Design and Evaluation of a Portable Electronic Flight Progress Strip System

by

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Abstract

There has been growing interest in using electronic alternatives to the paper Flight Progress Strip (FPS) for air traffic control. However, most research has been centered on radar-based control environments, and has not considered the unique operational needs of the airport air traffic control tower. Based on an analysis of the human factors issues for control tower Decision Support Tool (DST) interfaces, a requirement has been identified for an interaction mechanism which replicates the advantages of the paper FPS (e.g., minimal head-down time, portability) but also enables input and output with DSTs. An approach has been developed which uses a Portable Electronic FPS that has attributes of both a paper flight strip and an electronic flight strip. The prototype Portable Electronic Flight Progress Strip system uses handheld computers to replace individual paper strips in addition to a central management interface which is displayed on a desktop computer. Each electronic FPS is connected to the management interface via a wireless local area network. The Portable Electronic FPSs replicate the core functionality of paper flight strips and have additional features which provide an interface to a DST. A departure DST is used as a motivating example. This thesis presents the rationale for a Portable Electronic FPS system and discusses the formatting and functionalities of the prototype displays. A usability study has been conducted to determine the utility of the Portable Electronic FPS in comparison to paper flight strips. This study consisted of a human-in-the-loop experiment which simulated the tasks of an air traffic controller in an airport control tower environment. Specific issues explored during the experiment include the appropriateness of displaying departure advisories on the Portable Electronic FPS, the importance of FPS portability, and the advantages of interaction mechanisms enabled by an electronic interface. Experimental results are presented which show that test subjects preferred the Portable Electronic FPS to a paper FPS. However, results for performance-based measures were partially confounded by a dominance of practice effects, experimental limitations, and characteristics of the prototype hardware itself. The implications of the experimental results are discussed with the aim of directing further research toward the goal of creating an operationally-deployable Portable Electronic FPS system. Future research should explore emergent display technologies which better emulate the physical characteristics of the paper FPS. Once this is accomplished, higher-fidelity performance-based analyses may be conducted, engaging air traffic controllers on design and implementation issues.

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First, my advisor, Professor John Hansman, always kept me focused on the big picture when I was mired in details and never hesitated to give me a needed kick in the pants every now and then.

Terran Melconian and Fred Donovan helped me conquer the internet. Without their help, I'd probably still be fiddling with IP addresses, wondering why my flight strips weren't talking to each other. Phyllis Collymore and Jeanette Marchocki accommodated all my requests to get access to Building 33's most posh addresses at all hours of the day. Ken Steele and Larry Rudolph, of the MIT Laboratory for Computer Science, were quite generous in lending me the Pocket PCs necessary to run my experiment.

To my ten test subjects, thanks for showing up at odd hours just to be yelled at while watching airplanes move around on a computer screen. Chapters 4 and 5 would have been a little sparse without your help.

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List of Acronyms

A/C	Aircraft
ARTCC	Air Route Traffic Control Center
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
CENA	Centre d'Etudes de la Navigation Aerienne
DP	Departure Planner
DST	Decision Support Tool
EDCT	Expected Departure Clearance Time
FAA	Federal Aviation Administration
FPS	Flight Progress Strip
IEEE	Institute of Electrical and Electronics Engineers
IFR	Instrument Flight Rules
LAN	Local Area Network
MINIT	Minutes-In-Trail
MIT	Miles-In-Trail
NTSB	National Transportation Safety Board
T/O	Takeoff
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool

CHAPTER 1: INTRODUCTION

1.1 Objective

The objective of this thesis is to present the design and evaluation of an electronic flight progress strip (FPS) system which acts as an air traffic control (ATC) decision support tool interface and which is appropriate for the airport control tower environment. This will be accomplished through the following steps:

- *A discussion of the limitations and benefits of both paper and electronic FPS systems and the introduction of the Portable Electronic Flight Progress Strip concept.* By combining the strengths of the paper strip with the possibilities of an electronic interface, a design may result which best meets the needs of air traffic controllers. This discussion will be applicable to all ATC facilities, but will also include human factors issues particular to airport control towers. Resulting from this discussion will be the concept of the Portable Electronic Flight Progress Strip—a design for an electronic FPS which attempts to replicate as closely as possible the benefits of the paper flight strip for airport control tower operations.

- *An analysis of requirements for a combined departure flight progress strip and departure decision support tool (DST) interface.* To ensure that functionalities of the paper FPS are preserved in an electronic system, an analysis of the information and interaction requirements for paper FPS usage will be presented. In addition, the information requirements for a DST interface will be examined—both the information that must be output to a controller and the information that the controller must input to the DST. The specific DST studied is the Departure Planner developed at the Massachusetts Institute of Technology, which is designed to optimize the flow of departure aircraft at an airport in order to maximize runway throughput [Anagnostakis, 2000]. Consequently, the requirements analysis for the FPS will only consider departure strips, which differ in both form and function from the flight strips used in airport control towers for arrival aircraft.

- *A prototype hardware implementation and display design of the Portable Electronic Flight Progress Strip system.* By synthesizing the results of the above requirements analysis with the Portable Electronic Flight Strip system concept, prototype interfaces can be designed for a Portable Electronic FPS system which also acts as a Departure Planner interface. Displays will be shown and the means of controller interaction with the displays will be discussed. For many of the functionalities described in the requirements analysis, alternative display formats and interaction mechanisms will be shown, illustrating the opportunity for further research in this area.

- *An evaluation of the Portable Electronic FPS prototype system.* A part-task, human-in-the-loop ATC simulation has been developed to study the usability of the Portable Electronic FPS. The design and results of this experiment will be discussed.

1.2 Motivation

This work is motivated by two emergent trends in air traffic control. First, electronic or "stripless" systems are increasingly being proposed or implemented as replacements for the traditional paper flight progress strip used in ATC facilities. Second, controllers are beginning to use decision support tools to assist in both tactical and strategic ATC decision-making. Both of these trends are precipitated by a need to increase capacity within the already-strained National Airspace System.

As discussed in Section 1.3, most of the DSTs and electronic FPS systems have first appeared in ARTCCs and TRACONs. These facilities handle enroute and transition traffic and use radar as a primary means of aircraft separation. Fewer DSTs and electronic FPS systems have been implemented in airport control towers. The control tower environment presents unique human factors challenges, as controllers use both radar and visual observation to identify air and surface traffic. The unique visual demands on these controllers may have implications for DST interface design. In addition, FPS usage in the control tower differs from other facilities in the way that the FPS is shared among controller positions. This may have implications for the design of electronic FPS systems for the tower.

With current or near-future technology, it now may be possible to design an interface which acts as both an electronic FPS system and a DST display, and which addresses the unique operational requirements for the control tower.

1.3 Background

1.3.1 The Flight Progress Strip

The paper FPS, along with radar, voice communication, and visual observation, is one of the primary tools controllers use to monitor air traffic. Figures 1.1-1.3 show FPSs used in U.S. air traffic control facilities. Each FPS is approximately eight inches long by one inch wide, although the exact size and format of the FPS differs depending on whether it is being used for departure, enroute, or arrival aircraft (the arrival FPS is considerably smaller). However, all FPS variants contain information about an aircraft which is relevant to an air traffic controller for a particular phase of flight—information such as the aircraft's callsign, navigation equipage, route of flight, cruise altitude, gate assignment, runway assignment, and proposed departure time.

Figure 1.1: Departure Flight Progress Strip

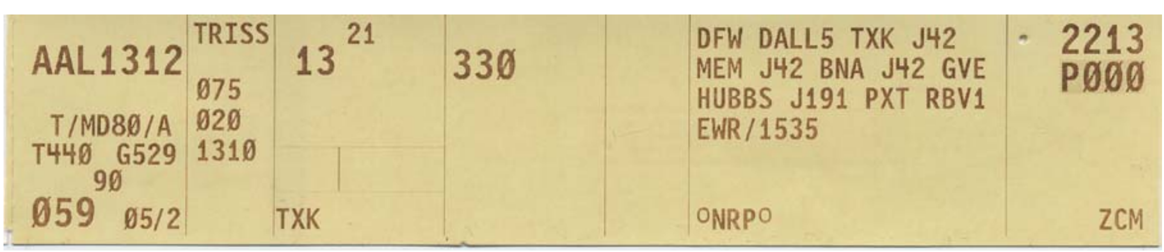

Figure 1.2: Enroute Flight Progress Strip

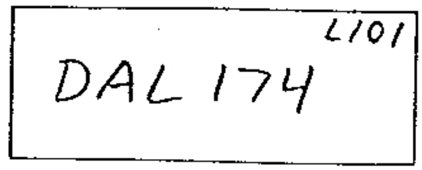

Figure 1.3: Arrival Flight Progress Strip [FAA, 1995]

The paper FPS has changed little since its introduction. The flight plan information on the FPS is now stored in a computer system and printed automatically instead of being written by hand, but annotations are still handwritten by controllers to update the information shown on the strip [Nolan, 1999]. Controllers organize the flight strips in a strip bay or other surface, with the strips positioned to indicate some relevant order of the air traffic, such as departure time, arrival time, or altitude. As control of an aircraft is handed off from one controller to another, the FPS is also passed from controller to controller, either physically (in the case of an airport control tower) or by printing a new strip (in the case of enroute facilities). In this way, the FPS acts as a surrogate to the aircraft as it moves through the air traffic control system and serves as a record of the control actions that were used for a particular flight.

For a summary of FPS usage, see [Hopkin, 1995]. For a summary of controller tasks at enroute, approach, and tower facilities, see [Wickens, 1997].

1.3.2 Prior Research

1.3.2.1 Enroute Facilities

Several research efforts are underway to study electronic FPS systems for enroute ATC facilities. The DigiStrips program at France's Centre d'Etudes de la Navigation Aerienne (CENA) has prototyped a system that consists of a touch screen which creates an electronic analogue of the strip board [Mertz, 2000]. The touch screen contains multiple electronic representations of flight strips and includes the following features: FPS annotation through gesture recognition and animated, pop-up menus; differentiation between computer-generated and controller-modified flight data through "computer" fonts and "handwritten" fonts; and movable flight strips for strip board management, via drag-and-drop actions on the touch screen.

In the United States, the User Request Evaluation Tool (URET), developed by The MITRE Corporation, was originally designed to be a conflict detection and resolution DST. However, its interface also contains an electronic FPS display, which has replaced paper strips in ARTCCs using URET [Celio, 2000]. Similar to DigiStrips, the URET flight strip interface consists of a single screen which shows flight data for multiple flights. Unlike DigiStrips, the URET interface does not use a touch screen and has no provisions for strip board management or annotations through gesture recognition on the display. Rather, a mouse and keyboard are used for controller input.

For more basic research into the utility of the paper FPS at enroute ATC facilities, an experiment was conducted by the University of Oklahoma and the FAA in which controllers handled traffic without using flight strips [Albright, 1995]. The study found no difference in performance or perceived workload between the no-strip scenarios and scenarios when controllers were allowed to use FPSs. However, controllers requested more readouts of flight plan information and took a longer time to grant pilot requests in the no-strip scenarios.

In another study, air traffic controllers at a Paris enroute facility were observed for four months to gain a better understanding of the role the paper FPS plays in their work [Mackay, 1999]. Several benefits of the paper interface were noted, and will be discussed in Section 2.1 . One conclusion from this work was that the input/output issues for paper and electronic interfaces should be separated from the information content on the FPS [Mackay, 1998]. Several systems were proposed which addressed this issue, including using video cameras or transparent strips over a touch-screen to record controller annotations. This work also addressed the issue of FPS position tracking with a strip board that detected resistance differences among specially-designed strip holders.

1.3.2.2 Tower Facilities

To date, little research has focused specifically on electronic FPS systems for the control tower environment. Most of the research has been preliminary in nature, focusing on gaining a better understanding of the way in which paper FPSs are used, and the advantages that could be realized through a more automated system.

CENA observed controllers at the Paris Charles de Gaulle airport control tower, recording FPS manipulation and annotation patterns [Pavet, 2001]. This work noted several benefits that could be achieved through an electronic FPS system, including the possibility to couple the FPS to an alerting system. It was also suggested that several functionalities of the paper FPS be preserved in an electronic system. These recommendations will be further discussed in Sections 2.3 and 3.1.3

CHAPTER 2: COMPARATIVE ANALYSIS OF PAPER AND ELECTRONIC FLIGHT PROGRESS STRIPS

2.1 Benefits of Paper Flight Progress Strips

The paper FPS initially may seem to be an antiquated technology. However, for supporting ATC work practices, many benefits of the paper FPS have been noted in comparison to automated systems and computer displays. It could be argued that the paper FPS is not as useful as it seems, and that successful ATC work practices evolved around the paper FPS because that was the only technology available when ATC procedures were first being developed. Nevertheless, the paper FPS has a number of features which may be difficult to replicate with an electronic system.

First, the paper FPS is flexible [Mackay, 1999]. There does exist a standardized set of FAA-approved annotations for the paper FPS [FAA, 2002]. However, each control facility has its own standard operating procedures which may differ slightly from the FAA-prescribed standard [FAA, 1995]. The paper FPS can easily adapt to these facility-specific conventions. In addition, the paper FPS can adapt to differences between individual controllers. For example, controllers in France may use two different annotations to indicate a direct route, whereby an aircraft is cleared to bypass intermediate waypoints on its flight plan [Mackay, 1999]. It may be difficult to support individual controller preferences such as this in an electronic system.

The paper FPS is reliable [Pavet, 2001]. The only failure point in the system is the strip printer. If the strip printer is not functioning, the information contained on the FPS can be written by hand [Mackay, 1999]. Indeed, controllers regularly hand-write strips for helicopters and other aircraft not flying under IFR flight plans.

The paper FPS is portable. This portability has important implications due to the collaborative nature of ATC work. Possession of the FPS, either by holding it or placing it in a controller's strip bay, conveys ownership of a flight. When a controller wants to draw attention to a particular flight—either for himself or for another controller—the position of the FPS in the strip bay can be offset [Sellen, 2002].

The portability of the paper FPS also has benefits specific to the control tower environment. Unlike enroute facilities, where a new FPS is printed for each sector transited by a flight, at an airport control tower there is only one flight strip for each departure or arrival aircraft. Aircraft handoffs in the control tower are accomplished by physically transferring the flight strip between clearance delivery, ground, and local controllers. In addition, the portability of the paper FPS allows tower controllers to perform their visual, out-the-window task of observing airport surface traffic with a minimum of head-down time. For example, a pushback controller may need to move about the control tower to see aircraft that would be otherwise obscured from his eye position near the strip bay. With the paper FPS, a controller can pick up the flight strip from the strip bay, move about the control tower to observe aircraft, and still refer to information on the FPS and annotate the FPS. To further underscore the importance of flight strip portability in the control tower, it was observed at Paris Charles de Gaulle airport that controllers performed roughly three times more physical manipulations than annotations per FPS for departure operations [Pavet, 2001].

Finally, the paper FPS is an interface whereby controllers can make annotations directly on the strip. This direct interface may have advantages over a keyboard or mouse input method, both in terms of input speed and the amount of visual attention required by controllers while making annotations [Mertz, 2000].

2.2 Limitations of Paper Flight Progress Strips

While the paper FPS has proven to be a useful tool for managing air traffic and an interface with attributes difficult to replicate with an electronic system, it nevertheless has a number of limitations, especially with a proliferation of information-intensive ATC subsystems such as runway incursion monitors, airborne conflict probes, and conformance monitors.

Figure 2.1 shows a simplified air traffic control loop using a paper FPS. Voice is the primary means for disseminating ATC clearances to aircraft. These clearances are based on information gathered from surveillance (visual observation, radar, or aircraft position reports, depending on the control facility) and possibly from one or more DSTs. Some of these clearances are input into the Host flight data computer via a separate Flight Data Input/Output device. However, many of these clearances are either noted only on the paper FPS or not recorded at all. Examples of such clearances are temporary heading or altitude changes which will only affect the controller currently handling an aircraft. Because there is no direct data transfer between the paper FPS and any other air traffic control system, DSTs may be acting on incomplete information about aircraft state and intent. This lack of accurate information could result in deteriorated DST performance.

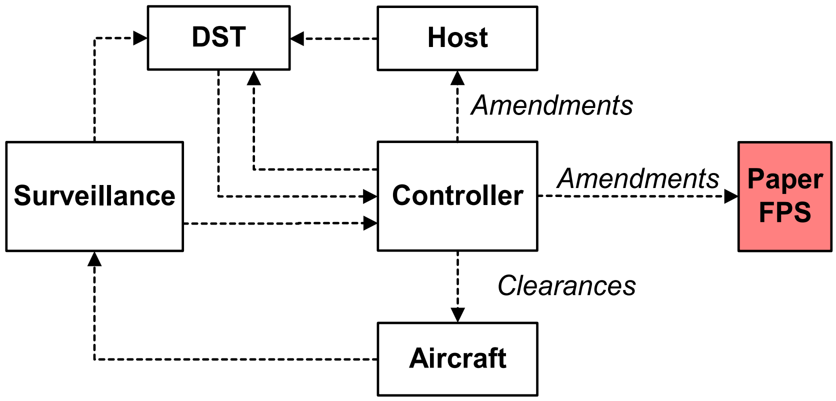

Figure 2.1: Simplified Air Traffic Control Loop with Paper FPS

A separate DST input device could be used to ensure that a DST had the most complete information available (e.g., a conformance monitor interface could be used to input temporary heading changes). However, a requirement to use another input device could have adverse effects on controller workload. By automatically accessing and disseminating the information shown on the paper flight strip, it may be possible for DSTs to act on more complete information without increasing controller workload.

In addition to poor data accessibility, the paper FPS has limited interactivity. While the controllers can interact with the flight strip by manually manipulating the strip in the strip board or writing annotations, the paper FPS cannot provide feedback to the controller annotations or adapt by automatically changing the information displayed on the flight strip.

Finally, while the flexibility of the paper flight strip has important benefits, it is also a potential liability. FPS usage has been noted in several aircraft accidents. For example, in 1991, two aircraft collided at Los Angeles International Airport when one aircraft was cleared to hold in position on the same runway for which another aircraft was cleared to land. Cited as a cause of the accident was a local operating procedure that did not require the FPS to be processed through the ground (taxiway) control position [NTSB, 1991].

2.3 Possible Benefits of Electronic Flight Progress Strips

Two possible benefits of an electronic FPS include better observability of control actions and the ability to directly interface with decision support tools.

2.3.1 Increased Observability of Control Actions

As discussed in Section 2.2, it is impossible to access the information handwritten on the paper FPS without an additional input/output mechanism. An electronic FPS would enable the dissemination of more clearances, which could improve the utility of a DST. For example, the trajectory synthesizer of a conflict detection tool could use updated heading and altitude clearance information to construct more accurate trajectories. This ATC information flow is shown in Figure 2.2, with flight plan amendments and clearances automatically passed to a DST, either directly or via the Host flight data computer.

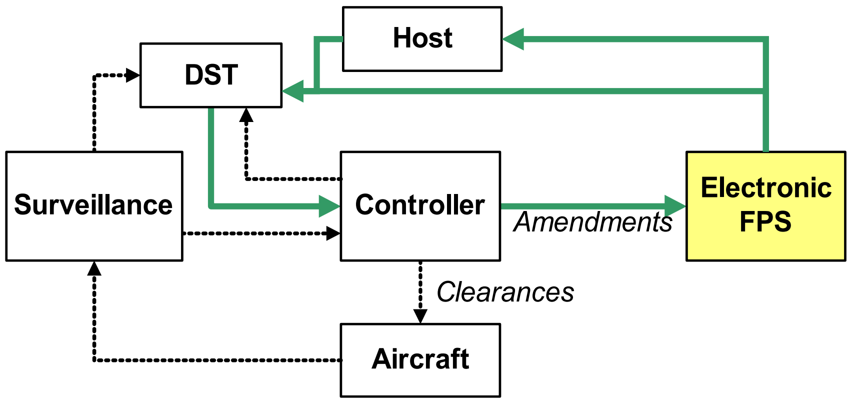

Figure 2.2: Simplified Air Traffic Control Loop with Electronic FPS

2.3.2 Using the Flight Strip as a DST Interface

An electronic FPS could enable the flight strip to be more than a device for displaying flight data and recording clearances. The electronic FPS could have greater interactivity and could act as an interface to one or more DSTs. This information flow is shown in Figure 2.3. The electronic FPS is now both the input and output mechanism for the DST, eliminating the need for a separate DST interface.

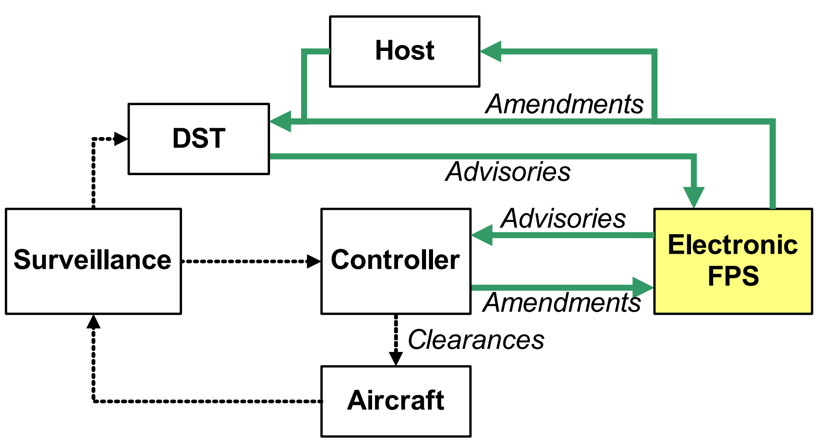

Figure 2.3: Simplified Air Traffic Control Loop with Electronic FPS as DST Interface

Using the electronic FPS as both a flight strip and a DST input/output interface could allow the introduction of more decision support for controllers without increasing the number of displays a controller would need to monitor. This would be especially important for the control tower environment, where space for new displays is limited, and where a proliferation of displays could increase head-down time and adversely affect a controller's ability to maintain his out-the-window view. For example, an electronic FPS could be used as an interface to a runway incursion monitor. In 2000, two aircraft collided on the runway at Sarasota, Florida after one aircraft was cleared to hold in position on the runway in front of another aircraft taking off. The local (runway) controller issued the position-and-hold clearance based on FPS annotations written by the ground controller, without verifying the location of the aircraft [NTSB, 2001]. With an electronic FPS linked to a runway incursion monitor, the flight strip itself could have alerted the controller to the discrepancy between the annotated position of the aircraft on the FPS and the actual position of the aircraft on the airport surface [Pavet, 2001].

