DESIGN FRAMEWORK FOR THE GRAPHICAL USER INTERFACE OF A TERMINAL AREA AIR TRAFFIC ADVISORY SYSTEM

by

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(ABSTRACT)

The purpose of this research thesis was to develop a framework and methodology for the design of a graphical user interface to be used by air traffic controllers. The interface is intended to be only a part of a complete Advisory System designed to supplement the tasks of terminal area air traffic controllers.

This research addresses many of the human factors issues associated with the development of the display. The research takes a user-perspective and applies the prinicples of rapid prototyping to develop the framework for the design of the interface. Attention is also given to the previous research that explores the implications of automating various air traffic control tasks.

Finally, a prototype system was developed to fulfill one of the primary rapid prototyping steps. The prototype displays the general format for the various advisories and presents three typical scenarios where the system may be of particular use. In the future, the prototype can be used to gather additional information on the opinions and requirements of the future system users – air traffic controllers. It is anticipated that moderate benefits can be attained through the implementation of such a system, provided that the interface satisfies the user requirements.

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1. Introduction

1.1 Background

It is a widely accepted fact that the volume of air traffic activity will continue to increase significantly in the foreseeable future. In order to continue to provide safe and efficient service to the airspace users, the existing Air Traffic Control, or ATC, system must be updated and improved. The Federal Aviation Administration, or FAA, has shown recent interest in gradually automating many of the routine ATC procedures. [Hunt & Zellweger, 1987]

In addition to reducing the stress on air traffic controllers, an automated system would increase the productivity of ATC personnel, which would in turn, increase the capacity of the system. In addition, an automated system has the potential of improving the safety of the existing system.

An effective automation system must consist of two important components: 1) algorithms, and 2) displays. The backbone of an automated system is a set of algorithms that generates a desired output in real time. However, the output is useless without a means of conveying the output to the human users – in this case, the air traffic controllers. Since, oftentimes, the safety of the air traffic is subject to the performance of the air traffic controllers, the graphical user interface is an integral component of an automated air traffic control system. The design of such an interface must address the human factor-related needs of the user.

1.2 Air Traffic Control System in the United States

"As defined in federal aviation regulations, air traffic control is a service operated by the Federal Aviation Administration to promote the safe, orderly, and expeditious flow of air traffic. This service involves a myriad of interrelated elements that have been combined in an evolutionary process, over the years, to form the ATC system. This system uses a complex of ground equipment, airborne equipment, personnel, communications, navigational aids, displays, radar, computers, facilities, and airways." [Hunt & Zellweger, 1987]

There are two types of ATC facilities: en route and terminal area. Many researchers have addressed issues related to en route facilities; however, terminal area facilities have traditionally been ignored. There are two components to the terminal area ATC facility: the terminal radar-approach control facility (TRACON) and the Airport Traffic Control Tower (ATCT).

The TRACON "has jurisdiction in the control and separation of air traffic from the boundary area of the air traffic control tower at an airport to a distance of up to 50 miles from the airport and to an altitude ranging up to 17,000 feet." The FAA currently operates over 200 various types of TRACONs. Depending on the volume of traffic normally handled, there are various degrees of automation in TRACONs. The principal type of hardware used in approach control facilities is an automated radar terminal system (ARTS). An ARTS I facility has the lowest degree of automation while ARTS III denotes the highest. ARTS IIIA and ARTS IIIE are enhanced and updated to accommodate automation data. [Horonjeff & McKelvey, 1994]

The airport traffic control tower is the second component of the terminal area ATC facility. The tower "supervises, directs, and monitors the arrival and departure traffic at the airport and in the immediate airspace within about 5 miles from the airport. The tower is responsible for issuing clearances to all departing aircraft; providing pilots with information on wind, temperature, barometric pressure, and operating conditions at the airport; and controlling all aircraft on the ground except in the ... ramp area." Towers can either be operated by the FAA directly or under contract to the FAA. In 1990, there were 400 and 25 of these type facilities, respectively. [Horonjeff & McKelvey 1994]

Under normal operations, the TRACON transfers control of an arriving aircraft to the tower when the aircraft is lined up with the runway about 5 miles from the airport. Likewise, a departing aircraft is handed off in the opposite direction. [Horonjeff & McKelvey 1994]

1.3 Air Traffic Growth and Airspace Congestion

The air traffic in the United States can be divided into three categories: air carrier traffic; air cargo traffic; and small, regional and commuter air carriers. Each of these three categories of air traffic has experienced growth in recent years and all forecasts indicate that each of these markets will continue to grow.

In 1995, the air carrier industry experienced a growth rate of 5%. In addition, the short haul component of this industry – trips less than 500 miles – comprises 55% of the scheduled domestic flights. Air cargo traffic in the United States is expected to grow at an even faster pace.

The Deregulation Act of 1978 has also contributed to the growth of air travel in the United States. Small regional and commuter air carriers have now been able to succeed in this deregulated industry. This component is also expected to grow continually through the foreseeable future.

Finally, the deregulation has influenced many of the major carriers to utilize a hub and spoke system which increases congestion around the principal hubs. Altogether, the overall increased traffic as well as the increased short haul traffic has served to increase the traffic around terminal areas to a highly congested state. [Horonjeff & McKelvey 1994]

The critical bottleneck in the nation's ATC network is the capacity of the region of the radius 30-40 miles around an airport (i.e.,., terminal area). So current researchers have focused on the air traffic control around this area.

1.4 Movement toward Automation

Over the past decade there has been a strong movement to improve and automate the existing ATC system that provides service to flights in United States airspace. The current ATC system has been the subject of numerous media reports and is generally perceived by the public as antiquated and perhaps even a safety hazard. For these reasons, as well as others, the FAA has promoted efforts to bring the ATC system up to modern-day standards.

