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Complexity in Airport Traffic Control Towers: A Field Study.

Part 2. Controller Strategies and Information Requirements

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16. Abstract

This two-part field study investigated sources of 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 participated in the study, providing ratings and descriptions of the complexity sources from a local- and ground-controller perspective. The first report represented a key step in identifying and characterizing the primary sources of complexity within ATCTs and assessing their relative incidence and importance. The second report identifies the strategies that tower controllers use to mitigate complexity, the types of information that they require, and the sources of this information. The participants reported relying on two to three core strategies, which they supplemented with ad hoc techniques. Results from this field study hold implications for future tower automation equipment design. Future research efforts should systematically investigate tower controller information needs and focus, in particular, on sources such as high traffic volume and frequency congestion, which are among the most prevalent sources of complexity within this environment.

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Executive Summary

Air Traffic Control Specialists (ATCSs) are decision makers in a highly complex and dynamic environment. They must maintain situation awareness in a setting of constantly changing information and balance conflicting goals under time pressure, frequently in the presence of high workload. Despite these challenges, the number of operational errors remains low.

Human Factors Specialists (HFSs) from the William J. Hughes Technical Center interviewed 62 participants from six Airport Traffic Control Towers (ATCTs). This field study culminated in two reports describing the sources of complexity in the ATCT, their incidence, and subsequent controller information requirements. The first report presented the relative complexity, incidence, and descriptions of 29 common sources of complexity in the tower (Koros, Panjwani, Ingurgio, Della Rocco, & D'Arcy, 2003). The current report expands on this information, examining the strategies that controllers use to mitigate complexity, the types of information they require, and the information sources that they consult.

The participants reported using two or three common strategies to mitigate complexity, although they often supplemented these with ad hoc techniques. In some situations, they employed as many as nine different strategies. ATCSs' information requirements differed significantly based on position. The most critical information element reported for both local and ground controllers was aircraft position followed by aircraft identification. The most commonly cited information sources for both were visual observation, flight strips, communicating with the pilot, Digital Bright Radar Indicator Tower Equipment (DBRITE), and memory. Participants reported relying heavily on visual observation to identify aircraft position, type, category, speed, taxi route, runway status, and weather conditions. Taxi route and assigned gate represented more importance to the ground controller. Local controllers relied heavily on the DBRITE to identify aircraft type and category, as well as aircraft speed.

This study confirmed that displays and other information sources within the tower simultaneously convey several information elements. As such, it is important that these sources present the information in a consistent, integrated, and synchronized manner to the controller. Furthermore, it is essential that maintaining the integrity of these data requires minimal controller resources and avoids compromising their ability to scan the airport surface and conduct other important tasks. Tower design, equipment layout, operational procedures, and automation equipment, in particular, must be supportive of the dynamic needs of the controller. This is especially important because controllers employ many different strategies, which they adjust dynamically, potentially resulting in the application of several tactics for a single aircraft.

The purpose of this two-part study was to further understand the primary sources of complexity in ATCTs. The researchers will use the results to identify key sources of complexity, evaluate the impact of new automation on perceived complexity, and promote the continued safety and efficiency of the National Airspace System. Future research efforts should focus on the leading sources of complexity and ensure that the resulting displays and decision-support systems are designed to meet controller information requirements.

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. In support of the goals presented by the panel on Human Factors in Air Traffic Control Automation (Wickens, Mavor, & McGee, 1997), researchers are investigating the underlying elements in the process of controller decision making. The Federal Aviation Administration (FAA) Human Factors Division (AAR-100) sponsored a series of studies exploring ATCS cognitive processes and decision making. In support of this activity, Human Factors Specialists (HFSs) at the FAA William J. Hughes Technical Center conducted two studies. The first represented a field study of ATCS decision making and strategic planning across ATC domains (D'Arcy, & Della Rocco, 2001). The second study focused specifically on complexity and decision making in ATCTs. The results of the second study appear in two reports. The first report examined ATCS ratings of 29 complexity sources in Airport Traffic Control Towers (ATCTs) (Koros, Panjwani, Ingurgio, Della Rocco, & D'Arcy, 2003).

This second report examines the strategies ATCSs use to manage complexity in the tower environment and the information sources they consult. The research team, which comprised team members of the National Air Space (NAS) Human Factors Group (ATO-P), selected sites from among the busiest tower facilities (FAA, 2001) with consideration for the region represented as well as the cognitive complexity drivers 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 few decades (Wickens, Mavor, Parasuraman, & McGee, 1998). This initiative, combined with the move toward a free flight environment, emphasized the importance of understanding how ATCSs perceive and respond to traffic complexity (Pawlak, Brinton, Crouch, & Lancaster, 1996). In an effort to support the panel's proposal, in 1999, AAR-100 requested a series of studies investigating ATCS decision-making strategies. HFSs from ATO-P conducted semi-structured interviews with 100 ATCSs to examine their perspective regarding controller decision making and planning (D'Arcy & Della Rocco, 2001). The goal of the study was to explore controllers' views of important issues related to the information they use, difficulties encountered, and potential improvements. In an effort to expand upon that knowledge, ATO-P designed the current 2-part study to examine ATC decision-making strategies in ATCTs as a foundation on which to build future automation.

1.2 Literature Review

Since the 1950s researchers have investigated many aspects of human performance relevant to the ATC environment. ATCS decision making and ATC complexity are among the areas that have received considerable attention.

1.2.1 ATCS Decision Making

ATCSs are decision makers in a dynamic time-critical environment involving many actors and elements. It is the responsibility of the controller to manage the potentially offsetting goals of NAS safety and efficiency. The density of aircraft in the terminal environment, "combined with the complexity of operations and the requirement for split-second timing, conspire to make the airport surface and proximal airspace extremely unforgiving of pilot and controller errors" (Cardosi & Yost, 2001, p. ix). Researchers from the Massachusetts Institute of Technology described the tower system in the following manner (Anagnostakis et al., 2000):

> Air traffic controllers usually prefer to assign arrivals and departures to different runways. However, this is not always feasible, especially in tightly constrained airports such as Boston Logan. For many configurations, the runway resource utilized by departing aircraft is shared with arriving aircraft, which in most cases have priority over departures. In addition, the runway system is frequently shared with taxiing aircraft that have to cross active runways . . . controllers often have to introduce gaps in the arrival stream in an effort to accommodate departures between arrivals and to allow taxiing aircraft to cross active runways (p. 1).

The tower environment differs from the en route environment in that towers typically have less airspace, which results in less time for controllers to direct aircraft traffic. The proximity of their scope of control (i.e., close to the airport) often makes it possible for them to visually monitor the aircraft by looking out the window. The tower environment typically provides less decision making time and places a higher demand for prompt action. Therefore, the strategies used in the two facilities can vary significantly (D'Arcy & Della Rocco, 2001). Communication density also varies considerably, averaging near 1.8 transmissions per minute in the en route environment to nearly 4 transmissions per minute in the tower (Burki-Cohen, 1995).

In addition, tower controllers must maintain safety and maximize airport efficiency while implementing Traffic Management Initiatives (TMIs), noise abatement procedures, wake turbulence, and other restrictions. All of this is completed in the presence of complicating drivers such as inclement weather and unfamiliar pilots. Weather, in particular, is problematic, causing delays and cancellations and overlapping traffic peaks, increasing minimum traffic separation requirements, adding to workload, erratically changing manpower requirements, and so on (D'Arcy & Della Rocco, 2001; Dareing & Hoitomt, 2002). Yet, despite these challenges, the number of operational errors remains very low.

1.2.2 ATC Complexity

The controller's primary task is to maintain separation and ensure overall safety while trying to meet the secondary objectives of efficiency and providing Air Traffic (AT) services. The task consists of four primary processes: planning, implementation, monitoring, and evaluation (Pawlak et al., 1996).

According to the authors, each of the processes represents a heavy reliance upon the controllers' cognitive abilities, with the possible exception of implementation, which may consist predominantly of the physical actions required to carry out the plan.

Research into ATC complexity has predominantly focused upon the en route environment (Grossberg, 1989; Mogford, Guttman, Morrow, & Kopardekar, 1995; Mogford, Murphy, Yastrop, Guttman, & Roske-Hofstrand, 1993; Rodgers, Mogford, & Mogford, 1998; Stein, 1985; Wickens et al., 1997). However, much of this research is directly applicable to the tower environment. For instance, Mogford et al. (1995) defined complexity as a "multidimensional construct that includes static sector characteristics (sector complexity) and dynamic traffic patterns (traffic complexity)" (p. v). They acknowledged that there might be objective, measurable features of sectors and aircraft but that the controller subjectively defines the concept of ATC complexity. Traffic patterns remain an important determinant of complexity within the ATCT. However, the sector characteristics to which they alluded must be expanded to incorporate the aspects of complexity included on the airport surface.

Complexity is not evident to the observer. Therefore, some researchers have used physical measures of workload as an estimate. Others, considering the degree of cognitive activity inherent in the ATC task to be important, have suggested that controller strategies and decision-making tasks (i.e., cognitive tasks) might be a better means of evaluating ATC complexity (Pawlak et al., 1996). The authors state that many factors influence the complexity of ATC, including the abilities of each specific controller, the equipment available, and the complexities of the ATC environment itself. Rodgers et al. (1998) represented the relationship of these variables in their model of complexity for en route ATC. The authors suggest that mediating factors influence the sources of complexity (i.e., AT pattern and sector characteristics). Cognitive strategies, equipment-related factors, and individual differences shape source factors to define controller workload. Figure 1 presents an adaptation of this model for the tower domain.

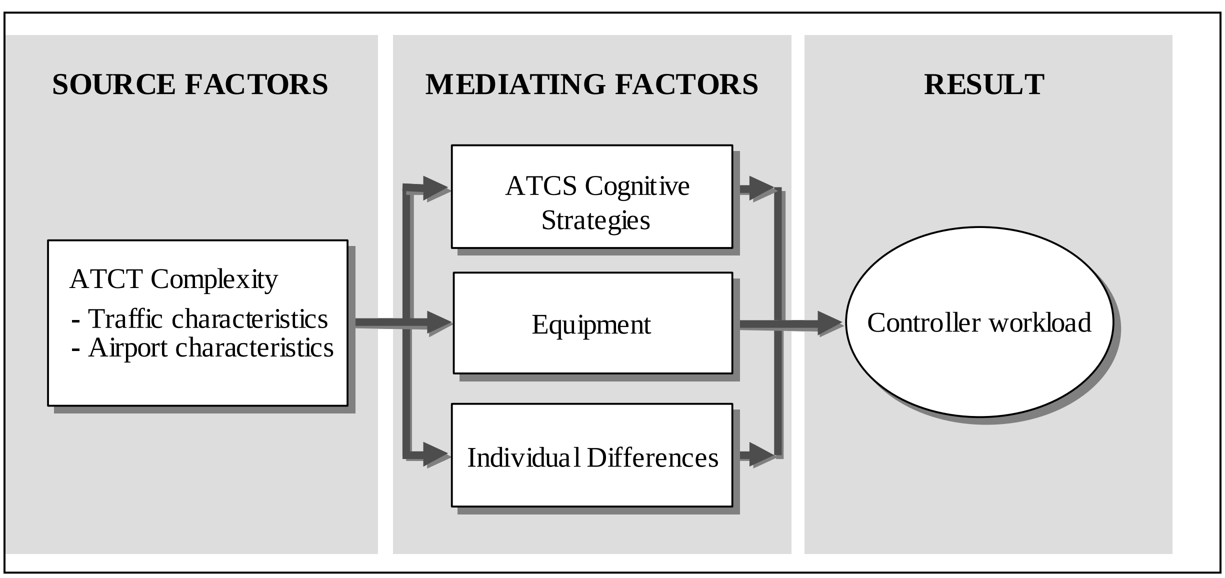

Figure 1. Cognitive model of ATCT task (Adapted from Rodgers et al., 1998, p. 25).