2.4 The Portable Electronic Flight Progress Strip Concept

An ideal flight progress strip should attempt to retain the benefits and address the limitations of the paper FPS while realizing the advantages of an electronic FPS. For the airport control tower environment especially, it is desirable to maintain the FPS as a portable, physical artifact. Previously-designed electronic FPS systems for enroute control environments have used a fixed monitor to show electronic representations of multiple flight progress strips on a single display [Celio, 2000]. While some of these electronic FPS systems have used a touch-screen to preserve the manual manipulation and direct annotation of the paper FPS [Mertz, 2000], such designs still do not address the portability benefits of the paper FPS.

In order to fully replicate the portability of the paper FPS in an electronic device, it is necessary to create an electronic analogue of the individual FPS rather than an electronic analogue of the entire strip bay. This leads to the concept of the Portable Electronic Flight Progress Strip. With the Portable Electronic Flight Progress Strip system, each flight strip will have its own, dedicated, handheld, portable, electronic interface. Wireless communications will be used to transfer data to and from the flight strips. Controllers will use pen-based methods to input information directly onto the electronic strips. Control handoffs will continue to be accomplished by physically transferring the FPS from one controller to another. In these ways, the Portable Electronic Flight Progress Strip will retain many of the benefits of the paper FPS.

CHAPTER 3: DESIGN OF A PROTOTYPE PORTABLE ELECTRONIC FLIGHT PROGRESS STRIP SYSTEM

3.1 Requirements Analysis

The remainder of this document will discuss the design and evaluation of a prototype Portable Electronic FPS system, beginning with a requirements analysis. This electronic FPS system will be designed specifically for use in airport control towers and with departure aircraft. To explore the possibility suggested in Section 2.3.2 , the electronic FPS will also act as an interface for a departure DST. The particular DST concept used to derive requirements for an interface is one developed at the Massachusetts Institute of Technology [Anagnostakis, 2000]. Hereafter, this DST will be referred to as the Departure Planner (DP). The electronic FPS system must retain the functionality present in the paper FPS while adding the functionality required by the Departure Planner.

3.1.1 Core FPS Functional Requirements

The functionality currently present in paper flight strips must be preserved in any electronic FPS. These functionalities are referred to as "core" functional requirements and consist of the following, derived from an analysis of the FAA Air Traffic Control Handbook [FAA, 2002] and the Boston Logan International Airport control tower standard operating procedures [FAA, 1995]:

Table 3.1: Core FPS Functional Requirements by Requirement Category

Requirement Category	Core FPS Requirement
Flight Data	Display and modification of: aircraft callsign, aircraft type and navigation equipage, transponder code, route of flight, cruise altitude, proposed departure time, initial heading, and departure airport Indication of a revised FPS
Aircraft Departure State	Indication that an aircraft is unable to receive an electronic pre-departure clearance Notation of an aircraft having the current version of the hourly Automatic Terminal Information Service (ATIS) airport weather information Notation of the time an aircraft calls ready for gate pushback (for jet aircraft) or ready for taxi (for turboprop and piston aircraft) Notation of the expected pushback/taxi time for aircraft that are not immediately granted pushback/taxi clearance Indication that an aircraft has waived a wake turbulence restriction Indication of clearance for position-and-hold on a departure runway Notation of the actual departure (takeoff) time
Traffic Flow	Indication of the last aircraft to depart before a runway configuration change Highlighting of the restricted waypoint for aircraft with an in-trail restriction in their route of flight Highlighting of the Expected Departure Clearance Time (EDCT) for aircraft with EDCT restrictions
Nonstandard Operations	Indication when nonstandard taxiways, runways, or runway intersections are used Indication of any other nonstandard operations

Specific methods are outlined by the FAA to implement these functionalities with a paper FPS (e.g., writing a vertical line on a specific region of the FPS to indicate position-and-hold clearance). However, an electronic FPS should not be required to adhere to these methods if the electronic interface enables better ways of accomplishing the same tasks (i.e., ways which lower workload or increase a controller's cognitive understanding of the air traffic situation). For this reason, the exact display and annotation methods used with paper flight strips are not discussed in the core functional requirements.

3.1.2 Departure Planner Interface Requirements

The Departure Planner consists of two primary components: a strategic planner and a tactical planner. The strategic planner would operate with a three to four hour time horizon and would give advisories for future runway configurations (which runways are used for arrival and departure) and airport operating modes (arrival/departure balances such as accelerated departure procedures). The tactical planner would operate with a 15 to 30 minute time horizon and would provide individual aircraft advisories for pushback, taxi, and takeoff times (including runway assignment) in the form of "virtual" queues. Together, the strategic and tactical planners would optimize departing traffic and close unnecessary gaps between arrivals and departures, given the planned airport weather conditions and demand for airport resources. This system architecture, along with the airport resources that each DP system component would affect, is shown in Figure 3.1.

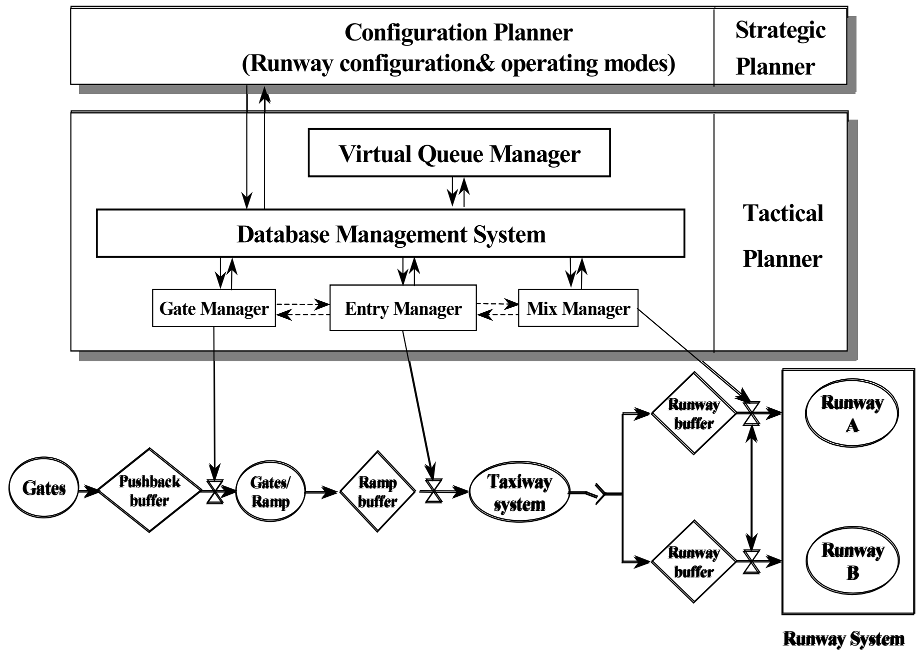

Figure 3.1: Departure Planner System Architecture [Anagnostakis, 2000]

From an analysis of [Anagnostakis, 2000], the following requirements have been identified for a Departure Planner interface, shown in Table 3.2.

Table 3.2: Departure Planner Interface Input and Output Requirements

Air Traffic Controller Inputs to Departure Planner	Departure Planner Outputs to Air Traffic Controller
Aircraft "call ready for pushback" time Actual aircraft pushback time Aircraft taxi start time Aircraft takeoff time Airport current runway configuration and operating mode Downstream constraints (minutes-in-trail, miles-in-trail, ground delay program, etc.)	Suggested runway configuration changes and airport operating modes changes Virtual runway queues, showing runway assignments and suggested sequences/times for pushback, taxi, and takeoff

Note that this is not a complete listing of DP inputs, but only those that would be input by an air traffic controller. Other inputs, such as the airport topology, aircraft flight plans, local ATC procedures, and aircraft performance data would either be stored in a static database or be input to DP via other ATC subsystems, such as the Host flight data computer.

3.1.3 Additional Desired Features

While not specifically required by the Departure Planner or by existing paper FPS functionality, it is recognized that a useful addition to the Departure Planner interface would be a display of airport surface traffic (and perhaps airborne traffic in the immediate vicinity of the airport). This display could either be explicitly part of the Departure Planner or hosted on a separate monitor, such as a runway incursion alerting system display. By connecting the Portable Electronic FPS to the surface traffic display, a controller could use the flight strip to locate an aircraft on the surface, or select an aircraft on the surface traffic display to locate its FPS [Pavet, 2001]. This could be of particular help during low-visibility conditions or at hub airports where many aircraft of the same airline and aircraft type may be operating on the airport surface at the same time.

3.1.4 Appropriateness of FPS for Departure Planner Interface

To judge the appropriateness of the Portable Electronic FPS as a Departure Planner interface, it may be useful to regroup the functional requirements listed above into two different categories: airport-wide requirements and aircraft-specific requirements. This reorganization is shown in Table 3.3.

Table 3.3: Departure Planner Requirements Grouped by Scope

Airport-Wide DP Inputs and Outputs	Aircraft-Specific DP Inputs and Outputs
Airport current runway configuration and operating mode	Aircraft "call ready for pushback" time
Suggested runway configuration changes and airport operating mode changes	Actual aircraft pushback time
Virtual runway queues, showing runway assignments and suggested sequences/times for pushback, taxi, and takeoff	Aircraft taxi start time
All downstream constraints (minutes-in-trail, miles-in-trail, ground delay program, etc.)	Aircraft takeoff time
Surface traffic display	Individual aircraft placement within virtual queues
	Individual aircraft downstream constraints

The Portable Electronic FPS is well-suited for showing aircraft-specific information. Indeed, some of the required Departure Planner inputs, such as the pushback and takeoff times, are already contained on the paper FPS. However, airport-wide information has been determined to be more appropriate for a centralized interface, rather than distributed throughout individual Portable Electronic FPSs. Such an interface could either be used by the ground and local controllers or by the Traffic Management Coordinator in the control tower. Thus, a complete Departure Planner system should consist of individual electronic flight strips for aircraft-specific input and outputs, plus a centralized display for airport-wide inputs and outputs.

3.2 Prototype Implementation

3.2.1 System Architecture

Based on the observations of Section 3.1.4 , the prototype Electronic Flight Progress Strip system consists of individual Portable Electronic FPSs communicating wirelessly with a fixed Management Interface. The Management Interface acts as a server for the information displayed on each FPS, relaying controller inputs and outputs between the FPS and the Departure Planner algorithms, as well as transferring information to and from other ATC components such as the Host flight data computer, surveillance sources, weather forecasts, other DSTs, and airlines. In addition, the Management Interface acts as the display for the airport-wide elements of the Departure Planner interface, showing virtual queues, suggested future runway configurations and operating modes, and an airport surface traffic map, as well as providing a means for controllers to input the current runway configuration and downstream restrictions. This system architecture is shown in Figure 3.2. A more detailed block diagram of the information flow between the air traffic controller and the various system components is shown in Figure 3.3. Dashed lines indicate links which are not modeled in this thesis but which would be included in an operational system.

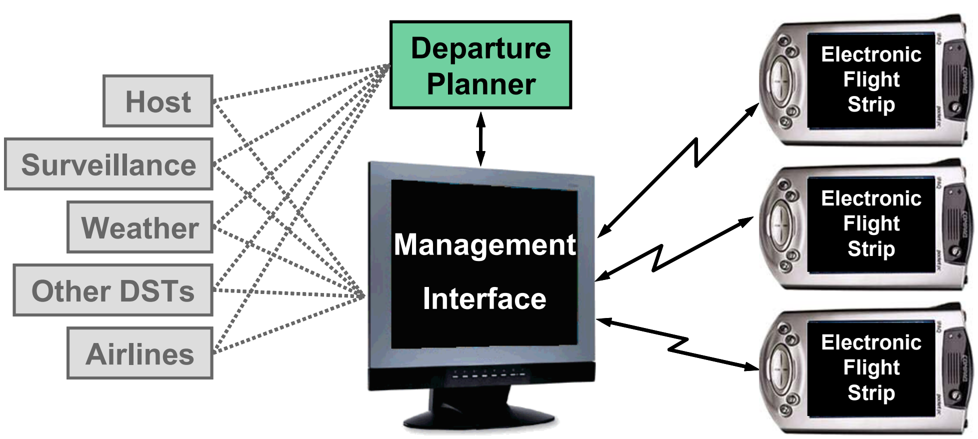

Figure 3.2: Prototype Portable Electronic Flight Strip System Architecture

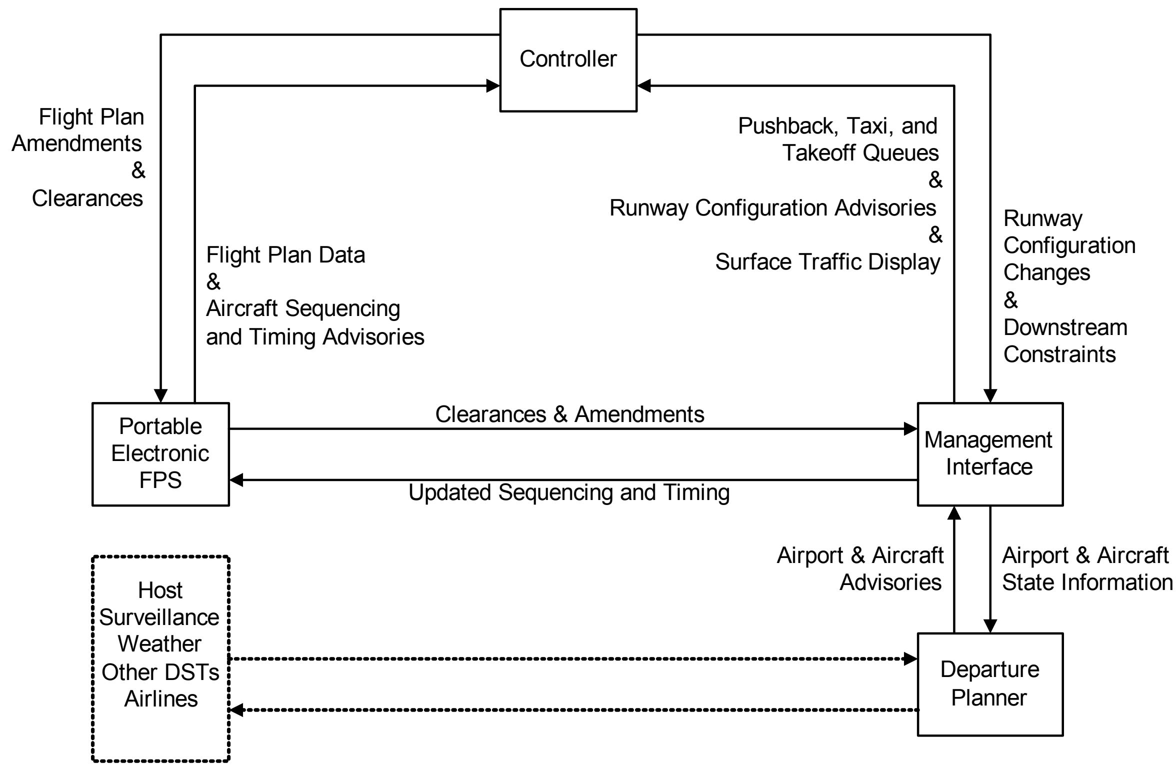

Figure 3.3: Information Flow Between Controller and Portable Electronic FPS System Components

3.2.2 Hardware

The prototype design of the Portable Electronic FPS system has been implemented using Compaq iPAQ Pocket PCs for the individual Portable Electronic FPSs and a desktop computer for the Management Interface. The Pocket PCs have backlit, color displays and run the Windows CE operating system. Each iPAQ is equipped with an IEEE 802.11b-compatible wireless local area network (LAN) card to transfer data to and from a wireless access point. In turn, the wireless access point is directly connected to the Management Interface via an Ethernet crossover cable. This prototype hardware is shown in Figure 3.4.

Figure 3.4: Prototype Hardware for Portable Electronic FPS System

It is important to note that this hardware was chosen for prototyping purposes only. The Pocket PCs are not considered appropriate for an operationally-deployed system. However, they have a number of attributes which are useful for prototyping the Portable Electronic FPS design: they reasonably approximate the size of the paper FPS, they have a straightforward software development environment (in this case, Microsoft Embedded Visual C++), they have a touch-screen for direct, pen-based input, and it is relatively simple to add wireless networking capability to the Pocket PCs. With the growth of handheld computing technology, it is not unrealistic to assume that devices will be available for an operationally-deployed Portable Electronic FPS which will have greater functionality than currently available devices, lower costs, lower weight, lower energy consumption, and a form factor customized for this application.

3.2.3 Management Interface Display

The prototype Management Interface consists of runway, taxi, and pushback virtual queues, a map of airport surface traffic, and a listing of currently-active downstream restrictions. An example of this display layout is shown in Figure 3.5.

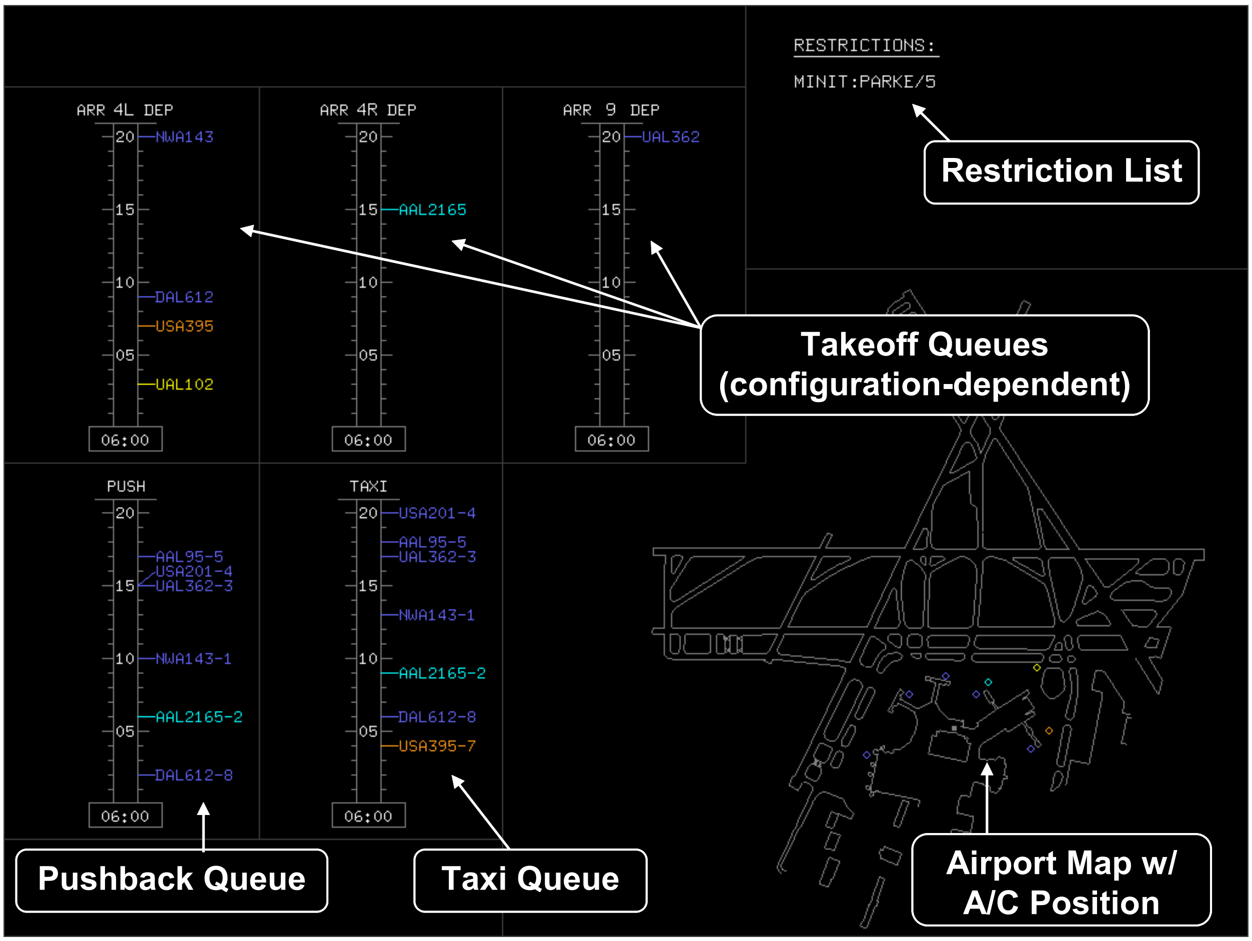

Figure 3.5: Prototype Management Interface Display

3.2.3.1 Airport Surface Map Format and Functionality

The airport surface traffic map shown in Figure 3.5 is for Boston Logan International Airport. It shows a plan-view of the airport terminals, taxiways, and runways, and is oriented in the same direction that the ground controller faces in the control tower cab (i.e., when the ground controller looks straight out the window, he is facing in the "up" direction on the surface traffic display). This display orientation is consistent with the orientation of the existing Airport Surface Detection Equipment (ASDE) monitor in the control tower.

The symbology used for surface aircraft is a hollow diamond shape. The diamond is color-coded by the departure state of the aircraft. The departure states modeled are: at gate, ready to push, cleared for push, cleared for taxi, and cleared for takeoff. Arrival aircraft and non-aircraft surface vehicles are not included in the prototype.