The National Airspace System Plan is the FAA's most recent effort, a comprehensive plan implemented in 1989, to update and modernize the United State's ATC system. According to the plan, there are a number of reasons for updating and automating the ATC system. Some of which include:

1. Having an operational system that is capable of being technically expanded in incremental steps to meet the needs of aviation as time requires

2. Accommodating increasing demands in a manner that allows users to operate in the airspace with minimal regulatory constraints and in a fuel-efficient way

3. Reducing the risks of midair and surface traffic collisions, landing and weather-related accidents and collisions with the ground

4. Increasing the productivity of air traffic control personnel terms of the amount of air traffic handled

5. Decreasing the technical staff required to maintain and operate the system

6. Maintaining the overall operating costs of the system at reasonable levels

7. Increasing the capacity of the airspace by reducing the spacing between aircraft through improved systems to monitor aircraft with more accurate airborne systems [Horonjeff & McKelvey 1994]

1.5 Research Scope, Objective and Approach

To resolve this "bottleneck phenomenon" that is present in the nation's airspace network, we need to look towards optimal sequencing of arrivals and departures. Although controllers currently work with the daily flight schedules to sequence arrivals and departures, this system is not efficient enough. Unfortunately, changes in the flight schedules due to weather, mechanical failures, etc., are commonplace in airports today. Currently, controllers are relying on their experience alone to determine when to accept arrivals and when flights can be released between arrivals. This is not the most efficient method.

With the aid of computers and mathematical algorithms that can be used to determine the optimal sequencing of arrivals and departures based on minimizing the total delay costs, the national ATC system can become much more effective.

However, raw data generated from a computer cannot alone solve the problems. Instead, an automated system that provides the information to air traffic controllers in real time and in a usable format is much more desirable.

"Perhaps the most neglected aspect in the development of large computer systems has been the interface between the computer and the user. Proper design of the system to meet functional and performance characteristics and to support, at a reasonable cost, future system maintenance and evolution is necessary, but the most important objective for the ATC automation system design is that it allow the air traffic controllers to do their jobs safely and effectively." [Hunt & Zellweger, 1987]

The purpose of this research thesis is to develop a prototype for a graphical user interface that provides the terminal area air traffic controller with flight information and advisories concerning the appropriate times to accept and release flights. The procedure described in this thesis takes a human factors engineering approach to addressing the needs of the air traffic controller.

The first step in the approach is determining exactly what information needs to be provided to the controller through the user-interface. The next step is determining how best to convey the desired information. Finally, a prototype will be developed using a multi-media software program that will simulate the actual automated system that could eventually be implemented by the FAA. In addition, this thesis will include provisions for obtaining feedback from controllers, and recommendations for implementation methods that will cause the least disturbance to and a smooth transition from the existing system.

Recognizing that those who do the job know their job best, a group of air traffic controllers will play a key role in the development of the prototype. Focus groups and questionnaires will be used to determine the wants and needs of the controllers. A task analysis will be performed to learn the groups of actions that should be kept together in order to attain an efficient design. Finally, a prototype will be developed and evaluated by the controllers using standards established by the FAA.

1.6 Limitations and Applications

The graphical user interface that will be developed must fit into the existing air traffic control center; either replacing current information sources or supplementing the current sources. Today, the controller's principal source of information is a 19 inch diameter monochrome plan view display (PVD). This PVD provides several kinds of information: 1) the actual ground track of each aircraft, 2) the local navigation air (navaid) locations, 3) weather and other environmental data including the status of both the arrival and departure facilities, and 4) all of the airways passing through a sector. Flight Progress Strips (FPS) are the second source of data provided to the controller. The FPS convey information regarding the pilot's intended flight path and progress along that path. These are placed in plastic holders to permit the controller to arrange strips in an appropriate order on a board next to the PVD and to manually mark the strips with the information regarding clearances and recent flight progress. The third source of information are radio messages to and from the pilot, and to and from the other controllers who will later assume control responsibility for the aircraft as it moves to the next sector. [Hunt & Zellweger, 1987]

In addition to fitting into the existing facility, the proposed system must also have the acceptance of the air traffic controllers. This could require extensive education and marketing efforts; because, without their acceptance, all of the positives provided by the systems will go unnoticed. In fact, the system could become more of a hindrance than a help.

Finally, in order to economically justify the implementation of such a new system, the traffic at the airport facility must be great enough that benefits could be obtained through the system. If an airport does not ordinarily experience regular delays, a system that reduces the total costs of delays will be of limited benefit.

2. Literature Review

2.1 Introduction

When embarking upon the development of a graphical user-interface for terminal area air traffic control, it is important to investigate the relationship between the human and the machine, and, ultimately, achieve a proper balance between the two.

Human Factors is defined as "the technology concerned in optimizing the relationships between people and their activities by the systematic application of the human sciences, integrated within the framework of system engineering." Since the machine will be providing the user with advisories and other information, designers must focus primary attention on the most efficient use of these tools. [Pozesky, 1991]

The objective when designing and evaluating the user-interface is to make the physical and functional interfaces as compatible as possible with the cognitive interface. Therefore, it is intrinsic that the cognitive interface be understood before the physical or functional interface is designed. The first step is to identify the human factors issues associated with the design and evaluation of ATC displays and controls. Appropriate analyses are then performed to identify the controller's information requirements as dictated by context-specific objectives. [Cardosi & Murphy, 1995]

2.2 Controller's Functions and Tasks

As is commonly recognized, the role of the air traffic controller in the national airspace system is crucial and a complex one at best. Air traffic controllers sort out and project the paths of an ever increasing number of aircraft in order to insure goals of minimum separation and safe, efficient take-off, en route and landing operations. This taxing job relies upon the situational awareness of controllers who must maintain up-to-date assessments of the rapidly changing location of each aircraft and their projected future locations relative to each other, along with other pertinent aircraft parameters such as final destination, fuel consumption characteristics, on-board communications equipment, etc.

