indicator. Line two of the data block is the type of aircraft. In line three, the near term destination information alternates with the long term destination. For departures, departure procedures alternate with final destination (e.g., DFW). For arrivals, taxiways alternate with final parking destination (e.g., Spartan Aviation).

Shared field for departures. Another option is simply not to include taxi. In such a display, departures could be distinguished from arrivals by virtue of the fact that the former would have a field that changed perceptibly from DEPROC to Destination, and the latter's datablock would have a steady-state datablock.

At this point, whether or not taxi is included, the common display accounts for 96.76 % of the ground information requests and 94.14 % of the local information requests.

Applying the common display to the data from the 2006 Booz-Allen-Hamilton study suggests the common display has validity. The Booz-Allen-Hamilton group concluded that ground controllers needed aircraft position, ACID, aircraft type, destination, flight route (DEPROC), taxi route, and runway. Except for runway, the common display includes all of the suggested information. For the local controllers, again ACID, aircraft position, and aircraft type are included, but runway is not.

Thus far, the 96% and 94% for ground and local respectively ignore any variation due to scenario. We turn now to a consideration of how information requests vary by the situation (i.e., scenario).

How scenarios affect information requests

We began by assuming that each scenario could generate requests not typically prominent and that these variations in scenario likely also varied with position. The alternative, to assume that the two staffing positions are equivalent across information needs or that all situations are equivalent, would not be prudent and could result in flaws in the display design. There were only six expert controllers who participated in this multiday experiment, thus statistical tests would at best be suggestive. Nevertheless, we looked at a 2 (position) x 5 (scenario) within-subjects MANOVA on arc-sine transforms of proportions to determine if there was any suggestion that the type of information which controllers asked for varied with type of position and scenario. Although neither the main effect for position, $F(1, 5) < 1$, nor scenario, $F(4, 20) < 1$, was significant, the interaction between scenario and position was marginal, $F(4, 20) = 2.34$, $p = .09$. Thus, despite the low number of participants and the concomitant low power, the differences between position as a function of the type of information request was clearly worth considering in more detail, lest one prematurely believes a particular display was universally appropriate. Although conducting any follow up analysis reflects a liberal statistical position, from a display design and development position it is a conservative stance. Specifically, we conducted two-way (position x scenario) within-subjects ANOVAs for each of the information request types.

Understanding these relationships in detail can have practical implications. This allows us to evaluate the extent to which information on the display is needed by both positions across all scenarios. Some information may be needed in all situations (and by both positions) whereas other information may be situation specific.

To preview, 13 information requests varied with either position or scenario. Eleven varied with scenario as either a main effect or interaction. Only INBOUNDS, DESTINATION, GRAPHIC_1LOC_ACID, and GRAPHIC_LOC_ACIDS_OTHER were uninfluenced by scenario. Although the focus in this section is on scenario, we present all sources of variance for completeness.

For ACID requests, main effects for position, $F(1, 5) = 27.51$, partial $\eta2 = .85$, and scenario, $F(4, 20) = 7.65$, partial $\eta2 = .60$, were significant, and the interaction, $F(4, 20) = 2.28$, $p = .097$, partial $\eta2 = .31$, was marginally significant. Ground control requests always had a greater proportion of ACID requests than did local, although Bonferroni t-tests detected only the largest difference, in the aircraft malfunction scenario when almost 50% of the ground controller requests were for ACID. ACID is part of the common display thus far, and as is evident from Table 16, was often needed regardless of position or scenario.

Insert Table 16 Here

For DEPROC requests, position, $F(1, 5) = 18.41$, partial $\eta 2 = .79$, and the interaction were significant, $F(4, 20) = 5.18$, partial $\eta 2 = .51$, while the scenarios showed a marginal difference, $F(4, 20) = 2.26$, $p = .099$. Typically, Local has a greater proportion of DEPROC requests than does ground, but this was actually reversed in the Rain/EDCT scenario, which can be seen in Table 11. Bonferroni t-tests confirmed the difference in the fog scenario, $t(5) = - 4.41$, and night scenario, $t(5) = - 4.21$, and marginally so in the aircraft malfunction scenario, $t(5) = - 4.06$, $p = .01$. Although DEPROC is on the common display, Table 17 indicates it is of little value to the ground controller with the exception of the EDCT scenario.

Insert Table 17 Here

To understand better why ground controllers requested DEPROC information in the EDCT scenario, we studied the contextual codings that preceded each DEPROC request. We found that ground controllers were assisting the local controllers in dealing with the noise abatement that was also part of that scenario. Because of the noise abatement, certain departure procedures were disallowed and the ground controller modified the departures of those on the disallowed procedure.

Overall, providing DEPROC to the ground controller is usually of little value and is a factor on the side of position specific displays. However, the occasional need for ground to know DEPROC along with the reduced expense associated with a common display makes its consideration worthwhile.

For LOC requests, a significant main effect for position, $F(1, 5) = 9.84$, partial $\eta 2 = .67$, and scenario, $F(4, 20) = 14.79$, partial $\eta 2 = .75$, was found. These effects, however, were qualified by an interaction between position and scenario, $F(4, 20) = 3.01$, partial $\eta 2 = .38$. Of course, LOC information is on the common display, and as Table 18 indicates it is often used by both positions in every scenario. However, LOC was a larger proportion of the ground controller's requests compared with the local controller's requests. In fact, during the ground fog scenario, the ground controller asked for location information over half of the time, substantially more often than did local, t = 3.3, p = .02. As with DEPROC, the EDCT scenario eliminated or reversed what was typical in the other scenarios, t = -2.31, p = .07.

Insert Table 18 Here

For DISTANCE requests, all three sources of variance were reliable: position, $F(1, 5) = 7.52$, partial $\eta 2 = .60$, scenario, $F(4, 20) = 3.30$, partial $\eta 2 = .40$, and the interaction, $F(4, 20) = 3.82$, partial $\eta 2 = .43$. Local controllers ($M = .07$) had significantly higher proportions of distance requests than ground controllers ($M = .002$). In fact, as Table 19 indicates, requests for distance were virtually exclusive to the local controller. Because location and distance are conveyed by presenting primary target location on a graphical display, these results are mute in deciding between a common and position-specific display, assuming both are graphical representations of the area.

Insert Table 19 Here

For FR requests, a significant main effect for position was found, $F(1, 5) = 19.01$, partial $\eta2 = .79$, indicating that local controllers ($M = .13$) made proportionally more requests than ground controllers ($M = .04$). The scenario effect was marginal, $F(4, 20) = 2.34$, $p = .09$. Although the lack of an interaction suggested these differences were not influenced by scenario, it is worth noting that in the EDCT scenario the difference virtually disappears (Local- $M = .05$; Ground- $M = .04$), which can be seen in Table 20. Again, FR seems to be of value to the local controller and may be an additional display feature to be ignored by ground in a common display. However, given that only VFR traffic will have a flight rule indicator, this may be a minor issue.

Insert Table 20 Here

For INBOUNDS requests, only the main effect of position was significant, $F(1, 5) = 14.54$, partial $\eta2 = .74$, indicating that local controllers ($M = .03$) made proportionally more requests than ground controllers ($M = .001$), as indicated in Table 21.

Insert Table 21 Here

For HOLDSHORT requests, only a significant main effect for scenario was found, $F(4, 20) = 12.78$, partial $\eta2 = .72$. Essentially, holdshort requests were only made during the ground fog, as indicated in Table 22. However, there was not enough power for the pairwise comparisons to confirm this.

Insert Table 22 Here

For TIME requests, a significant main effect for scenario was found, $F(4, 20) = 23.04$, partial $\eta 2 = .82$, showing that time is requested proportionally more in the EDCT scenario than in other scenarios. As indicated in Table 23, this is especially true for the ground controllers, contributing to a significant interaction between position and scenario, $F(4, 20) = 7.55$, partial $\eta 2 = .60$.

Insert Table 23 Here

For TYPE requests, a significant interaction was found between position and scenario, $F(4, 20) = 4.18$, partial $\eta 2 = .46$. As Table 24 indicates, which controller made more type requests depended on the situation. Essentially, local controllers were constant in requesting type information about 10% of the time regardless of scenario, whereas ground controllers varied with scenario, $F(4, 20) = 3.51$, $p = .02$, partial $\eta 2 = .41$, although pairwise comparisons could not isolate the effect.

Insert Table 24 Here

There were also several other marginal effects. One of these was the main effect for position for DESTINATION requests, $F(1, 5) = 4.81$, $p = .08$. As indicated in Table 25, this effect is due to ground controllers ($M = .07$) having proportionally more destination requests than local controllers ($M = .008$).

Insert Table 25 Here

For REPORT requests, there were marginal effects for scenario, $F(4, 20) = 2.45$, $p = .08$, and the position x scenario interaction, $F(4, 20) = 2.45$, $p = .08$. These effects were due to report requests only occurring in the fog scenario by ground controllers, as shown in Table 26.

Insert Table 26 Here

There were also marginal position effects for graphics with one aircraft's location and ACID, $F(1, 5) = 4.2$, $p = .096$, and graphics with multiple aircrafts' location and ACIDs with additional information, $F(1, 5) = 4.65$, $p = .08$. As can be seen in Tables 27 and 28, these effects are due to local controllers making all of the requests.

Insert Tables 27 and 28 Here

All other effects were not significant ($p > .05$).

Situational effects

In our analysis of the details of the information requests, two general issues were apparent. First, the EDCT scenario was unusual compared to the other scenarios, often reversing effects that would have been expected based on the other four scenarios. Second, of 11 information requests that varied reliably with either position or scenario, only TIME, HOLDSHORT, and REPORT are not on the common display we have developed thus far.

Time and the EDCT scenario

The three scenarios involving visibility manipulations—rain, fog, night—all showed an occasional deviation from what would be expected based on the other scenarios. Of all the scenarios, the Rain/EDCT scenario was the most idiosyncratic. It showed one of the largest or the largest difference between ground and local in terms of ACID, DISTANCE, and

INBOUNDS. It also showed the smallest difference, or actually reversed the typical direction of the local and ground comparison, in DEPROC, LOC, and FR. Finally, it was essentially the only scenario that showed a difference in the proportion of TIME requests.

To begin, the EDCT scenario strongly suggests that TIME should be included in the display, at least during some situations. Obviously, TIME is important in that scenario because of the EDCT (although the rain may also affect timing). To provide controllers' time information, but only in the situations in which it is relevant, the displays could have time information on the third line of the data block for those flights expecting a departure clearance time. This allows the display to account for an additional 40 information requests in the EDCT scenario. One might also imagine using such a feature to account for other needs for TIME, as during the A/C malfunction scenario.

Looking back at Figure 5, the pieces of the pie that are pulled away from each chart are those information requests that are not accounted for by the common display with time that we have developed. The display does account for as much as 99.0% of the information requests from the ground controller during the EDCT scenario. The lowest percentage is 89.8% for the ground controller during the ground fog scenario.

Of course, one may choose to make further additions to the display in an effort to account for the 1.0 to 10.2% (ground fog) information requests that are not immediately available from the display. One might consider, for example, implementing a hold short option for the ground fog scenario.

Hold short and the Ground Fog scenario

Requests for hold short information were clearly situation dependent: Such requests occurred almost exclusively when there was a ground fog (there were two in the runway closure scenario). Although more were made by ground (n = 11) than local (n = 2), there were proportionately not very many of these, even with the fog. However, given the critical safety role of such information and given that it is situationally constrained, it may make some sense to add that information to a common display.

A holding short request always involved the question *if* an aircraft was holding and usually also involved *where* the aircraft was holding (62%). Thus, if controllers were given the option of labeling the holding position of an aircraft this would supply both the needed prospective memory information and the locative information. Our data imply that this option will only be exercised during ground fog, although we suspect if available, controllers will find other situations in which to use it. Should such a design modification be implemented, accounting for this information in a display would improve the fog scenario for ground from 89.8% to 96.2%.

Off-nominal events

The display generated from the data generated by the controllers is relatively simple and does a good job of handling the information needs that would normally occur in a variety of situations. However, we were interested in exploring the information needs that occur in abnormal, or off-nominal, situations and then to see if the display developed provides the information needed to handle the off-nominal situations.

Off-nominal events can range “from slightly less-than-perfect operational and environmental conditions to partial or full system failures or inaccuracies” (Foyle & Hooey, 2003, p. 398). The study of off-nominal events has been far from extensive. Because off-nominal events occur infrequently, it is difficult to study them in the field. Therefore, off-nominal events must be studied using simulations of events. One study that included the testing of off-nominal events is Hooey, Foyle, and Andre (2000). In this study, cockpit navigation displays designed for low-visibility airport ground operations were studied in both nominal and off-nominal scenarios to assess their integration with cockpit procedures. The suite of displays, called the Taxiway Navigation and Situation Awareness (T-NASA) system, consists of an electronic moving map (EMM), a head-up display (HUD), and auditory alerts and warnings. To study EMM usage, HUD usage, and clearance information usage, three off-nominal events were investigated. Potential problems with automation trust and error detection were found as a result of including the off-nominal events.

Foyle and Hooey (2003) discuss the importance of testing off-nominal events to ensure that a system has been adequately evaluated. A method of including off-nominal events in testing is presented in which low or moderately disruptive off-nominal events can be included in between nominal events without affecting the accurate measurement of nominal event effects, while highly disruptive off-nominal events can be included as a final trial in testing. This methodology was used while measuring performance with different aircraft taxi display systems. Foyle and Hooey point out that test scenarios often have an inappropriate balance between nominal and off-nominal events. Two philosophies contribute to this inappropriate balance: 1) off-nominal events are disruptive to nominal events and must be placed as the last trial in a sequence of tests and 2) the collection of data for off-nominal events is of most interest during testing, so time should not be wasted on testing nominal events. The inclusion of nominal and off-nominal events in a scenario, however, has several benefits, such as allowing the experimenter to examine the system under both normal and non-normal conditions, allowing nominal events to serve as the experimental control for off-nominal events, and helping the user engage in normal behavior before the off-nominal event instead of looking for unexpected events (Foyle & Hooey, 2003).

We looked at two specific off-nominal events embedded in our scenarios. One was the closing of a runway due to a lightning strike and the other was an aircraft malfunction. Both of these off-nominal events occupy an extended, but finite, amount of time in the scenario, and both are relatively rare in the field but not bizarre.

For each of the off-nominal events we began by computing the proportion of each information request during the time before the onset of the off-nominal event (baseline phase), the time during the off-nominal event (treatment phase), and the time after the treatment (return to baseline). It is possible to determine whether the off-nominal event caused a change in the information needs if the frequency of requests in baseline increases (or decreases) during treatment and then returns to baseline with the offset of the off-nominal event. For example, if the controller rarely asks for ACID before the off-nominal event, then increases requests for ACID during the off-nominal event, and finally returns to no requesting ACID after the end of the off-nominal event, then the logic of the baseline design would argue that there is evidence of a causal influence of the off-nominal event on the frequency of information requests.

To even begin to entertain that the off-nominal event was causal, we required that 1) the change compared to baseline found in the treatment or off-nominal phase was at least 8%, and 2) that most (60%) of the baseline was recovered when the off-nominal event ceased. If an information request met those criteria for an off-nominal event, we then also looked at two other criteria: 3) the data minute-by-minute smoothed curves had to show the typical improvement above baseline followed by a return to baseline, and 4) this pattern had to hold for the majority of participants when we looked at the 6 participants individually. The smoothed minute-by-minute frequencies and the smoothed minute-by-minute proportions showed similar patterns in all cases and thus only the frequency curves are reported. Smoothing was produced by averaging the frequency of requests for each minute with the immediately preceding and following minute.

Runway closure

In the runway closure scenario, there were four information types that met both initial criteria for attributing the changes to the runway closure (see Table 29). However, only one of them, ACID continued to show an evident change from baseline and return to baseline when a minute-by-minute analysis and subject-by-subject analysis were conducted.

Insert Figure 8, 9, 10

Flight rules. The proportions reported in Figure 8 are the proportion of total information requests during each time period (before, during, after) that were flight rules requests, averaged across participants. Although proportion of requests for flight rules from ground controllers decreased 9.23% and completely (119.85%) recovered the baseline, as shown in Figure 8, this pattern, shown minute-by-minute in Figure 9, proved to be more due to averaging across participants than evidence for causal influence of runway closure on the need for flight rules information. Participants 1, 2, and 5 did not have any requests for flight rules throughout the scenario. There was an increase in frequency of flight rules requests after the runway closure for Participant 3 and a decrease in frequency of flight rules requests from before the runway closure for Participants 4 and 6 (see Figure 10). Thus, although there was an overall decrease in flight rule requests during the runway closure followed by an increase after the closure, no individual participant showed this return to baseline that would make the decrease in requests attributable to the runway closure.

Insert Figures 11, 12, 13, about here

Departure procedure. For local controllers, there was an 8.09% increase in departure procedure requests and a 72.15% return to baseline, which can be seen in Figure 11. The smoothed frequency curves appear in Figure 12. Participant 1 did not make any requests for departure procedures, so frequencies for Participants 2 through 6 were inspected (see Figure 13). The frequencies of requests for Participant 3 demonstrates the increase in departure procedure requests, with the sharp increase in requests right after the runway closure due to the participant making three departure procedure requests in the minute immediately following the runway reopening. Participants 2 and 4 also showed the increase in departure procedure requests during the runway closure, although less so than Participant 3. Participants 5 and 6, however, do not show a clear return to baseline. Thus, there no compelling evidence to claim that runway closure caused an increase in departure procedure requests.

Insert Figures 14, 15, 16, about here

Type of aircraft. Requests for aircraft type by the local controller decreased 9.94% during the runway closure and recovered 82.29% of baseline afterward (Figure 14). Minute-by-minute frequency changes in type requests for local controllers can be seen in Figure 15, and frequency changes for individual participants are shown in Figure 16. There is no clear indication in the smoothed minute-by-minute graph that a return to baseline occurred. There were suggestions in participant 2 and 6 that runway closure may have caused those participants to increase their need to know the type of aircraft, but even in those cases the recovery of baseline was not clear. Thus, because the majority of participants did not show a clear recovery of baseline, the decrease in type requests cannot be attributable to the runway closure with any certainty.

Insert Figures 17, 18, 19 here

ACID. One type of information request that increased dramatically due to the runway closure and then recovered 60% of the baseline was aircraft identification (ACID) requests for ground controllers, which had a 27.70% increase in requests during the runway closure and a 61.87% return to the baseline. This change in proportion for ACID requests can be seen in Figure 17. It can also be seen in this figure that although the runway closure caused a change in the needs for ACID for ground controllers, ACID requests for local controllers continued to increase in proportion throughout the scenario.

The smoothed minute-by-minute rise in ACIDs is depicted in Figure 18. By viewing the changes in frequency for each participant, as indicated in Figure 19, it can be seen that every participant except Participant 4 had more ACID requests during the runway closure than before or after the closure. Thus, requests for ACID showed a dramatic increase during runway closure, and fell noticeably after the runway reopened. This pattern was found for most (5 of 6) of the participants. Thus, there is reasonable evidence from the logic of baseline designs to conclude that a runway closure causes an increase in the need for ACID among ground controllers.

Of course, ACID is a prominent part of the displays that emerged from a consideration of the basic scenarios and thus the need for ACID information that emerges during this off-nominal event is in some sense already anticipated in the design. One might argue that it would be worth the additional cost to make the ACID even more salient during a runway closure. However, whereas such a change may decrease the latency of locating the ACID, it would not actually add any information to the display. Of course, our data are mute to whether or not information is need more urgently in the off-nominal situation.

Aircraft malfunction

Aircraft type. The other off-nominal event that influenced information needs was an aircraft malfunction. Once again, several information types varied in their proportions requested, as shown in Table 30, but only the change in requests for aircraft type information was caused by the malfunction event. As displayed in Figure 20, requests for type increased 9.72% during the aircraft malfunction and recovered 116.90% of the baseline. The minute-by-minute frequencies of type requests are displayed in Figure 21. As shown in Figure 22, all participants had more type requests during the aircraft malfunction than before or after the malfunction. One exception to this was Participant 2, who did not have a period after the malfunction because the scenario ended before the malfunction event ended.

As with ACID which occupied line one of the data block, type of aircraft is already a prominent component of the display, occupying line two of the datablock. Again, the display provides as a matter of course the information especially needed during the off-nominal event. Although, it may make sense to highlight the information in the malfunctioning aircraft's datablock, our data are mute as to the effect of emphases on already present information.

Return to the situation model dimensions

The relationship between the display that summarizes the details of the operational analysis and the situation model dimensions is an interesting one. If we substitute each specific information request with its situation model dimension, it becomes apparent that the dimensional information tends to cluster. Lines 1 and 2 of the datablock have three pieces of protagonist information: ACID, Flight Rules, and Aircraft Type. It is interesting to note that off-nominal events tended to increase requests for protagonist information, ACID during a runway closure and Type during an aircraft malfunction. In line three, two pieces of intentionality information timeshare, Destination and Departure Procedure in the case of departures. For arrivals, line three holds either only Destination or shares Destination with the ambiguous (in terms of situation model dimensions) TAXI. All of this protagonist and intentionality information is overlaid on a background which allows the depiction of space. Finally, time information, when it is needed, is also a separate part of the datablock.

Conclusions

By requiring tower controllers to request information explicitly and precisely, we were able to determine those pieces of information needed by the ground controller and local controller. Theoretically, these information requests were well captured by the existing theory of situation dimensions proposed by Zwaan and Radvansky (1998), although information requests in ATC were almost exclusively protagonist, intentionality, and space. Even our attempts to anticipate other types of requests, such as queries about motion, the environment, or controller-as-protagonist, did not substantially alter this view.

Operationally, the particular requests broke into 28 operational categories. Although there were tendencies for ground and local to need different information, there were a number of similairities. By looking at the frequency of occurrence of the requests, we were able to create position specific displays. By aligning the information requests for ground with those of local, we made additional modifications to the display that allowed logical similarities to be captured in a common display. That display was able to account for the large majority of information requests with only a three line datablock. We added time information to account for that information need during certain situations, but other situational information needs, including off-nominal runway closures and aircraft malfunctions, were already part of the display.

Summarizing data by developing a display, rather than only using statistical procedures, has some interesting consequences. First, the display has the advantage of being immediately accessible to subject matter experts, who are not usually trained in statistical methods. Second, the summary display may serve as a large first step in designing an operational version. Third, display design provides different constraints than do hypothesis-testing procedures from statistics, thus forcing the researcher to think both about the validity of the outcome in new ways.

Finally, we note that the theoretical classification scheme borrowed from the reading comprehension literature mapped surprisingly well onto the operational display. The data block has both protagonist and intentionality information. Protagonist information (i.e., ACID, Flight Rules, AC Type) occupies the first two lines of the datablock of the summary display in a constant display. Intentionality information time occupies the third line in an alternating format, alternating between departure procedure and destination for departures, and between taxi procedure & parking for arrivals. These datablocks are superimposed on a map of the airport (i.e., space information).