When the Management Interface's mouse pointer is positioned near an aircraft symbol, the diamond increases in size, becomes filled-in with the appropriate color-coding, and is given a white border. The corresponding aircraft datatag is highlighted with a white border in all the departure queues in which it appears. In this way, a controller can quickly see where an aircraft is located in both the virtual departure queues and on the physical airport surface. This functionality is shown in Figure 3.6. In addition, by holding the right mouse button when an aircraft symbol is highlighted, a "strip view" of the aircraft's flight data will appear in the lower-left hand corner of the display. This is shown in Figure 3.7. The "strip view" shows the same information displayed on the Portable Electronic FPS, which will be discussed in Section 3.2.4.2 This information includes the aircraft's callsign, type, equipage, transponder code, gate location, departure runway, initial heading, initial altitude, filed cruise altitude, and route of flight.

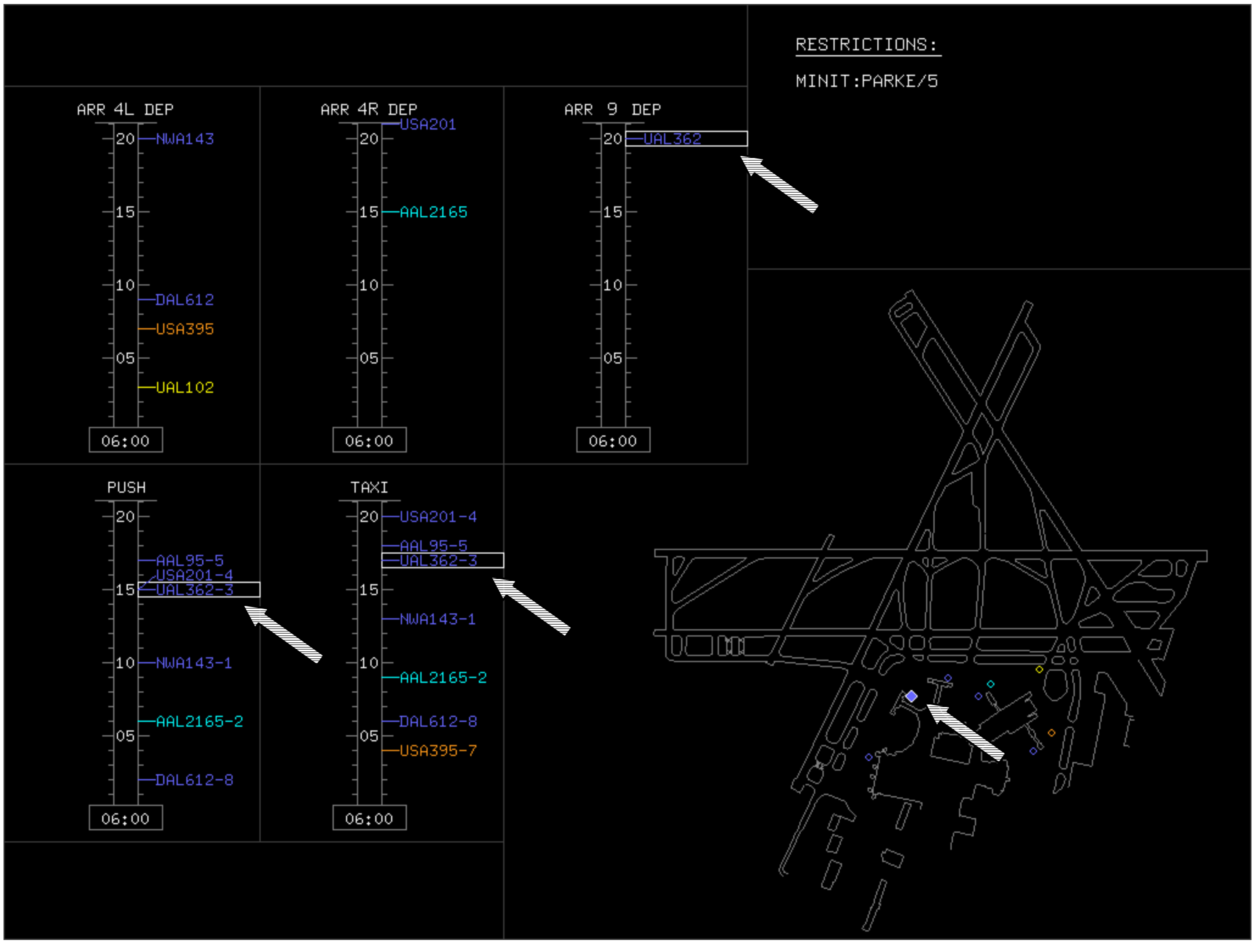

Figure 3.6: Highlighted Datatags and Aircraft Position Symbol on Prototype Management Interface (Indicated by Arrows)

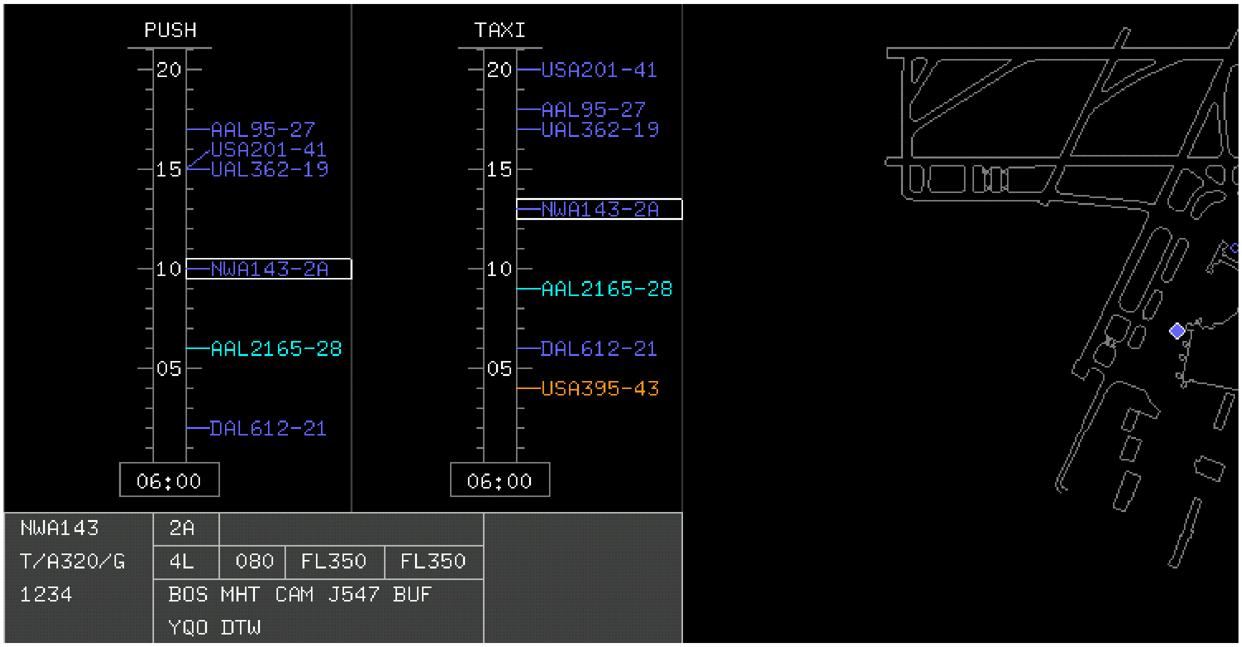

Figure 3.7: Portion of Management Interface Showing Highlighted Aircraft Position Symbol, Highlighted Queue Datatags, and "Strip View" of Flight Data

3.2.3.2 Virtual Departue Queue Format and Functionality

Two virtual queue formats have been developed for the prototype Management Interface: sequence-based queues and time-based queues. Figure 3.5 shows an example of time-based queues. This type of queue is loosely based on the queue format of the NASA Traffic Management Advisor, a DST for sequencing and spacing arrival traffic [Hoang, 1997]. The queue type is shown at the top of the queue ("PUSH", "TAXI", or a runway identifier such as "4L"). The Push and Taxi queues are shown for all runway configurations. However, the runway queues change depending on the runways currently being used for arrivals and departures. Thus, the example shown in Figure 3.5 represents an eastbound traffic flow with runways 4L, 4R, and 9 in use. The runway queues are designed to display both arrival and departure aircraft (showing landing times and takeoff times, respectively). However, only departure aircraft are modeled for the prototype system.

The time-based queues show the current time in HH:MM format at the bottom of each queue. Future times are shown extending upward from the bottom of the queue. Short hash marks are displayed for each minute interval, and long hash marks are displayed for each five minute interval. In addition, the minute value is shown at every five minute interval. The hash marks, minute values, and aircraft datatags slowly creep downward as time progresses. An example of this progression is shown in Figure 3.8. The time horizon for each queue is approximately 20 minutes. While this is within the proposed time horizon window for the Departure Planner's tactical planning components, it was chosen primarily because of space constraints on the monitor used for the prototype Management Interface.

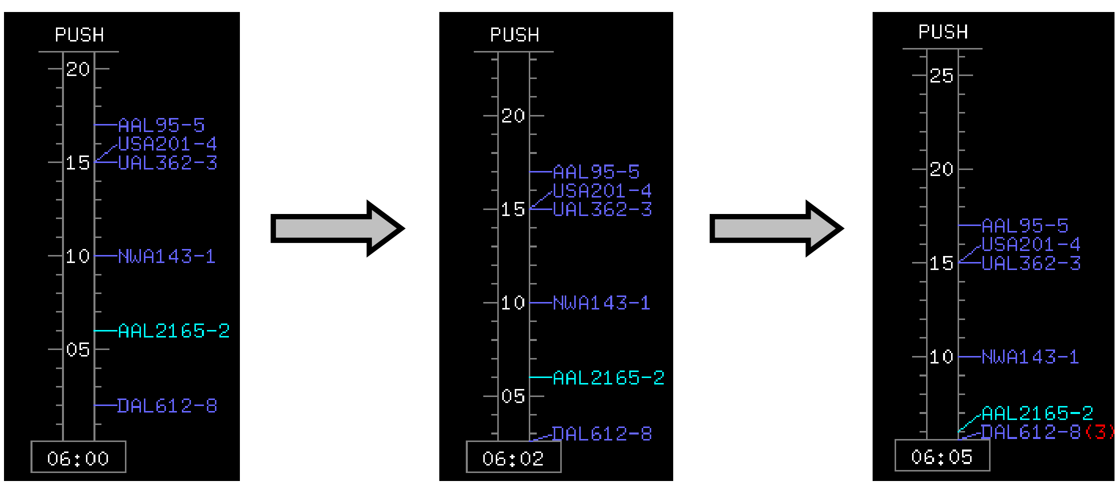

Figure 3.8: Progression of Time-Based Virtual Queues

For the push and taxi queues, the datatags show the aircraft's callsign and departure gate. For the runway (takeoff) queues, the datatags only show the aircraft's callsign, as gate information is not necessary at that point in the departure process. The datatags on the virtual queues are color-coded in the same manner as the diamond-shaped aircraft symbols on the surface traffic map. As aircraft change departure state, their datatags are removed from the corresponding queue. For example, when an aircraft is given pushback clearance, it is removed from the pushback queue. Thus, the pushback queue only shows aircraft that are at the gate or ready to push. The taxi queue shows aircraft that are at the gate, ready to push, or cleared to push. The runway queue shows aircraft that are at the gate, ready to push, cleared to push, or cleared to taxi. These aircraft state changes are communicated to the Management Interface via the Portable Electronic FPSs. The method for doing this will be discussed in Section 3.2.4.8

Provisions have been made so that datatags do not overlap when two aircraft are scheduled to complete a departure state change at the same time (e.g., two aircraft at different terminals are advised to push at the same time but will reach the runway at different times due to different taxi path lengths). In addition, when events are supposed to have happened in the past, the affected aircraft datatag does not disappear off the bottom of the display. Rather, it stays displayed while the number of minutes "past due" for the clearance action is displayed between parentheses in red text next to the datatag. Both of these features can be seen in Figure 3.8.

It is unknown if the Departure Planner can operate with enough precision to enable time-based departure advisories, or even if time-based queuing is the most appropriate method of presenting information to tower controllers. For these reasons, an alternative to time-based queues has been prototyped. These sequence-based queues only show the relative order in which departure events should occur. An example of sequence-based queues is shown in Figure 3.9.

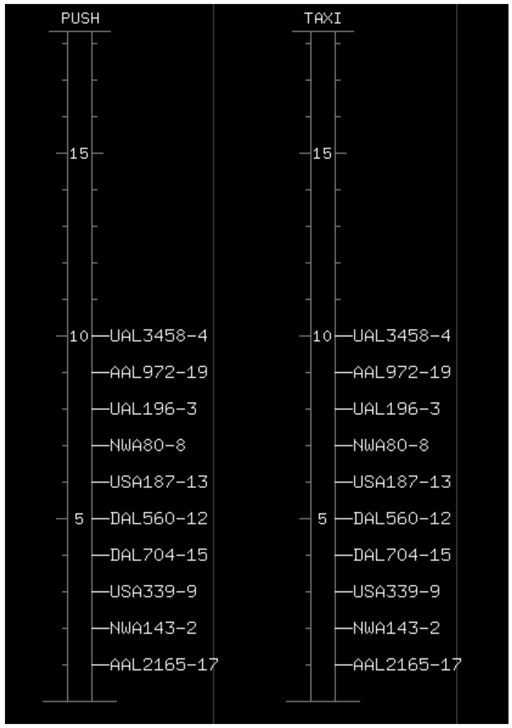

Figure 3.9: Sequence-Based Virtual Queues for Pushback and Taxi

Unlike the time-based queues, the sequence-based queues do not display the current time. Hash marks now represent sequence numbers, starting with the first aircraft in sequence at the bottom of the queue and subsequent aircraft progressing upward along the length of the queue. All aircraft are equally spaced along the queue, and unlike time-based queues, this style of queue does not suffer from problems of displaying coincident events or events scheduled to happen in the past. However, the sequence-based queues retain the same datatag information and color-coding as the time-based queues.

For both time-based and sequence-based queues, the aircraft datatags have the same functionality as the position symbols on the airport surface traffic display. That is, when the mouse is positioned over a datatag, that datatag is highlighted with a white border. Also, datatags on other queues for the same aircraft are highlighted, as well as that aircraft's position symbol on the airport surface traffic display. If the right mouse button is held down when a datatag is highlighted, the "strip view" of the corresponding aircraft's flight data will appear in the lower left-hand corner of the display. This functionality was illustrated in Figure 3.7.

3.2.3.3 Downstream Restriction List Format

The downstream restriction list shows the currently-active restrictions for departure aircraft which apply to a downstream resource but which must be addressed at the departure airport. Such restrictions include minutes-in-trail (MINIT) separation requirements over a flight plan waypoint for successive aircraft, miles-in-trail (MIT) separation requirements for successive aircraft, and ground delay programs. The restriction list displays the type of restriction, the downstream resource to which it applies, and the amount of restriction. For example, Figure 3.10 shows that the only downstream restriction currently active is a minutes-in-trail restriction over the PARKE intersection in which successive aircraft passing over the intersection must be spaced at least five minutes apart.

Figure 3.10: Portion of Management Interface Showing Downstream Restriction List

3.2.3.4 Additional Functionality not Enabled in Prototype

Some of the required Management Interface functionalities have not been enabled in the prototype. While necessary for an operationally-deployed system, these functionalities were omitted because it was known they would not be needed for the Portable Electronic FPS system evaluation described in Chapter 4. Such functionalities include: runway configuration and operating mode advisories, the ability for controllers to input the current runway configuration and operating mode, and the ability for controllers to input currently-active downstream restrictions.

3.2.4 Portable Electronic Flight Progress Strip Display

3.2.4.1 Overall Display Layout

The Portable Electronic Flight Progress Strip contains flight data information (aircraft callsign, transponder code, filed cruise altitude, route of flight, etc.), departure advisories from the Departure Planner, and a means of recording aircraft clearances. Figure 3.11 is a photograph of a Pocket PC running the Portable Electronic FPS software, Figure 3.12 shows the same display as a screen capture image, and Figure 3.13 is a key to the information shown on the display.

Figure 3.11: Photograph of Portable Electronic FPS Software on Pocket PC

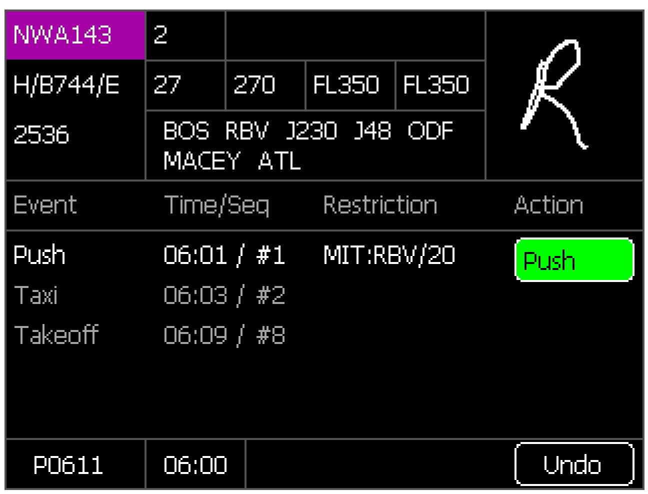

Figure 3.12: Example Screen Capture of Portable Electronic FPS Display

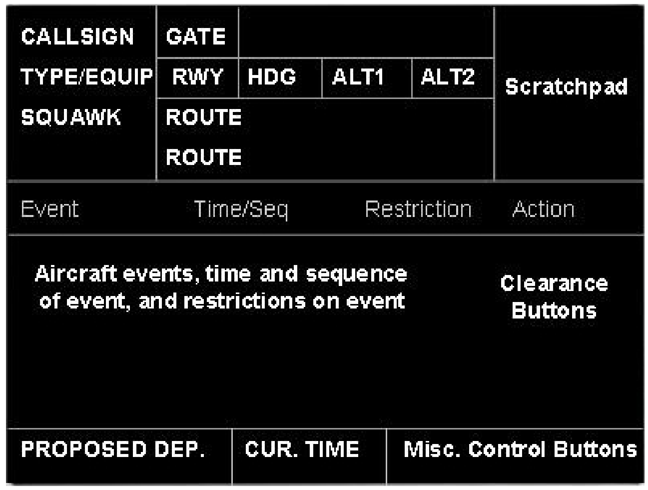

Figure 3.13: Key to Portable Electronic FPS Information

3.2.4.2 Flight Plan Data Layout

The top half of the display contains similar information to that shown on paper flight progress strips. In the top-left corner is the aircraft callsign, aircraft type and navigation equipage, and transponder (squawk) code. The background of the callsign field is color-coded in the same manner as the Management Interface datatags to indicate the aircraft's departure status (at gate, ready to push, cleared for pushback, cleared to taxi, cleared for position-and-hold on the runway, and cleared for takeoff).

The top-center portion of the display contains the aircraft gate location, suggested departure runway, initial heading, route of flight, and two altitude fields—one for the filed cruise altitude (shown on the paper FPS) and one for the initial altitude clearance. Although not required by the core or Departure Planner requirements, the initial altitude clearance field is included because it could be useful both for controllers and for any DSTs incorporating a trajectory synthesizer.

The bottom-left corner of the display contains the aircraft's proposed departure time and the current time. The proposed departure time is located next to the current time to facilitate quick calculations of delay with respect to airline schedules. The current time is located here to be in-line with the Departure Planner timing advisories discussed in Section 3.2.4.6

Information shown on a paper FPS and omitted on the Portable Electronic FPS includes the computer identification number and the departure airport. A separate field for the departure airport is not shown because it always appears as the first waypoint on the route of flight for departure aircraft. The computer identification number does not need to be displayed because it is not used for control purposes. However, a unique FPS identification number could still be encoded within the Portable Electronic FPS system.

3.2.4.3 Flight Plan Data Modification

To modify flight data on the paper FPS, annotations are written directly on the flight strip to indicate the new value. As discussed in Section 2.1 , this annotation method has important benefits because it makes use of a direct interface and therefore has speed advantages over a separate mouse or keyboard input device. In addition, nearby controllers are better able to observe the annotations being made when they are written directly on the FPS.

Retaining the benefits of handwritten annotations in an electronic form would suggest the use of handwriting recognition to interpret and disseminate any flight data modification. However, with the Portable Electronic FPS, handwriting recognition approaches were rejected for two reasons. First, controller workload would likely increase due to the additional task of verifying that the handwriting recognition algorithms have correctly interpreted controller annotations. Second, most of the flight data fields on the Portable Electronic FPS have a discreet number of possible values which can be conditionally determined. For example, at any given airport, there is a small, fixed number of possible departure runways from which to choose. Due to local standard operating procedures, there is similarly a discreet number of possible initial headings and altitudes from which to choose. This leads to the conclusion that a simple, menu-based system for modifying flight data is most appropriate for the Portable Electronic FPS.

Figure 3.14 illustrates one method for changing the assigned departure runway. When the runway field is tapped with the Pocket PC stylus, the runway field background is highlighted in yellow. The bottom half of the display—which normally displays departure advisories, restrictions, and clearance buttons—is replaced with a grid of buttons for each runway.

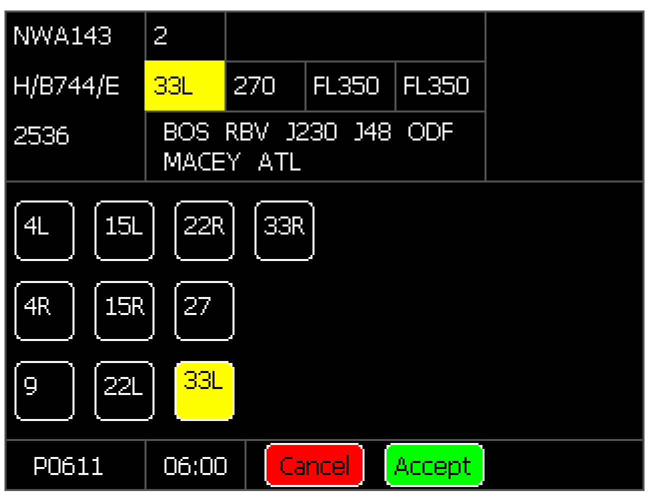

Figure 3.14: Modification of Departure Runway Assignment Using Number Pad

The button for the current runway is highlighted in yellow. To change the departure runway, the button for the new runway is tapped with the Pocket PC stylus, which is then highlighted in yellow. To accept the new runway choice, the green “Accept” button is tapped. To dismiss the new runway choice and return to the previous departure runway assignment, the red “Cancel” button is tapped. The “Accept” and “Cancel” buttons appear whenever a flight data modification menu is used.