The first report focused on 29 complexity drivers in the tower environment (Koros et al., 2003). Twenty-two of the drivers represent source factors. Traffic and airport characteristics are among the predominant sources, although other elements such as operational constraints can exert substantial effects. The remaining items comprised mediating factors. These included ATCS cognitive strategies, equipment-related aspects (malfunctions, location, reduced visibility, and distractions) and individual differences (unfamiliar pilots, pilot's weak mastery of English, and controller fatigue).

Equipment characteristics exert important influences on the controller's task. The influences encompass the availability of automation and its location, as well as the format and content of the information displayed. The loss of a critical piece of equipment increases complexity and workload by requiring the use of non-Standard Operating Procedures (SOPs) and alternative information sources. The design of the user interface also holds important implications for controller performance. Mogford, Guttman, Morrow, and Kopardekar (1995) noted that any variance between the information required by the controller and the presentation of these data can make the controller's job more complex. Cluttered displays exacerbate difficulties with visual sampling and impair situation awareness (SA) (Wickens et al., 1998).

Finally, individual differences mediate controller workload and the effects of complexity. Controllers differ in terms of personal attributes including age, experience, susceptibility to anxiety, strategy usage, and a myriad of other characteristics. ATCS performance decrements due to aging have received much attention. Investigators since the early 1960s have identified and confirmed decrements in ATCS performance with increasing age (Buckley, O'Connor, & Beebe, 1969; Heil, 1998; Mogford et al., 1994; Rodgers et al., 1998). Although individual controller differences and the equipment itself are important aspects of complexity, the current study predominantly focused upon their cognitive strategies in response to traffic and airport characteristics.

1.3 Scope

The current report focuses on cognitive strategies and information requirements in the ATCT. Tower controllers use a variety of sources to meet information requirements and ensure aircraft separation. The following sections expand on these aspects.

1.3.1 Cognitive Strategies

A strategy is defined as "a goal-directed use of resources, over time, in response to a situation that calls for judgment and choice among options" (Mogford et al., 1994, p. 1). A number of site-specific issues constrain the repertoire of ATC strategies available. In the tower environment, these include the tower domain itself as well as airport and traffic characteristics. D'Arcy and Della Rocco (2001) reported that en route controllers are more able than their terminal facility counterparts to "wait and see" if there is a conflict before taking action. The authors partially attributed this to the typically larger sector size and greater aircraft separation found in en route sectors.

The influence of time of day, inclement weather, and other factors also define the controller's task and constrain the number of available options. Mogford et al. (1995) report that "controllers appear to be flexible in their response to ATC complexity and can adapt their information processing and decision-making strategies to suit a given situation" (p. 16). New ATCSs typically use rule-based behaviors (e.g., memorized rules). However, as they gain experience, they become increasingly adept at handling relatively complex events using expert behaviors (e.g., considering the global context and making logical leaps beyond the application of rules to quickly reach a solution) (Wickens et al., 1998). D'Arcy and Della Rocco (2001) determined that the decisions made by controllers are contingent on many factors. Controllers reported adopting different strategies according to the traffic level and presence of inclement weather, as well as the difficulty or complexity of the situation. For example, they reported being more conservative and cautious when confronted with difficult situations such as bad weather, high workload, or fatigue. As traffic volume increases, controllers tend to use more economical control methods as a means of regulating workload to maintain safety through simpler or more precise actions (Mogford et al., 1995; Rodgers et al., 1998; Sperandio, 1971, 1978).

Experience also influences strategy selection. Researchers conducting a protocol task analysis of en route controllers' mental models identified three categories of controller strategies: planning, monitoring, and workload management (Redding et al., 1991). They reported that experts tend to use fewer strategies, use workload management strategies more frequently, and use a wider diversity of strategies overall when compared to intermediate and novice controllers. More recently, Histon and Hansman (2002) investigated the mechanisms underlying controller strategies to mitigate complexity. They proposed a model of ATC complexity in which structure forms the basis for abstractions to simplify the controller's working mental model. They presented three examples of abstractions (Figure 2). In standard flow abstraction, aircraft following a standard route no longer have to be considered on an individual basis, simplifying the task of projecting their future position. Group abstraction addresses complexity by segregating aircraft into distinct groups. Critical point abstraction allows the interaction of aircraft flows to be based on "hot spots" or merge points. Tower controllers likely employ similar abstractions to those illustrated.

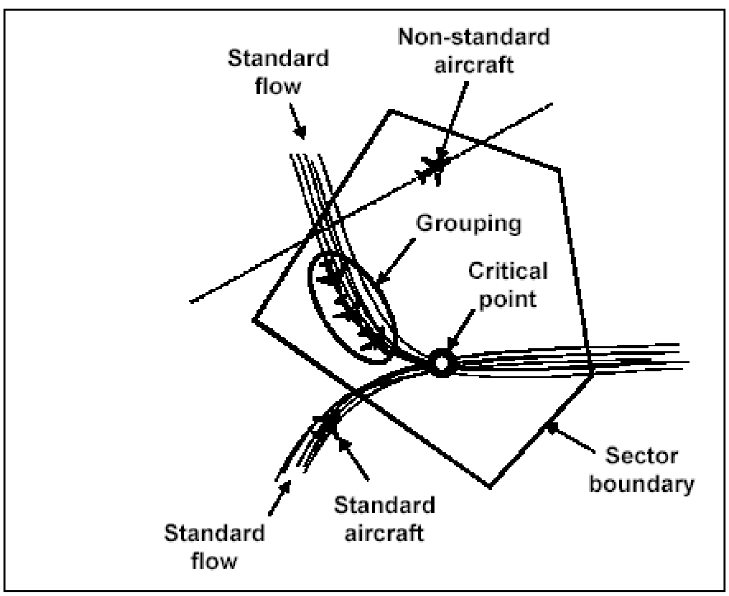

Figure 2. Illustration of three structure-based abstractions (Histon & Hansman, 2002).

1.3.2 Information Requirements

Controllers must maintain awareness of information on aircraft, airport surface activity, the airspace, weather, and several other elements to effectively maintain separation. There are numerous information elements (wind direction and speed, weather disturbances, airspace considerations, aircraft turn rate, descent and ascent rate, etc.), but some represent a higher priority. As with other research efforts, much of the focus has centered upon the en route domain. In a study of controller information requirements, callsign, altitude, cleared altitude, and exit waypoint accounted for 93% of all information demands (Hutton, Olszewski, Thordsen, & Kaempf, 1997). Bisseret (1971) confirmed that controllers used altitude and relative position more frequently and that they recalled this information more easily. Controllers participating in a study of ATC complexity within Jacksonville Air Route Traffic Control Center en route sectors reported altitude, location, heading, and speed among the most critical pieces of aircraft data (Mogford et al., 1994). The participants differed in their assessment of the usefulness of other types of data such as aircraft type.

Although the tower and en route environments differ in some potentially important respects, they exhibit many similarities. Recently, in a study of en route controller information requirements under different team configurations, researchers concluded that most types of flight, radar, and datablock information are important with a few exceptions (e.g., fix posting, departure airport, and aircraft beacon code) (Willems, Heiney, & Sollenberger, 2002). However, the specific information requirements would certainly differ between AT domains. As with their en route counterparts, tower controllers depend highly on their working memory to maintain the information needed to accomplish their tasks. Even if all aircraft with which they communicate are nominally within sight, controllers must remember the callsign.

The tower controllers' most critical task is to keep track of who is where, and this can be especially challenging in busy airports (Wickens et al., 1997). Visual observation is the tower controllers' most important resource, potentially accounting for nearly 50% of a controller's time (Bruce, 1996). The capability to rely on direct visual observation represents one of the most significant differences between AT domains. In addition to direct observation, external representations such as flights strips, tower radar (e.g., Digital Bright Radar Indicator Tower Equipment [DBRITE]), and surface radar displays (e.g., Airport Surface Detection Equipment [ASDE]) support tower controllers' memory and decision making (Fields, Wright, Marti, & Palmonari, 1998; Marti, 2000). These external representations are important to mediate the interactions between coworkers in collaborative environments (Fields et al.). Determining the information requirements and their priority in the tower environment during different situations (e.g., under different runway configurations, weather conditions, runway/taxiway restrictions) are essential to the development of displays that present information in an appropriate form and that are sensitive to the array of strategies used by controllers (Endsley, 1995; Vingelis, Schaeffer, Stringer, Gromelski, & Ahmed, 1990; Wickens et al., 1997).

1.4 Purpose and Rationale

This study explored the relative importance of several sources of complexity in the tower environment and identified the strategies that controllers used to mitigate these complexity drivers. As the Panel on Human Factors in Air Traffic Control Automation noted, "decision making may be improved by training and displays that are sensitive to strategies that do work in real-world environments" (Wickens et al., 1997, p. 108). The first report examined the nature and relative importance of 29 complexity drivers from a ground-controller and local-controller perspective (Koros et al., 2003). In this, the second report, we identify the range of strategies and information elements that controllers employ to manage complexity. 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. In addition, an enhanced understanding of ATCSs' decision-making and tower-complexity drivers will help researchers predict the impact of future automation and emerging technologies on controller performance and, ultimately, NAS safety and efficiency.

1.5 Variables and Hypotheses

This was an exploratory study. The variables include the procedures, strategies, and information sources controllers reported using for each of the sources of complexity. The resulting information will help form and refine hypotheses for future research efforts. The research team hypothesized that controllers would use a variety of strategies including planning, monitoring, and workload management tactics. We anticipated that looking out the window would be among the most common information gathering techniques because visual observation has long been established as an important resource to tower controllers (Bruce, 1996; FAA, 2002a). We expected flight strips to be used as a memory aid at the local and ground control positions. The team anticipated that there would be differences in the overall importance of information elements (aircraft position, aircraft speed, taxi route, etc.). The findings regarding these hypotheses represent important considerations for the development of future automation within the tower.

2. Method

The first report entitled *Complexity in Air Traffic Control Towers: A Field Study. Part 1. Complexity Factors* (Koros et al., 2003), described the methodology and data collection forms the researchers used to assess the 29 sources of complexity. It provides details regarding the site selection process, the methodology employed, and the participant's demographic information.

The principal selection criteria for the six sites were high traffic volume, traffic mix, and converging runways. The research team interviewed 62 tower controllers who represented between 1 and 30 years of experience at their current facility and averaged 11 years. Data collection consisted of a rating form followed by a face-to-face interview. The interview focused on the two sources of complexity that the participant had rated as the most influential from a ground- and a local-controller perspective. The interviewees provided information on the nature of the complexity, the mitigating strategies that they employed, and the information sources that they consulted.

The data presented in this second report reflects comments provided during the semi-structured interviews focusing on strategies and information requirements. As an exploratory study, this methodology enabled insights into controllers' cognitive strategies and information requirements across an extensive range of conditions in support of future research efforts. Data analyses consisted of descriptive statistics, predominantly counts and averages. The results comprised counts of self-reports of sources for standard procedures, strategy usage, and sources of control information. After identifying the information source, the participants rated the importance of the information.

3. Results

This section presents the results of information collected during interviews with 62 tower controllers. It depicts their accounts of the strategies used to manage 29 sources of complexity in the ATCT. The results comprise five sections: mitigating strategies, information needs, information sources, information requirements summary, and controller recommendations.

