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Complexity in Air Traffic Control Towers: A Field Study

Part 1. Complexity Factors

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16. Abstract

This study investigated factors that contribute to complexity and their incidence within Federal Aviation Administration Air Traffic Control Towers (ATCTs). Human Factors Specialists from the William J. Hughes Technical Center selected six sites representing a combination of high traffic volume, traffic mix, and/or converging runways. Sixty-two Air Traffic Control Specialists (ATCSs) from the six ATCTs rated 29 complexity factors from local and ground controller perspective. The relative contribution of each of the complexity factors was site- and position- specific. High traffic volume, frequency congestion, and runway/taxiway configuration were among the leading complexity factors at all sites and for both control positions. This study characterized the differences between facilities in terms of the key factors and their incidence and summarized the interview data describing the nature of the complexity. An enhanced understanding of ATCSs' decision making and tower complexity factors will help researchers predict the impact of automation and emerging technologies on controllers and ensure the continued safety and efficiency of the National Airspace System.

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Executive Summary

Air Traffic Control (ATC) is a complex environment involving real time data acquisition and decision making on the part of the Air Traffic Control Specialist (ATCS). Numerous studies have investigated the complexity factors faced by controllers and their decision-making process. However, few of these investigations have focused specifically on the tower environment.

Human Factors Specialists (HFSs) from the William J. Hughes Technical Center conducted the study, which focused on complexity factors and their incidence, how these contributed to controller's job performance and strategies, and information sources used to deal with complexity within Air Traffic Control Towers (ATCTs). This is the first of two reports on the study. It documents controllers' ratings and descriptions of complexity in the ATCT. A second report examines the strategies and information sources that tower controllers used when dealing with these complexity factors.

Sixty-two participants, representing six ATCTs, completed a rating form that assessed the contribution to complexity and incidence of several ATC relevant factors. The study characterized the differences between the facilities on 29 complexity factors and culminated in descriptions of the nature of these factors and the mitigating strategies that controllers employed.

The results demonstrated that the relative contribution of each of the complexity factors was site-specific. Even so, high traffic volume and frequency congestion were among the primary complexity factors influencing controllers across all sites. Active runway crossings, runway/taxiway restrictions, Traffic Management Initiatives (TMIs), runway/taxiway configuration, on-the-job training, and reduced visibility due to weather were among the other top-rated factors. The ratings indicated that the complexity added by each of the factors was different for the local and ground control positions. Runway/taxiway restrictions and TMIs tended to contribute more to complexity for the ground control position. Active runway crossings and aircraft differing in performance characteristics were the most highly rated complexity factors for the local controller.

This study examined the relative contributions of complexity factors in the tower environment and the mitigation strategies that ATCSs employed. By applying this knowledge, designers of decision-support systems will have a basis to more closely match the tools and information requirements of a task with controller needs.

The HFSs recommend the collection of data from additional tower facilities representing a broad range of facility levels. These supplemental data will aid in assessing the impact of other site-specific factors and provide a first step in validating the exploratory factor analysis groupings identified during the current study. The HFSs also recommend collecting data from other ATC domains, including the terminal and en route environments, to investigate whether the sources and incidence of complexity are similar or if they pose other unique challenges to the ATCS.

An enhanced understanding of ATCSs' decision making and tower complexity factors will help researchers predict the impact of automation and emerging technologies on controllers and ensure the continued safety and efficiency of the National Airspace System.

1. Introduction

In the multi-faceted environment of Air Traffic Control (ATC), the Air Traffic Control Specialists' (ATCSs') decision-making process is crucial to aviation safety and efficiency. Research seeks to identify the underlying factors in the process of decision making. Complexity represents one factor underlying decision making. This current study focuses on complexity in Air Traffic Control Towers (ATCTs).

A research team from the National Airspace System (NAS) Human Factors Group (ACB-220) of the Federal Aviation Administration (FAA) William J. Hughes Technical Center (WJHTC) conducted this study. The team, consisting of two Human Factors Specialists (HFSs) and one Air Traffic (AT) Subject Matter Expert (SME), investigated controllers' perceived sources of complexity, decision strategies, and methods for managing complexity. The research team investigated these factors from the perspective of both local and ground controllers. They selected from among the busiest tower facilities (FAA, 2001a) with consideration for the facilities' region and the cognitive complexity factors of converging runways and traffic mix. This research was not involved with the classification of the tower or the tower staffing.

1.1 Background

The Panel on Human Factors in Air Traffic Control Automation proposed increasing the level of decision support automation in ATC facilities to accommodate the growth in the number of flights projected over the next decades (Hopkin, 1998; Wickens, Mavor, Parasuraman, & McGee, 1998).

In an effort to support the Panel's proposal, in FY 1999, the Research Development and Human Factors Laboratory at the WJHTC initiated the first in a series of studies to investigate ATCS decision-making strategies (D'Arcy & Della Rocco, 2001). HFSs from ACB-220 conducted semi-structured interviews with 100 ATCSs to examine their perspective regarding controller decision making and planning (D'Arcy & Della Rocco). The goal was to explore controllers' views of important issues related to the information they use, difficulties encountered, and potential improvements. ACB-220 designed the study to expand the knowledge base on ATC decision strategies and serve as a foundation on which to build future research on decision support automation.

1.2 Literature Review

1.2.1 Decision Making

ATCSs are decision makers in a dynamic environment involving many factors, such as constantly updating relevant information and resolving conflicting goals. They often make difficult decisions with incomplete information, under time pressure, and with high workload. Despite the challenges confronting ATCSs, the number of operational errors remains relatively low.

Even with the recent decrease in air travel, air traffic is predicted to grow over the years. Therefore, Federal resources continue to focus attention on reducing runway incursions and operational errors (DOT, 2001).

Airports/terminals represent major constrictions on NAS capacity. To overcome this constraint, automation and new technologies have been implemented so that terminal ATC can increase its efficiency (FAA, 1999; Hopkin, 1998; Wickens et al., 1998) and decrease runway incursions.

Since 1990, there have been four major accidents attributable to runway incursions, and the number of incursions increased from 1993 to 1997 (FAA, 1998a). In response to this and the concerns of the National Transportation Safety Board (1991), the FAA established the Runway Safety Office, which embarked on a Runway Incursion Reduction Program. This led to an increased focus on tower operations and an anticipated increase in system changes at the terminals. Cardosi and Yost (2001) report that, for what were formerly designated as Level 5 towers (the busiest), two of the top five contributing factors to operational errors or deviations were complex runway configuration and complexity due to the number of aircraft. Therefore, understanding the decision-making processes and determining the strategies that tower controllers use in managing the complexity of ATC is crucial for a smoother transition to new automation.

The Panel on Human Factors in Air Traffic Control Automation suggested "decision making may be improved by training and displays that are sensitive to strategies that do work in real-world environments" (Wickens, Mavor, & McGee, 1997, p. 108). The panel subsequently recommended that automation efforts in the near future focus on the development of decision aids primarily for conflict resolution and maintaining separation (Wickens et al., 1998). A concern was that automated decision aids that rely on incorrect models of human decision making may result in systems that are less efficient than the human alone (Mosier, 1997; Mosier & Skitka, 1996). Kaempt and Orasanu (1997) suggested that, to be effective, decision-support and decision-training systems must be tailored to the cognitive processes naturally invoked by the decision maker. Automated systems should not impose a process or organization that is foreign to the decision maker. The development of decision-support technologies should, therefore, be based on an enhanced understanding of the decision-making strategies used in operational settings by ATCSs.

D'Arcy and Della Rocco (2001) examined ATCSs' perspective regarding decision making and planning and related cognitive processes such as learning, memory, and situation awareness (SA). Strategies used are a direct outcome of the decision-making process. This study identified the decision strategies used and information required, in general. The authors recommended a detailed analysis of the information requirements for various controller roles in future research.

The majority of the participants in the D'Arcy and Della Rocco (2001) study were en route controllers. Factors existing in Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) facilities are different than in the ATCT environment. Towers generally have less airspace, providing less time for controllers to direct aircraft traffic, and their scope of control (airport) makes it possible for them to visually monitor the aircraft by looking out the window. ARTCC controllers are more likely than their terminal facility counterparts to wait and see when they are unsure of a conflict. The limited decision time available in towers necessitates time sensitive decision making, and, as a result, the strategies used in the two facilities vary significantly (D'Arcy & Della Rocco).

1.2.2 Complexity Factors

Since the early 1960s, several studies have examined the effects of ATC complexity on controller workload, performance, and operational errors. These studies used a variety of measurement techniques to assess complexity and its associated factors (see Appendix A).

Researchers suggest that ATC complexity is an underlying driver of controller workload (Rodgers, Mogford, & Mogford, 1998). Mogford, Guttman, Morrow, and Kopardekar (1995) defined complexity as “a multidimensional construct that includes static sector characteristics (sector complexity) and dynamic traffic patterns (traffic complexity)” (p. v). The authors also noted “although there may be objective, measurable features of sectors and aircraft, the concept of ATC complexity is subjectively defined by the controller. It is developed from the controller’s perception of and interaction with the sector and the air traffic within it” (Mogford et al., p. 3). Much of the complexity is characterized by unplanned demands and having to dynamically replan in response to weather, Traffic Management Initiatives (TMIs), airport construction, maintenance activities, and other events. Unplanned tasks are difficult because the controller cannot prepare for them and levy workload-leveling strategies.

ATC complexity is a construct composed of a number of sector and traffic factors. A construct “is a process which is not directly observable, but gives rise to measurable phenomena” (Reber, 1985, as cited in Mogford et al., 1995, p. 3). Schmeidler and D’Avanzo (1994) reported that traffic complexity is an important component of workload, but there is no consensus on how to define or measure complexity. Wickens, Mavor, and McGee (1997) suggest that the number of aircraft being handled by the controller could be identified as an important complexity factor. They further suggest that this variable is insufficient on its own; it is dependent upon other factors. Therefore, one needs to identify all potential complexity variables and determine their interrelationships. Although many studies have investigated the effects of specific airspace and traffic factors on the workload and performance of ATCSs, an understanding of ATC complexity requires an understanding of mediating factors (Rodgers et al., 1998).

Controller decisions are contingent on many task-related factors. For example, the complexity of the sector, the volume and complexity of the traffic, and time pressure may influence the controller (D’Arcy & Della Rocco, 2001; Mogford et al., 1995). Controllers adopt different strategies according to the level of difficulty or complexity of the situation. For example, they become more conservative or cautious (i.e., use a larger buffer) when confronted with difficult situations such as bad weather, high workload, or fatigue. Mogford et al. proposed that ATC complexity is mediated by the quality of the equipment, individual differences, and the strategies used.

1.3 Purpose and Rationale

This study identified and characterized common complexity factors facing controllers in the tower environment. It also captured the repertoire of strategies and the information that controllers use to deal with these situations. In this, the first of two reports, we examine the relative importance of 29 complexity factors from a local controller and ground controller perspective and provide descriptions of these factors. In the second report, we will investigate the decision-making tactics that controllers use when selecting a strategy and the importance of various sources of information. By applying this knowledge, designers of decision-support systems will be able to focus on the key sources of complexity and have a basis to more closely match the tools and information requirements of tasks with controller needs. In addition, this knowledge will help to identify areas for future studies in tower environments. An enhanced understanding of ATCSs’ decision making and tower complexity factors will also assist in evaluating the impact of new automation and emerging technologies on perceived complexity and support controller performance, ensuring the continued safety and efficiency of the NAS.

1.4 Variables and Hypotheses

This study was, predominantly, exploratory in nature. It contains quantitative measures in the form of controller ratings of the frequency and complexity of 29 factors. It also contains qualitative data in the form of controller descriptions of the nature of the complexity. The research team expected to identify differences between local and ground position ratings as well as differences among facilities. The results will aid in forming and refining hypotheses for exploration during future research efforts.

2. Method

The research team developed and administered complexity rating forms and a semi-structured face-to-face interview. These forms gathered information on ATCT-specific complexity factors and the strategies and information sources controllers typically use in dealing with the factors. This section characterizes the participants and describes the site selection process, material development, procedures, and data analysis that the HFSs used to conduct the study.

2.1 Participants

The research team recruited 62 tower controller volunteers from six ATCT facilities. All participants maintained operational currency. The researchers interviewed 47 ATCSs (all of whom were Certified Professional Controllers [CPCs]), 3 Traffic Management Coordinators (TMCs), and 12 Supervisory ATCS (SATCSs). Table 1 summarizes the demographics of the participants.

Table 1. Participant Demographic Information

Item	Category	Count	Percent
Age[a]	18-25	0	0
	26-30	0	0
	31-35	2	3
	36-40	17	27
	41-45	19	31
	46-50	16	26
	51-55	6	10
	56+	2	3
Gender[a]	Female	12	19
	Male	50	81
Current job title[a]	ATCT	47	76
	TMC	3	5
	SATCS	12	19

[a] n=62

Approximately one third of the participants had military ATC experience (Table 2). Forty percent of the participants reported having worked in a combined tower and TRACON at one point in their careers. They averaged just over 2 years in developmental training, taking anywhere from 1 to 5 years to complete this training. The participants had worked at their current facility for as little as 1 year, to as many as 30 years. As such, the participants represented a broad range of site-specific experience.

Table 2. Years of ATC Experience

Item	Category	Count	Percent	Median (yrs)	Range (yrs)
Overall ATC experience[a]	Military	24	39	4	3 - 13
	Developmental	62	100	2	1 - 5
	CPC	62	100	17	4 - 32
ATC experience by facility type[a]	Tower only	56	90	14	1 - 26
	TRACON only	20	32	3	1 - 15
	Combined Tower and TRACON	25	40	7	1 - 31
	ARTCC	17	27	4	1 - 7
	Flight Services	3	5	4	2 - 5
Time at current facility[b]	Less than 5 years	15	25	–	–
	5 – 9 years	13	21	–	–
	10 – 14 years	14	23	–	–
	15 – 19 years	12	20	–	–
	20 – 24 years	4	7	–	–
	Over 25 years	3	5	–	–

[a] n=62, [b] n=61

All of the participants had worked in the tower during the previous 30 days. For most of them, working in the tower represented the majority of their time, as reflected by the averages of 90%. Roughly half had performed administrative duties during that time, but this activity tended to be limited, with a median estimate of 10% of their time. For two SATCSs, administrative duties accounted for 95% of their time. However, because of their extensive ATC experience and currency, we included their data in the sample.

On average during the previous 30 days, the ATCSs distributed their time equally across the positions of local control, ground control, and combined flight delivery/clearance delivery/ground control. The majority of the ATCSs (72%) had acted as a Controller-in-Charge during the previous 30 days; however, this responsibility never accounted for more than one third of their time. Other controller duties specifically identified by the ATCSs were working all controller positions combined, performing Automated Radar Terminal System-related duties, and performing tower cab coordination activities. The three TMCs reported working almost exclusively on tasks within the Traffic Management domain (with estimates ranging between 85% and 90% of their time).

Twenty-one interviewees (i.e., 20 ATCSs and 1 TMC) reported conducting On-the-Job Training (OJT). Each facility had at least one participant who had performed OJT within the previous 3 months. The amount of time reported for this activity ranged from 2 hours to 75 hours, with a median of 10 hours.

2.2 Site Selection

In collaboration with AAR-100, the HFSs decided on three factors as the primary facility selection criteria because Mogford, Murphy, Roske-Hofstrand, Yastrop, & Guttman (1994) reported these factors to be among the foremost determinants of complexity. These included high traffic volume, traffic mix, and converging runways. Our secondary selection consideration included a broad representation of FAA regions. Using calendar year (CY) 2000 ATCT operations data (FAA, 2001a), the HFSs selected facilities from among the busiest towers. They identified six sites from different regions with high traffic volume and then ensured that two sites had converging runways and two sites had significant traffic mix.

Table 3 presents the six study sites and their 3-letter identifier. The team selected ATL tower due to its high traffic volume, ranking first in total operations. ORD and BOS towers, which ranked second and eleventh respectively in terms of total operations, represented high traffic sites with converging runways. PHX and OAK both demonstrated a substantial traffic mix. With the exception of these two sites, each facility represented a different region. However, the team included OAK (a second facility in the Western Pacific Region) because of its volume and high concentration of general aviation traffic, particularly for local operations. HFSs substituted BJC for a large volume tower based upon discussions with AAR-100. It provided the opportunity to investigate the complexity factors of a smaller facility.

Table 3. Study Sites

Identifier	Tower	Airport
ATL	Atlanta Tower	William B Hartsfield Atlanta International Airport
BJC	JEFFCO Tower	Jefferson County Airport
BOS	Boston Tower	General Edward Lawrence Logan International Airport
OAK	Oakland Tower	Metropolitan Oakland International Airport
ORD	O'Hare Tower	Chicago O'Hare International Airport
PHX	Phoenix Tower	Phoenix Sky Harbor International Airport

Table 4 presents the facility profile and traffic operations mix for each of the study sites. In the "Percent of Traffic Operations" section of the table, some of the rows do not equal 100% due to rounding. Airport maps depicting the runway layouts for each of the towers appear in Appendix B.

Table 4. CY 2000 Traffic Levels and Traffic Mix for Interview Sites

Tower	**Facility Profile**			**Percent of Traffic Operations**				
				Itinerant				Local
	Level	Total Ops	Rank	Air Carrier	Air Taxi	General Aviation	Military	General Aviation
ATL	12	913,449	1	75	22	2	0	0
ORD	12	908,977	2	76	21	3	0	0
PHX	10	638,757	5	64	15	11	1	9
BOS	11	508,283	11	53	40	6	0	0
OAK	10	449,050	20	33	9	33	0	24
BJC	6	172,460	120	0	1	53	0	46

2.3 Materials

Based on the review of the relevant literature, the HFSs compiled a comprehensive list of ATC complexity factors. From this, we developed a preliminary rating form and conducted pretests. In the following sections, we review the question selection process and the pretests we conducted to develop the final version of the data collection form.

2.3.1 Question Selection

The rating form and interview questions included close-ended and open-ended items focusing on ATCT complexity and strategies. The research team selected the factors from several sources, including Schmeidler and D'Avanzo (1994), Cardosi and Yost (2001), Mogford et al. (1995), the FAA's position classification standard formula (FAA, 1998b), and D'Arcy and Della Rocco (2001). The team reviewed the factors and categorized them into logical groupings. Table 5 presents the resulting list of 29 factors categorized into nine groups. The factors predominantly represent traffic pattern and airport characteristics similar to the source factors of air traffic pattern and sector characteristics referenced by Rodgers et al. (1998) for en route controllers.

Wickens et al. (1997) noted that among four related dimensions that influence controller resource allocation are the extent to which the events are complex and the frequency with which the events occur in time. To explore the relative contribution of each of these factors, we had participants rate both. First, we asked the degree to which each factor contributed to complexity. In addition to the degree of complexity contributed by a factor, its incidence also has a direct bearing on its influence on a controller. For instance, a factor may occur infrequently but be extremely complex, or a factor with low complexity could occur several times in a single shift. Therefore, we collected ratings on both variables.

The team prepared 5-point scales to assess contribution to complexity (1-Very low to 5-Very high) and frequency of occurrence (1-Almost never to 5-Almost always). The form provided space to identify any missing complexity factors and to rate the factor using these same two scales. AT SMEs reviewed the forms and assessed their relevance, understandability, and comprehensiveness. The HFSs integrated the SMEs' suggestions into the data collection forms and conducted pretests.

Table 5. Complexity Factors by Category

Category	Complexity Factor
I. Physical factors	1. Runway/taxiway restrictions
	2. Active runway crossings
	3. Runway/taxiway configuration
	4. Non visibility areas
	5. Airspace configuration
	6. Terrain/obstructions
	7. Satellite airports
II. Aircraft/traffic characteristics	8. High traffic volume
	9. Aircraft differing in performance characteristics
	10. Emergency operations
	11. Wake turbulence
	12. Special flights (e.g., medivac, helicopters, other local traffic)
	13. Overflights
	14. Vehicular traffic
III. Weather	15. At or below minimums
	16. Reduced visibility (e.g., fog, sun glare)
	17. Inclement weather (e.g., wind, thunderstorms, lightning)
IV. Ground operation	18. Airport surface activity (e.g., lawn mowing, construction)
V. Equipment factors	19. Equipment malfunctions
	20. Frequency congestion
	21. Equipment location (e.g., accessibility of control panels)
	22. Reduced visibility (e.g., reflections in tower cab)
VI. Individual factors	23. Unfamiliar pilots (e.g., unfamiliar with airport or procedures)
	24. Pilot's weak mastery of English language
	25. Controller fatigue
VII. ATC procedures	26. Traffic management initiatives
VIII. Distractions	27. Equipment distractions (e.g., altitude alarms)
	28. Other distractions (e.g., visitors in tower cab, conversation)
IX. Training	29. On-the-job training

2.3.2 Pretests

The research team conducted two pretests. In October 2001, the team interviewed three SATCSs from the Atlantic City International Airport ATCT. These participants represented the sample population and had no prior experience with the study. They provided valuable input into the relevance and understandability of the data collection process and the interview questions. As a result, the team implemented some minor revisions to the complexity rating form. Following this, the team conducted an in-depth review with two National Air Traffic Controllers Association (NATCA)-designated representatives from two Level 12 ATCT facilities. The team integrated their suggestions and finalized the data collection forms.

2.4 Procedure

The following sections detail the coordination and data collection procedures. The procedure comprised three major activities: study coordination, orientation, and interviews.

2.4.1 Study Coordination

The research team obtained approval for the study from the FAA Institutional Review Board. In preparation for the site visits, the Labor Management Relations Division (ATX-500) provided a synopsis of the study, the data study forms, and the study goals to NATCA, in accordance with the 1998 FAA/NATCA Bargaining Agreement Article 50. The Flight Service and Cross Domain Branch (ATP-430) coordinated each visit with the regional Air Traffic Resource Management Branches (540s). The 540s then coordinated with the facility management. NATCA provided two human factors ATCS representatives to consult on the study. They coordinated with the NATCA Regional Vice Presidents and facility representatives. The Research and Strategic Requirements Division (ARQ-200) provided a representative to facilitate coordination from the headquarters level and to support the field visits.

2.4.2 Orientation

In preparation for each facility visit, the research team conducted a telephone conference with management and union representatives from the facility, as well as representatives from ATP-430, the appropriate FAA region, and the NATCA project representatives. Before the telecoms, we disseminated information on the objectives, methods, and procedures of the study (Appendix C) as well as a PowerPoint briefing. The ACB-220 project lead reviewed the briefing, addressed the interview site requirements, and requested that the site select a Point of Contact (POC) for the visit. The researchers reiterated that we would maintain the confidentiality and the rights of all volunteers and requested 10 participants matching the study requirements in their facility (i.e., eight bargaining unit controllers and two staff members). The research team answered any questions on the study and assured the facility manager that the operation of the facility was of paramount importance and that participants would always be available to them. This process resulted in exceptional accommodation at each facility. In fact, frequently, the POC had already identified and scheduled the participants by the time the team reached the facility.

2.4.3 Interviews

The interview team consisted of two HFSs and one AT SME. In preparation for on-site data collection, the team participated in an interview techniques training session conducted by an ACB-220 professional trained in interview techniques.

A representative from ARQ-200 accompanied the team to each facility. Upon arriving, they conducted an inbriefing with the facility manager or designated representative and a NATCA representative. The ARQ-200 representative ensured that the facility was comfortable with the study and its procedures. Next, the team reviewed the goals of the study and the data collection process. After answering any questions raised by the manager or NATCA representative, the team began to interview the volunteers. When possible, on-site personnel provided a tour of the facility and offered insights into site-specific complexity factors.

The team remained flexible to the needs of the facility and conducted interviews as volunteers became available. With few exceptions, we were able to complete the interview process before the allotted time expired or the facility required the controller to return to the operation. Typically, we completed the on-site data collection in 2 days, conducting five sessions each day.

At the beginning of each interview, the team described the goals of the study and reviewed the Informed Consent Form (Appendix D). Next, the participant completed the Complexity Rating Form (Appendix E) from both a local and ground controllers' perspective. While the controllers completed the Background Questionnaire (Appendix F), the HFSs reviewed the participants' ratings and selected three local and three ground control factors on which to interview. The three local factors included the two with the highest complexity and highest frequency ratings, and one factor representing the lowest frequency rating but a high complexity rating. We repeated this procedure for the ground position. We noted at the first site that participants exhibited a high degree of consistency in their ratings, resulting in only a minimal subset of the factors being selected for the interviews. As a result, the team modified the selection procedure to select the next highest rated factor in cases where they had already conducted an interview on the highest rated factor. After five interviews, the team began the selection procedure anew to ensure that they focused on the most complex factors.

The team distributed the data collection form (Appendix G) to interview participants. We interviewed the participants regarding the nature of the complexity factor, their decision-making process when selecting a strategy, the importance of various items of information, and the relative importance of each element. The HFSs alternated between conducting the interview and taking notes. We counterbalanced the focus of the interviews between the local and ground positions. During the interviews, the AT SME intervened only to summarize technical AT procedures and processes or to identify terminology for the interviewer, saving critical interview time. We encouraged the participants to elaborate on their responses. We clarified the meanings of questions and response choices if participants expressed uncertainty or asked for help. Many researchers have suggested that rigid interviewing (a prevailing principle in survey research that instructs interviewers to avoid interfering in this manner) might compromise data quality (Briggs, 1986; Mishler, 1986; Suchman & Jordan, 1990). Schober and Conrad (1997) demonstrated that conversational interviewing could enhance the validity of reports. Gromelski, Davidson, and Stein (1992) suggested that the major advantages of conducting an in-depth (conversational) interview are "that the interviewer

a. can ask for examples to clarify a point;
b. can explore the meanings of various phrases that respondents use;
c. can probe, that is, ask a question in a variety of ways, to ensure that he or she understands the point that the respondent is making;
d. can observe the body language of the respondent; and
e. can pursue new topics that the respondent raises, thereby adding to the comprehensiveness of the data gathered" (p. 7).

At the conclusion of the interview, the team gave the participants an opportunity to identify types of information or alternate methods of presentation that would aid them in dealing with the complexity factors. The team made their notes available to the participant for review.

2.5 Data Analysis

To explore the data, the research team calculated the Complexity Index (CI) as an estimate of the relative importance of each source. The team summed the average complexity and frequency ratings for each factor into a single value [i.e., $CI = S (C + F)$]. Complexity scores ranged from 1 (very low) to 5 (very high). Frequency ratings ranged from 1 (almost never) to 5 (almost always). For factors that participants rated as N/A (i.e., indicating that they did not contribute to complexity), we entered a value of 0. The resulting CI scale begins at 0 (i.e., the factor was of no influence) and increases in complexity and/or frequency until it reaches a maximum rating of 10, where it represents the absolute highest level of complexity and frequency of occurrence.

We then graphed the complexity and frequency ratings for each position on a single figure to identify the key complexity factors. This represented a straightforward means of differentiating between factors that were very complex but occurred infrequently and those that represented low to moderate complexity but were much more pervasive.

The team conducted Analysis of Variance (ANOVA) tests and an exploratory factor analysis on the CI data. The ANOVAs investigated whether complexity factor ratings demonstrated significant differences based on site or controller position; the factor analysis explored which complexity factors tended to group together. The team used STATISTICA, Version 6.0 (StatSoft, Inc., 2001) for all analyses.

2.5.1 Analysis of Variance

The research team conducted a Friedman ANOVA by Ranks test, a nonparametric equivalent of the repeated measures ANOVA, to test the relative rankings of the factors. Next, we performed a Kendall concordance coefficient to assess the agreement between the controllers as to the relative rankings of the factors.

Following confirmation of differences among factor rankings, we analyzed the differences using mixed model repeated measures ANOVAs of 28 of the 29 complexity factors. Factor 13, overflights, was not analyzed because it applied only to the local and not the ground position. The model consisted of a 2 (within) x 6 (between) design, representing two positions (local and ground) and six sites (ATL, BOS, BJC, OAK, ORD, and PHX Towers). Position represented the within subject variable. These analyses investigated whether there were differences in ratings between sites and controller position and whether there was an interaction between site and position. The team applied an alpha criterion of .05 for all tests. To maintain this level for the current design, we applied the Bonferroni procedure (i.e., dividing the alpha criterion, .05, by the total number of analyses, 28, for an adjusted alpha level of significance per test of .002). The team analyzed factors returning a significant interaction using an analysis of simple effects. We determined the source underlying the significant interaction by conducting 1-way ANOVAs, first by holding position constant and then by holding location constant. The adjusted alpha for these tests was .006. For analyses returning significant findings when holding position constant, the team conducted a Tukey's test to identify the sites accounting for the effect.

2.5.2 Exploratory Factor Analysis

The current field study was unique because it focused on the ATCT environment, gathering complexity and incidence ratings from multiple controllers and sites on an extensive list of established complexity factors. As such, it provided an opportunity to investigate the groupings of these factors for potential insights into their nature and inter-relationships. We performed a factor analysis, using principal components extraction, to group interrelated variables into a few factors (StatSoft, Inc. 2001). Although researchers recommend a minimum of 150 participants for factor analyses, the current sample size of 62 was adequate because solutions with several high-loading marker variables do not require as many cases (VanVoorhis & Morgan, in press). The team applied Varimax rotation and Kaiser normalization when analyzing the data. Varimax rotation, the most common rotation method, is an orthogonal rotation technique that yields results that make it possible to identify each variable with a single factor (SPSS, Inc., 1999).

3. Results

This section presents the results of the participants' ratings on the Complexity Rating Form and their responses to the initial interview question regarding the nature of the complexity factor. The complexity factors predominantly consisted of items related to the dimensions of traffic pattern and airport characteristics. The results comprise four sections: 1) factor descriptions, 2) factor ratings, 3) key complexity factors, and 4) exploratory statistics using factor analysis. The complexity factor descriptions appear first because they help elucidate the principal mechanisms underlying each of the factors from a controller's perspective.

3.1 Complexity Factor Descriptions

During the 62 interviews, the team covered 26 of the 29 complexity factors. We completed 285 factor discussions, representing an average of just over four factors per person. Of the 285 discussions, 141 focused on the local controller perspective and 144 on the ground controller perspective. The procedure used to select the interview factor inherently focused on the most prevalent. As a result, some factors were the focus of many more discussions. For instance, high traffic volume (one of the primary selection criteria) received 25 separate discussions. Three factors received no interviews (overflights, reduced visibility due to equipment, and equipment distractions). Appendix H identifies the number of interviews we conducted for each factor.

Table 6 presents a synopsis of the controllers' comments describing the nature of the complexity factor. Appendix I contains more detailed descriptions and includes representative comments regarding the complexity factors. The team distilled the comments into common elements that applied to all sites. We note the contribution of site- and position-specific sources, where appropriate. Although the HFSs did not specifically interview on three of the complexity factors, relevant aspects surfaced during related discussions. We identified these factors in the table.