To change the initial heading assignment, initial cleared altitude, or filed cruise altitude, the appropriate flight data field is first tapped, after which it is highlighted in yellow and a “soft” number pad appears in the lower half of the Portable Electronic FPS display. A new heading or altitude is entered by tapping the digits of the new value. For example, tapping “3 5 0” would change the initial heading to 350 degrees. Tapping “6 0” would change the initial altitude to 6000 ft. (To increase the speed of altitude modification, it is not necessary to include the two trailing zeros because altitude clearances are always given in 100-foot increments.) A backspace button is included in the number pad to correct mistakes, and the same “Accept” and “Cancel” buttons are used as above. Figure 3.15 shows modification of the initial heading using the number pad. The altitude number pad is identical to the heading number pad.

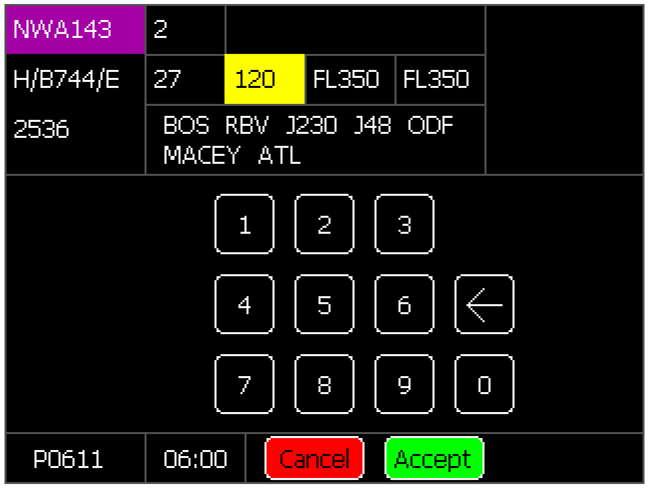

Figure 3.15: Modification of Initial Heading Using Number Pad

3.2.4.4 Alternative Flight Data Modification Formats

While the software buttons for changing runway, altitude, and heading provide a straightforward way to modify flight data, it may be advantageous to exploit the capabilities of the FPS's electronic display to present controllers with more graphical methods for changing flight data. Alternative formats have been prototyped both for changing the assigned departure runway and for changing the initial heading assignment. The graphical method for modifying the assigned runway is shown in Figure 3.16. A simplified plan-view of the departure runways is depicted, oriented in the same manner as the surface traffic map discussed in Section 3.2.3.1 . Next to the departure end of each runway is a soft button used to select the runway assignment. The currently-selected runway is highlighted in white. The other runways are shown in a dimmed gray.

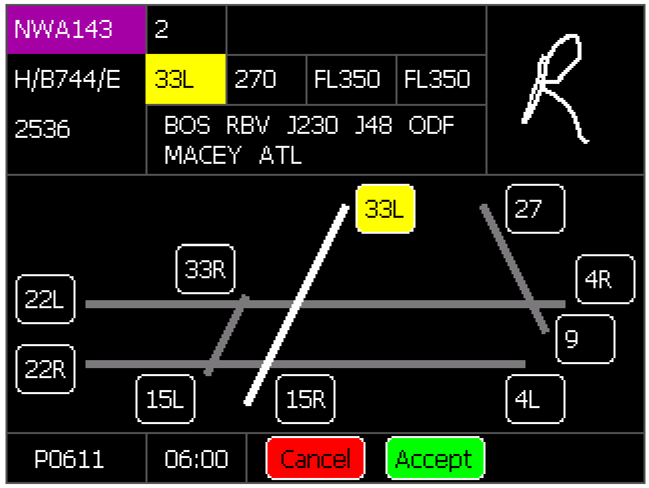

Figure 3.16: Alternative Graphical Method for Modifying Runway Assignment

Figure 3.17 shows the alternative format prototyped for changing the initial assigned heading. A circle is displayed with heading values at north, south, east, and west, and hash marks every thirty degrees. The previous heading is shown with a dimmed gray line extending from the center of the circle to the edge of the circle in the direction chosen. The new heading is shown with a highlighted white line. The stylus is used to change the heading by tapping the screen in the direction desired—the heading is calculated by determining the angle between the stylus position and the center of the center of the compass circle. Fine changes (in increments of five degrees) are accomplished by using the "up" and "down" portions of the 4-way, directional hardware button at the bottom of the Pocket PC.

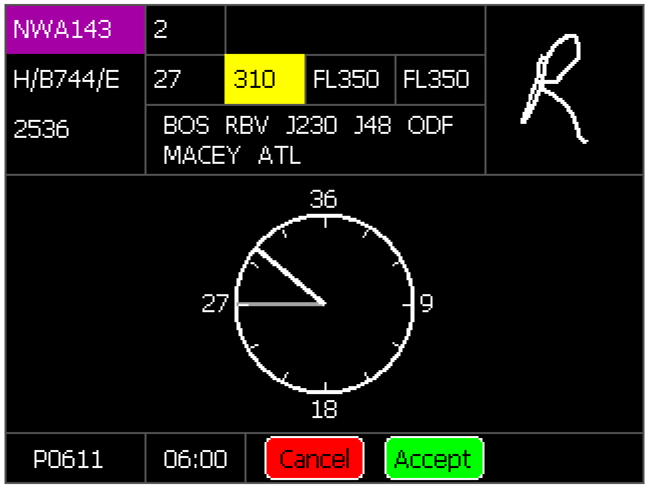

Figure 3.17: Alternative Graphical Format for Modifying Initial Heading Assignment

3.2.4.5 Scratchpad

The top-right corner of the display contains a scratchpad, used for writing miscellaneous controller annotations. The ability to record such annotations is an important part of why the paper FPS is so flexible, and should be retained in any electronic system [Pavet, 2001]. In addition, one of the core FPS requirements is the indication of any nonstandard instructions. By using the Pocket PC stylus to write on the scratchpad, this requirement is fulfilled. This is the only area of the Portable Electronic FPS display where annotations can be recorded which are not interpreted by the software. The scratchpad annotations are only stored as a sequence of line-segment endpoints. Like paper strips, in order to avoid accidental deletion of important information, there is no means enabled for erasure of the scratchpad annotations. Examples of scratchpad annotations are shown above in Figure 3.11 and Figure 3.12.

3.2.4.6 Departure Planner Advisories

Advisories from the Departure Planner are located in the bottom-left portion of the display, under the "Event" and "Time/Seq" headings. These advisories are listed in a tabular format and show suggested times and/or sequence positions that aircraft should complete departure events (pushback, taxi, and takeoff) according to the optimal virtual queues calculated by the Departure Planner. This information is the same as that shown on the Management Interface queues, but presents the information in the context of the departure flow for a single aircraft instead of an entire airport. Like the Management Interface, once a departure event has occurred, the advisory for that event disappears from the screen.

Three different formats have been prototyped for the Departure Planner advisories: sequence positions plus absolute time, sequence positions plus relative time, and sequence positions only. These three formats are shown in Figure 3.18, Figure 3.19, and Figure 3.20, respectively.

Figure 3.18: Departure Advisory Format: Absolute Time Plus Sequence Position

Figure 3.19: Departure Advisory Format: Relative Time Plus Sequence Position

Figure 3.20: Departure Advisory Format: Sequence Position Only

Three different advisory formats have been chosen because it is unknown at this time which method of presenting advisories would be most useful to controllers. Furthermore, it is unknown if it is necessary, or even feasible, for the Departure Planner to operate with enough precision to enable time-based advisories.

Another question raised by the introduction of departure advisories onto the Portable Electronic FPS is whether or not controllers should be able to view the departure event history—that is, the actual time of occurrence for past departure events in addition to proposed times/sequences of future events. One method prototyped for viewing the event history is to keep records of past departure events on the display, but to replace the time/sequence advisory with the actual time of occurrence. To help distinguish future events from past events and determine the aircraft's status within the departure process, the immediate next event is displayed in white text, while past events and subsequent future events are showed in dimmed gray text. This method for viewing an aircraft's departure event history is shown in Figure 3.21 alongside the default format of removing past events from the Portable Electronic FPS display.

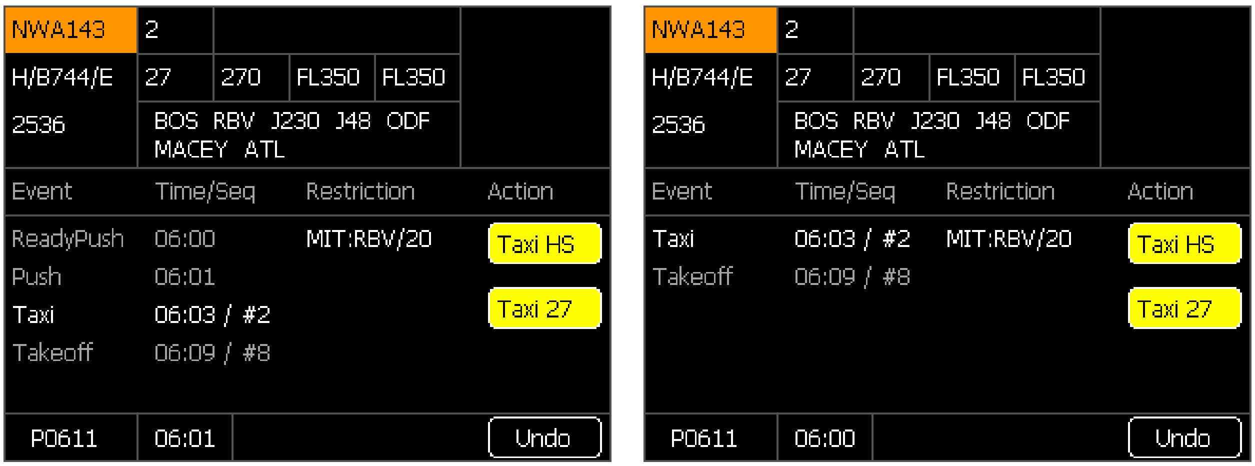

Figure 3.21: Displaying Departure History (left) vs. Hiding Departure History (right) for an Aircraft Waiting for Taxi Clearance

3.2.4.7 Downstream Restrictions

Any downstream constraints applicable to the aircraft are shown to the immediate right of the departure advisories, under the "Restrictions" heading. This is the same information shown on the downstream restrictions list of the Management Interface, but the only restrictions displayed are those which are applicable to the particular aircraft on the FPS. This feature eliminates the need for a controller to underline any restricted waypoints in the route of flight field, as is currently done with paper flight strips.

3.2.4.8 Clearance Buttons

Clearance buttons are located in the bottom-right portion of the display, under the "Action" heading. These are "soft" buttons, as opposed to the physical buttons along the bottom of the Pocket PC, and are activated by an air traffic controller tapping them with the Pocket PC stylus. The clearance buttons perform two important tasks. First, they are the means by which the Management Interface receives updates about an aircraft's departure status. Second, they replace the need for controllers to write down the ready-for-pushback, pushback clearance, and takeoff clearance times as is currently done with the paper FPS. By tapping a button instead of looking at a clock and writing down a time, controller workload may be reduced. In addition, by recording and disseminating clearance times in an electronic format, the observability of the departure process may be increased. The benefits of this were noted in Section 2.3.1 .

There is a clearance button for each of the following events: confirmation that the aircraft has the current ATIS code, aircraft ready for pushback, pushback clearance, taxi clearance to a hold-short point, taxi clearance to the departure runway, position-and-hold clearance, and takeoff clearance. Which clearance button(s) are displayed depends on the current departure state of the aircraft. For example, an aircraft awaiting pushback clearance would only have the "Clear Push" button displayed on its Portable Electronic FPS while an aircraft at the Runway 27 threshold would have both "Pos Hold" (for position-and-hold on the runway) and "T/O 27" (for takeoff on Runway 27) displayed on the FPS. Figure 3.22 shows the series of clearance buttons displayed as an aircraft progresses from the gate to takeoff.

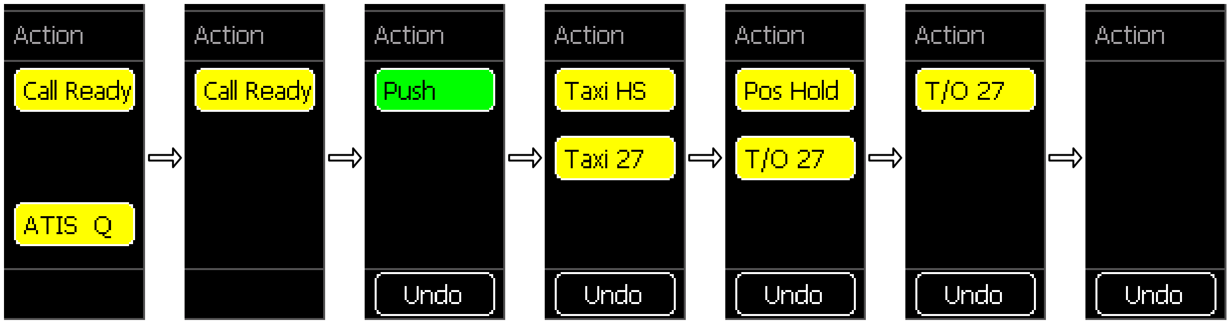

Figure 3.22: Clearance Buttons Displayed as Aircraft Progresses from Gate to Takeoff

If a clearance button is mistakenly tapped by a controller, the flight strip can be returned to its previous state by tapping the "Undo" button, displayed in the extreme bottom-right corner of the display. In addition, the clearance buttons are color-coded such that they have a green background when an aircraft is first in sequence for a particular departure event and a yellow background when an aircraft is not first in sequence. This functionality could be extended were the Portable Electronic FPS connected to a runway incursion monitor. For instance, a red clearance button background could indicate that it is unsafe to issue a clearance.

3.2.4.9 Functionality not Enabled in Prototype

The following functions, listed under the core requirements of Section 3.1.1 , have not been implemented in the prototype Portable Electronic FPS:

- Modification of the aircraft callsign, aircraft type and navigation equipage, transponder code, and route of flight
- Indication of a revised FPS
- Indication that an aircraft is unable to receive an electronic pre-departure clearance

- Indication that an aircraft has waived a wake turbulence restriction
- Highlighting of EDCT times
- Indication of the last aircraft to depart before a runway configuration change

"Modification of the aircraft callsign, aircraft type and navigation equipage, and route of flight" are not included in the prototype because it was known that these functions would not be needed for the evaluation described in Chapter 4. Furthermore, such functions would likely require a separate keyboard interface. "Modification of the transponder code" also is not included in the prototype because it was known this functionality would not be needed for the FPS evaluation. However, it is conceivable that a soft button could be added to the Portable Electronic FPS which would automatically search for and assign a new, unused transponder code.

"Indication of a revised FPS" is not included in the prototype Portable Electronic flight strip because this introduces the larger question of how to best represent historical flight data with an electronic FPS system. This question is outside the scope of the evaluation portion of this thesis and is left for subsequent research. Similarly, "indication that an aircraft is unable to receive an electronic pre-departure clearance" is not included because this introduces the larger question of data integrity and communications network reliability, which is also outside the scope of this thesis. However, it is conceivable that a visual alert could be added to the Portable Electronic FPS display which would notify controllers that a departure clearance needs to be issued verbally for a particular aircraft.

“Indication that an aircraft has waived a wake-turbulence restriction” is not included in the prototype Portable Electronic FPS because it was known this function would not be needed in the FPS evaluation described in Chapter 4. However, a soft “Waive Wake” button could be added to the clearance buttons which would appear once the aircraft has taxied to the runway threshold. “Highlighting of EDCT times” is not included in the prototype because it is assumed this functionality would be superseded by the Departure Planner advisories. Finally, “indication of the last aircraft to depart before a runway configuration change” was not included in the prototype because it was known that this feature would not be needed for the FPS evaluation. However, the Departure Planner could easily find the last aircraft to depart before a runway configuration change and display this information on the FPS.

CHAPTER 4: EVALUATION OF A PROTOTYPE PORTABLE ELECTRONIC FLIGHT PROGRESS STRIP SYSTEM

4.1 Motivation

Broadly, the goals of the Portable Electronic FPS evaluation are to explore the usability of such a system in comparison to paper flight strips. Through subjective evaluations and objective performance measures of typical ATC tasks, variations of the Portable Electronic FPS are tested to identify the features which are most useful and to identify aspects of the system which warrant further research. Specifically, the evaluation is motivated by the following questions:

- Is the Portable Electronic FPS an appropriate interface for Departure Planner advisories? How does the display of departure advisories on the individual electronic FPS affect a controller's ability to efficiently sequence departure aircraft? How do these advisories affect a controller's ability to visually observe airport surface traffic? Do users prefer having departure advisories displayed on the individual FPS, or is it sufficient to display these advisories only on the Management Interface?

- How important is the portability of the Portable Electronic FPS? How does the portability of the Portable Electronic FPS affect a controller's ability to efficiently sequence departure aircraft? How does the portability affect a controller's ability to visually observe airport surface traffic? Do users prefer the Portable Electronic FPS over a system where flight strip movement is restricted?

- How useful are the interface features of the Portable Electronic FPS, such as clearance buttons and the color-coded aircraft departure status indication? Do these features affect a controller's ability to efficiently sequence departure aircraft? Do these features affect a controller's ability to visually observe airport surface traffic? Do users prefer these features over the interaction mechanisms of a traditional paper FPS?

4.2 Methodology

4.2.1 Overview

A part-task, human-in-the-loop simulation of the pushback/ground controller position in an airport air traffic control tower has been developed to explore the questions posed in Section 4.1 . The air traffic controller tasks modeled in the simulation are: sequencing aircraft for departures, issuing pushback and taxi clearances via voice communication, using flight progress strips, and visually observing airport surface traffic.

Figure 4.1 shows the experiment structure used to model the air traffic controller tasks and simulate a control tower environment. The test subject is given flight progress strips for a set of 10 departure aircraft, as well as the Management Interface. The flight progress strips will either be paper or a variant of the prototype Portable Electronic FPS, depending on the test scenario. The test subject must use the information on the FPSs and Management Interface in order to construct an optimal departure sequence. The optimal sequence is carried out by issuing voice clearances to the aircraft. When these clearances are issued, the test subject must perform some required annotations on the flight strips. The test administrator acts as a pseudopilot for all the aircraft, verbally requesting and responding to clearances.

To simulate the visual environment of the control tower so that test subjects can see the results of their clearances, a two-dimensional plan-view of a fictional airport is also displayed for the test subject. This Out-The-Window view shows portions of the airport terminal, gate, ramp, taxiway, and runway systems. As aircraft are given clearances, they are shown pushing back form their gates and taxiing toward the runway, their movement controlled by the test administrator. Additionally, other aircraft are intermittently shown taxiing in ways which create runway incursions. The secondary task of the test subject (aside from sequencing departures, and the associated tasks of FPS annotation and verbal clearance issuance) is to stop these runway incursions whenever they are observed. Each test scenario begins with all 10 departure aircraft at their gates and ends when all 10 aircraft have taxied to the departure runway. Test subjects participate in multiple scenarios in order to evaluate the different FPS variants under consideration.

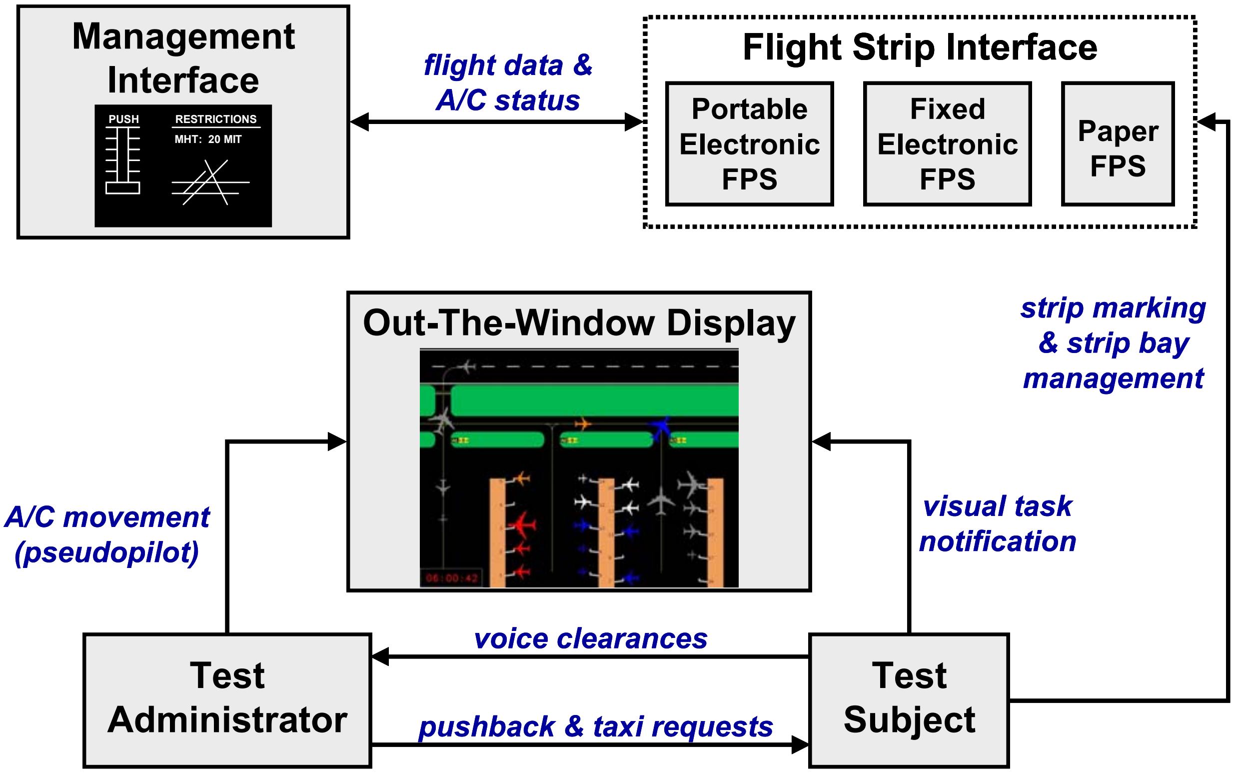

Figure 4.1: Block Diagram of FPS Experiment

4.2.2 Test Setup

Figure 4.2 and Figure 4.3 show photographs of the experimental setup in the test environment. The test subject stands in front of a table on which the flight progress strips are placed. The Management Interface is displayed on a 19-inch computer monitor, which sits on a stand behind the table. A keyboard is placed on the table, to the left of the flight progress strips. The test subject uses the spacebar on this keyboard to register reactions to runway incursion events. The Out-The-Window view is projected onto a 6-foot diagonal screen approximately 10 feet in front of the test subject. The test administrator sits to the side, controlling the movement of aircraft on the projected Out-The-Window view with a separate monitor showing the same Out-The-Window display. The lighting in the test environment is constant for every test subject and every test scenario, and is controlled such that it is dark enough to easily see the projected Out-The-

Window view and the electronic FPS displays, yet light enough to easily read the information on the paper FPSs.

