IMPLEMENTING ELECTRONIC FLIGHT DATA IN AIRPORT TRAFFIC CONTROL TOWERS

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The Federal Aviation Administration (FAA) is investigating the potential effects of implementing electronic flight data systems (EFDSs) at Airport Traffic Control Towers (ATCTs). I use existing task analyses, published literature, and recent field observation data to determine the basic functionality of flight progress strips (FPSs) in the ATCT. I identify gaps in the research and formed a general set of principles to guide the design of an EFDS prototype. Given the proper application of principles for design and automation, the EFDS should maintain some of the basic functionality and benefits of the FPSs, reduce workload related to flight data entry, tracking and sharing, and provide new features that will enhance controller performance and encourage use. I present possible risks and outcomes that are likely to accompany an EFDS in FAA ATCTs.

Background

Airport operations logged by the 449 Federal Aviation Administration (FAA) airport traffic control towers (ATCTs) are projected to increase from 62.7 million in 2003, to 70 million in 2007 (FAA, 2004a). In anticipation of the increase in air traffic, the FAA is investigating the potential effects of implementing an electronic flight data system (EFDS) in ATCTs. One primary interest is how to preserve the current benefits of paper flight progress strips (FPSs) while enhancing the performance of air traffic controllers and the National Airspace System (NAS). To do so, we must understand the similarities and differences among ATCTs as well as all of the tasks involving FPSs, flight data, and the communication of information among air traffic controllers. Researchers can contribute to the success of an EFDS if they address some major gaps in the existing research and address long-standing organizational norms during the design process.

In general, the controller positions in an ATCT include flight data (FD), clearance delivery (CD), ground control (GC), and local control (LC). ATCTs often combine the FD and CD positions during periods of lower taskload, and some ATCTs may staff positions in addition to those just mentioned (FAA, 2004b). Each controller position has a general set of duties. Typically, the FD/CD position enters flight plans and flight plan amendments into the computer, distributes flight data, issues initial long-range clearances, enters and updates the automatic terminal information service (ATIS) information, and coordinates clearances with air route traffic control centers. The GC position provides aircraft and vehicle taxi instructions to and from the airport movement area and the ramp and gate area, coordinates crossing or use of active runways, and determines the departure sequence. The LC position provides departure and arrival sequencing and spacing by issuing clearances to all aircraft in the airport traffic area and all aircraft and vehicles on the active runways. Both the GC and LC positions may be required to coordinate among multiple other LC and GC positions.

Among the 449 ATCTs in the United States, each provides a particular type of service including visual flight rules only, non-radar, or radar approach control. Within each ATCT, there are different types of equipment, specific controller positions, and duties that vary by facility. Each ATCT typically has its own facility directive that provides a set of supplemental standard operating procedures to address local idiosyncrasies.

How controllers use FPSs in the ATCT

Even though there is substantial variability among ATCTs, the use of FPSs is relatively ubiquitous. In addition to FPSs, controllers use other sources of information along with tools for communication, coordination, information organization, and decision making. However, one of the arguably central tools used in the ATCT along with the radio, is the FPS (Bruce, 1996; FAA, 2004c). The use of FPS has a long history, and since their inception in the 1930's and 1940's, very little has changed. Over time, the FAA has rooted the FPS through training regimens, handbooks, standard operating procedures, and facility directives. There is currently a significant amount of pressure exerted upon controllers to use FPSs (Durso & Manning, 2002).

Because the use of FPSs and the information they contain has become an integral part of the ATCT task, it is important to understand how controllers use FPSs in the ATCT domain and how the FPSs aid in the flow of information. Acknowledging differences among ATCTs, the general flow of information for departure aircraft is from FD/CD to GC to LC to terminal radar control (TRACON). For arrival aircraft, the information moves in the opposite direction from the TRACON to LC to GC. The type of information that controllers pass among each another varies too depending on the phase of an aircraft's flight (e.g., arrival, departure, or over flight).

The differences among ATCTs and individual controllers also reflects in the functions that FPSs serve. While controllers amend the FPSs using a standard set of symbols in accordance with the 7110.65P (FAA, 2004c) and a few unique markings as published in their own facility directive, there are also individual preferences for FPS use. While the individual needs of ATCTs and controllers are important, it is not yet necessary to understand how every one conducts operations in particular. We must first collect empirical evidence regarding the critical functions of FPSs and how to best support these functions with an EFDS.