The current study provided details of the information needs of tower controllers in the current environment. These needs can be of value in designing future systems targeted for the NextGen timeframe. Ultimately the display developed here should be tested with field controllers and against current and other alternative displays to determine which is best able to aid the tower controller. Such empirical tests also would be valuable parts of an iterative design process that would lead to superior tower displays and safer, more efficient air traffic control.

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Author Note

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Table 1.

Information about each scenario

Scenario	Visibility	AC for Ground	AC for Local	Major event	Other events
Runway closure	25 miles visibility; few clouds at 25000	29	30	Closure of a runway. Occurred approximately 5 minutes into the scenario. Airport manager states runway 28R closed due to lightening strike. Runway reopens in 15 min.	Pointout to TRACON; temporary communication failure
EDCT	Drizzling reduces visibility to 3 m.	29	30	Expect Departure Clearance Time (EDCT) was scheduled to occur approximately 6 min into the scenario when an aircraft requested to hold off of the gate.	Rain; noise abatement procedure in effect; runway deviation
Fog	Ground fog; overcast at 25000	28	26	30’ ground fog	Takeoff cancellation; aircraft conflict
Night	Night; visibility 25 miles; scattered at 5000, broken at 12000	27	30	Night	Taxi deviation; runway request; NORDO

Aircraft malfunction	25 miles; clear skies	27	26	Ground: Approx. 13 min into the scenario, an aircraft began smoking and requested emergency vehicles; Local: approx. 4 min in, aircraft reported an unsafe landing gear indicator.	

Table 2.

Contextual Code Example

Speaker	Contextual Code	Transcription
Pilot	CALLINDEPARTURE (TACID, LOC, FR, ATIS, DESTINATION)	“Academy ground Challenger 903PQ at Spartan Aviation information papa ready to go IFR Peachtree DeKalb.”
Ground Controller	TAXI (TACID, RW)	“Challenger 9PQ Academy ground, taxi to RW 28R”
Pilot	READBACK (TAXI)	“Challenger 3PQ taxi to RW 28R”

Table 3.

Information Codes and Examples

Information Types	Example
Aircraft Identification (ACID)	“Information, what was FedEx’s number?”
Airborne	“Is there anybody that's airborne right now?”
Altimeter	“Information, what is the altimeter?”
Altitude	“What's his altitude, about twelve hundred feet?”
Call in	“Did I talk to him?”
Cross Runway	“Information, is 40DC crossing RW 16?”
Departures	“Information on American 43 is an outbound it's ready to taxi, is that right?”
Departure Procedures	“4FR what is his direction of flight?
Distance	“How far out is the first Baron 31B?”
Expected Departure Clearance Time (EDCT)	“American 210 he has an EDCT?”
Flight Rules (FR)	“Is he IFR?”
Fuel	“I need information on Eagle Flight 616, fuel on board.”
Graphic with One Aircraft’s Location and ACID	“I would like to see a graphic of 28L on left base”
Graphic with multiple Aircrafts’ Locations and ACID	“I need a graphic of inbounds.”
Graphic with multiple Aircrafts’ Locations, ACID, and additional information (e.g., aircraft speeds)	“I'd like to see a depiction of the uh airborne aircraft, please…(with) speed, and the spatial relationship.”
Graphic (previous graphic categories combined)	
Hold Short	“So we’ve got Continental on echo and ZW still holding, correct?”
Inbounds	“Information, do I have ILSs coming in?”
Location	“Well I guess I need to know where uh BW is?”
Parking/Destination	“Where are they going to park?” “Where’s he going?
Report	“He reported on alpha? Wasn't that the report I got?”
Runway	“Okay and he is set up for the right side?”
Sequence	“Which order are they in?”
Souls	“I need information on Eagle Flight 616, souls-on-board.”

Speed	"Info, what's the speed on the 4VP?"
Taxi	"That's the only two I've got taxiing out right now is 3NZ and 4VR?"
Time	"Information, time?"
Type	"What type aircraft is 8964A"
Wind	"Information, what is the wind?"

Table 4.

Means and standard deviations of scenario lengths

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	35 min 27 s (4 min 13 s)	34 min 15 s (5 min 13 s)	39 min 42 s (1 min 59 s)	30 min 30 s (2 min 9s)	33 min 34 s (2 min 33 s)	34 min 42 s
Local	39 min 40 s (3 min 51 s)	40 min 36 s (2 min 31 s)	32 min 41 s (3 min 13 s)	33 min 12 s (2 min 48 s)	38 min 1 s (2 min 18 s)	36 min 50 s
	37 min 34 s	37 min 25 s	36 min 12 s	31 min 51 s	35 min 47 s	

Table 5.

Means and standard deviations of number of statements

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	534.50 (127.41)	453.33 (96.33)	597.00 (186.61)	477.33 (121.96)	441.33 (117.84)	500.70
Local	622.17 (175.83)	572.67 (147.60)	474.83 (142.16)	543.50 (185.87)	560.33 (166.31)	554.70
	578.33	513.00	535.92	510.42	500.83	

Table 6.

Means and standard deviations of number of pauses

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	5.33 (1.03)	5.00 (.89)	6.00 (1.41)	5.50 (1.38)	5.00 (.63)	5.37
Local	6.33 (.82)	6.67 (1.37)	5.50 (.55)	5.67 (.52)	5.83 (.75)	6.00
	5.83	5.83	5.75	5.83	5.42	

Table 7.

Means and standard deviations of total number of information requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	19.33 (11.34)	21.33 (12.64)	26.17 (7.25)	16.67 (9.50)	12.50 (6.12)	19.20
Local	40.33 (12.06)	43.83 (14.08)	30.33 (15.68)	29.33 (18.79)	34.00 (7.40)	35.57
	29.83	32.58	28.25	23.00	23.25	

Table 8.

Means and standard deviations of proportions of protagonist requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.53 (.14)	.47 (.20)	.24 (.16)	.64 (.12)	.63 (.14)	.50
Local	.51 (.06)	.30 (.09)	.32 (.13)	.54 (.15)	.45 (.05)	.43
	.52	.39	.28	.59	.54	

Table 9.

Means and standard deviations of proportions of intentionality requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.06 (.05)	.23 (.20)	.08 (.06)	.14 (.13)	.09 (.13)	.12
Local	.19 (.07)	.13 (.07)	.34 (.11)	.17 (.09)	.18 (.06)	.20
	.13	.18	.21	.16	.14	

Table 10.

Means and standard deviations of proportions of space requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.39 (.19)	.05 (.09)	.62 (.16)	.20 (.13)	.27 (.16)	.31
Local	.25 (.10)	.44 (.15)	.32 (.21)	.26 (.20)	.32 (.11)	.32
	.32	.25	.47	.23	.29	

Table 11.

Means and standard deviations of proportions of time requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.23 (.14)	.00 (.00)	.00 (.00)	.00 (.00)	.05
Local	.00 (.00)	.07 (.06)	.02 (.04)	.01 (.02)	.03 (.06)	.02
	.00	.15	.01	.005	.01	

Table 12.

Means and standard deviations of proportions of controller memory requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.006 (.02)	.005 (.01)	.03 (.03)	.00 (.00)	.00 (.00)	.008
Local	.004 (.01)	.008 (.01)	.00 (.00)	.00 (.00)	.00 (.00)	.002
	.005	.006	.01	.00	.00	

Table 13.

Means and standard deviations of proportions of motion requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00
Local	.01 (.01)	.02 (.03)	.01 (.02)	.01 (.03)	.02 (.04)	.01
	.004	.01	.003	.007	.01	

Table 14.

Means and standard deviations of proportions of environment requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00
Local	.01 (.01)	.005 (.01)	.00 (.00)	.00 (.00)	.00 (.00)	.002
	.004	.002	.00	.00	.00	

Table 15.

Categories included in dual-coded information requests

	Environment	Causality	Intentionality	Protagonist	Space	Controller Memory	Motion
Environment	0	2					
Causality	2	0		1			
Intentionality			0	5	6		
Protagonist		1	5	0	2		
Space			6	2	0	2	2
Controller Memory					1	0	
Motion					2		0
Total	2	3	11	8	11	2	2

Table 16.

Means and standard deviations of proportions of ACID requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.31 (.12)	.34 (.18)	.15 (.12)	.33 (.12)	.46 (.16)	.32
Local	.21 (.11)	.11 (.05)	.07 (.04)	.20 (.13)	.19 (.05)	.16
	.26	.22	.11	.26	.32	

Table 17.

Means and standard deviations of proportions of DEPROC requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.01 (.02)	.13 (.16)	.00 (.00)	.00 (.00)	.02 (.06)	.03
Local	.15 (.09)	.09 (.05)	.27 (.15)	.16 (.09)	.16 (.05)	.16
	.08	.11	.14	.08	.09	

Table 18.

Means and standard deviations of proportions of LOC requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.32 (.26)	.08 (.16)	.51 (.19)	.18 (.11)	.16 (.22)	.25
Local	.13 (.10)	.16 (.15)	.26 (.19)	.10 (.15)	.15 (.09)	.16
	.23	.12	.38	.14	.16	

Table 19.

Means and standard deviations of proportions of DISTANCE requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.01 (.03)	.002
Local	.07 (.03)	.16 (.17)	.01 (.02)	.08 (.09)	.04 (.05)	.07
	.03	.08	.005	.04	.02	

Table 20.

Means and standard deviations of proportions of FR requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.08 (.10)	.04 (.07)	.02 (.03)	.04 (.04)	.01 (.03)	.04
Local	.16 (.10)	.05 (.04)	.11 (.10)	.17 (.10)	.14 (.06)	.13
	.12	.05	.07	.11	.08	

Table 21.

Means and standard deviations of proportions of INBOUNDS requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.005 (.01)	.00 (.00)	.00 (.00)	.00 (.00)	.001
Local	.01 (.02)	.06 (.08)	.02 (.03)	.05 (.08)	.03 (.02)	.03
	.007	.03	.01	.02	.01	

Table 22.

Means and standard deviations of proportions of HOLDSHORT requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.005 (.01)	.00 (.00)	.05 (.05)	.00 (.00)	.00 (.00)	.01
Local	.003 (.01)	.00 (.00)	.02 (.05)	.00 (.00)	.00 (.00)	.005
	.004	.00	.04	.00	.00	

Table 23.

Means and standard deviations of proportions of TIME requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.23 (.14)	.00 (.00)	.00 (.00)	.00 (.00)	.05
Local	.00 (.00)	.06 (.06)	.02 (.04)	.01 (.02)	.03 (.06)	.02
	.00	.15	.01	.005	.01	

Table 24.

Means and standard deviations of proportions of TYPE requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.09 (.08)	.05 (.06)	.02 (.03)	.22 (.21)	.14 (.14)	.11
Local	.10 (.08)	.11 (.06)	.10 (.03)	.08 (.05)	.08 (.06)	.10
	.10	.08	.06	.15	.11	

Table 25.

Means and standard deviation of proportions of DESTINATION requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.05 (.04)	.06 (.08)	.06 (.06)	.13 (.14)	.05 (.10)	.07
Local	.008 (.02)	.01 (.01)	.02 (.03)	.00 (.00)	.00 (.00)	.01
	.03	.04	.04	.06	.02	

Table 26.

Means and standard deviation of proportions of REPORT requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.01 (.02)	.00 (.00)	.00 (.00)	.002
Local	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00
	.00	.00	.006	.00	.00	

Table 27.

Means and standard deviation of proportions of GRAPHIC_1LOC_ACID requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00
Local	.01 (.01)	.003 (.007)	.008 (.01)	.006 (.01)	.004 (.01)	.007
	.006	.001	.004	.003	.002	

Table 28.

Means and standard deviation of proportions of GRAPHIC_LOC_ACIDS_OTHER requests

	RW	EDCT	Fog	Night	AC Malfunction	
Ground	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00 (.00)	.00
Local	.01 (.02)	.02 (.03)	.00 (.00)	.009 (.02)	.01 (.02)	.01
	.007	.01	.00	.004	.007	

Table 29

Information types for the runway closure event. Types are ordered in terms of largest proportion change.

PROPORTIONS FOR RW CLOSURE		Baseline	Off-nominal event	Return
Ground	ACID	.13	.48	.26
	Location	.43	.20	.31
	Flight Rules	.12	.03	.13
	Departure procedures	.12	.00	.00
	Graphics w/multiple AC location and ACID	.04	.09	.04
Local	Type	.19	.08	.17
	Departure procedures	.08	.18	.11
	Graphics w/multiple AC location, ACID, and other information	.17	.01	.01
	Inbounds	.13	.006	.00
	Flight Rules	.08	.18	.15

Table 30.

Information types for the aircraft malfunction event. Types are ordered in terms of largest proportion change.

PROPORTIONS FOR AC MALFUNCTION		Baseline	Off-nominal event	Return
Ground	ACID	.49	.39	.68
	Cross Runway	.00	.17	.00
	Location	.03	.16	.18
	Graphics w/multiple AC location and ACID	.10	.097	0
	AC Type	.21	.11	.08
Local	Departure procedures	.33	.09	.23
	Type	.05	.14	.03
	Location	.07	.17	.11
	Time	.10	.00	.06
	Graphics w/multiple AC location and ACID	.00	.10	.05

Figure Caption

Figure 1. Air traffic control simulator used in the present study.

Figure 2. Layout of the Academy airport.

Figure 3. Diagram of the experimental setup.

Figure 4. Proportion of information requests for ground and local controllers categorized into the situation model categories.

Figure 5. Proportions and frequencies of requested information types for each position and scenario. Proportions are represented by the sizes of the pie slices. Pie slices that are pulled out represent information that is not represented in the common display. Pie charts for the ground position are in the left column, and pie charts for the local position are in the right column.

Figure 6. Position-specific displays for ground (a) and local (b).

Figure 7. Common display for ground and local controllers

Figure 1. Air traffic control simulator used in the present study.

Figure 2. Layout of the Academy airport.

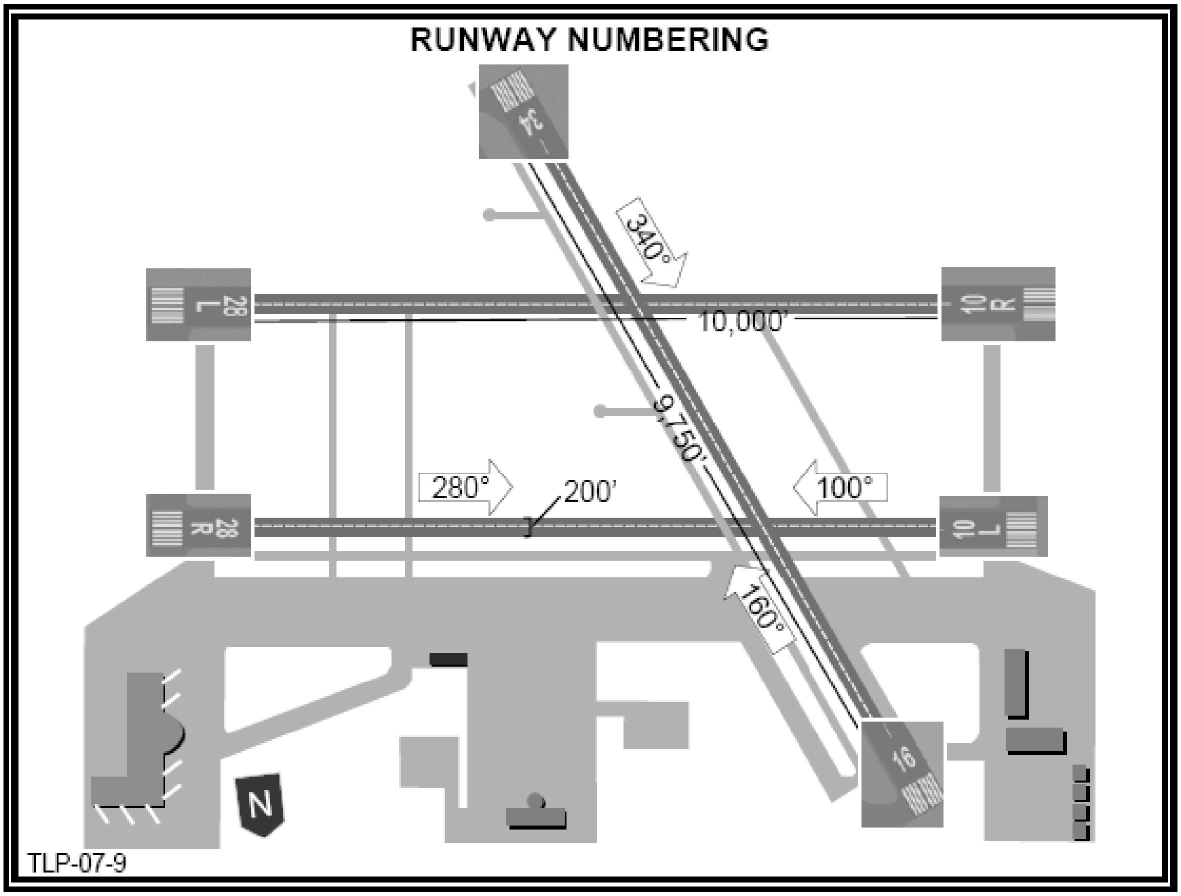


Figure 3. Diagram of the experimental setup.

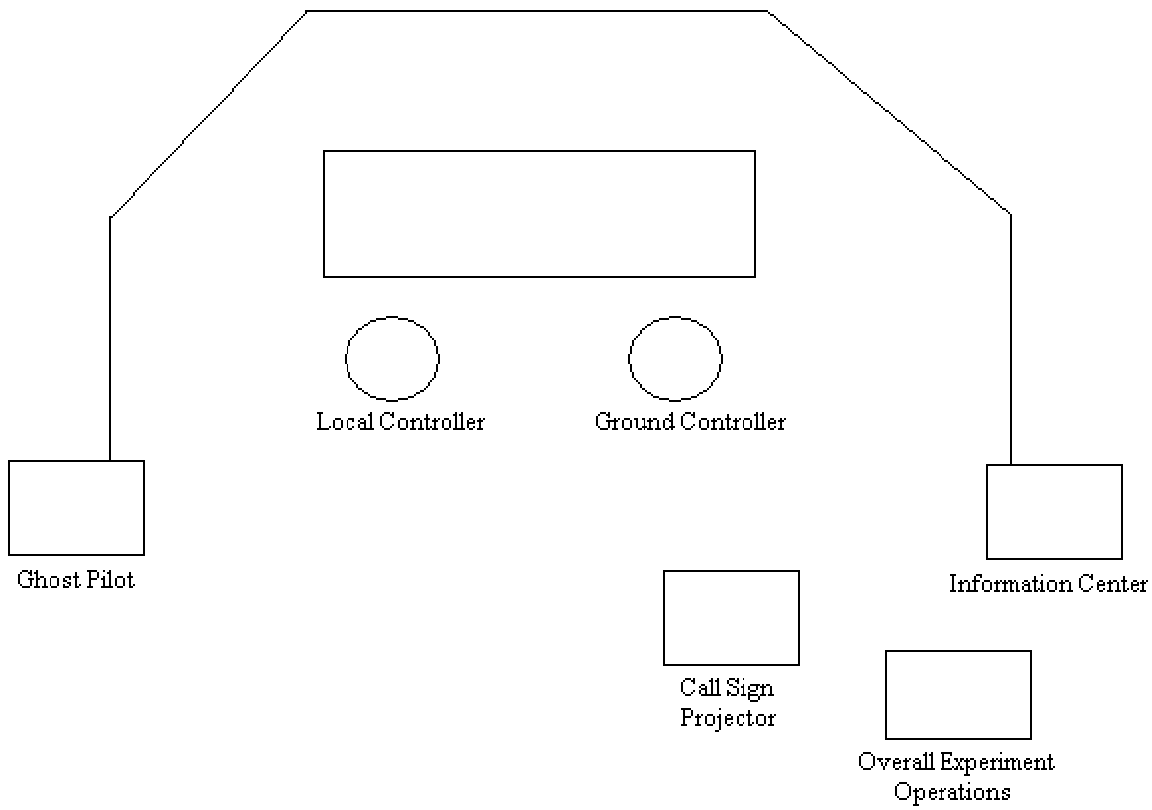


Figure 4. Proportion of information requests for ground and local controllers categorized into the situation model categories.