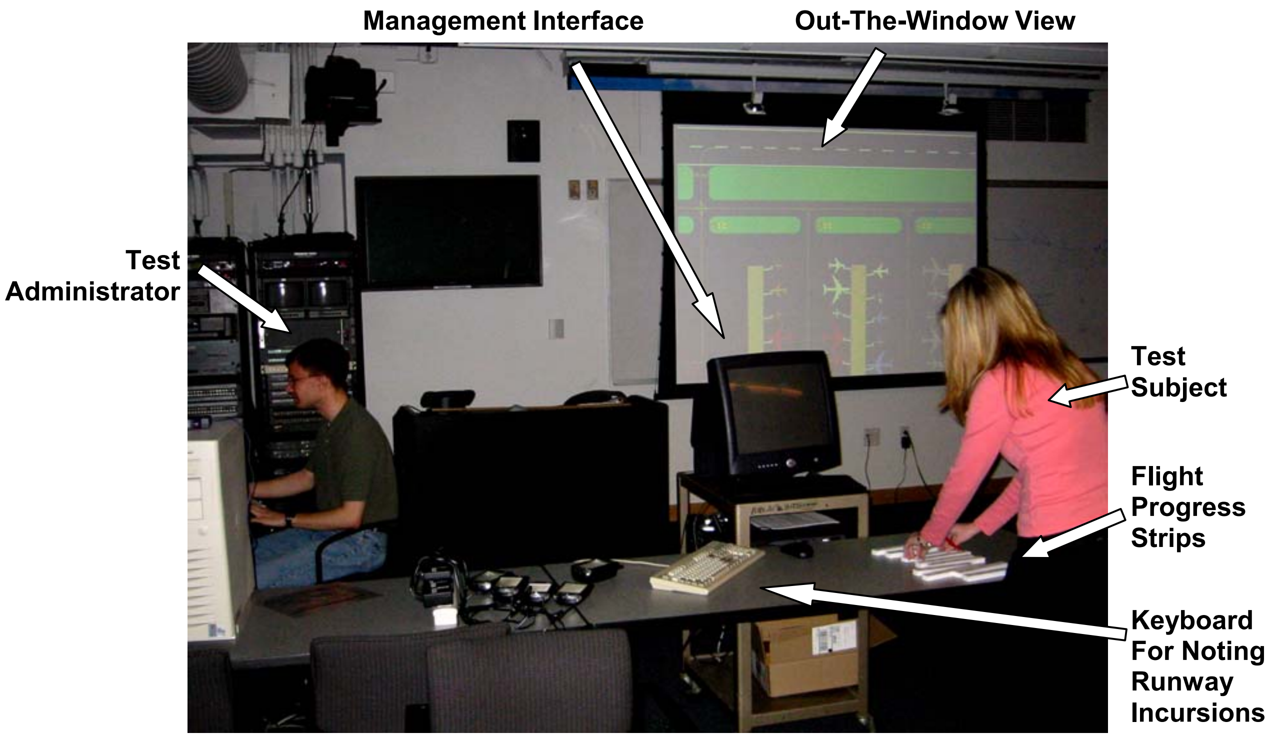

Figure 4.2: Photograph of Test Setup (Paper FPS)

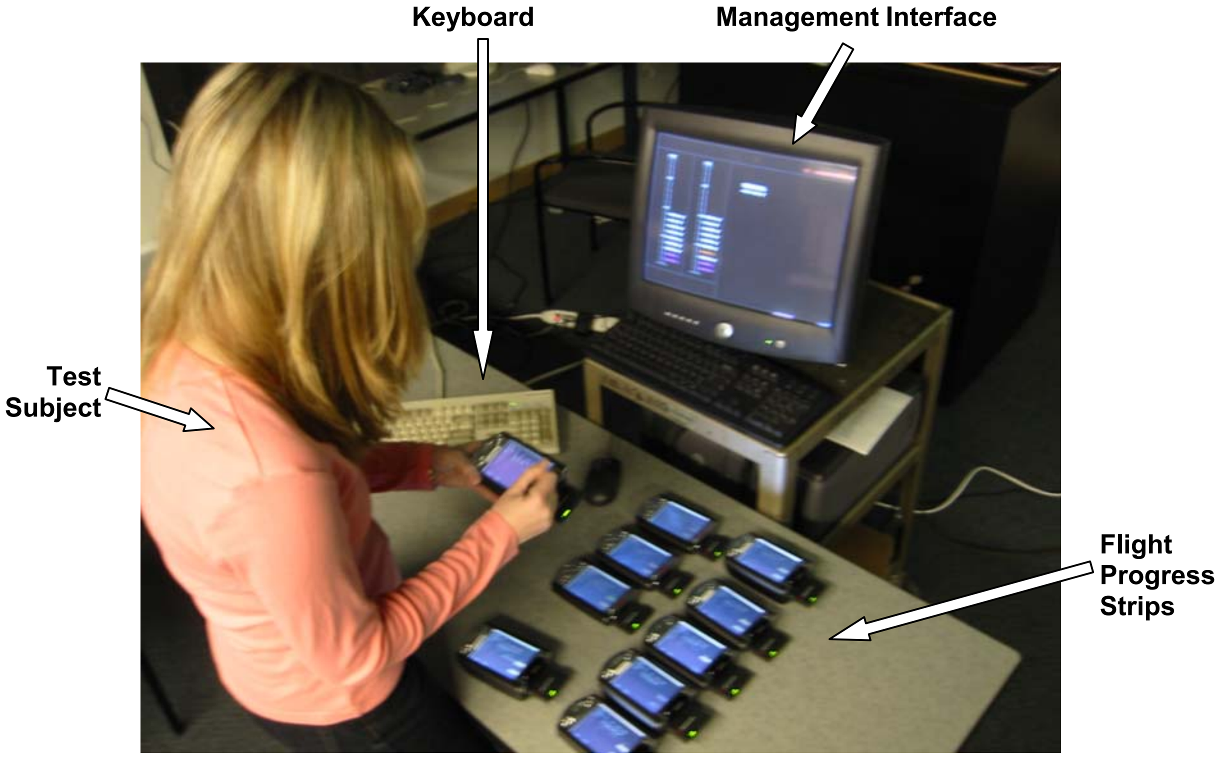

Figure 4.3: Close-Up Photograph of Test Setup (Portable Electronic FPS)

4.2.3 The Out-The-Window View

Figure 4.4 shows the Out-The-Window view in detail. The bottom half of the display contains three terminal concourses with 20 gates split between two alleys. The gate numbers are shown in black letters next to each gate. The top half of the display shows a simple taxiway and runway system. In the lower-left corner of the display is a clock, used for recording pushback times on the paper FPS.

The aircraft on the display are of only three different models, which correspond to three different wake turbulence weight classes (heavy, large, and small). All heavy aircraft look roughly like a Boeing 747, all large aircraft look roughly like a Boeing 737, and all small aircraft look roughly like a Beech 1900. In addition, the aircraft are color-coded by airline. Five different airlines are used in the experiment.

The following four different types of aircraft are shown on the Out-The-Window view:

- Departure Aircraft: Each scenario contains 10 of these aircraft. The test subject is given an FPS for each of these aircraft in order to create an optimal departure sequence. These aircraft are initially at their departure gates at the start of each scenario. The test administrator acts as pseudopilot for these aircraft, requesting and responding to pushback and taxi clearances from the test subject. The test administrator also controls the movement of these aircraft on the display via mouse commands such that each aircraft will push from the gate and taxi to the runway by the end of the scenario. The departure aircraft all follow standard taxipaths: A2 to B (taxiing to the right on B) for aircraft with gates in the left alley, and A3 to B (taxiing to the right on B) for aircraft in the right alley. Aircraft all taxi at the same constant speed, and may be stopped at any point along their taxipath. Each scenario contains three heavy, four large, and three small departure aircraft. There are two departure aircraft for each airline.
- Visual Task Aircraft: These aircraft appear at the left edge of taxiway B, taxi along B to taxiway A1, and then turn right on A1 toward the ramp area or left on A1 toward the runway. Those aircraft that turn left, upon reaching the runway, turn left again and taxi off the left edge of the screen. Those aircraft that turn right eventually taxi off the bottom edge of the screen. All aircraft are supposed to turn right at A1 toward the ramp area. Those aircraft that turn left at A1 create a runway incursion. Whenever the test subject sees a runway incursion, he or she must press the spacebar on the provided keyboard. This will cause the aircraft creating the incursion to disappear from the display. The

incursion aircraft appear according to a Poisson process with a 10 second mean interarrival time. The aircraft weight class (heavy, large, or small) is randomly chosen such that each weight class appears with equal probability. Aircraft turn right or left at A1 with equal probability according to a Bernoulli trial sequence. This sequence of visual task aircraft is generated prior to the experiment and is the same for all scenarios and for all test subjects.

- Runway Aircraft: Every 30 seconds, an aircraft appears at the right edge of the runway, decelerates while taxiing toward the left edge of the display, and disappears off the left end of the runway. The aircraft model is randomly chosen such that each weight class appears with equal probability. This sequence is generated prior to the experiment and is the same for all scenarios and for all test subjects. These aircraft cannot be controlled by the test subject or the test administrator. The presence or absence of an aircraft on the runway has no bearing on the calculation of test subject performance for the secondary task of runway incursion detection.
- Dummy Aircraft: Each scenario contains 10 of these aircraft. These aircraft remain at the gate for the duration of the scenario. They cannot be controlled by the test subject or the test administrator. Each scenario contains three heavy, four large, and three small dummy aircraft. There are between one and three dummy aircraft for each airline.

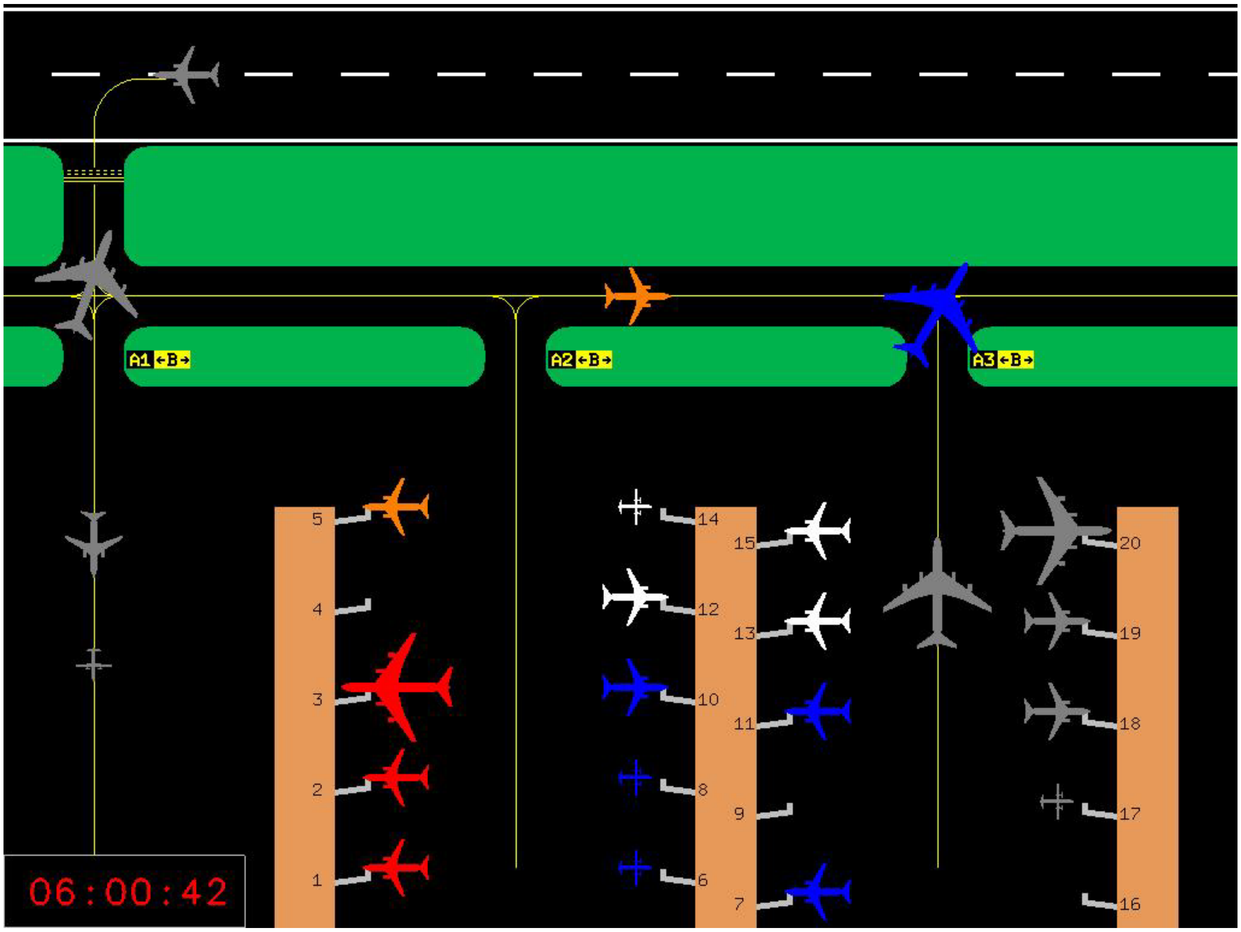

Figure 4.4: Out-The-Window View

4.2.4 Sequencing Task Goals and Constraints

The goal of the departure sequencing task is for the test subject to issue pushback and taxi clearances to achieve the maximum departure throughput available. Stated another way, the controller should create a departure sequence such that the minimum amount of time passes from the first aircraft takeoff to the last aircraft takeoff in each scenario. The interdeparture delay times between subsequent aircraft are determined by three factors: wake turbulence restrictions, downstream constraints, and actual runway threshold arrival times (the time the aircraft reaches the runway end after taxiing from its gate).

For the purposes of this experiment, interdeparture delay times due to wake turbulence requirements are given in Table 4.1. From this table, it can be seen that in the absence of other constraints, the most efficient departure sequence is achieved by grouping heavy aircraft together.

Table 4.1: Interdeparture Wake Turbulence Delay (sec) [de Neufville, 2003]

		Trailing Aircraft		
		Heavy	*Large*	*Small*
Leading Aircraft	*Heavy*	90	120	120
	Large	60	60	60
	Small	45	45	45

For each scenario, two aircraft are given a five-minute, minutes-in-trail restriction over a downstream waypoint on their flight plans. These two aircraft must always takeoff at least five minutes apart. If the wake turbulence interdeparture times for the two restricted aircraft (and the aircraft which depart between them) do not total at least five minutes, the trailing restricted aircraft—and all subsequent aircraft—are assumed to accrue a delay at the runway threshold until five minutes has elapsed.

If the actual runway threshold arrival times are spaced greater than the times given by the interdeparture wake turbulence delays or the downstream restriction, then these values are used to calculate the departure throughput. For this experiment, the time of arrival at the runway threshold is calculated as the time each aircraft passes the A3-B taxiway intersection (see Figure 4.4). At this point, the departure sequence is fixed, as aircraft all taxi at the same speed and there is no means for aircraft to pass each other on the taxiway. For this reason, the test subject must construct an efficient departure sequence via pushback and taxi clearance timing, taking into account differences in taxipath length and blocking conditions caused by aircraft gate locations.

In addition to the wake turbulence delays and downstream restrictions, an additional constraint is added to ensure that the sequence created by the test subject retains a degree of fairness. This "shift" constraint prescribes that aircraft may be shifted out of their proposed departure time sequence by a maximum of two positions. If this constraint is violated for any aircraft, the departure sequence is considered invalid. This constraint does not apply to the two aircraft in each scenario with a minutes-in-trail restriction; these aircraft can be placed anywhere in the departure sequence.

4.2.5 Independent Variables

The independent variables for the experiment are the types of FPS systems used by the test subject. Five different scenarios are tested, for five different FPS system formats. The differences between each scenario are listed below, along with the names which will subsequently be used to identify each scenario:

- Paper FPS: The test subject uses mock paper flight strips. These flight strips consist of a piece of paper mounted with a repositionable spray adhesive onto a piece of 1 cm. thick, foam-core tagboard. The mock paper flight strips have the same form factor, layout, and information content as an actual departure FPS. However, there is no strip board provided. Therefore, FPS manipulation is accomplished by picking up the flight strips or sliding them around the table in front of the test subject. The paper flight strips are initially ordered according to their proposed departure time, which is the same order that aircraft request pushback clearance during the scenario. The test subjects are required to perform the following annotations on the paper FPS: underlining of the restricted waypoint/airport on the route of flight field for any aircraft with a downstream restriction, writing the ATIS phonetic letter identifier when an aircraft calls ready for pushback, writing the time an aircraft requests pushback, and writing the actual time of pushback for any aircraft which are delayed at the gate. For this scenario, the Management Interface only shows a list of downstream restrictions. The departure queues and airport surface traffic display are not shown.

- Portable Electronic FPS with Advisories: The test subject uses 10 Portable Electronic FPSs. The flight strips show suggested pushback and taxi sequence positions as well as downstream restriction information for any applicable aircraft. The Management Interface shows both a list of downstream restrictions and sequence-based virtual pushback and taxi queues, but does not show an airport surface traffic map. Test Subjects are required to perform the following FPS annotations: tap the "ATIS" button when an aircraft indicates it has the current ATIS information, tap the "Call Ready" button when an aircraft requests pushback, tap the "Clear Push" button when the aircraft is cleared for pushback, and tap the "Taxi" button when the aircraft is cleared to taxi. For this scenario, the flight strips are initially positioned according to the optimal departure sequence. However, aircraft still request pushback according to their proposed departure time.
- Portable Electronic FPS with Advisories only on Management Interface: This scenario is identical to the "Portable Electronic FPS with Advisories" scenario, except the Portable

Electronic FPS does not display any sequence advisories or downstream restriction information. In addition, the clearance buttons on the FPS are not color-coded to indicate when an aircraft is first in sequence. Rather, they have a black background.

- Portable Electronic FPS without Advisories: This scenario is identical to the "Portable Electronic FPS with Advisories only on Management Interface" scenario, except the Management Interface does not display any departure queues; it only shows a listing of downstream restrictions. For this scenario, the flight strips are initially positioned according to their proposed departure time.
- Fixed Electronic FPS without Advisories: This scenario is identical to the "Portable Electronic FPS without Advisories" scenario, but with the stipulation that the test subject cannot pick up any FPS off of the table on which they are placed. However, they may still slide the electronic FPS around the table. This restriction is designed to emulate a fixed, touch-screen based FPS display.

The experiment is designed in a repeated-measures format, such that each test subject completes all five scenarios. In order to compensate for practice and fatigue effects, the order in which the five scenarios are presented to each subject varies according to a balanced Latin Square design [Myers, 2003]. Because there are an odd number of scenarios, there must be at least twice the number of test subjects as test scenarios to complete the balanced Latin Square. Thus, a minimum of 10 test subjects are required for the experiment.

Apart from differences in decision support and FPS format, each scenario is designed to be of approximately the same difficulty in terms of both the sequencing task and the runway incursion detection task. Each scenario contains roughly the same number of valid departure sequences and optimal departure sequences, according to the constraints and goals described in Section 4.2.4 . Quantitatively, there are 3628800 possible ways to order the 10 departure aircraft in each scenario. For the sequences chosen for the five scenarios, between 5744 and 8560 of these permutations are valid according to the "shift" constraint, and between 16 and 56 of these valid permutations produce a sequence with the maximum departure throughput (minimum total runway occupancy time). In addition, the test subject is presented with the same series of runway incursion aircraft for each scenario.

The data from these five scenarios will be compared in a pair-wise manner in order to explore the questions posed in Section 4.1 . The three pairs compared are shown below in Table 4.2.

Table 4.2: Pair-Wise Scenario Comparisons

Compared Scenarios		
Portable Electronic FPS with Advisories	Vs.	Portable Electronic FPS with Advisories only on Management Interface
Portable Electronic FPS without Advisories	Vs.	Fixed Electronic FPS without Advisories
Portable Electronic FPS without Advisories	Vs.	Paper FPS

4.2.6 Dependent Variables

For each scenario, quantitative dependent variables are measured to assess controller performance on the sequencing task and on the runway incursion detection task. Questionnaires are also used to record subjective data.