Table 6. Summary of Complexity Factor Descriptions

Complexity Factor	Synopsis
1. Runway/taxiway restrictions	Unavailable or restricted runways and taxiways impede traffic flow, limiting options, thereby increasing planning, communication, and coordination.
2. Active runway crossings	Timing is critical. They require sustained vigilance and increased coordination and communication, especially if the local or ground positions are split.
3. Runway/taxiway configuration	The taxiways, coordination, airspace, trouble areas, etc. change based on the operational configuration. Changing configurations adds to communication, coordination, and SA demands. Some sites have 23+ configurations available.
4. Non-Visibility areas	Controllers lose their primary means of gathering information—visual observation. They must rely on other information sources (Air Surface Detection Equipment [ASDE], DBRITE, pilot reports, etc.) to compensate for this loss, adding complexity and workload.
5. Airspace configuration	Airspace configuration determines runway/taxiway usage, coordination, trouble areas, and so on. Configurations change depending on conditions, adding to communication, coordination, and SA demands. Efficient aircraft sequencing can be especially challenging.

Complexity Factor	Synopsis
6. Terrain/obstructions	Cranes, buildings, mountains, and other obstructions require controllers to reroute aircraft to alternate runways and taxiways. Often the aircraft must travel in the opposite direction of the standard flow of traffic, increasing coordination and workload.
7. Satellite Airports	Satellite airports increase traffic volume and communication/coordination requirements and require controllers to prioritize the traffic to each airport. Some facilities may have six or more satellite airports.
8. High traffic volume	Traffic volume results in high workload (number of tasks, communication, coordination, etc.) and frequency congestion. It requires sustained SA, pushes the limits of the airport, and raises the potential for error. It is especially challenging when it occurs in conjunction with other factors.
9. Aircraft differing in performance characteristics	Mixing traffic types raises the likelihood of overtakes, requires sustained SA, and increases the number of speed and heading directives required. As the number of heavy jets increases, wake turbulence requirements can slow the operation.
10. Emergency operations	These situations are non-routine and require controllers to adjust their priorities dynamically. They increase communication and coordination requirements. Controllers have limited time to gather and prioritize the information.
11. Wake turbulence	Controllers must meet different separation requirements based on aircraft type. The challenge is sequencing aircraft effectively, particularly those subject to wake turbulence restrictions, to maintain traffic flow.
12. Special flights	These require coordination and add complexity by contributing to the traffic volume and mix. Helicopters, though common at some sites, may not have standard routes, contributing to communications requirements.
13. Overflights (No factor-specific interviews)	Overflights are non-routine and take the controller's focus away from scanning the airport surface, potentially decreasing SA. They add to workload because they require flightstrips for the point-out.
14. Vehicular traffic	Vehicles require communication, coordination, and sustained vigilance. Construction can lead to a large number of vehicles, multiple runway crossings, removal of airport signs, a mix of vehicle types, unfamiliar users, and other complicating factors.
15. At or below minimums	These conditions require the use of much more restrictive procedures and may be more challenging if these conditions rarely occur. Under these conditions, resequencing aircraft is common. Complexity increases due to the loss of visibility.
16. Reduced visibility (weather)	This requires the use of non-routine, much more restrictive procedures. Complexity increases due to the loss of visibility and reliance on alternate information sources.
17. Inclement weather	Workload and complexity increase because of changes in configuration and runway usage. There is increased vectoring, more pilot requests for alternate headings, increased monitoring, and the addition of weather-related activities (e.g., coordination for snow removal vehicles).
18. Airport surface activity	This can close taxiways and runways, requiring rerouting and sustained vigilance. This increases communication and coordination requirements. Some vehicle operators may have limited knowledge of airport procedures.
19. Equipment malfunctions	Malfunctions introduce non-routine situations and require the use of standby equipment and procedures. Though rare, the most significant malfunction is the loss of communications.

Complexity Factor	Synopsis
20. Frequency congestion	This contributes to blocked transmissions, requiring repeats, increasing workload, and occupying additional controller time. Splitting a busy position is beneficial but results in additional coordination.
21. Equipment location	The non-integration of systems increases the controllers' head down time, workload, and scanning time. Though the primary information source is outside, the controller must consult multiple sources within the tower cab.
22. Reduced visibility (equipment) (No factor-specific interviews)	Glare on a display can result in the inability to gather valuable information. The presence of a piece of equipment can restrict or obstruct the controller's ability to scan the airport surface. These may result in a loss of SA.
23. Unfamiliar pilots	They require sustained attention and often require progressive taxi instructions. They may require repeats, adding to frequency congestion and workload. The controller is unaware of what the aircraft will do and must plan for every contingency.
24. Pilot's weak mastery of English language	These pilots require sustained visual attention because of a lack of understanding on both ends of the communication. The number of communications is often increased. The aircraft may not perform as instructed.
25. Controller fatigue	Although fatigue can result from extended heavy workload conditions, it can also be shift work related. Fatigue can result in loss of focus, missed calls, increased thought possessing time, and impaired SA.
26. TMIs	These initiatives increase heads down time, coordination, communications, re-sequencing, and workload. TMIs restrict controller options and may necessitate the use of progressive instructions.
27. Equipment distractions (No factor-specific interviews)	Aural alerts and other equipment distractions interrupt the current task and, if particularly loud, may lead to speech interference.
28. Other distractions	Ambient and equipment noise can result in the loss of focus and SA, thereby requiring repeats and increased workload. If not effectively supervised, visitors may block visibility of equipment, restrict movement through the tower cab, or raise noise levels.
29. On-the-job training	Developmental controllers are unpredictable, may make poor judgments, and can slow the operation. They require close supervision, possibly focusing the instructor's attention inside the tower cab.

3.2 Complexity Factor Ratings

This section summarizes the participants' factor ratings and the results of the analyses. The data are presented as CI scores. To compute the CI, we summed the contribution to complexity and frequency of occurrence ratings for each factor into a single CI score [i.e., Σ (C + F)]. The CI scale ranges from 0 (no influence) to 10 (a very high contribution to complexity that almost always occurs). This section summarizes the overall ratings and presents descriptive and parametric statistics of the site and position ratings.

3.2.1 Overall Ratings

Average CI scores appear in Table 7. The table presents the average local and ground CI scores for each factor, along with the minimum and maximum site averages. The team ordered the factors from highest to lowest average local CI score. Overflights do not impact ground controllers, and so the cells representing this condition are shaded. The entire data set, including averages and standard deviations for the CI, complexity ratings, and frequency ratings appears in Appendix J.

Table 7. Average, Minimum, and Maximum CI Scores for the Local and Ground Positions

Factor	Average		Minimum		Maximum	
	Local	Ground	Local	Ground	Local	Ground
8. High traffic volume	8.3	8.6	7.6	7.2	9.6	9.7
2. Active Runway Crossings	8.2	7.0	6.9	5.0	8.9	9.0
20. Frequency congestion	7.6	8.0	7.2	6.2	8.1	8.8
9. Aircraft differing in performance chars.	7.5	5.4	6.5	4.0	8.2	6.1
1. Runway/Taxiway Restrictions	7.2	7.5	6.3	7.1	8.4	8.5
3. Runway/Taxiway configuration	7.2	7.3	6.6	5.9	8.2	8.0
26. Traffic Management Initiatives	7.2	7.4	5.7	5.9	8.3	8.4
11. Wake turbulence	7.0	4.5	4.3	2.5	8.5	5.5
29. On-the-Job Training	7.0	6.4	5.4	4.7	8.3	7.7
16. Reduced visibility	6.8	6.3	5.3	3.8	7.6	8.0
17. Inclement weather	6.6	6.1	5.7	4.8	7.4	7.3
23. Unfamiliar pilots	6.6	6.8	5.6	6.0	7.6	7.8
15. At or below Minimums	6.5	6.3	5.2	4.3	7.7	7.8
14. Vehicular traffic	6.3	6.5	5.0	4.5	7.6	8.5
24. Pilot's weak mastery of English language	6.3	6.3	5.0	4.8	7.4	7.3
12. Special flights	6.0	3.7	5.0	2.8	7.2	4.4
25. Controller fatigue	5.9	5.8	5.0	4.2	7.1	6.9
19. Equipment malfunctions	5.8	5.1	5.4	4.5	6.3	5.5
10. Emergency operations	5.7	5.9	5.3	5.4	6.2	6.5
28. Other distractions	5.5	5.4	4.3	4.4	6.9	7.1
5. Airspace Configuration	5.3	4.0	3.5	2.8	7.1	5.3
22. Reduced visibility	5.3	4.9	3.5	3.7	6.1	6.2
18. Airport surface activity	5.0	5.4	3.8	4.4	5.8	7.2
4. Non Visibility Areas	4.9	5.5	3.3	3.1	6.6	7.3
27. Equipment distractions	4.9	4.2	4.4	3.4	5.3	5.0
7. Satellite Airports	4.6	2.5	2.9	1.2	6.7	4.2
21. Equipment location	4.6	4.2	3.4	3.2	6.0	5.2
13. Overflights	4.1	▨	2.2	▨	6.9	▨
6. Terrain/Obstructions	3.9	2.5	2.2	1.7	5.5	3.5

High traffic volume was the highest rated factor for both the local and ground position. The highest site averages were very near the upper end of the 10-point CI scale, returning values of 9.6 and 9.7 for the local and ground position, respectively. Its importance is predictable because it was one of the site selection criteria. Yet, even with the inclusion of Level 10 and Level 6 facilities, average site ratings never dropped below 7.2. Active runway crossings appear next in the table, reflecting that, on average, they are the second most influential factor for a local controller. These crossings received somewhat lower ratings from the ground control perspective (7.0) and were clearly less of an issue for them than frequency congestion, which received an average CI of 8.0.

In preparation for performing detailed position- and site-specific analyses, the research team conducted preliminary statistical tests. These preliminary tests consisted of analyses to confirm the presence of differences between factor ratings and the presence of reasonable consistency in the ratings between participants from the same site. The Friedman ANOVA by Ranks test confirmed significant factor rating differences ($\chi 2 = 1126.7, p < .001$). The controllers' ratings exhibited a good deal of agreement in their ratings. The Kendall concordance statistic, which assesses inter-rater reliability, ranges from 0 to +1. Zero represents complete lack of agreement in the factor rankings between raters, and 1 represents perfect agreement. The condition representing the least agreement, OAK ground control, still represented statistical significance (Kendall's concordance coefficient of $W = .43, p < .001$). The concordance reached a maximum value of $W = .64, p < .001$ for the BOS ground condition. The results for all sites and positions appear in Table K2, Appendix K.

3.2.2 Ratings by Position and by Site

To determine whether controllers rated each factor differently by site or position, the team conducted ANOVAs on each factor. Table 8 summarizes the results of the ANOVAs returning significant main effects or interactions. Using the method described earlier, we maintained an alpha of .05 for all tests. Eleven complexity factors demonstrated significant site main effects, indicating that the impact of these factors was different across sites. Nine factors demonstrated significant position main effects. This confirmed the presence of differences in ratings between local and ground controllers. Six factors demonstrated significant position by site interactions. A significant interaction indicated that the relationship between the local and ground ratings was different between sites requiring further examination. Appendix L contains results for the factors returning significant main effects and interactions. The following sections of the report address the nature of these differences, where appropriate.

Table 8. Significant ANOVAs

Complexity Factor	**Site**			**Position**			**Position by Site** *		
	df	***F***	***p***	**df**	***F***	***p***	**df**	***F***	***p***
2. Active runway crossings	(5, 56)	7.78	.001	(1, 56)	17.94	.001	(5, 56)	4.34	.002
5. Airspace configuration	(5, 56)	6.33	.001	—	—	—	—	—	—
6. Terrain/obstructions	—	—	—	(1, 56)	20.76	.001	—	—	—
7. Satellite airports	(5, 56)	4.73	.001	(1, 56)	68.55	.001	(5, 56)	4.66	.001
8. High traffic volume	(5, 56)	12.41	.001	—	—	—	(5, 56)	5.62	.001
9. Aircraft differing in performance characteristics	—	—	—	(1, 56)	83.01	.001	—	—	—
11. Wake turbulence	(5, 56)	5.70	.001	(1, 56)	66.31	.001	—	—	—
12. Special flights	—	—	—	(1, 56)	102.02	.001	(5, 56)	4.38	.002
14. Vehicular traffic	—	—	—	—	—	—	(5, 56)	6.53	.001
15. At or below minimums	(5, 56)	6.89	.001	—	—	—	—	—	—
16. Reduced visibility (weather)	(5, 56)	7.31	.001	—	—	—	—	—	—
17. Inclement weather	(5, 56)	6.42	.001	—	—	—	—	—	—
19. Equipment malfunctions	—	—	—	(1, 56)	20.27	.001	—	—	—
20. Frequency congestion	(5, 56)	4.53	.002	—	—	—	(5, 56)	5.71	.001
27. Equipment distractions	—	—	—	(1, 56)	16.21	.001	—	—	—
28. Other distractions	(5, 56)	5.58	.001	—	—	—	—	—	—
29. OJT	(5, 56)	5.47	.001	(1, 56)	10.87	.002	—	—	—

Analyses of the ratings for high traffic volume resulted in an interaction between position and site. Local and ground ratings were not statistically different at any site except BOS, where ground ratings were significantly above local control ratings (Table L3, Appendix L). Preliminary review of controllers' comments at BOS suggested that aircraft pushing back into active taxiways contributed to the complexity of the ground controller's tasks and potentially accounted for these data.

Frequency congestion (Factor 20), which is inherently tied to traffic volume, also received high CI ratings. It represented the highest rated factor at BOS and third highest at another three sites (ATL, ORD, and PHX). Analyses of frequency congestion ratings resulted in a significant site-by-position interaction, indicating that the relationship of ground ratings to local ratings varied by site. Ground ratings were higher than local ratings at four sites, two of which represented statistically significant differences. However, at BJC and OAK, ground ratings were slightly lower than local ratings.

Active runway crossings (Factor 2) also resulted in a significant interaction between position and site. Three sites (OAK, ATL, and PHX) rated it among their three most influential complexity factors. Local ratings for this factor were high at BOS, but ground ratings were much lower.

On special flights, local controller ratings were higher than ground ratings at all sites, indicating this factor has less influence on ground control. These differences were statistically significant at ORD, OAK, and BOS. Comparison of the local ratings across sites and ground ratings across sites did not reveal differences between sites. Together, these data suggest that special flights contribute to complexity, particularly for the local controller. The number of special flights and coordination requirements, whether helicopter corridors are in place, and other related factors define the degree of complexity associated with this factor.

Satellite airports and vehicular traffic both exhibited a significant interaction. At most sites, local controller ratings for satellite airports were 1 to 2 points above ground ratings. At BOS, OAK, and ORD, these differences were statistically significant (Table L3, Appendix L); however, at PHX, local and ground ratings were almost identical. During the interviews, participants at OAK noted that traffic to and from San Francisco International Airport substantially influenced their operation. PHX reflected minimal influence from satellite airports.

Ground ratings for vehicular traffic tended to be at or just below local ratings across all sites. However, at ATL and OAK, ground ratings exceeded local ratings. In ATL, the difference in ratings reached statistical significance. Potential sources for these findings were the high number of construction vehicles at OAK and the volume of tugs crossing an active runway at ATL. The following sections discuss the differences among facilities by controller position.

3.2.2.1 Local

Figure 1 presents the average local controller ratings for each factor, ordered from highest to lowest CI score. The shaded bar represents the average rating for each factor. The six symbols depict the site averages.

High traffic volume, active runway crossings, frequency congestion, and aircraft differing in performance characteristics represented the top four factors facing local controllers based on average CI scores. Runway/taxiway configuration, TMIs, and runway/taxiway restrictions all tied as the next most influential factors.

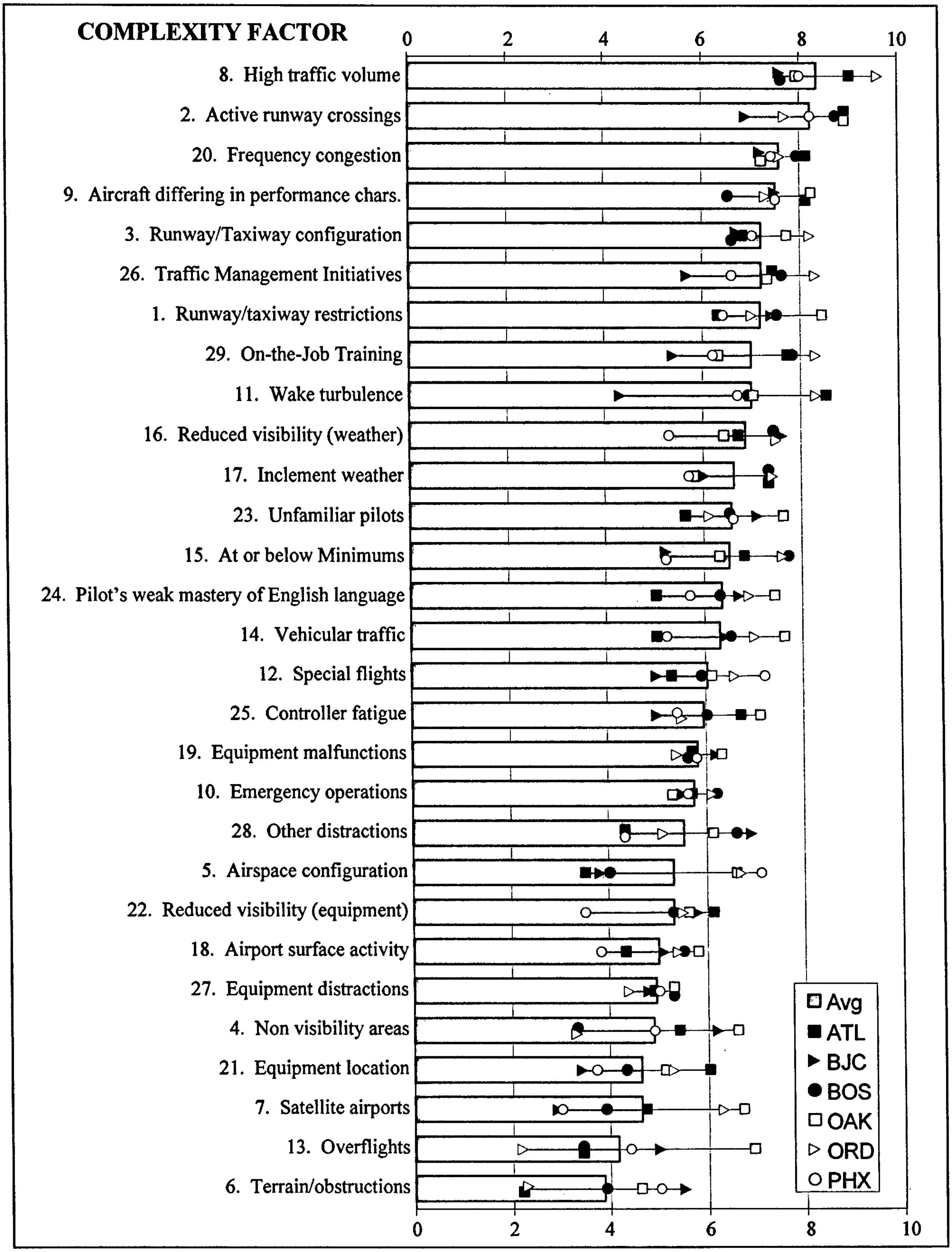


Figure 1. Average CI ratings for the local control position.

High traffic volume, one of the traffic characteristics noted by Rodgers et al. (1998) as holding significant implications for controller workload, received high complexity and incidence ratings across all sites. Participants' ratings were highest at those sites with the heaviest traffic volumes and essentially followed the facility level rankings. ORD and ATL, both Level 12 facilities, represented the upper end of the distribution, with averages of at least 9.0. The remaining facilities fell roughly in order with BJC, a Level 6 facility, anchoring the low end of the ratings with an average CI of 7.6. BJC ranked 120 in terms of overall operations, and ATL and ORD ranked 1 and 2. Still, the range in CI scores between the sites was relatively small (2.0), implying that traffic volume is an important consideration for local controllers at all sites.

Active runway crossings ranked as the second most influential complexity factor for the local controller. These operations inherently increase workload due to their associated coordination requirements. The ratings ranged from a low of 6.9 at BJC to 8.9 at OAK and ATL, resulting in the finding of statistical differences between sites. Local controllers are responsible for coordinating all active runway crossings, and these are especially prevalent at some sites. Participants at ATL and OAK noted that active runway crossings were a big factor. Incidence ratings were very similar, ranging less than 1 across all sites and suggesting that these operations are a common source of complexity for the local controllers' task. The degree of complexity appeared to be influenced by operational aspects. Participants at OAK, ATL, and BOS towers rated active runway crossings as more complex than other sites. They attributed much of the reason for the high ratings to the physical layout of the runways and taxiways. At some sites, much of the arrival and departure traffic has to cross an active runway.

Frequency congestion ranked as the third most influential source of complexity for this control position. Ratings were very similar across sites, demonstrating a range of less than 1 point across all facilities. This factor returned significant results for the site main effect and site-by-position interaction. This suggests that the complexity and incidence associated with frequency congestion and the amount of influence on the local controller is different between sites. The high ratings for this factor combined with their minimal range suggest that frequency congestion is a pervasive challenge facing tower controllers. In fact, the ratings for ground control suggest that it may be even more of a challenge for that position. Although high traffic volume is among the chief causes of frequency congestion, many other factors, such as the need for progressive instructions and pilot position reports, may contribute to its occurrence and compound its effect.

The fourth leading complexity source for the local control position was aircraft differing in performance characteristics. It was much more significant to this control position than the ground position, averaging 7.5 and 5.4, respectively. This factor ranked 4th for local versus 17th for ground control. The ratings exhibited a significant position main effect, suggesting that its influence varies greatly between positions. This is not surprising because aircraft in the air must be constantly monitored for overtake situations, wake turbulence implications, and other conditions. CI scores across sites varied moderately, ranging from 6.5 to 8.2.

Controllers rated runway/taxiway configuration, TMIs, and runway/taxiway restrictions as equally important to the local position. They tied for the fifth position in terms of influence, with an average CI score near 7. Each represented a relatively small range averaging approximately 2 points across facilities, characterized by minimal differences in ratings between positions. As a result, none of the factors returned a significant main effect or interaction. Of the factors, TMIs exhibited the widest range. BJC's average CI ratings for TMIs (mean CI = 5.7, *SD* = 2.2) anchored the low end of the scale. ORD rated the impact of these initiatives much higher (mean

CI = 8.3, *SD* = 1.4). The participants' comments during the interviews suggested that ORD's geographic location made it subject to restrictions from both coasts. Still, these preliminary data suggest that, overall, these factors tend to be relatively equal in terms of their importance to local and ground controllers and across sites.

Two complexity factors, wake turbulence and overflights, demonstrated large site differences, resulting in statistically significant findings. Wake turbulence ratings demonstrated significant site and position effects. The ratings appeared to be directly related to the number of heavy jets at a site. ATL and ORD towers represented the highest ratings, with CI averages above 8. OAK, BOS, and PHX towers averaged around 7, nearly 2 points above the mid-point, with BJC returning the lowest average rating of 4. The average CI ratings for wake turbulence ranged 4.2 points across sites. BJC (mean CI = 4.3, *SD* = 1.3) was statistically different from ORD (mean CI = 8.5, *SD* = 2.0). Overflights, which applied to the local position only, exhibited a range of nearly 5 points between facilities, with OAK averaging near 7 and ORD just above 2. The participants at OAK identified the restraints imposed by overflights from San Francisco International Airport as contributing to the complexity experienced by local controllers at their facility.

In Figure 2, we present the top five local control factors for each site, as determined by average CI scores. High traffic volume and active runway received the highest average ratings, accounting for the top position at three sites each. High traffic volume was the most common factor in the top five local control factors, with six occurrences. Active runway crossings, frequency congestion, and aircraft differing in performance characteristics tied for the next most common factors, with four occurrences each. Of these, only active runway crossings ranked first or second.

ATL	
8. High traffic volume	9.0
2. Active runway crossings	8.9
11. Wake turbulence	8.5
20. Frequency congestion	8.1
9. Aircraft differing in performance characteristics	8.1

BJC	
8. High traffic volume	7.6
16. Reduced vis. (weather)	7.6
9. Aircraft differing in performance characteristics	7.5
1. R/T restrictions	7.4
20. Frequency congestion	7.2

BOS	
2. Active runway crossings	8.7
20. Frequency congestion	7.9
29. On-the-job training	7.8
15. At or below minimums	7.7
8. High traffic volume	7.6

OAK	
2. Active runway crossings	8.9
1. R/T restrictions	8.4
9. Aircraft differing in performance characteristics	8.2
8. High traffic volume	7.9
3. R/T configuration	7.7

ORD	
8. High traffic volume	9.6
26. Traffic management	8.3
29. On-the-job training	8.3
11. Wake turbulence	8.3
3. R/T configuration	8.2

PHX	
2. Active runway crossings	8.2
8. High traffic volume	8.0
9. Aircraft differing in performance characteristics	7.5
20. Frequency congestion	7.4
12. Special flights	7.2

Figure 2. Five highest rated local control complexity factors by site.

3.2.2.2 Ground

Figure 3 depicts the average ground controller CI score for each of the complexity factors. The format of the figure is the same as that presented for the local controller. Overflights do not apply to the ground control position and, therefore, are identified as N/A. The factors receiving

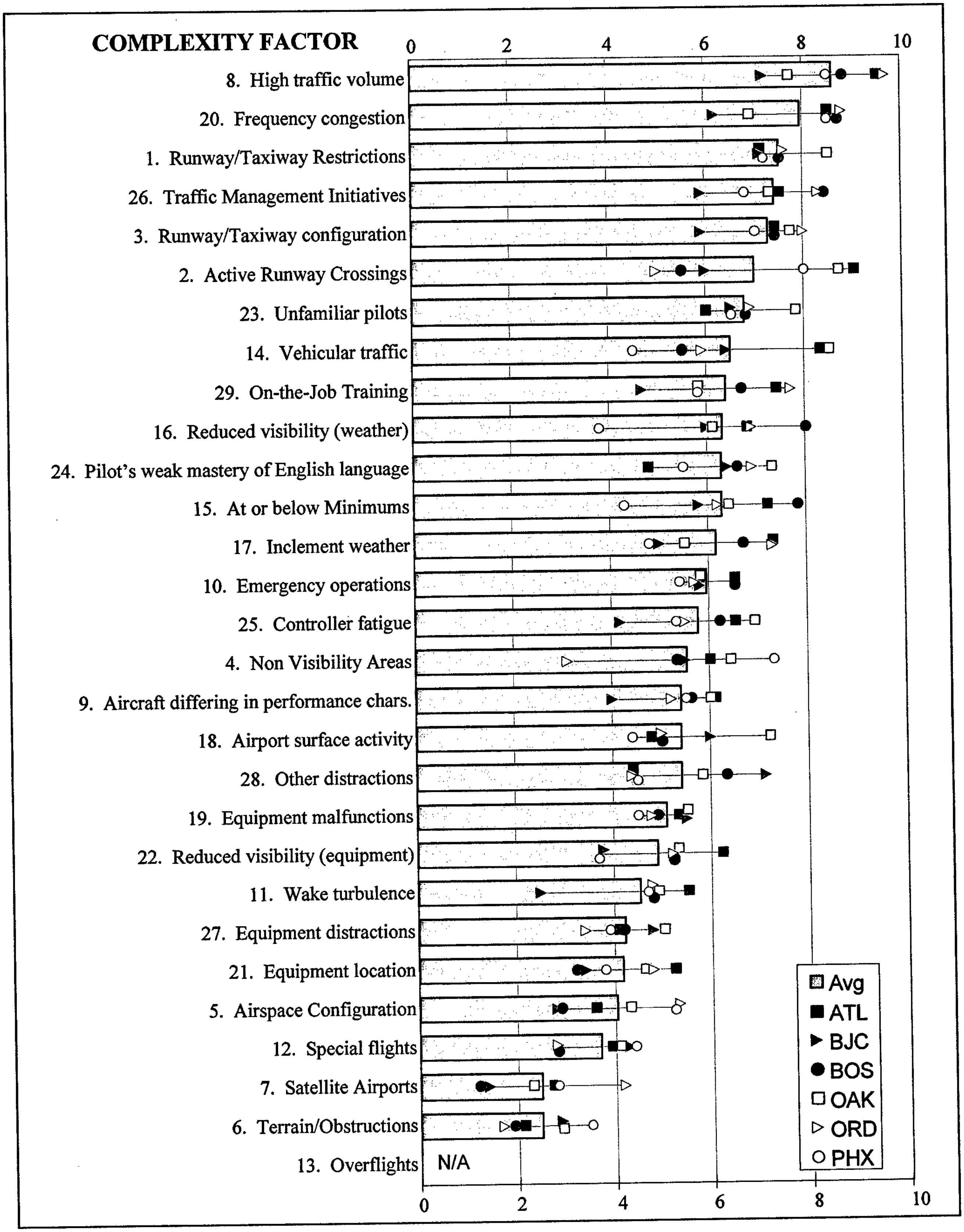


Figure 3. Average CI ratings for the ground control position.

the highest scores from a ground control perspective across all sites were (in decreasing order) high traffic volume, frequency congestion, runway/taxiway restrictions, TMIs, and runway/ taxiway configuration.

As with the local control position, high traffic volume received the highest average rating across all complexity factors. Controllers at ORD and ATL indicated that high traffic volume was the most influential of all factors from a ground controller's perspective. This is understandable because it represented one of the site selection criteria, and these sites rank as 1 and 2 in overall annual operations. CI scores at BJC (mean CI = 7.2, *SD* = 0.4) for high traffic volume were significantly lower than those provided by ground controllers at BOS (mean CI = 8.8, *SD* = 1.0), ATL (mean CI = 9.5, *SD* = 0.5), and ORD (mean CI = 9.7, *SD* = 0.8). Even so, BJC tower, which ranks 120 in terms of traffic volume in 2000, still posted a relatively high score, falling above the mid-point on the scale. The physical volume of traffic controlled at BOS, ORD, and ATL is inordinately higher than at BJC, and controller ratings reflected this difference. However, the range between average scores from these sites as well as the relatively high score from BJC (7.2) suggests that even at smaller facilities, traffic volume remains an important complexity factor for ground controllers.

Frequency congestion represented the second highest source of complexity for ground controllers. Clearly, this factor is directly related to traffic volume, and, based on the sampling procedure used, we expected it to be high. As in the case of high traffic volume, ORD and ATL again were at the top of the range of scores, joined by BOS and PHX. ORD and BOS represented the highest average complexity ratings and were statistically higher than ratings at OAK. BJC anchored the lower end, although its average CI again remained above the mid-point of the scale. Average CI scores for frequency congestion at BJC (CI = 6.2, *SD* = 1.1) were significantly lower than those at PHX (CI = 8.5, *SD* = 1.2), ATL (CI = 8.5, *SD* = 1.3), BOS (CI = 8.7, *SD* = 1.3), and ORD (CI = 8.8, *SD* = 1.1). At four sites, ground control ratings were above the local control ratings, reaching statistical significance at ORD and BOS. During the interviews, participants at all sites noted that frequency congestion was a challenge, especially for the ground controller.