This situational awareness can be broken into three levels: perception, comprehension, and projection. Following is a partial list of situational awareness parameters that fall into the various categories. [Endsley and Rogers, 1994]

Level 1: Perception of elements

Aircraft (identification, position, heading, altitude, flight plan, type, etc.)
Emergencies (type of emergency, time of fuel remaining, souls on board)
Requests (pilot/controller requests, reason for request)
Clearances
Sector
Special Operations
ATC Equipment Malfunctions
Airports
Weather

Level 2: Comprehension of their meaning

Conformance
Current Separation
Timing
Deviations
Other Sector/Airspace
Significance
Confidence Level/Accuracy of Information

Level 3: Projection of the future

Projected Aircraft Route (Current / Potential)
Projected Separation
Predicted Changes in Weather
Impact of Potential Route Changes

It is important for the researcher to understand the situational awareness characteristics when designing automated aids for the controller. Automation can help to predict and even prevent conflicts, providing an optimum scenario that controllers can choose to implement.

Obviously, conflicts arise when multiple aircraft require the same resource at the same time. "Arrival and departure time on runways, and convergence on ground-based navigation aids at the same altitude, frequently cause conflicts. Bad weather can further constrain these resources, aggravating contention. In addition, aircraft operating at different speeds must be accommodated sequentially in crowded areas around airport terminals. Automation has provided controllers with tools to improve the use of these limited resources, while increasing the use of these limited resources, while increasing the assurance that safe separation is maintained." [Debelack et al, 1995]

2.3 Human Capabilities and Limitations

In order to design the best possible graphical user-interface, one must have a basic understanding of the capabilities and limitations of air traffic controllers. The following is a brief overview of the characteristics that should be considered during the design phase.

2.3.1 Perception

Air traffic controllers synthesize two broad kinds of information: what is known beforehand and what is being presented. One perception-related issue is that of compatibility during integration of the presented information with the already known information which is mainly in the form of professional knowledge. Data presentation should adhere to two criteria. In terms of data sensing, the cues must be visible or audible to the controller. In terms of data perception, the controller must interpret their structure, coherence, unity, and meaning correctly. Successful information presentation entails correct sensing and correct perception. In other words, data must be sensed and make sense.

Technically, the direction of viewing visual stimuli can greatly affect their capability to command attention. Successful perception depends on the absolute intensity of the visual or auditory stimuli, and on their relative intensity in context. To be perceived, visual data have to be of appropriate size, duration, intensity, contrast, shape and color, and must not move too quickly. Auditory cues must also be appropriately designed as to complement, not hinder, the performance of the controller. [Hopkin, 1995]

With the advent of computer technology, there are countless possibilities for data presentation. A designer should not attempt to utilize all of the graphic potential that software has; instead, the number of colors should be limited, and the graphics presented should be large enough and simple enough to be perceived quickly. More attention is given to this topic in the Visual Coding section.

2.3.2 Attention

Traditionally, in human-machine systems the limitations imposed by attention are more severe than perceptual limitations. Far more information can be presented than can be attended to. Attending occupies time, and switching attention occupies additional time.

Task analyses or equivalent methods should be employed during the design of air traffic control systems to describe the routine tasks of the controller and to identify the informational requirements associated with a given task. After such an analysis, the information requirements at each workspace can be specified.

"The characteristics of human attention limit the amount of information that the controller can deal with. The main means to optimize attention in air traffic control are:

1. to code and present information in familiar forms so that the controller needs to attend to each item for as short a time as possible, can interpret it immediately, and does not have to recode any of it;
2. to train the controller so that all the presented information can be understood correctly;

3. to use appropriate codings to direct attention to the most pertinent items in the best sequence;
4. to present information at the optimum levels of detail for the tasks so that the controller does not have to seek more detailed information nor attend to irrelevant information only to discard it;
5. to eliminate the need to spend time searching for information, which employs attention unproductively;
6. to ensure adequate discriminability of all information so that attention to it is not prolonged by poor discrimination;
7. to use codings that make apparent and thus draw attention to significant associations between displayed items;
8. to minimize the distraction or disruption of attention from extraneous sources;

to select codings to attract attention to what is relevant, but select other codings to divert attention from what is irrelevant." [Hopkin, 1995]

2.3.3 Learning

To someone with no knowledge of air traffic control, an air traffic control workspace is nearly meaningless. "It contains very little information about its nature, objectives, functionality, tasks, or forms of feedback. There is no information at all on a paper flight progress strip about what it is or what it is for. Air traffic control therefore depends entirely on human learning. Even in the most sophisticated systems now being planned, with extensive automation and computer assistance, without the presence of the human air traffic controller there would be no air traffic control." [Hopkin, 1995]

Automated aids enable the controller to apply what has already been learned. Labeling, changes in menu and dialogue design, the formulation and presentation of options and reminders, and the direction of attention can be refined with future efforts to improve learning. However, the systems must not impose excessive learning demands.