4.2.6.1 Sequencing Task

For each departure aircraft in each scenario, the time that aircraft enters a final runway sequence is recorded. For this experiment, the final in-sequence time is defined as the time that an aircraft crosses the A3-B taxiway intersection on the Out-The-Window display, as there is no opportunity for resequencing after this point and all aircraft taxi at the same constant speed.

The final runway in-sequence times are used to compute the total runway occupancy time, defined as the time elapsed between the first aircraft departure and the last (tenth) aircraft departure, according to the rules established in Section 4.2.4 . The metric to judge performance in the sequencing task is the difference between the total runway occupancy time for the test subject's sequence and that for the optimal sequence, hereafter called the Time-Over-Optimal. An absolute, rather than relative, comparison is used because different scenarios have different optimal runway occupancy times due to the initial aircraft sequences. Suboptimal performance on the sequencing task adds runway occupancy time in an absolute rather than relative manner.

For the Time-Over-Optimal data, mean values across test subjects are reported for each scenario. To determine significance between the Time-Over-Optimal values, a two-sided Mann-Whitney test will be used for the three pairs of compared scenarios listed in Section 4.2.5 [Brase, 1999]. The Mann-Whitney test is used instead of the Student's t-test because it is not assumed that Time-Over-Optimal data is normally distributed.

In addition to calculating the total runway occupancy time, for each scenario it is noted whether or not the test subject constructed a valid sequence according to the "shift" constraint.

4.2.6.2 Runway Incursion Task

One of three possible events is recorded each time the test subject presses the spacebar to react to a runway incursion. These events are named according to alerting system conventions [Kuchar, 1996].

- Correct Detection: A Correct Detection occurs if the spacebar is pressed when a Visual Task Aircraft is displayed on the Out-The-Window view which has turned left at taxiway A1 toward the runway. The elapsed time from the instant the aircraft starts its turn at A1 to the time the test subject presses the spacebar is measured, and is hereafter referred to as the Reaction Time. When the spacebar is pressed, the incurring aircraft disappears from the display.
- Missed Detection: A Missed Detection occurs if a Visual Task aircraft turns left at taxiway A1, turns left at the runway, and taxies off the screen without the test subject reacting by pressing the spacebar. For the purposes of Reaction Time calculations, a Missed Detection is given a Reaction Time of 18 seconds, the total time required for an aircraft to taxi off the screen once it has started its turn at A1.
- False Alarm: A False Alarm occurs if the spacebar is pressed when no incurring aircraft are present on the Out-The-Window view. False Alarm events are not used in the calculation of Reaction Time, but are used for qualitative results only. Test subjects are instructed not to "game" the system by continuously pressing the spacebar because False Alarm events are recorded.

For this experiment, Correct Rejections (aircraft correctly identified as not creating a runway incursion) are not recorded. Also, Late Detections (aircraft for which the controller reacts too late to avoid an incursion) and Induced Collisons (aircraft which create an incursion but would not have in the absence of a controller reaction) have no meaning for this experiment.

Correct Detection and Missed Detection Reaction Time is the performance metric for the runway incursion task. Reaction Time mean values will be computed for each scenario for each test subject. This averaging is done so that scenarios which experienced a higher number of Visual Task Aircraft (i.e., those that took longer to complete) are not weighted more heavily than scenarios which experienced a lower number of Visual Task Aircraft. Reaction Time mean values across test subjects are reported for each scenario. To determine significance between the Reaction Time values, a two-sided Mann-Whitney test will be used for the three pairs of compared scenarios listed in Section 4.2.5 [Brase, 1999]. The Mann-Whitney test is used instead of the Student's t-test because it is not assumed that Reaction Time data is normally distributed.

4.2.6.3 Subjective Evaluations

After each of the five experiment scenarios, test subjects are given a questionnaire to complete. This questionnaire asks the following:

- *Overall, how difficult was this scenario?* (1 to 5 ranking, with descriptions for each number ranging from "Very Easy: Sequencing task and runway-incursion tasks completed successfully with a large amount of idle time" to "Very Difficult: Runway-incursion task performance very much degraded due to effort required for sequencing."

- *Why was this scenario easy or difficult?* (Free response)
- *Did you have enough time to look at the Out-The-Window display?* (Yes/No choice)

At the conclusion of the experiment, after all five scenarios are completed, test subjects are given another questionnaire to complete. This questionnaire asks the following:

- *Age and sex?*
- *Air traffic controller experience?* (years)
- *Pilot experience?* (total hours and ratings)
- *Personal Digital Assistant experience (PalmPilot, Pocket PC, etc.)?* (choice of None/General/Extensive)
- *Rank each flight strip format from 1 (favorite) to 5 (least favorite).*
- *Why did you choose this order?* (free response)
- *What did you like most about the electronic flight strips?* (free response)
- *What did you like least about the electronic flight strips?* (free response)
- *Did you prefer having departure advisories on the individual electronic flight strips in addition to the management interface? Why or why not?* (free response)
- *Did the strip movement restriction during the "Fixed Electronic Flight Strip" scenario affect your performance during that scenario? Why or why not?* (free response)
- *Any other comments or suggestions about the electronic flight strips or the experiment itself?* (free response)

4.2.7 Experimental Protocol

All test subjects began the experiment by signing an informed consent statement in accordance with the policies of the Massachusetts Institute of Technology Committee On the Use of Humans as Experimental Subjects. The test subjects were then given as much time as needed (all subjects took between 20 and 40 minutes) to read an introductory tutorial document (see Appendix). The tutorial document contained the following information:

- An introduction to the goals of the experiment and the basic test setup
- An explanation of the information content and interaction mechanisms of the Portable Electronic FPS, the Management Interface, and the paper FPS
- A description of the Out-The-Window view, including displayed aircraft types, gate locations, airline color-coding, and taxiway structure
- An explanation of the five different experiment scenarios, including test subject tasks and the duties of the test administrator
- A description of the departure sequence goals and constraints
- Examples of annotations and verbal clearances for both paper FPS and electronic FPS scenarios
- A summary of the salient points of the document, including: a reiteration of the primary and secondary tasks, a listing of the required FPS annotations, and hints for achieving the optimal departure sequence

Subjects were welcome to ask questions of the test administrator while they were reading the document. When they were finished with the tutorial document, the test administrator gave a verbal summary of the important points in the tutorial document. This verbal summary included: an illustration of the required FPS annotations, an illustration of the interaction between the Portable Electronic FPS and the Management Interface, a description of the capabilities and behavior of the pushback and taxi sequence advisories, and a reminder to pay attention to gate location such that aircraft are not trapped behind other aircraft in the alleyways.

After the verbal briefing, four practice scenarios were completed to further familiarize the test subjects with the experiment before data recording began. Each test subject completed the practice scenarios in the following order: "Paper FPS," "Portable Electronic FPS with Advisories," "Portable Electronic FPS with Advisories only on Management Interface," and "Portable Electronic FPS without Advisories." The "Paper FPS" scenario was carried to completion, ending after all ten aircraft were given clearance to taxi to the runway. The three electronic FPS scenarios were only partially-completed, ending after 6-8 aircraft had been given taxi clearance. This was done to devote a relatively equal amount of time for practice with the paper FPS and the electronic FPS. The "Fixed Electronic FPS without Advisories" scenario was not practiced because this scenario contains the same decision aids and annotation requirements as the "Portable Electronic FPS without Advisories" scenario. Subjects were again welcome to ask questions at any point during the practice scenarios.

After the practice scenarios, the data-recording scenarios began, presented in the order prescribed by the balanced Latin Square discussed in Section 4.2.5 . At the start of each scenario, test subjects were given approximately five seconds to assess the given departure sequence before aircraft would start requesting pushback, in the order of their proposed departure times.

Pushback requests occurred approximately every 20 seconds (this varied more toward the end of each scenario as the timing of verbal requests depended on the timing and amount of verbal clearances the test subject was issuing). After each scenario, the test subject completed a Post-Scenario Questionnaire. At the conclusion of the experiment, after completing all five scenarios, the subject completed a Post-Experiment Questionnaire.

4.3 Results

4.3.1 Test Subject Demographics

Ten subjects completed the experiment. They were between the ages of 22 and 30. Six subjects were male and four were female. All subjects were graduate students at the Massachusetts Institute of Technology, either with air transportation research experience or pilot experience. The four pilots had each accumulated between 30 and 170 flight hours and held either student or private pilot ratings. None of the subjects were professional air traffic controllers.

4.3.2 Test Duration

All subjects took between 20 and 40 minutes to read the introductory tutorial document. The practice scenarios took approximately 30 minutes to complete. The data-recording scenarios, including breaks and time to complete questionnaires, took approximately one hour to complete. Total experiment duration for each test subject was approximately two hours. Individual scenario duration ranged from 4 minutes, 37 seconds to 7 minutes, 5 seconds from the time the Out-The-Window view clock was started until the last taxi clearance command was given.

4.3.3 General Objective Results

The objective results for the primary, departure sequencing task performance metric are shown in Table 4.3. This table lists the Time-Over-Optimal runway occupancy values for each test scenario, averaged across all test participants. For reference, optimal total runway occupancy times were approximately 550 to 650 seconds.

Table 4.3: Mean Time-Over-Optimal Runway Occupancy Values by Scenario

Scenario	**Mean Time-Over-Optimal (sec)**	**Standard Deviation**
Paper FPS	88.50	71.57
Portable Electronic FPS with Advisories	126.00	71.83
Portable Electronic FPS with Advisories only on Management Interface	42.00	20.98
Portable Electronic FPS without Advisories	100.50	106.08
Fixed Electronic FPS without Advisories	136.50	104.99

The objective results for the secondary, runway incursion task performance metric are shown in Table 4.4. This table lists Reaction Time values for each test scenario, averaged for individual scenarios (a total of 50 scenarios) then averaged across all test participants. These values are bounded between zero and 18 seconds.

Table 4.4: Mean Runway Incursion Reaction Time Values by Scenario

Scenario	Mean Reaction Time (sec)	Standard Deviation
Paper FPS	9.60	5.66
Portable Electronic FPS with Advisories	9.74	5.22
Portable Electronic FPS with Advisories only on Management Interface	9.95	5.56
Portable Electronic FPS without Advisories	10.42	4.82
Fixed Electronic FPS without Advisories	8.88	5.07

Table 4.5 shows the mean number of False Alarms registered during each scenario. Test subjects were instructed not to decrease their runway incursion Reaction Times at the expense of increasing their False Alarm rate. From the data, it appears this admonition was successful, as there was, on average, less than one false alarm per scenario.

Table 4.5: Mean Number of False Alarms by Scenario

Scenario	Mean False Alarms (count)	Standard Deviation
Paper FPS	0.70	0.67
Portable Electronic FPS with Advisories	0.20	0.63
Portable Electronic FPS with Advisories only on Management Interface	0.60	0.70
Portable Electronic FPS without Advisories	0.40	0.52
Fixed Electronic FPS without Advisories	0.30	0.48

4.3.4 Pair-wise Objective Results

The objective results for mean Time-Over-Optimal and mean Reaction Time are compared in the pair-wise fashion described in Section 4.2.5 . A two-sided Mann-Whitney test at a five percent level of significance is applied to each of the pairs to determine if the variations in FPS format produce significant differences in controller performance. In order to reject the null hypothesis that the different FPS formats do not produce significant differences in task performance, the z-statistic calculated from the Mann-Whitney test must be larger than the critical z-value. Table 4.6 shows the pair-wise results for sequencing task performance, and Table 4.1 shows the pair-wise results for the runway incursion task performance. For each comparison, the scenario with the better test subject performance is italicized and marked with an asterisk. From these tables, it can be seen that the only case in which a significant difference in performance is observed is that for the "Portable Electronic FPS with Advisories" vs. the "Portable Electronic FPS with Advisories only on Management Interface." In this case, test subjects performed significantly better on the sequencing task when only given departure advisories on the Management Interface.

Table 4.6: Sequencing Task Performance, Two-sided Mann-Whitney Test, 5% Level of Significance

Compared Scenarios			z	$z_{critical}$	Significant?
Portable Electronic FPS with Advisories	Vs.	**Portable Electronic FPS with Advisories only on Management Interface*	2.87	1.96	Yes
**Portable Electronic FPS without Advisories*	Vs.	Fixed Electronic FPS without Advisories	1.13	1.96	No
Portable Electronic FPS without Advisories	Vs.	**Paper FPS*	0.30	1.96	No

Table 4.7: Runway Incursion Task Performance, Two-sided Mann-Whitney Test, 5% Level of Significance

Compared Scenarios			z	$z_{critical}$	Significant?
**Portable Electronic FPS with Advisories*	Vs.	Portable Electronic FPS with Advisories only on Management Interface	0.23	1.96	No
Portable Electronic FPS without Advisories	Vs.	**Fixed Electronic FPS without Advisories*	0.23	1.96	No
Portable Electronic FPS without Advisories	Vs.	**Paper FPS*	0.22	1.96	No

4.3.5 General Subjective Results

Quantitative results are tabulated for two subjective measures: scenario difficulty and FPS format preference. The scenario difficulty ratings are recorded by the test subject after each scenario. The FPS preference rankings are recorded by the test subject at the conclusion of the experiment, after completing all five scenarios. Table 4.8 summarizes the subjective difficulty ratings for each scenario, averaged across all 10 test subjects. Table 4.9 summarizes the subjective preference ratings for each scenario, averaged across all 10 test subjects. On average, test subjects rated the “Portable Electronic FPS with Advisories” scenario easiest, and the “Paper FPS” scenario most difficult. On average, test subjects rated the “Portable Electronic FPS with Advisories” as the most preferred FPS format, and the “Fixed Electronic FPS without Advisories” as the least preferred FPS format. Overall, nine out of ten test subjects preferred some variation of the electronic FPS over the paper FPS.

Table 4.8: Mean Subjective Difficulty Ratings by Scenario

Scenario	**Mean Difficulty (1 to 5 scale, 1 = easiest)**	**Standard Deviation**
Paper FPS	4.05	0.96
Portable Electronic FPS with Advisories	2.70	0.95
Portable Electronic FPS with Advisories only on Management Interface	2.90	1.10
Portable Electronic FPS without Advisories	3.60	0.84
Fixed Electronic FPS without Advisories	3.55	1.12

Table 4.9: Mean Subjective Preference Rankings by Scenario

Scenario	**Mean Preference (1 to 5 ranking, 1 = favorite)**	**Standard Deviation**
Paper FPS	4.00	1.49
Portable Electronic FPS with Advisories	1.55	1.07
Portable Electronic FPS with Advisories only on Management Interface	2.35	1.00
Portable Electronic FPS without Advisories	3.00	0.94
Fixed Electronic FPS without Advisories	4.10	0.74

4.3.6 Pair-wise Subjective Results

4.3.6.1 Portable Electronic FPS with Advisories vs. Portable Electronic FPS with Advisories only on Management Interface

On a 1 to 5 scale, with 1 being the most preferred, test subjects gave the "Portable Electronic FPS with Advisories" a mean rank of 1.55 and the "Portable Electronic FPS with Advisories only on Management Interface" a mean rank of 2.35. Seven of ten test subjects preferred the "Portable Electronic FPS with Advisories" to the "Portable Electronic FPS with Advisories only on Management Interface." However, only 3 subjects indicated in the free response that having the departure advisories on the individual Portable Electronic FPS helped them. Two of these test subjects stated that the reason they preferred advisories on the FPS was that it reduced the number of places they needed to look from three (Out-The-Window, FPSs, Management Interface) to two (Out-The-Window and FPSs). Three subjects indicated that they only used the advisories on the Management Interface and never looked at the advisories on the individual flight strips. Four subjects stated that they didn't use the advisories at all, and that they just used the initial order of the strips, as the flight strips were pre-ordered according to the optimal departure sequence for both the "Portable Electronic FPS with Advisories" and the "Portable Electronic FPS with Advisories only on Management Interface" scenarios.

4.3.6.2 Portable Electronic FPS without Advisories vs. Fixed Electronic FPS without Advisories

On a 1 to 5 scale, with 1 being the most preferred, test subjects gave the "Portable Electronic FPS without Advisories" a mean rank of 3 and the "Fixed Electronic FPS without Advisories" a mean rank of 4.1. All ten test subjects preferred the “Portable Electronic FPS without Advisories” over the “Fixed Electronic FPS without Advisories.” However, only 4 test subjects indicated that the restricted movement during the “Fixed Electronic FPS without Advisories” scenario affected their performance. The other 6 subjects stated either that they still had room to slide the Portable Electronic FPS on the table, or that they didn’t move the Portable Electronic FPSs during the experiment.

4.3.6.3 Portable Electronic FPS without Advisories vs. Paper FPS

On a 1 to 5 scale, with 1 being the most preferred, test subjects gave the “Portable Electronic FPS without Advisories” a mean rank of 3, and the “Paper FPS” a mean rank of 4. Seven out of ten test subjects preferred the “Portable Electronic FPS without Advisories” to the “Paper FPS.” Seven out of 10 subjects indicated in free responses that they liked using the clearance buttons on the Portable Electronic FPS instead of writing times on the Paper FPS. Reasons cited for preferring the Paper FPS included easier to read text, easier manipulation due to their lighter weight and smaller size, and the ability to align the Paper FPSs in one column instead of two, as was required of the Portable Electronic FPSs due to space limitations in the test environment.

4.3.7 Practice Effects

Practice effects were observed according to several different measures. Figure 4.5 shows the Time-Over-Optimal runway occupancy times averaged over all ten test subjects for each scenario, in the order that the scenario was presented to the test subject (starting with scenario A and ending with scenario E). Because a balanced Latin Square design was used, each FPS format appeared twice in every presentation position. Even after completing the practice scenarios, test subject performance on the sequencing task monotonically improved as the subjects gained more experience during the data-recording scenarios. Similar behavior is observed for performance in the incursion detection task and the test subjects' subjective difficulty ratings for each scenario. These behaviors are shown in Figure 4.6 and Figure 4.7, respectively. In contrast, the test subjects' subjective rankings of FPS format preference do not appear to have any strong correlation to the order in which the FPS formats were presented. This data is shown in Figure 4.8.

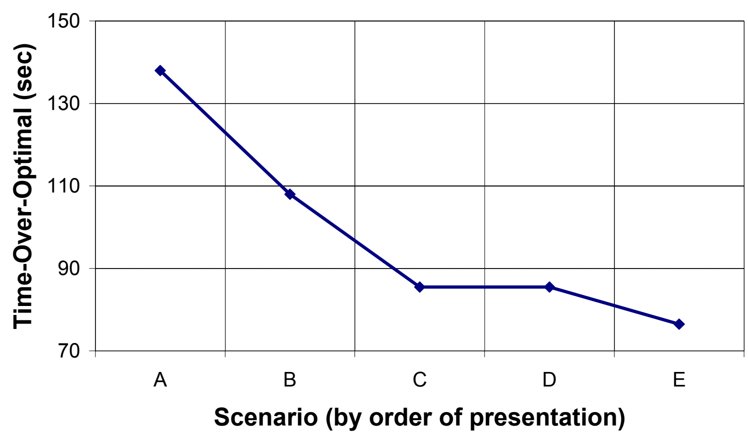

Figure 4.5: Practice Effects Observed in Departure Sequencing Task Performance

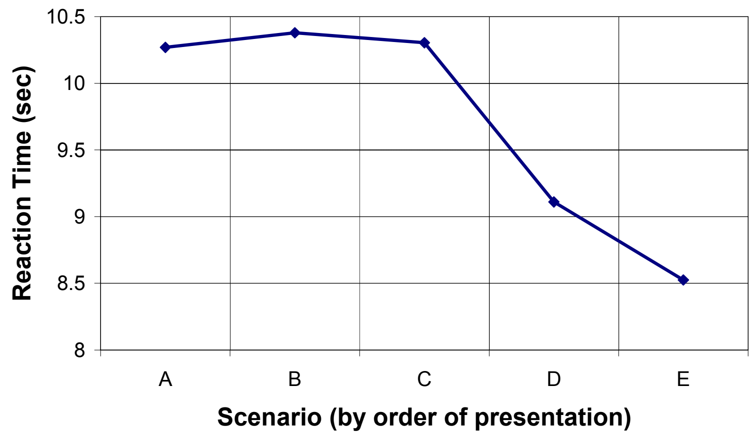

Figure 4.6: Practice Effects Observed in Incursion Detection Task Performance

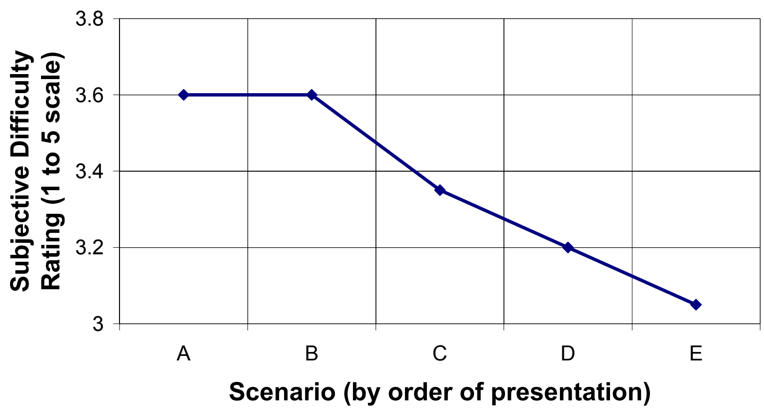

Figure 4.7: Practice Effects Observed in Subjective Scenario Difficulty Ratings

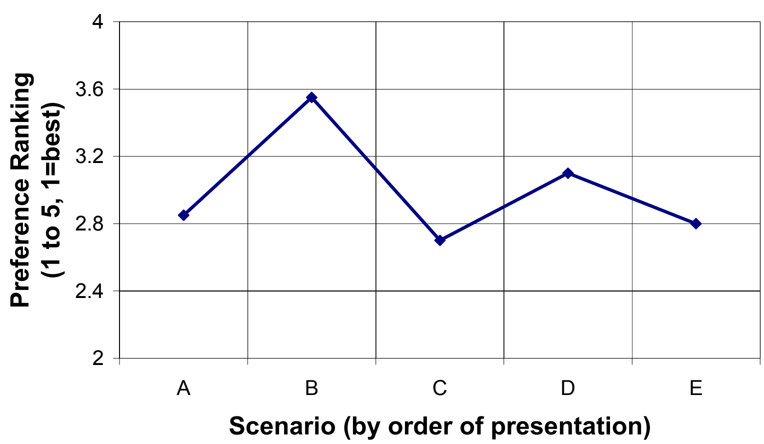

Figure 4.8: No Practice Effects Observed for Rankings of FPS Format Preference

CHAPTER 5: CONCLUSIONS

5.1 Discussion of Experimental Results

The experimental results have highlighted a number of promising features of the prototype Portable Electronic FPS and have shown areas which need further research. In addition, from the completion of the experiment much can be learned about what type of testing should be done in the future to elicit more substantive conclusions about the performance benefits of a Portable Electronic FPS system.