3.1 Mitigating Strategies

The research team interviewed participating controllers regarding complexity from a local and ground control perspective. See Appendix I in the first tower complexity report for detailed descriptions of the nature of each of the complexity sources (Koros et al., 2003). We asked participants to identify, from a list of core strategies, those strategies that they typically used to mitigate the specific source of complexity. We encouraged them to supplement the list with additional techniques if they did not already appear in the core strategies list. The core list of mitigation strategies was relatively comprehensive because we developed it with the aid of several subject matter experts (SMEs) at the Technical Center. The list included general strategies such as slowing down the operation and adhering to SOPs and other more specific strategies such as applying sections of the ATC Order. For example, Strategy S1, adhering to SOPs, refers to those situations in which controllers apply standard procedures as a means of reducing complexity. Examples of the use of this strategy include employing standard arrival and departure routes, which represent an application of standard flow abstraction. Strategy 11 refers to employing the procedures described in FAA Order FAAO 7110.65 paragraphs 3-9-5 and 3-10-6 (FAA, 2002a) to maintain anticipated separation for departure and arrival traffic in the tower environment. We provided the core strategies list (Table 1) to the participants to initiate conversation and to ensure that the interview resulted in a relatively exhaustive list of strategies.

Table 1. Core Strategies

No.	Strategy	No.	Strategy
S1.	Adhere to SOPs	S11.	Use the anticipated separation rule
S2.	Ask for more in-trail spacing from Terminal Radar Control (TRACON) facility	S12.	Point out traffic to another controller
S3.	Ask people in towercab to be quiet	S13.	Training
S4.	Request supervisory assistance	S14.	Team briefing
S5.	Apply visual separation criteria	S15.	Read and initial
S6.	Coordinate to expedite traffic (i.e., “point-outs” with TRACON)	S16.	Relief from position
S7.	Gather complete information prior to making decision (operator acknowledgements, etc.)	S17.	Rotation to less workload position
S8.	Slow down the operation	S18.	Decombine position [if appropriate]
S9.	Slow down the operation while attending to higher priority duties	S19.	Closer monitor of elements impacting training, (developmental abilities, workload, etc.)
S10.	Use “expedite” in control instruction	S20.	Additional classroom time
		S21.	Procedures committee to review operations
		S22.	Recommend changes to SOP

The researchers compiled controller responses regarding strategy usage. Table 2 describes the core strategies and the additional strategies that controllers reported using to mitigate complexity. We did not conduct interviews on complexity sources of overflights, reduced visibility due to equipment, and equipment distractions (i.e., sources 13, 22, and 27, respectively) because the participants rated them as infrequent and of nominal complexity. The descriptions contained in the table present the most frequent responses first. On average, controllers reported using two to three core strategies for each source of complexity. The strategies selected from the list for the ground- and local-control position were very similar, averaging 2.3 and 2.4, respectively.

Table 2. Controller Reported Strategies for Mitigating Complexity

Source of Complexity	Core Strategies	Additional Strategies
1. Runway/ taxiway restrictions	For long-term or common restrictions, site-specific procedures are often available. In other situations, controllers use strategies learned through their own experience or by observing other controllers.	Pay special attention to coordination with other controllers; use progressive taxi instructions; and anticipate and prepare for the workload increases that accompany these restrictions.
2. Active runway crossings	SOPs, which may be used concurrently with “expedite” in the control instruction or slowing the operation. Expediting tends to be used when the crossing traffic is slow and an arrival is approaching. Slowing the operation typically represents a product of the circumstances (not a consciously selected strategy), but a few local controllers reported slowing an arrival to allow for a crossing if traffic volume was low.	Select the best intersection to cross (don’t cross just anywhere); observe the crossing traffic to verify that they have exited the intersection.
3. Runway/ taxiway configuration	This accounted for the largest range of strategies (9). Besides SOPs, controllers reported expediting traffic and slowing the operation. Though controllers identified expediting as an important strategy, they stressed the need to use it sparingly. Some indicated that the condition itself slowed the operation and that they did not actively choose this strategy. Ground controllers reported using anticipated separation.	Focus on potential trouble areas (dependent upon configuration); anticipate and prepare for workload peaks; use frequency management procedures; anticipate push backs.
4. Non-visibility areas	Obstruction sources were predominantly outside of the tower (physical structures on airport property, terrain, sun glare, and tower beams). Ground controllers rely on pilot reports to build mental pictures of the traffic and issue “advisory” information to the pilots. In the case of sun glare, controllers pull down the shades or, if possible, change runway direction.	Move to another location within the tower to view obscured areas; write the callsigns of obscured traffic on a scratchpad and mark a box around it to indicate it is in a non-visible area.
5. Airspace configuration	SOPs, particularly 7110.2, dictate the strategies for managing airspace-related complexities. Controllers primarily rely on these and actively gather complete information.	None reported.

Source of Complexity	Core Strategies	Additional Strategies
6. Terrain/ obstructions	Sources were site-specific and included aircraft blending into mountainous terrain and structures impinging upon the airspace (cranes, ship masts, etc.). Controllers followed SOPs to mitigate the complexity and, if necessary, slow the operation.	Moving around the towercab to gain a better view of an aircraft.
7. Satellite airports	The participant noted that local SOPs effectively address this complexity.	On occasion, it is necessary to redirect the aircraft to a primary departure runway.
8. High traffic volume	Controllers reported using as few as 1 to as many as 5 different strategies. Nearly all reported that adhering to SOPs, the most common strategy, was effective. Local controllers were more likely to report using anticipated separation rule and visual separation criteria.	Shorten communications; inflect with your voice that you are busy; ensure multiple aircraft with the same in-trail restriction are not lined up one behind the other for departure.
9. Aircraft differing in performance characteristics	Local controllers typically reported 2-3 strategies, though one reported 7. Ground controllers selected 1 strategy (i.e., SOPs). Local controllers ask for more in-trail spacing, which they typically paired with adhering to SOPs.	Actively heighten SA (listen to pilot's voice for indications of potential upcoming problems, monitor traffic for overtakes, etc.). Ground controllers sequence the traffic appropriately for the local controller (time permitting).
10. Emergency operations	Local and ground controllers reported using a common set of 3-4 procedures across sites. These included coordinating to expedite traffic, gathering complete information prior to making decision, adhering to SOPs, and applying visual separation criteria.	None reported.
11. Wake turbulence	With a single exception, every participant reported the same strategy – SOPs, followed by asking for more in-trail spacing.	Consider wake turbulence requirements when sequencing traffic for the local controller.
12. Special flights	All participants relied on a combination of SOPs, coordinating to expedite traffic, gathering complete information, and applying visual separation criteria.	None reported.
14. Vehicular traffic	Most indicated relying on SOPs in combination with gathering complete information, using anticipated separation, or expediting traffic.	Contacting the TRACON to request a gap in the traffic; actively trying to maintain their own SA; providing tug operators sufficient information to promote SA.
15. At or below minimums	Most used 3-4 strategies simultaneously. The initial strategy tended to be adhering to SOPs, followed closely by slowing the operation and gathering complete information. Asking for more in-trail spacing was common during high traffic or when several aircraft were going to the same place.	None reported.

Source of Complexity	Core Strategies	Additional Strategies
16. Reduced visibility (weather)	Almost without exception they reported using a combination of SOPs, slowing the operation (dictated by the situation, not the controller), and gathering complete information. If necessary, they also would request more in-trail spacing.	None reported.
17. Inclement weather	All reported using the same three strategies - SOPs (particularly the Severe Weather Avoidance Procedure), slowing the operation (dictated by situation), and gathering complete information.	None reported.
18. Airport surface activity	Controllers reported employing a combination of SOPs and anticipated separation.	None reported.
19. Equipment malfunctions	The type of equipment malfunction determines the operational impact and procedures to be employed. Controllers emphasized the importance of adhering to the standardized procedures. The majority of these situations inherently slow the operation (failure of headset, DBRITE, Instrument Landing System, etc.).	None reported.
20. Frequency congestion	Controllers averaged 3 strategies. All employed SOPs, often in conjunction with frequency control techniques. Slowing the operation was common, but it was predominantly attributed to the frequency congestion itself and not a controller strategy.	Frequency control techniques (maintaining control of frequency, broadcast announcement, speaking calmly); opening additional frequencies; adding more positions; taking care of highest priority communications first.
21. Equipment location	None reported.	Strategies addressed two separate issues resulting from tower design. Equipment location is not standardized by position - controllers must remain flexible when moving between positions. At one site, a ground controller reported that, not being collocated, they have to actively attempt to "get the other guy's picture" (listening more attentively, remaining vigilant, etc.).
23. Unfamiliar pilots	Controllers employ SOPs in conjunction with slowing the operation. Many used these in concert with ad hoc strategies.	Employing progressive taxi instructions; promote effective communications - speak more slowly, speak more clearly, and maintain composure.
24. Pilot's weak mastery of English	On average, controllers employed two strategies. With a single exception, all reported slowing the operation. Employing SOPs was the next most common strategy.	Focus on effective communications; formulate a backup plan; use progressive taxi instructions; focus attention on the aircraft; work around them.
25. Controller fatigue	Participants employed two to three different strategies. These usually included relief from position, rotating to a position with less workload, and, less frequently, decombining the position.	Drink caffeine.

Source of Complexity	Core Strategies	Additional Strategies
26. Traffic management initiatives	Controllers typically gathered complete information in combination with SOPs, therefore (by default) slowing the operation.	Coordinate closely with Traffic Management Specialist and ground control; use progressive taxi instructions.
28. Other distractions	The predominant distraction was ambient noise from pilot-controller communications, but visitors and equipment noise were also identified. Controllers typically ask the individual to be quiet.	Increase headset volume; ask visitors to move; submit an Unsafe Condition Report (if related to excessive equipment noise).
29. On-the-job (OJT) training	All closely monitor the elements of training. In conjunction, many indicated that they recommend additional classroom time, if warranted.	Employ experiential building; brief the trainee especially ensuring they avoid "tunnel vision"; work with trainees to build their confidence.

The following sections provide specific results regarding the use of strategies. The sections comprise core and additional strategies. Additional strategies represent those strategies that controllers identified as other techniques, beyond those appearing on the core strategies list, which they used to mitigate complexity.

3.1.1 Core Strategies

We divided the core strategies into SOPs and other strategies because the use of SOPs was such a prevalent response. SOPs were by far the most commonly identified strategy on the core strategies list, being specifically identified in 177 of the 285 separate discussions we conducted on the sources of complexity.

3.1.1.1 Standard Operating Procedures

The primary sources the participants identified for SOPs included FAA order 7110.65, local orders, and Letters of Agreement (LOAs). Chapter 3 of Order 7110.65, the national standard governing all ATC domains, addresses procedures for the terminal environment (FAA, 2002a). The order includes sections addressing vehicles and personnel on runways, airport conditions, airport lighting, runway selection, airport surface detection procedures, taxi and ground movement procedures, spacing and sequencing, departure procedures and separation, and arrival procedures and separation. Local procedures appear in an SOP directive, typically the 7210 series, although this varies by site. Section 2-1-2 of Order 7210.3S specifies that the AT manager is responsible for developing the local SOP directive but does not provide guidance on the document number (FAA, 2002b). Chapter 10 of the order governs terminal general procedures (flight progress strip usage, low visibility operations, areas of non visibility, etc.), position binders, operations, and services (e.g., gate hold procedures and reduced separation on final). In addition to the national and local orders, each facility negotiates LOAs with outside organizations, such as the local airport authority, to define organizational responsibilities and standard coordination procedures.

During the interviews, the research team asked participants to indicate the source of any standard procedures that they used when addressing the source of complexity. Table 3 presents the results, which include references to all three primary sources of procedures. We sorted the results from the most frequently reported source (i.e., primary) to the least frequently reported source (i.e., tertiary). In cases when two sources of procedures received identical counts, they appear in the same column. Four of the complexity sources received fewer than five discussions (i.e., 5-Airspace configuration, 6-Terrain/obstructions, 7-Satellite airports, and 12-Special flights). We recommend interpreting these data with caution because they represent a minimal sampling.