"It is not sufficient for a task to be feasible; it must be teachable so that all or almost all current and future controllers will be able to learn to perform it consistently to an acceptable standard. This implies that the task must meet the following requirements:

1. it must make sense in air traffic control terms;
2. it must, after learning, be performed to the required standards, and must not take too long or impose undue demands on the controller's time and resources;
3. it must enable all who have to do the task to learn how to do it without any protracted training or high failure rates during training, and without any modification of controller selection procedures to accommodate the task requirements;
4. it must be fully compatible with existing learning, knowledge, skills, procedures and experience;
5. it must provide sufficient knowledge of results for the performance of those learning it to improve with experience;
6. it should have definable required levels of learning and achievement, with objective measures to prove that each controller has attained those levels;
7. it should preferably incorporate a hierarchy of skills so that learning can progress beyond procedures, rules and knowledge, to improved situational awareness and understanding and to appropriate forms of automaticity." [Hopkin, 1995]

2.3.4 Memory

Since few aspects of air traffic control are self-evident, each controller relies on memory to interpret what is displayed or available for display, and to control the air traffic. As a result, in the air traffic control community, much attention has been devoted to human memory – how to sustain and support it with guidance and direction, when it seems prudent to provide automated reminders rather than rely on human memory, and methods to influence and improve memory.

"Various forms of computer assistance are intended to aid human memory. Computer assistance can aid memory by signaling a need to confirm, initiate, contact or act, but the signals must be self-evident and familiar so that their significance is remembered correctly. If they remain unheeded, it must be possible to render them more obtrusive by increased intensity or other means. Codings intended initially to attract attention, such as of a pair of aircraft in potential conflict, can double as memory aids if they are in a suitable form to be retained until the conflict has been resolved. They denote the presence of a conflict rather than a solution of it." [Hopkin, 1995]

2.3.5 Information Processing

The design of the human-computer interface must facilitate the controller's processing of information. "Information processing that precedes task performance by the controller involves the following:

1. the gathering of information;
2. the collation of information of different kinds or from different sources;
3. the categorization of information according to its meaning and implication;
4. the selection of the relevant information for each task and the discarding of the irrelevant;
5. the recognition of the interrelationships among information categories;
6. the definition and appraisal of options, choices and alternatives;

7. the condensation, summarizing and integration of information;
8. the identification and search for any essential information that is lacking;
9. the processes of reviewing the relevant information available." [Hopkin, 1995]

Training and experience ensure that the controller is aware of all the information that should be processed, and automated systems can assist with queries and reminders if relevant data seem to be ignored.

2.3.6 Understanding

Understanding is the desired culmination of all the foregoing processes of perception, attention, learning, memory and information processing. Foremost among concepts dealing with aspects of understanding is the notion of the controller's mental picture of the air traffic. The picture is not static but evolves continuously with the traffic flow. Potential loss of the picture concerns the controller because it brings about an impression of temporary loss of control.

If active human involvement in tasks is replaced by passive human monitoring of a machine performing them, understanding can be impaired. The system's affect on understanding can therefore be predicted by evaluating the level of human involvement. ATC errors associated with misunderstanding or inadequate understanding may be alleviated if they can be traced to deficiencies in perception, attention, learning, remembering of information processing." [Hopkin, 1995]

2.3.7 Planning

With the steadily increasing air traffic and the advent of new technology, the role of the air traffic controller has evolved from the tactical control of a single aircraft to the organization of a traffic flow. This shift in roles has emphasized the importance of long-term planning. With an emphasis on planning, human cognitive capabilities and limitations assume greater significance. [Hopkin, 1995]

Many information parameters are available to formulate plans for the air traffic. Parameters can include any number of the following:

- current traffic situation
- pending flights (filed flight plans)
- professional skills and knowledge
- experience on how situations are likely to evolve
- possible circumstances that could invalidate the plans
- appropriate solutions for predicted problems
- optimal timing of solutions

Computers can supplement the controller's planning efforts by analyzing the applicable data. Controllers can then combine these advisories with experience to formulate the best plan.

In addition, in order for the planning process to be effective, the controller must obtain regular feedback on the outcome of the previous plans. Feedback enables learning from experience, and is crucial to improved performance. [Hopkin, 1995]

2.3.8 Problem Solving

Problem solving is an intrinsic feature of air traffic control. "Traditional problem solving has been associated with the following air traffic control functions:

1. air traffic demands that exceed the traffic-handling capability of the system;
2. the planning and continuing verification of safe separations between aircraft;
3. the detection and resolution of specific potential conflicts between aircraft;
4. the crossing or amalgamation of routs and traffic flows;
5. the resolution of the disparate air traffic control requirements of various air users;
6. the successful control of particularly difficult or complex patterns of air traffic;
7. acceding to user's requests;
8. the provision of an efficient air traffic control service with minimum delays;
9. the recognition and resolution of inadequacies or ambiguities in the information provided;
10. the maintenance of safety;
11. the optimum usage of the available traffic-handling capacity;
12. the scheduling or work activities in relation to the current and pending traffic;
13. the quick detection of any sudden and unperfected aircraft maneuvers or emergencies and the safe resolution of their consequences.

An unforeseeable set of circumstances may arise at any time and demand urgent action. All other activities should be planned so that their safety would not be jeopardized in such a situation. In practice, this means that the timescale for problem solving must always be sufficient. Since there may be difficulties in contacting a pilot or controller through busy communications channels, in resolving ambiguities, in reaching agreement on the best solution, or in responding to changed circumstances. Problem solving in air traffic control can never afford to become totally time constrained by pressures of demand.

"Technological advances can assist many problem-solving functions. In principle, a computer can derive a future traffic scenario from the current one better than the human controller can, and therefore it may formulate for the controller solutions to problems that can be foreseen when this is done. The acceptability of the products of such problem-solving aids depends on how well their functioning is understood, how far they are trusted, whether the controller can interrogate them about the factors contribution got or excluded from the proposed solutions, and the legal status of the solutions offered." [Hopkin, 1995]

2.3.9 Decision Making

"Controllers need to be able to choose and assimilate the relevant information quickly, weight it correctly, reach safe decisions, and act upon them confidently. Ideally it is always desirable to make the optimum decision, but it is not always possible to agree on the correct weighting of the various factors sufficiently to specify an optimum. In practice, each decision must be safe, effective and acceptable. Time to mull over alternatives is often limited, and dithering over decisions is obstructive."