It is clear that controllers use the FPSs and their associated markings for a number of purposes. A number of researchers have examined the particular functions of FPSs, whereas others have examined the higher-level cognitive processes that controllers support with FPSs. These researchers have shown that across various ATC domains controllers use FPSs for workload management (Durso & Manning, 2002; Gronlund, Dougherty, Durso, Canning & Mills, 2001; Dattel, Johnson, Durso, Hackworth & Manning, 2005), memory aids (Buisson & Jestin, 2001; Cardosi, 1999; Durso & Manning; Gronlund et al.; Hopkin, 1988; Dattel et al.; Pavet, 2001; Stein & Bailey, 1994; Zingale, Gromelski, Ahmed, & Stein, 1993; Zingale, Gromelski, & Stein, 1992), facilitating communication and coordination (Berndtsson & Normark, 1999; Buisson & Jestin; Durso & Manning; Gronlund et al.; Dattel et al.; Pavet), cognitive information organization (Durso & Manning; Dattel et al.), and planning (Cardosi; Dattel et al.; Gronlund et al.; Pavet; Zingale et al.). However, researchers have debated the necessity of FPSs and their use. A primary debate has centered on whether or not the FPSs provide any real benefit to memory, and ultimately, performance.

While researchers have conducted a number of studies in the en route domain, the debate between the Interaction and Cognitive Resource hypotheses (for a brief review, see Vortac, et al., 1996) has not surfaced in the ATCT domain until now. In fact, researchers conducted only a few controlled studies to understand what controllers are doing in the ATCT and how they are doing it. Bruce (1996) conducted a study that focused on the physical performance of controllers in the ATCT and provided valuable information about what controllers did while working. For example, her data showed that controllers most often manipulated FPSs, microphones, and writing pens. Along with their human abilities, these are the controllers' primary tools. Bruce also showed that GCs spent about one-half of their time directly observing traffic out of the window, whereas LCs spent only about one-third of their time looking outside. Incidentally, the LC's time observing traffic doubled when radar data were available in the ATCT.

Ammerman, Becker, Bergen, et al. (1987), Ammerman, Becker, Jones, et al. (1987), and Alexander, et al. (1989) published a comprehensive set of task analyses of ATCT activity, which are still relevant today. Alexander et al. examined the baseline, or current activity, of ATCTs, while Ammerman, Becker, Bergen, et al. explored the future concept of the Tower Control Computer Complex (TCCC) envisioned within the Advanced Automation System concept. As the name implied, the TCCC was to rely more on computer power, shared information, and automation and rely less on pen and paper. Some of the concepts envisioned for the TCCC like Airport Surface Detection Equipment (ASDE) have materialized while others, like reconfigurable tower position consoles at each controller position, have not. Despite the current state of affairs, these task analyses are still valuable today in that they provide, among other things, compositional graphs that show the logical flow of operational tasks, information requirements, and necessary cognitive/sensory attributes.

Researchers have conducted numerous other studies as well, but these studies have lacked the data required to consider hypotheses regarding the cognitive effects of an EFDS in FAA ATCTs. Nevertheless, this past research is very helpful in providing insights into risks and benefits of an EFDS. For example, Chistophe Mertz and his co-authors present an array of interface usability research that provides many valuable lessons on the use of touch screens in air traffic control (e.g., Mertz, Chatty, Vinot, 2000a, 2000b; Mertz & Lecoanet, 1996; Mertz & Vinot, 1999). Doble and Hansman (2003) examined the concept of using pocket computers to replace FPSs; a concept that Buisson and Jestin (2001) also explored. These authors present significant insight into the advantages and limitations of using pocket computers as FPS replacements.

Only recently have researchers collected data specifically on controllers' FPS activity in the ATCT. Dattel et al. (2005) used subject matter expert observers to record controllers' FPS marking and handling behavior during live operations. Their observations included the three primary control positions (FD/CD, GC, LC) at 10 ATCTs located across the United States. The ATCTs were of various sizes and handled differing levels and complexity of traffic. The authors examined both the frequency and the importance of FPS marking by controller position and facility size. In addition, they followed the observation sessions with directed interviews and questionnaires to gain insight about the perceived psychological benefits of FPSs including communications, memory, organization, situation awareness, and workload. Dattel et al. found that each controller position used the FPSs for different reasons, and these uses did not depend on facility size. Controllers at the FD/CD position reported that FPS activity benefited communication, workload, and memory. FD/CD used marking primarily for the benefit of others. Controllers at the GC position reported that FPS activity supported all five psychological functions. Controllers at the LC position reported FPS benefits for memory, organization, and situation awareness. However, controllers at both the GC and LC positions believed that the primary benefits of FPS were associated with memory and situation awareness. Researchers have yet to determine whether any of these reported benefits are actual or just perceived, and if they are real, the size and duration of any effect on controllers' performance.