The data provide insights into the applicability of ATC procedures for each complexity source. This study represents the first inquiry into the influence of complexity and the applicability of ATC procedural documents. It relied heavily on verbal reports; therefore, the results should be considered as a foundation for any future exploration. The team noted substantial differences between participants in their assessment of what constituted the availability of a specific procedure. Some individuals considered procedures to be in place if they could be applied as a general standard, for example, employing progressive taxi instructions based on the 7110.65 as a means of managing a pilot who was not fluent with the English language (FAA, 2002b). Others reported that a procedure was available to address the specific source of complexity only if they could identify a specific section of the document that was relevant.

Table 3. Use of Standard Operating Procedures by Complexity Source

Source of Complexity	Standard Operating Procedures		
	Primary	Secondary	Tertiary
1. Runway/Taxiway Restrictions	Local	National	LOA
2. Active Runway Crossings	Local	National	LOA
3. Runway/Taxiway Configuration	Local	LOA	National
4. Non Visibility Areas	Local	National	
5. Airspace Configuration [a]	Local	LOA	
6. Terrain/Obstructions [a]	Local		
7. Satellite Airports [a]	Local		
8. High Traffic Volume	Local	National	
9. Aircraft Differing In Performance Chars.	National	Local	
10. Emergency Operations	Local	LOA	National
11. Wake Turbulence	National		
12. Special Flights [a]	LOA	Local	
14. Vehicular Traffic	LOA	National	Local
15. At Or Below Minimums	Local/National	LOA	
16. Reduced Visibility (Weather)	Local	National	
17. Inclement Weather	Local	National	
18. Airport Surface Activity	Local/LOA	National	
19. Equipment Malfunctions	Local	National	
20. Frequency Congestion	Local	National	
23. Unfamiliar Pilots	National		
24. Pilot's Weak Mastery Of English	National		
25. Controller Fatigue	National		
26. Traffic Management Initiatives	Local	National/LOA	
28. Other Distractions	National	Local	
29. On–The–Job Training	National	Local	

[a] received less than five interviews.

3.1.1.2 Other Common Core Strategies

Figure 3 depicts the 10 most commonly cited core strategies. The 22 core strategies, counts of their reported usage, and the average ratings of their frequency of use are included in Table A-1 (Appendix A). Table A-2 in Appendix A provides counts for each strategy by source of complexity. The responses confirmed that controllers employ a variety of strategies that are situation-dependent and differ by complexity source and control position. Five strategies (i.e., adhering to SOPs, gathering complete information prior to making a decision, slowing the operation, using "expedite," and using the anticipated separation rule) accounted for three quarters of all responses.

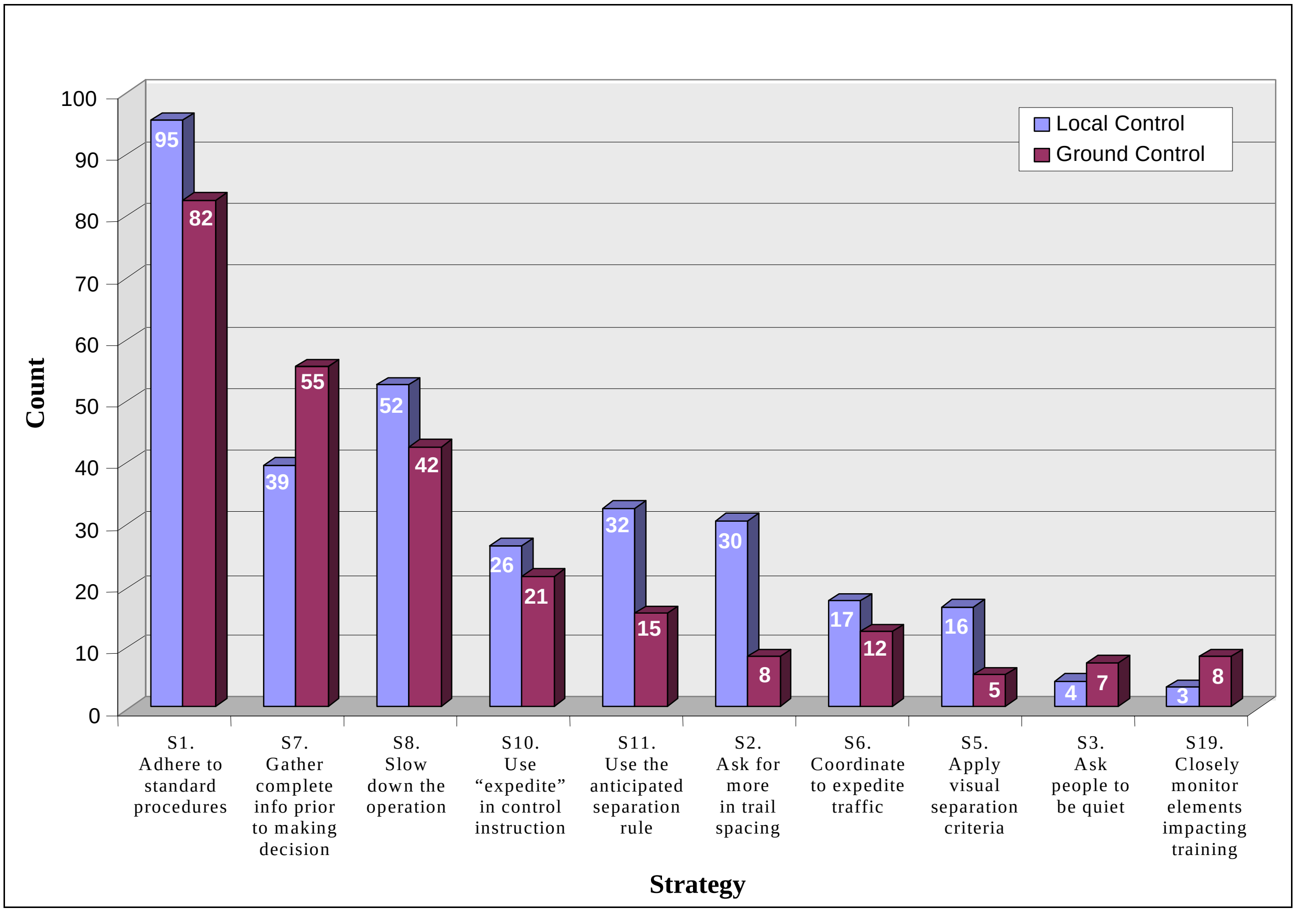

Figure 3. Top 10 strategies reported by control position.

Gathering complete information represented the second most frequently reported strategy. Ground controllers indicated using this approach more often than local controllers did. Another common strategy employed almost equally by both control positions was slowing down the operation. Local controllers predominantly reported using expedite and anticipated separation. Participants reported using strategies in combination. For example, to address complexity due to ground traffic, some participants noted that they verified the operators' intentions before the situation occurred, tried to keep the traffic clear of movement areas, and expedited traffic as necessary.

3.1.2 Additional Strategies

Additional strategies represent supplemental strategies that did not already appear in the list of core strategies identified by the ATCT SMEs. A critical element in the controllers' task is to react promptly and appropriately to unexpected changes, even when faced with unique situations. As controllers develop expertise, they learn to effectively use a variety of different strategies. Therefore, the number of strategies added by the participants represented a large proportion of the responses, being cited on 91 separate occasions. The researchers categorized and tallied these responses. The most common categories of responses appear in Table 4. Table A-3 (Appendix A) contains the entire list of additional strategies organized by source of complexity.

Table 4. Most Common Additional Mitigation Strategies

Count	Strategy	Source of Complexity
10	Maintain control of frequency	Frequency congestion, high traffic volume.
9	Actively attempt to maintain SA (be more vigilant)	Vehicular traffic, unfamiliar vehicles, OJT, Runway/Taxiway configuration, non-standardized towercab equipment locations, no charted visual approach to runway (site-specific factor).
6	Sequence aircraft based on past experience (time permitting)	Aircraft differing in performance characteristics, wake turbulence.
5	Speak more slowly (pay more attention to clarity of speech and phraseology)	Pilot's weak mastery of English, Unfamiliar pilots, Runway/Taxiway configuration.
4	Coordinate with other team members (maintain team SA)	Active runway crossings, TMIs, Runway/Taxiway restrictions.
4	Anticipate and prepare for workload peaks	High traffic volume, runway/taxiway restrictions, runway/ taxiway configuration, aircraft differing in performance characteristics.
4	Use progressive taxi instructions	Runway/Taxiway restrictions, unfamiliar pilots, pilot's weak mastery of English, TMIs.
4	Rely on past experience	Runway/Taxiway configuration, Runway/Taxiway restrictions, TMIs.
3	Formulate a backup plan	Runway/Taxiway configuration, Pilot's weak mastery of English.
3	Open more frequencies	Frequency congestion, Runway/Taxiway configuration.

3.2 Information Needs

After identifying what information they required, the participants rated the usefulness of the information element using a 5-point rating scale. The scale ranged from minimally useful (1) to extremely useful (5). Several participants commented that their information needs were very similar regardless of the source of complexity that they were addressing or the strategy that they employed. However, we could not evaluate the influence of the sources of complexity on information needs because in meeting the objectives of this exploratory study, we focused the majority of interviews on the most prevalent tower complexity sources. The participants indicated that their information needs were different depending on whether they were working the local- or ground-control position.

We compared average local- and ground-controller ratings to investigate the influence of control position on the relative importance of each information element (Table 5). The ratings were different for many of the elements. The relative importance of aircraft category was much higher for the local position. It tied for third most important element for the local position and last for the ground position. The participants rated assigned gate and taxi route much higher for the ground position. These ratings, and controller comments during the interviews, confirmed the importance and the interrelationship between these two information elements for the ground controller. Even with these differences, there were many similarities. Overall, aircraft position and aircraft identification (ACID) were clearly the most important information elements for both control positions. Runway status represented the midpoint for each position, with weather conditions falling a few positions lower on the scale.

Table 5. Average Usefulness Ratings for Information Elements

Local position			**Ground position**		
Information	Rating	*SD*	Information	Rating	*SD*
Aircraft position	4.8	0.6	Aircraft position	4.9	0.3
ACID	4.6	0.9	ACID	4.8	0.5
Aircraft type	4.2	0.9	Taxi route	4.5	0.6
Aircraft category	4.2	1.0	Assigned gate	4.2	1.0
Runway status	4.2	1.1	Runway status	4.1	0.9
Aircraft speed	4.0	1.0	Aircraft type	3.8	0.9
Weather conditions	3.9	0.8	Traffic management	3.7	1.0
Taxi route	3.8	1.0	Weather conditions	3.7	0.9
Traffic management	3.7	1.3	Aircraft category	3.6	1.2
Assigned gate	3.3	1.1	Aircraft speed	3.6	1.0

3.3 Information Sources

The interview team provided participants with a list of 10 potential sources for each information element. Figure 4 depicts a count of the sources participants reported using as a local and ground controller. Though the list was rather comprehensive, participants identified additional sources during roughly one third of the interviews, accounting for 105 responses.

The most frequently added resources, communicating with a Traffic Management Coordinator (TMC) specialist or supervisor, accounted for 34 and 18 responses, respectively. Table B-1 (Appendix B) contains the list of 29 information sources in its entirety, along with their respective counts. Some information sources served multiple information needs, and in these instances, the counts exceeded the number of interviews. For example, participants reported relying on visual observation to determine aircraft position, aircraft type, weather conditions, runway status, aircraft speed, and other information.