Except in very light traffic, the implementation of any tactical decision normally has significant consequences for other decisions. The purpose of each decision is not merely to ensure the safety and expedition of the flight or flights to which it applies, but also to maintain a smooth traffic flow and an effective ATC service.

"Decision making in the course of the active control of air traffic is a continuing activity that utilizes the controller's comprehensive understanding of information at several levels of detail, together with the controller's knowledge of rules, procedures and instructions and their permissible flexibility. Tactical decisions about the air traffic are influenced by the controller's competence, experience and skill, by local customs and conditions, and by the planning of decision making. Decision making may be impaired by fatigue, by unsuitable procedures, by inadequate data or equipment, by poor communications, or by inappropriate system designs. It may also be impaired by deficiencies in the individual controller, in management, or in conditions of employment."

[Hopkin, 1995]

2.4 Human - Machine Interface

A sizable portion of delivered computer systems do not meet the needs of their intended users. As a result, they either go unused or only a portion of their capabilities are utilized. Researchers propose that the reason behind this phenomenon is that "our current methods of requirements analysis are incomplete and the analysis of the system requirements often misunderstands the true nature of the work which is to be supported by the computer system." [Sommerville et al, 1994]

A frequently neglected aspect in the development of large computer systems has been the interface between the computer and the user. In the final analysis, users are the ones who best understand their requirements and are the best judges of whether a particular implementation of these requirements meets operations needs.

Of course, the system should still be designed to meet functional and performance characteristics and to support, at a reasonable cost, future system maintenance and evolution is necessary; however, the most important objective for the ATC automation system design is that it allow the air traffic controllers to do their jobs safely and effectively.

[Hunt & Zellweger, 1987]

"Human-centered automation can be defined as "automation designed to work cooperatively with human operators in the pursuit of stated objectives." Given the assumption that the human is the manager and director, automation can be thought of as one of a number of resources, some human, others inanimate, that can be evoked in the process of reaching the objective (here, accomplishing the mission). The responsibility for mission accomplishment remains with the human operator, who must therefore possess the authority necessary to fulfill that responsibility."

Communication between the human and the system is the key to successful implementation of human-centered automation. In order to keep track of what the automation is doing, the human must be closely coupled to the automation at some level. Interfaces should display information in an integrated manner with regard to the human's perceptual capabilities and internal models of the system." [Billings, 1991] [Pozesky, 1991]

2.5 ATC Displays

2.5.1 Location within the workstation

The location of ATC displays is determined by principles of workspace design, and the specification and layout of suites and consoles.

The first step in locating a display is assessing the purpose of the display and identifying the information that will be present on the display. The decision should then be made on whether the display should be present at each workstation or wall-mounted so that it can be seen from many stations.

Line of sight constraints and lighting specifications should also be considered. [Hopkin, 1995]

2.5.2 Physical Characteristics

The size and shape of an ATC display also have human factors implications. Recent advancements in technology have made large screens widely available. The optimum visual diameter of a display is 350mm when viewed at a distance of 500mm. Much larger displays have introduced various complications.

There are both benefits and disadvantages associated with large displays. Benefits include their availability, flexibility and their popularity among controllers. The larger size also provides a greater area in which to lay out information, which reduces clutter and label overlap, and emphasizes the relationships between different kinds of data such as positional and tabular information.

Disadvantages include a greater viewing distance, a reduced maximum intensity and a poorer brightness contrast. Larger displays also have a greater weight and higher initial cost. Finally, because of their size, larger displays may be more difficult to see around or to light satisfactorily. [Hopkin, 1995]

2.5.3 Information Content

A task analysis or alternate method is used to derive the required information content of ATC displays. Not only should the analysis identify which information parameters should be included, but also what other information is required for it's correct interpretation. The analysis should also determine the sequencing of the information as well as the appropriate level of detail and timescales.

Obviously, the amount of information available for presentation for exceeds the controller's needs or the display's capabilities. As a result, various principles of selectivity have to be applied. Temporary displays and displays on demand can be employed to allow flexibility and enable the controllers to adjust the display to meet their needs. [Hopkin, 1995]

In developing the display, various configurations should be explored to ensure that the controller's needs are met. "Prototype visual displays must be evaluated for usability, operational suitability, and acceptability within the ATC context." [Cardosi & Murphy, 1995]

2.5.4 Visual Coding

How the information is coded and presented on the ATC display is crucial to the success of the user / interface relationship. "The controller needs to be presented with automation information that can be absorbed readily and does not detract from the fundamental task" of controlling the air traffic. [Tobias, 1991

Text & Symbols:

The text and symbols on an air traffic control display should be sized appropriately. A good rule of thumb for monochromatic displays is that the minimum height of the characters should be 1/200th of the viewing distance. The use of color changes the visual requirements, therefore, the exact size will depend upon many characteristics, including the viewing distance and the actual task at hand. For an ideal system, symbol and font sizes should be adjustable by the controller. [Cardosi & Murphy, 1995]

Emphasis Techniques:

"The following coding and emphasis techniques can be used to attract attention to specific information or to categorize information on a display: [Cardosi & Murphy, 1995]

- *Blinking or flashing* – flash coding or blinking should be used sparingly and never for text or numbers that are critical or that the controller needs to read quickly.
- *Reverse video*

- *Use of different sizes (of text or symbols)* – if size coding is used, ICAO (1993) recommends using only two widely different sizes. Emphasis should be placed on simplicity and clarity.
- *Color* – color coding is especially useful for highlighting or categorizing information on a display. Highlighting must be used sparingly so that emphasized items will actually "pop-out" from others.
- *Locations"*