An Alternative to FPSs

Replacing the FPSs used in the ATCT with an EFDS would require new hardware, procedures, and automation that relieve the controller of workload arising from non-essential, "housekeeping" tasks while improving performance. Performance could benefit simply by reducing the workload associated with FPSs, but properly designed interfaces and automation could elevate performance beyond that which controllers might obtain only by addressing workload. A feasible EFDS in the ATCT should integrate the controller's perceptual abilities with improvements in navigation, radar, and automation including weather detection and traffic alerting systems (Ammerman, Becker, Bergen, et al., 1987). The EFDS should provide the same proven critical benefits as FPS while eliminating outdated uses such as recording of some clearances to establish a legal record. The EFDS, resting on the concept of System Wide Information Management (SWIM) (FAA, 2004d) will provide new functionality through automation, especially in terms of information sharing. Such new functionality should make some current tasks easier and provide controllers with the ability to perform actions that they could not perform with FPSs.

There are a number of features that an EFDS could provide in the ATCT. The ability to display and input flight data from a single interface opens many possibilities, but the ability to share information among various systems is what will make an EFDS especially useful. Information will be able to move between a flight data element and any other component of the primary system. Two-way information updates provide easy access and sharing of flight data such as clearance amendments, predicted runway/taxiway incursions, aircraft location on a taxiway, posting and updating expected departure clearance times, alerts for traffic flow restrictions, and wake turbulence warnings. An EFDS allows for the elements of one or more situation displays to be linked so that items of interest can be emphasized and identified simultaneously for categorization. Electronic flight data elements can appear only when controllers need them the most and still preserve the ability to access all information about any flight at any time. An EFDS would provide an interface for digital communications such as controller-pilot data link communications (CPDLC). CPDLC via the EFDS interface would allow the controller to provide flight information services (e.g., pilot reports, weather reports, maps, approach plates, etc.), pre-departure clearances, full taxi instructions including gate information and visual depiction of taxi route, digital ATIS (D-ATIS), and even landing and takeoff clearances. An EFDS also allows for simplified data input such as recording certain clearances or updating an ATIS code with simple motions or gestures while preserving the ability to make freehand notation. Moreover, all data entries on an EFDS are shared and become available to other controllers as necessary. Researchers have already designed automation tools that could potentially be integrated with an EFDS under the SWIM concept. Such tools may provide assistance with taxi sequencing (e.g., Departure Planner Decision Aid, Anagnostakis, et al., 2000) changing runway configuration (e.g., Surface Management System, Atkins & Brinton, 2002), and digital watermarking (e.g., Hering, Hagmüller & Kubin, 2003; Prinz, Sajatovic, & Hering, 2004).

The potential advantages of an EFDS are numerous. An EFDS would eliminate workload associated with placing FPSs in holders, distributing FPSs, and handling multiple FPSs for a single flight. Controllers may increase the time they spend looking out the window of the tower cab and directly observing the traffic situation. Controllers also may increase their awareness of others controllers' actions through the use of both distributed displays that share flight data elements and through the use of shared displays (Mertz & Lecoanet, 1996). Flight data activity that is currently tallied by time-consuming, manual processes could be automatically tracked on an EFDS to allow for automatic traffic counts and the recording of timing information and clearances. An EFDS simplifies the act of passing flight data among controller positions within the ATCT and between the ATCT and TRACON. Electronic flight data allows controllers to pass information virtually rather than having to move away from their control position and physically transfer a FPS. An EFDS even creates the potential for saving money budgeted for the purchase of paper FPSs, FPS holders, and the maintenance of the thermal printers.