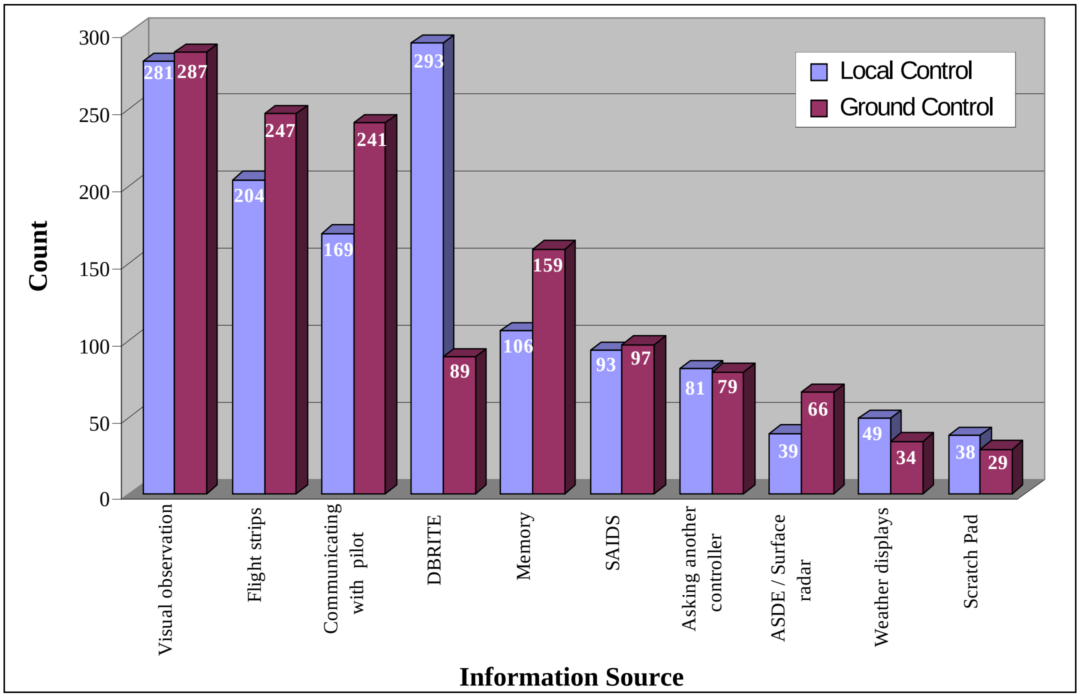

Figure 4. Most commonly reported information sources for local and ground control.

3.4 Information Requirements Summary

The participants' indicated that they acquired several pieces of information from each of the sources available to them within the tower. To investigate which sources they commonly relied upon, the researchers compiled counts of the information reported and its associated source. Table 6 presents a summary of the results. The complete data set for all sources appears in Table B-2 (Appendix B) including additional sources identified by the participants. These additional sources were, in order of most frequently cited: TMC, other equipment, supervisor, runway closure strip, and position relief briefing.

Table 6 shows that controllers reported relying primarily upon visual observation for determining aircraft position, but that they used communicating with the pilot and viewing the DBRITE as supplemental mechanisms for confirming aircraft position. During the interviews, controllers indicated that the secondary methods were especially important during reduced visibility conditions or in the presence of obstructions. As its location in the first row implies, aircraft position represented the most commonly cited information need. The table shows that visual observation fulfilled several information needs, representing the primary means for determining aircraft position and weather conditions, and as a supplemental method for another five elements.

Table 6. Summary of Common Sources of Required Information

SOURCE	Aircraft position	Aircraft identification	Aircraft type	Weather conditions	Runway status	Taxi route	Aircraft speed	Traffic management	Assigned gate	Aircraft category
	REQUIRED INFORMATION									
Visual observation	●		◐	●	◐	◐	◐			○
Flight strips		●	●						◐	●
Communicating with pilot	◐	○				○			●	
DBRITE	○	◐	○				●			◐
Memory					○	●	○		○	
SAIDS				○	●			●		
Asking another controller								○		
Weather displays				◐						
Other Sources (TMC)								◐		

● Primary source ◐ Secondary source ○ Tertiary source

3.5 Controller Recommendations

To conclude the interviews, the HFSs asked participants what other information, besides the information needs identified previously, would help them in their ATC duties. The controllers forwarded a number of technologies and recommendations, which we summarize in Table 7 beginning with the most commonly cited items. The participants' recommendations fell into the categories of revising existing procedures or systems, implementing new technologies within the tower, and employing good human factors principles in the design of future systems.

The participants' suggestions for revising existing systems included upgrading radio communications equipment to minimize dead spots on the airport surface and to overcome stuck "mike" situations, providing wireless headsets, and adding data tags to the ASDE display. Other suggestions centered upon reviewing existing TMIs, wake turbulence advisory, tower visit, and other procedures to identify opportunities for improvement.

Common controller recommendations regarding the introduction of new technology into the tower were to develop electronic strips, implement datalink, and promote communications and information dissemination through the use of palm pilots. As one controller suggested, "move information you do not deal with every day (local SOPs, aircraft routes, etc.) from paper. It's better to have it electronically." Besides procedures, another individual noted that electronically providing information on the availability of ramps and gates would be useful. Improving airport signage was another recommendation.

Table 7. Controllers' Recommendations for Implementing Technology in the Tower

Recommendation	Representative Comments
Review procedures	▪ Publish procedures as they become common practice. ▪ Review the TMI process and minimize the number of restrictions and their impact where possible.
Implement new technologies	▪ Develop electronic strips. ▪ Employ datalink, "especially for issuing flight plans." ▪ Use palm pilots. It would be useful "for aircraft handoffs, information . . . [and] coordination" between ground and local controller and other contacts (e.g., TRACON). ▪ "Move information you do not deal with every day (local SOPs, aircraft routes, etc.) from paper. It's better to have it electronically." ▪ "Technology to know where aircraft are at all times. Currently we need to make several calls . . . . A satellite system could overcome the limitations of obstructions (which affect current surface radar systems). We need continuous tracking." ▪ "Decision support software to help select appropriate configuration. You must take into account arrival flow, departure flow, weather, TMI, and other factors."
Install ASDE-X at this site	▪ ASDE-X would aid in poor visibility conditions such as identification of traffic at night; dealing with fog, snowstorms, sandstorms; non-visibility areas; and congested gates.
Apply human factors to equipment design	▪ Non-standardized systems require more head down time when the "most important thing for the controller is still to scan out the windows." ▪ "Technology is not necessarily making it easier. It tends to take your focus from looking out the window . . . entering keystrokes, etc." ▪ "New pieces of equipment are not integrated. We have 6 different systems. . . .[and] new systems make their own screens." ▪ "Automation, like ARTS, helps, but makes you lazy . . . [leading to] over reliance on tools and technology, potentially leading to reduced use of skills, memory, and might not always be good."
Ergonomically design towers	▪ "You have to physically move to see all gates . . . you need a pedestal to see all areas." ▪ "Integrate tower equipment - we have so many different pieces of equipment." ▪ "Standardize equipment location from position to position." ▪ Consider "polarized windows."
Reduce noise and distractions in the tower	▪ Consider implementing "something like the sterile cockpit" in the tower. ▪ "Telephones ring incessantly. Restrict the number to those that need it. We sometimes get calls from someone to get the barometric setting for the barometer they just got."
Provide wireless headsets	▪ "We have blind spots on the east side of the airport when working ground, and wireless headsets would make moving around the tower easier." ▪ "Cordless headsets would be especially useful for the TMC person . . . .they must be mobile." ▪ "One position has the same [volume] controls for instructor and developmental."
Improve radio communications equipment	▪ Eliminate dead spots on areas on the airport surface sites. ▪ "We need 10 watt transmitters." ▪ Provide "separate the volume controls for OJT instructors."
Automate repetitious tasks	▪ Currently "you must copy all arrival information from the DBRITE, then check it, and then cross it out as you accept, taxi, or park aircraft. . . the information is already available electronically." ▪ "TMU must track traffic delays and must currently look over local's shoulder to know when an aircraft is released. Automate gathering of taxi time to departure time to track delays." ▪ "Information on all departures has to be sent to the TRACON. Consider having ARTS send this information automatically as it tags the target."
Improve airport signage	▪ "We need better taxiway and runway markings." ▪ "Some taxiways are not marked due to construction. The book has taxiways marked, but you want the pilot looking outside the cockpit, not at the book."

Many of the suggestions addressed human factors related aspects and the design of future systems. Examples of these comments included applying a systems approach when integrating new systems into the tower, automating repetitive tasks, and effectively utilizing electronic media. As one participant noted, “You must use pen and paper for information that is already available electronically.” Another individual noted that equipment designers should keep automation simple to minimize potential errors and to enable the controller to offload tasks to Supervisory ATCSs or others in the tower so that the controller can continue to scan the airport surface.

4. Discussion

The results confirm that tower controllers use an assortment of strategies to address the various sources of complexity. This section contains a discussion of these strategies, controller information needs, and the relevant sources of information. It concludes with recommendations for future research efforts.

4.1 Strategies

The most commonly reported strategy was employing SOPs. These procedures are predominantly drawn from a combination of FAA Order 7110.65, local orders, and LOAs (FAA, 2002a, 2002b). The participants reported that specific procedures were in place for all sources of complexity, with the single exception of equipment location. This item received only two interviews. They reported that local orders directly addressed 16 of the complexity drivers and that Order 7110.65 addressed 8 drivers. LOAs were the most frequent response for dealing with special flights, vehicular traffic, and airport surface activity. The participants indicated that situation-specific procedures were available for virtually all of the sources of complexity. One notable exception besides equipment location was in dealing with pilot’s weak mastery of the English language. For this source, only 2 of the 16 respondents indicated specific procedures were available.

Following standard traffic flow patterns, such as those contained in local procedures or national procedures (e.g., Severe Weather Avoidance Program routes), represents an effective means of mitigating complexity because these procedures represent examples of standard flow abstractions (i.e., rules) like those proposed by Histon and Hansman (2002). These procedures do not necessarily have to be formalized to be effective. Local, unpublished, common practices and traffic flow patterns can also promote complexity reduction. By employing this abstraction technique, controllers are able to associate higher-level attributes to those aircraft falling within the standard class. By doing so, they are able to reduce the complexity associated with projecting future aircraft locations and issuing commands (i.e., members of the same class follow the same route and will likely receive identical instructions).

Overall, the participants recognized the vital and requisite role of SOPs but indicated that there are situations when the SOPs may not represent the best solution. They identified specific instances in which they considered SOPs to be inefficient in mitigating a source of complexity, for example, continuing to use standard phraseology for a pilot who has exhibited difficulty understanding the standard instruction.

On average, the controllers reported using two to three different strategies for each source of complexity. However, the number varied considerably depending on the source, ranging from as few as one strategy to as many as nine; the latter being reported for runway/taxiway configuration. Two sources, OJT and pilot's weak mastery of English, returned a relatively small subset of procedures when compared to the number of interviews. OJT raises challenges because developmental controllers may be unpredictable, throw the timing off, make poor judgments, and slow the entire operation. Ground controllers relied more frequently on "gathering complete information prior to making a decision" than local controllers. This strategy referred to the need to actively gather required information because it was not readily available. The participants indicated that, as a ground controller, they predominantly used this strategy to determine the location of non-visible aircraft resulting from physical obstructions such as terminal buildings, weather, or other sources. Slowing the operation was both a strategy and an artifact of the situation. As a strategy, it represented those situations when a controller consciously chose to decrease the flow of traffic to maintain safety or for some other purpose. Examples when they might consider using this strategy included handing off to a trainee, dealing with an unfamiliar pilot, or if they have been interrupted and "lose the picture." The other circumstances in which the conditions intrinsically slowed the operation included reduced visibility due to weather and wake turbulence. None of the participants specifically identified using three of the strategies contained in the ATCT strategies list. These strategies included training, team briefings, and the use of read and initial files. However, in subsequent discussions, it was apparent that they used these strategies effectively in mitigating some other sources of complexity.