First, it is clear that the test subjects much preferred the electronic FPS over the paper FPS. In a direct comparison (where the electronic FPS contained the same information as the paper FPS), 70% of test subjects preferred the "Portable Electronic FPS without Advisories" to the "Paper FPS." And although it is difficult to compare different versions of the electronic FPS to the paper FPS, due to the differing amounts of information content and decision support, 90% of test subjects preferred at least one of the four electronic FPS formats over the paper FPS. In addition, the most often mentioned reason for preferring the electronic FPS over the paper FPS was the ability to use the clearance buttons, saving test subjects the time needed to write clearance times. This benefit may have been exaggerated due to the fast pace of the scenarios, however it still highlights an important capability of the electronic interface which paper is unable to emulate. Furthermore, the test subject free responses showed that most of the complaints about the Portable Electronic FPS were hardware-dependent. Such issues include the weight of the Pocket PC, the font size, the brightness of the display, and the form factor of the device. These limitations could be overcome through advances in display technology, discussed further in Section 5.2 .

On the issue of the appropriateness of displaying Departure Planner advisories on the individual electronic FPSs, the objective test results would seem to indicate that departure advisories are better left to a centralized display, as the only significant improvement in sequencing task performance was found for the "Portable Electronic FPS with Advisories only on Management Interface" in comparison to the "Portable Electronic FPS with Advisories." This is somewhat surprising, as the departure advisories on the individual FPSs only repeat the information shown on the Management Interface and many test subjects indicated they did not even use the advisories on the flight strips. However, it may be that the extra information confused the test subjects, and due to the learning effects apparent throughout the experiment, many test subjects never developed a successful method for integrating the advisories on the flight strips with the advisories on the Management Interface. It should also be noted that in the initial aircraft sequence for the "Portable Electronic FPS with Advisories only on Management Interface" scenario, the two aircraft with departure restrictions were placed further apart than in any other scenario. This could have improved performance on the sequencing task, although no test subjects indicated that the initial aircraft sequence for this scenario was particularly easy.

It is believed that the appropriateness of distributed departure advisories on the flight progress strips is closely tied to the fidelity of the advisories. To avoid having this experiment become excessively complex, the departure advisories were not adaptive. That is, they could not react to controller actions to recalculate the optimal sequence for remaining aircraft if test subjects deviated from the a priori optimal sequence. In addition, the optimal pushback and taxi queues did not account for taxipath length differences, merging taxi streams, or blocking effects caused by gate positions. Thus, the pushback and taxi queues were more appropriately described as takeoff queues for aircraft that have yet to push, and takeoff queues for aircraft that have yet to taxi, respectively. While this behavior was explained to the test subjects, it is speculated that the Management Interface allowed test subjects to obtain a "big picture" view of the departure process in order to compensate for the limitations of the departure advisories. If an advisory were provided which accounted for the details described above, departure advisories distributed among individual Portable Electronic FPSs may prove to be more beneficial. In addition, the prototype hardware may have reduced the effectiveness of the on-strip advisories. Due to the size of the Pocket PC displays, test subjects were required to scan over a relatively large surface area in order to assimilate the advisory data on all ten of the electronic flight strips.

On the issue of the importance of FPS portability, two factors prevented useful results from being obtained. First, the experiment was poorly designed to exploit the perceived benefits of FPS portability, as test subjects could read the flight strips, the Management Interface, and the Out-The-Window view all from nearly the same eye position. A more useful experiment would have split the Out-The-Window view into two separate displays. This could be done either by splitting the ramp area from the taxiway area, or by showing the gate areas on two displays to emulate two different airport terminals. Such an experiment, at the expense of complexity, would have more closely replicated the control tower environment and the need for ground controllers to move about the control tower cab to observe aircraft at different gates. Second, the prototype Portable Electronic FPS hardware itself may have discouraged test subjects from picking up the flight strips. Many test subjects remarked on the weight of the Pocket PC displays. Indeed, with the addition of an expansion jacket to hold the wireless LAN card (and its associated extra battery), each Pocket PC weighed approximately one pound, considerably more than a paper FPS.

Finally, while learning effects were mitigated through the use of a balanced Latin Square experimental design, it is clear that learning effects were a large factor in test subject performance. These effects may have dominated the results and caused the lack of significant differences among sequencing task and runway incursion task measures. At the very least, however, it was shown that the electronic FPS never caused the test subjects to perform significantly worse on the sequencing or runway incursion tasks. While more training would have been desired for this experiment, there was a tradeoff between the amount of training and the experiment duration. However, it would appear that more extensive training should be a part of any subsequent experiments. This also introduces the larger question of the best method to quickly evaluate the usability of a new system when the system is ultimately intended for the expert user. This is a question which is not addressed in this research.

5.2 Opportunities for Further Research

The experimental results suggest that it would be difficult to conduct more detailed analyses of the benefits of a Portable Electronic FPS system and still keep the conclusions independent of the prototype hardware. Several technologies are emerging which may enable an electronic display which better emulates the reflectivity of paper, eliminating the need for a backlit display and the associated high power consumption and viewing difficulty under certain lighting conditions. Such technologies include cholesteric liquid-crystal displays and electrophoretic displays [Crawford, 2000]. Decreasing power consumption would provide further benefits in terms of decreased battery weight or increased battery life.

This leads to other implementation issues which would have to be addressed before a Portable Electronic FPS system is operationally deployed. Such issues include the security of wireless transmissions, the method for keeping the batteries in the electronic devices charged, and the durability of the electronic devices. One possible solution to the issue of battery life would be to create a device which charges when it is placed in the strip bay. The strip bay could also be used to transfer information to and from the FPS, although this would preclude the ability to always display real-time information on the FPS. This is a significant limitation, especially when the integration of the FPS with an alerting system is considered.

In addition to implementation issues, a number of display formatting and interaction mechanism alternatives for the Portable Electronic FPS have been presented in this thesis. The utility of many of these alternatives was not explored in the evaluation of the Portable Electronic FPS. Further research should explore the areas of menu-based interaction vs. handwriting recognition, text-based menus vs. more graphical flight data modification methods, and sequence-based advisories vs. time-based advisories.

Finally, further research should also engage air traffic controllers in the design and evaluation process. While some informal input from air traffic controllers was used to guide the development of the Portable Electronic FPS, air traffic controllers were not available for the FPS evaluation, largely due to restrictions put in place after September 11, 2001. Using non-controllers for the experiment had the advantage that the test subjects did not already have extensive experience with one of the tested FPS formats. Using actual controllers may have biased the results in favor of the paper FPS. However, it is clear that the input of air traffic controllers is needed as the design of displays and interaction mechanisms becomes more refined, should the Portable Electronic FPS concept advance toward an operationally-deployed system.

5.3 Summary

In conclusion, the design and evaluation of a prototype Portable Electronic flight progress strip system has been presented. This system resulted from an attempt to address the limitations and retain the benefits of a paper flight progress strip, considering specifically the operational issues particular to the airport control tower environment. A requirements analysis identified the necessary information content for an electronic FPS system, in the context of airport departure operations and the coupling of an electronic FPS to a decision support tool. Using prototype hardware, the displays and interaction mechanisms for the prototype Portable Electronic FPS system were developed. A usability study was then conducted to determine the utility of the electronic FPS in comparison to paper flight strips. This study consisted of a human-in-the-loop experiment which simulated the tasks of an air traffic controller in an airport control tower environment. Specific issues explored during the experiment include the appropriateness of displaying departure advisories on the Portable Electronic FPS, the importance of FPS portability, and the advantages of interaction mechanisms enabled by an electronic interface. Among the conclusions from the experiment, test subjects clearly preferred the Portable Electronic FPS to a paper FPS. However, more detailed results were confounded by the domination of learning effects and the characteristics of the prototype hardware itself. Further research should include more extensive air traffic controller input in the design and evaluation process, address implementation issues necessary for an operationally-deployed system to overcome, and explore emergent display technologies which may better emulate the physical characteristics of the paper FPS.

Appendix

TUTORIAL FOR EXPERIMENTAL EVALUATION OF PORTABLE ELECTRONIC FLIGHT PROGRESS STRIPS

INTRODUCTION

The experiment you are participating in is designed to be a semi-realistic simulation of the tasks that an air traffic controller performs for departure aircraft at a major airport. The tasks that are modeled are: sequencing departures, issuing voice clearances, using flight strips, and visually observing airport surface traffic.

The goal of this experiment is to determine differences in controller workload and performance on these tasks when using different types of flight strips. Depending on the scenario, you will be using either a paper or electronic flight strip system. In addition, the electronic strip system will have varying amounts of decision-support information.

This document will explain in detail your tasks for the experiment, and the displays and hardware you will be using. Once you have read this, you will complete some sample scenarios to further familiarize yourself with the test procedures. If anything is unclear in this document, please ask questions.

BASIC SETUP

For each of 5 different experimental scenarios, you will stand in front of a table on which 10 departure flight progress strips will be placed. Your primary task is to sequence the 10 aircraft for departure, using the information on the flight strips. You will be required to annotate the flight strips when you issue clearances to the aircraft. These clearances will be issued verbally, and I will act as the pseudopilot for each aircraft, making verbal requests, and responding verbally to your clearances.

The ramp, taxiways, and runway of a fictional airport will be projected on a screen in front of you to simulate the out-the-window view of an airport control tower. This display will show the 10 departure aircraft pushing back from their gates and taxiing around the airport, based on the clearances you issue. In addition, other aircraft will be shown on the taxiways. These aircraft are all supposed to follow a standard path, but they occasionally take a wrong turn toward the runway. It is your secondary task (to be done whenever you are not busy with your primary task of sequencing departures) to catch these runway incursions. Each scenario will end when all 10 departure aircraft have taxied toward the runway. After each scenario, and after the experiment is finished, you will complete a short questionnaire.

HARDWARE AND DISPLAYS

Paper Flight Strip

For some scenarios, you will be using mock paper flight strips. These consist of a strip of paper mounted on a piece of foam-core tagboard. They are roughly the same size and shape as the genuine article. You can pick them up and move them around on the table. But you will not have a strip bay to place them in. Figure 1 shows an example paper flight progress strip, and Figure 2 explains the information shown on the strip.

AAL972	0153	FSA	FSA RBV J230 AIR J110 VHP VLA STL			
T/B738/E	P0609					
882	310					

Figure 1. Paper Flight Strip

Callsign	Transponder Code	Departure Airport	Route of Flight			
Aircraft Type	Proposed Depart Time					
Computer ID	Cruise Altitude					

Figure 2. Key to Paper Flight Strip Information

Electronic Flight Strip

For some scenarios, you will be using electronic flight strips that are displayed on Compaq iPAQ PocketPCs. Figure 3 shows an example electronic flight strip and Figure 4 explains the information shown on the strip.

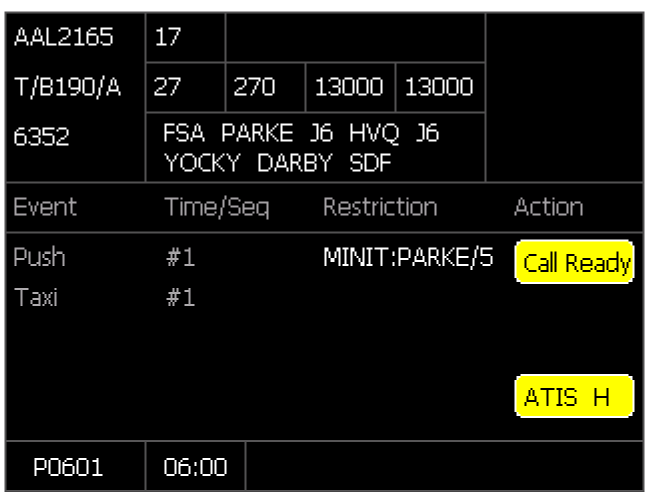

Figure 3. Electronic Flight Strip

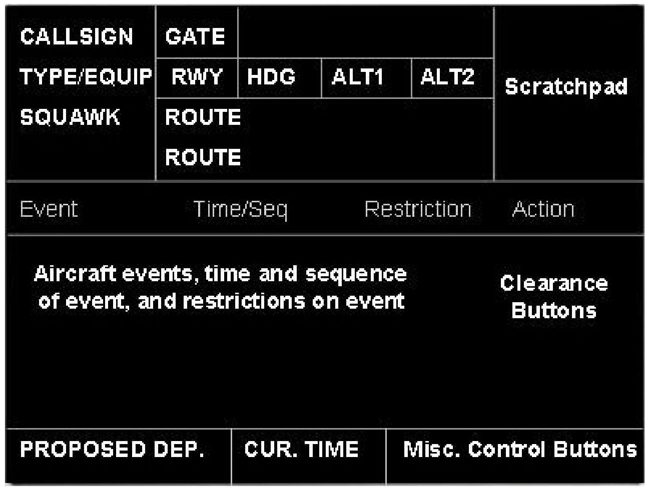

Figure 4. Key to Electronic Flight Strip Information

Note that the upper half of the electronic flight strip display contains the same information shown on the paper flight strip, with the following changes:

- The Computer ID is not shown.
- The Proposed Departure Time is shown in the lower left-hand corner of the display.
- There are two altitude fields (one for the current cleared altitude and one for the filed cruise altitude).
- The Departure Airport does not have its own field, as it is always shown on the route of flight.
- The callsign field is color-coded depending on the departure state of the aircraft (at gate, ready to push, cleared to push, cleared to taxi). The color-coding will be explained further in the Examples section.
- The aircraft gate location and assigned runway are shown

It is possible to modify the flight data fields using the iPAQ stylus. However, because this is not required for the simulation, these features have been disabled.

In the upper-right hand corner of the display is a “scratchpad.” You can use this area for making miscellaneous annotations by using the iPAQ stylus to draw within the scratchpad box. However, it is not required for you to do so during the simulation.

The lower half of the display consists of departure advisories and clearance buttons. Depending on the scenario, the departure advisories (under the Event, Time/Seq, and Restriction headings) may or may not be shown. When they are shown, they provide the following information:

- The suggested sequence that the aircraft should push and taxi for maximum runway throughput. These two numbers will usually be the same because the simulation assumes the aircraft will be given taxi clearance immediately after push clearance. (Note: this does not mean you have to clear aircraft for pushback and taxi in this manner.)
- Downstream departure restrictions for the aircraft. For this experiment, all restrictions are minutes-in-trail restrictions, and have the following format: “MINIT:AAAAA/B” where AAAAA is a fix on the aircraft’s flight plan, and B is the number of minutes required between successive aircraft flying over the fix.

You will tap the clearance buttons with the stylus every time you do the following: confirm the aircraft has the correct ATIS (Airport Terminal Information Service) weather information, confirm the aircraft is ready to pushback, issue pushback clearance, and issue taxi clearance. The buttons change depending on the state of the aircraft. For example, Figure 3 shows the buttons for an aircraft that is at the gate, not yet called ready for pushback, and not yet indicated they have the current ATIS. In addition, when departure advisories are shown, the clearance buttons will be color-coded. A green button indicates the aircraft is #1 in sequence for pushback or taxi. A yellow button indicates the aircraft is not yet #1 in the suggested sequence. When the departure advisories are not shown, these buttons will always have a black background.

Management Interface

In addition to the flight strips, you will have a Management Interface, displayed on a desktop computer monitor. Shown in Figure 5, this display has two components: suggested departure queues, and a listing of downstream departure restrictions. Depending on the scenario, the suggested departure queues may or may not be shown. When they are shown, they give the same information as the departure advisories on the electronic flight strips—the suggested push and taxi sequence for maximum runway throughput. (Hint: This sequence will always be correct.) The queues are sequence-based, not time-based, and they display the aircraft's sequence position, callsign, and gate. The queue data tags are color-coded in the same way the callsign field is color-coded on the electronic flight strips.

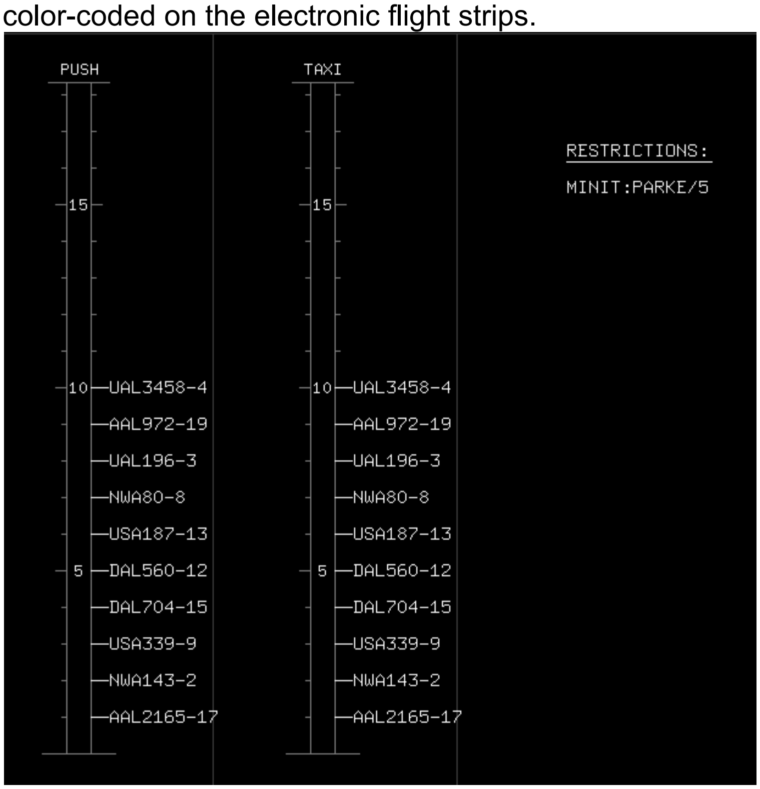

Figure 5. Management Interface

The Out-The-Window View

To observe airport surface traffic, a two-dimensional, top-down view of a fictional airport's gates, taxiways, and runway will be projected on a screen for you, as shown in Figure 6. Departure aircraft will be shown pushing back from the gate and taxiing to the runway based on the clearances you issue. Arrival aircraft (which you will not control) will be shown decelerating on the runway. Other aircraft (which you will not control) will be shown taxiing.

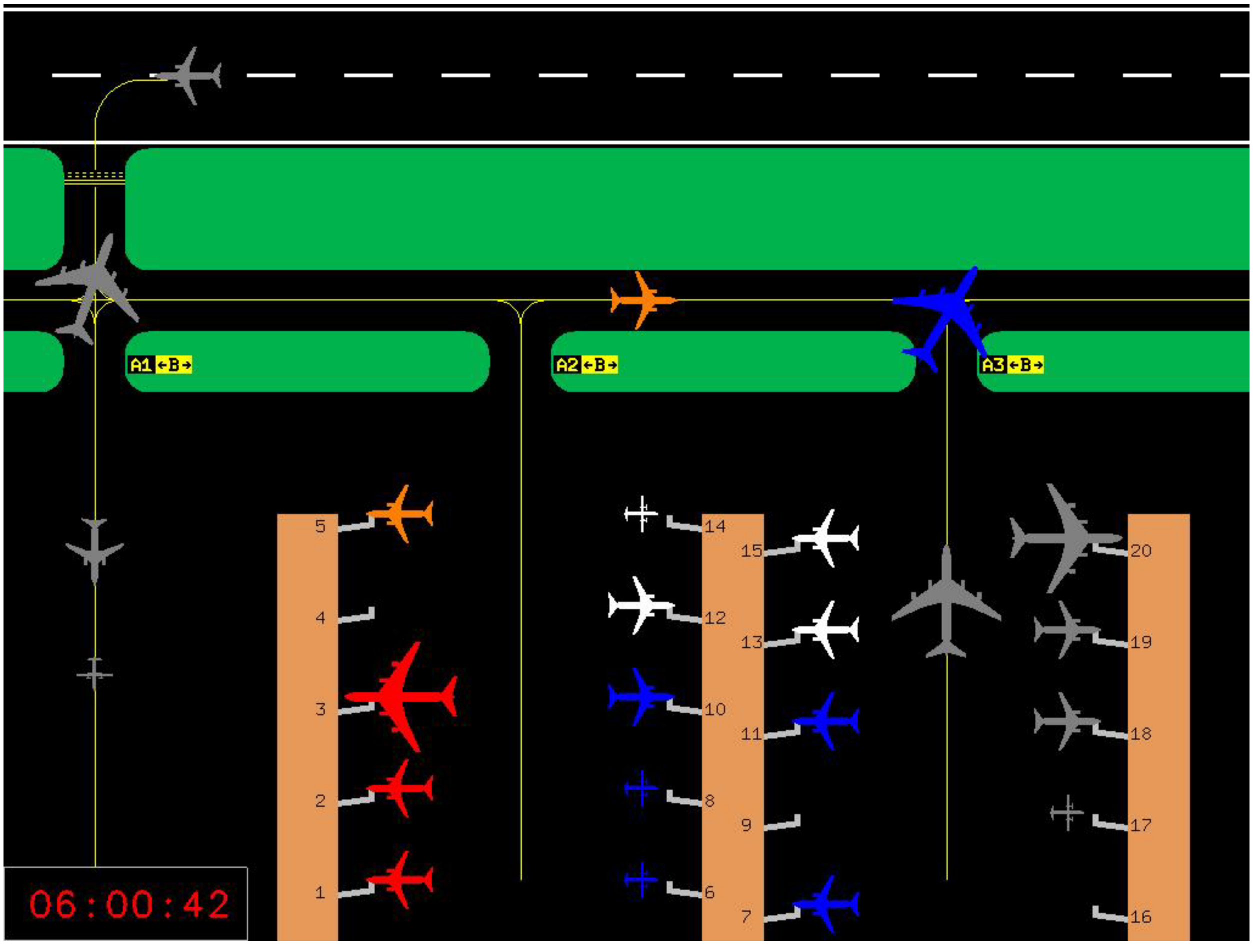

Figure 6. Out-The-Window Display

The bottom half of the display shows 3 terminal concourses and 20 gates split between 2 alleys. The gate numbers are shown in black letters next to each gate. The aircraft on the display are of only 3 different types, for 3 different departure weight classes (Small, Large, Heavy). All Heavy aircraft are B747s (equipment code B744), all Large aircraft are B737s (equipment code B738), and all Small aircraft are Beech 1900s (equipment code B190). In addition, the aircraft are color-coded by airline as follows:

Color	Airline
White	Delta (DAL)
Gray	American (AAL)
Blue	US Airways (USA)
Red	Northwest (NWA)
Orange	United (UAL)

(I know that the aircraft types shown don't necessarily match up with the airline fleets. This was done to simplify the simulation.)