The potential disadvantages of an EFDS are not as obvious as the advantages. I have already discussed the need for researchers to learn about the effects that any new system will have on users. If the EFDS does affect controller performance, the extent and direction of change will depend in part on the design of the EFDS and on how the FAA trains controllers to use it. Even if an initial decrement in performance does occur, controllers may be able to overcome changes to their task rather quickly. Unfortunately, there currently aren't any data on the ATCT domain to inform us about the effects of changing the format of flight data information or changing the way that controllers interact with flight data. Previous data suggests that although the new EFDS will not eliminate physical interaction with flight data, it may change the frequency and types of interactions that controllers perform. Such a change in behavior may have positive or negative effects upon controllers' performance (e.g., Vortac et al., 1996) memory (e.g., Hopkin, 1988; Stein & Bailey, 1994; Zingale, Gromelski & Stein, 1992), or situation awareness (Endsley & Rodgers. 1996; Hopkin, 1995). However, these are empirical questions that researchers must still answer within the ATCT domain.

Another potential disadvantage of an EFDS is that a pen- or gesture-based system may be more difficult to use than paper FPSs, especially at first (Mertz & Vinot, 1999; Mertz, Chatty, & Vinot, 2000b). Data entry will also become more critical as more information is shared with more people (Della Rocco, Manning, & Wing, 1990). We can't forget that this flight data is being used for safety critical functions. Data entry errors could potentially result in other, more serious unwanted outcomes. EFDS designers should make data entry as easy as possible and methods for identifying and correcting errors are needed. The transition from FPSs to an EFDS may also impact the controller selection and training process rendering them less useful and in need of modification (Della Rocco et al.).

The FAA recently implemented a policy establishing that no new displays occupy the ATCT except by an explicit waiver process. This "no new glass" policy arose from the numerous systems that have already been deployed in the ATCT. Not only have these new systems taken up precious space inside the tower cab, they also operate independently of one another. In other words, the FAA has filled the ATCT with a multitude of non-integrated systems creating a crowding of the physical space, increased maintenance costs, and the inability of systems to cooperate with one another.

Given the FAA's "no new glass" policy and the various levels of traffic and technology at the 449 ATCTs in the United States, it is very likely that different EFDSs may have to be developed for different types of ATCTs. For example, ATCTs that have ASDE or other types of surface radar displays may be able to take advantage of an existing data source by integrating the flight data with it. The suggestion of integrating flight data with surface radar data is a viable one. Such an approach has already begun at Nav Canada. Airports without ASDE could still take advantage of an EFDS, but the optimal presentation of flight data may require a different form. To take full advantage of electronic flight data, FAA researchers must consider deploying alternative perceptual-spatial displays that don't rely on ASDE. There is one thing that we know about ATCTs; there is a great deal of variation and one solution will not fit well for all.

Whatever form any new features take, they must be reliable, provide valid information, and have a wide and demonstrable effect before controllers are likely to accept them. The new features that an EFDS would enable should also provide some incentive for controllers to overcome the well-entrenched FPS and to adopt the new EFDS. By providing an irresistible alternative to FPS, I hope overcome the organizational norms that have made FPSs a well-entrenched tool in the ATCT domain.

Making the Transition

Beyond providing new tools for controllers, researchers and system designers must also get participation from controllers and controller union representatives during the entire research and development process to aid in overcoming the organizational norms that embody FPSs. Controllers should serve as subject matter experts to help researchers understand the ATCT domain and to provide insight on interface design and functionality. By involving controllers throughout the entire process, the FAA can get the support that will be needed when change is upon the controllers. Furthermore, controllers will have a stake in the process and be anticipating the change knowing that the transition to an EFDS will be worthwhile because researchers and system designers have already considered their actual job requirements

Summary and Conclusion

Having the support of controllers is a necessary condition, but not sufficient to ensure the success of an EFDS. Researchers also need to learn more about the psychology of FPSs. As previously mentioned, there is very little data concerning how controllers in the ATCT perceive and gather flight data, but the ATCT domain poses some familiar questions. The Interaction and Cognitive Resource hypotheses become relevant again. It is appropriate and necessary to ask these same questions again because the task of controllers in the ATCT is quite different than that of controllers in the en route environment. Our knowledge of how controllers use FPSs in the en route domain does not allow us to fully understand other domains. During the development of an EFDS for the ATCT, we must know if changes to the presentation of flight data in an EFDS will affect the controllers' ability to find or use that information. We must know if the controllers' ability to find and use flight data will be affected by the way they physically interact with the system. Researchers need to employ various part-task or low-fidelity simulations to understand basic cognitive functions, but they must also perform high fidelity, human-in-the-loop simulations to test the concepts they create. With the support of empirical data and proper system design, the FAA will be able to capitalize on the benefits of an EFDS and mitigate the associated risks.

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