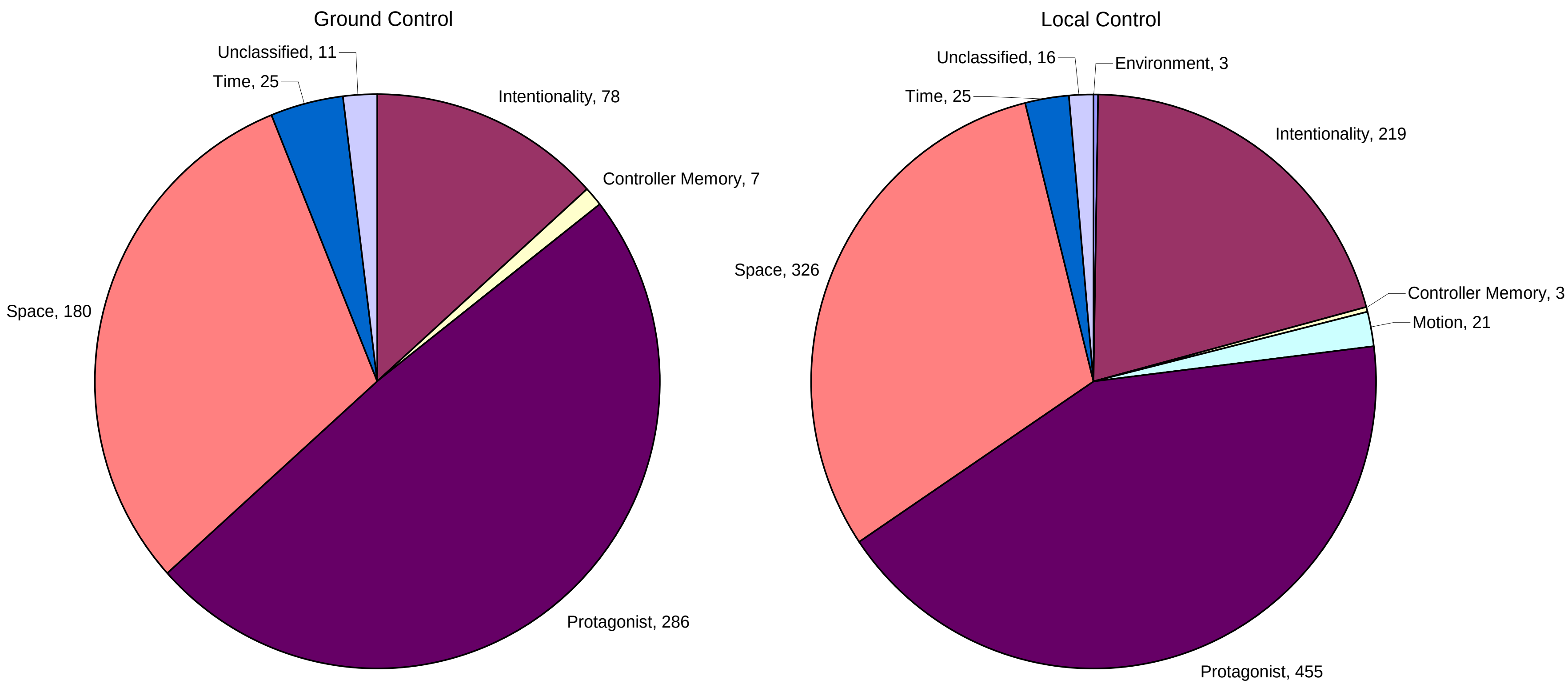
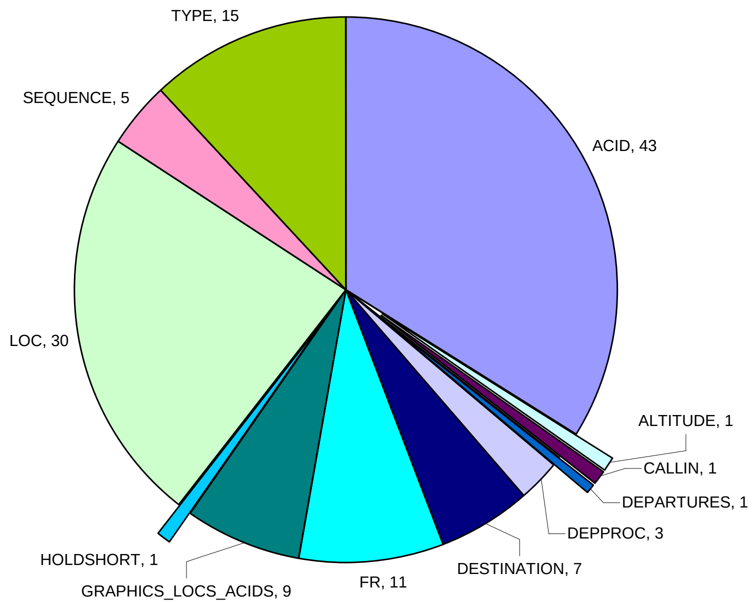
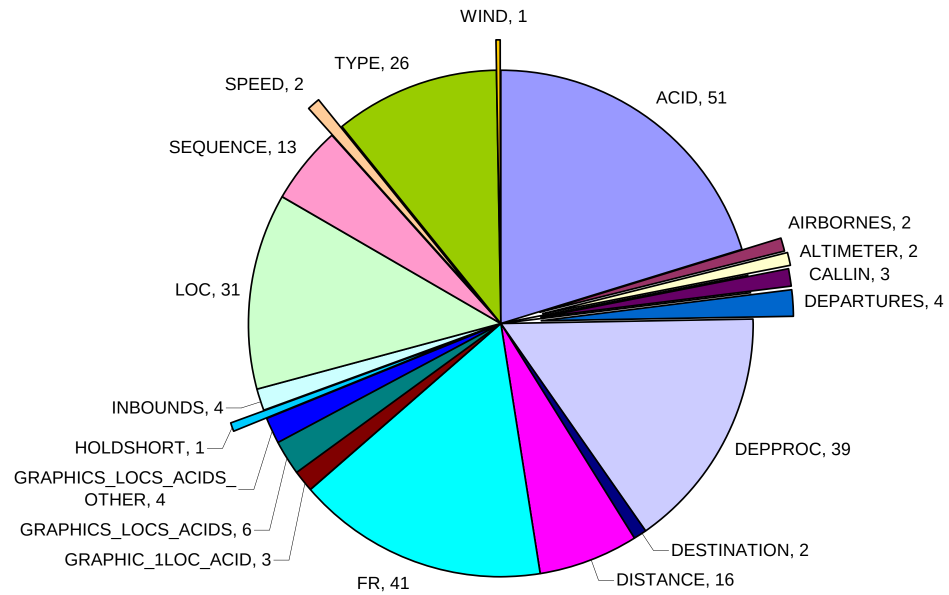


Figure 5. Proportions and frequencies of requested information types for each position and scenario. Proportions are represented by the sizes of the pie slices. Frequencies are the numbers next to the labels. Pie slices that are pulled out represent information that is not represented in the common display. Pie charts for the ground position are in the left column, and pie charts for the local position are in the right column.

Runway Closure





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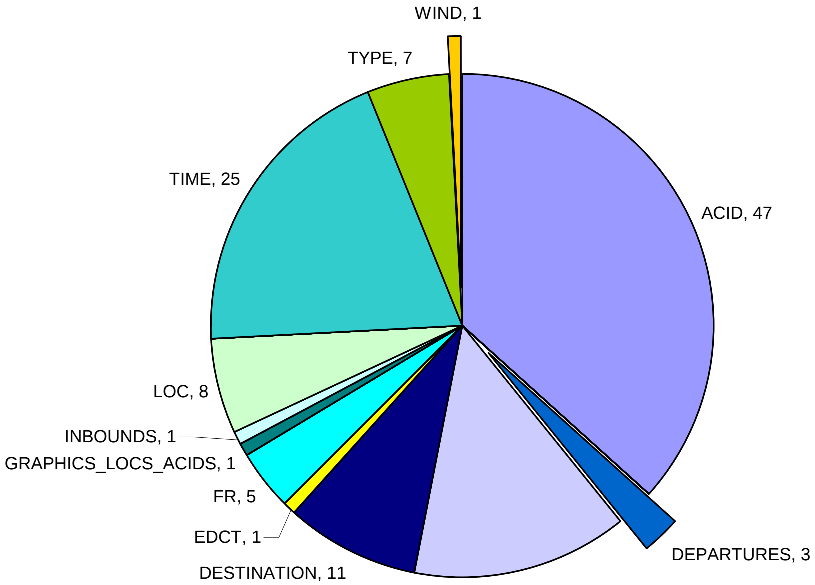
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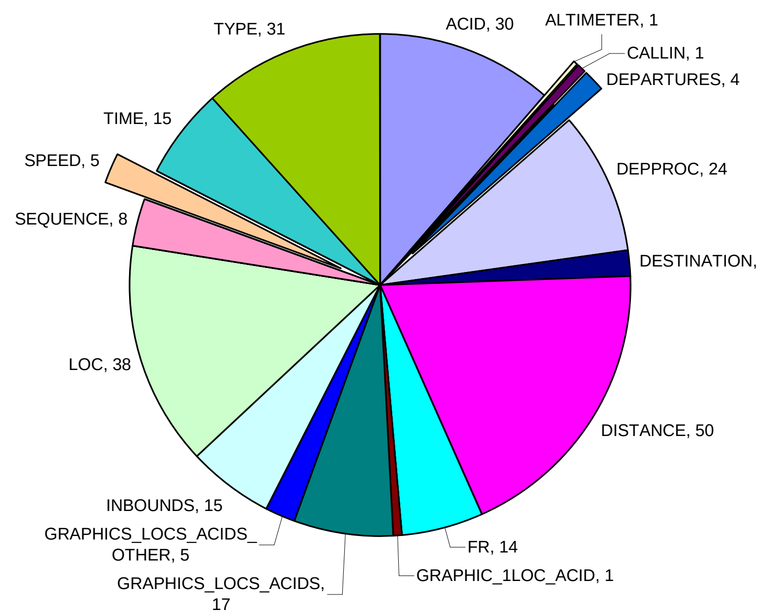
DEPPROC, 18
DEPARTURES, 3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DISTANCE, 50
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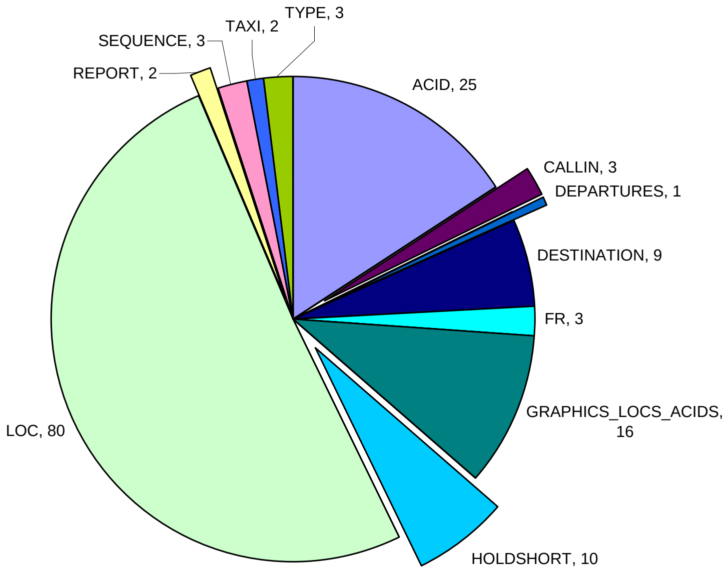
Fog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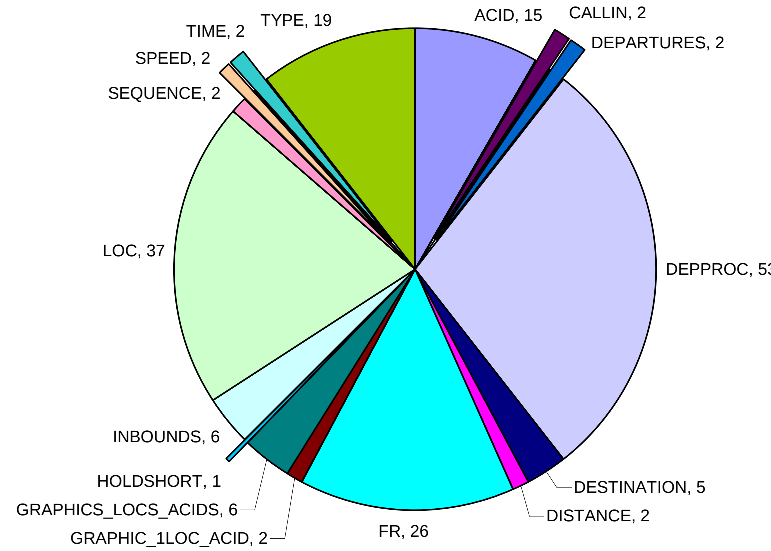
HOLDSHORT, 10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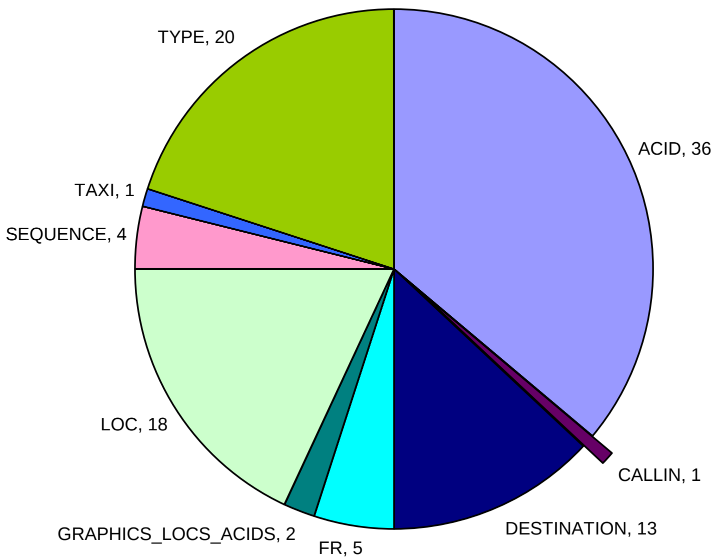
Night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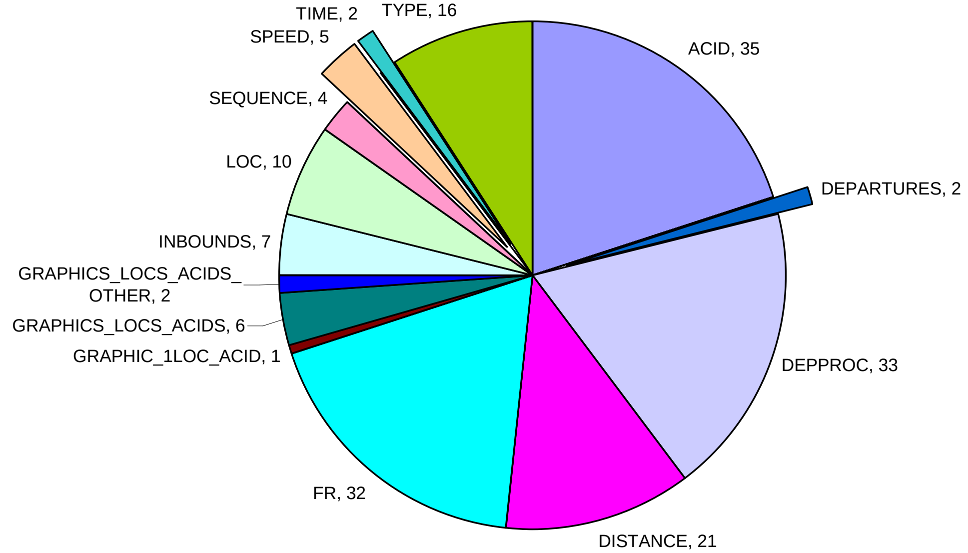
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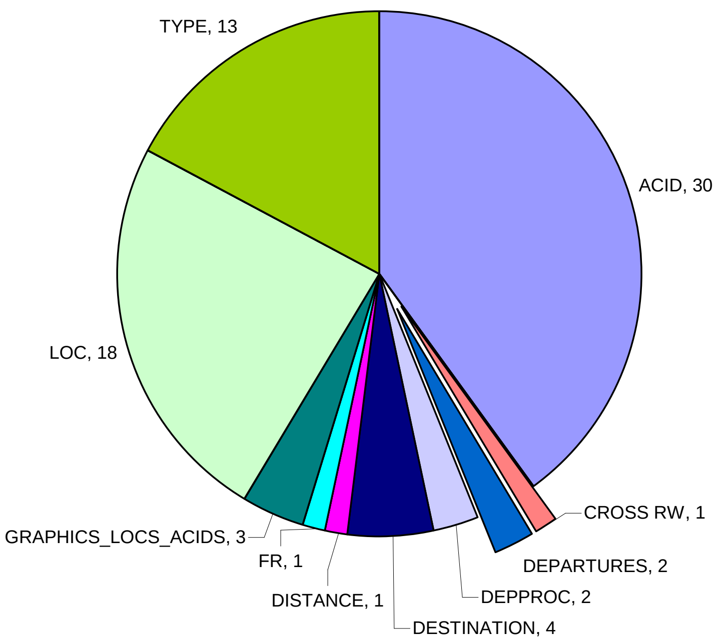
DISTANCE, 21

Aircraft Malfunction



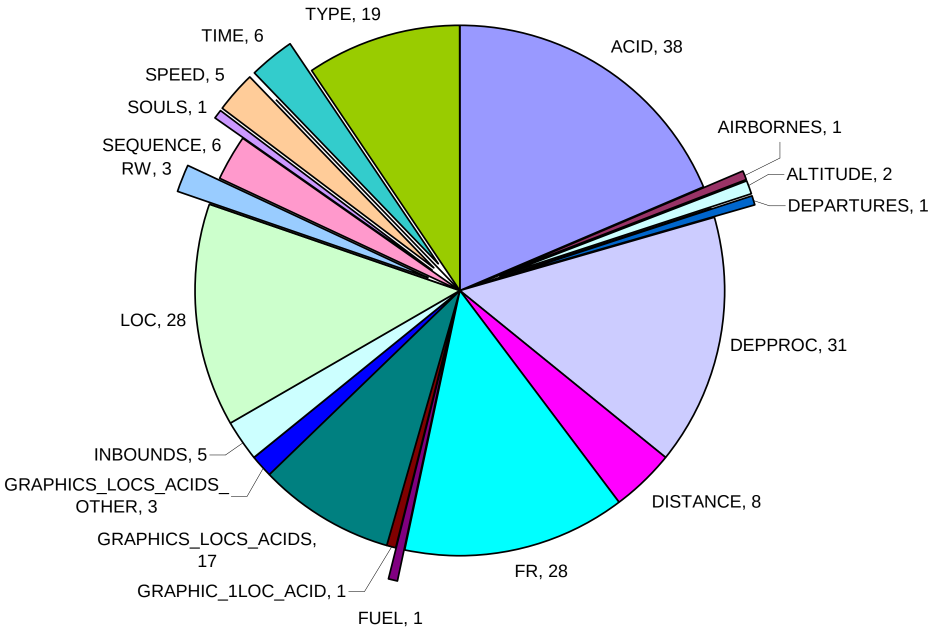


Figure 6. Position-specific displays for ground (a) and local (b).

a) ACID

TYPE * DESTINATION

b) ACID * FR

TYPE

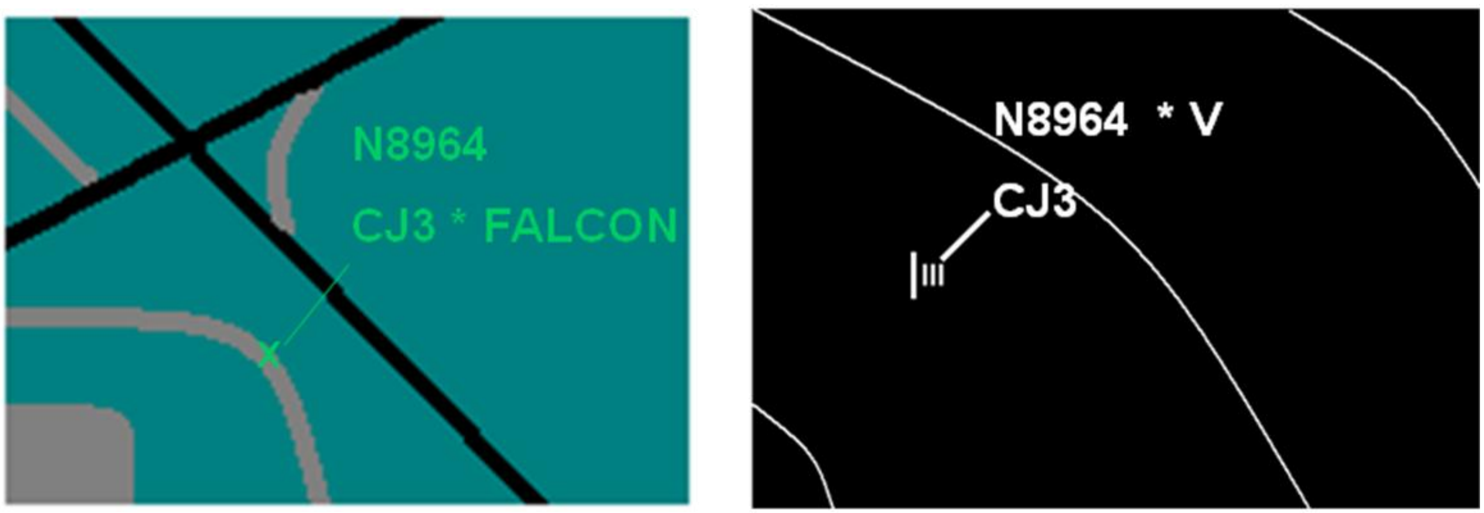
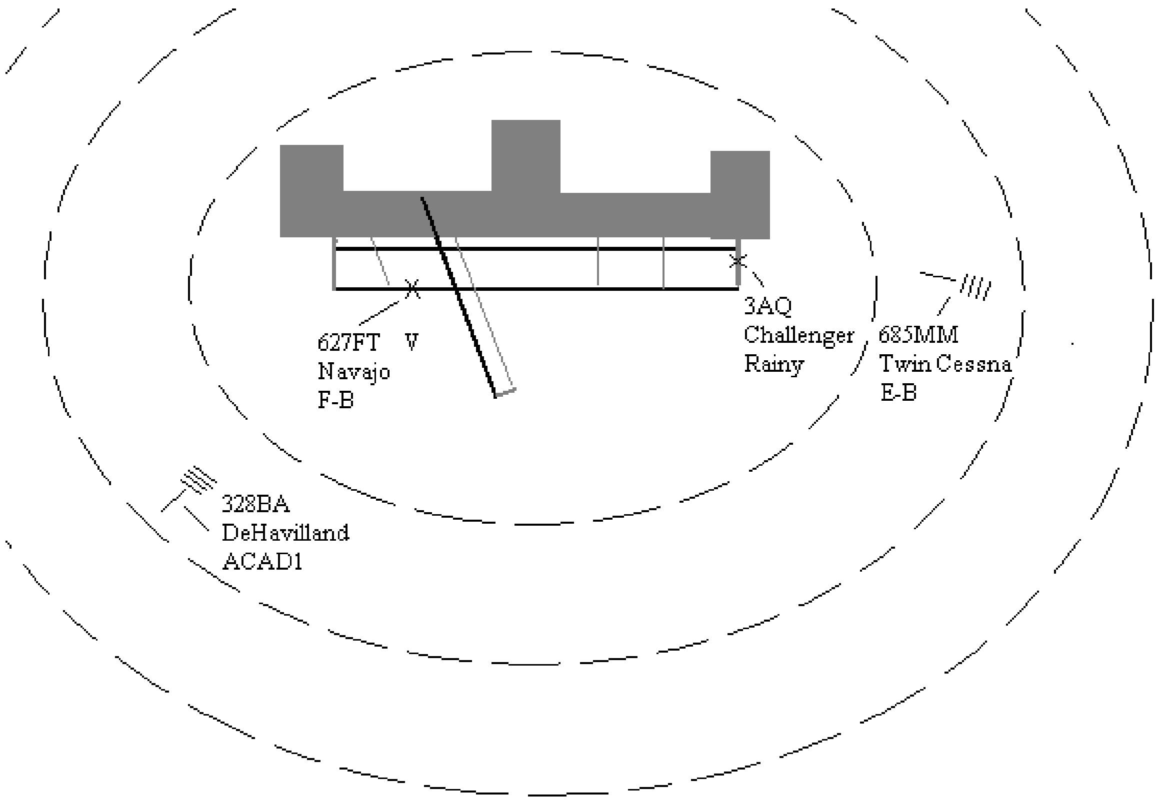


Figure 7. Common display for ground and local controllers



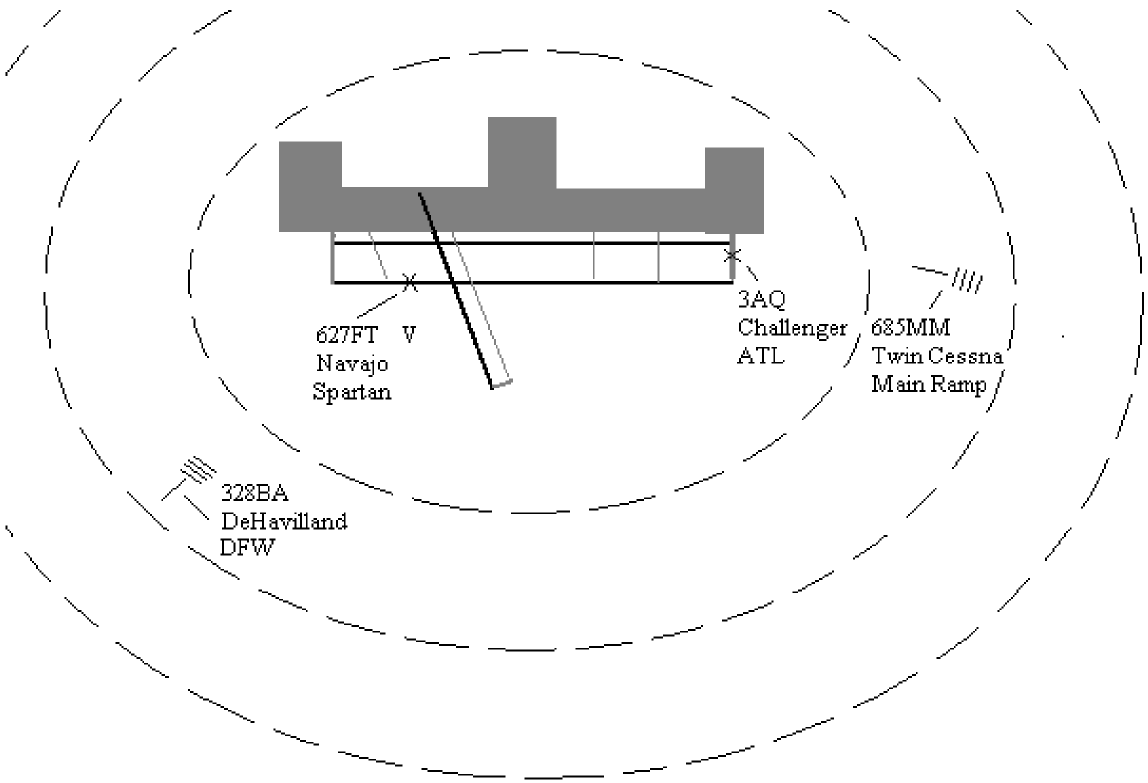

627FT V
Navajo
Spartan
3AQ
Challenger
ATL
685MM
Twin Cessna
Main Ramp
328BA
DeHavilland
DFW

Figure 8. Average proportion of flight rules requests before, during, and after a runway closure.