Participants tended to rate runway/taxiway restrictions as the third highest rated factor for this position, similarly across sites, as illustrated by the minimal range (Figure 3). The research team expected BOS and ORD to reflect high complexity ratings because their physical runway configuration included converging runways. However, though not statistically significant, ratings for OAK were noticeably higher than all other sites. Review of the data demonstrated that the average complexity ratings at OAK and ORD were equivalent at 4.3, but that the incidence at OAK was much higher (averaging 4.2 versus 3.3 at ORD).

The distribution of ratings for TMIs and runway/taxiway configuration, which ranked fourth and fifth respectively, was very similar. Both factors averaged near 7 and exhibited a range of approximately 2; the sites fell in a similar order. As suggested by this characterization, neither factor demonstrated statistically significant main effects or interactions. BJC, a Level 6 facility, anchored the low end of the distribution for both factors, averaging just under 6.0. ORD and BOS represented the highest TMI ratings, with averages above 8.5. These results were similar to those for runway/taxiway configuration. With the exception of BJC, which fell a point or so lower than PHX (the next closest site), all sites tended to rate runway/taxiway configuration similarly. The data suggest that both factors represent relatively important sources of complexity to the ground controller and that these effects are common across facilities.

Four factors exhibited extremely large site differences and returned statistically significant differences among sites. These included non-visibility areas (range = 4.2), reduced visibility due to weather (range = 4.2), active runway crossings (range = 4.0), and vehicular traffic (range = 4.0). The latter two exhibited significant differences among ground ratings across sites. The participants at ORD rated non-visibility areas as a minimal factor at their site, as indicated by the 3.1 CI score average. Four of the other five sites averaged CI scores near 6, whereas, PHX fell above 7. The participants at PHX indicated that the terminal obstructed their view of some of the taxiways. They also identified the terminal as the source of non-visibility areas at BOS. Another common source was hangars limiting their view of the ramp area at BJC and OAK.

Reduced visibility due to weather, which ranked 10th, also exhibited a large range. PHX and BOS tended to represent the extremes of the distribution, with the rest of the sites falling near the center. Not surprisingly, participants at BOS rated the influence of this factor as high, averaging a CI score of 8, whereas PHX averaged just above 4. Controllers at PHX indicated that weather was rarely an issue; however, at BOS, participants noted that fog was a particular concern.

Active runway crossings represented one of the six factors returning an interaction between site and position. The simple effects analysis indicated that ground ratings for active runway crossings were different across sites. ATL returned the highest average rating and was statistically different from BJC, ORD, and BOS. Participants at ATL indicated that tugs crossing the active runway accounted for much of this activity.

Vehicular traffic was the remaining factor that showed a sizeable range between site averages. It ranked just above reduced visibility due to weather in terms of its ratings overall. However, for OAK and ATL, it represented a much more significant factor. These sites averaged above 8, whereas BJC, ORD, and BOS tended to be clustered around 6. PHX returned the lowest average (just above 4), reflecting that vehicular traffic was less of an influence for this facility. Ground ratings varied substantially between sites, with ATL and OAK returning significantly higher averages than ORD, BOS, and PHX. Controllers at OAK indicated during subsequent interviews that there was a great deal of construction and maintenance activity at their site. At ATL, tugs crossing the active runway represented much of this activity.

Figure 4 summarizes the top five ground control factors based on average CI scores across sites. As the figure illustrates, controllers rated high traffic volume as the highest factor at all but one of the sites. At OAK, the volume of runway crossings due to construction represented the highest rated factor. This factor was most likely closely associated with the high ratings provided for runway/taxiway restrictions, vehicular traffic, and unfamiliar pilots as well.

ATL		
8.	High traffic volume	9.5
2.	Active runway crossings	9.0
20.	Frequency congestion	8.5
14.	Vehicular traffic	8.3
26.	Traffic management	7.5

BJC		
8.	High traffic volume	7.2
1.	R/T restrictions	7.1
28.	Other distractions	7.1
23.	Unfamiliar pilots	6.5
14.	Vehicular traffic	6.4

BOS		
8.	High traffic volume	8.8
20.	Frequency congestion	8.7
26.	Traffic management	8.4
16.	Reduced vis. (weather)	8.0
15.	At or below minimums	7.8

OAK		
2.	Active runway crossings	8.7
1.	R/T restrictions	8.5
14.	Vehicular traffic	8.5
23.	Unfamiliar pilots	7.8
8.	High traffic volume	7.7

ORD		
8.	High traffic volume	9.7
20.	Frequency congestion	8.8
26.	Traffic management	8.3
3.	R/T configuration	8.0
29.	On-the-job training	7.7

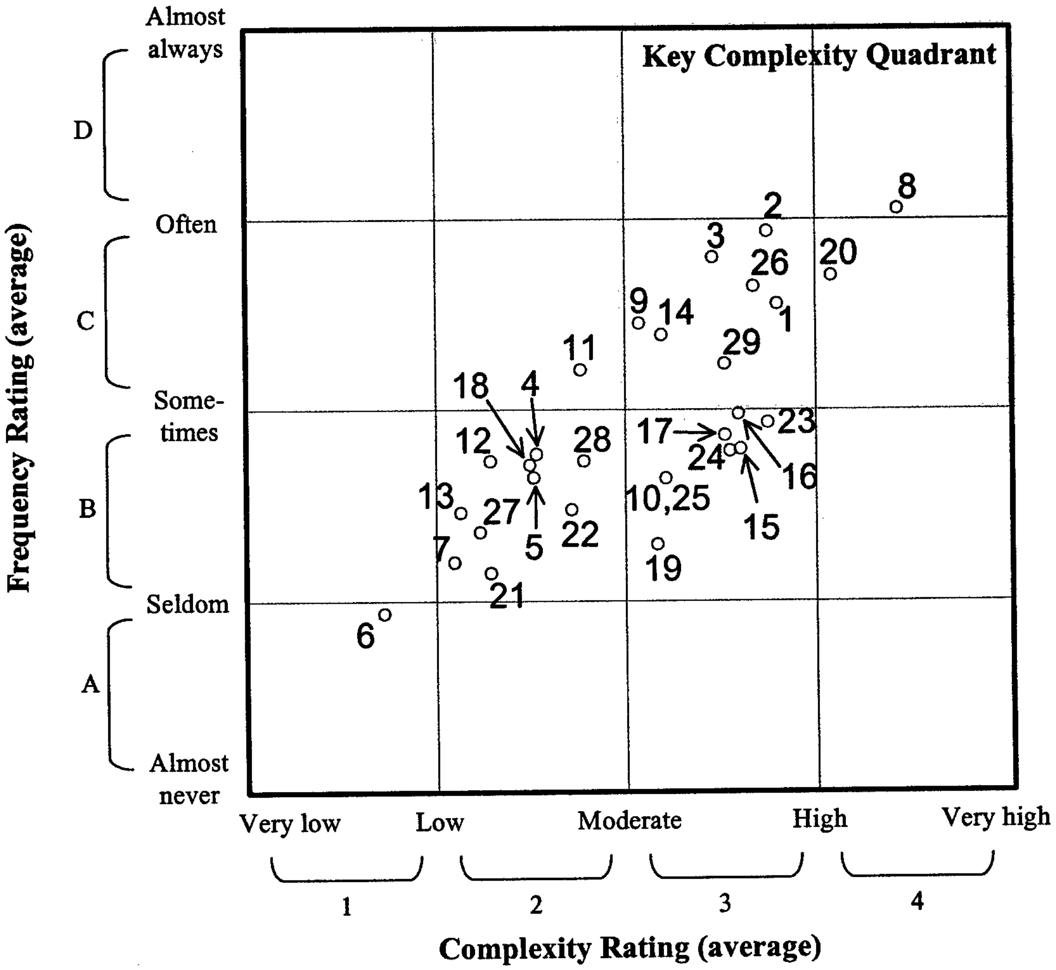
PHX		
8.	High traffic volume	8.5
20.	Frequency congestion	8.5
2.	Active runway crossings	8.0
4.	Non-visibility areas	7.3
1.	R/T restrictions	7.2

Figure 4. Five highest rated ground control complexity factors by site.

3.3 Key Complexity Factors

Figure 5 depicts the average complexity and average frequency on the x- and y-axis, respectively. The graph fulfilled two primary objectives. First, it visually presents the interrelationship of the components of complexity and frequency for each of the complexity factors that the CI alone did not convey. Secondly, it enabled the team to identify those factors that should be considered as leading candidates for preliminary research efforts. The numbered points represent the overall mean for each factor across all participants and both control positions. They are labeled by factor number and identified in the key in Figure 5. Both axes range from 1 to 5 and show the anchors for each of the variables. The team divided the matrix into a grid to explore the overall significance of each of the items. The upper-right quadrant corresponds to highly complex factors that frequently occur within the tower ATC environment. We considered this area, which we termed the key complexity quadrant, to contain the most important complexity related sources. These items are highlighted within the table along with their corresponding matrix score.

Matrix scores range from 1A to 4D. The digit represents a continuum of the average complexity and ranges from very low (1) to very high (4). The letter designates the relative incidence of the factor, ranging from a rare event (A) to one that occurs very frequently (D). For example, high traffic volume (Factor 8) corresponds to a matrix score of 4D. The 4 indicates that this factor is among the most complex factors. The D designates it as among the most frequently occurring complexity factors. High traffic volume and frequency congestion both fall within the highest complexity zone designation (4), suggesting that these should be considered as among the primary candidates for future complexity mitigation efforts. Terrain and obstructions (Factor 6) anchor the opposite end of the spectrum. The matrix score of 1A for this item is indicative of a factor that rarely impacts day-to-day tower operations and contributes minimally to ATC complexity.



KEY

No.	Complexity Factor	Matrix Score
1	Runway/Taxiway restrictions	3C
2	Active runway crossings	3C
3	Runway/Taxiway configuration	3C
4	Non Visibility Areas	2B
5	Airspace Configuration	2B
6	Terrain/Obstructions	1A
7	Satellite Airports	2B
8	High traffic volume	4D
9	Aircraft differing in performance chars	3C
10	Emergency Operations	3B
11	Wake turbulence	2C
12	Special Flights	2B
13	Overflights	2B
14	Vehicular Traffic	3C
15	At or below Minimums	3B
16	Reduced visibility (weather)	3B
17	Inclement weather	3B
18	Airport surface activity	2B
19	Equipment malfunctions	3B
20	Frequency congestion	4C
21	Equipment location	2B
22	Reduced visibility (equipment)	2B
23	Unfamiliar pilots	3B
24	Pilot's weak mastery of English	3B
25	Controller fatigue	3B
26	Traffic Management Initiatives	3C
27	Equipment distractions	2B
28	Other distractions	2B
29	On-the-job training	3C

Figure 5. Key complexity factors of average complexity by average frequency.

Seven other factors fell within the key complexity quadrant and warrant consideration for future investigation. These include active runway crossings, runway/taxiway configuration, runway/taxiway restrictions, TMIs, aircraft differing in performance characteristics, vehicular traffic, and OJT. Each contributes a relatively high degree of complexity to the controller's task and occurs on a frequent basis.

The figure graphically illustrates that there are several other factors that may be of interest due to their inherent complexity. For example, the cluster of items within coordinate 3B is equally as complex as many of the factors in the key complexity quadrant, but they occur less frequently. These areas of interest include emergency operations, operating at or below minimums, reduced visibility due to weather conditions, inclement weather, equipment malfunctions, unfamiliar pilots, pilot's weak mastery of English, and controller fatigue. Though these factors are likely to be somewhat lower in terms of overall priority, it is important to note that the figure presents average ratings and that the significance of any of the factors may be much higher either in terms of complexity or frequency depending on the specific tower.

3.4 Exploratory Factor Analysis

The Kaiser-Meyer-Olkin statistic (KMO = .72) and Bartlett's test of sphericity (Bartlett's Test = 1408, $p < .001$) supported the application of factor analysis to the data. The KMO is indicative of the degree of common variance among the factors. Although a KMO of .9 is ideal, the value for the current data set was high enough to ensure that the factors extracted would account for a reasonable amount of the variance. The significant Bartlett's test result indicated that we could reject the null hypothesis and conclude that the factors were correlated. Combined, these results suggested that the data contained groups of correlated factors.

The factor analysis resulted in the identification of eight distinct groupings that accounted for 23 of the complexity factors (Table 9). The table presents the groups, their associated complexity factors, the percentage of variance accounted for, and the category title, which are the proposed category titles for each of the groups. The groupings accounted for 67% of the variance, with the first group accounting for just over 20%. Eight components returned Eigenvalues greater than 1, a common threshold for component selection; therefore, they are represented in the table. Five factors did return factor loadings greater than 0.5 with at least a 0.2 difference across components and, therefore, are not represented in the table. The factors omitted from the table are runway/taxiway restrictions, runway/taxiway configuration, emergency operations, controller fatigue, and high traffic volume. Of these, high traffic volume returned a loading greater than 0.5 for Group 6 (Workload), suggesting that it belonged to that grouping. However, it also returned a negative loading of –0.5 for Group 2 (Distractions/terrain). This does not represent a dispersion of greater than 0.2; therefore, it is not included in the table. Appendix M presents the complete results of the analyses, including the loadings for all 28 factors.

Table 9. Factor Analysis Groupings

Group	Complexity Factor	Variance Accounted for	Category
1	15. At or below minimums 16. Reduced visibility (weather) 17. Inclement weather	21%	Weather
2	27. Equipment distractions 28. Other distractions 6. Terrain/obstructions	11%	Distractions/terrain
3	12. Special flights 11. Wake turbulence 7. Satellite airports 5. Airspace configuration 9. Aircraft differing in performance chars.	8%	Sequencing/spacing
4	23. Unfamiliar pilots 24. Pilot's weak mastery of English language	7%	Progressive instructions
5	21. Equipment location 22. Reduced visibility (equipment) 19. Equipment malfunctions	6%	Equipment
6	26. Traffic management initiatives 29. On-the-job training 20. Frequency congestion	5%	Workload
7	2. Active runway crossings 4. Non visibility areas	5%	Persistent visual attention
8	14. Vehicular traffic 18. Airport surface activity	4%	Ground traffic

4. Discussion

This report identified and described 29 tower complexity factors, reported ATCT controllers' ratings of the relative importance of each of these factors, and presented the calculation of a CI. Part 2 will address the influence of these factors on controller strategies, information needs, and sources of information. These findings pave the way for future research efforts and define preliminary issues for the design of tower automation equipment.

The relative contribution of each of the factors varied by site and position and provided important insights into the nature of complexity in the ATCT. Seventeen of the 29 complexity factors returned significant findings on at least one of the analyses (site, position, or site by position). The comments provided by the controllers helped to elucidate the basis of the complexity factors and corroborate their ratings. These findings, combined with the results of the exploratory factor analysis, suggest that complexity in the ATCT environment is comprised of multiple inter-related and site-specific factors. As Rodgers et al. (1998) noted, workload may be increased "through the presence and interaction of several complexity factors that create competition for similar cognitive resources" (p. 2).

The research team selected the facilities for this study using one of three factors commonly identified as complexity factors: high traffic volume, crossing runways, or aircraft mix. The participants consistently rated high traffic volume as among the leading complexity factors. We anticipated these high ratings because the majority of facilities represented the busiest ATCT facilities. However, the controllers rated the factors associated with crossing runways and aircraft mix as somewhat less complex than we had anticipated. On closer examination, we found that this was most likely due to site-specific operations mitigating the complexity resulting from these two factors. For example, we selected OAK because of the mix of commercial and general aviation traffic. The operations appeared to moderate the potential complexity arising from traffic mix by assigning commercial jet aircraft to one runway and general aviation traffic to another runway. Likewise, BOS and ORD typically run operational configurations that minimize the number of runway crossings and the traffic problems associated with them.

Although the current study included only 6 of the 200+ FAA-operated ATCTs, the facilities we visited demonstrated considerable site differences. Eleven of the 29 factors returned statistically significant site differences, and 9 returned significant position differences. Six factors (active runway crossings, satellite airports, high traffic volume, special flights, vehicular traffic, and frequency congestion) demonstrated significant site-by-position interactions.

The most common factors contributing to complexity at the towers we visited were high traffic volume and frequency congestion. Five sites indicated these to be among their primary sources of complexity. The fact that high traffic volume represented the highest rated complexity factor at BJC, a Level 6 facility, underscores the impact of this factor on the controller's task. In the interviews, controllers reported that during traffic peaks, they feel increased pressure to avoid slowing the operation. In addition to the inherent workload associated with high traffic volume, these situations can compromise the controller's ability to scan effectively and to selectively attend to information sources (Wickens et al., 1997). Increases in traffic volume also contribute to frequency congestion, leading to blocked transmissions, limited time for read backs, and other efficiency-reducing conditions.

Active runway crossings represented another major source of complexity, especially for controllers at OAK, ATL, and PHX. The airport layout at ATL and ongoing construction at OAK and PHX were among the primary factors contributing to the number of runway crossings. Controllers at all sites reported that active runway crossings require sustained attention and add workload through increases in communication and coordination.

Complexity due to runway/taxiway restrictions received high ratings across all sites, but it ranked as the second highest factor at OAK and BJC. Controllers at these sites indicated that weight and other restrictions, when combined with the large numbers of construction vehicles, represented a primary source of complexity. A unique source of complexity at OAK is a single taxiway joining the north and south complexes. Controllers across all facilities reported that restrictions on runways and taxiways impede traffic flow, limit their options, and increase planning, communication, and coordination.

TMIs were another common complexity source. ORD and BOS, in particular, noted these to be among their primary contributors to complexity, although they shared their influence across all sites. These initiatives increase heads down time, coordination, communications, re-sequencing, and workload.

Although the complexity factors at each facility coalesced into a unique combination, common complexity factors emerged. Local and ground controller ratings differed significantly on nine of the factors. We discuss the factors in terms of their relative importance to the local and ground control positions in the following sections.

4.1 Common Complexity Factors

The controllers' ratings demonstrated site differences in terms of the relative contribution of each of the 29 complexity factors. The relative importance of each was unique to the facility and to the controller positions within that facility. However, several factors proved to be influential across all sites we studied. Table 10 presents the five highest-ranked complexity factors for the local and ground controller positions. Three of the factors (high traffic volume, frequency congestion, and runway/taxiway configuration) are common to both positions, and we bolded them in the table to emphasize their importance. In fact, of the other factors listed in the table, only aircraft differing in performance characteristics did not rank within the top 10 factors for both positions. Key factors for both control positions, high traffic volume and frequency congestion represent a greater influence on the ground position than local, as indicated by results of the repeated measures ANOVA on position.

Table 10. Highest Rated Complexity Factors by Position

	Local Control	Ground Control
1	**8. High traffic volume**	**8. High traffic volume**
2	2. Active runway crossings	**20. Frequency congestion**
3	**20. Frequency congestion**	1. Runway/taxiway restrictions
4	9. Aircraft differing in performance chars.	26. Traffic management initiatives
5	**3. Runway/taxiway configuration**	**3. Runway/taxiway configuration**

In the following sections, we list the highest rated complexity factors common to both control positions. Next, we present the factors unique to the local and then ground control list.

4.1.1 High Traffic Volume

High traffic volume interacts with other complexity factors (e.g., airport layout) and transient factors (e.g., current operational configuration, weather, TMIs, OJT, unfamiliar pilots, and construction) to produce a prevailing complexity level. Although traffic volume alone does not account for complexity, ratings for both the local and ground control positions indicated that it represented the most significant factor for ATC complexity.

High traffic volume represented the single most significant factor to both the local and ground positions. There were differences in average ratings between sites. Not surprisingly, the Level 12 facilities (ORD and ATL) returned statistically higher ratings than the Level 6 (BJC) and Level 10 facilities (OAK and PHX). In fact, ORD averaged 5.0 on the 5-point contribution to complexity scale for the local position, indicating that it almost always represented a contribution to complexity. With the exception of BOS, local and ground complexity ratings were very similar within each site. At BOS, ground ratings were considerably higher than local ratings. As previously noted, the increased complexity for the ground position may be explained, at least in part, by aircraft pushing back into active taxiways. Ground controllers must reroute traffic around blocked taxiways, and this becomes increasingly complex and workload intensive as traffic levels increase.

Traffic volume is well documented as a complexity factor for ATCSs (D'Arcy & Della Rocco, 2001; Grossberg, 1989; Kuhar et al., 1976). Operational data collected by the National Aviation Safety Data Analysis Center (NASDAC) emphasize the prevalence and importance of this complexity factor. In a 1999 review of FAA tower operational deviations contained in the NASDAC database, 27% of the 256 reports on operational errors and deviations listed the large number of aircraft as a contributing factor (Cardosi & Yost, 2001).

When traffic volume increases, controllers feel an increased pressure to move aircraft to avoid backing up the operation. Although many factors occur in combination at any given site, as one participant noted, it is frequently high traffic volume that "will put you down." This is not surprising because high traffic volume leads to heavy workload, which has been shown to compromise effective scanning and selective attention (Wickens et al., 1997). These effects, combined with the possible breakdown of prospective memory due to high levels of workload, serve to degrade SA and, ultimately, performance. Wickens et al. report that during high workload periods, controllers forget to check on the status of certain aircraft. They note that this process was partially responsible for the collision between two aircraft at Los Angeles International Airport in 1991 and a separate incident at St. Louis Lambert Field in 1994.

4.1.2 Frequency Congestion

Frequency congestion is a concern to the entire AT system. However, as Cardosi and Yost (2001) report, it is far more of an issue to the terminal environment than to the en route environment. The results from the current study showed that frequency congestion represented the second and third highest ranked factor, respectively, for the local and ground controller positions. This is not surprising because, in 2000, the Runway Incursion Joint Safety Analysis Team concluded that one-at-a-time radio transmissions are "one of the weakest areas" of modern aviation (Cardosi & Yost, p. 16). In fact, in a survey of more than 1100 controllers and managers from 63 different towers, of the more than 500 responses to this item, 36% rated frequency congestion as at least a moderate risk factor for surface incidents (Kelley & Jacobs, 1998).

Earlier, Cardosi and Yost (2001) reported "at many major airports and other facilities with high traffic volume, radio communication is approaching its limits of effectiveness as a mode for transferring information between pilots and controllers" (p. 7, as cited in Kelly & Steinbacher, 1993) (Figure 6). Participants in the current study identified other sources, in addition to traffic volume, as contributing to frequency congestion. At PHX, local controllers indicated that they had to instruct arrival aircraft to sidestep to a parallel runway because the standard arrival route was not published. They also pointed to the presence of airline hubs and their associated "pushes" as contributing to frequency congestion and complexity, in accordance with previous research (Mogford, Murphy, Yastrop, Guttman, & Roske-Hofstrand, 1993). OAK and BJC housed resident flight training schools, potentially resulting in the increased use of progressive taxi instructions, more repeats, stuck microphones, and other related factors. The possibility of these situations is increased especially when student pilots make solo flights. Stuck microphones, in particular, were a concern for many of the tower participants Kelley and Jacobs (1998) surveyed. One quarter of the 500+ respondents for this item indicated that they considered stuck microphones to be associated with a significant risk of surface incidents (Kelley & Jacobs).

Despite these site differences, each of the facilities indicated that frequency congestion represented a high contribution to complexity. Its effects tended to be higher for the ground position and were particularly higher at ORD and BOS. These ratings were also statistically higher than OAK and BJC ground ratings. During the interviews, the participants addressed the complexities associated with frequency congestion, particularly for the ground position. Local

Figure 6. High traffic volume contributes to frequency congestion.

controllers' ratings did not differ substantially across sites, suggesting that the influence of frequency congestion is relatively similar across sites. Although important to both positions, this factor reflects more significance for the ground controller. Current FAA programs such as Next Generation Air/Ground Communications (NEXCOM) and Controller Pilot Data Link Communications are aimed at leveraging new technologies that will, at least partially, mitigate this factor.

4.1.3 Runway/Taxiway Configuration

Runway/taxiway configuration, the sixth highest rated issue overall, ranked fifth for both the local and ground control positions. For the ground position, it was within the top six factors for the Level 10, 11, and 12 sites, whereas it dropped to 12th for the Level 6 facility. This is consistent with earlier research. In their review of the NASDAC database, Cardosi and Yost (2001) also found that complex runway configuration ranked in the top five factors at Level 5 (Level 11 and 12 under the current system) facilities.

We included two sites with intersecting runways in our sample because intersecting runways are a source of added complexity and operational deviations. However, complexity ratings at these sites were not significantly different from other sites included in our sample. The HFSs expected runway/taxiway configuration and, to a lesser extent, active runway crossings, to be higher at those facilities with intersecting runways. However, this was not the case. Average CI ratings across control positions for runway/taxiway configuration were relatively high at ORD (mean = 8.1). But, BOS, the other site representing intersecting runways, returned an average CI of 7. This is somewhat below the 7.7 posted by OAK, which does not have intersecting runways. Active runway crossings received the highest ratings at ATL (mean = 9), representing a non-intersecting runway configuration. BOS and ORD were among the sites receiving the lowest ratings for this factor, with averages of 7.1 and 6.3, respectively. These findings could possibly reflect differences in airport operations (i.e., even though runways physically cross, it is the operation that dictates the number of active crossings).

The ratings on these factors did not appear to explicitly address the influence of intersecting runways. Other aspects of runway/taxiway configuration clearly fell within this category and would account for the high ratings for this factor. Controllers elaborated on many of these during the interviews. At OAK and ATL in particular, they identified the increased coordination and workload associated with active runway crossings. Limited concrete was another common concern, particularly at BOS. Other sites reported lack of runway visibility, but the most significant example was at BJC, where the tower is at a lower elevation than one of the runways. Land and Hold Short Operations procedures, which were in use at two of the sites we visited, also introduced additional complexity and, in the past, were cited as a direct cause of operational deviations (Cardosi & Yost, 2001). These instances suggest that runway/taxiway configuration is a collection of a variety of related factors. We recommend that this category be refined in the future. Differentiating between runway and taxiway configuration may be sufficient.

4.1.4 Active Runway Crossings

Results from the current study indicate that, on average, active runway crossings represent the second most influential factor for local controllers. This is due, in part, to the volume of crossings and to the complexity inherently associated with these crossings. Figure 7 shows aircraft holding at an active runway crossing. With an active runway crossing, timing is critical (there is pressure not to miss a crossing opportunity). These crossings add coordination and increased communications (especially if the local or ground position is split) and demand visual attention and SA. One facility reported that the local controller's duties might be split into four positions.

Local and ground controller ratings were virtually identical at four sites (BJC, ATL, OAK, and PHX); however, at ORD and BOS, ground ratings were much lower. The local controller at OAK, ATL, and BOS rated active runway crossings as the primary source of complexity, whereas it tended to be a moderate contribution at BJC. Ground ratings demonstrated a broader range, with BOS and ORD falling near moderate and ATL near the maximum point on the scale (very high). Both local and ground controller ratings demonstrated significant differences across sites. The differences in ratings most likely result from variations in airport runway/taxiway layout and configuration. Operations typically in use at ORD minimize the number of active runway crossings. At ATL, active runway crossings are especially prevalent because, depending on configuration, the majority of arrivals or departures must cross an active runway. These require significant coordination. Aircraft repositioning, particularly at ATL, also represented another significant component of crossing traffic. In addition, controllers at OAK reported a high number of runway crossings, particularly on the north operation. Also, all business jet departures must cross two active runways to meet noise abatement requirements. At BOS, some configurations require virtually all departures and arrivals to cross an active runway.

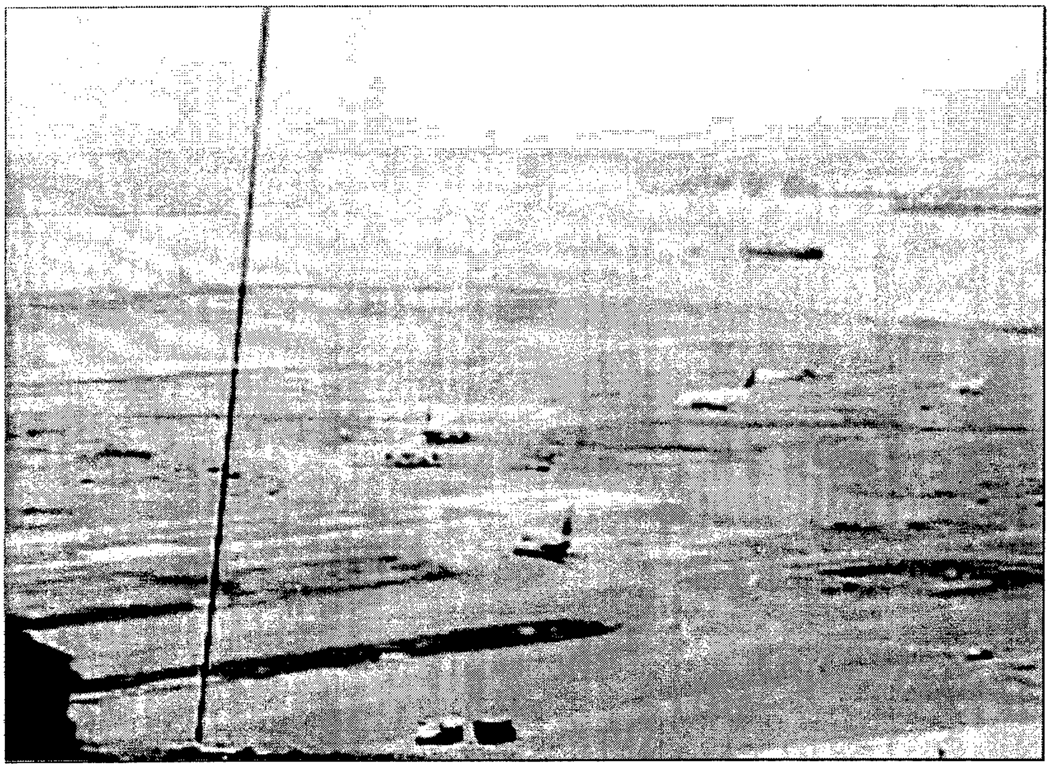


Figure 7. Aircraft holding at an active runway crossing.

Participants at two facilities indicated that active runway crossings are more difficult at night because aircraft blend into the field lights when viewing the airfield from the tower. This finding is not unique to the current study. In response to a 1998 survey investigating the causes and prevention of runway incursions, one controller stated that, "During night operations, runways and taxiways are very confusing . . . . It's just a sea of blue/white lights" (Kelley & Jacobs, 1998, p. 6-2).

Vehicular traffic represented another key aspect of complexity for this factor. One controller stated that snow removal teams in particular add complexity to runway crossings because they may consist of as many as 25 pieces of equipment. Other statements addressed the unfamiliarity of some vehicle operators with standard crossing procedures. These observations reiterated those forwarded by controllers in Kelley and Jacobs' (1998) survey. In that survey, the respondents identified construction vehicles, unauthorized vehicles, snowplows, and maintenance vehicles as the vehicles representing the greatest surface incident risk (Kelley & Jacobs). They reported that some vehicle operators are unaware of the need for approval to cross a runway and that construction vehicle operators are not well versed in airport procedures.