The participants reported using a variety of additional mitigation strategies. Among the most common were using frequency control techniques, actively attempting to maintain SA, and relying on past experience to mitigate a source of complexity. By far the most frequently reported category was maintaining control of the frequency. Among the techniques participants specifically reported using were making a broadcast announcement, shortening communications, and inflecting with their voice that they are busy. The participants specifically identified using these techniques in 10 incidences to address either frequency congestion or high traffic volume. Conveying urgency through the tone of voice has been recognized as one means of enhancing communications (Wickens et al., 1997). Opening more frequencies, the last item in the table, represented an additional strategy for mitigating frequency congestion. The incidence of responses regarding frequency congestion is not surprising because it is one of the major challenges in the tower environment (Cardosi & Yost, 2001).

The participants emphasized the importance of maintaining team SA. The tower is a highly collaborative environment and mandates the exchange of information between many different parties including controller teams (e.g., local/ground), pilots, and vehicle operators. This exchange is essential to the development and maintenance of a shared mental model. Breakdowns in information transfer have been established as the largest single cause of ATC incidents (Wickens et al., 1997).

Other common strategies reported by the participants included anticipating workload peaks and formulating a backup plan. D'Arcy and Della Rocco (2001) reported that the majority of controllers they interviewed developed backup plans, and those with more experience were more likely to have a backup plan. Other strategies adopted by controllers included speaking calmly to unfamiliar pilots or those with poor English-speaking skills. By doing so, they avoided leveraging additional stress on the pilot and potentially exacerbating the situation.

Another strategy specifically identified for reduced visibility due to weather was reducing "touch and go" and curtailing services. One participant indicated that equipment location was not standardized between positions, and they had to adapt to each position. The significance of this observation is that as controllers develop expertise, they know where to look or what to listen to, to gather critical information at the time it is needed and available (Wickens et al., 1997).

4.2 Information Requirements

Controllers must maintain information on individual aircraft, airport surface activity, the airspace, weather, and a number of other key elements to effectively maintain separation. In presenting this information to controllers, Wickens et al. (1997) suggested "situation awareness may be better preserved by display formats that are compatible with the controller's mental model of the airspace and by the integration and easy accessibility of all necessary information" (pp 106-107). To achieve this, it is essential that the tower controllers' information requirements be precisely defined. However, as they represent cognitive aspects, they cannot be observed directly. Therefore, the current study relied on participants to identify their information needs and the sources that they consulted to determine the information.

4.2.1 Information Elements

Aircraft position was the most common information element cited as being required, substantiating its importance as among the most critical pieces of information to tower controllers. This concurs with other research indicating that the most critical task is to keep track of who is where (Wickens et al., 1997). The controllers in the current study indicated that they used a variety of information sources to ascertain an aircraft's location. As Table 6 shows, the most common means was visual observation, followed by communicating with the pilot and the DBRITE. As noted earlier, local controllers, in particular, reported relying on the DBRITE. Ground controllers indicated greater reliance on communicating with the pilot for identifying the position of aircraft as they pushed back from the gate and for situations when visibility of the aircraft was limited.

ACID, the second most reported element, is a critical factor because it is required for all communications with individual targets. The participants predominantly reported using flight strips to gather ACIDs, although they also relied upon communications with the pilot and the DBRITE for this purpose. The participants also noted using communications with the pilot and DBRITE to identify aircraft position.

Aircraft type fell closely behind ACID in terms of incidence. The controllers reported gathering this information predominantly from flight strips, although visual observation was a secondary widely used resource. They indicated that aircraft type is crucial in identifying performance characteristics, wake turbulence implications, compliance with noise abatement restrictions, compliance with taxiway weight and wingspan restrictions, and various other factors. Many interviewees indicated that the information provided by aircraft category was subsumed by aircraft type and, consequently, cited they needed this element infrequently.

The relative importance of the remaining information requirements, based on count, were weather conditions, runway status, taxi route, aircraft speed, TMIs, assigned gate, and aircraft category. Clearly, the significance of each is indistinguishably tied to the current situation and strategies in use by the controller. For example, the speed for an aircraft on final approach is vital. However, in the presence of a thunderstorm, information such as the presence of wind sheer or a sudden shift in wind direction and speed may take precedence.

The participants supplemented the list of information sources provided to them by the team. The sources they identified addressed several specific needs. For instance, they reported relying principally upon the TMC for information related to TMIs. They received runway status information from a variety of sources including runway closure strips, position relief briefing, or the towercab supervisor.

4.2.2 Information Element Usage by Control Position

The most commonly cited information element for local and ground controllers was aircraft position followed by ACID. The participants also rated these information elements as the two most important elements. The ratings and the number of references to each were very similar for local and ground controllers, for almost all information elements. However, as suggested previously, there were differences in the usefulness of some information elements between the positions. Local controllers rated aircraft speed, type, and aircraft category, in particular, higher than ground controllers. For the ground position, assigned gate, taxi route, and to a lesser extent, TMIs, held more importance than when working as a local controller. Both positions rated the usefulness of runway status and weather conditions as falling near the middle of their information needs. Aircraft category received the least number of references across positions. However, many participants indicated that this information was redundant to and less informative than aircraft type.

Local and ground controllers reported relying upon essentially the same resources to gather needed information. For many of these sources, the relative numbers of references were equivalent. These included visual observation, asking another controller, and use of Systems Atlanta Information Display System (SAIDS), weather displays, and scratch pads. Overall, participants identified visual observation as the leading source, accounting for approximately one fifth of the nearly 2800 reports. The team anticipated the importance of visual observation because previous researchers had recognized this as a primary means of gathering information in the tower environment (Bruce, 1996; Wickens et al., 1997). Controllers reported looking out the towercab to determine several elements of critical information including aircraft position, type, category, speed, taxi route, runway status, and weather conditions. A time and motion study of the tower controllers' task confirmed that the principal activity for tower controllers was looking out of the window (Bruce). In that sampling, ground controllers spent approximately one half of their time focused out of the window, whereas local controllers spent slightly more than one third of their time engaged in this activity. The next closest activities, both of which returned a value of 22%, were interacting with flight strips for the ground position and looking at the DBRITE for the local position. Continuously scanning the airport surface also supports the tower controllers' ability to maintain SA.

A report of the use of the DBRITE demonstrated the most significant differences between positions and coincidentally was the most commonly cited resource for the local controller. It accounted for 21% of local control responses and just 6% for ground control. These results substantiate previous tower research suggesting ranges fall between 20%-24% for local controllers and 0%-6% for ground control (Bruce, 1996). Some participants elaborated during our interviews that the DBRITE was of limited use to them on ground control. As ground controllers noted, DBRITE provided them the location of arrival and departure traffic but that ACID was only available for the arrival traffic.

Ground controllers reported consulting four information sources more frequently than local controllers did. These included flight strips, communicating with the pilot, memory, and ASDE/ surface radar. For flight strips and communicating with the pilot, ground control counts exceeded local counts by 10% and 18%, respectively. The participants indicated that at the ground-control position, they tended to rely more heavily upon flight strips for aircraft type and category, whereas, at the local-control position, they were more likely to gather this information, as well as aircraft speed, from the DBRITE. Some interviewees noted that as a ground controller, they relied on communications with the pilot to augment their information on ACID, position, taxi route, and assigned gate.

4.2.3 Primary Sources by Element

As demonstrated by the information requirements summary, each of the information sources within the tower conveys several critical elements of information to the controller. Six of the sources fulfilled multiple information needs.

Visual observation, the most frequently cited source, represented the primary information means of determining aircraft position and weather conditions. Controllers reported visually scanning the airport surface to gather other information such as aircraft type, runway status, taxi route, aircraft speed, and aircraft category. The results underscore the importance of visual observation to the tower controllers' task.

Flights strips, the second most frequently cited source, also fulfill several information needs. In fact, the current data suggest that they are the primary means of gathering information for three elements: aircraft type, ACID, and aircraft category. Controllers reported using strips to determine assigned gate although they typically determined this by communicating with the pilot.

Communicating with the pilot also represented a supplemental means for determining aircraft position (especially in the case of obstruction or weather related non-visibility), ACID, and taxi route. The DBRITE, another multipurpose resource, furnishes controllers with aircraft position, type, identification, and category, in addition to being the leading means of determining aircraft speed.

ASDE and other surface radar systems do not appear within the table because they accounted for very few responses. However, this is not representative of the utility of this technology because the capability was available at only three of the facilities we visited. In fact, when asked what other information would help in their ATC duties, more than one third of the participants from sites without ASDE indicated that this system would be useful. For sites with ASDE, a common request was to add ACID to the display. Participants at the sites with ASDE reported using it primarily for confirming aircraft position, but it also provided taxi route, aircraft speed, ACID, assigned gate, runway status, and aircraft type.

It is essential that the information presented to the tower controller across all sources is timely, accurate, and consistent. In addition, controllers should not be required to expend significant resources maintaining the integrity of the data, regardless of whether it is derived from flight strips, displays (DBRITE, ASDE, SAIDS, etc.), or other means. Requiring a controller to perform substantial visual or data entry tasks minimizes the time available for scanning the airport surface, which is arguably the most critical and fundamental resource available to them.

4.3 Future Research

Future research efforts should focus on the key complexity sources identified in the previous report (Koros et al., 2003). In all, nine sources fall within the key complexity quadrant of the matrix. These include high traffic volume, frequency congestion, active runway crossings, runway/taxiway configuration, runway/taxiway restrictions, TMIs, aircraft differing in performance characteristics, vehicular traffic, and OJT. High traffic volume and frequency congestion are of particular interest because both present highly complex situations that occur very frequently.

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, 2002c). Building new runways and maximizing the use of existing runways are among the strategies that the OEP delineates to help airports meet peak demand. New runways will help offset complexities associated with high traffic volume and promote airport capacity and efficiency; however, this is a long-term solution. 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 document outlines the implementation and evaluation of crossing runway procedures at 18 benchmark airports and making traffic management advisory tools operational at new sites.

Future research efforts should focus on the cognitive drivers, dependencies, information needs, and information sources related to each of the key complexity areas. Further knowledge will enable researchers to characterize ATC complexity and its primary components. Once these key complexity drivers are known, designers can apply this knowledge

1) to design airports, traffic flow, and SOPs that minimize complexity;
2) to assess the impact of new technologies on perceived complexity;
3) to develop automation that is sensitive to the needs of the user and the situation (e.g., error-tolerant automation);
4) to develop a better metric of perceived complexity; and
5) to identify and predict situations of peak complexity and investigate whether operational errors are more likely during these times.

Researchers based the final item on the assertion that it is possible that controllers have limits on the level of complexity that is manageable. This measure of complexity would allow researchers to determine when a controller is approaching the limits of his or her processing abilities (Pawlak et al., 1996). The information gathered may also be applied to further refine the factor groupings identified during the current study and to collect similar data from a broader range of facilities (e.g., Level 6-10 towers, terminal facilities, and en route facilities). Comparing data and groupings across ATC domains would elucidate the sources and incidence of complexity within each and serve to identify similarities and the unique challenges facing the ATCS. When designing future systems, it is important to set realistic goals such as the development of error-tolerant designs, and not, as Wickens et al. (1998) notes, the unobtainable goal of “the complete elimination of all human error” (p. 104). Effectively integrating new automation in the tower will minimize training requirements and errors and enable controllers to maintain their focus outside of the towercab.