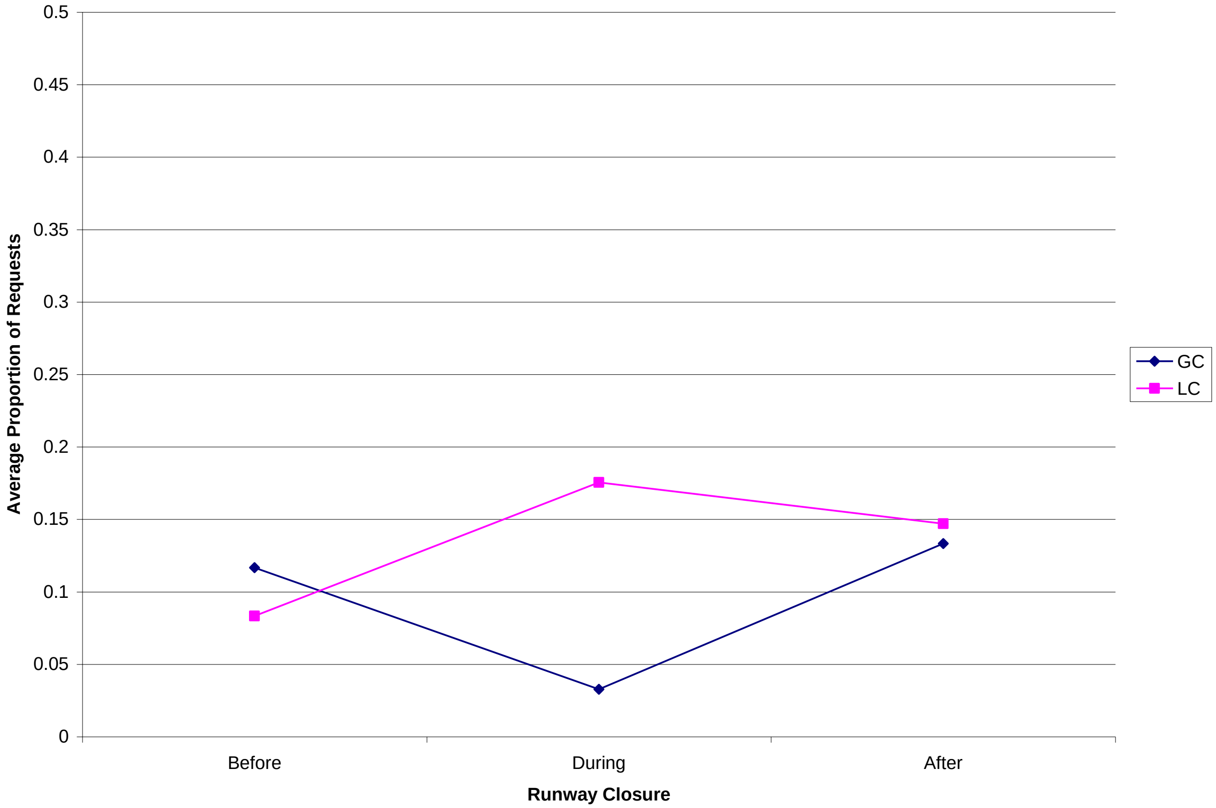


Figure 9. Minute-by-minute display of average frequency of flight rules requests for ground controllers in the runway closure scenario.

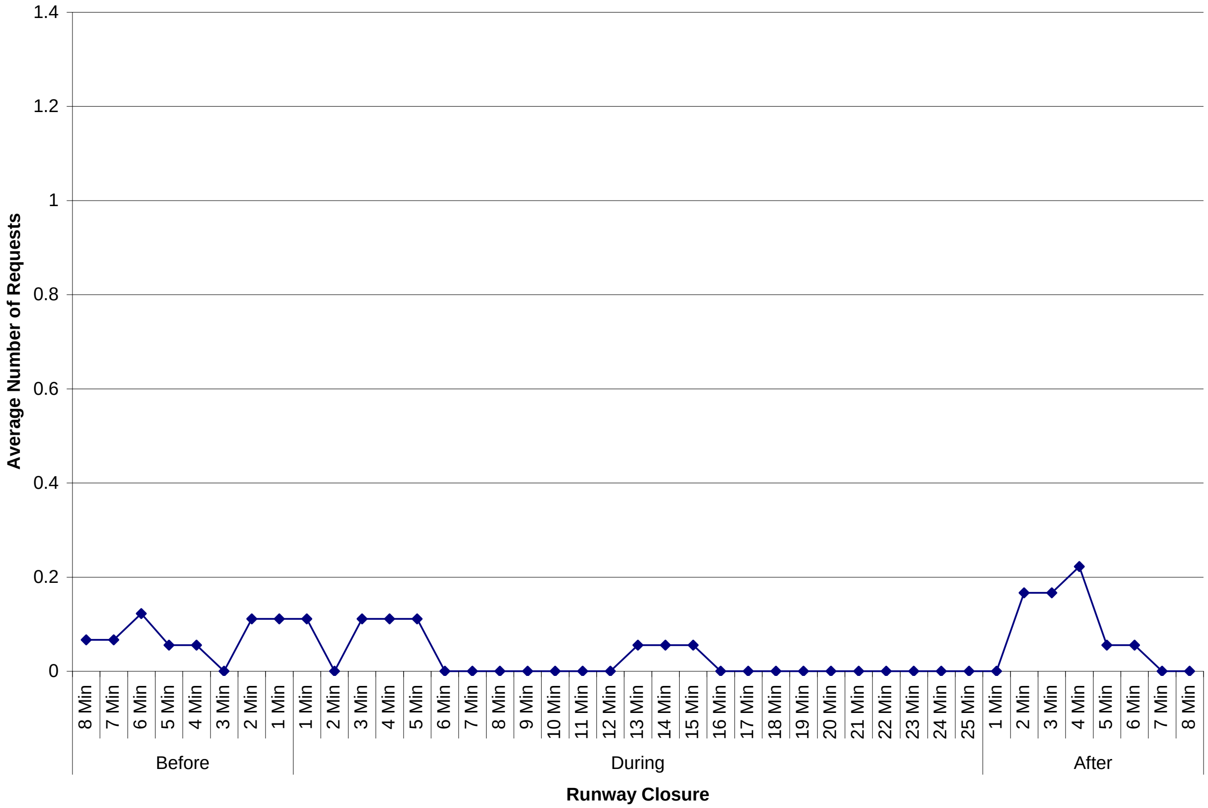
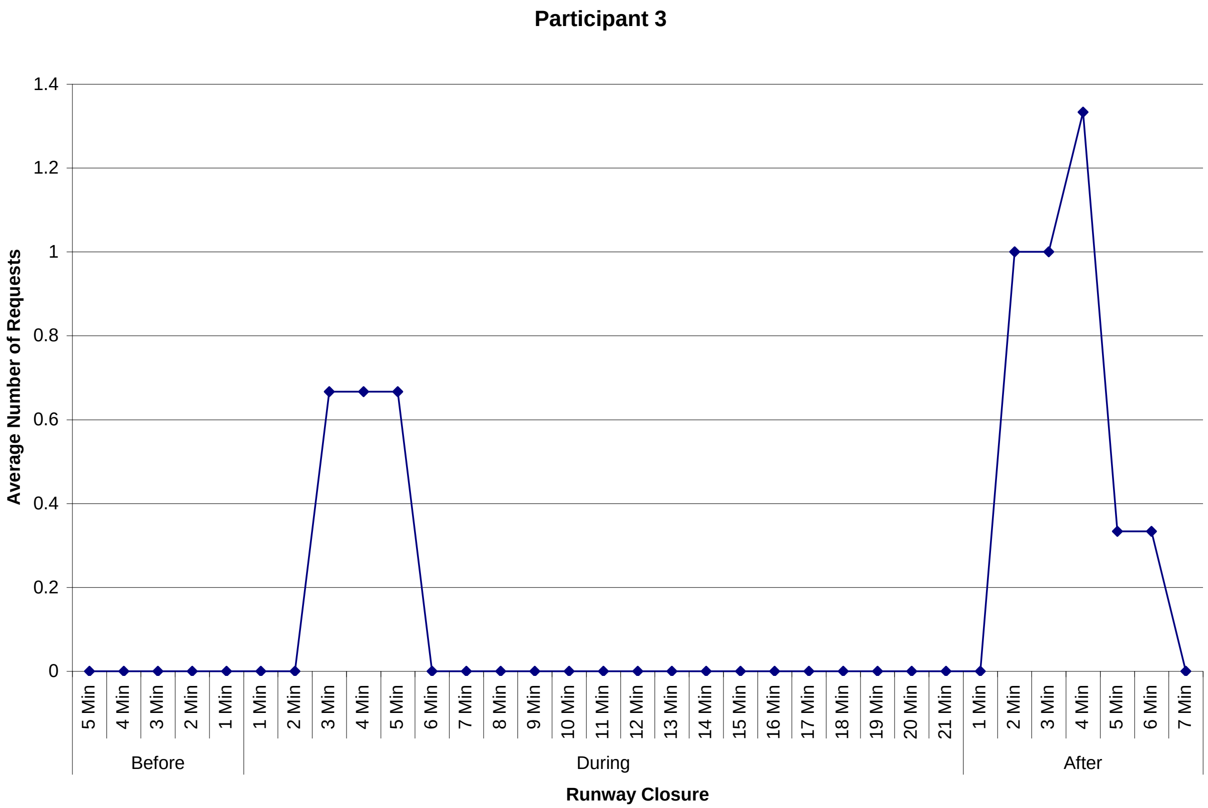
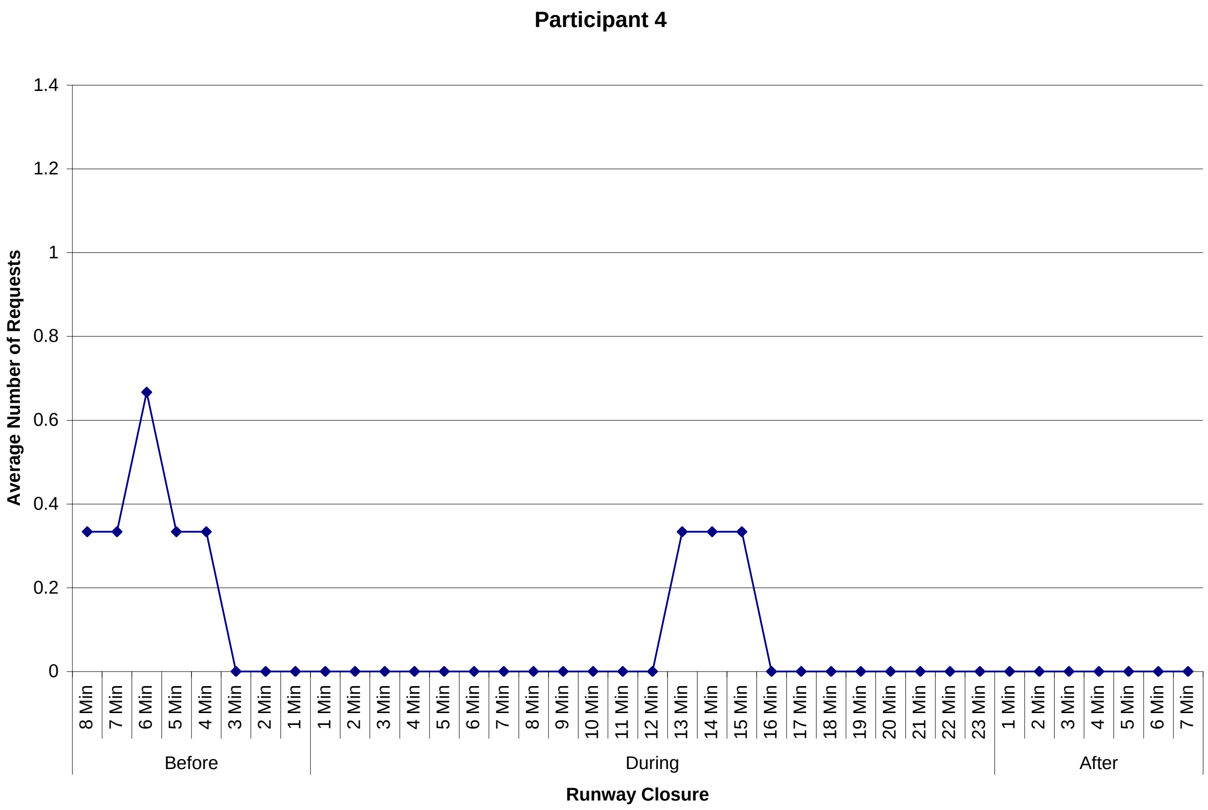


Figure 10. Minute-by-minute frequencies of flight rules requests for participants 3, 4, and 6 serving as ground controllers in the runway closure scenario.




Participant 4
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8 Min
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure

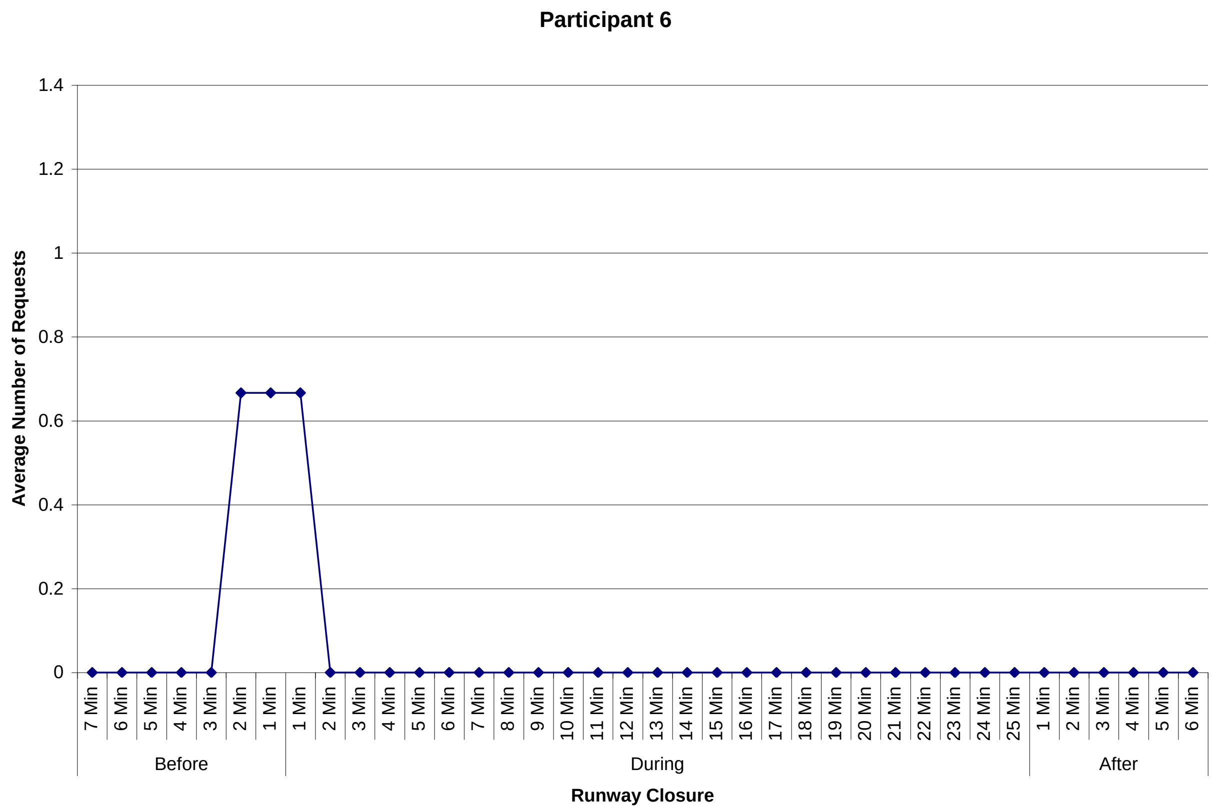

Participant 6
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
Before
During
After
Runway Closure

Figure 11. Average proportion of departure procedure requests before, during, and after a runway closure.

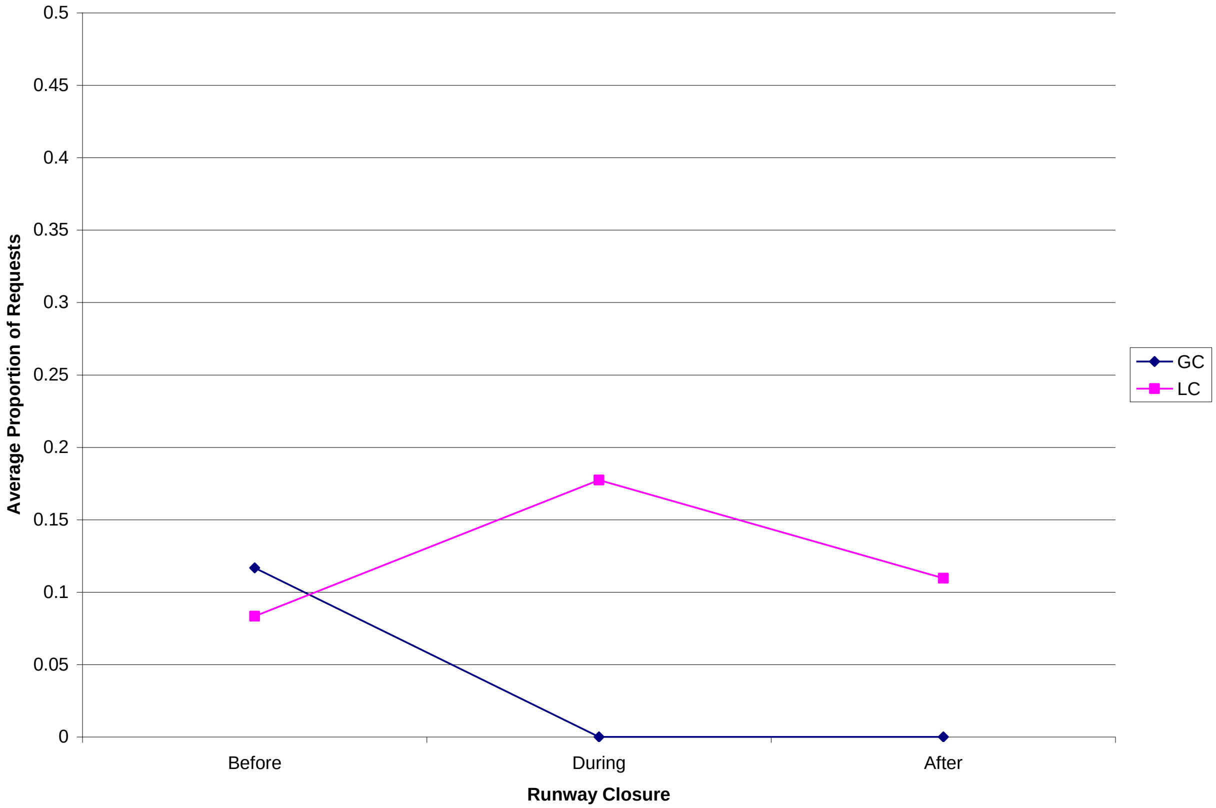


Figure 12. Minute-by-minute display of average frequency of departure procedure requests for local controllers in the runway closure scenario.