4.1.5 Aircraft Differing in Performance Characteristics

The research team elected to use traffic mix as one of the site selection criterion because it has long been recognized as one of the primary complexity related factors (Davis, Danaher, & Fischl, 1963; Grossberg, 1989; Mogford et al., 1993; Mogford et al., 1994). In fact, FAA Order 7210.46 incorporates special flights and number of operations representing heavy aircraft when calculating complexity. Controllers interviewed during the ACB-220 field study of ATCS decision making and strategic planning identified aircraft varying in performance as among the most difficult situations in which to maintain separation (D'Arcy & Della Rocco, 2001).

Although this factor has implications for ground control, such as for departure sequencing, it is far more significant for the local position, ranking it as the fourth factor. The facilities we visited exhibited a considerable mix of traffic, including air carriers, air taxies, banner aircraft, helicopters, general aviation, and cargo aircraft. Therefore, the average complexity ratings for this factor were high. The average local controller ratings at all facilities did not fall below the midpoint of the scale. In identifying the nature of the complexity, the interviewees noted aircraft spacing requirements differ, as do their characteristics (e.g., weight, climb rate, turn rate, and minimum runway requirements for takeoff and landing). Controllers also stressed the need to remain vigilant for overtake situations. They indicated that departures are particularly challenging, especially when a jet follows a prop, because controllers do not normally assign speeds for departures.

4.1.6 Runway/Taxiway Restrictions

Runway/taxiway restrictions ranked as the third highest factor for the ground control position in the current study. The restrictions may be short-term, such as for mowing or a spill (Figure 8), or much longer in duration as in the case of construction. In a previous study of 100 controllers, some identified restrictions as one of the most difficult situations in which to maintain separation (D'Arcy & Della Rocco, 2001). Besides restrictions, this factor also includes closed runway/taxiway situations. Restrictions by definition limit controllers' options, requiring more planning, rerouting, communicating, and coordinating.

In a review of 256 tower operational errors and deviations, 5% were attributed to controllers forgetting that a runway was closed (Cardosi, 2001). Not surprisingly, ratings from the current study indicated that runway/taxiway restrictions were among the leading sources of complexity. It was the second highest ranked ground control factor for OAK and BJC, as well as for the local position at OAK. It fell in the top five factors for PHX ground and BJC local control. OAK rated this factor higher than other sites for the local position and tied with ORD for the ground position. Controllers at OAK indicated that weight restrictions on taxiways G and H add significantly to the complexity of their operation.

Also, construction was prevalent at OAK, as it was at many facilities during our visit. Construction increases the amount of ground traffic and limits the availability and use of taxiways and runways. Another contributing factor was that OAK has a single taxiway (taxiway Bravo) joining the north and south complexes. Combined with this, noise restrictions require turbojets to depart and arrive on Runway 29, making them use taxiway Bravo. The high overall placement of this factor indicates that all sites face similar concerns because of runway and taxiway restrictions. Construction is ubiquitous to all facilities, with projects often lasting a year or more. Due to their proximity to the runway, taxiway restrictions like those in place at PHX are also commonplace. Proximity of parallel runways restricting the use of Instrument Landing System approaches (e.g., BOS) is widespread.

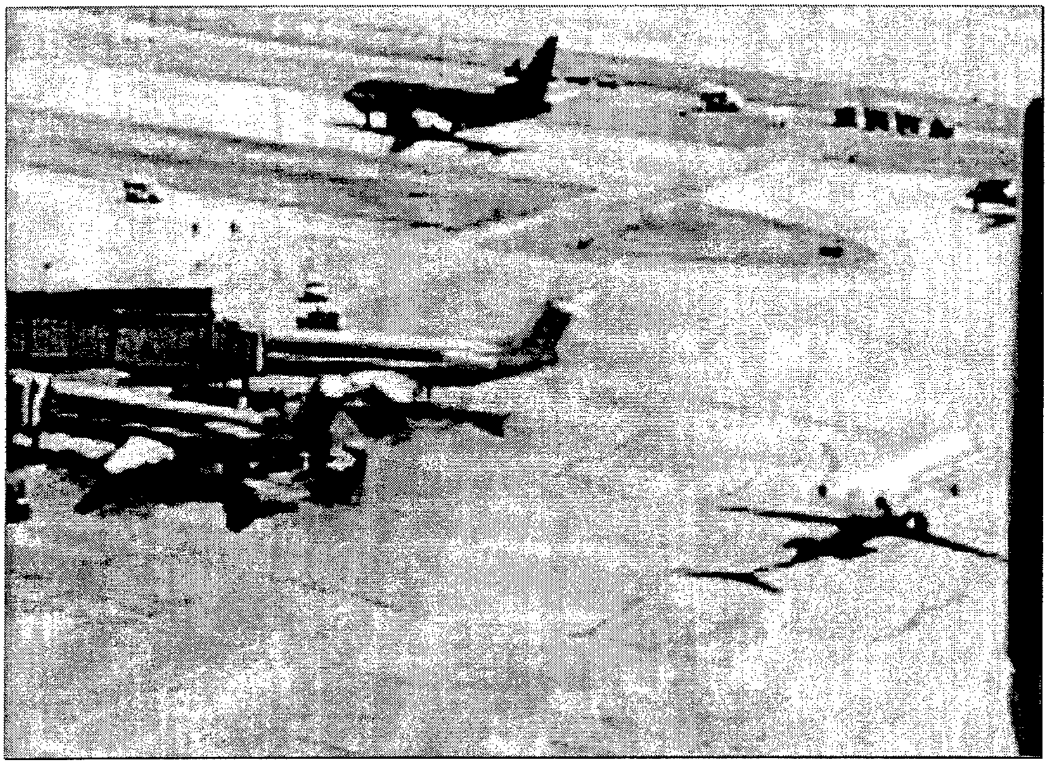


Figure 8. Aircraft being directed around a closed taxiway due to a deicing spill.

4.1.7 Traffic Management Initiatives

TMIs ranked fourth for the ground control position. The TMC collaborates with the en route Traffic Management Units and Air Traffic Control System Command Center to develop TMIs that promote efficient regional and national traffic flow. It is up to the tower approach control to implement them. These initiatives added complexity through increased maneuvering, re-sequencing, coordination, communications, and workload. These initiatives include eight distinct categories, many of which apply to the tower. The FAA Order 7210.3, Facility Operation and Administration publication, identifies these eight categories as follows:

a. Altitude
b. Miles-in-trail/minutes-in-trail
c. Speed control
d. Fix balancing
e. Airborne holding
f. Sequencing programs
    1. Departure Sequencing Program
    2. En route Sequencing Program
    3. Arrival Sequencing Program
g. Ground Delay Programs
h. Ground stop

Besides affecting multiple aircraft, one aircraft may be subject to multiple restrictions, further adding to the complexity involved in sequencing to meet these restrictions. Ratings for TMIs demonstrated a relatively large range. As one would expect, Level 11 and 12 facilities, and, to a limited extent, Level 10 facilities, rated the contribution of this factor as high. Ratings at BJC, a Level 6 facility, showed the complexity contribution of these initiatives to be much lower (i.e., moderate) than, for example, the contribution of runway/taxiway restrictions. TMIs appeared within the top 10 factors for both the local and ground positions at the Level 10, 11, and 12 facilities we visited. Its relative ranking for the Level 6 facility was 11th and 26th, respectively.

4.2 Complexity Rating Form

The methodology and data collection forms proved to be an effective means for investigating ATC complexity.

- The ratings reflected much agreement, with the *SD* across sites averaging 1.5 for the local position and 1.7 for the ground position on the 10-point CI scale.
- The methodology discriminated between factors. The ranges between the highest-rated to lowest-rated factors were 4.3 for local control position and 6.2 for the ground position.
- The participants were able to differentiate between the local and ground positions on the complexity factors, as shown by the range of scores. For example, wake turbulence averaged 7.2 for the local position and 4.5 for the ground position. In addition, the participants noted why they provided higher ratings for one position over the other. For example, many of the interviewees indicated that wake turbulence held significant implications for sequencing and maintaining separation from the local perspective, but that it had much less of an influence on the ground control position.
- The anchor points on the scales returned an acceptable overall range. However, one site appeared to exhibit a ceiling effect (i.e., a loss of range at the top of the scale). This occurred for what is conceivably the most extreme instance—high traffic volume (the highest rated complexity factor) for the busiest position (ground control) at the busiest facility (ORD).

The team recommends that the N/A option be reserved specifically for factors that do not apply to a control position, as in the case of overflights for the ground controller. The complexity form should include an option to indicate the factor has no influence on complexity.

The team could not determine from the current sample whether ATCS and SATCS complexity ratings are significantly different from each other. The average range between their scores across all factors was 0.2 on the 10-point scale. The difference between average ATCS and SATCS scores exceeded 1.0 on only two factors: wake turbulence and non-visibility areas. In both cases, SATCSs rated the factor as more complex than ATCSs.

4.3 Future Research

Controller ratings suggest that the following factors should be considered as among the primary areas for initial research efforts:

- high traffic volume (local and ground control perspective),
- frequency congestion (local and ground control perspective),
- runway/taxiway configuration (local and ground control perspective),

- active runway crossings (local control perspective),
- aircraft differing in performance characteristics (local control perspective),
- runway/taxiway restrictions (ground control perspective), or
- traffic management initiatives (ground control perspective).

In addition, vehicular traffic and OJT represent other common and important sources of tower complexity.

The FAA has already undertaken initiatives to address many of these complexities, several of which are documented in the NAS Operational Evolution Plan (OEP) (FAA, 2002). For example, in regard to high traffic volume, the OEP delineates building new runways and maximizing the use of existing runways to help airports meet peak demands. Although a long-term solution, building new runways will help offset complexities associated with high traffic volume and promote airport capacity and efficiency. The OEP prescribes the use of a combination of AT procedures, new technologies, improved airspace design, surface management, and decision support tools to make better use of existing runways. The FAA is addressing frequency congestion, another key source of complexity within the tower, through current and planned efforts. Participants we interviewed noted that the expanding use of pre-departure clearances through the Aircraft Communications Addressing and Reporting System has offloaded the need for some voice requirements, alleviating some of the frequency congestion for the ground controller. In addition, this factor will be at least partially mitigated through new technologies being implemented under other FAA programs such as NEXCOM. This program will leverage technological advances in digital air-to-ground communications to expand the number of available channels, provide data link communications capability, reduce air-to-ground radio frequency interference, and provide other benefits.

Even though the current study sampled only 6 of the 200+ FAA-operated ATCTs, we found considerable site differences among sites on many of the factors. We recommend that future research efforts focus on collecting comparable data from additional tower facilities, particularly Level 6-10 facilities, to investigate the interaction of complexity factors at these smaller facilities. BJC gave the research team insights into factors that present substantial complexity even at a smaller facility. Additional ATCT complexity data would provide an opportunity to begin validating the exploratory factor analysis groupings identified during the current study. We recommend collecting similar data from other ATC domains, such as the terminal and en route environments, to investigate whether the sources and incidence of complexity are similar or if they pose other unique challenges to the ATCS.

The usefulness of the Complexity Rating Form and interview protocol is that it provides an opportunity to gain insights into, and to continue to assess, the most significant sources of complexity within the ATCT environment. Leveraging knowledge regarding the sources of complexity and ATCSs decision making will aid in the design of future tower automation equipment as well as airports themselves. Another viable application is assessing the impact of new technologies on perceived complexity within this environment. As digital radio communications and other new automation is deployed, this instrument could aid in measuring the degree of change in terms of perceived complexity on frequency congestion and other relevant factors.

5. Conclusions

This field study examined the relative contributions of a broad range of complexity factors in the tower environment and the mitigation strategies that controllers employ to address these factors. This technical note represents the first step in identifying and characterizing the primary tower complexity sources with consideration for their inherent complexity, incidence, and shared importance. In the second technical note, we will investigate the influence of each of the complexity factors on controller strategies, information needs, and sources of information.

High traffic volume and frequency congestion represented the leading factors influencing complexity in the facilities we visited. High traffic volume is well documented as a source of complexity for ATCSs, and in the current survey, the participants rated it as the single most significant factor for both local and ground control. Not surprisingly, busier facilities returned statistically higher ratings for this source of complexity. Previous research suggests that workload demands imposed by high traffic volume may compromise effective scanning and selective attention. Thus, a focus on automation that helps controllers manage that workload and maintain SA may be necessary. Frequency congestion was the second and third highest ranked factor, respectively, for the local and ground positions. Although high volumes of traffic contribute to frequency congestion, other factors such as unfamiliar pilots, inclement weather, and runway/taxiway restrictions may compound its effect. It is important that we continue efforts to improve the frequency congestion problems in the system.

The methodology employed proved to be a viable means of assessing complexity within the ATCT environment. Among potential uses for this tool are as a metric that will minimize the perceived complexity in the design of airports, traffic flow, and standard procedures; to assess the impact of new technologies on perceived complexity; and to identify situations of peak complexity and investigate whether there is an increased likelihood of operational errors at these times.

By applying the knowledge gained through this and future research efforts, designers of tower automation systems will have a basis to more closely match the tools and information requirements of a task with controller needs, thereby promoting the continued safety and efficiency of the NAS. The findings from the current study pave the way for future research efforts and define preliminary principles for the design of tower automation equipment. The second technical note will investigate controller strategies, information needs, and sources of information in response to each of the complexity factors.

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Acronyms

ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
AT	Air Traffic
ATC	Air Traffic Controller
ATCS	Air Traffic Control Specialist
ATCT	Air Traffic Control Tower
ATL	William B. Hartsfield Atlanta International Airport
BJC	Jefferson County Airport
BOS	General Edward Lawrence Logan International Airport
CI	Complexity Index
CPC	Certified Professional Controller
CY	Calendar Year
FAA	Federal Aviation Administration
HFS	Human Factors Specialist
KMO	Kaiser-Mayer-Olkin
NAS	National Airspace System
NASDAC	National Aviation Safety Data Analysis Center
NATCA	National Air Traffic Controllers Association
NEXCOM	Next generation air/ground communications
OAK	Metropolitan Oakland International Airport
OEP	Operational Evolution Plan
OJT	On-the-Job Training
ORD	Chicago O'Hare International Airport
PHX	Phoenix Sky Harbor International Airport
POC	Point of Contact
SA	Situation Awareness
SATCS	Supervisor Air Traffic Control Specialist
SD	Standard Deviation
SME	Subject Matter Expert
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TRACON	Terminal Radar Approach Control

Appendix A

Complexity Factors Sources

Factor	Source
Number of departures Number of arrivals Emergencies Special flights En-route aircraft requiring control function En-route aircraft requiring no control function Coordination	FAA Order 7210.46 (1984)
Traffic density Traffic mixture (arriving/departing vs. overflying aircraft) Number of airport terminals	Davis, Danaher, and Fischl, (1963)
Traffic volume Traffic distribution Staffing Weather conditions Equipment status	Kuhar et al. (1976)
Sector geometry Traffic density	Buckley et al. (1983)
Background load Routine load Airspace load	Arad (1964)
DEL Routine load Traffic density	Jolitz (1965)
Communications with aircraft Presence of conflicts Number of path changes	Soede, Coeterier, & Stassen (1971)
Preventing a crossing conflict Preventing an overtaking conflict Hand-offs Pointouts Coordination with other controllers Handling pilot requests Traffic structuring	Schmidt (1976)
Clustering of aircraft in a small amount of airspace Number of handoffs outbound Total number of flights handled Number of handoffs inbound	Stein (1985)

Factor	Source
Control adjustments involved in merging and spacing aircraft	Grossberg (1989)
Climbing and descending aircraft flight paths	
Mixture of aircraft types	
Frequent coordination with other controllers	
Traffic density	
Amount of climbing or descending traffic	Mogford et al. (1993)
Aircraft mix	
Number of intersecting flight paths	
Multiple functions	
Number of required procedures	
Number of military flights	
Amount of coordination	
Airline hubbing	
Weather	
Complex aircraft routings	
Restricted areas, warning areas, and military operating areas	
Sector size	
Requirements for longitudinal sequencing and spacing	
Adequacy of radio and radar coverage	
Radio frequency congestion	
Bad weather	D'Arcy & Della Rocco (2001)
Weaker controllers	
Traffic (high volume or complex)	
Equipment failure and outage	
Weaker or uncooperative pilots	
Poor communications	
Restrictions	
Unusual situations	
Disturbance in control room	
Aircraft varying in performance	
Boredom	

Appendix B

Airport Maps for Interview Sites (FAA, 2001b)

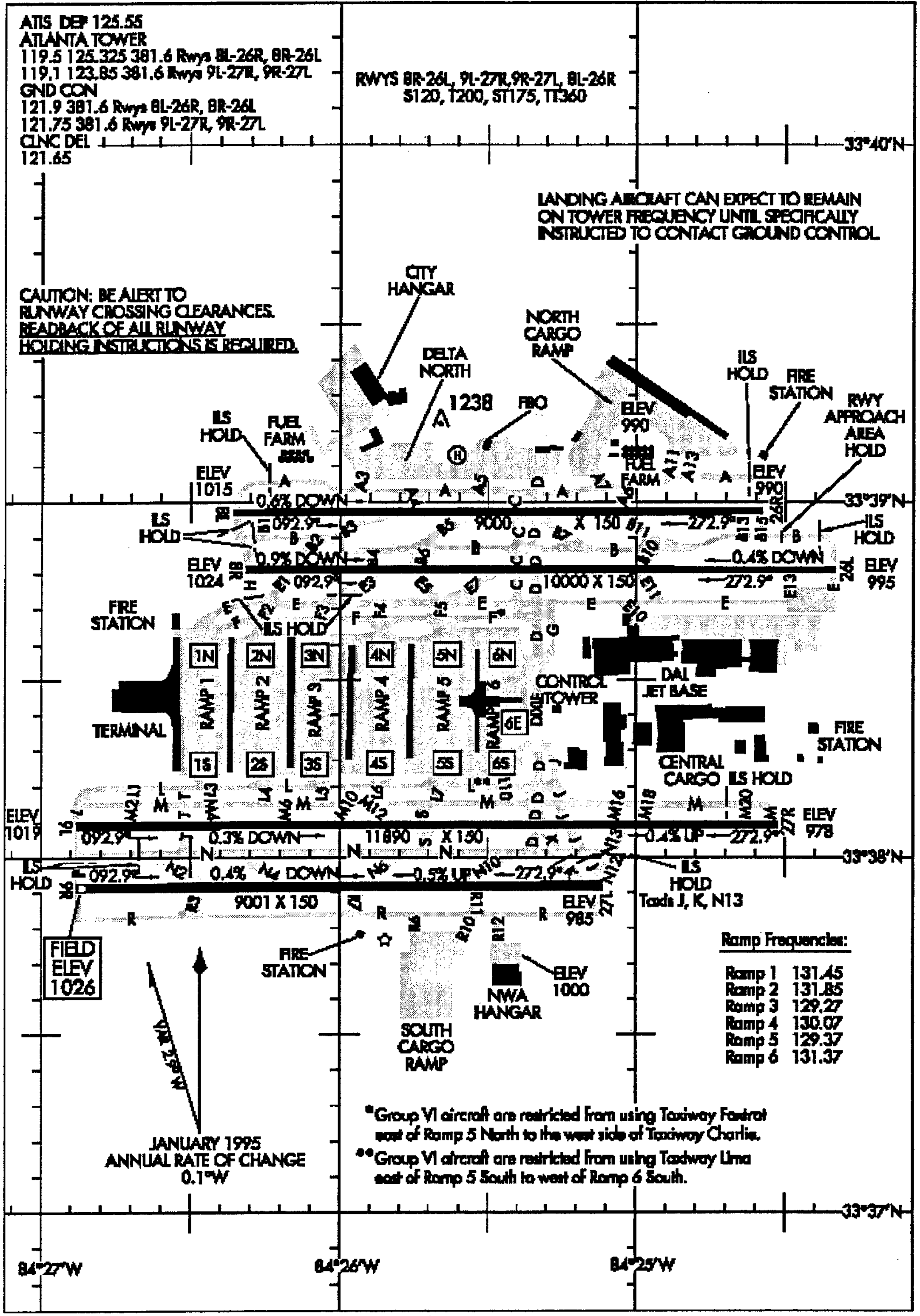
01193

AIRPORT DIAGRAM

ATLANTA/THE WILLIAM B. HARTSFIELD ATLANTA INTL (ATL)

AL-26 (FAA)

ATLANTA, GEORGIA



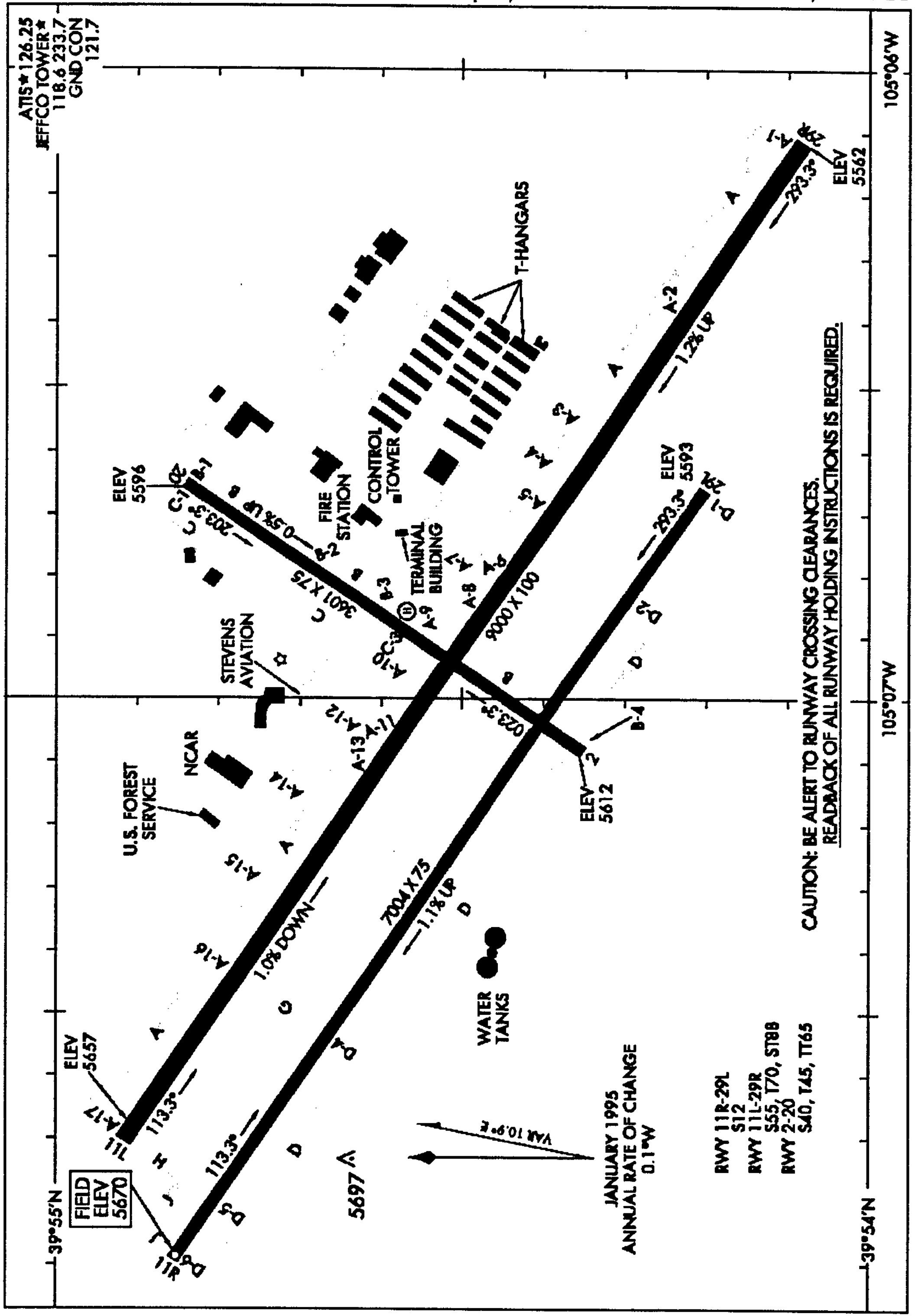
AIRPORT DIAGRAM
01193
ATLANTA, GEORGIA
ATLANTA/THE WILLIAM B. HARTSFIELD ATLANTA INTL (ATL)

01305

AIRPORT DIAGRAM

AL-5612 (FAA)

DENVER/JEFFCO (BJC)
DENVER, COLORADO



ATIS ★ 126.25
JEFFCO TOWER ★ 118.6 233.7
GND CON 121.7

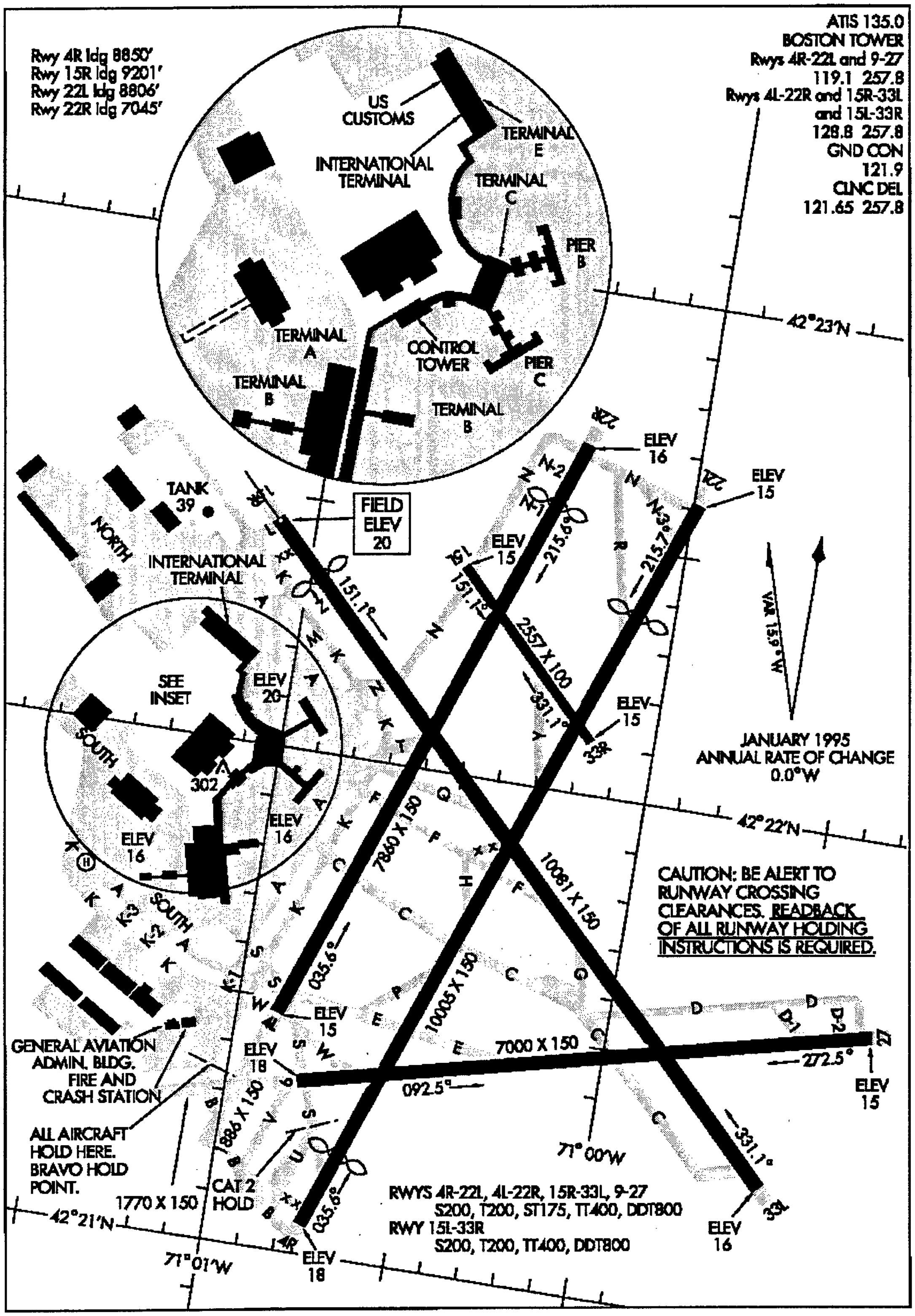
CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

RWY 11R-29L
S12
RWY 11L-29R
S55, T70, ST88
RWY 2-20
S40, T45, TT65

JANUARY 1995
ANNUAL RATE OF CHANGE
0.1°W

01137
AIRPORT DIAGRAM

BOSTON/ GENERAL EDWARD LAWRENCE LOGAN INTL (BOS)
AL-58 (FAA)
BOSTON, MASSACHUSETTS



CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES. READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

RWYS 4R-22L, 4L-22R, 15R-33L, 9-27
S200, T200, ST175, TT400, DDT800
RWY 15L-33R
S200, T200, TT400, DDT800

AIRPORT DIAGRAM
01137

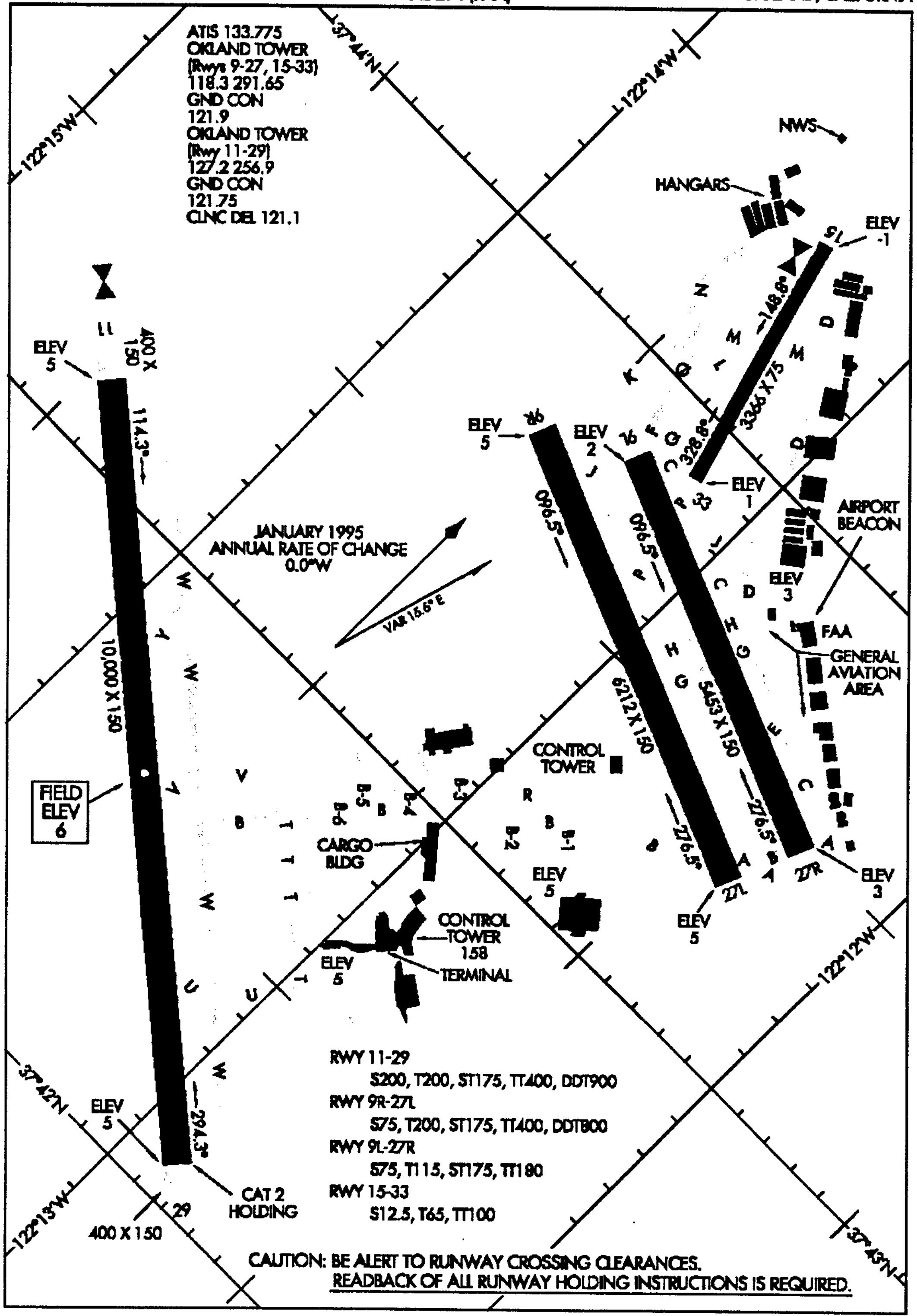
BOSTON, MASSACHUSETTS
BOSTON/ GENERAL EDWARD LAWRENCE LOGAN INTL (BOS)