5. Conclusions

This study fulfilled a number of research needs. The first report, Part 1, described the nature of key sources of tower complexity from the controllers' perspective and presented complexity and frequency ratings for each of the sources (Koros et al., 2003). It prioritized the sources in terms of their importance and identified those of particular interest. The current document, Part 2, addresses controller's strategies, information needs, and sources of information in response to these drivers. These findings pave the way for future research efforts and define preliminary principles for the design of tower automation equipment.

Controllers in this survey typically selected two to three standard strategies to mitigate a complexity source, although they supplemented these with ad hoc techniques. In some situations, a controller may have a repertoire of nine different strategies available. Overall, SOPs are almost always available to address each of the sources of complexity. These procedures are predominantly drawn from FAA Order 7110.65 (FAA, 2002a), local orders (typically the 7210 series) (FAA, 2002b), and LOAs. Standard national and local procedures, though extremely comprehensive, cannot possibly address all situations, and, therefore, they are supplemented with ad hoc procedures. Common supplemental strategies included employing frequency control techniques, actively attempting to maintain SA, and relying on past experience. Maintaining control of the frequency, which was specifically useful in addressing high traffic volume and frequency congestion, included the techniques of making a broadcast announcement, shortening communications, and inflecting in their voice that they are busy.

Information requirements appeared to be very similar regardless of the strategy employed or the source of complexity being mitigated. The most commonly reported information elements were aircraft position, identification, and type, followed by weather conditions and runway status. There were differences in information requirements between control positions. Ratings of the importance of taxi route and assigned gate were higher for the ground-control position. Local controllers identified the need for aircraft type and speed information more frequently than ground controllers.

The most commonly cited information sources were visual observation, flight strips, communicating with the pilot, DBRITE, and memory. Visual observation is well established as among the leading means of information gathering in the tower environment (Bruce, 1996; Wickens et al., 1997). The participants reported relying upon visual observation to determine several elements of critical information including aircraft position, type, category, speed, taxi route, runway status, and weather conditions. Ground controllers reported consulting flight strips and ASDE/surface radar more frequently than local controllers. They indicated that they used flight strips to identify aircraft type and category. Local controllers were more likely to report gathering this information as well as aircraft speed from the DBRITE.

Results from the current study hold implications for tower automation equipment design. Information sources within the tower may simultaneously convey a number of information elements. The participants reported that visual observation, directly or indirectly, provided information on aircraft position and type, weather conditions, runway status, aircraft speed, assigned gate, and other elements. Similarly, many of these elements were also available from flight strips, communicating with the pilot, surface radar, and other sources. This emphasizes the importance of ensuring the availability of multiple, integrated, and synchronized information sources to tower controllers. Furthermore, maintaining the integrity of the data presented on these displays must require minimal controller resources (i.e., visual or manual data entry), or else the time available for scanning the airport surface or other important tasks may suffer. As in other ATC domains, the participants in this survey reported that they adopt different strategies depending on the presence of inclement weather, the current operational configuration, and many other often site-specific factors. The participants also indicated that these adjustments must often occur dynamically, such as in the case of changing runway configurations in response to a wind shift. They use many strategies - often employing a combination of strategies simultaneously or changing from one tactic to another for the same aircraft. Therefore, it is essential that automation equipment, as well as the equipment layout, the tower design, operational procedures, and other relevant aspects remain flexible to the needs of the controller. Previous research has suggested that SA may be better preserved by displays that are compatible with a controller's mental model of the airspace and by the integration and availability of all necessary information. Clearly, the equipment designer will have significant challenges to meet these requirements. The FAA has already initiated programs to address a number of these factors, many of which are defined in the OEP.

Specifically, we recommend future research efforts focus on conducting systematic analyses of the ATC constructs within the tower environment, concentrating, in particular, on those related to the key sources of complexity. Though the specific influence of each of the sources differs by site, common focal areas include high traffic volume, active runway crossings, runway/taxiway configuration, runway/taxiway restrictions, frequency congestion, TMIs, and OJT. Research efforts should focus on the cognitive drivers, dependencies, information needs, and information sources related to each of the areas. Additional knowledge will enable researchers to characterize ATC complexity and its primary components and promote an understanding of the mechanisms and abstractions underlying controller mitigation strategies. Once designers know these key complexity drivers, they can apply this knowledge to the design of decision support and other tower systems that closely match information and task requirements with controller needs. This information will promote the design of flexible error-tolerant automation, represent a means of assessing the impact of new technologies on perceived complexity, and enable researchers to investigate whether perceived complexity influences the potential for operational errors. A more complete understanding of ATCSs' decision making and sources of complexity in the tower environment will enhance future automation, emerging technologies, controller performance, and, ultimately, NAS safety and efficiency.

References

Anagnostakis, I., Idris, H., Clarke, J., Feron, E., Hansman, R., Odoni, A., & Hall, W. (2000). A conceptual design of a departure planner decision aid. *Proceedings of the 3rd USA/Europe Air Traffic Management R&D Seminar*. Napoli, June 13-16.

Bisseret, A. (1971). Analysis of mental model processes involved in Air Traffic Control. *Ergonomics*, *14*(5), 565-570.

Bruce, D. S. (1996). *Physical performance criteria for air traffic control tower specialists*. Washington, DC: Federal Aviation Administration.

Buckley, E., O'Connor, W. & Beebe, T. (1969). *A comparative analysis of individual and system performance indices for the Air Traffic Control system* (NA-69-40). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Burki-Cohen, J. (1995). *An analysis of tower (ground) controller-pilot voice communications* (DOT/FAA/AR-96/19). Washington, DC: DOT/FAA, Office of Aviation Research.

Cardosi, K., & Yost, A. (2001). *Controller and pilot error in airport operations: A review of previous research and analysis of safety data* (DOT/FAA/AR-00-51). Washington, DC: DOT/FAA, Office of Aviation Research.

D'Arcy, J. F., & Della Rocco, P. (2001). *Air Traffic Control Specialist decision making and strategic planning – A field survey* (DOT/FAA/CT-TN01/05). Atlantic City International Airport, NJ: DOT/FAA William J. Hughes Technical Center.

Dareing, S., & Hoitomt, D. (2002). Traffic management and airline operations. *American Control Conference*, Anchorage, May 8-10.

Endsley, M. R. (1995). Toward a theory of SA in dynamic systems. *Human Factors,* 37(1), 32-64.

Federal Aviation Administration. (2001). *Administrator's fact book: January 2001*. Retrieved February 16, 2001, from http://www.atctraining.faa.gov/factbook

Federal Aviation Administration. (2002a). *Air traffic control* (FAA Order 7110.65N). Washington, DC: Federal Aviation Administration.

Federal Aviation Administration. (2002b). *Facility operation and administration* (FAA Order 7210.3S). Washington, DC: Federal Aviation Administration.

Federal Aviation Administration. (2002c). *National airspace system operational evolution plan (OEP): A foundation for capacity enhancement 2003-2013* (Version 5.0). Washington, DC: Federal Aviation Administration.

Fields, R. E., Wright, P. C., Marti, P., & Palmonari, M. (1998). Air traffic control as a distributed cognitive system: A study of external representations. *Proceedings of the Ninth European Conference on Cognitive Ergonomics*, 85-90.

Grossberg, M. (1989). Relation of sector complexity to operational errors. *Quarterly Report of the FAA Office of Air Traffic Evaluations and Analysis.* Washington, DC: Federal Aviation Administration.

Heil, M. (1998). *Air Traffic Control Specialist age and cognitive test performance* (DOT/FAA/AM-98/23). Washington, DC: DOT/FAA Office of Aviation Medicine.

Histon, J. M., & Hansman, R. J. (2002). *The impact of structure on cognitive complexity in air traffic control* (ICAT-2002-4). Cambridge, MA: MIT International Center for Air Transportation.

Hutton, R. J. B., Olszewski, R., Thordsen, M. L., & Kaempf, G. L. (1997). *En Route air traffic controller decision making model and decision maker vulnerabilities*. Dayton, OH: Klein Associates.

Koros, A., Panjwani, G., Ingurgio, V., Della Rocco, P., & D'Arcy, J. F. (2003). *Complexity in air traffic control towers: A field study. Part 1. Complexity factors* (DOT/FAA/CT-TN03/14). Atlantic City International Airport, NJ: DOT/FAA William J. Hughes Technical Center.

Marti, P. (2000). The choice of the unit of analysis for modeling real work settings. *Cognition, Technology & Work, 2*, 62-74.

Mogford, R. H., Guttman, J. A., Morrow, S. L., & Kopardekar, P. (1995). *The complexity construct in air traffic control: A review and synthesis of the literature* (DOT/FAA/CT-TN95/22). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Mogford, R. H., Murphy, E. D., Roske-Hofstrand, R. J., Yastrop, G., & Guttman, J. A. (1994). *Application of research techniques for documenting cognitive processes in air traffic control: Sector complexity and decision making* (DOT/FAA/CT-TN94/3). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Mogford, R. H., Murphy, E. D., Yastrop, G., Guttman, J. A., & Roske-Hofstrand, R. J. (1993). *The application of research techniques for documenting cognitive processes in air traffic control* (DOT/FAA/CT-TN93/39). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Pawlak, W. S., Brinton C. R., Crouch, K., & Lancaster, K. M. (1996). A framework for evaluation of air traffic control complexity. *Proceedings of the AIAA Guidance, Navigation, and Control Conference.* San Diego, CA.

Redding, R. E., Cannon, J.R., Lierman, B., Ryder, J., Purcell, J., & Seamster, T. L. (1991). The analysis of expert performance in the redesign of the en route air traffic control curriculum. *Proceedings of the Human Factors Society, 35*, 1403-1407. Santa Monica, CA: Human Factors Society.

Rodgers, M. D., Mogford, R. H., & Mogford, L. S. (1998). *The relationship of sector characteristics to operational errors* (DOT/FAA/AM-98/14). Washington, DC: DOT/FAA Office of Aviation Medicine.

Sperandio, J. C. (1971). Variation of operator's strategies and regulating effects on workload. *Ergonomics*, *14*(5), 571-577.

Sperandio, J. C. (1978). The regulation of working methods as a function of workload among air traffic controllers. *Ergonomics, 21*, 195-202.

Stein, E. S. (1985). *Air traffic controller workload: An examination of workload probe* (DOT/FAA/CT-TN84/24). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Vingelis, P. J., Schaeffer, E., Stringer, P., Gromelski, S., & Ahmed, B. (1990). *Air traffic controller memory enhancement* (DOT/FAA/CT-TN90/38). Atlantic City International Airport, NJ: DOT Federal Aviation Administration Technical Center.

Wickens, C. D., Mavor, A. S., & McGee, J. P. (1997). *Flight to the future: Human factors in air traffic control*. Washington, DC: National Academy Press.

Wickens, C. D., Mavor, A. S., Parasuraman, R., & McGee, J. P. (Eds.). (1998). *The future of air traffic control: Human operators and automation*. Washington, DC: National Academy Press.

Willems, B., Heiney, M., & Sollenberger, R. (2002). *Study of an ATC baseline for the evaluation of team configurations: Information requirements* (DOT/FAA/CT-02/17). Atlantic City International Airport, NJ: DOT/FAA William J. Hughes Technical Center.