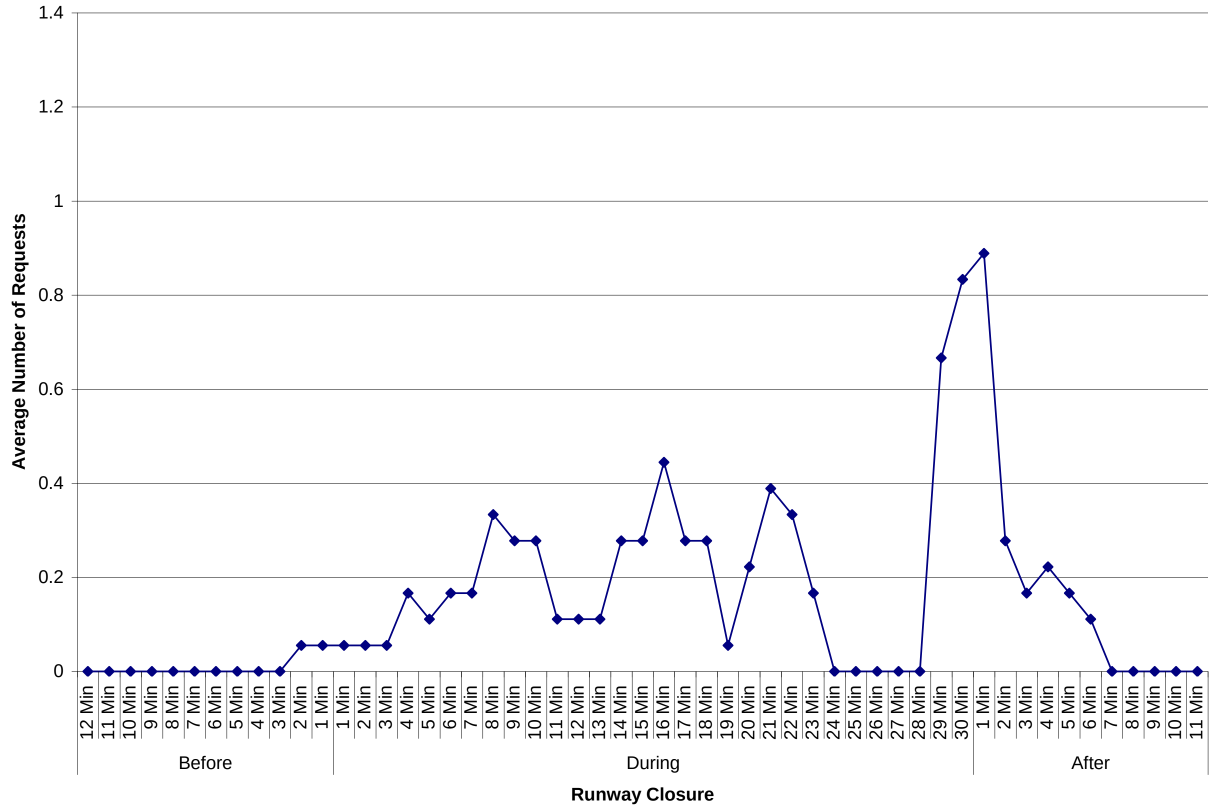
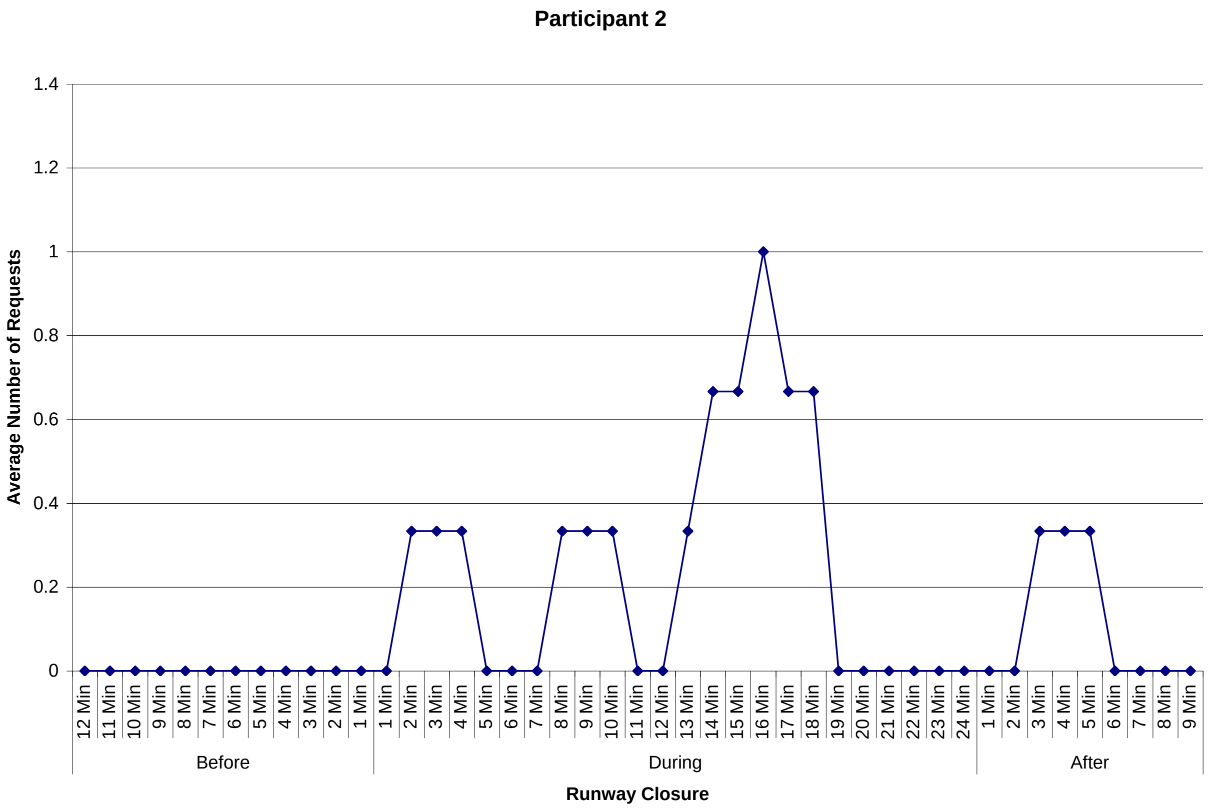
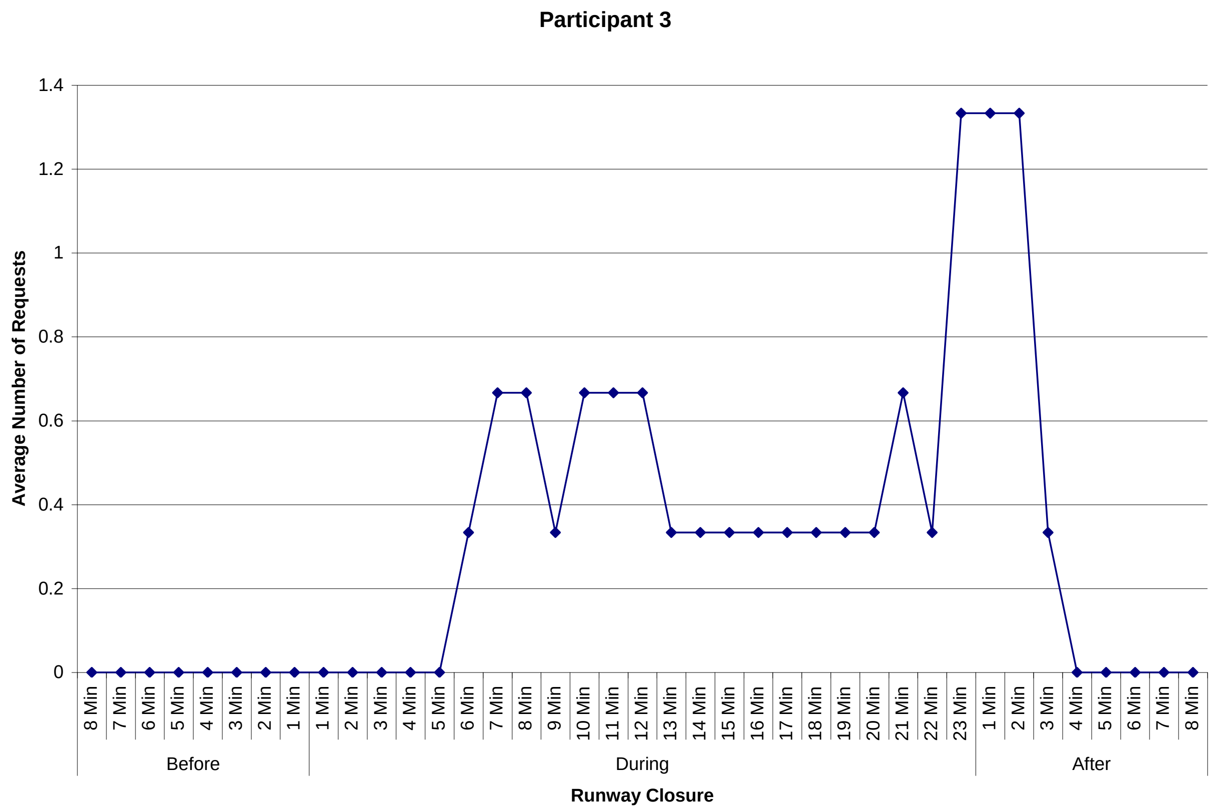
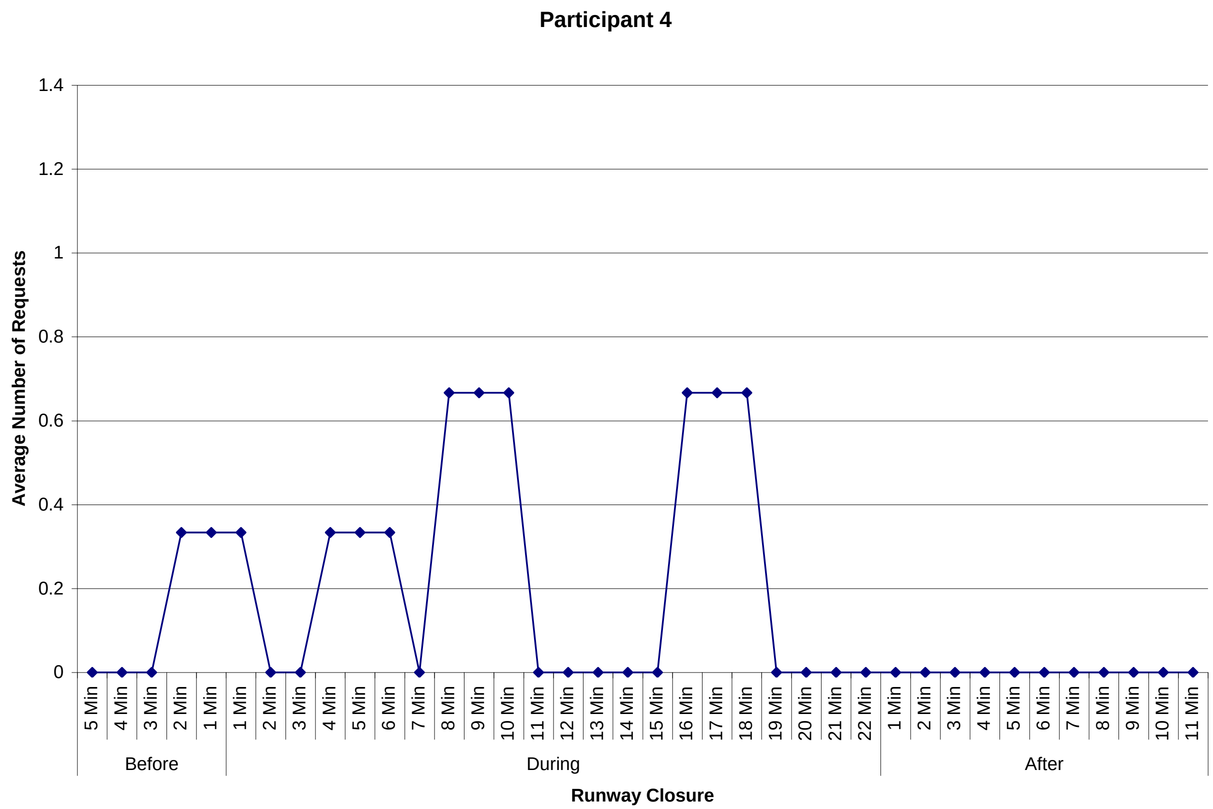
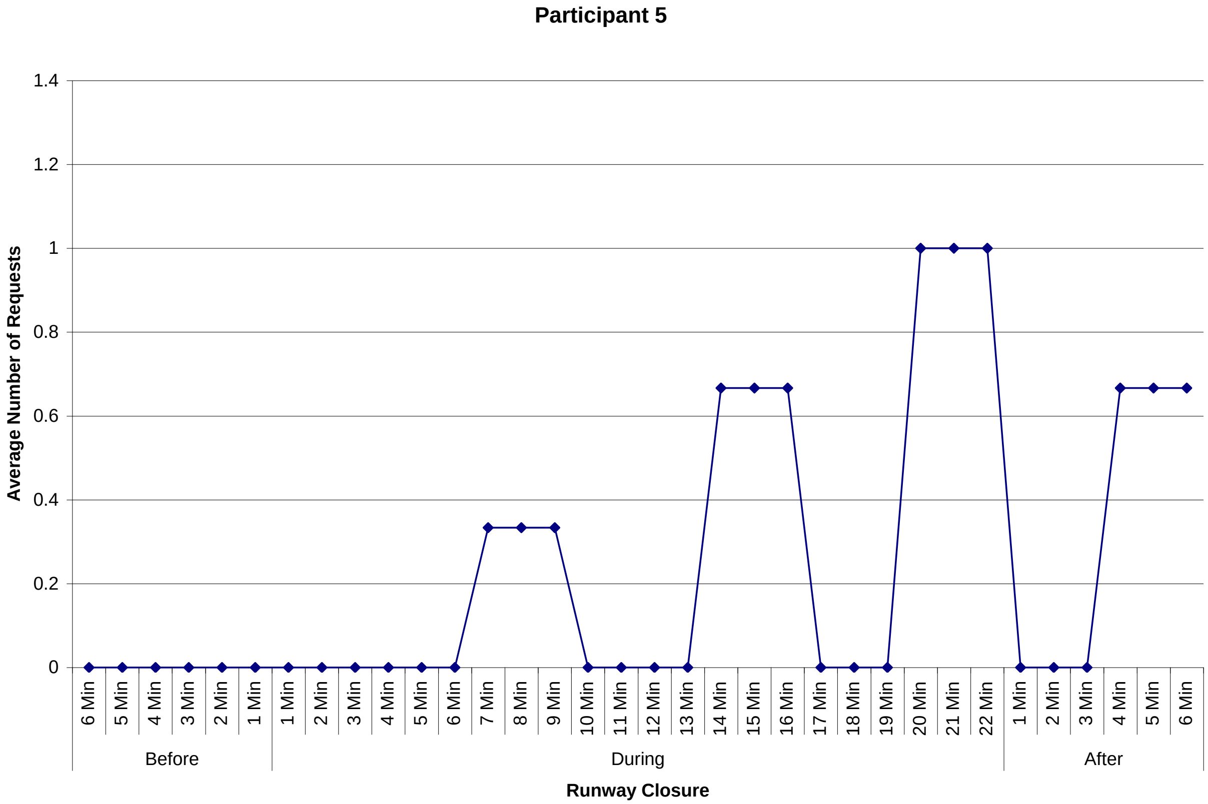


Figure 13. Minute-by-minute frequencies of departure procedure requests for Participants 2 through 6 serving as local controllers in the runway closure scenario.




Participant 3
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8 Min
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
Before
During
After
Runway Closure


Participant 4
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
Before
During
After
Runway Closure


Participant 5
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
Before
During
After
Runway Closure

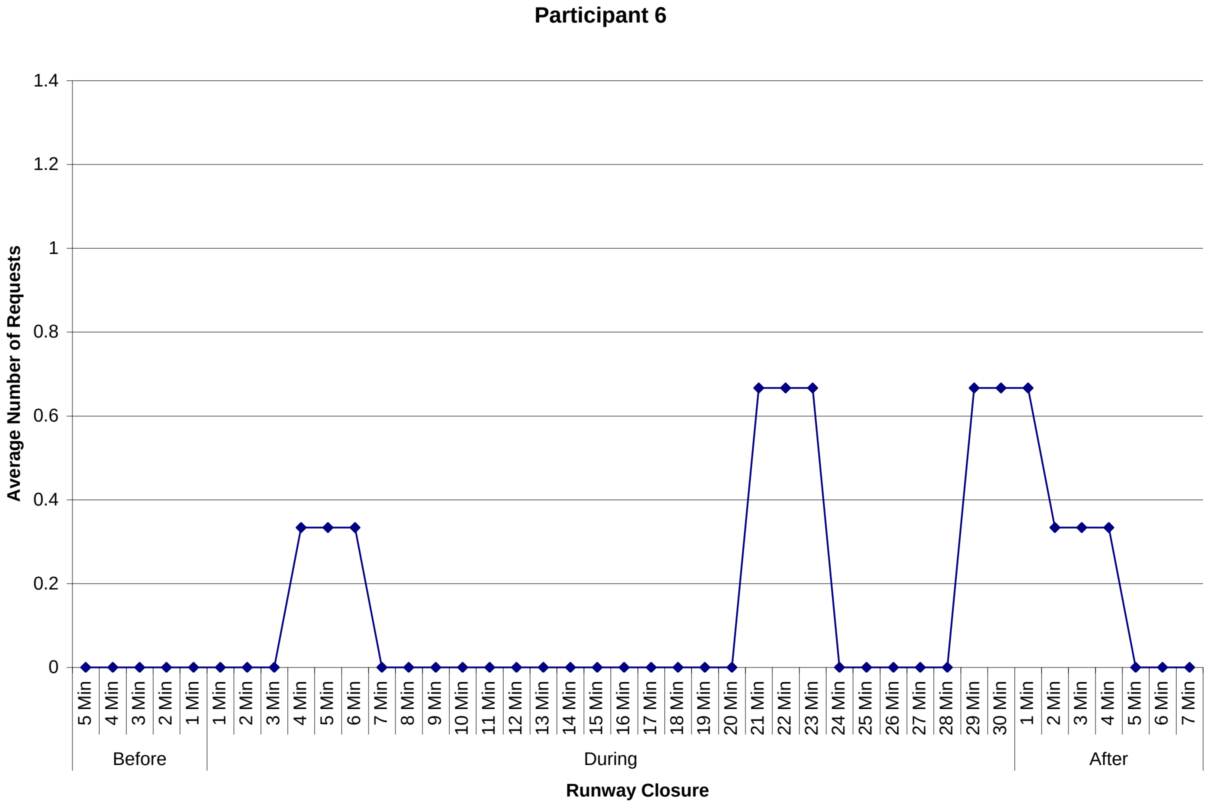

Participant 6
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
26 Min
27 Min
28 Min
29 Min
30 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure

Figure 14. Average proportion of type requests before, during, and after a runway closure.

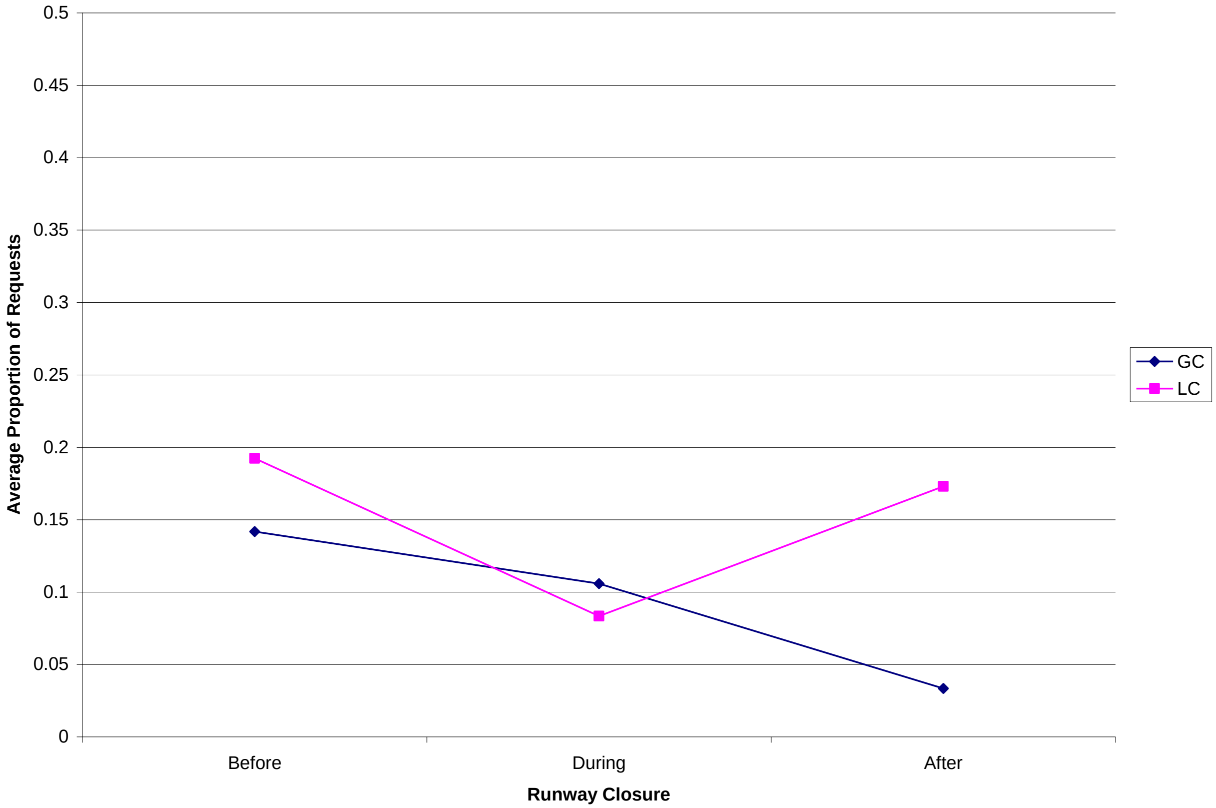


Figure 15. Minute-by-minute display of average frequency of type requests for local controllers in the runway closure scenario.