01249

AIRPORT DIAGRAM

AL-294 (FAA)

OAKLAND/METROPOLITAN OKLAND INTL (OAK)
OAKLAND, CALIFORNIA



ATIS 133.775
OKLAND TOWER
(Rwys 9-27, 15-33)
118.3 291.65
GND CON
121.9
OKLAND TOWER
(Rwy 11-29)
127.2 256.9
GND CON
121.75
CLNC DEL 121.1

JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W

RWY 11-29
S200, T200, ST175, TT400, DDT900
RWY 9R-27L
S75, T200, ST175, TT400, DDT800
RWY 9L-27R
S75, T115, ST175, TT180
RWY 15-33
S12.5, T65, TT100

CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

AIRPORT DIAGRAM

01249

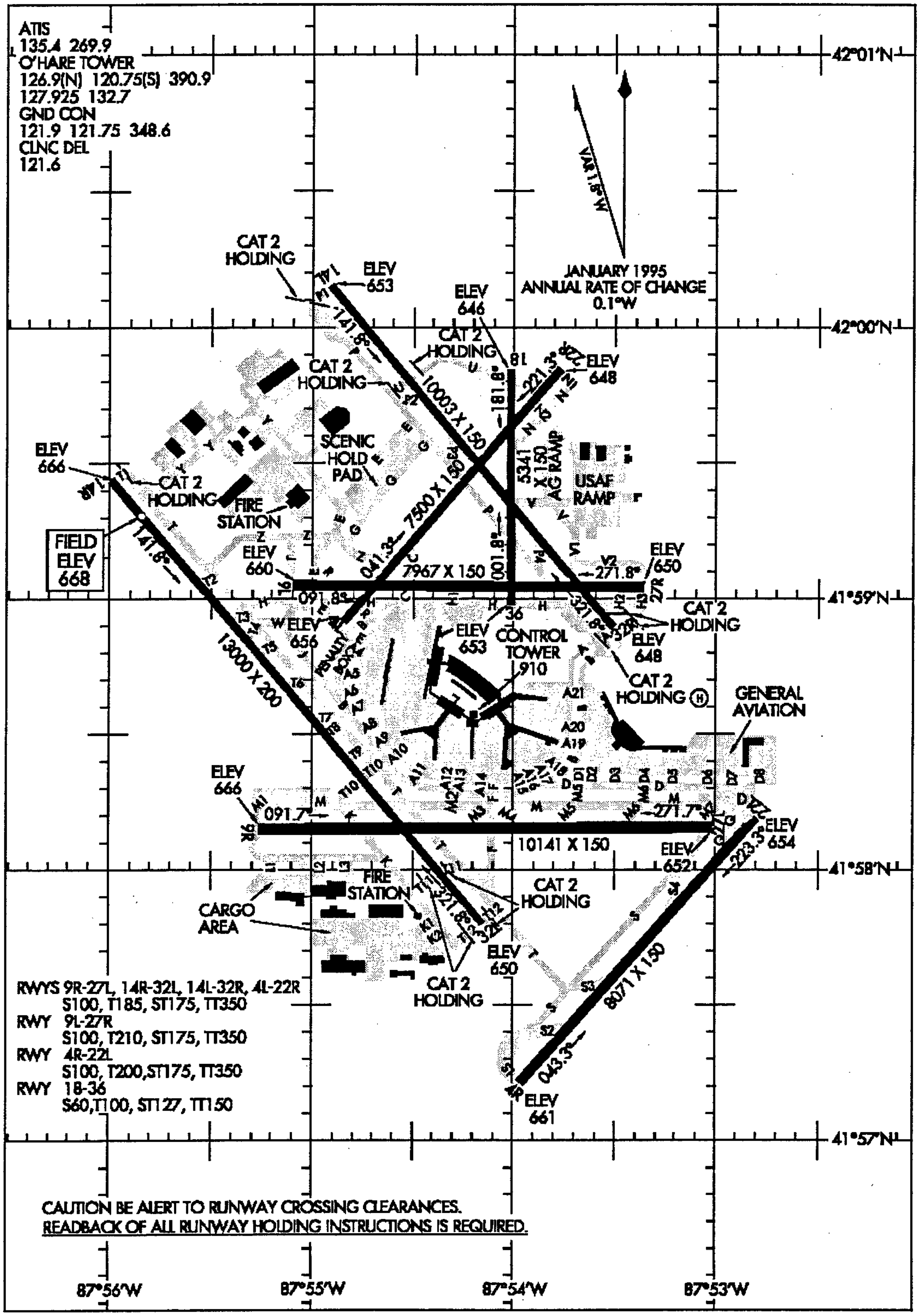
OAKLAND, CALIFORNIA
OAKLAND/METROPOLITAN OKLAND INTL (OAK)

01081

AIRPORT DIAGRAM

AL-166 (FAA)

CHICAGO-O'HARE INTL (ORD)
CHICAGO, ILLINOIS



ATIS
135.4 269.9
O'HARE TOWER
126.9(N) 120.75(S) 390.9
127.925 132.7
GND CON
121.9 121.75 348.6
CLNC DEL
121.6

RWYS 9R-27L, 14R-32L, 14L-32R, 4L-22R
S100, T185, ST175, TT350
RWY 9L-27R
S100, T210, ST175, TT350
RWY 4R-22L
S100, T200, ST175, TT350
RWY 18-36
S60, T100, ST127, TT150

CAUTION BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

AIRPORT DIAGRAM
01081

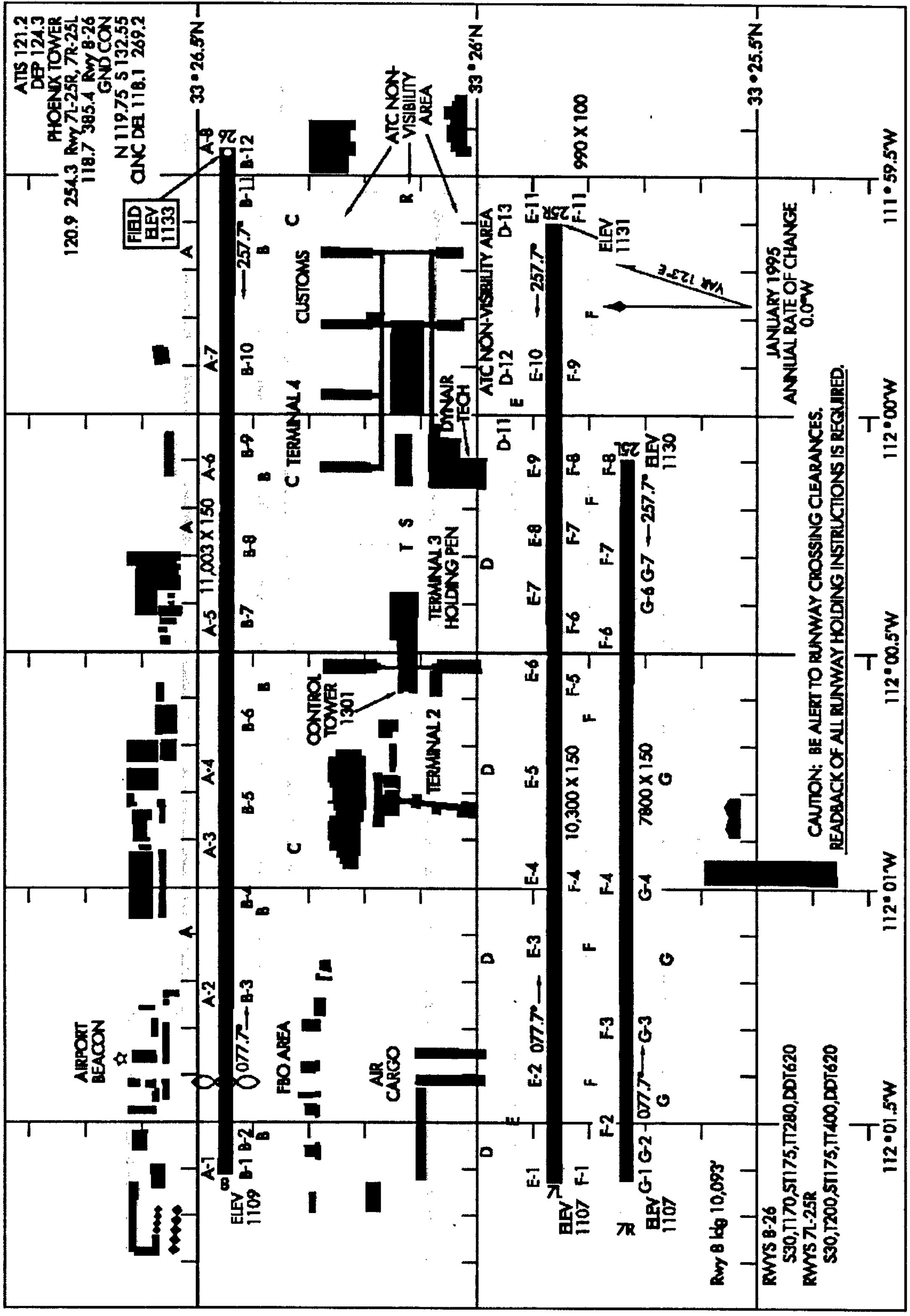
CHICAGO, ILLINOIS
CHICAGO-O'HARE INTL (ORD)

01025

AIRPORT DIAGRAM

AL-322 (FAA)

PHOENIX SKY HARBOR INT (PHX)
PHOENIX, ARIZONA



ATIS 121.2
DEP 124.3
PHOENIX TOWER
120.9 254.3 Rwy 7L-25R, 7R-25L
118.7 385.4 Rwy 8-26
GND CON
N 119.75 S 132.55
CLNC DEL 118.1 269.2

CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

JANUARY 1995
ANNUAL RATE OF CHANGE
0.0°W

Rwy 8 ldg 10,093'

RWYS 8-26
S30,T170,ST175,TT280,DDT620
RWYS 7L-25R
S30,T200,ST175,TT400,DDT620

AIRPORT DIAGRAM
01137

PHOENIX, ARIZONA
PHOENIX SKY HARBOR INT (PHX)

Appendix C

Instructions for Facility Points of Contact

Instructions for Facility Point of Contacts

Purpose

To understand the decision-making strategies of ATCSs under complex situations in tower facilities.

Participants

We are requesting approximately 10 volunteers per facility. The participants must be CPCs or Supervisory ATCSs. Among the participants, 8 should be bargaining unit controllers and 2 Supervisory ATCSs. When planning the interview schedule, please allocate one hour for each individual interview.

General Information

- Participants will be involved in an interview for about 45 minutes with a subject matter expert and an engineering research psychologist.
- The participants will be asked about the factors that contribute to complexities in the tower environment and the types of strategies, type of information and the mode of information that they use to deal with the complex scenarios.
- The participants will be asked to answer the questions from a perspective of a ground as well as local controller.
- The interviewers will take notes to document the interview. The interviewees may see or refer to interviewer notes at any time.
- There are no risks or discomforts involved in this research study.
- The study complies with Article 50 of the FAA/NATCA Bargaining Agreement.

Confidentiality

Participation in this study is strictly voluntary. The confidentiality of participants will be strictly protected. No individual names will be recorded or released in any reports.

Schedule

The interviews should be scheduled on two consecutive days in the week of _________. Five-8 participants should be scheduled each day.

Place

The interviewers will travel to the facility. A room located in a private setting is requested for the interviews in order to help ensure confidentiality and minimize organizational disturbance.

Contact Person

Dr. Pam Della Rocco, (609) 485-7376, pam.dellarocco@tc.faa.gov

Project Coordinators

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Appendix D

Informed Consent Form

Individual's Consent to Voluntary Participation in a Research Project

I understand that this study, entitled "Complexity in Air Traffic Control Towers: A Field Study", is sponsored by the Federal Aviation Administration and directed by Dr. Pam Della Rocco, ACB-220 NAS Human Factors Laboratory.

Nature and Purpose:

I have been recruited to volunteer as a participant in the project named above. The purpose of this study is to explore the complexity factors and the decision-making strategies used by Air Traffic Control Specialists in tower operational settings. Participants are subject matter experts and researchers are not evaluating them in any way: The purpose of this study is to scientifically investigate decision-making concepts.

Study Procedure

During the study, I will answer questions regarding decision making, complexity, and automated aids in air traffic control towers and provide some biographical information. The time requirement for this task is approximately 45 minutes.

Benefits

I understand that the only direct benefit to me is the satisfaction of knowing that I contributed to our knowledge about decision making and complexity in air traffic control.

Risks

No risks are expected.

Participant's Assurances:

I understand that my participation in this study is completely voluntary. I am participating because I want to. I understand that the research team will be available to answer any questions concerning procedures regarding this study. I have not given up any of my legal rights by consenting to this study. I understand that I can withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled.

Confidentiality and Anonymity

I understand that records of this study will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this study. My name will not be attached to any information provided in any records.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Pam Della Rocco (609) 485-7376 (pam.dellarocco@tc.faa.gov), the Air Traffic Human Factors Technical Lead. I may also contact Gulshan Panjwani at (609) 485-7764, Anton Koros at (609) 485-5609, or Victor Ingurgio at (609) 485-6814.

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described.

Research Participant: ________________________________ Date: ______________

Investigator: ____ Date: ______________

Appendix E

Complexity Rating Form

COMPLEXITY RATINGS

The goal of this study is to understand the decision-making process in ATCTs under complex situations. This section asks about what factors make ATC complex at this facility.

1. Please rate the following factors as to:
   i) How much each contributes to complexity (**Contribution to Complexity**), and
   ii) How often you deal with it (**Frequency of Occurrence**).
2. Please answer the items from the **local control** perspective.
3. Fill in the circle that indicates your answer.

LOCAL CONTROL

Complexity Factors	N/A	Contribution to Complexity					Frequency of Occurrence				
		Very low	Low	Moderate	High	Very high	Almost Never	Seldom	Sometimes	Often	Almost Always
Physical Factors											
1. Runway/taxiway restrictions	☐	①	②	③	④	⑤	①	②	③	④	⑤
2. Active runway crossings	☐	①	②	③	④	⑤	①	②	③	④	⑤
3. Runway/taxiway configuration	☐	①	②	③	④	⑤	①	②	③	④	⑤
4. Non visibility areas	☐	①	②	③	④	⑤	①	②	③	④	⑤
5. Airspace configuration	☐	①	②	③	④	⑤	①	②	③	④	⑤
6. Terrain/obstructions	☐	①	②	③	④	⑤	①	②	③	④	⑤
7. Satellite airports	☐	①	②	③	④	⑤	①	②	③	④	⑤
Aircraft/Traffic Characteristics											
8. High traffic volume (e.g., high number of arrivals and departures)	☐	①	②	③	④	⑤	①	②	③	④	⑤
9. Aircraft differing in performance characteristics	☐	①	②	③	④	⑤	①	②	③	④	⑤
10. Emergency operations	☐	①	②	③	④	⑤	①	②	③	④	⑤
11. Wake turbulence	☐	①	②	③	④	⑤	①	②	③	④	⑤
12. Special flights (e.g. medivac, helicopters, other local traffic)	☐	①	②	③	④	⑤	①	②	③	④	⑤
13. Overflights	☐	①	②	③	④	⑤	①	②	③	④	⑤
14. Vehicular traffic	☐	①	②	③	④	⑤	①	②	③	④	⑤
Weather											
15. At or below minimums	☐	①	②	③	④	⑤	①	②	③	④	⑤
16. Reduced visibility (e.g. fog, sun glare)	☐	①	②	③	④	⑤	①	②	③	④	⑤
17. Inclement weather (e.g., wind, thunderstorms, lightning)	☐	①	②	③	④	⑤	①	②	③	④	⑤

LOCAL CONTROL

Complexity Factors	N/A	Contribution to Complexity					Frequency of Occurrence				
		Very low	Low	Moderate	High	Very high	Almost Never	Seldom	Sometimes	Often	Almost Always
Ground Operation											
18. Airport surface activity (e.g., lawn mowing, lighting repair)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Equipment Factors											
19. Equipment malfunctions	☐	①	②	③	④	⑤	①	②	③	④	⑤
20. Frequency congestion	☐	①	②	③	④	⑤	①	②	③	④	⑤
21. Equipment location	☐	①	②	③	④	⑤	①	②	③	④	⑤
22. Reduced visibility (e.g., reflections)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Individual Factors											
23. Unfamiliar pilots (e.g., unfamiliar with airport or procedures)	☐	①	②	③	④	⑤	①	②	③	④	⑤
24. Pilot's weak mastery of English language	☐	①	②	③	④	⑤	①	②	③	④	⑤
25. Controller fatigue	☐	①	②	③	④	⑤	①	②	③	④	⑤
ATC Procedures											
26. Traffic management initiatives (e.g., LOAs, ATPs, ATMs)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Distractions											
27. Equipment distractions (e.g., altitude alarms)	☐	①	②	③	④	⑤	①	②	③	④	⑤
28. Other distractions (e.g., visitors in tower cab, phone calls, noise)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Training											
29. OJT	☐	①	②	③	④	⑤	①	②	③	④	⑤

If you think of complexity factors that are not included in the above list, please add them in the following list and rate their difficulty and their frequency.

	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤

Please answer the items from the **ground control** perspective.

GROUND CONTROL

		Contribution to Complexity					Frequency of Occurrence				
Complexity Factors	N/A	Very low	Low	Moderate	High	Very high	Almost Never	Seldom	Sometimes	Often	Almost Always
Physical Factors											
1. Runway/taxiway restrictions	☐	①	②	③	④	⑤	①	②	③	④	⑤
2. Active runway crossings	☐	①	②	③	④	⑤	①	②	③	④	⑤
3. Runway/taxiway configuration	☐	①	②	③	④	⑤	①	②	③	④	⑤
4. Non visibility areas	☐	①	②	③	④	⑤	①	②	③	④	⑤
5. Airspace configuration	☐	①	②	③	④	⑤	①	②	③	④	⑤
6. Terrain/obstructions	☐	①	②	③	④	⑤	①	②	③	④	⑤
7. Satellite airports	☐	①	②	③	④	⑤	①	②	③	④	⑤
Aircraft/Traffic Characteristics											
8. High traffic volume (e.g., high number of arrivals and departures)	☐	①	②	③	④	⑤	①	②	③	④	⑤
9. Aircraft differing in performance characteristics	☐	①	②	③	④	⑤	①	②	③	④	⑤
10. Emergency operations	☐	①	②	③	④	⑤	①	②	③	④	⑤
11. Wake turbulence	☐	①	②	③	④	⑤	①	②	③	④	⑤
12. Special flights (e.g. medivac, helicopters, other local traffic)	☐	①	②	③	④	⑤	①	②	③	④	⑤
13. Overflights (N/A)	☒	①	②	③	④	⑤	①	②	③	④	⑤
14. Vehicular traffic	☐	①	②	③	④	⑤	①	②	③	④	⑤
Weather											
15. At or below minimums	☐	①	②	③	④	⑤	①	②	③	④	⑤
16. Reduced visibility (e.g. fog, sun glare)	☐	①	②	③	④	⑤	①	②	③	④	⑤
17. Inclement weather (e.g., wind, thunderstorms, lightning)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Ground Operation											
18. Airport surface activity (e.g., lawn mowing, lighting repair)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Equipment Factors											
19. Equipment malfunctions	☐	①	②	③	④	⑤	①	②	③	④	⑤
20. Frequency congestion	☐	①	②	③	④	⑤	①	②	③	④	⑤
21. Equipment location	☐	①	②	③	④	⑤	①	②	③	④	⑤
22. Reduced visibility (e.g., reflections)	☐	①	②	③	④	⑤	①	②	③	④	⑤

GROUND CONTROL

Complexity Factors	N/A	Contribution to Complexity					Frequency of Occurrence				
		Very low	Low	Moderate	High	Very high	Almost Never	Seldom	Sometimes	Often	Almost Always
Individual Factors											
23. Unfamiliar pilots (e.g., unfamiliar with airport or procedures)	☐	①	②	③	④	⑤	①	②	③	④	⑤
24. Pilot's weak mastery of English language	☐	①	②	③	④	⑤	①	②	③	④	⑤
25. Controller fatigue	☐	①	②	③	④	⑤	①	②	③	④	⑤
ATC Procedures											
26. Traffic management initiatives (e.g., LOAs, ATPs, ATMs)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Distractions											
27. Equipment distractions (e.g., altitude alarms)	☐	①	②	③	④	⑤	①	②	③	④	⑤
28. Other distractions (e.g., visitors in tower cab, phone calls, noise)	☐	①	②	③	④	⑤	①	②	③	④	⑤
Training											
29. OJT	☐	①	②	③	④	⑤	①	②	③	④	⑤

If you think of complexity factors that are not included in the above list, please add them in the following list and rate their difficulty and their frequency.

	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤
	①	②	③	④	⑤	①	②	③	④	⑤

This concludes the rating form

Appendix F

Controller Background Questionnaire

CONTROLLER BACKGROUND INFORMATION

1. Age:
   - ☐ 18-25
   - ☐ 26-30
   - ☐ 31-35
   - ☐ 36-40
   - ☐ 41-45
   - ☐ 46-50
   - ☐ 51-55
   - ☐ 56+
2. Gender:
   - ☐ Female
   - ☐ Male
3. What is your current position (or which of the following best describes your current position)?
   - ☐ Certified Professional Controller
   - ☐ Traffic Management Coordinator
   - ☐ Staff Specialist
   - ☐ Operational Supervisor/First-Level Supervisor
   - ☐ Operational Manager/Second-Level Supervisor
   - ☐ Manager/Assistant Manager
   - ☐ Developmental
   - ☐ Other (specify): ________________________
4. Do you maintain operational currency?
   - ☐ Yes
   - ☐ No → If no, for how many years have you not been current: _______
5. How many years experience do you have in the following:

   Military ATC _______ yrs
   Developmental _______ yrs
   CPC _______ yrs
6. How many years have you worked in your present facility? ______ years
7. How many years of FAA experience do you have in each of the following types of facility?

Tower only: _________ years
TRACON only: _________ years
Combined Tower and TRACON: _________ years
ARTCC: _________ years
Flight Services: _________ years

8. During the last 30 days, what percentage of the time would you estimate that you spent doing the following activities?

Working in the TRACON ________ %
Working in the tower ________ %
Assuming administrative tasks ________ %

9. During the last 30 days when you worked in the tower, what percentage of the time would you estimate that you spent at the following positions? (Note: 8 hrs = 5%)

Controller

Combined duties	
- Flight Data/ Clearance Delivery	___________%
- Other (specify) ___________	___________%
Local Controller	___________%
Assistant Local Controller	___________%
Ground Controller	___________%
Controller in Charge	___________%
Other duties (please specify) ___________	___________%
Total	___________%
	100%

Supervisor

Maintaining currency	___________%
Administrative duties	___________%
Operational duties	___________%
Other duties (please specify) ___________	___________%
Total	___________%
	100%

10. In the last 90 days, how many hours have you worked as a Training Instructor (OJT)?

___________ hours

Please provide us any comments you may have regarding this study.

____

____

____

____

Appendix G

Interviewer Data Collection Forms

INTERVIEWER INSTRUCTIONS

1. Identify the 3 complexity factors from the completed Complexity Ratings form with the highest impact. Select those factors with the highest complexity rating and highest frequency of occurrence. Complete for the Local Controller and Ground Controller positions.
2. Enter the three highest impact factors below:

	Local	Ground
Complexity Factor 1		
Complexity Factor 2		
Complexity Factor 3		

3. Transfer the factors in the space provided on the Strategy Forms (i.e., Complexity Factor 1 and Complexity Factor 2).

Note: if a strategy has been completed 3 times for a single position (i.e., local or ground), select the Complexity Factor 3.

4. Complete the information below at the time the interview is conducted.
5. NOTE: if participant number is even then complete local information first, for odd numbers complete ground information first.
6. Inform the participant that we will begin focusing on FACTORS, then STRATEGIES, and then the INFORMATION required for these strategies.

Interview Information

Facility: ______________________

Date: ______________________

Time: ______________________

Interviewer: ______________________

LOCAL CONTROL

Complexity Factor 1: ______________________________

1. In your own words, what is it about this factor that makes it complex?

____

____

____

____

____

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None**)
   Are the procedures effective: ☐ Yes ☐ No

____

____

____

____

3. What strategies (i.e., techniques) do they use and how often using the following scale. **Enter the most common on the next page.**

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

⇩ ⇩

Strategy	***What would influence you to use this strategy?***	**Freq**
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____

LOCAL CONTROL INFORMATION

Most Common Strategy for Complexity Factor 1: ______________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful 1	Somewhat Useful 2	Moderately Useful 3	Very Useful 4	Extremely Useful 5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	____	____/____/____/____/____/____
☐ Aircraft position	____	____/____/____/____/____/____
☐ Aircraft type	____	____/____/____/____/____/____
☐ Aircraft category (I, II, and III)	____	____/____/____/____/____/____
☐ Aircraft speed	____	____/____/____/____/____/____
☐ Route to be used while taxiing	____	____/____/____/____/____/____
☐ Assigned gate (or parking area)	____	____/____/____/____/____/____
☐ Runway status	____	____/____/____/____/____/____
☐ Weather conditions (e.g. wind)	____	____/____/____/____/____/____
☐ Traffic management	____	____/____/____/____/____/____
☐ Other (specify) ______________	____	____/____/____/____/____/____
______________________________	____	____/____/____/____/____/____

Location

L1. Visual observation (looking out window)
L2. Flight strips
L3. ASDE / Surface radar
L4. DBRITE
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Info'l Display)
L10. Memory

Notes:____

____

____

____

LOCAL CONTROL

Complexity Factor 2:______________________________

1. In your own words, what is it about this factor that makes it complex?

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None**)
Are the procedures effective: ☐ Yes ☐ No

3. What strategies (i.e., techniques) do they use and how often using the following scale. Enter the most common on the next page.

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

⇩ ⇩

Strategy	*What would influence you to use this strategy?*	Freq

LOCAL CONTROL INFORMATION

Most Common Strategy for Complexity Factor 2: ______________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful	Somewhat Useful	Moderately Useful	Very Useful	Extremely Useful
1	2	3	4	5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft position	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft type	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft category (I, II, and III)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft speed	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Route to be used while taxiing	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Assigned gate (or parking area)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Runway status	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Weather conditions (e.g. wind)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Traffic management	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Other (specify) ______________	_____	____ / ____ / ____ / ____ / ____ / ____
______________________	_____	____ / ____ / ____ / ____ / ____ / ____

Location

L1. Visual observation (looking out window)
L2. Flight strips
L3. ASDE / Surface radar
L4. DBRITE
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Info'l Display)
L10. Memory

Notes: ____

____

____

____

LOCAL CONTROL

Complexity Factor 3: ______________________________

1. In your own words, what is it about this factor that makes it complex?

____

____

____

____

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None**)
   Are the procedures effective: ☐ Yes ☐ No

____

____

____

3. What strategies (i.e., techniques) do they use and how often using the following scale. Enter the most common on the next page.

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

⇩

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

Strategy	***What would influence you to use this strategy?***	**Freq**
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____

LOCAL CONTROL INFORMATION

Most Common Strategy for Complexity Factor 3: ______________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful 1	Somewhat Useful 2	Moderately Useful 3	Very Useful 4	Extremely Useful 5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft position	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft type	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft category (I, II, and III)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft speed	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Route to be used while taxiing	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Assigned gate (or parking area)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Runway status	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Weather conditions (e.g. wind)	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Traffic management	_____	____ / ____ / ____ / ____ / ____ / ____
☐ Other (specify) ________________	_____	____ / ____ / ____ / ____ / ____ / ____
______________________________	_____	____ / ____ / ____ / ____ / ____ / ____

Location

L1. Visual observation (looking out window)
L2. Flight strips
L3. ASDE / Surface radar
L4. DBRITE
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Info'l Display)
L10. Memory

Notes:____

____

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____

GROUND CONTROL

Complexity Factor 1: ______________________________

1. In your own words, what is it about this factor that makes it complex?

____
____
____
____
____

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None)**
Are the procedures effective: ☐ Yes ☐ No

____
____
____

3. What strategies (i.e., techniques) do they use and how often using the following scale. Enter the most common on the next page.

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

⇩

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

⇩

Strategy	***What would influence you to use this strategy?***	**Freq**
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____
____	______________________________	____

GROUND CONTROL INFORMATION

Most Common Strategy for Complexity Factor 1: ________________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful 1	Somewhat Useful 2	Moderately Useful 3	Very Useful 4	Extremely Useful 5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	_____	____/____/____/____/____/____
☐ Aircraft position	_____	____/____/____/____/____/____
☐ Aircraft type	_____	____/____/____/____/____/____
☐ Aircraft category (I, II, and III)	_____	____/____/____/____/____/____
☐ Aircraft speed	_____	____/____/____/____/____/____
☐ Route to be used while taxiing	_____	____/____/____/____/____/____
☐ Assigned gate (or parking area)	_____	____/____/____/____/____/____
☐ Runway status	_____	____/____/____/____/____/____
☐ Weather conditions (e.g. wind)	_____	____/____/____/____/____/____
☐ Traffic management	_____	____/____/____/____/____/____
☐ Other (specify) ______________	_____	____/____/____/____/____/____
______________________	_____	____/____/____/____/____/____

Location

L1. Visual observation (looking out window)	L6. Weather displays
L2. Flight strips	L7. Asking another controller
L3. ASDE / Surface radar	L8. Scratch pad
L4. DBRITE	L9. SAIDS (Systems Atlanta Info'l Display)
L5. Communicating with the pilot	L10. Memory

Notes:____

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GROUND CONTROL

Complexity Factor 2: ______________________

1. In your own words, what is it about this factor that makes it complex?

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None**)

   Are the procedures effective: ☐ Yes ☐ No

3. What strategies (i.e., techniques) do they use and how often using the following scale. Enter the most common on the next page.