Acronyms

ACID	Aircraft Identification
ASDE	Airport Surface Detection Equipment
AT	Air Traffic
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATCT	Airport Traffic Control Tower
DBRITE	Digital Bright Radar Indicator Tower Equipment
FAA	Federal Aviation Administration
HFS	Human Factors Specialist
LOA	Letter of Agreement
NAS	National Airspace System
NATCA	National Air Traffic Controllers AssociationDB
OEP	Operational Evolution Plan
OJT	On-the-Job Training
SA	Situation Awareness
SAIDS	Systems Atlanta Information Display System
SOP	Standard Operating Procedure
SME	Subject Matter Expert
TMC	Traffic Management Coordinator
TMI	Traffic Management Initiative
TRACON	Terminal Radar Control

Appendix A

Controller Strategies

Table A-1. Core Strategy Usage and Average Frequency of Use Rating by Control Position

Strategy	Count			Frequency of Use [a] (average)		
	Local	Ground	Total	Local	Ground	Total
S1. Adhere to SOPs	95	82	177	4.8	4.8	4.8
S2. Ask for more in-trail spacing	30	8	38	3.7	3.4	3.6
S3. Ask people to be quiet	4	7	11	3.3	4.0	3.7
S4. Request supervisory assistance	1	1	2	3.0	3.0	3.0
S5. Apply visual separation criteria	16	5	21	3.9	4.6	4.1
S6. Coordinate to expedite traffic	17	12	29	4.1	3.8	4.0
S7. Gather complete information prior to making decision	39	55	94	4.8	4.6	4.7
S8. Slow down the operation	52	42	94	3.4	3.8	3.6
S9. Slow down operation while attending to higher priority duties		2	2		3.5	3.5
S10. Use "expedite" in control instruction	26	21	47	3.2	2.9	3.1
S11. Use the anticipated separation rule	32	15	47	4.3	3.7	4.1
S12. Point out traffic	3	–	3	4.0	–	4.0
S13. Training	–	–	–	–	–	–
S14. Team briefing	–	–	–	–	–	–
S15. Read and initial	–	–	–	–	–	–
S16. Relief from Position	5	4	9	3.6	3.0	3.4
S17. Rotation to less workload position	5	2	7	2.6	3.0	2.7
S18. Decombine position	3	4	7	4.0	4.0	4.0
S19. Closer monitor of elements impacting training	3	8	11	4.3	4.8	4.6
S20. Additional classroom time	1	5	6	2.0	2.8	2.6
S21. Procedures Committee to review operations	–	1	1	–	3.0	3.0
S22. Recommend changes to SOP	1	–	1	3.0	–	3.0
S23. Other strategy	38	53	91	4.4	4.4	4.4

[a]Scale: 5=Almost always, 4=Often, 3=Sometimes, 2=Seldom, 1=Almost never

Table A-2. Core Strategy Usage by Complexity Source

Complexity Source	Strategy reported (count)																				
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S16**	**S17**	**S18**	**S19**	**S20**	**S21**	**S22**	**Other**	**Total**
1. Runway/ Taxiway Restrictions	14		1			14	19				12									5	**65**
2. Active Runway Crossings	20					2	1	10		16	8									4	**61**
3. Runway/ Taxiway Configuration	14				1		2	10	1	12	7	1								10	**58**
4. Non Visibility Areas							7													3	**10**
5*. Airspace Configuration	2						2				1										**5**
6*. Terrain/ Obstructions	2						1	2												2	**7**
7*. Satellite Airports																				1	**1**
8. High Traffic Volume	21	8		1	11					14	13		1							1	**70**
9. Aircraft Differing In Performance Chars.	8	9			1	1					1	1							1	7	**29**
10. Emergency Operations	6				4	7	7														**24**
11. Wake Turbulence	7	6																		2	**15**
12*. Special Flights	3				3	3	3														**12**
14. Vehicular Traffic	6			1			2			2	2									5	**18**
15. At Or Below Minimums	9	6					10	8													**33**
16. Reduced Visibility (Wx)	7	2					9	10													**28**
17. Inclement Weather	7	2					6	5													**20**
18. Airport Surface Activity	4										3										**7**
19. Equipment Malfunctions	7	4						7							1						**19**
20. Frequency Congestion	17		1				12	9		1										12	**52**
21. Equipment Location																				3	**3**
23. Unfamiliar Pilots	6							7												6	**19**
24. Pilot's Weak Mastery	7		1					15												9	**32**

Table A-2. Core Strategy Usage by Complexity Source (continued)

Of English																					
25. Controller Fatigue													7	7	4					2	**20**
26. Traffic Management Initiatives	7						11	7												3	**28**
28. Other Distractions			7					2					1							3	**13**
29. On–The–Job Training																11	6			6	**23**
Other	3	1	1		1	2	2	2	1	2		1			2			1		7	**26**
Total	**177**	**38**	**11**	**2**	**21**	**29**	**94**	**94**	**2**	**47**	**47**	**3**	**9**	**7**	**7**	**11**	**6**	**1**	**1**	**91**	**698**

* This source received less than 5 interviews

KEY (Strategy)	
S1. Adhere to SOPs	S12. Point out traffic
S2. Ask for more in-trail spacing	S13. Training
S3. Ask people to be quiet	S14. Team briefing
S4. Request supervisory assistance	S15. Read and initial
S5. Apply visual separation criteria	S16. Relief from Position
S6. Coordinate to expedite traffic	S17. Rotation to less workload position
S7. Gather complete information prior to making decision	S18. Decombine position
S8. Slow down the operation	S19. Closer monitor of elements impacting training
S9. Slow down operation while attending to higher priority duties	S20. Recommend additional classroom time
S10. Use "expedite" in control instruction	S21. Procedures Committee to review operations
S11. Use the anticipated separation rule	S22. Recommend changes to SOP

Table A-3. Additional Strategies

Source of Complexity	Count	Category
1. Runway/Taxiway restrictions	1	Rely on past experience.
	1	Expedite: coordinate controller to controller.
	1	Expedite: coordinate supervisor to supervisor.
	1	Coordinate with other team members/Maintain SA teamwork.
	1	Anticipate and prepare for workload peaks (get pen and paper ready, etc.).
2. Active runway crossings	1	Visually verify compliance with instructions.
	1	Coordinate with other team members/Maintain SA teamwork.
	1	Identify good intersections to cross, not just anywhere.
	1	Cross in order/as sequenced.
3. Runway/Taxiway configuration	2	Anticipate and prepare for workload peaks.
	2	Rely on past experience.
	1	Actively attempt to maintain SA (be more vigilant).
	1	Anticipate pushbacks.
	1	Formulate a backup plan.
	1	Give pilot full picture.
	1	Open more frequencies.
	1	Speak more slowly (attend to clarity of speech and phraseology).
4. Non Visibility Areas	1	Use memory aid (notepad).
	1	Have aircraft hold short of taxiway.
	1	Move around towercab.
6. Terrain/Obstructions	1	Move around towercab.
	1	Use 500' separation rule.
7. Satellite Airports	1	Redirect aircraft to primary departure runway.
8. High traffic volume	1	Shorten communications; inflect with voice that you are busy.
9. Aircraft differing in performance characteristics	4	Sequence aircraft based on past experience (time permitting).
	1	Sequence aircraft based on your preference.
	1	Pay attention to potential upcoming problems.
	1	Pay attention to how pilots sound.
11. Wake turbulence	1	Sequence aircraft based on past experience (time permitting).
	1	Issue wake turbulence advisory.
14. Vehicular Traffic	3	Actively attempt to maintain SA (be more vigilant).
	1	Call vehicles that have not coordinated access.
	1	Ask for gap from TRACON.
20. Frequency congestion	4	Maintain control of frequency.
	3	Maintain control of frequency (make a broadcast announcement).
	2	Open more frequencies.
	1	Maintain control of frequency (key microphone and issue instructions to multiple aircraft).
	1	Wait for readbacks on hold short.
	1	Prioritize duties (open gate less important than a/c on active runway).

Table A-3. Additional Strategies (continued)

Source of Complexity	Count	Category
21. Equipment location	1	Remember location of equipment for each position.
	1	Actively attempt to maintain SA (be more vigilant).
	1	Yield to Taxiway A and B.
23. Unfamiliar pilots	3	Use progressive taxi instructions.
	1	Speak more slowly (pay more attention to clarity of speech).
	1	Speak more slowly (pay more attention to phraseology).
	1	Stay calm to avoid additional stress on pilot.
24. Pilot's weak mastery of English	2	Formulate a backup plan.
	1	Work around them.
	1	Speak more slowly.
	1	Speak more slowly (pay more attention to clarity of speech, phonetics).
	1	Use progressive taxi instructions.
	1	Stay calm to avoid additional stress on pilot.
	1	Best guess (have someone else listen).
	1	Ask if instructor onboard.
25. Controller fatigue	2	Use caffeine.
26. Traffic Management Initiatives	1	Coordinate with other team members (ground controller, TMC).
	1	Maintain team situation awareness.
	1	Rely on past experience.
28. Other distractions	1	Submit Unsafe Condition Report (for equipment noise).
	1	Increase headset volume.
	1	Make visitor move.
29. OJT	1	Use experiential building.
	1	Make trainee feel at ease.
	1	Build trainees confidence.
	1	Brief the trainee.
	1	Work from runway out.
	1	Actively attempt to maintain SA (be more vigilant).
OTHER: No charted Visual Approach	2	Actively attempt to maintain SA (be more vigilant) - especially for readbacks.
	1	Verify position with DBRITE.
OTHER: Pilot's missing non-routine calls	1	Actively attempt to maintain SA (be more vigilant).
	1	Maintain control of frequency.
OTHER: Day vs. Night Operations	1	Use standard taxi routes.
OTHER: ADO mandates	1	Maintain team SA/teamwork (ground controller).

Appendix B

Information Sources

Table B-1. Count of Information Sources by Control Position

Location	Local	Ground
Visual observation	281	287
Flight strips	204	247
Communicating with pilot	169	241
DBRITE	293	89
Memory	106	159
SAIDS	93	97
Asking another controller	81	79
ASDE/Surface radar	39	66
Weather displays	49	34
Scratch Pad	39	29
OTHER		
TMC specialist	16	18
Supervisor	7	11
Position relief briefing	7	2
Experience		3
Schedule	1	1
LOA		1
Self		2
TRACON		1
Center	1	
Other Equipment		
SMA	1	4
FDIO	2	2
AMASS	1	1
IDS4	4	6
IDSB 4		1
ACARS/PDC		2
Speed direction indicator	1	
Radio		1
Runway closure strips	6	2
Taxiway closure strips		1

Table B-2. Count of Information Needs by Source

SOURCE	INFORMATION NEEDS (Count)											
	Aircraft position	Aircraft Identification	Aircraft type	Weather conditions	Runway status	Taxi route	Aircraft speed	Traffic Mgt. Initiatives	Assigned gate	Aircraft category	Other	**Total**
Visual observation	136	44	104	90	51	47	54	2	11	21	8	**568**
Flight strips	69	144	115	-	5	20	11	20	26	37	4	**451**
Communicating with pilot	95	83	53	17	13	33	17	-	79	10	10	**410**
DBRITE	93	95	85	6	5	-	67	-	1	26	4	**382**
Memory	18	15	13	10	39	93	23	11	18	13	13	**266**
SAIDS	-	-	-	61	60	2	-	64	1	1	1	**190**
Asking another controller	38	24	16	8	21	18	-	22	4	-	9	**160**
ASDE/Surface radar	48	13	6	2	7	15	10	-	4	-	-	**105**
Weather displays	-	1	-	75	6	-	-	1	-	-	-	**83**
Scratch Pad	10	27	4	-	13	1	-	10	1	-	2	**68**
Other Sources												
TMC	-	1	-	1	-	-	-	31	-	-	-	**33**
Other equipment	-	1	-	10	4	-	-	2	8	-	-	**25**
Supervisor	-	1	-	5	8	-	-	3	-	-	-	**17**
Non-differentiated	-	1	-	-	3	3	-	4	2	-	2	**15**
Runway closure strips	-	-	-	-	9	-	-	-	-	-	1	**10**
Position relief Briefing	-	-	-	1	8	-	-	-	-	-	-	**9**
Total	**507**	**450**	**396**	**286**	**252**	**232**	**182**	**170**	**155**	**108**	**54**	**2792**