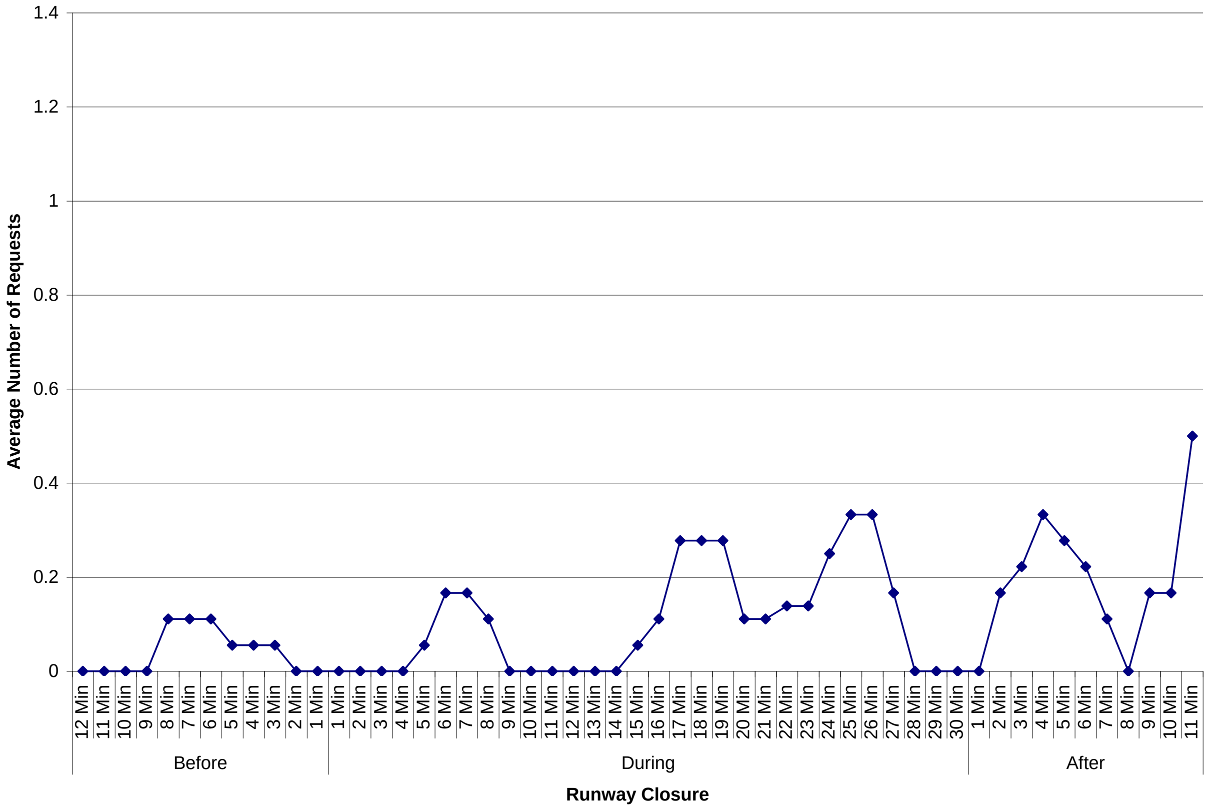
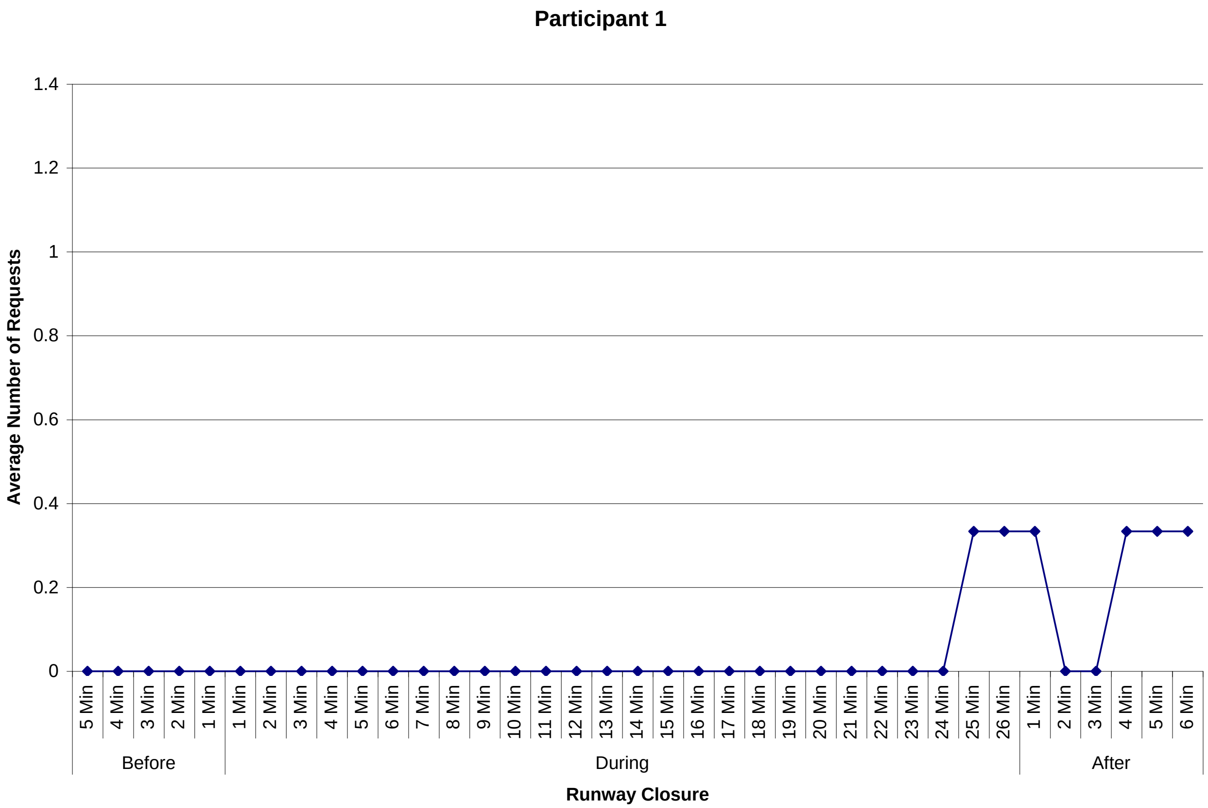
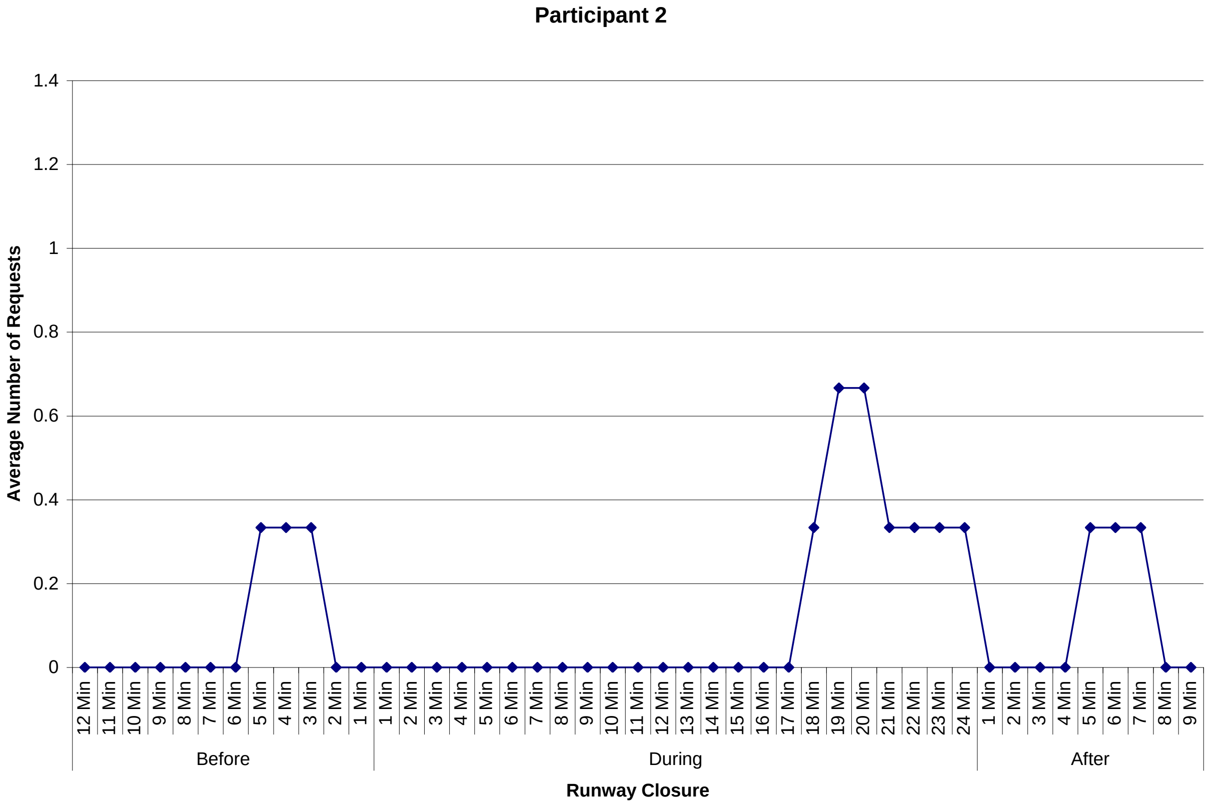
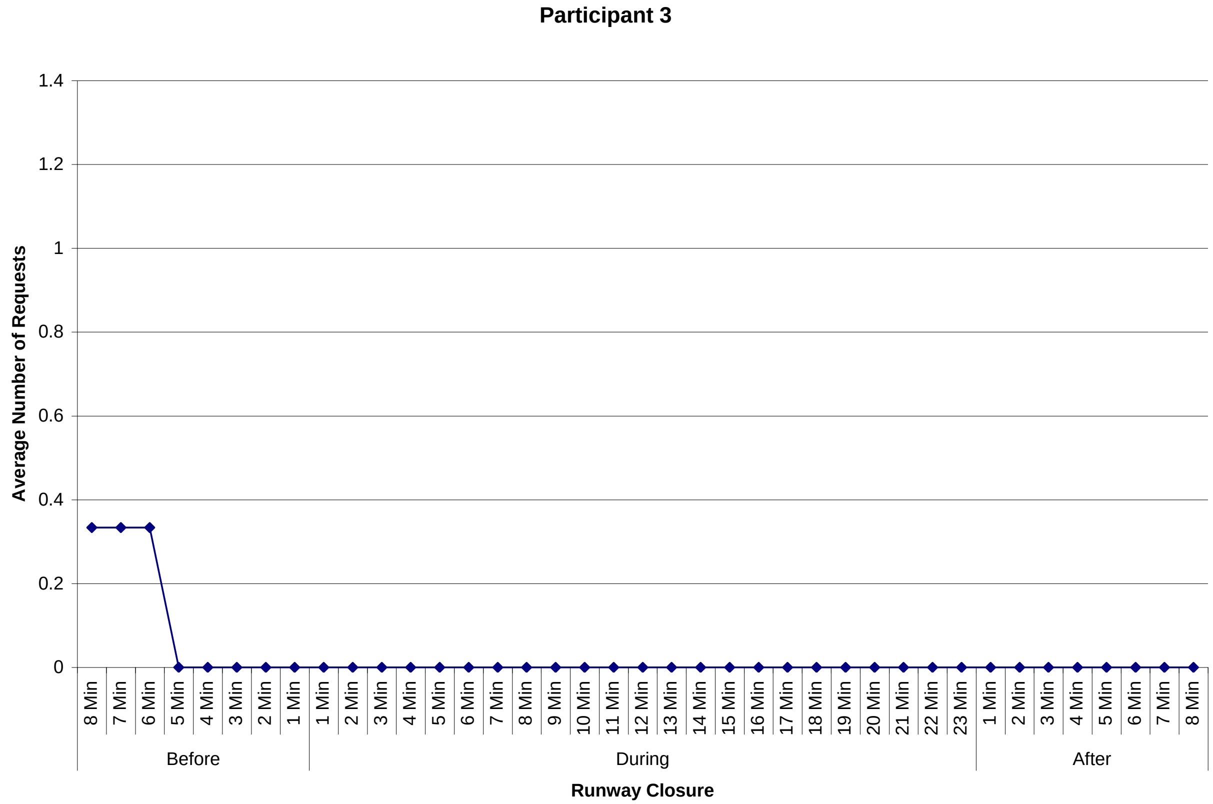
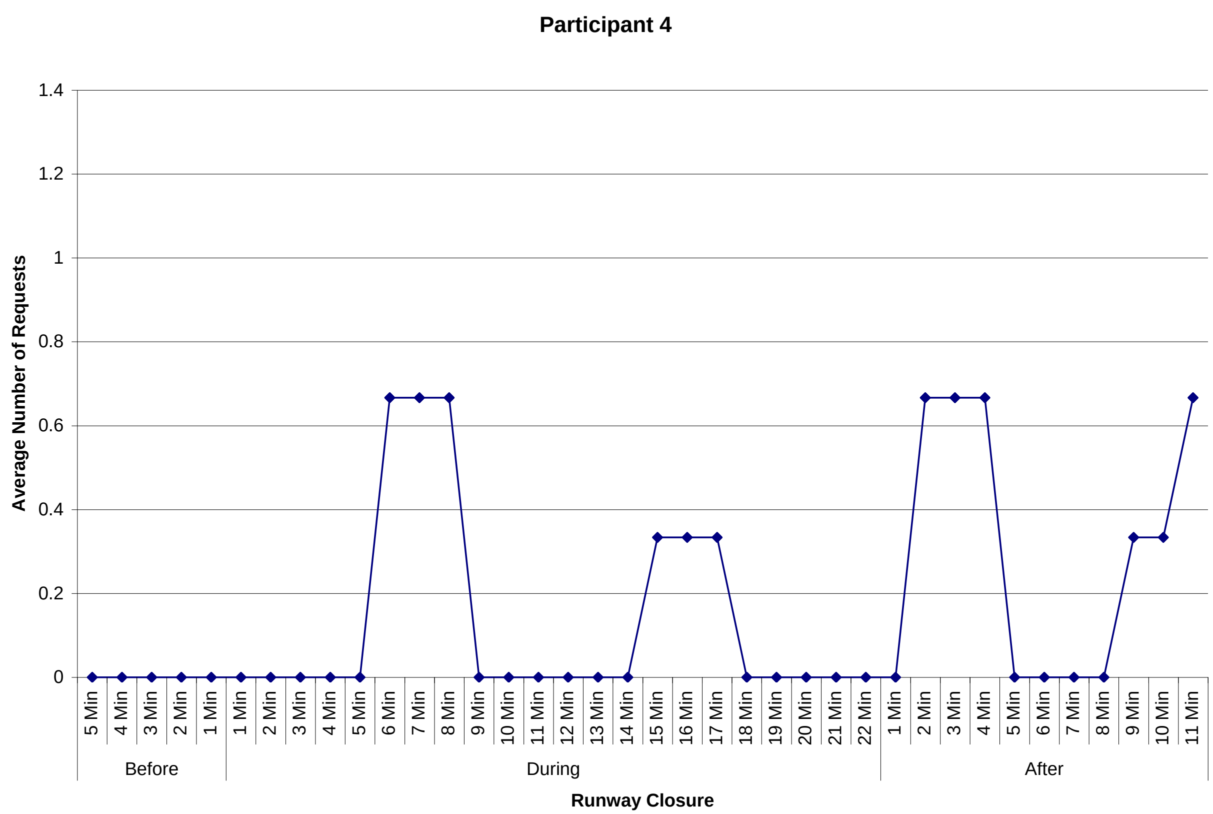


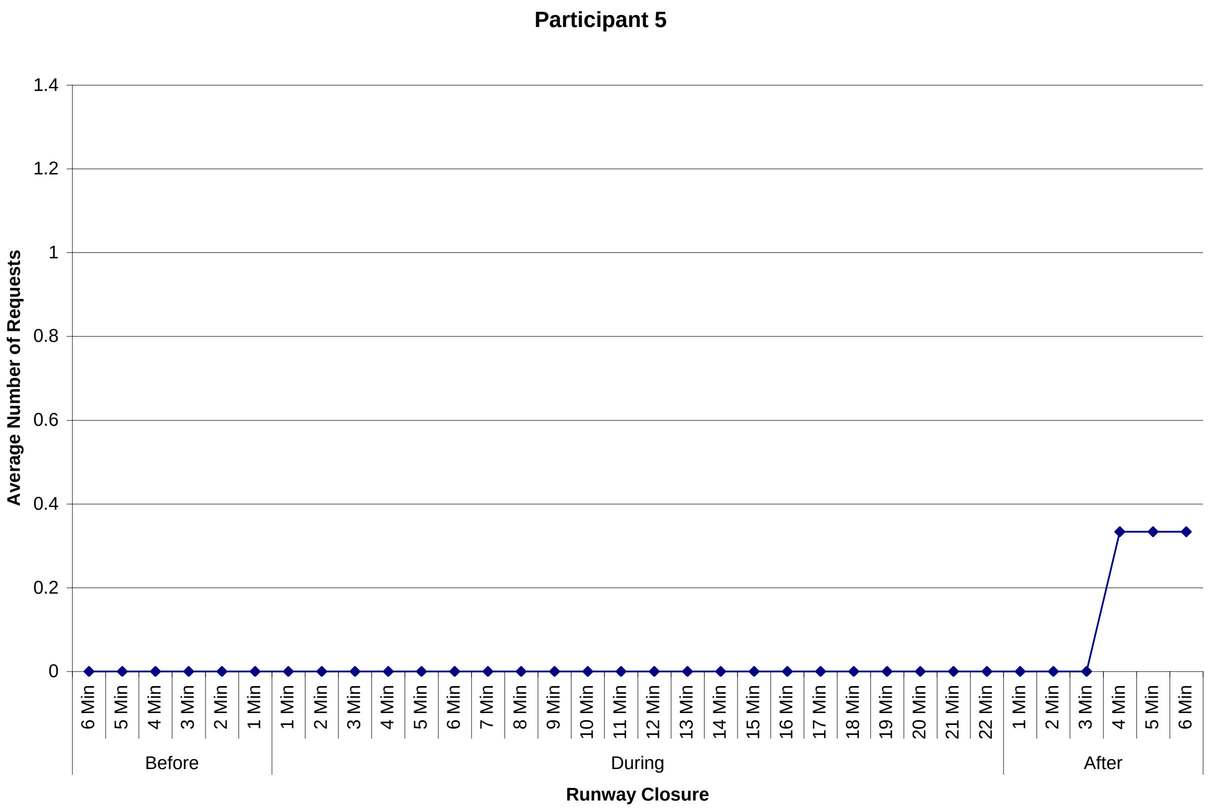
Figure 16. Minute-by-minute frequencies of type requests for each participant serving as local controllers in the runway closure scenario.




Participant 2
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12 Min
11 Min
10 Min
9 Min
8 Min
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
Before
During
After
Runway Closure


Participant 3
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8 Min
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
Before
During
After
Runway Closure


Participant 4
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
Before
During
After
Runway Closure


Participant 5
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
Before
During
After
Runway Closure

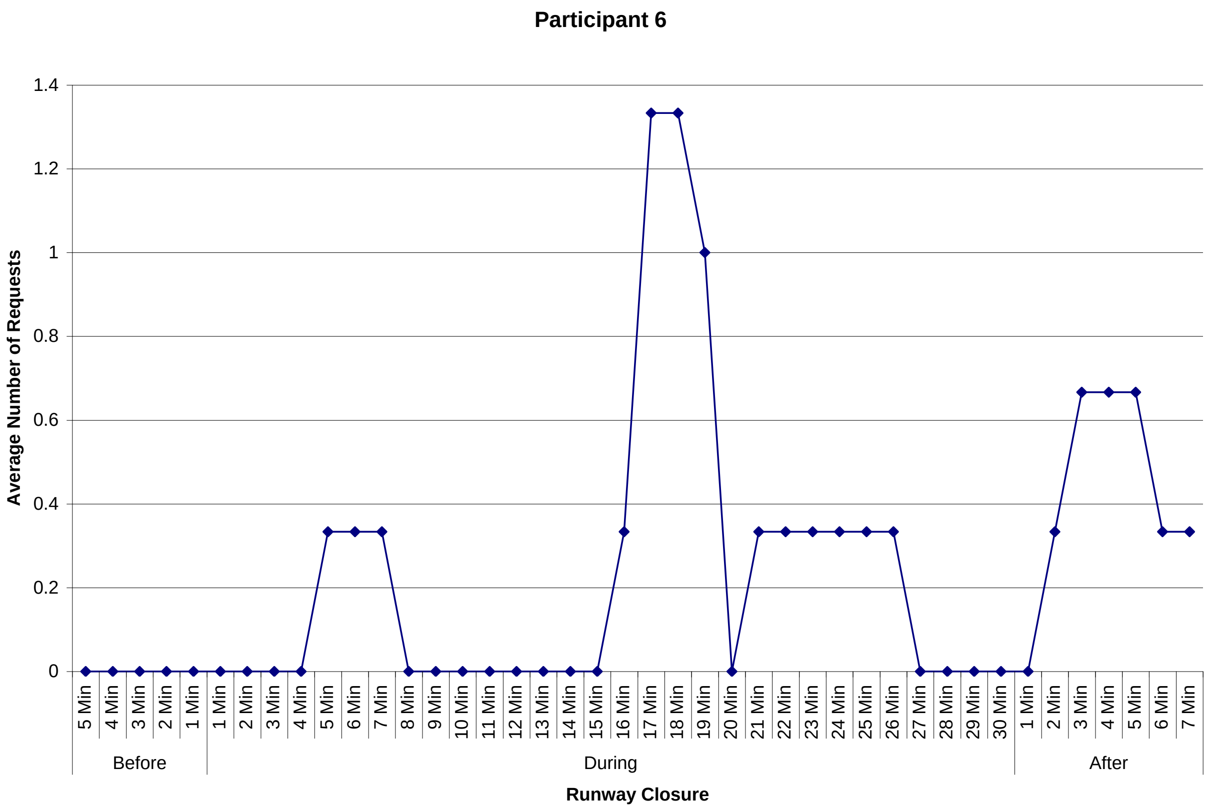

Participant 6
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
26 Min
27 Min
28 Min
29 Min
30 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure

Figure 17. Average proportion of ACID requests before, during, and after a runway closure.

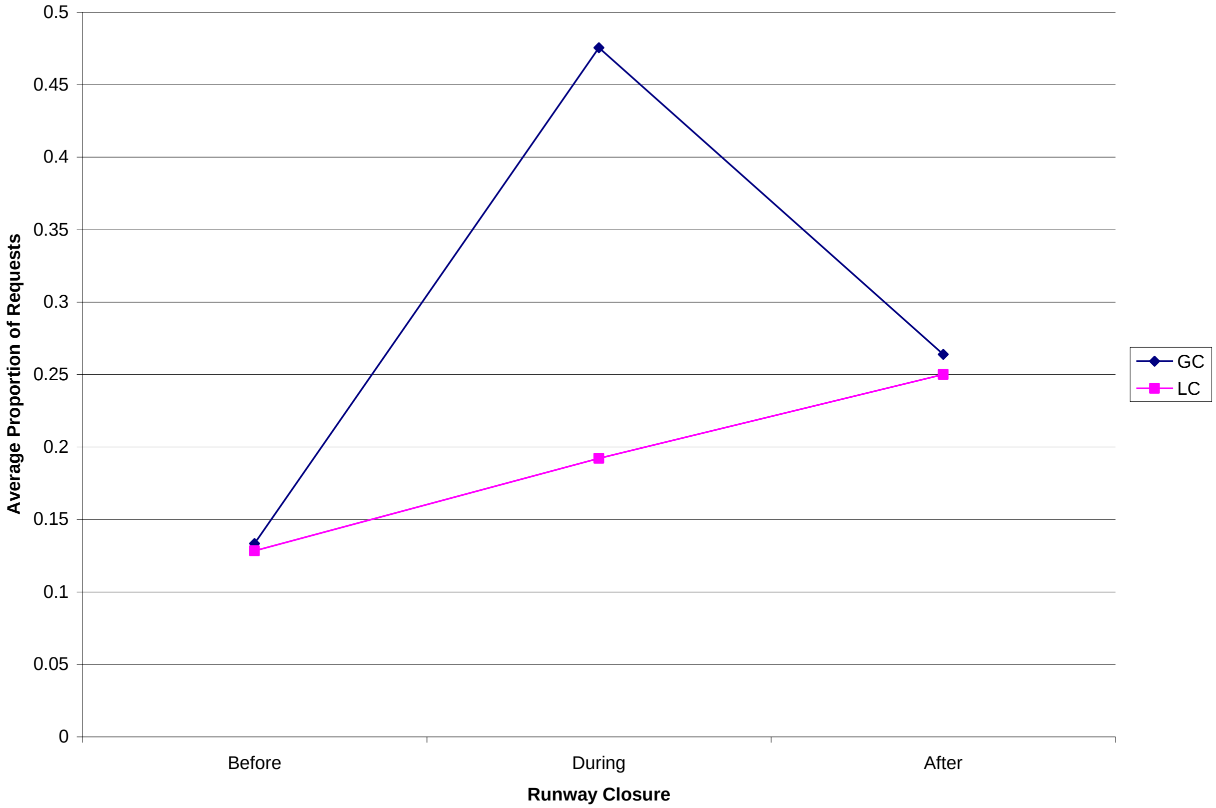


Figure 18.. Minute-by-minute display of average frequency of ACID requests for ground controllers in the runway closure scenario.