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

☐ ⇩

Strategy	*What would influence you to use this strategy?*	Freq

GROUND CONTROL INFORMATION

Most Common Strategy for Complexity Factor 2: ____________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful	Somewhat Useful	Moderately Useful	Very Useful	Extremely Useful
1	2	3	4	5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	_____	____/____/____/____/____/____
☐ Aircraft position	_____	____/____/____/____/____/____
☐ Aircraft type	_____	____/____/____/____/____/____
☐ Aircraft category (I, II, and III)	_____	____/____/____/____/____/____
☐ Aircraft speed	_____	____/____/____/____/____/____
☐ Route to be used while taxiing	_____	____/____/____/____/____/____
☐ Assigned gate (or parking area)	_____	____/____/____/____/____/____
☐ Runway status	_____	____/____/____/____/____/____
☐ Weather conditions (e.g. wind)	_____	____/____/____/____/____/____
☐ Traffic management	_____	____/____/____/____/____/____
☐ Other (specify) ______________	_____	____/____/____/____/____/____
______________________	_____	____/____/____/____/____/____

Location

L1. Visual observation (looking out window)
L2. Flight strips
L3. ASDE / Surface radar
L4. DBRITE
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Info'l Display)
L10. Memory

Notes:____

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____

GROUND CONTROL

Complexity Factor 3: ______________________________

1. In your own words, what is it about this factor that makes it complex?

2. What procedures are in place for this situation? (Circle all that apply: **7110.65 / 7110.2 / Other / None**)
Are the procedures effective: ☐ Yes ☐ No

3. What strategies (i.e., techniques) do they use and how often using the following scale. Enter the most common on the next page.

See List 4 for a complete list of strategies
- List 1 provides a factor specific list

Almost Never	Seldom	Sometimes	Often	Almost Always
1	2	3	4	5

Strategy	*What would influence you to use this strategy?*	Freq

GROUND CONTROL INFORMATION

Most Common Strategy for Complexity Factor 3: ____________________

1. Identify the information required to use this strategy.
2. Rate the usefulness of the information from Not/Applicable (1) to Extremely Useful (5).
3. Identify the location of the information using the key below.

Minimally Useful	Somewhat Useful	Moderately Useful	Very Useful	Extremely Useful
1	2	3	4	5

⇩

Information used for this strategy	Rating	Location (see below)
☐ Aircraft identification	____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft position	____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft type	____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft category (I, II, and III)	____	____ / ____ / ____ / ____ / ____ / ____
☐ Aircraft speed	____	____ / ____ / ____ / ____ / ____ / ____
☐ Route to be used while taxiing	____	____ / ____ / ____ / ____ / ____ / ____
☐ Assigned gate (or parking area)	____	____ / ____ / ____ / ____ / ____ / ____
☐ Runway status	____	____ / ____ / ____ / ____ / ____ / ____
☐ Weather conditions (e.g. wind)	____	____ / ____ / ____ / ____ / ____ / ____
☐ Traffic management	____	____ / ____ / ____ / ____ / ____ / ____
☐ Other (specify) ____________	____	____ / ____ / ____ / ____ / ____ / ____
____________________	____	____ / ____ / ____ / ____ / ____ / ____

Location

L1. Visual observation (looking out window)
L2. Flight strips
L3. ASDE / Surface radar
L4. DBRITE
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Info'l Display)
L10. Memory

Notes: ____

____

____

____

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____

EXIT QUESTION

1. What other information besides those listed below would help you in your ATC duties?
    - Aircraft identification
    - Aircraft position
    - Aircraft type
    - Aircraft category (I, II, and III)
    - Aircraft speed
    - Route to be used while taxiing
    - Assigned gate (or parking area)
    - Runway status
    - Weather conditions (e.g. wind)
    - Traffic management

INTERVIEWEE REFERENCE MATERIALS

List 1. Individual Strategies for Complexity Factors

1. Runway / Taxiway restrictions

S1. Adhere to standard procedures
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S11. Use the anticipated separation rule
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)

2. Active runway crossings

S1. Adhere to standard procedures
S10. Use "expedite" in control instruction
S8. Slow down the operation
S11. Use the anticipated separation rule

3. Runway/Taxiway configuration

S1. Adhere to standard procedures
S10. Use "expedite" in control instruction
S8. Slow down the operation
S11. Use the anticipated separation rule

4. Non Visibility Areas

S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)

5. Airspace Configuration

S1. Adhere to standard procedures
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S11. Use the anticipated separation rule
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)

6. Terrain / Obstructions

S1. Adhere to standard procedures

7. Satellite Airports

S21. Procedures Committee" to review operations
S22. Recommend changes to SOP.

8. High traffic volume

S1. Adhere to standard procedures
S10. Use "expedite" in control instruction
S11. Use the anticipated separation rule
S5. Apply visual separation criteria
S2. Apply greater in-trail spacing

9. Aircraft differing in performance characteristics

S1. Adhere to standard procedures
S2. Apply greater in-trail spacing

10. Emergency Operations

S1. Adhere to standard procedures
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S5. Apply visual separation criteria
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)

Scale:	Almost Never—	Seldom—	Sometimes—	Often—	Almost Always
	1	2	3	4	5

11. Wake Turbulence

S1. Adhere to standard procedures
S2. Ask for more in trail spacing

12. Special Flights (e.g., medivac, helicopters, other local traffic)

S1. Adhere to standard procedures
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S5. Apply visual separation criteria
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)

13. Overflights

S1. Adhere to standard procedures
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S5. Apply visual separation criteria
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)

14. Vehicular traffic

S1. Adhere to standard procedures
S11. Use the anticipated separation rule

15. At or below Minimums

S1. Adhere to standard procedures
S8. Slow down the operation
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S2. Apply greater in-trail spacing

16. Reduced visibility (e.g., fog, sun glare)

S1. Adhere to standard procedures
S8. Slow down the operation
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S2. Apply greater in-trail spacing

17. Inclement weather (e.g., wind, thunderstorms, lightning)

S1. Adhere to standard procedures
S8. Slow down the operation
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S2. Apply greater in-trail spacing

18. Airport surface activity (e.g., lawn mowing, lighting repair, construction)

S1. Adhere to standard procedures
S11. Use the anticipated separation rule

19. Equipment malfunctions

S1. Adhere to standard procedures
S8. Slow down the operation
S2. Apply greater in-trail spacing

20. Frequency congestion

S1. Adhere to standard procedures and phraseology
S8. Slow down the operation
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)

Scale:	Almost Never—Seldom—Sometimes—Often—Almost Always 1 2 3 4 5

21. Equipment Location

S4. Request supervisory assistance

22. Reduced visibility (e.g., reflections in tower cab)

S1. Adhere to standard procedures
S8. Slow down the operation
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S2. Apply greater in-trail spacing

23. Unfamiliar pilots (e.g. unfamiliar with airport, inexperienced)

S1. Adhere to standard procedures
S8. Slow down the operation

24. Pilot's weak mastery of English language

S1. Adhere to standard procedures
S8. Slow down the operation

25. Controller fatigue

S16. Relief from position
S17. Rotation to less workload position.
S18. Decombine position [if appropriate].

26. Traffic management initiatives

S1. Adhere to standard procedures
S8. Slow down the operation
S7. Gather complete information prior to making decision

27. Equipment distractions (e.g., low altitude alarms)

S8. Slow down the operation while attending to higher priority duties

28. Other distractions (e.g. visitors in tower cab, answering phone calls, noise)

S8. Slow down the operation
S3. Ask people to be quiet

29. OJT

S19. Closer monitor of elements impacting training, i.e., Developmental abilities, distractions, workload, etc.
S20. Additional classroom time.

Scale:	Almost Never—	Seldom—	Sometimes—	Often—	Almost Always
	1	2	3	4	5

List 2. Types of Information

1. Aircraft identification
2. Aircraft position
3. Aircraft type
4. Aircraft category (I, II, and III)
5. Aircraft speed
6. Route to be used while taxiing
7. Assigned gate (or parking area)
8. Runway status
9. Weather conditions (e.g.,wind)
10. Traffic management
11. Other (specify) _______________

List 3. Information Locations

L1. Visual observation (Looking through the window)
L2. Flight strips
L3. ASDE / surface radar
L4. DBRITE (Digital Bright Radar Indicator Tower Equipment)
L5. Communicating with the pilot
L6. Weather displays
L7. Asking another controller
L8. Scratch pad
L9. SAIDS (Systems Atlanta Informational Display)
L10. Memory

List 4. Strategies

S1. Adhere to standard procedures
S2. Ask for more in trail spacing
S3. Ask people to be quiet
S4. Request supervisory assistance
S5. Apply visual separation criteria
S6. Coordinate to expedite traffic (i.e., 'point-outs' with TRACON)
S7. Gather complete information prior to making decision (i.e., pilot/vehicle operator acknowledgements)
S8. Slow down the operation
S9. Slow down the operation while attending to higher priority duties
S10. Use "expedite" in control instruction
S11. Use the anticipated separation rule
S12. Point out traffic
S13. Training
S14. Team briefing
S15. Read and initial
S16. Relief from position
S17. Rotation to less workload position
S18. Decombine position [if appropriate]
S19. Closer monitor of elements impacting training, (i.e., developmental abilities, distractions, workload, etc.)
S20. Additional classroom time
S21. Procedures committee to review operations
S22. Recommend changes to SOP

Appendix H

Interview Counts

Table H1. Interview Counts by Controller Position

Category	Complexity Factor	Number of Interviews		
		Local	Ground	Total
I. Physical factors	1. Runway/taxiway restrictions	8	13	21
	2. Active runway crossings	10	11	21
	3. Runway/taxiway configuration	11	8	19
	4. Non-Visibility areas	4	5	9
	5. Airspace configuration	1	2	3
	6. Terrain/obstructions	3	1	4
	7. Satellite airports	1	–	1
II. Aircraft/traffic characteristics	8. High traffic volume	12	13	25
	9. Aircraft differing in performance chars	10	3	13
	10. Emergency operations	4	3	7
	11. Wake turbulence	7	2	9
	12. Special flights	3	–	3
	13. Overflights	–	–	–
	14. Vehicular traffic	5	3	8
III. Weather	15. At or below minimums	4	6	10
	16. Reduced visibility (weather)	4	8	12
	17. Inclement weather	4	3	7
IV. Ground operation	18. Airport surface activity	2	3	5
V. Equipment factors	19. Equipment malfunctions	5	4	9
	20. Frequency congestion	7	11	18
	21. Equipment location	–	2	2
	22. Reduced visibility (equipment)	–	–	–
VI. Individual factors	23. Unfamiliar pilots	5	5	10
	24. Pilot's weak mastery of English	7	9	16
	25. Controller fatigue	5	3	8
VII. ATC procedures	26. Traffic management initiatives	6	8	14
VIII. Distractions	27. Equipment distractions	–	–	–
	28. Other distractions	3	4	7
IX. Training	29. On-the-job training	3	8	11
X. Other	30. Site specific factors	7	6	13
		141	**144**	**285**

Appendix I

Complexity Factor Descriptions

Complexity Factor Descriptions

This section provides summaries of the ATCSs descriptions of how each factor contributes to complexity. The quotations following the descriptions serve to elucidate some of the points the participants expressed to our interviewers. For those factors on which we conducted no interviews, we have included information from other interviews that applied.

Physical Factors

1. Runway/Taxiway Restrictions

Complexity arises from impeded traffic flow, loss of options, the need to do more planning, and the need for additional communication and coordination. They occur due to the unavailability or restriction of runways/taxiways. The restrictions may be short-term, such as mowing activity or a spill, or much longer in duration, as in the case of construction. When a runway or taxiway is closed, it "decreases your options, requiring more creativity and maneuvering." It may also result in the need for more communications and contribute to delays. Taxiway restrictions place similar demands on the controller. Among the restrictions specifically noted were construction, traffic management initiatives, weight, wingspan, and noise abatement. The loss of options means that "you can't afford to lose anything" and that any other event, such as a push or unfamiliar pilot, will seriously bottleneck the operation. The effect of a closure, when taken into combination with the traffic volume, limited concrete, and restrictions such as weight, wingspan, noise, and metering, can severely limit alternatives. This can result in go-rounds, delays, the need to back taxi an aircraft down an active runway, or other measures. Runway/taxiway restrictions result in increased communications for both the local and ground control positions. Ground controllers, for example, may be forced to use progressive taxi instructions.

- "You already have high volume and a taxiway restriction limits your options to find a way to get an aircraft where it needs to be."
- "Very limited concrete means any closures really make an impact."
- "Taxiways too close to the runway . . . require extra coordination and communications."

2. Active Runway Crossings

A major determinant of the complexity of active runway crossings is the criticality of timing, particularly when both the local and ground controllers are busy. There is only limited time between arrivals and there is pressure not to miss a crossing opportunity. Active runway crossings add coordination (especially if the ground or local position is split), increase communication requirements, require sustained vigilance ("will the guy hold short?"), and can interrupt task flow (i.e., rhythm). The increased coordination includes ground-to-local controller communications as well as local-to-local controller, in those situations when the position is split. The volume of crossings, the type of vehicle or aircraft that is crossing, taxiway restrictions (especially weight), whether the taxiway crossing is perpendicular to the runway, time of day, as well as other factors influence the complexity of this factor. Tugs can be especially challenging since directives often have to be relayed from the cockpit to the tug operator. Some controllers noted that active runway crossings are more difficult at night because small aircraft blend into the runway lights when viewing the intersection from the tower. Airport design and configuration dictate the number of active runway crossings. At some sites, these crossings are rare, whereas at others they are required for all arrivals and departures. Some facilities also have configurations that require a single aircraft to cross at several points.

- "It is the volume of crossings. Virtually all planes [landing and departing] have to cross an active runway."
- ". . . your timing cannot be off at all. It is critical that your plan goes right."
- "It is tougher [to see aircraft] at night. Due to the height of the tower, small aircraft blend into the runway lights."
- "You must get the local controllers attention (write a strip and you are already busy). . . . your aircraft is often going against the flow."

3. Runway/Taxiway Configuration

The complexity caused by runway/taxiway configuration varies by site and configuration in use. Some sites have as many as 23 different configurations available and the routes, trouble areas, coordination, airspace, and overall complexity change based on the configuration. Remaining flexible, particularly as configurations change, contributes to the complexity of this factor. These changes add significantly to the number of communications, amount of coordination, and situation awareness demands. Controllers must take into account aircraft type, current aircraft configuration, route of flight, taxiway limitations, and other variables for each aircraft and these change for each configuration. Runway/taxiway configurations vary in terms of the number of traffic crossings, the number and length of runways, availability of high-speed turnoffs, availability of taxiways, runway/taxiway restrictions, non-visibility areas, availability of staging areas, and many other site- and configuration-unique characteristics. Lack of concrete, a common concern among many facilities, results in much more coordination, re-sequencing, and communication. Complexity arises at many locations from attempting to stack as many aircraft as possible without blocking an intersection or runway while maintaining the flexibility to meet traffic management initiatives. Runway/taxiway configuration poses a challenge to both local and ground controllers. Each must be flexible to the demands of the operation and move aircraft as dictated by the needs of the situation.

- "Some configurations are really complex. You may be clearing departures under arrivals, or landing to hold short. Complexity is from crossing departures with arrivals, and crossing taxiways."
- "Trying to determine how many aircraft you can stack since centerlines are only 800' apart. . . you must plan ahead for LAHSO."
- "The airport layout adds complexity . . . crossing runways, minimal concrete. Parallel runways are too close for separate ILS approaches."

4. Non-Visibility Areas

Complexity arises from the loss of the primary means of gathering information—visual observation. Controllers must rely on ASDE, pilot reports, memory, and flight strips to compensate, adding complexity and workload. For outbound aircraft, controllers have flight strips; however, for inbound aircraft these memory aids are typically not available. Non-visibility areas usually take the form of obscured taxiways and runways due to the presence of terminals, hangars, or other buildings. However, on occasion they may result from landing aircraft blending into mountains, having runways higher than the tower cab, or other site-specific factors.

- "You need to sequence an aircraft that you can't see . . .may be 9 or 10 [non-visible] aircraft."
- "Taxiways behind Terminal 4 and Taxiway R are obscured . . .increases communications and means you have to visualize the situation."
- "Taxiway C is hard to see at night."

5. Airspace Configuration

Among the aspects of this factor that controllers reported contributed to complexity was the need to remain flexible and adjust to configurations (and their idiosyncrasies) as they change, sequencing aircraft to promote efficiency while meeting restrictions. Airspace configuration determines runway/taxiway usage. Each configuration is different in terms of taxiways, routes, coordination, crossing points, and trouble areas. The restrictions may include taxiway and runway restriction, noise abatement procedures, and traffic management initiatives. This factor affects both the local and ground controller. The challenge for the ground controller is to sequence the aircraft appropriately for the local controller. Workload and complexity for the local controller arises from re-sequencing the aircraft as necessary to maintain efficiency.

- As configuration changes, "all routes, hot spot/trouble areas, and coordination changes."

6. Terrain/Obstructions

Complexity arises from the need to reroute aircraft to alternate runways and routes. Frequently the aircraft must travel in the opposite direction of the standard flow of traffic increasing coordination requirements and contributing to workload. Among the sources of obstructions infringing on the airspace at the sites we visited were mountains, crane at nearby construction sites, and the masts of ships in the adjoining bay.

- "Runway 4R has a 100' crane off the end of it."
- "Aircraft blend in with the mountains. It takes more time to locate them."

7. Satellite Airports

Satellite airports augment controller complexity by increasing traffic volume and leveraging responsibility for prioritizing the traffic to each airport. Some facilities may have as many as six satellite airports, increasing the complexity appreciably. In addition, these airports contribute considerably to communication and coordination requirements.

- "Increased coordination is involved."

Aircraft/Traffic Characteristics

8. High Traffic Volume

The volume of traffic itself increases workload (number of tasks, communication, etc.), requires sustained high situation awareness, pushes the limits of the airport, and raises the potential for error. As one controller stated, if you are already dealing with another factor (alternate runway due to a weight restriction, frequency congestion, an unfamiliar pilot, OJT, etc) then "the high traffic will put you down." Complexity arises from the pressure to move aircraft as expeditiously as possible and to maintain safe operations in the face of constraints. These constraints may be physical, as in the case of limited concrete (e.g., taxiways and runways) or gates, procedural (e.g., traffic management initiatives), or technological (e.g., limited frequencies). Along with the increase in complexity due to high traffic, controllers report spending more time entering flight information on strips or electronically instead of looking outside the tower cab where they need to be focused. The presence of an airline hub at an airport will almost certainly lead to extreme peaks in controller workload. For the ground position, high traffic volume requires nonstop talking and contributes to frequency congestion. Aircraft repositioning, aircraft pushing back into active taxiways or having to "back taxi," having more aircraft in non-visible areas, and other activities can seriously hamper ground operations. Local controllers face condensed finals meaning reduced separation between aircraft despite increased pressure "not [to] miss any holes." Wake turbulence and traffic management restrictions become a major factor during high traffic.

- "You can't stop. . .nonstop talking and awareness. No downtime during pushes."
- It's "almost overwhelming when it gets crazy."
- You are under "pressure to keep things going. Not miss any holes. Get planes in the air ASAP."
- "Finals are condensed, [you] have more things to watch for . . . [you have] aircraft doing S turns. . .you are busy punching in strips for the TRACON. . . and you are working departures as well . . .ensuring you meet traffic management restrictions."

9. Aircraft Differing In Performance Characteristics

We included this as a site selection criterion because of the complexity it introduces. Mixing aircraft with different performance characteristics increases the need for sustained situation awareness, increases the number of communications, requires the use of different separation criterion, and slows the operation as wake turbulence requirements become more prevalent. Mixing traffic types raises the likelihood of overtakes, requiring constant monitoring, and increasing the number of speed and heading assignments needed. Controllers must sequence aircraft appropriately for departure otherwise efficiency can be seriously compromised. The types of aircraft and their characteristics differ tremendously, ranging from heavy aircraft to GA, cargo, banner, helicopters, and the blimp airship. As a result, controllers must divert some aircraft to alternate runways and taxiways to meet restrictions. Local controllers must be aware of the capabilities of various aircraft to make runway turn offs, as well as speed and performance (climbing, turning, etc.) characteristics for departures. For ground, at facilities that do not have a designated GA runway, complexity is added by having to sequence jets, IFR, and props efficiently.

- "The complexity is trying to mix Cessna's with jets . . .the speeds are different."
- "You have to decide who to take first. Heavy needs more in trail . . .[some] operations have more props."

10. Emergency Operations

The complexity of emergency operations is that it is a non-routine situation and controllers must adjust priorities dynamically. In addition, the controller must either stop what they are doing, deal with the emergency, and return to their original traffic, or continue to also manage their original traffic, potentially losing their focus and situation awareness. Also, there is limited time to gather and prioritize the information. Emergency operations significantly increase coordination and communications. Local controllers have to divert aircraft to alternate routes. Ground controllers must stop all aircraft so that emergency vehicles can respond and they may have mixed vehicular and aircraft traffic. Emergencies require coordination with several parties and as a result, many facilities minimize frequency congestion through the use a separate frequency for emergencies. At some sites, the lack of familiarity with emergency procedures by some emergency response team members contributed to controller complexity and workload.

- Complexity arises from "[trying] to stop as many aircraft as possible to let emergency vehicles by . . . You must stop them from passing by firehouse. Runway crossings are a concern . . . emergency services are excellent."
- "Have to change original plan. The priority changes at the drop of a hat. Local fire department adds to the complexity . . . may have trouble with radios, several guys calling . . ."

11. Wake Turbulence

The major aspect of wake turbulence complexity is sequencing. Complexity results from the need to meet different separation requirements based on aircraft type and the need to sequence them effectively to maintain traffic flow. Some aircraft may require up to three minutes between departures, which can seriously hamper the operation. Some controllers noted that judging the gaps for airborne intersections is especially complex. Wake turbulence is a major determinant in aircraft sequencing. Wake turbulence also results in increased communication requirements and workload. Controllers must issue wake turbulence advisories to each aircraft as part of their control instructions, which slows the operation and contributes to frequency congestion. Wake turbulence situations requires the local and ground controller to work collaboratively to sequence departures appropriately to avoid delays, to minimize the need for re-sequencing, and to effectively use the gaps between arrivals and departures to move ground traffic. When busy on the ground position, missing one or two gaps will back up the entire operation. For local controllers, inefficient sequencing can seriously delay the number of departures and quickly back up the operation.

- "Slows down the airport, especially with big planes. Third arrival runway has an airborne intersection and it is difficult to judge the gap. . . If you miss a gap or two you will get backed up."
- ". . . you need to provide more separation behind larger aircraft. Can't get as many aircraft off the ground. . . [and timing] . . .trying to depart aircraft between arrivals."

12. Special Flights

Special flights include helicopters, flight check aircraft, special interest flights, and hot air balloons. These require coordination, add complexity by contributing to the traffic, and may remain on the boundary of an area taking attention away from other routine flights. Controllers identified helicopters as being particularly prevalent at three of the facilities and two of these noted that the lack of a standard route for this traffic contributed to the complexity.

- Our facility has "many special flights. . . .[including] a Helicopter training school with many foreign trainees."
- "[we have] lots of helicopter crossings . . .and no standard routes for helicopters."

13. Overflights

We conducted no interviews specifically on this factor. Overflights require controllers to prepare flight strips for the point-out. This adds workload and contributes to complexity because it is non-routine and it takes the controllers focus away from scanning the airport surface, potentially decreasing situation awareness.

14. Vehicular Traffic

Vehicular traffic contributes to complexity by adding communication and coordination, but in particular, it requires sustained vigilance. As one controller stated, "whenever vehicles cross or are near a runway there is a chance for incursions." Ongoing construction can be especially challenging due to the high volume of crossings, the potential for some personnel to have limited familiarity with crossing procedures, and for the removal or obstruction of airport signage. Snow removal teams also represent another unique aspect at some sites, comprising up to 25 pieces of equipment with a mix of various types of vehicles. These require extremely large gaps and slow the operation. In a survey of controllers and managers from 63 towers respondents indicated that construction vehicles, unauthorized vehicles, snowplows, and maintenance vehicles were among the most problematic vehicles. Almost half of the respondents selected improving vehicle operations on the airport movement area as their highest-priority solution (Kelley & Jacobs, 1998). Vehicular traffic is predominantly a factor for ground control, however it does affect the local position. All active runway crossings must be coordinated through the local position, contributing to workload. Also, local controllers must remain aware of maintenance, mowing, and other ground operations, particularly those near runways, so that they are prepared to send an aircraft round or hold a departure if necessary.

- " You need to coordinate all runway crossings with the local controller. You must stop what you are doing and get his attention and he must give approval for the crossing. . .meanwhile you need to put everything else on hold."
- "We have lots of construction and maintenance. . .Port activity, fuel trucks, mowers, construction personnel . . . [some are not well versed in crossing procedures]"

Weather

15. At Or Below Minimums

This factor is very similar to reduced visibility due to weather (Factor 16). It requires the use of more restrictive procedures and may be particularly demanding at facilities where these conditions rarely occur. This situation demands high levels of concentration and significantly more voice communications, particularly at facilities without surface radar. It is common for controllers to have to re-sequence aircraft during these conditions. During at or below minimum conditions, not as many aircraft can be moved due to use of more conservative separation criterion, there is increased reliance on additional information sources to supplement the loss of the "out the window" view, and the situation often encompasses the loss of the use of some runways and taxiways. In the words of one controller, "across the board, workload is higher per plane." Controllers reported feeling continued pressure to move the traffic even though faced with these constraints and having no margin for error. Local controllers must do much more planning, for example for missed approaches and issue many more directives. Ground controllers must adjust taxi routes to keep traffic clear of critical equipment or to meet wingspan or other restrictions. Participants indicated that limited concrete and gate space can be especially challenging.

- Relying on ASDE... "takes a high level of concentration... [and you] use a totally different set of rules ...complicated by very limited gate space . . . can't see some areas on ASDE."
- "Snow and thunderstorms often take ASDE out so you must rely on position reports."

16. Reduced Visibility (Weather)

Weather represents a major source of complexity to air traffic controllers because it invokes a very different set of rules. Depending on the facility, these rules may occur infrequently, because of infrequent bad weather. Among the changes resulting from reduced visibility are the use of more restrictive separation criteria (slowing the operation), the use of different taxi routes, and the loss of the use of ILS critical areas. These changes lead to the need for more verbal communications (especially in the form of pilot reports), reliance on more varied tools to ensure separation (resulting in increased scanning within the Tower cab), and the need for "high levels of concentration since you are using a totally different set of rules." By losing the ability to scan out the window, controllers must rely more upon multiple information sources including ASDE, DBRITE, memory, scratch pads, pilot reports, and flight strips. In one participant's estimation, this "triples the workload." Reduced visibility forces local and ground controllers to use different procedures and raises additional considerations. Among the challenges for ground controllers is that the aircraft are not already sequenced, they call in blind, they are in closer proximity, and at many facilities the ground controller does not have data tags available. Local controllers must rely on the DBRITE and lose the use of visual separation, significantly increasing their workload.

- "You can't see who you're talking to. . .you're relying on ASDE [which] increases communications. . . . the rules change. . .[and] you can't use ILS critical areas."
- "You are relying on ASDE and pilot reports. . .requires more communication."

17. Inclement Weather

Inclement weather adds to workload and complexity through changes in configuration and runway usage, increased vectoring, increases in the number of pilot requests for different headings (especially for thunderstorms), increased monitoring requirements contributing to fatigue, and the addition of weather-related activities (e.g., coordination for snow removal vehicles and test actions to measure traction, issuance of wind sheer alerts). In the case of fog, snowstorms, dust storms, and other visibility related phenomenon, the effect is similar to reduced visibility. However, thunderstorms, windshear, and other events may have additional considerations besides the increased vigilance and use of non-routine routes and procedures. In the case of windshear, for example, the controller must issue a low-level wind shear alert system (LLWAS); however, some facilities rarely use this equipment, and its associated procedures and phraseology. LLWAS also add complexity due to the unpredictability of what an aircraft may do in response to the advisory.

- "Fog is the most common and worst situation. . . You lose one of your senses. . . and need [to focus] ASDE and SMIGS [ship channel radar]."
- "Fog in particular is bad. Means you are using the radar—can't see a target out the window."
- "The loss of visibility is not a big deal. The most complex thing is changing the runways. You have a rush on one way and then the weather changes and you have to change direction. You rush to one runway and take the others opposite direction."

Ground Operation

18. Airport Surface Activity

Airport surface activity increases complexity by closing taxiways and runways, requiring controllers to reroute traffic around the activity, and requiring sustained vigilance. Common sources of activity are FAA maintenance vehicles, airport vehicles, city vehicles, mowers, and construction vehicles. Some construction vehicle operators in particular demonstrate limited knowledge of airport crossing procedures. Construction projects can be long term and often require rerouting of aircraft, contributing to communication and coordination requirements. Airport surface activity affects the ground controller to a larger degree, however local controllers must be aware of the activity and use runway closure strips as a memory aid.

- "There are lots of city vehicles, a lot of construction . . .need to coordinate their active runway crossings."

Equipment Factors

19. Equipment Malfunctions

Equipment malfunctions introduce non-routine situations and require the use of standby equipment and procedures. As one controller stated, the complexity is that "you are out of your comfort zone." The degree of impact is dependent on the type of equipment that fails. Though rare because of the very high reliability of the equipment and the availability of backup systems, the most significant malfunction is the loss of communications. Loss of communications shuts down the airport and means that aircraft cannot be moved in or out. The loss of the DBRITE or ASDE is not as consequential and essentially results in an increased reliance upon flight strips and memory. Controllers at some of the sites indicated that the DBRITE and/or ASDE equipment was unavailable on occasion. The loss of a headset is more of an "inconvenience." The controller will attempt to replace it with another handset or headset; failing this they will send their traffic to another position. Though not necessarily due to an ATC equipment malfunction, stuck mikes are a relatively common occurrence. These events add to workload by forcing the controller to repeat instructions and may require them to go to a second frequency.

- "Radio most important . . .really the only equipment ground has . . .. [if communications lost]. . .ground halts, can't get aircraft in or out."
- "You are out of your comfort zone."
- "Loss of communications are especially bad. You have to stop everything and send all traffic to another position to work."