Color Displays:

Careful attention must be given when designing color displays. Color derived from the stereotypical meaning associated with various color by different cultures is advised. For example, in Western cultures, red is widely associated with warnings/danger, while amber typically indicates caution, and green indicates normal status. It is strongly recommended that visual displays first be designed to meet human performance criteria under monochrome conditions, with color being added only if it will help the user in performing a task. ICAO (1993) lists the following recommendations on color usage for ATC displays:

- "In general, use pastel and desaturated colors. (An obvious exception to this is in tower dipoles viewed in direct sunlight, since sunlight washes out colors and desaturated colors would appear white.)
- Use saturated colors only for critical and temporary information because they can be visually disruptive.
- Do not use saturated colors for small visual objects or areas
- Do not use saturated colors, especially blue, that can induce problems such as false impressions of depth. Saturated red and blue should not be presented next to each other for this reason.

- Ensure that all colors meet the brightness contrast requirements.
- Use colors that are clearly different from each other to avoid confusion.
- Use colors that have obvious names familiar to all controllers.
- Use colors that allow for permissible deficiencies in color vision." [Cardosi & Murphy, 1995]

There are numerous benefits that can be associated with the use of color in the design of ATC displays. The use of color visually emphasizes the most important data and directs attention to them. This, in turn, reduces the controller's information processing load. In addition, this enables the addition of information that is not currently available on ATC displays without increasing the visual complexity of the display.

Color also creates a more visually restful display and allows the display to be viewed at normal office lighting levels. [Reynolds, 1994]

Typography:

Typography is also an important element of a graphical user-interface, the following are rules that should be followed whenever possible:

- "Abbreviations should be used sparingly.
- Punctuation should be used conservatively.
- Upper case should be reserved for the first letter in a sentence or a typically capitalized work, and acronyms should be upper case. Text presented in all upper case is more difficult to read as compare to mixed case.

- Upper case can be used for short items to draw the controller's attention to important text, such as for field labels or a window title.
- When controllers must read a length amount of text, they should be given printouts.
- Commands should be written in the active voice (rather than the passive voice.)
- Commands should be written in the affirmative.
- Error messages should be direct and precise, without being cryptic, cute, or insulting. Error messages should give the user a clear instruction in what to do next to recover from the error. [Cardosi & Murphy, 1995]

Graphical Format:

Consistency is also crucial when designing the format for the displays. The following is a partial style guide that is popularly used in the design process:

- Label placement is to the left of the associated field.
- A colon is placed immediately after all field labels.
- Data entry fields are surrounded by a rectangular box indicating maximum field length.
- Wherever a unit of measure is associated with a field, the unit of measure is displayed one space to the right of the field.
- Time and date are presented as MM/DD/YY HH:MM:SS.
- Helvetica font is used for all text.
- Assuming a viewing distance of 18 inches, .11 inch character height is used for the main menu title bar and main menu options; and .11 inch character height is used for window and display titles.
- .09 inch character height is used for all other text.

- Command push buttons and command icons are placed at the bottom of a display or window and left justified.

"It is a key design goal to ensure that the computer present all data required to accomplish individual or team tasks without any extraneous data cluttering the display. At the same time, controllers should be able to modify the amount and detail of task-related data being presented. Critical information should never disappear from the screen without being deleted or suppressed by the controller." [Cardosi & Murphy, 1995]

A key objective of any communications system in air traffic control (ATC) should be to enable the controller to integrate new with existing information regarding the state of the airspace in order to most rapidly and accurately update or evaluate "the big picture."

"Research in engineering psychology has indicated that one key feature that could facilitate the integration of new information with old (i.e., the spatial request with the existing traffic pattern situation) is the similarity of the format of representation of the two items of information . As applied to the current scenario, this guideline would suggest that, since the controller's display, as well as the controller's "mental picture" of the airspace is visual-spatial, so too the request should be presented in a visual spatial format. This format would alleviate the need to mentally transform a request in a vocal format to its visual-spatial trajectory in order to evaluate its feasibility." [Wickens, Miller, Tham, 1994]

2.5.5 Touchscreens

"Touch-sensitive screens are used in data input for ATC systems, where space is at a premium and where use of a keyboard is not recommended. Using a touchscreen, controllers can be guided through complex activities. Some early problems associated with touchscreens have been alleviated (e.g., hand obscuring screen, fatigue, screen smudging), but human factors issues must be addressed with every specific application of touchscreen technology to ensure that is appropriate for a particular ATC situation. An advantage of a touchscreen is that all valid inputs are displayed on the screen, and the relationship between the user's input and display output is straightforward."

To eliminate potential errors when touching the screen, touch keys should be at least 20.32 mm wide, 10.16 mm tall, with 5.08 mm vertical spacing and 10.16 mm horizontal spacing. [Cardosi & Murphy, 1995]

2.6 Computer Assistance

Computer technology and other methods of automation are available in several forms. The two principle types of computer aids are problem-solving and decision-making. Within these categories are two options: optional and mandatory forms of assistance.

2.6.1 Problem Solving Aids

Within the area of problem solving aids there are various levels of assistance. At the most fundamental level, the simplest problem-solving aids merely indicate the existence of a problem. Although action or increased monitoring may be required on the part of the controller, a basic problem-solving system makes no recommendations.

The next level of aid not only prompts the user, but also supports an aspect of the problem-solving process. "It may automatically provide further information, or offer menu options, or illustrate applicable constraints, or indicate possible benefits or penalties associated with alternative solutions."