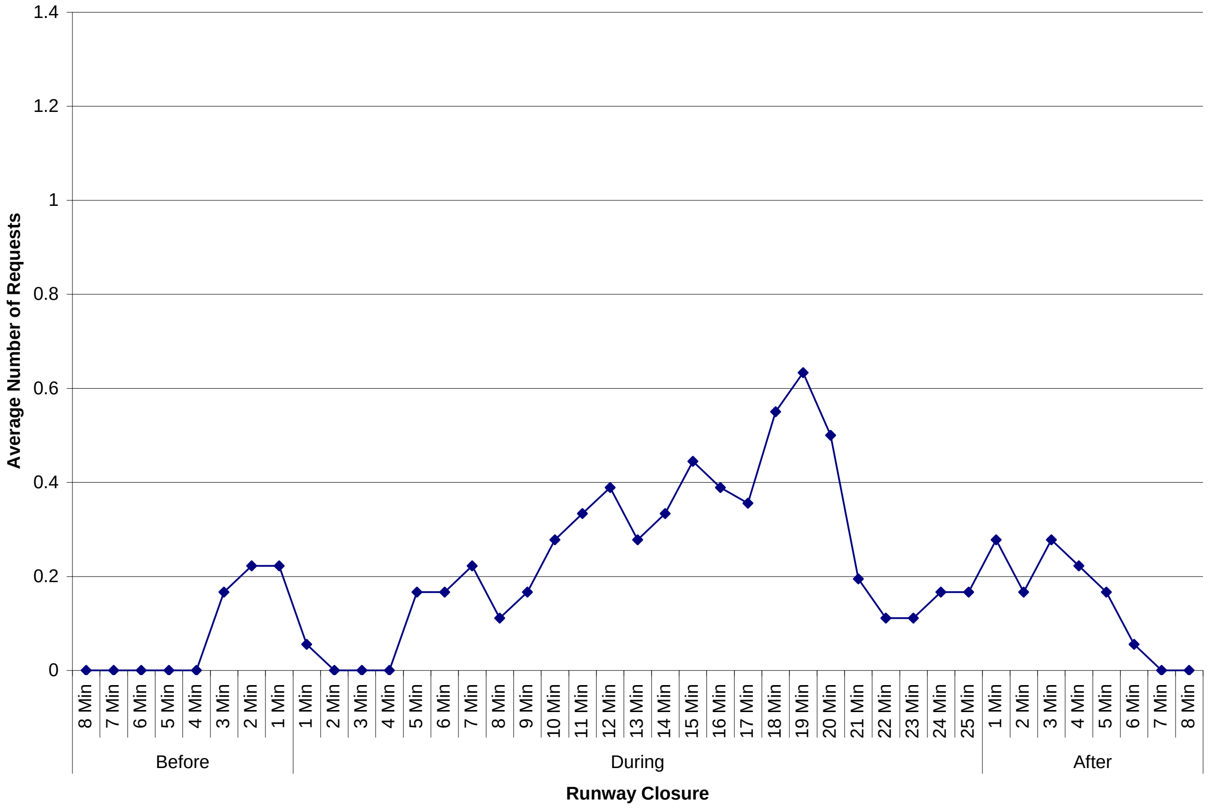
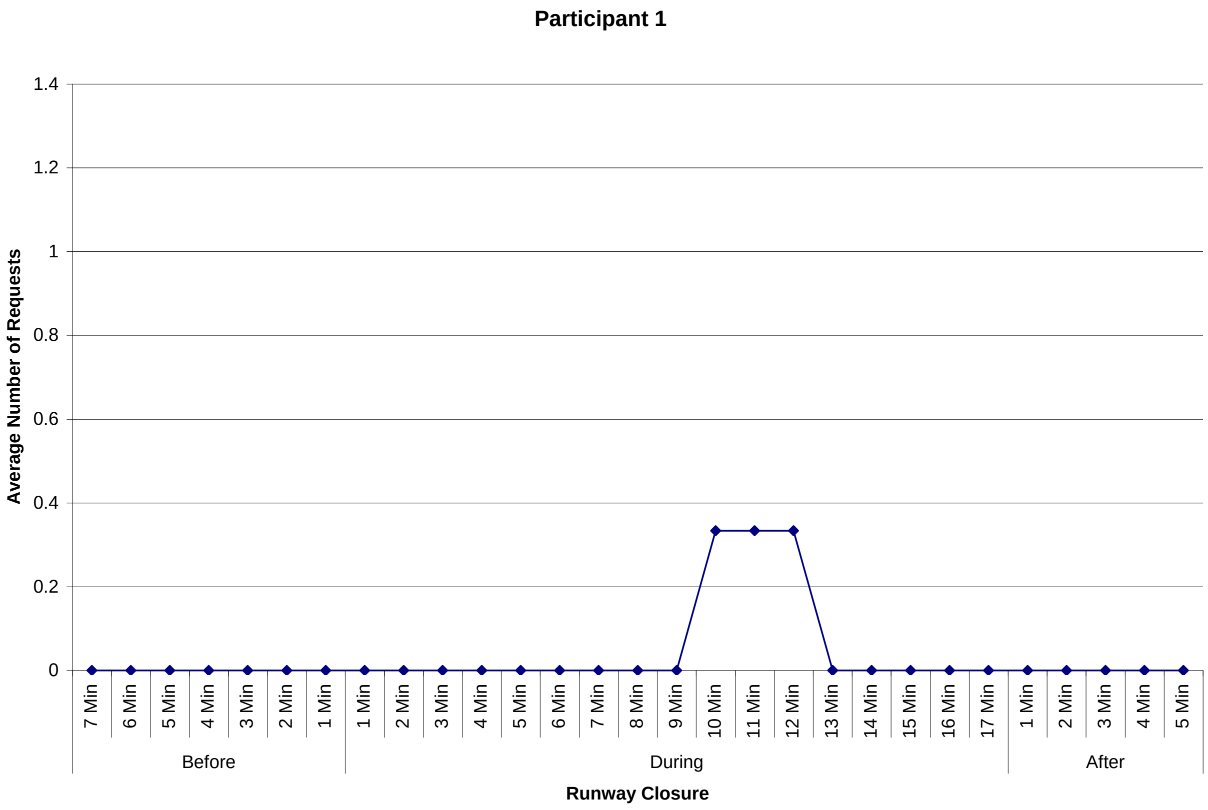
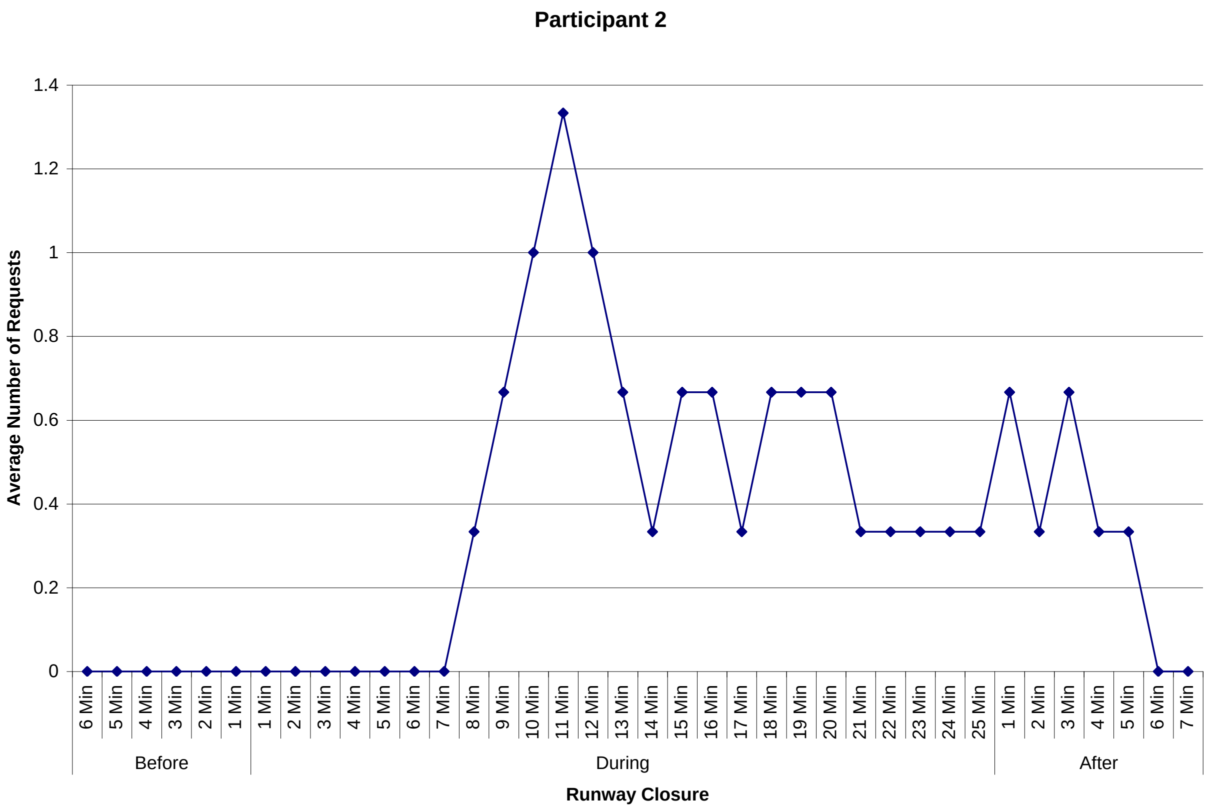
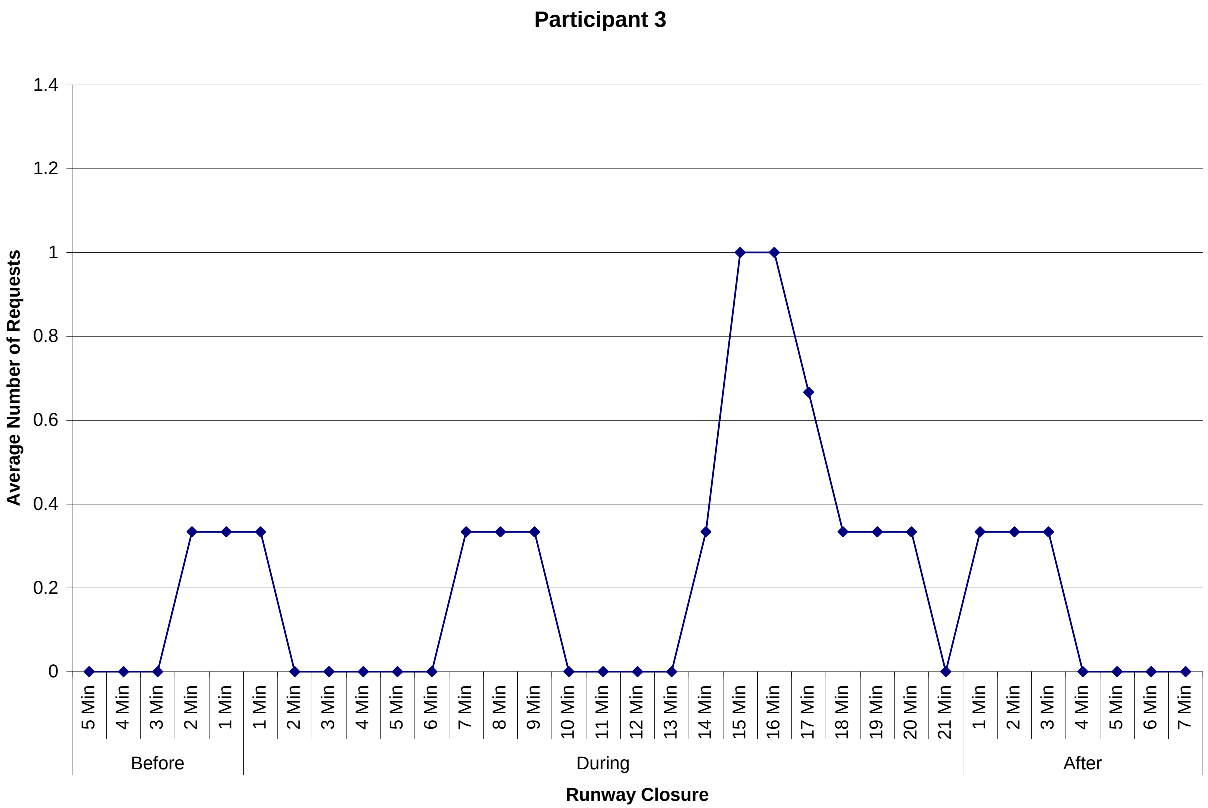
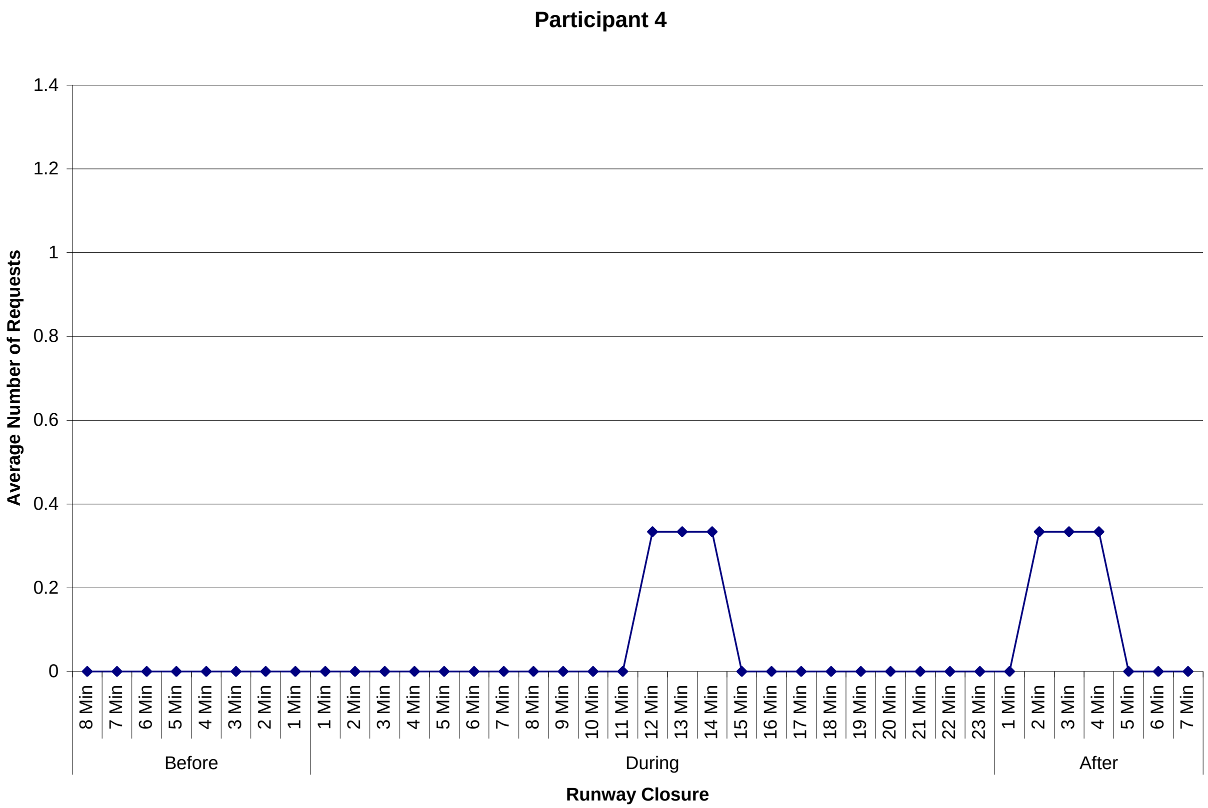


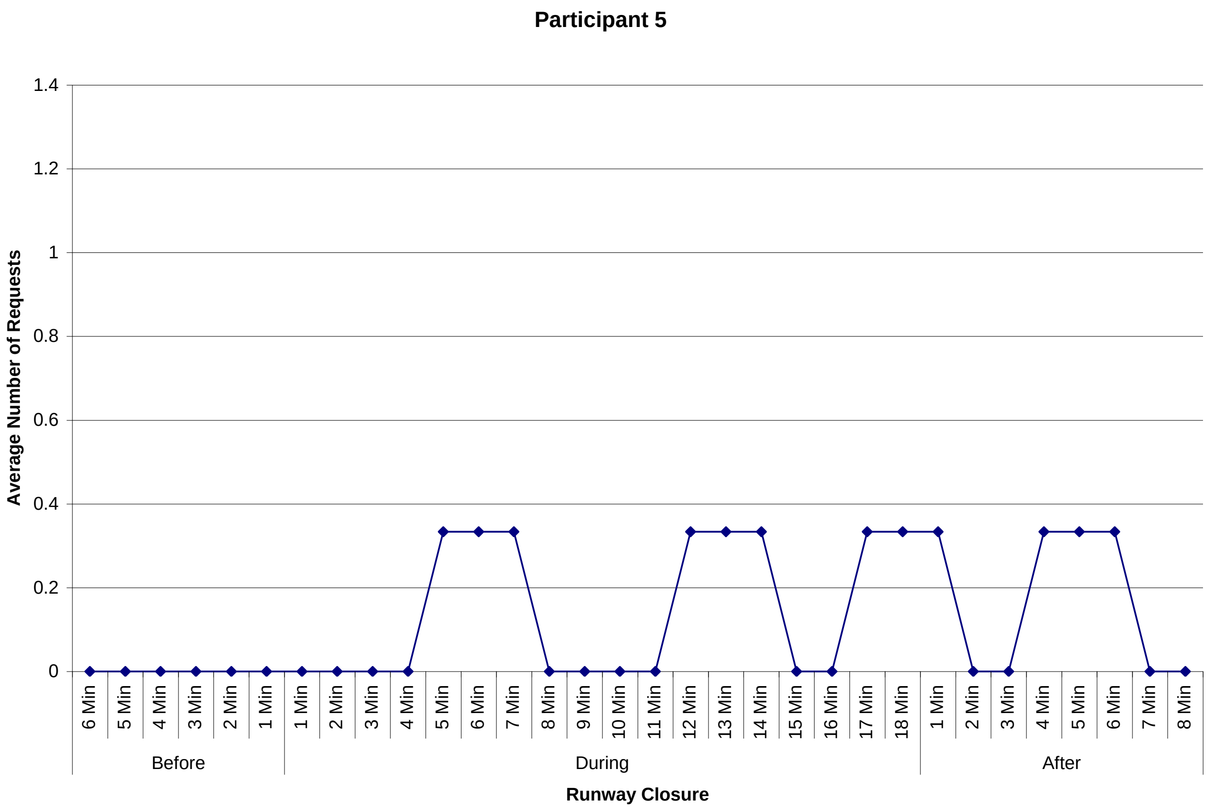
Figure 19. Minute-by-minute frequencies of ACID requests for each participant serving as ground control in the runway closure scenario.




Participant 2
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure


Participant 3
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure


Participant 4
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8 Min
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
Before
During
After
Runway Closure


Participant 5
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
Before
During
After
Runway Closure

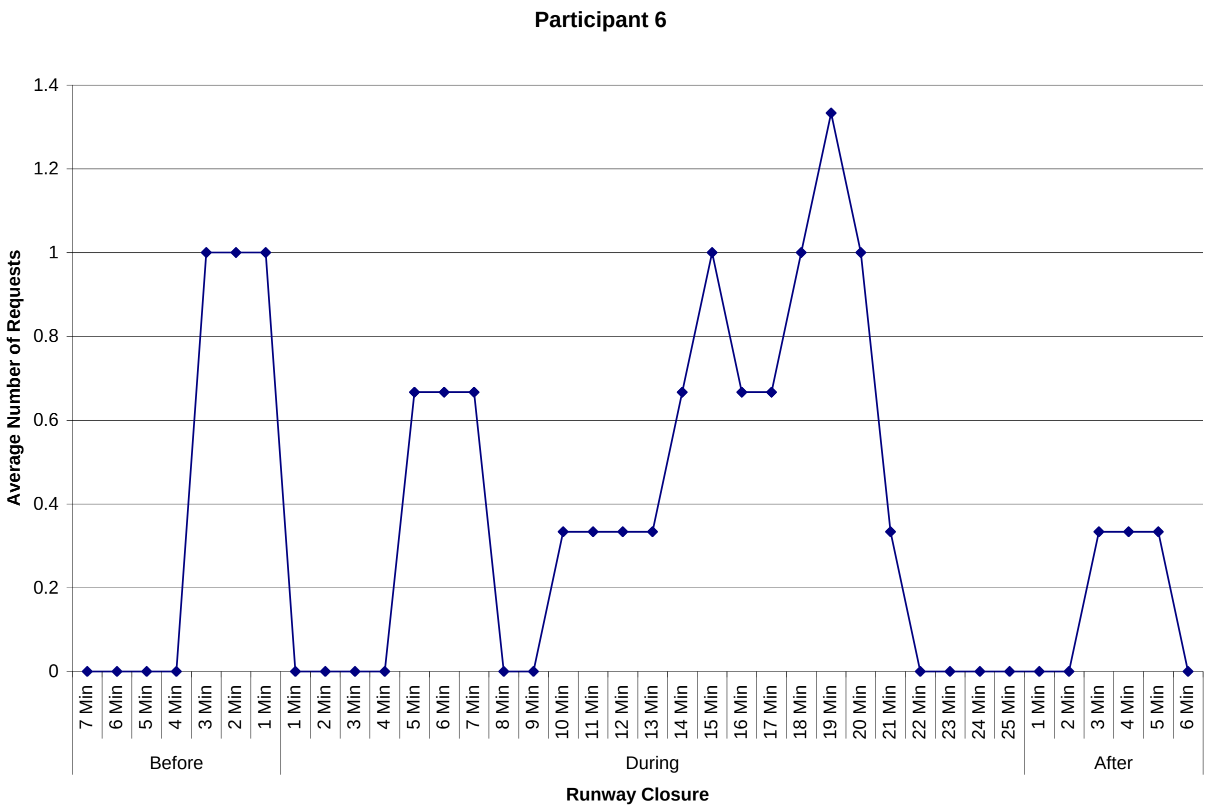

Participant 6
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
Before
During
After
Runway Closure

Figure 20. Average proportion of type requests before, during, and after an aircraft malfunction.