20. Frequency Congestion

Frequency congestion results from the sheer number of aircraft. It contributes to complexity by increasing controller workload and the number of communications when time is critical. Frequency congestion leads to blocked transmissions requiring repeats and occupying additional controller time; it can interrupt rhythm (which "can cause you to forget where you are"); and may require the controller to re-sequence aircraft. High traffic volume, inexperienced pilots, and stuck mikes are among the factors that contribute to frequency congestion. Facilities where additional frequencies are available may elect to split the busy position (local or ground). This practice is beneficial, however it results in additional coordination and may lead to additional effort for others in the tower by requiring them to take extra steps to determine who is responsible for a specific aircraft. This complexity factor affects both the local and ground positions. For the local position, time criticality is a major driver. For the ground position it tends to be the volume of traffic.

- "There are so many aircraft [calling in] that you can't hear each other."
- "Everybody wants in and out at the same time."
- It is often "difficult to get transmissions out without getting stepped on."
- The high volume of aircraft means you have to "block with your own [transmission]."
- "I get four new aircraft each 60 seconds or so—which means I have 12 seconds per aircraft to get the call, give them the route, and take the read back. I can't afford to slow the operation—either incoming or outgoing."

21. Equipment Location

Complexity arises from the non-integration of information systems. This increases heads down time, workload, and scanning time, even though the controller's primary information source remains looking outside the tower cab. As one interviewee stated, "the clocks, radar, radio, landlines, wind instruments, and RVR are all scattered [around the tower]." In addition to these sources, controllers must consult several other systems including the ATIS, TIMPs/OPSNET, SAIDS, DBRITE, and ASDE. Controllers underscored the importance of looking outside, not scanning the inside of the tower for information. Another contributing factor is that the equipment location is not consistent between positions. This requires the controller to adjust their scanning. Also, the equipment locations are subject to change as new systems or additional pieces of equipment are added to the tower. An NRC report indicates that the FAA is undertaking a tower integration program aimed at consolidating disparate displays and controls (Wickens et al., 1998, p. 67).

- “Ergonomics. All sources are spread out. Altimeter, clocks, radar, radio, land lines, wind instruments, RVR. . .are all scattered.”
- “Because of the equipment layout in the new tower local and ground share an ASDE… but they need to focus on different areas [of the airport].”

22. Reduced Visibility (Equipment)

We conducted no interviews on this factor due to its low incidence at the facilities we visited. It includes glare on computer monitors and the loss of visibility outside the tower cab due to the presence of equipment in the tower itself. Complexity arises either from the loss of information available on the display or from the loss of visibility of targets outside the tower cab reducing the controller’s ability to scan the airport surface. Both result in a loss of situation awareness.

Individual Factors

23. Unfamiliar Pilots

Unfamiliar pilots contribute to complexity by requiring sustained attention and repeats, adding to frequency congestion and workload and slowing the operation. Another aspect, that can potentially be more significant, is that the controller has no idea of what the aircraft will do and they have to keep other aircraft out of their way. Controllers relayed incidents that included crossing an active runway without clearance, turning the wrong way on a taxiway, requiring progressive instructions, and blocking the frequency. These actions are much more common at facilities with training facilities located near their primary runway, as in the case of two of the sites visited. Unfamiliar pilots can be more of an issue for local control, since ground controllers have the option to hold an aircraft in position until instructions can be communicated to them.

- “The ramp is very close to the primary runway. A training facility is located near there, and there are inadequate taxiway markings . . .. Pilots go down between them [Taxiway C and D] and end up on the runway.”
- “They require extra time and care and more visual time.”

24. Pilot’s Weak Mastery of English

A pilot’s weak mastery of English contributes to controller complexity by requiring sustained attention, repeats, and changes in controller plans. Though lack of understanding on both ends of the communication is a big consideration, the leading aspect is the need for the controller to constantly divert much of their attention to a single aircraft. This adds to frequency congestion and workload and slows the operation. The controller cannot be sure that the pilot understands what they are trying to get across. As a result, the aircraft may not perform as instructed. These events are rare at some sites; however, at others, for example sites with foreign flights and foreign training schools, they may occur much more frequently. At one site, for example, an interviewee estimated that it occurs “at least once a day.”

- “It’s like hitting a speed bump.”
- “You have no idea what they will do.”
- “All your attention is diverted to one person.”
- “You don’t know if they understood your instructions . . . you keep everybody else away from them.”

- "I use the Hamster Theory. . . like a hamster on its wheel, they will eventually get tired and stop. I watch them closely and keep other traffic away."

25. Controller Fatigue

Although fatigue can result from extended heavy workload conditions, it is also shiftwork related. The loss of sleep results from changes in sleep patterns and in some cases minimal time available for sleep due to long commute times. Fatigue adds complexity through impaired situation awareness, loss of focus, increased thought possessing time, and it makes planning more difficult. This may result in missed calls, contributing to frequency congestion, or possibly mistakes. Some controllers indicated that when fatigued, there was more of a chance of forgetting their directives to aircraft, especially for ground since they had the aircraft longer.

- "Mids are busy and I may only get four hours of sleep before [the shift]."
- "Difficult to stay focused."
- "Planning is difficult."
- "You don't feel right."
- "Can lead to mistakes."

ATC Procedures

26. Traffic Management Initiatives

Traffic management initiatives add complexity through increased maneuvering, re-sequencing, coordination, communications, and workload to meet the restrictions; all of which seriously slow the operation. It means that in addition to separating aircraft and maintaining traffic efficiently, they now must comply with multiple restrictions. The initiatives also require much more heads down time to identify and meet the restrictions and may require the use of progressive instructions. Traffic management initiatives restrict traffic flow and limit the controllers' options. There are several different sources of restrictions, but they typically result from traffic volume and weather disturbances. One aircraft may have restrictions that must be met including estimated departure clearance time and En Route Sequencing Program initiatives. In-trail restrictions are especially difficult if coupled with bad weather. For ground controllers, the complexity arises from trying to sequence aircraft based on the traffic restrictions to make the local controllers job easier. They may also need to go to progressive instructions in order to re-sequence aircraft. Facilities with limited concrete significantly increase the ground controllers' effort since they have inadequate staging areas to pass aircraft. The ground controllers reported needing to make plans before the aircraft leaves the gates, although at some facilities they do not control aircraft pushbacks. Local controllers must take care of what ground control couldn't do and re-sequence as necessary to meet the restrictions.

- "It's like playing Chess . . .sequencing, trying to move a guy to where he needs to be."
- Difficulty for ground control is that "you can't pass aircraft on ground areas because of limited concrete and taxiways . . .once in line you are stuck."
- You are "being burdened with positioning aircraft to meet an ambiguous slot time without regard for the impact on flow of other traffic at your facility."

Distractions

27. Equipment Distractions

We conducted no interviews on this factor. Equipment distractions include aural alerts from MSAW, STARS, and other systems. The complexity results from the interruption of the current task and if the alert is loud, it may also lead to speech interference. Aural alerts are more intrusive if they are considered "nuisance" or "false" alarms.

28. Other Distractions

This factor includes visitors to the tower cab, ambient and equipment noise, as well as other sources such as phones ringing. Distractions result in the loss of focus, loss of situation awareness, repeats, and increased workload. Controllers reported difficulty filtering out other communications while listening to pilots. Visitors in particular, if not effectively supervised, may block visibility of equipment, restrict movement through the cab, or raise noise levels to a point that interferes with pilot-to-controller communications. Equipment noise can be intrusive, resulting in annoyance and speech interference. Controllers at one site indicated that the electric whine of the ASDE-3 equipment above the tower cab was particularly intrusive.

- "Visitors are extremely distracting . . .before 911 we could have tours of 10+ individuals."
- "[Distractions] cause you to lose focus . . .[and result in the] repetition of calls."
- "Difficulty listening . . . hard to filter out other noises."

Training

29. On-the-Job Training

Air Traffic Controllers work in a highly collaborative team oriented environment. As such, the introduction of a developmental controller can hamper the operation. At large facilities, in particular, training is an ongoing process and teams may have two or three trainees on position at a time. Though OJT raises challenges for the team, the interviewees recognized that it is an essential element. Developmental controllers contribute complexity by being unpredictable, slowing the operation, and making poor judgments, all of which may potentially lead to errors. They may stop an aircraft on a taxiway interrupting traffic flow, not use concrete and taxiways effectively, or overload a runway. One participant characterized it like having someone "trying to take your ticket away." Instructors must closely monitor every action, possibly focusing much of their attention on the trainee and not out of the window. Perhaps the most challenging aspect of developmental trainees is that as they gain experience they become increasingly more capable and approach the limits of the instructor. OJT is a factor for local and ground controllers.

- "Speed is reduced [which] throws timing off, leads to mistakes. You basically have a guy trying to take your ticket away."
- "Potential for error is high. You have limited time to explain to them while ensuring traffic is moving."
- "You do not know how far to let them go before bailing them out."
- "The Developmentals' inexperience leads to poor judgment, especially with heavy volume. They may stop aircraft and interrupt traffic flow, or not use concrete and taxiway effectively. . . you must monitor them very closely."

- "Training is always going on. You may have two or three trainees on at a time. Trainer may put trainee in middle of a rush and get in over trainees head. You may have to send aircraft around them."

Appendix J

Average Complexity Factor Ratings

Table J1. Mean CI ratings and Standard Deviations (*SD*) by Site:

Local Control Position

Complexity Factor	**ATL (n=10)**		**BJC (n=10)**		**BOS (n=10)**		**OAK (n=10)**		**ORD (n=12)**		**PHX (n=10)**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
1. Runway/taxiway restrictions	6.3	1.3	7.4	1.4	7.5	1.3	8.4	1.0	7.0	1.2	6.4	1.6
2. Active runway crossings	8.9	1.1	6.9	0.9	8.7	1.3	8.9	1.4	7.7	1.5	8.2	1.3
3. Runway/taxiway configuration	6.8	1.8	6.7	1.7	6.6	1.3	7.7	1.6	8.2	1.3	7.0	1.6
4. Non-visibility areas	5.4	2.8	6.2	2.1	3.3	2.3	6.6	1.3	3.3	1.1	4.9	3.0
5. Airspace configuration	3.5	1.5	3.8	1.5	4.0	1.7	6.6	1.6	6.7	1.1	7.1	1.3
6. Terrain/obstructions	2.2	1.0	5.5	2.8	3.9	2.3	4.6	1.3	2.3	1.0	5.0	2.2
7. Satellite airports	4.7	2.7	2.9	1.8	3.9	2.1	6.7	1.7	6.3	1.4	3.0	2.4
8. High traffic volume	9.0	0.9	7.6	0.5	7.6	1.4	7.9	0.9	9.6	0.7	8.0	1.1
9. Aircraft differing in performance chars	8.1	1.6	7.5	1.1	6.5	2.0	8.2	0.9	7.3	1.5	7.5	1.4
10. Emergency operations	5.7	1.1	5.5	1.4	6.2	1.4	5.3	1.2	6.1	1.2	5.6	1.3
11. Wake turbulence	8.5	2.0	4.3	1.3	6.9	1.4	7.0	1.8	8.3	2.0	6.7	1.4
12. Special flights	5.3	1.4	5.0	1.3	5.9	1.1	6.1	2.0	6.6	0.9	7.2	1.3
13. Overflights	3.4	2.5	5.0	1.5	3.4	1.5	6.9	1.3	2.2	1.6	4.4	2.6
14. Vehicular traffic	5.0	4.1	6.4	1.2	6.5	1.6	7.6	2.0	7.0	1.7	5.2	1.9
15. At or below minimums	6.8	1.0	5.2	1.0	7.7	1.3	6.3	1.5	7.6	1.2	5.2	1.5
16. Reduced visibility (weather)	6.7	1.3	7.6	1.6	7.4	1.3	6.4	1.3	7.5	1.3	5.3	1.8
17. Inclement weather	7.3	0.9	6.0	1.1	7.3	1.4	5.8	1.1	7.4	1.3	5.7	1.6
18. Airport surface activity	4.3	2.3	5.1	1.5	5.5	1.9	5.8	1.8	5.4	2.1	3.8	1.4
19. Equipment malfunctions	5.7	1.7	6.2	1.5	5.6	1.7	6.3	1.1	5.4	1.2	5.8	1.2
20. Frequency congestion	8.1	1.0	7.2	0.9	7.9	1.0	7.2	0.9	7.6	1.5	7.4	1.6
21. Equipment location	6.0	2.8	3.4	1.3	4.3	1.7	5.1	1.3	5.3	2.3	3.7	1.7
22. Reduced visibility (equipment)	6.1	2.2	5.8	2.2	5.3	2.5	5.6	1.9	5.5	2.3	3.5	1.7
23. Unfamiliar pilots	5.6	1.3	7.1	1.4	6.5	1.0	7.6	0.8	6.1	1.6	6.6	1.3
24. Pilot's weak mastery of English	5.0	1.9	6.7	1.6	6.3	1.4	7.4	1.6	6.9	1.8	5.7	1.1
25. Controller fatigue	6.7	1.1	5.0	1.6	6.0	2.0	7.1	1.4	5.5	1.5	5.4	2.3
26. Traffic management initiatives	7.4	1.2	5.7	2.2	7.6	1.4	7.3	1.4	8.3	1.4	6.6	1.8
27. Equipment distractions	4.9	1.0	4.8	1.5	5.3	1.1	5.3	0.8	4.4	1.1	5.0	1.2
28. Other distractions	4.3	1.8	6.9	1.6	6.6	2.2	6.1	1.4	5.1	1.3	4.3	1.7
29. On-the-job training	7.7	1.3	5.4	1.3	7.8	1.5	6.3	1.7	8.3	1.4	6.2	1.6

Table J2. Mean CI ratings and Standard Deviations (*SD*) by Site:

Ground Control Position

Complexity Factor	ATL (n=10)		BJC (n=10)		BOS (n=10)		OAK (n=10)		ORD (n=12)		PHX (n=10)	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
1. Runway/taxiway restrictions	7.1	1.9	7.1	1.4	7.5	1.8	8.5	1.4	7.6	1.1	7.2	1.4
2. Active runway crossings	9.0	0.9	6.0	1.4	5.5	2.6	8.7	1.4	5.0	3.1	8.0	1.9
3. Runway/taxiway configuration	7.4	1.6	5.9	1.6	7.4	1.5	7.7	1.6	8.0	1.3	7.0	1.4
4. Non-visibility areas	6.0	2.6	5.5	2.1	5.3	2.1	6.4	1.1	3.1	1.0	7.3	1.6
5. Airspace configuration	3.6	2.6	2.8	2.1	2.9	2.5	4.3	2.6	5.3	2.6	5.2	3.1
6. Terrain/obstructions	2.1	1.4	2.9	2.8	1.9	1.7	2.9	2.3	1.7	1.2	3.5	2.8
7. Satellite airports	2.7	2.5	1.4	1.6	1.2	1.0	2.3	1.6	4.2	2.6	2.8	2.4
8. High traffic volume	9.5	0.5	7.2	0.4	8.8	1.0	7.7	1.1	9.7	0.8	8.5	0.8
9. Aircraft differing in performance chars	6.1	2.5	4.0	2.2	5.6	1.7	6.0	2.3	5.2	2.1	5.5	1.4
10. Emergency operations	6.5	1.1	5.8	1.0	6.5	1.4	5.8	1.5	5.7	1.4	5.4	1.0
11. Wake turbulence	5.5	3.1	2.5	2.1	4.8	2.0	4.9	2.1	4.8	2.7	4.7	1.5
12. Special flights	3.9	1.7	4.3	2.0	2.8	1.7	4.1	1.4	2.8	1.7	4.4	1.5
13. Overflights												
14. Vehicular traffic	8.3	2.0	6.4	1.6	5.5	1.8	8.5	1.3	5.9	2.0	4.5	1.6
15. At or below minimums	7.2	1.6	5.8	1.3	7.8	1.4	6.4	1.4	6.2	2.2	4.3	1.8
16. Reduced visibility (weather)	6.8	2.0	6.0	1.4	8.0	1.3	6.1	1.5	6.9	1.5	3.8	1.5
17. Inclement weather	7.3	1.2	5.0	1.2	6.7	1.6	5.5	1.8	7.3	1.6	4.8	2.3
18. Airport surface activity	4.8	2.1	6.0	1.3	5.0	1.7	7.2	2.1	5.0	1.9	4.4	2.2
19. Equipment malfunctions	5.3	2.0	5.5	2.0	4.9	1.6	5.5	1.3	4.8	1.9	4.5	1.6
20. Frequency congestion	8.5	1.3	6.2	1.1	8.7	1.3	6.9	1.0	8.8	1.1	8.5	1.2
21. Equipment location	5.2	2.7	3.4	2.0	3.2	1.7	4.6	1.1	4.8	2.8	3.8	1.7
22. Reduced visibility (equipment)	6.2	2.8	3.8	1.9	5.2	2.2	5.3	2.0	5.2	2.2	3.7	1.8
23. Unfamiliar pilots	6.0	1.3	6.5	1.3	6.8	1.2	7.8	1.5	6.9	1.1	6.5	1.2
24. Pilot's weak mastery of English	4.8	2.1	6.4	1.3	6.6	1.8	7.3	1.6	6.9	1.5	5.5	0.7
25. Controller fatigue	6.5	1.4	4.2	1.7	6.2	1.8	6.9	1.4	5.5	1.6	5.3	1.8
26. Traffic management initiatives	7.5	1.4	5.9	2.3	8.4	1.4	7.3	1.4	8.3	1.7	6.8	2.3
27. Equipment distractions	4.1	1.1	4.8	1.7	4.2	1.1	5.0	0.9	3.4	1.4	3.9	1.4
28. Other distractions	4.4	1.6	7.1	1.3	6.3	2.1	5.8	1.3	4.4	1.7	4.5	1.2
29. On-the-job training	7.4	1.3	4.7	1.4	6.7	2.6	5.8	1.8	7.7	2.1	5.8	2.0

Table J3. Mean Complexity Ratings and Standard Deviations (*SD*) by Site:
Local Control Position

Complexity Factor	**ATL (n=10)**		**BJC (n=10)**		**BOS (n=10)**		**OAK (n=10)**		**ORD (n=12)**		**PHX (n=10)**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
1. Runway/taxiway restrictions	3.3	0.5	3.9	0.7	3.7	0.9	4.3	0.7	3.7	1.0	3.2	0.9
2. Active runway crossings	4.3	1.1	3.1	0.6	4.2	0.8	4.4	0.8	3.7	1.0	3.6	1.0
3. Runway/taxiway configuration	3.1	1.4	3.0	1.2	3.1	0.6	3.8	0.8	3.8	0.8	3.0	0.8
4. Non-visibility areas	2.5	1.5	3.2	1.1	1.7	1.3	3.1	0.9	1.4	0.5	2.2	1.5
5. Airspace configuration	1.8	0.8	1.9	0.7	1.8	0.6	3.3	0.9	3.2	0.8	3.2	0.6
6. Terrain/obstructions	1.1	0.6	2.7	1.4	1.8	1.2	2.2	0.6	1.0	0.4	2.1	1.1
7. Satellite airports	2.3	1.5	1.4	0.9	1.8	1.1	3.1	0.7	3.2	1.0	1.3	1.2
8. High traffic volume	4.5	0.7	4.6	0.5	3.9	0.9	4.1	0.6	5.0	0.0	3.8	0.8
9. Aircraft differing in performance chars	4.0	0.9	3.8	1.0	3.0	1.1	4.1	0.7	3.4	0.5	3.6	0.8
10. Emergency operations	3.0	0.7	3.2	1.0	3.5	1.0	3.1	1.0	3.2	1.2	3.1	1.0
11. Wake turbulence	4.1	1.3	2.2	0.6	2.8	1.0	3.5	1.0	3.9	1.3	3.0	0.8
12. Special flights	2.7	0.8	2.1	0.7	2.5	0.7	3.0	1.1	3.0	0.7	3.0	0.9
13. Overflights	1.8	1.5	1.9	1.0	1.5	0.8	3.3	0.7	1.0	0.9	2.2	1.2
14. Vehicular traffic	2.5	2.2	3.1	0.6	2.9	0.8	3.7	1.2	3.5	1.2	2.3	0.8
15. At or below minimums	4.0	0.9	2.5	1.0	4.1	0.7	3.6	1.1	4.4	0.9	3.4	1.4
16. Reduced visibility (weather)	3.5	0.8	4.0	1.2	3.9	0.7	3.6	1.0	4.0	1.0	3.1	1.2
17. Inclement weather	4.1	0.7	2.8	0.9	3.9	0.9	3.3	0.9	4.1	1.0	3.5	1.1
18. Airport surface activity	2.0	1.2	2.3	0.7	2.6	1.1	2.8	0.8	2.5	1.3	1.7	0.7
19. Equipment malfunctions	3.5	1.2	3.8	1.0	3.2	1.1	3.6	0.8	3.0	1.0	3.4	0.8
20. Frequency congestion	4.1	0.9	3.9	0.6	4.1	0.7	3.9	0.9	3.6	0.9	3.9	1.0
21. Equipment location	2.9	1.4	1.8	0.6	2.1	0.7	2.9	0.8	2.7	1.1	1.8	0.6
22. Reduced visibility (equipment)	3.1	1.2	3.1	1.1	2.6	1.3	2.8	1.0	2.8	1.3	2.0	1.1
23. Unfamiliar pilots	3.4	1.0	3.9	1.0	3.4	1.0	3.9	0.6	3.4	1.2	3.9	0.9
24. Pilot's weak mastery of English	3.0	1.4	3.6	0.8	3.6	0.7	3.8	0.9	3.8	1.2	3.5	1.1
25. Controller fatigue	3.9	0.8	2.9	1.2	3.1	1.1	3.8	0.9	3.0	1.0	3.1	1.3
26. Traffic management initiatives	3.8	0.8	2.8	1.1	3.7	0.8	3.7	0.8	4.2	0.9	3.1	1.0
27. Equipment distractions	2.3	0.7	2.3	0.7	2.6	0.7	2.5	0.5	2.2	0.6	2.3	0.7
28. Other distractions	2.4	1.2	3.5	1.2	3.5	1.1	3.1	0.7	2.4	0.8	2.0	0.9
29. On-the-job training	3.7	0.9	3.4	0.8	3.7	1.3	3.4	1.0	4.1	0.8	3.4	1.2

Table J4. Mean Complexity ratings and Standard Deviations (*SD*) by Site: Ground Control Position

Complexity Factor	**ATL (n=10)**		**BJC (n=10)**		**BOS (n=10)**		**OAK (n=10)**		**ORD (n=12)**		**PHX (n=10)**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
1. Runway/taxiway restrictions	3.9	1.0	3.4	0.7	3.8	1.2	4.3	0.7	4.3	0.8	3.6	0.7
2. Active runway crossings	4.7	0.5	3.2	0.8	2.8	1.4	4.3	0.8	2.6	1.6	3.8	1.1
3. Runway/taxiway configuration	3.8	1.0	2.8	0.9	3.3	1.2	3.9	0.9	4.1	0.8	3.3	0.7
4. Non-visibility areas	2.9	1.4	2.6	1.0	2.6	1.2	3.1	0.6	1.5	0.5	3.4	1.0
5. Airspace configuration	1.9	1.5	1.4	1.0	1.4	1.2	2.1	1.3	2.7	1.5	2.5	1.6
6. Terrain/obstructions	1.1	0.7	1.3	1.2	0.9	0.7	1.4	1.0	0.8	0.6	1.6	1.5
7. Satellite airports	1.4	1.3	0.7	0.8	0.6	0.5	1.1	0.7	2.3	1.5	1.2	1.0
8. High traffic volume	4.8	0.4	4.2	0.4	4.7	0.5	3.9	0.7	4.9	0.3	4.4	0.5
9. Aircraft differing in performance chars	2.6	1.3	1.5	1.0	2.5	1.1	3.1	1.3	2.3	0.9	2.6	0.5
10. Emergency operations	3.6	0.8	3.5	0.7	3.5	0.8	3.0	0.9	2.9	1.0	2.9	0.7
11. Wake turbulence	2.3	1.6	1.4	1.2	2.1	0.9	2.4	1.3	2.1	1.2	2.0	0.7
12. Special flights	1.9	1.1	1.8	0.9	1.4	0.8	2.0	0.9	1.3	0.8	1.9	0.7
13. Overflights												
14. Vehicular traffic	4.2	1.0	3.0	0.8	2.4	1.0	4.1	0.7	3.3	1.3	2.1	0.6
15. At or below minimums	4.1	1.1	3.2	1.0	4.2	0.8	3.6	1.1	3.3	1.4	2.6	1.2
16. Reduced visibility (weather)	3.8	1.2	3.1	1.0	4.4	0.7	3.4	1.1	3.9	1.1	2.2	1.2
17. Inclement weather	4.1	0.7	2.3	0.7	3.8	1.1	3.0	1.1	4.3	1.1	2.8	1.4
18. Airport surface activity	2.2	1.2	3.1	0.9	2.3	0.9	3.8	1.1	2.5	1.3	2.1	0.9
19. Equipment malfunctions	3.1	1.6	3.3	1.4	2.6	0.8	3.2	1.1	2.8	1.3	2.5	1.2
20. Frequency congestion	4.3	0.8	3.6	0.7	4.6	0.7	3.8	0.6	4.5	0.5	4.5	0.5
21. Equipment location	2.8	1.5	1.8	1.0	1.6	0.8	2.6	0.5	2.4	1.6	1.8	0.6
22. Reduced visibility (equipment)	3.4	1.6	1.9	1.0	2.7	1.2	2.9	1.1	2.8	1.3	1.8	0.8
23. Unfamiliar pilots	3.7	1.1	3.4	0.8	3.8	0.6	4.1	0.9	4.2	0.8	3.7	0.8
24. Pilot's weak mastery of English	2.9	1.4	3.3	0.8	3.6	1.0	3.8	0.9	3.9	1.1	3.5	0.8
25. Controller fatigue	3.7	0.9	2.5	1.4	3.2	0.9	3.6	0.8	2.8	0.8	3.0	1.3
26. Traffic management initiatives	4.2	0.9	3.0	1.2	4.1	0.7	3.6	0.7	4.2	1.0	3.4	1.2
27. Equipment distractions	2.0	0.7	2.2	0.8	2.1	0.6	2.5	0.5	1.8	0.8	2.0	0.7
28. Other distractions	2.3	0.9	3.6	0.8	3.2	0.9	2.8	0.8	2.2	0.9	2.2	0.6
29. On-the-job training	3.6	1.0	2.9	1.0	3.2	1.5	3.0	0.9	3.9	1.2	3.1	1.3

Table J5. Mean Frequency Ratings and Standard Deviations (*SD*) by Site: Local Control Position

Complexity Factor	**ATL (n=10)**		**BJC (n=10)**		**BOS (n=10)**		**OAK (n=10)**		**ORD (n=12)**		**PHX (n=10)**	
	Avg	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
1. Runway/taxiway restrictions	3.0	0.9	3.5	1.0	3.8	0.8	4.1	0.6	3.3	0.8	3.2	0.8
2. Active runway crossings	4.6	0.5	3.8	0.8	4.5	0.7	4.5	0.7	4.0	0.7	4.6	0.7
3. Runway/taxiway configuration	3.7	1.1	3.7	1.2	3.5	0.8	3.9	0.9	4.3	0.8	4.0	1.2
4. Non-visibility areas	2.9	1.6	3.0	1.1	1.6	1.1	3.5	0.7	1.8	0.7	2.7	1.6
5. Airspace configuration	1.7	0.8	1.9	0.9	2.2	1.2	3.3	0.9	3.5	0.9	3.9	1.0
6. Terrain/obstructions	1.1	0.6	2.8	1.5	2.1	1.2	2.4	0.7	1.3	0.6	2.9	1.4
7. Satellite airports	2.4	1.3	1.5	1.0	2.1	1.2	3.6	1.2	3.1	0.7	1.7	1.3
8. High traffic volume	4.5	0.5	3.0	0.5	3.7	0.7	3.8	0.4	4.6	0.7	4.2	0.6
9. Aircraft differing in performance chars	4.1	1.0	3.7	0.8	3.5	1.0	4.1	0.3	3.8	1.2	3.9	0.7
10. Emergency operations	2.7	0.5	2.3	0.8	2.7	0.7	2.2	0.6	2.9	0.7	2.5	0.5
11. Wake turbulence	4.4	1.0	2.1	0.9	4.1	0.9	3.5	1.0	4.3	0.8	3.7	0.8
12. Special flights	2.6	0.7	2.9	0.9	3.4	1.0	3.1	1.1	3.6	0.8	4.2	0.6
13. Overflights	1.6	1.1	3.1	1.0	1.9	0.9	3.6	0.7	1.2	0.9	2.2	1.6
14. Vehicular traffic	2.5	2.0	3.3	0.8	3.6	1.1	3.9	1.0	3.5	0.9	2.9	1.2
15. At or below minimums	2.8	0.6	2.7	0.5	3.6	0.8	2.7	0.7	3.2	0.8	1.8	1.0
16. Reduced visibility (weather)	3.2	0.6	3.6	0.7	3.5	1.0	2.8	0.6	3.5	0.8	2.2	1.1
17. Inclement weather	3.2	0.4	3.2	0.8	3.4	1.1	2.5	0.5	3.3	0.7	2.2	0.8
18. Airport surface activity	2.3	1.2	2.8	1.0	2.9	1.0	3.0	1.1	2.9	0.9	2.1	0.9
19. Equipment malfunctions	2.2	0.8	2.4	0.8	2.4	0.8	2.7	0.8	2.4	0.5	2.4	0.7
20. Frequency congestion	4.0	0.5	3.3	0.5	3.8	0.4	3.3	0.5	4.0	0.9	3.5	0.8
21. Equipment location	3.1	1.6	1.6	0.7	2.2	1.0	2.3	0.8	2.6	1.3	1.9	1.3
22. Reduced visibility (equipment)	3.0	1.1	2.7	1.2	2.7	1.3	2.8	0.9	2.7	1.2	1.5	0.7
23. Unfamiliar pilots	2.2	0.6	3.2	0.6	3.1	1.0	3.7	0.5	2.7	0.9	2.7	0.7
24. Pilot's weak mastery of English	2.0	0.8	3.1	0.9	2.7	1.2	3.6	0.8	3.1	1.0	2.2	0.4
25. Controller fatigue	2.8	0.4	2.1	0.6	2.9	1.0	3.3	0.7	2.6	0.7	2.3	1.2
26. Traffic management initiatives	3.6	0.7	2.9	1.1	3.9	0.7	3.6	0.7	4.2	0.6	3.5	1.1
27. Equipment distractions	2.6	0.7	2.5	1.2	2.7	0.5	2.8	0.4	2.3	0.6	2.7	1.1
28. Other distractions	1.9	0.7	3.4	1.0	3.1	1.3	3.0	0.8	2.7	0.9	2.3	0.9
29. On-the-job training	4.0	0.5	2.0	0.8	4.0	0.9	2.9	0.9	4.2	0.8	2.8	0.6