"In a different category are more complex forms of computer assistance that do offer solutions to problems. The controller may be free to accept or reject the solution offered, and more than one alternative computed solution may be presented with or without an indicated computer preference, but the actual process of prelim solving is automated to the extent that the controller does not actually have to gather the relevant information and formulate a solution. The controller usually has to judge if solutions should be checked and how to do so, a dilemma that does not arise unless ready-made solutions are offered." [Hopkin, 1995]

2.6.2 Decision Making Aids

Like problem-solving aids, decision-making aids also must utilize ATC rules, regulations, instructions and procedures. The most basic decision-making aids simply alert the controller of the need to make a decision. The most fundamental decision for a controller is whether to intervene in a situation or not, and the optimal timing of any intervention.

Other aids support the decision making process directly. Frequently, the aids are associated with presentational changes. The system may introduce additional information or automatically emphasize existing information.

Decision making aids often have some fundamental problems involving interrogation of the computer about its decision. It is important that the system enable controllers to learn which information parameters influenced the decision. [Hopkin, 1995]

2.6.3 Optional and Mandatory forms of Assistance

Obviously, in the early stages of automation implementation, it is important that computer assistance be optional as opposed to mandatory. This distinction has important human factors implications. Some systems convey the impression that the assistance is optional because they actually present choices and alternatives; however, the assistance is nevertheless mandatory because they demand that a choice is made from the presented alternatives.

To avoid this phenomenon, it is important that an interface design include as many options as possible. Another trend is to provide computer assistance that the controller can switch on or off.

No matter how the system is designed, it will only achieve optimum benefit if the controller knows how to use the system, and if it has been optimally matched with human and ATC needs. [Hopkin, 1995]

2.7 Impacts of Automation

"There is little doubt that automation is inevitable and, in the end, largely beneficial. Nonetheless, numerous potential important concerns have been expressed about the psychological consequences of automation on air traffic controllers. The concerns typically revolve around the view that the manual performance of some tasks, although repetitive and burdensome, may be beneficial because it builds understanding relevant to overall performance. In this view, automation of routine activities may have unintended negative consequences for performance and, by implication, air traffic safety." [Vortac, 1994]

2.7.1 Monitoring

Research has suggested several recommendations to minimize the controller's performance impairment during monitoring:

1. Minimize scanning requirements by reducing the number of targets, stimulus sources, and displays that the controller must monitor. Studies have shown that individuals can effectively monitor 4 to 8 aircraft for even difficult critical events.
2. Increase the conspicuity of critical events in such a way that they literally "pop out" from background events. Flashing data blocks as employed in the conflict alerts of contemporary ATC displays are a good example of this. Flashing has been found to be far superior to color in this respect in attracting attention to unexpected peripheral events.
3. When a monitoring task requires individuals to expend considerable effort in order to detect critical events because of high information processing demands, scanning requirements, and/or time stress, a monitoring period should not exceed 1 hour in length without at least a five-minute rest period or change in activity. [Thackray, 1991]

2.7.2 Passive Roles

In many cases, computer assistance converts active human roles and tasks into more passive ones. The central purpose of most forms of computer assistance has not been to render human roles more passive, but to reduce the controller's workload associated with more air traffic.

"An effect of increased passivity can be to encourage the controller to access information only to look at it and not to use if for any control action. The controller's intention is to refresh memory or check the information, an additional task resulting from passivity because it was superfluous when the manual tasks that have become computer assisted were more active." [Hopkin, 1995]

2.7.3 Mental Picture

A controller's mental picture of the air traffic provides a basic understanding of the traffic scenario as a whole. The controller's processes of planning, scheduling, predicting, solving problems and making decisions depend on the picture. It also provides the basis for checking that instructions are obeyed, that decisions are correct, and that plans reach fruition. The controller's professional knowledge of ATC and of its procedures, rules and practices, make the mental picture meaningful.

Unfortunately, even quite simple forms of computer assistance that replace manual tasks with automated ones, may be accompanied by reports from controllers that they experienced a temporary loss of their mental picture. In other cases, controllers simply have the impression that automation causes their mental picture to become more vulnerable to being lost. However, the time saved by the computer assistance can be spent by controllers to rebuild their traffic picture to its former state. This can be accomplished by calling down information items onto their displays sequentially and thereby restoring some of the mental processing of the information about the traffic that the computer assistance has taken away. [Hopkin, 1995]

2.8 Flight Progress Strips

2.8.1 Definition

Since one of the principle roles of air traffic controllers is to anticipate potential problems so, "to supplement the radar, they use paper flight progress strips which carry information about expected and current flights being controlled, together with a record of controller's instructions to the controlled aircraft." [Sommerville et al, 1994]

The flight progress strip (FPS) includes numerous fields of information about a flight – both static and dynamic information parameters. These may include route, type of aircraft, flight number, heading or current altitude. When control decisions are made, these are communicated to the aircraft and recorded on the strip so that a record is maintained of controller actions. [Sommerville et al, 1994] [Vortac & Edwards, 1994]

Flight strips are organized on a flight progress board where strips are aligned and organized in a rack according to the reporting points over which a flight will pass. To the accomplished controller this display is an 'at a glance' means of showing the various flight attributes. [Sommerville et al, 1994]