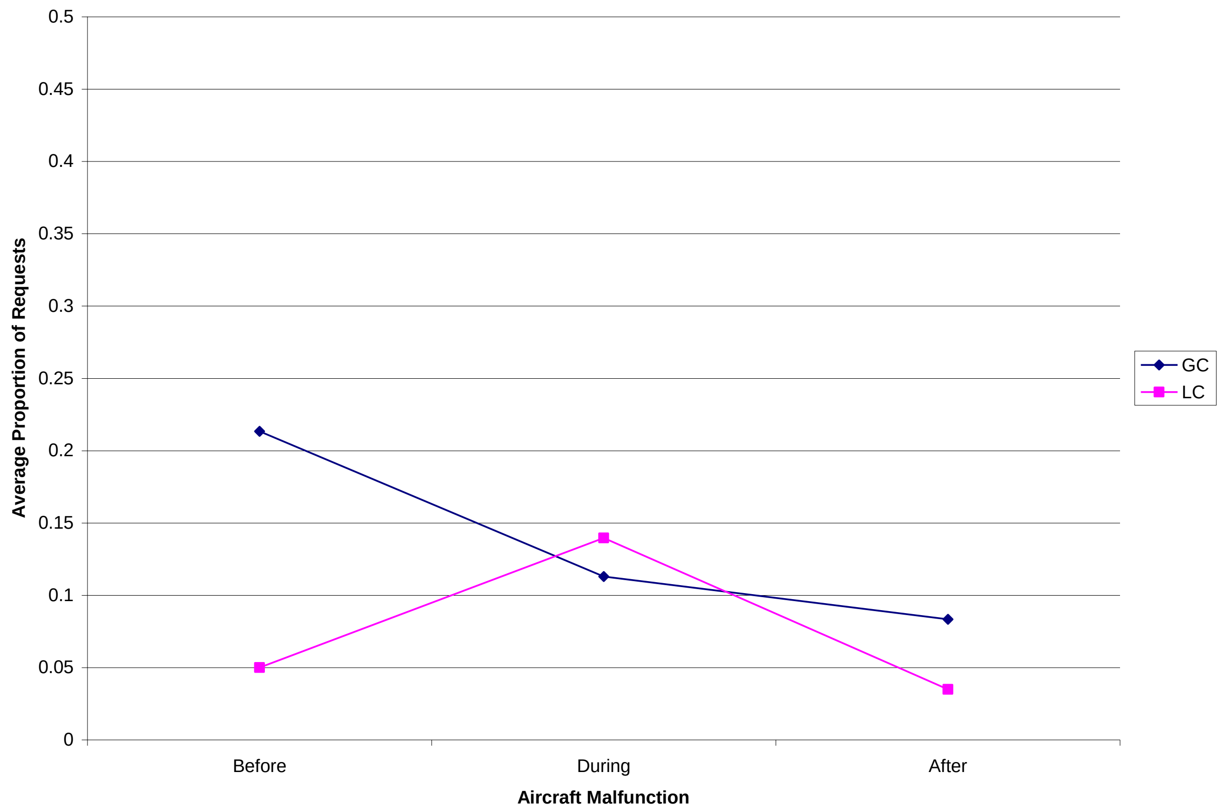


Figure 21. Minute-by-minute display of average frequency of type requests for local controllers in the aircraft malfunction scenario.

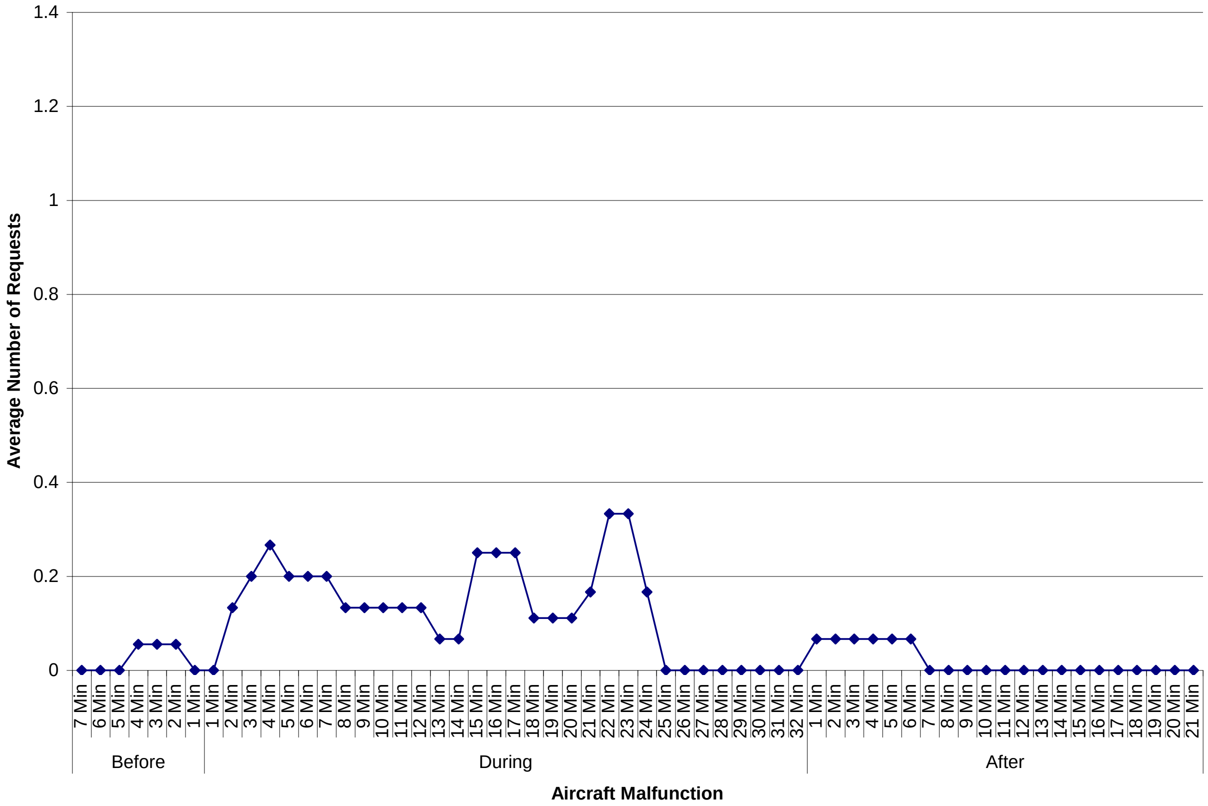
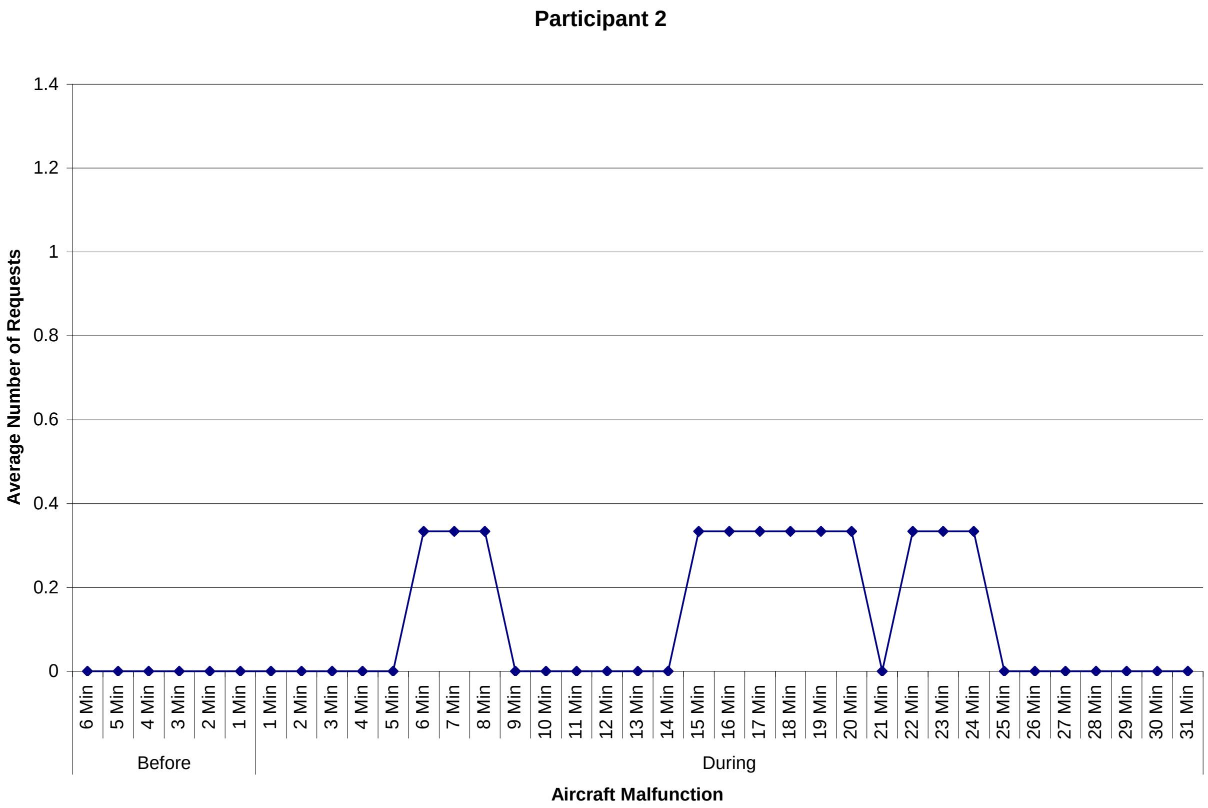
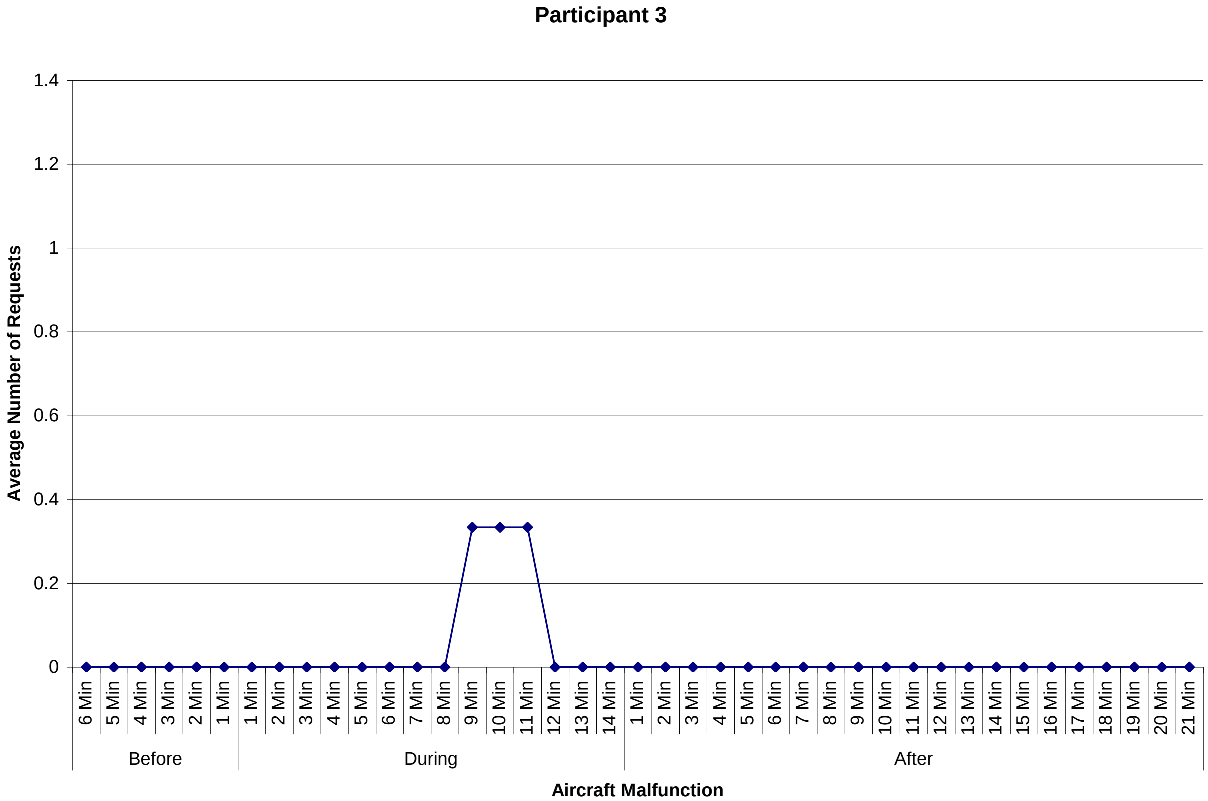
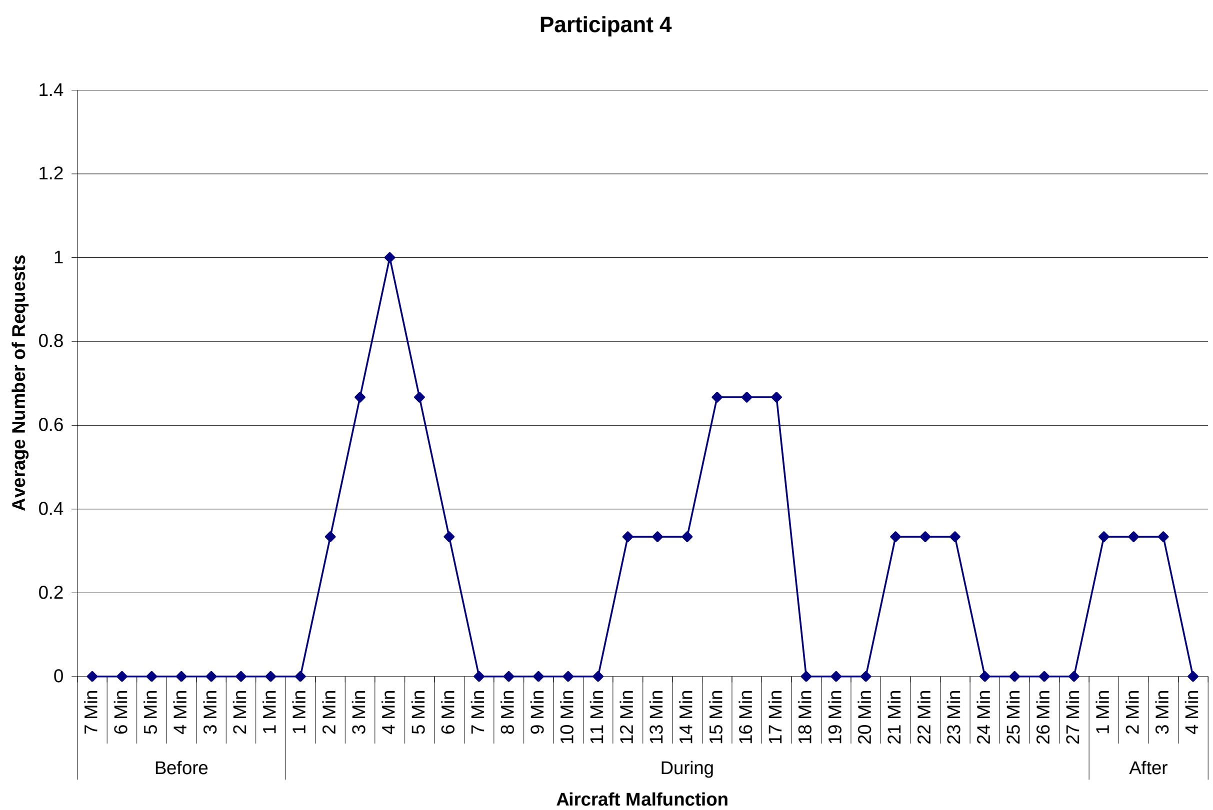
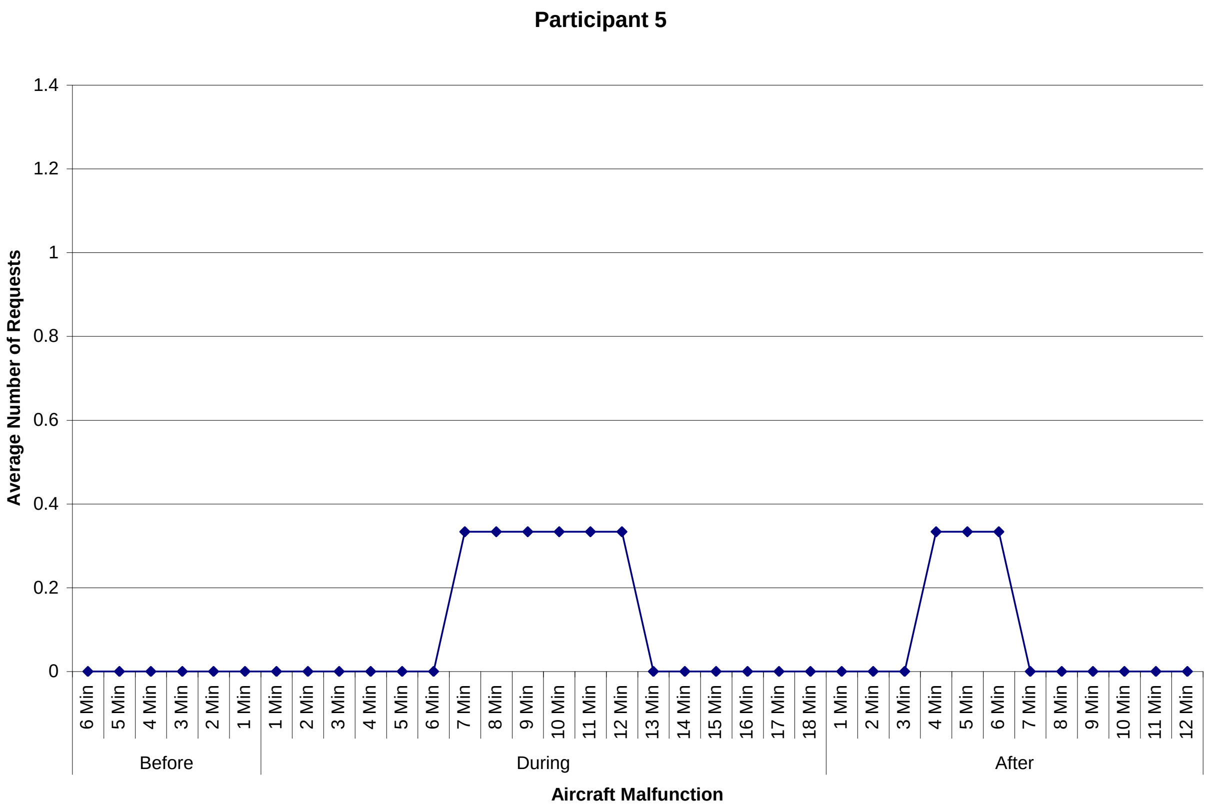


Figure 22. Minute-by-minute frequencies of type requests for participants 2 through 6 serving as local control in the aircraft malfunction scenario.




Participant 3
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
Before
During
After
Aircraft Malfunction


Participant 4
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7 Min
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
13 Min
14 Min
15 Min
16 Min
17 Min
18 Min
19 Min
20 Min
21 Min
22 Min
23 Min
24 Min
25 Min
26 Min
27 Min
1 Min
2 Min
3 Min
4 Min
Before
During
After
Aircraft Malfunction


Participant 5
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
6 Min
5 Min
4 Min
3 Min
2 Min
1 Min
1 Min
2 Min
3 Min
4 Min
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6 Min
7 Min
8 Min
9 Min
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16 Min
17 Min
18 Min
1 Min
2 Min
3 Min
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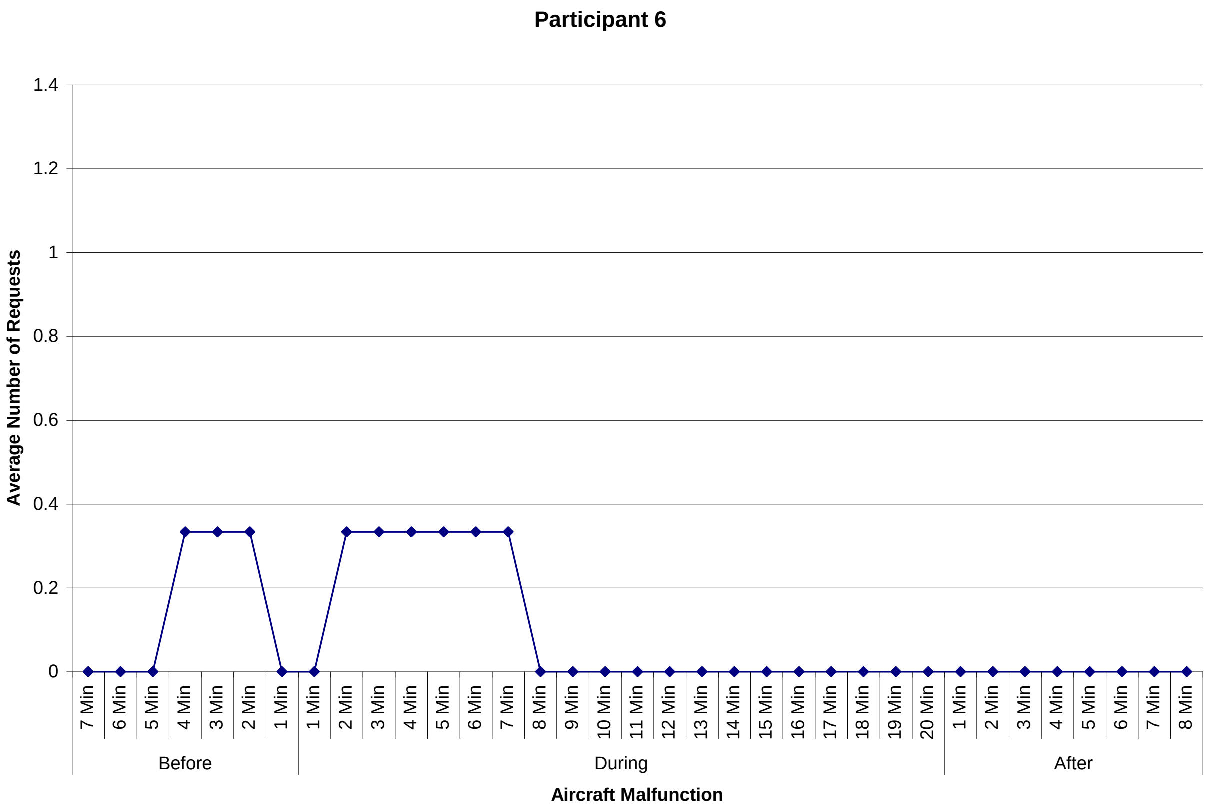
5 Min
6 Min
7 Min
8 Min
9 Min
10 Min
11 Min
12 Min
Before
During
After
Aircraft Malfunction


Participant 6
Average Number of Requests
1.4
1.2
1
0.8
0.6
0.4
0.2
0
7 Min
6 Min
5 Min
4 Min
3 Min
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1 Min
2 Min
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4 Min
5 Min
6 Min
7 Min
8 Min
Before
During
After
Aircraft Malfunction