All aircraft push back by moving straight back to the alleyway centerline and then rotating toward the taxiways. The gate alleys are only wide enough for one aircraft. Thus, there is only room horizontally for one aircraft to push back, but in the vertical direction up to 5 aircraft may push back at the same time. To illustrate this, in Figure 7, aircraft at gates 18, 9, and 7 may push at the same time, but aircraft at gates 18 and 11 may not push at the same time.

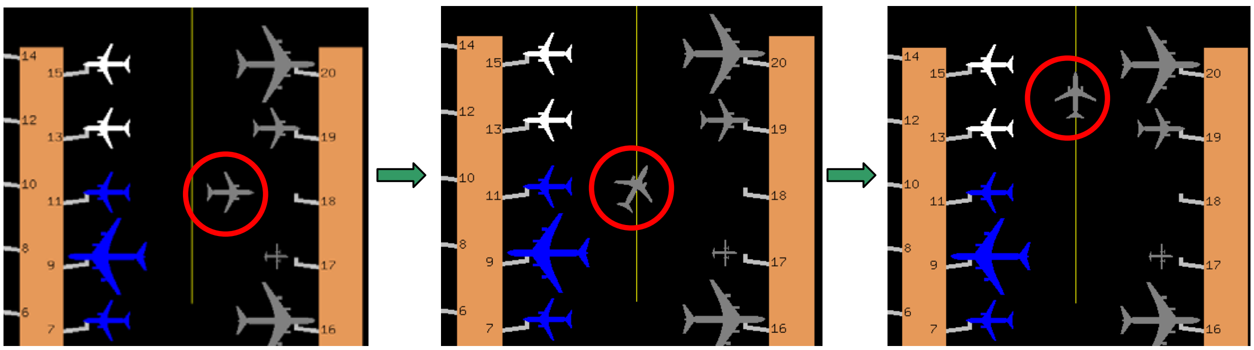

Figure 7. Aircraft Pushback

After aircraft have pushed and received taxi clearance, they taxi to the departure runway using either taxiways A2 and B (for gates in the left alley) or taxiways A3 and B (for gates in the right alley). It is *not possible* for aircraft coming from the left alley to use taxiway A3 or A1. It is *not possible* for aircraft coming from the right alley to use taxiway A2 or A1 (see Figure 6).

The winds today are such that the runway will always be used from right to left. Thus, once the departure aircraft reach taxiway B, they will turn right and eventually taxi off the screen.

In the upper-left corner of the display, aircraft will occasionally appear at the left end of taxiway B, taxi along B, then turn right or left at A1. In addition, aircraft will occasionally be shown landing and decelerating on the runway (see Figure 6).

In the lower-left corner of the display is a clock, used when writing push times (see Figure 6).

I will be using a mouse to control the pushback and taxiing of all the departure aircraft. Because of this, you may occasionally see a mouse pointer move across the screen.

SIMULATION SCENARIOS

You will participate in five different scenarios. As mentioned above, you will be using paper flight strips in some scenarios and electronic flight strips in other scenarios. Following is a description of the differences between each scenario.

1. Paper Strips: You will use paper flight strips and the management interface will only show a list of downstream restrictions.

2. Portable Electronic Strips with Advisories: You will use the electronic strips. The Management Interface will show both the downstream restrictions list and departure queues. Departure advisories and downstream restrictions will also be shown on the individual flight strips. The clearance buttons on the flight strips will be color-coded such that they turn from yellow to green when an aircraft is #1 in sequence for pushback and taxi.

3. Portable Electronic Strips with Advisories only on Management Interface: This scenario is the same as the previous one except that the individual strips contain no sequence or restriction information—this information is only shown on the Management Interface. In addition, the clearance buttons will not be color-coded, but will always have a black background.

4. Portable Electronic Strips without Advisories: In this scenario, no departure sequence advisories will be shown on the flight strips or on the Management Interface. Clearance buttons will not be color-coded. The Management Interface will only show a list of downstream restrictions.

5. Fixed Electronic Strips without Advisories: This scenario is the same as the previous one, but with the stipulation that you cannot pick up the electronic flight strips. The strips must remain on the table. You may shuffle them around on the table.

These scenarios will not necessarily occur in the above order.

Controller Tasks

Each departure scenario will begin with all 20 gates filled. You will be given flight strips for 10 of these aircraft in the order in which they will request pushback. (Note: This order will always be the same as the order of proposed departure times.) The other 10 aircraft at the gates are dummy aircraft—they will remain at the gates for the duration of the simulation.

Approximately every 15 seconds, an aircraft will request pushback. I will act as a pseudopilot for all aircraft and make verbal pushback and taxi requests and responses. You can either verbally issue a pushback clearance or tell the aircraft to hold at the gate. Once pushback has started, it cannot be stopped or reversed.

Once the aircraft has finished pushback, it will request taxi clearance. Again, you can either issue a taxi clearance, or tell the aircraft to hold position. You can tell the aircraft to hold position anywhere along its taxi path. For instance, aircraft coming from the left alley may need to hold on B at A3 for sequencing with aircraft from the right alley, as shown in Figure 8. Once aircraft have taxied past the A3-B intersection, it is not possible to resequence the departures—leapfrogging is not allowed on any of the taxiways, and there are no penalty boxes to hold aircraft at the runway threshold.

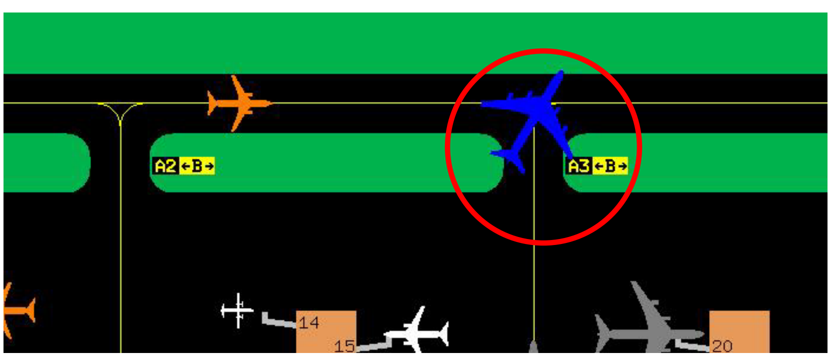

Figure 8. A3-B Merge Point

Your primary task is to create the most efficient departure sequence possible without violating any departure constraints. The most efficient sequence is the one in which the least amount of time passes from the time the simulation starts until the time the last (10th) aircraft departs. In other words, it is the sequence with the maximum average departure rate.

You will also be required to perform some flight strip marking. This will be illustrated in the Examples section.

Departure Constraints

It is assumed that the departure aircraft are taxiing to a runway which is being used solely for departures. Thus, the primary means for determining how long it takes an aircraft sequence to finish departing are departure-departure wake turbulence restrictions. For the purpose of this simulation, the minimum delays between successive departures are simplified to the following:

Interdeparture Times (sec)

		Trailing Aircraft		
		Heavy	Large	Small
Leading Aircraft	Heavy	90	120	120
	Large	60	60	60
	Small	45	45	45

From this chart, it can be seen that—*in the absence of any departure restrictions*—the most efficient sequence is to group all the heavy aircraft together.

All the wake turbulence restrictions are time-based. There are no distance-based metrics modeled in this simulation. Divergent departure headings are not modeled either.

In addition to wake turbulence restrictions, some aircraft may have downstream restrictions applied to them. All these restrictions will be minutes-in-trail (MINIT) restrictions for a downstream fix. Because there are no penalty boxes, the affected aircraft *and all subsequent departures* will be affected by the delay.

Example: If an aircraft is first in sequence at the runway and ready for takeoff, but still has two minutes left on a MINIT restriction, that aircraft and all the aircraft behind it must wait an additional two minutes. Once aircraft have taxied past the A3-B intersection, there is no method for resequencing aircraft. And even though some resequencing between aircraft in different alleys is possible at A3-B, most sequencing needs to be accomplished through the pushback order since aircraft in the same alley all follow the same taxipath.

The last departure restriction is a "shift" constraint. Even though you will not be using a first-come-first-serve strategy in this simulation (although you may, if you feel that is also the most efficient sequence), some method is needed to assure that individual aircraft don't accumulate unfairly long delays. Therefore, aircraft may be "shifted" from their original, "proposed departure time" order by a maximum of two places. For example, an aircraft that was the fourth to call for pushback may be the 2nd, 3rd, 4th, 5th, or 6th aircraft for takeoff, but not the 1st, 7th, 8th, 9th, or 10th. Even if a "shift" constraint is violated, aircraft will still depart in the order you instruct. However, it will be noted that you used an invalid sequence. *Shift constraints do not apply to aircraft with downstream restrictions. These aircraft can be placed anywhere in the departure sequence.*

Secondary Task

Your secondary task (of lower priority than the sequencing task) is to prevent runway incursions by observing the traffic on the Out-The-Window display. As mentioned above, aircraft will occasionally appear at the left end of taxiway B and turn right or left at taxiway A1. All aircraft should make a right turn toward the gate apron. However, approximately half of these aircraft will mistakenly take a left turn toward the runway, as shown in Figure 9.

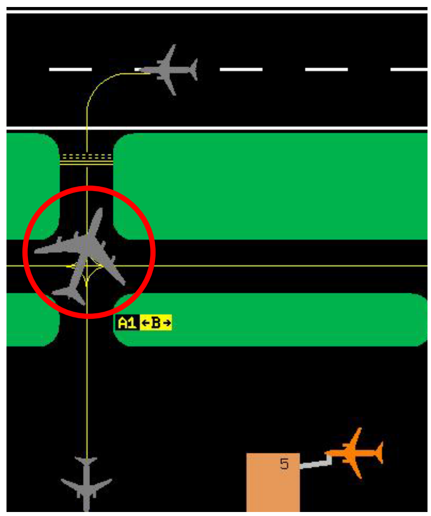

Figure 9. Incurring Aircraft

Whenever you are not busy sequencing departures or marking the flight strips and you notice an aircraft turning toward the runway, press the SPACEBAR on the keyboard for the Out-The-Window display, and the aircraft will disappear. However, *you should not attempt to game the simulation by continuously pressing the spacebar whenever you can*—if there is no incurring aircraft, this will be recorded as a false alarm.

The performance measure for this secondary task is the elapsed time from when an aircraft first turns toward the runway until you press the spacebar. The presence of another aircraft on the runway has no effect on the performance measure.

EXAMPLES

Following is a description of the actions you will take as a single aircraft progresses from sitting at the gate, to pushback, to taxi. Examples will be shown for both paper and electronic strips. Exact phraseology for the verbal clearances is not important as long as the intent is clear. All verbal instructions are shown in italics.

Paper Flight Strips

Begin by noting any downstream restrictions on the Management Interface. For any flights with a downstream restriction, underline the restricted fix in red pen in the route of flight field (Figure 10). Determine the optimal sequence that the aircraft should pushback and taxi. It may help to rearrange the flight strips on the table.

AAL972	0153	FSA	FSA RBV J230 AIR J110 VHP VLA STL			
T/B738/E	P0609					
882	310					

Figure 10. Underline Restricted Fix in Red Pen

Aircraft: *"Ground, American One-Twenty-Three, gate eight for push with Foxtrot."*

You: *"American One-Twenty-Three, Ground, cleared to push"* or *"American One-Twenty-Three, hold at the gate."*

In the upper-right corner box of the paper flight strip, write the "call ready to push" time in HHMM format (Figure 11).

AAL972	0153	FSA	FSA RBV J230 AIR J110 VHP VLA STL			0605
T/B738/E	P0609					
882	310					

Figure 11. Write "Call Ready to Push" Time

In the middle box of the paper flight strip, confirm that the aircraft has the correct ATIS by writing the letter identifier of the current ATIS (Figure 12). (Hotel = H, Sierra = S, etc.)

AAL972	0153	FSA	FSA RBV J230 AIR J110 VHP VLA STL			0605
T/B738/E	P0609				F	
882	310					

Figure 12. Write ATIS Identifier

If the aircraft is not immediately given pushback clearance, write the actual pushback time, either in HHMM or MM format, in the middle-right box after giving push clearance (Figure 13).

AAL972	0153	FSA	FSA RBV J230 AIR J110 VHP VLA STL			0605
T/B738/E	P0609				F	10
882	310					

Figure 13. Write Actual Push Time for Delayed Aircraft

Aircraft: *"Ground, American One-Twenty-Three, ready to taxi."*

Ground: *"American One-Twenty-Three, Ground, taxi to the runway"* or *"American One-Twenty-Three, Ground, hold position."*

At this point, the flight strip can be moved aside, as no more annotations are required. If the taxiing aircraft need to be resequenced after taxi has begun, you may give commands such as

"American One-Twenty-Three, hold position" or *"American One-Twenty-Three, hold at Bravo and follow the United seven-forty-seven"* or *"American One-Twenty-Three, resume taxi."* Again, the exact phraseology is not important as long as the intent is clear. Once all 10 departure aircraft have taxied past the B-A3 intersection (see Figure 6) the scenario will be over.

Electronic Flight Strips (with Departure Advisories on Strip)

***Note: The figures in this section are for scenarios with departure advisories on the electronic flight strip. For scenarios without advisories on the flight strip, the clearance buttons will always have white text with a black background.

Begin by noting any downstream restrictions on the Management Interface or the individual flight strips (if given). If no departure advisories are shown on the Management Interface or the flight strips, determine the optimal sequence that the aircraft should pushback and taxi. If departure advisories are shown, the given sequence may be used. (Hint: It will always be correct.) It may help to rearrange the flight strips on the table.

Aircraft: *"Ground, American One-Twenty-Three, gate eight for push with Hotel."*

You: *"American One-Twenty-Three, Ground, cleared to push"* or *"American One-Twenty-Three, hold at the gate."*

The electronic flight strip will initially look as it is shown in Figure 14. Tap the "ATIS" button on the electronic flight strip. The current ATIS identifier is automatically shown on the button. The "ATIS" button will disappear after you tap it (Figure 15).

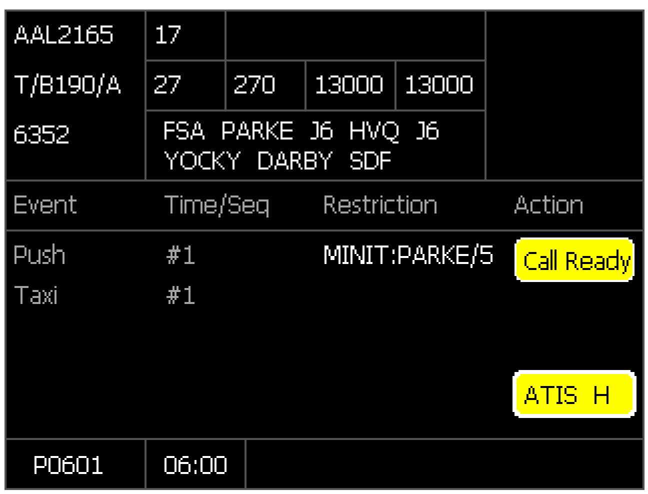

Figure 14. Electronic Flight Strip at Start of Scenario

Figure 15. "ATIS" Button Tapped

Tap the "Call Ready" button on the electronic flight strip. The clearance buttons will change after you tap the "Call Ready" button, the callsign field background will change to purple to indicate the aircraft has called ready to push, and the aircraft data tag on the Management Interface will also change to purple. If you tap the button by mistake, tap the "Undo" button (Figure 16).

Figure 16. "Call Ready" Button Tapped

When push clearance is given, tap the "Push" button on the flight strip. The background of the callsign field will change to orange to indicate the aircraft has received push clearance (Figure 17). The aircraft data tag on the Management Interface will also change to orange, and the aircraft will disappear from the Push queue.

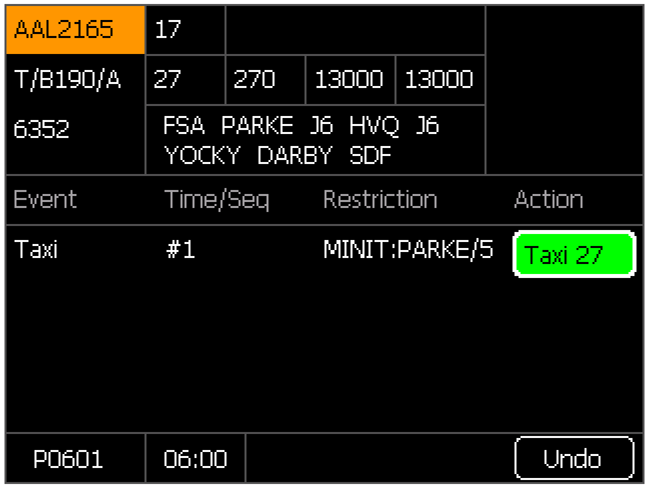

Figure 17. "Push" Button Tapped

Aircraft: *"Ground, American One-Twenty-Three, ready to taxi."*

Ground: *"American One-Twenty-Three, Ground, taxi to the runway"* or *"American One-Twenty-Three, Ground, hold position."*

When taxi clearance is given, tap the "Taxi" button on the flight strip. After tapping the "Taxi" button, the callsign field background will change to light blue to indicate the aircraft has received taxi clearance (Figure 18). Also, the aircraft data tag will disappear from the Taxi queue on the Management Interface.

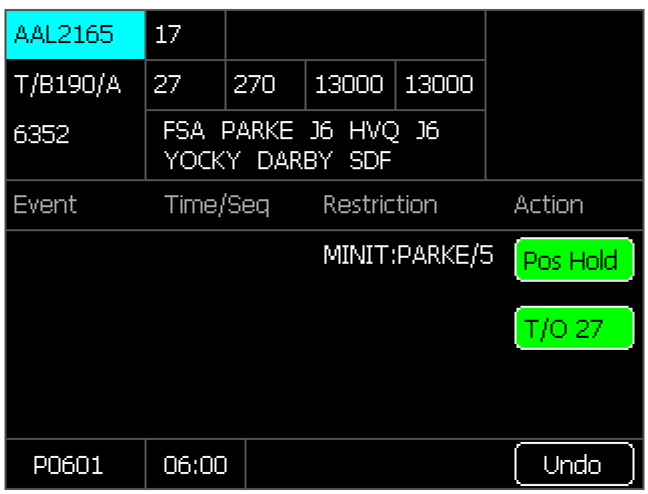

Figure 18. "Taxi" Button Tapped

At this point, the flight strip can be moved aside, as no more annotations are required. If the taxiing aircraft need to be resequenced after taxi has begun, you may give commands such as *"American One-Twenty-Three, hold position"* or *"American One-Twenty-Three, hold at Bravo and follow the United seven-forty-seven"* or *"American One-Twenty-Three, resume taxi."* Again, the exact phraseology is not important as long as the intent is clear. Once all 10 departure aircraft have taxied past the B-A3 intersection (see Figure 6) the scenario will be over.

SUMMARY

Your primary task is to create the most efficient departure sequence possible—without violating any departure constraints—while at the same time issuing verbal clearances and performing the required strip marking. The wake turbulence delays and downstream restrictions determine the optimal sequence. The “shift” constraint determines which sequences are allowed.

Your secondary task—to be completed whenever your attention is not required for the primary task—is to catch runway incursions. Whenever you notice one, hit the SPACEBAR.

The required strip marking for paper strips is:

- Underline any restricted fixes in red pen.
- Write down the “call ready to push” time.
- Write down the ATIS letter identifier when the pilot indicates he has the ATIS information.
- If the aircraft is not immediately given push clearance, write the actual push time.

The required strip marking for electronic strips is:

- Tap the “ATIS” button when the pilot indicates he has the ATIS information.
- Tap the “Call Ready” button when the pilot calls ready to push.
- Tap the “Clear Push” button when pushback clearance is issued.
- Tap the “Clear Taxi” button when taxi clearance is issued.

Hints for achieving the optimal sequence:

- Aircraft with downstream restrictions are not subject to the “shift” constraint. There may be situations where two restricted aircraft are near the end of the sequence and one of these needs to be far earlier in the departure sequence to achieve the optimal order.
- The wake turbulence delay after the 10th departure is not counted. Thus, if it is possible to put a Heavy or Large aircraft in the 10th position, this may improve your departure throughput.

You will now go through samples of each of the 5 scenarios. If anything in this document or in the sample scenarios is unclear, please ask questions.

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