Table J6. Mean Frequency Ratings and Standard Deviations(*SD*) by Site: Ground Control Position

Complexity Factor	ATL (n=10)		BJC (n=10)		BOS (n=10)		OAK (n=10)		ORD (n=12)		PHX (n=10)	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
1. Runway/taxiway restrictions	3.2	1.0	3.7	0.9	3.7	0.8	4.2	0.8	3.3	0.8	3.6	0.8
2. Active runway crossings	4.3	0.7	2.8	1.0	2.7	1.4	4.4	0.7	2.4	1.6	4.2	0.8
3. Runway/taxiway configuration	3.6	0.8	3.1	0.9	3.9	0.9	3.8	0.8	3.9	0.7	3.7	0.9
4. Non-visibility areas	3.1	1.3	2.9	1.3	2.7	0.9	3.3	0.7	1.6	0.5	3.9	1.0
5. Airspace configuration	1.7	1.2	1.4	1.2	1.5	1.4	2.2	1.4	2.6	1.3	2.7	1.8
6. Terrain/obstructions	1.0	0.7	1.6	1.7	1.0	0.9	1.5	1.4	0.8	0.6	1.9	1.7
7. Satellite airports	1.3	1.3	0.7	0.8	0.6	0.5	1.2	0.9	1.9	1.1	1.6	1.6
8. High traffic volume	4.7	0.5	3.0	0.0	4.1	0.7	3.8	0.4	4.8	0.6	4.1	0.6
9. Aircraft differing in performance chars	3.5	1.5	2.5	1.4	3.1	0.9	2.9	1.1	2.8	1.3	2.9	1.0
10. Emergency operations	2.9	0.6	2.3	0.8	3.0	0.9	2.8	0.9	2.8	0.6	2.5	0.5
11. Wake turbulence	3.2	1.8	1.1	1.0	2.7	1.3	2.5	1.0	2.7	1.6	2.7	1.3
12. Special flights	2.0	0.8	2.5	1.2	1.4	0.8	2.1	0.6	1.5	1.0	2.5	1.3
13. Overflights												
14. Vehicular traffic	4.1	1.1	3.4	0.8	3.0	1.0	4.4	0.7	2.7	1.0	2.4	1.3
15. At or below minimums	3.1	0.9	2.6	0.7	3.6	1.1	2.8	0.8	2.8	0.9	1.7	0.8
16. Reduced visibility (weather)	3.0	1.2	2.9	0.9	3.6	0.8	2.7	0.7	3.0	0.9	1.6	0.8
17. Inclement weather	3.2	0.8	2.7	0.8	2.9	0.7	2.5	0.8	3.1	0.8	2.0	0.9
18. Airport surface activity	2.6	1.1	2.9	0.9	2.7	0.9	3.4	1.1	2.5	0.8	2.3	1.3
19. Equipment malfunctions	2.2	0.6	2.2	0.9	2.3	0.8	2.3	0.8	2.0	0.7	2.0	0.7
20. Frequency congestion	4.2	0.6	2.6	0.7	4.1	0.7	3.1	0.6	4.3	0.8	4.0	0.8
21. Equipment location	2.4	1.2	1.6	1.0	1.6	0.8	2.0	0.8	2.3	1.4	2.0	1.3
22. Reduced visibility (equipment)	2.8	1.3	1.9	1.1	2.5	1.1	2.4	1.0	2.4	1.1	1.9	1.4
23. Unfamiliar pilots	2.3	0.7	3.1	0.7	3.0	0.7	3.7	0.8	2.8	0.6	2.8	0.8
24. Pilot's weak mastery of English	1.9	0.9	3.1	0.7	3.0	1.2	3.5	0.8	3.0	0.9	2.0	0.5
25. Controller fatigue	2.8	0.6	1.7	0.7	3.0	0.9	3.3	0.7	2.7	0.9	2.4	0.9
26. Traffic management initiatives	3.3	0.7	2.9	1.3	4.3	0.8	3.7	0.8	4.2	0.7	3.4	1.2
27. Equipment distractions	2.1	0.6	2.6	1.1	2.1	0.7	2.5	0.5	1.7	0.8	1.9	1.0
28. Other distractions	2.1	0.7	3.5	0.7	3.1	1.3	3.0	0.8	2.3	1.0	2.3	0.7
29. On-the-job training	3.8	0.6	1.8	0.6	3.5	1.4	2.8	0.9	3.8	1.1	2.7	0.8

Appendix K

Friedman ANOVA and Kendall's Concordance Coefficient Results

Table K1. Results for Overall Friedman ANOVA

- ANOVA Chi Sqr. (N = 124, df = 27) = 1126.670 $p < 0.00000$
- Coefficient of Concordance = .33652 Average rank r = .33113

Complexity Factor	Average of ranks	Sum of ranks	Mean	SD
8. High traffic	24	2989	8.5	1.2
20. Frequency congestion	21	2640	7.8	1.4
2. Active runway crossings	21	2592	7.6	2.2
1. Runway/taxiway restrictions	20	2490	7.3	1.5
26. Traffic Management Initiatives	20	2452	7.3	1.8
3. Runway/taxiway configuration	20	2438	7.2	1.6
29. OJT	17	2122	6.7	2.0
23. Unfamiliar pilots	17	2081	6.7	1.4
9. A/C differing in performance chars.	17	2069	6.4	2.1
16. Reduced vis (weather)	17	2069	6.6	1.8
14. Vehicular traffic	16	2035	6.4	2.3
15. At or below minimums	16	1976	6.4	1.8
17. Inclement weather	16	1951	6.4	1.7
24. Pilot's weak mastery of English	15	1920	6.3	1.7
11. Wake turbulence	14	1730	5.8	2.6
25. Controller fatigue	14	1695	5.9	1.8
10. Emergency operations	13	1654	5.8	1.3
28. Other distractions	13	1581	5.5	1.9
19. Equipment malfunctions	12	1500	5.5	1.6
4. Non visibility areas	12	1451	5.2	2.4
18. Airport surface activity	11	1380	5.2	2.0
22. Reduced visibility (equipment)	11	1368	5.1	2.2
5. Airspace configuration	10	1301	4.7	2.5
12. Special flights	10	1275	4.9	2.0
27. Equipment distractions	9	1069	4.6	1.3
21. Equipment location	8	1042	4.4	2.1
7. Satellite airports	7	806	3.6	2.6
6. Terrain/obstructions	5	676	3.2	2.3

Table K2. Results for Site and Position Kendall's Concordance Coefficients

Site	Local	Ground
ATL	.54	.57
BJC	.46	.48
BOS	.49	.64
OAK	.43	.55
ORD	.57	.58
PHX	.50	.51

Appendix L

Significant Post Hoc and Simple Effects Analyses Results

Table L1. Significant Tukey's Post Hoc Results for Site

Complexity Factor	Average Site CI Score		df	MS	*p*
	Site 1	Site 2			
2. Active runway crossings	ATL 9.0	BJC 6.5	(5, 56)	3.61	.002
		ORD 6.3			.001
		BOS 7.1			.036
	OAK 8.8	BJC 6.5			.003
		ORD 6.3			.002
5. Airspace configuration	ORD 6.0	BJC 3.3	“	5.95	.013
		ATL 3.6			.032
		BOS 3.5			.022
	PHX 6.2	BJC 3.3			.006
		ATL 3.6			.016
		BOS 3.5			.011
7. Satellite airports	ORD 5.2	BJC 2.14		6.45	.004
		BOS 2.6	“	“	.020
8. High traffic volume	ORD 9.6	BJC 7.4	“	1.26	.001
		OAK 7.8	“	“	.001
		BOS 8.2	“	“	.003
		PHX 8.3	“	“	.004
	ATL 9.3	BJC 7.4	“	“	.001
		OAK 7.8	“	“	.002
		BOS 8.2	“	“	.050
11. Wake turbulence	BJC 3.4	ORD 6.5	“	5.50	.001
		ATL 7.0	“	“	.001
		OAK 6.0	“	“	.013
		BOS 5.9	“	“	.020
		PHX 5.7	“	“	.034
15. At or below minimums	PHX 4.8	ORD 6.9	“	3.50	.002
		ATL 7.0	“	“	.005
		BOS 7.8			.001
	BJC 5.5	BOS 7.8			.005
16. Reduced visibility (weather)	PHX 4.6	BJC 6.8	“	3.30	.003
		ORD 7.2	“		.001
		ATL 6.8	“		.004
		OAK 6.3	“		.050
		BOS 7.7	“		.001
17. Inclement weather	ORD 7.4	BJC 5.5	“	3.12	.017
		OAK 5.7	“		.035
		PHX 5.3	“		.005
	ATL 7.3	BJC 5.5			.025
		OAK 5.7			.050
		PHX 5.3			.007
	BOS 7.0	PHX 5.3			.031
20. Frequency congestion	BJC 6.7	ORD 8.2		2.16	.030
		ATL 8.3	“		.013
		BOS 8.3	“		.013
28. Other distractions	BJC 7.0	ORD 4.8	“	4.70	.021
		ATL 4.4	“		.004
		PHX 4.4	“		.005
	BOS 6.5	ATL 4.4	“		.040
		PHX 4.4	“		.050
29. On-the-job training	BJC 5.1	ORD 8.0	“	4.8	.001
		ATL 7.6	“	“	.008
		BOS 7.3	“	“	.027

Table L2. Results of Significant Simple Effects Analyses (Position Held Constant)

Complexity Factor	Position	CI Score				df	MS	*p*
		Site 1	Avg	Site 2	Avg			
2. Active runway crossings	Ground	ORD	5.0	ATL	9.0	(5, 56)	4.30	.001
				OAK	8.7	“	“	.003
		BOS	5.5	ATL	9.0	“	“	.005
7. Satellite airports	Local	BJC	2.9	OAK	6.7	“	“	.002
				PHX	3.0	“	“	.002
8. High traffic volume	Ground	BJC	7.2	ORD	9.7	(5, 56)	.66	.001
				ATL	9.5	“	“	.001
				BOS	8.8	“	“	.001
				PHX	8.5	“	“	.001
		ORD	9.7	OAK	7.7	“	“	.001
		ATL	9.5	OAK	7.7	“	“	.001
8. High traffic volume	Local	ORD	9.6	BJC	7.6	(5, 56)	.93	.001
				OAK	7.9	“	“	.003
				BOS	7.6	“	“	.001
				PHX	8.0	“	“	.006
14. Vehicular Traffic	Ground	ATL	8.3	PHX	4.5	(5, 56)	3.01	.001
		OAK	8.5	BOS	5.5	“	“	.003
				PHX	4.5	“	“	.001
20. Frequency Congestion	Ground	BJC	6.2	ORD	8.8	(5, 56)	1.36	.001
				ATL	8.5	“	“	.001
				BOS	8.7	“	“	.001
				PHX	8.5	“	“	.001

Table L3. Results of Significant Simple Effects Analyses (Site Held Constant)

Complexity Factor	Site	CI Score		df	MS	*p*
		Ground	Local			
7. Satellite airports	BOS	1.2	3.9	(1, 9)	23.28	.001
	OAK	2.3	6.7	(1, 9)	53.78	.001
	ORD	4.2	6.3	(1, 11)	15.52	.002
8. High traffic volume	BOS	8.8	7.6	(1, 9)	23.14	.001
12. Special flights	PHX	4.4	7.2	(1, 9)	16.97	.003
	BOS	2.8	5.9	(1, 9)	22.23	.001
	OAK	4.1	6.1	(1, 9)	18.00	.002
	ORD	2.8	6.6	(1, 11)	54.20	.001
20. Frequency Congestion	BOS	8.7	7.9	(1, 9)	16.00	.003
	ORD	8.8	7.6	(1, 11)	13.15	.004

Significant Position by Site Interactions

Figure L1. Active Runway Crossings (Factor 2)

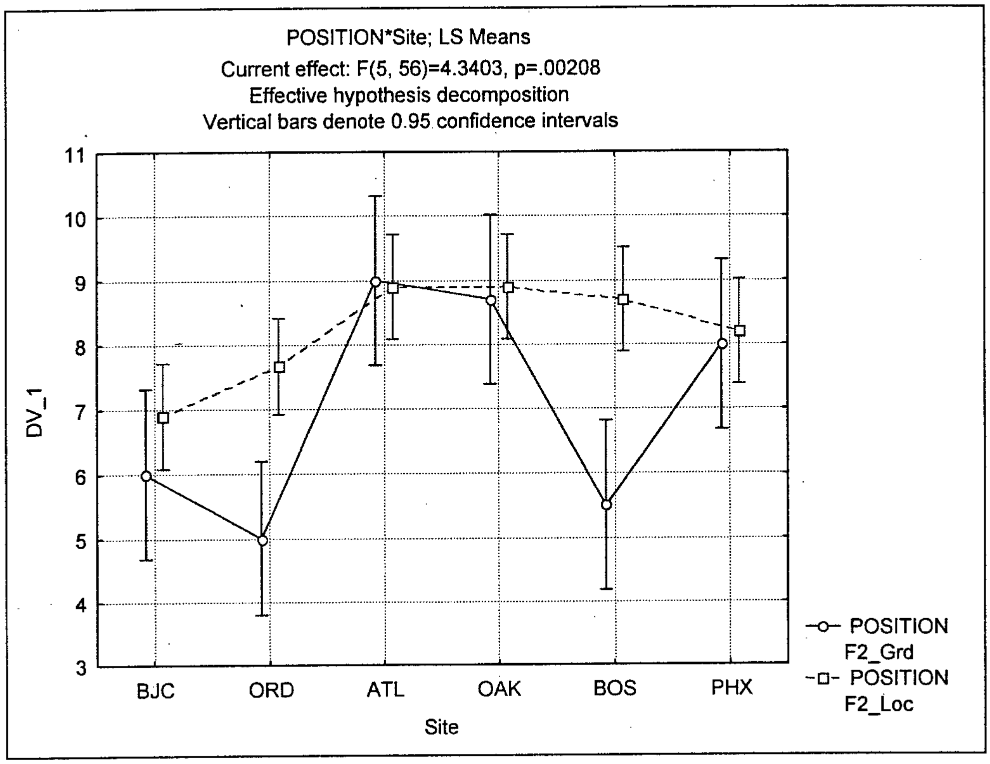


Figure L2. Satellite Airports (Factor 7)

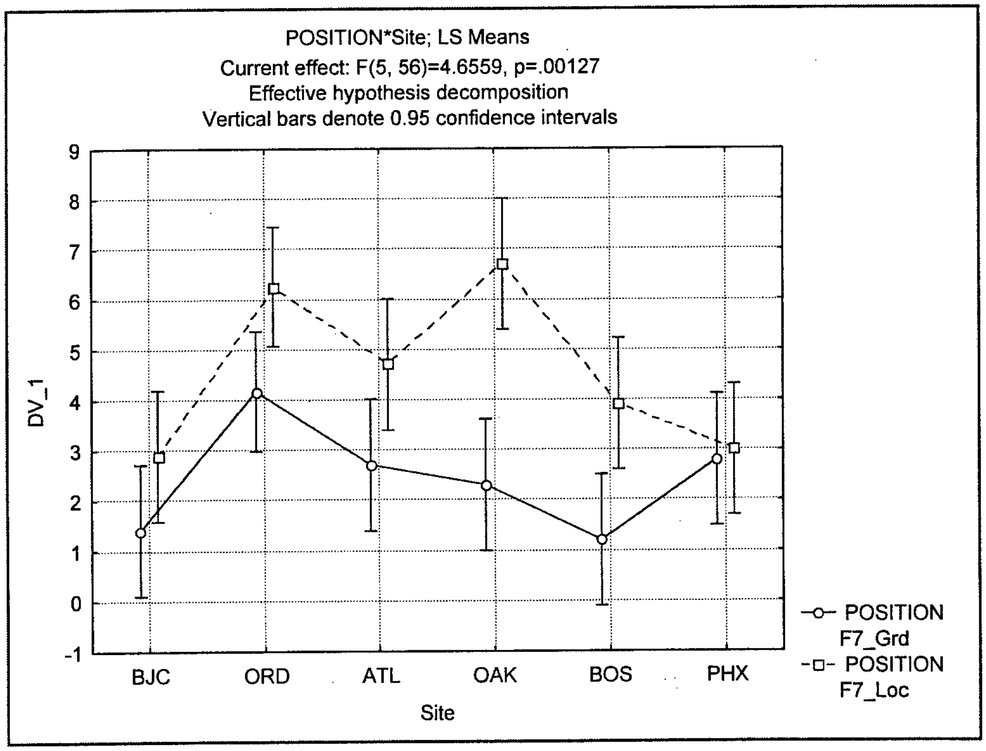


Figure L3. High Traffic Volume (Factor 8)

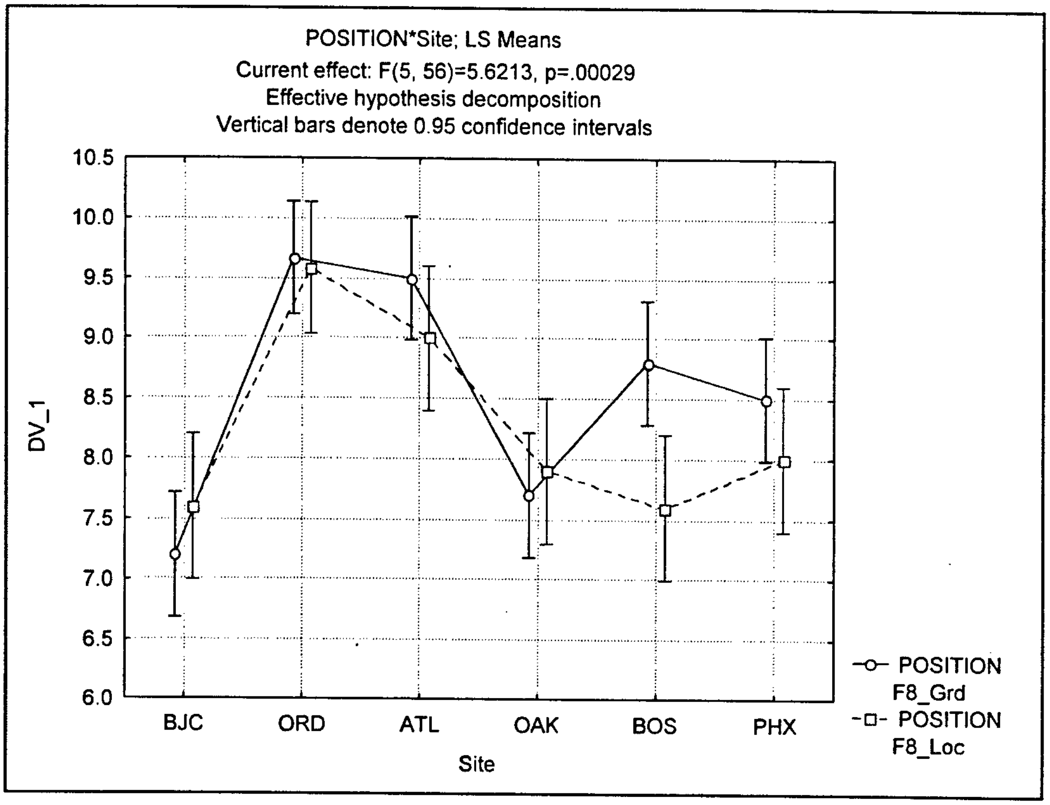


Figure L4. Special Flights (Factor 12)

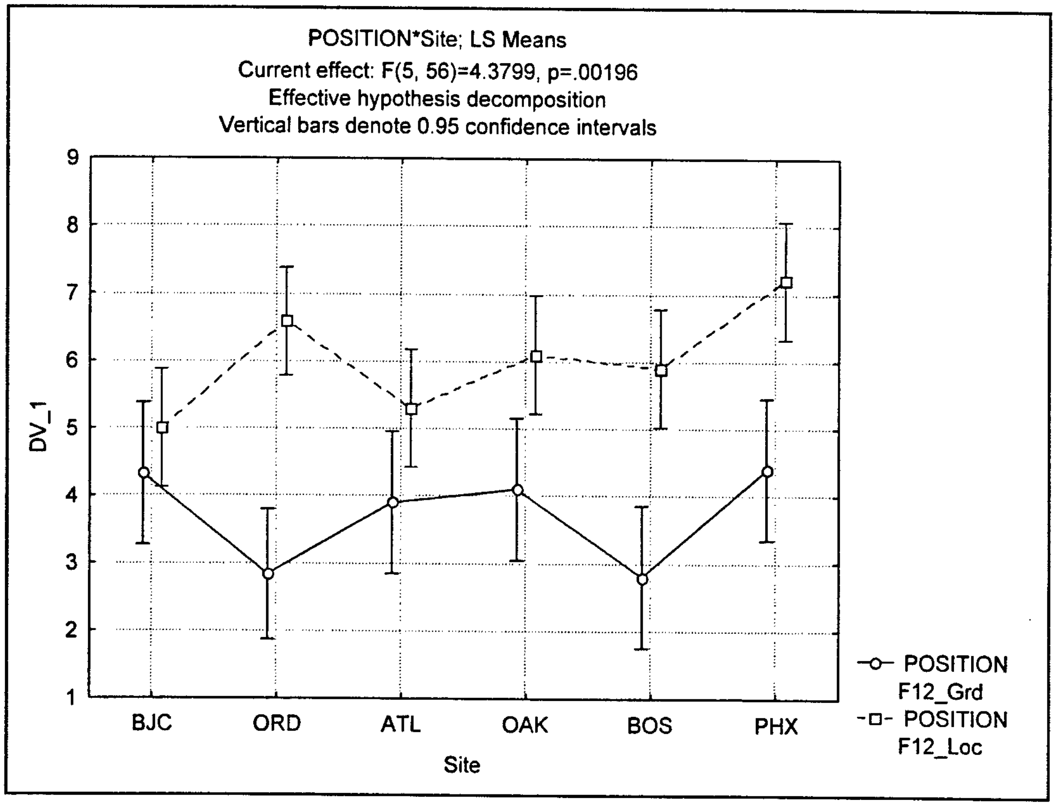


Figure L5. Vehicular Traffic (Factor 14)

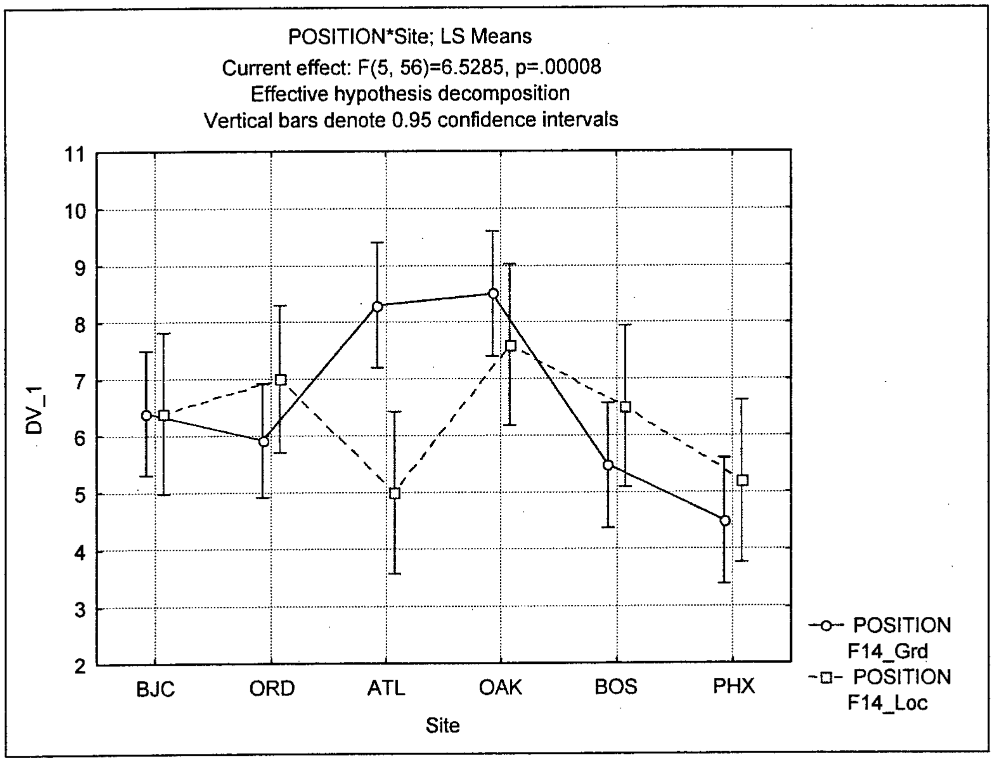
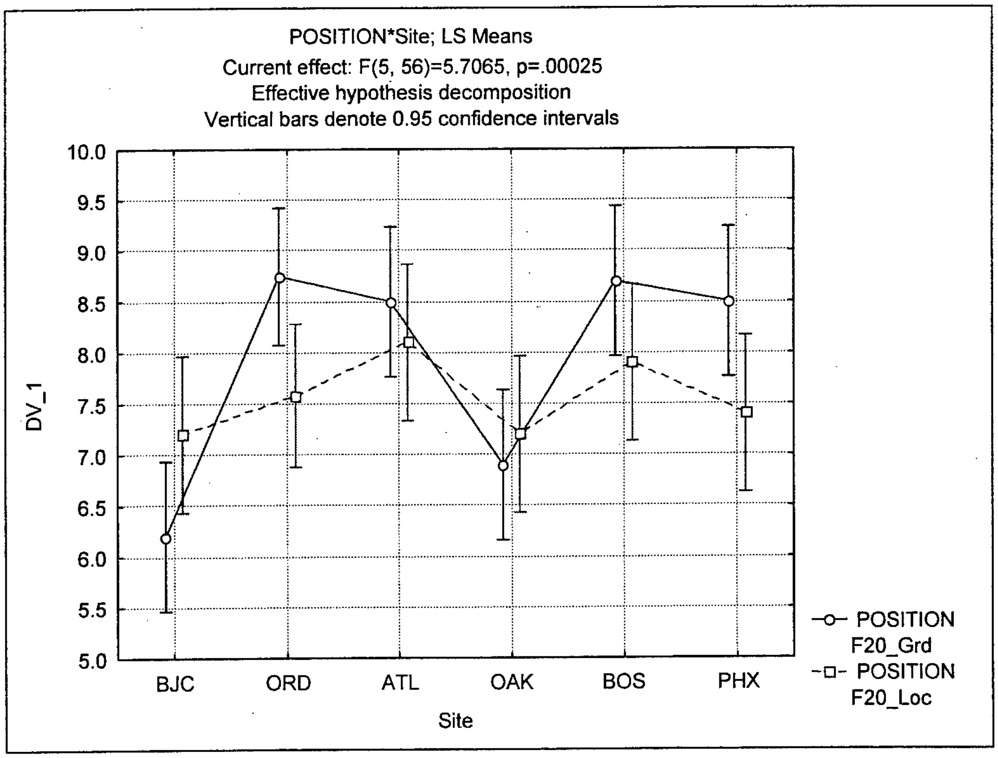


Figure L6. Frequency Congestion (Factor 20)



Appendix M

Factor Analysis Results

Table M1. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.718
Bartlett's Test of Sphericity	Approx. Chi-Square	1408.017
	df	378
	Sig.	.000

Note. Analysis performed with SPSS.

Table M2. Total Variance Explained

	Eigenvalue	% Total	Cumulative	Cumulative
1	5.860236	20.92941	5.86024	20.9294
2	3.076028	10.98582	8.93626	31.9152
3	2.340716	8.35970	11.27698	40.2749
4	1.932988	6.90353	13.20997	47.1785
5	1.611497	5.75535	14.82146	52.9338
6	1.515187	5.41138	16.33665	58.3452
7	1.285003	4.58930	17.62165	62.9345
8	1.165304	4.16180	18.78696	67.0963

Table M3. Rotated Component Matrix

Factor	**Component**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
15. At or below minimums	0.845	-0.024	0.070	0.025	0.059	0.174	0.127	0.190
16. Reduced visibility (weather)	0.844	0.002	-0.040	0.192	0.113	0.018	-0.047	0.060
17. Inclement weather	0.708	-0.018	0.199	0.028	0.177	0.243	-0.230	-0.179
10. Emergency ops	0.415	0.136	-0.062	0.055	0.172	0.260	0.093	0.268
27. Equipment distractions	0.137	0.735	0.168	-0.088	0.182	-0.040	0.116	0.062
28. Other distractions	0.042	0.710	-0.140	0.046	-0.033	-0.008	-0.025	0.126
6. Terrain/obstructions	-0.206	0.499	0.291	0.305	0.023	-0.035	0.254	-0.059
12. Special flights	0.031	0.087	0.781	-0.018	-0.041	-0.235	0.128	0.152
11. Wake turbulence	0.220	-0.107	0.761	-0.139	0.113	0.104	0.078	0.135
5. Airspace configuration	-0.260	0.024	0.694	0.231	0.135	0.270	-0.111	0.019
7. Satellite airports	-0.032	0.073	0.682	0.192	0.184	0.370	-0.086	0.069
9. A/C differing in performance	0.188	-0.015	0.679	0.112	0.209	0.003	0.253	-0.138
23. Unfamiliar pilots	0.066	-0.034	0.040	0.847	0.041	-0.025	0.099	0.103
24. Pilot's weak mastery of English	0.217	0.027	0.133	0.814	0.046	0.053	-0.095	0.175
1. R/T restrictions	-0.008	0.071	-0.014	0.499	0.162	0.279	0.187	0.487
21. Equipment location	0.118	0.048	0.216	-0.110	0.759	0.184	-0.016	0.106
22. Reduced visibility (equipment)	0.319	-0.156	0.074	0.107	0.740	0.028	0.052	0.221
19. Equipment malfunctions	0.049	0.269	0.233	0.276	0.624	0.018	0.052	0.088
26. Traffic management initiatives	0.180	0.067	0.143	0.072	-0.208	0.724	-0.177	0.220
29. On-the-job training	0.336	-0.118	0.240	-0.110	0.308	0.652	-0.031	-0.010
20. Frequency congestion	0.051	-0.268	-0.115	0.064	0.281	0.630	0.120	-0.199
8. High traffic volume	0.223	-0.585	0.090	0.029	0.094	0.573	0.125	0.013
2. Active runway crossings	0.050	0.073	0.320	-0.045	-0.049	0.006	0.789	0.167
4. Non visibility areas	-0.325	-0.011	-0.175	0.242	0.382	-0.086	0.583	-0.063
14. Vehicular traffic	0.196	-0.070	0.142	0.101	0.118	-0.093	0.120	0.786
18. Airport surface activity	-0.004	0.154	0.052	0.155	0.105	0.032	-0.065	0.704
3. R/T configuration	0.310	-0.380	0.305	0.187	0.105	0.233	0.057	0.223
25. Controller fatigue	0.333	0.375	0.109	0.087	-0.043	0.460	0.452	-0.089
Explained variance	0.845	-0.024	0.070	0.025	0.059	0.174	0.127	0.190
Proportion of total	0.844	0.002	-0.040	0.192	0.113	0.018	-0.047	0.060

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.