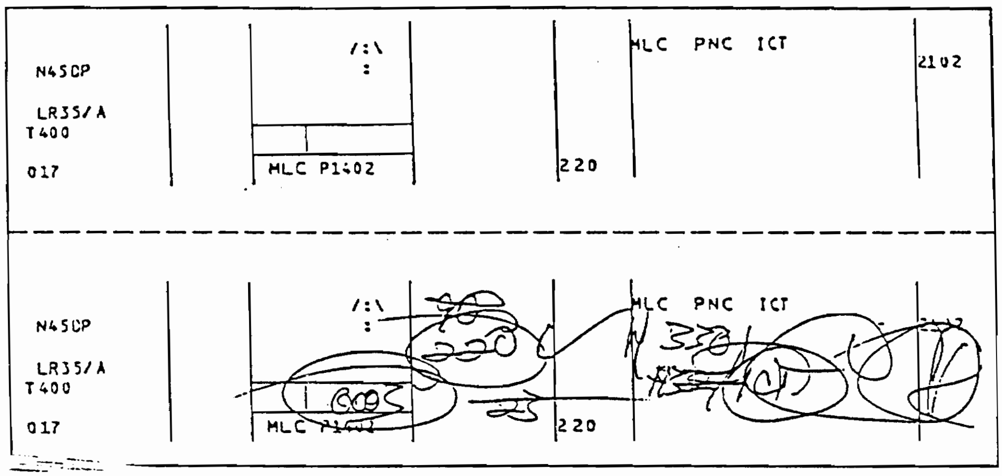

FIGURE 2.1: Depiction of a typical flight progress strip – before and after use.

2.8.2 Role of Flight Progress Strips

Flight progress strips are not simply a paper database – they have unique cognitive behavioral functions and serve as a memory aid.

The flight strips and progress boards are an individual work site, a planning tool and a team memory aid. The simple act of placing the FPS into the active bay forces the controller to integrate new data with existing data, helping to form the mental picture of the air traffic. [Sommerville et al, 1994] [Vortac & Edwards, 1994]

2.8.3 How to Automate Flight Progress Data

Many recent research efforts have focused on developing an automated version of the traditional flight progress strips. Although numerous pros and cons have been identified, the following design parameters have been proposed:

1. Strips should not be arbitrarily and automatically moved on the display. Instead, the controller should manually make adjustments. This is an attempt to replicate the current system.
2. To aid with flight identification, colored borders are assigned to strips based on the aircraft heading. In addition, the activity of "handing a strip over' is maintained as a manual activity.
3. To make use of limited screen space, the user-interface cannot be tailored except for switching from full-sized to summarized strips. [Sommerville et al, 1994]

2.8.4 Effects of Automating Flight Progress Strips

The effect of changing flight data over from physical entities to electronic representatives is unknown. In support, the use of electronic flight progress data may enhance controller performance because it contains more accurate flight data. On the other hand, it is possible that use of the electronic replicas could have unforeseen and negative consequences.

Many aviation experts discourage efforts to automate flight progress strips. When controllers convert to using electronic flight progress strips they will no longer be able to physically manipulate the information in the same way as before. This switch is believed to degrade the cognitive effects associated with manual strip manipulation.

"Strips help the controller to organize work and resolve problems, to plan future work, and to adjust current work in accordance with future plans. The physical act of transferring the strip from the pending to the active bay on assuming control responsibility for an aircraft involves a recapitulation and review of knowledge and previous decisions. This process reinforces the picture of the air traffic as a whole, and the details recalled about each aircraft. The physical action in moving a strip aids memory of its contents, or its location on the board, and of why it is there. Writing on flight strips seems more memorable than watching the automatic updating of information, and these functions are not cognitively equivalent." [Hopkin, 1995]

While this line of theory has merit, other researchers have found that the switch to the electronic version had little adverse effect on controller performance. "Overall, it seems that a severe reduction in direct interactions with flight progress strips will not have dramatic negative consequences, and may, in fact, have some positive ones: Relieving controllers of board management responsibilities will not adversely affect attention and retrospective memory, and will have a positive effect on at least some manifestations of prospective memory and perhaps planning. Current research suggests that less interactions with flight progress strips should not be viewed as a large handicap and could instead enhance the controller's ability to consider future events." [Vortac et al, 1994]

2.9 Environmental Constraints

2.9.1 Air Traffic Control Towers

An air traffic control tower presents some unique human factors challenges that are not found in traditional air traffic control centers:

- "The physical environment, particularly the lighting, is not constant in towers but variable. Ambient lighting levels can vary from bright sunlight to those provided within the tower during the night. The direction of the light source varies with the time of data: in certain positions sunlight may shine directly onto, and be reflected from, operational displays.
- The tower controller integrates into the air traffic control tasks the view from the tower of aircraft on or near the airport, and thus combines direct and indirect sources of information.
- The controller has a panoramic view through a large visual arc and must be free to scan in many directions, with the minimum interference between the height of any consoles or other equipment installed in the tower and the controller's view over them looking down at aircraft maneuvering. The tower controller's postural and viewing positions cannot be wholly standardized.
- The controller must see and perhaps hear aircraft movements against a wide range of visual backgrounds including sky, cloud, darkness, restricted visibility, and light patterns on the ground, none of which must induce misperceptions.
- Towers have to be sited in relation to the runway length and orientation, the surrounding terrain, other buildings and facilities within the airport, and the positions of the sun. Many local conditions should influence their siting, to minimize interference with the controller's view of circuits, approach and departure paths, runways, taxiways and aprons. The controller's view must not be impeded more than absolutely necessary by stanchions or other structural features of the tower, or by

other controllers at their workstations in the tower. The designs of towers must overcome these limitations and satisfy their requirements. [Hopkin, 1995]

2.9.2 Workspace Design

Following are some of the primary objectives of workspace design that must be met when working with air traffic control:

1. "To achieve the highest standards of operational efficiency and safety by avoiding all unnecessary constraints on task performance and on its accuracy, reliability and pace.
2. To design workspaces that promote system policies and objectives regarding the division of tasks, the allocation of responsibilities and the balance between individual and team decision making.
3. To ensure that the workspace permits the whole envisaged range of staffing flexibility, so that staffing can always be matched with traffic demands.
4. To fulfill within the workspace all its ancillary functions, including handover, training, assessment, supervision, assistance, and maintenance.
5. To meet all the envisaged requirements for liaison, coordination and communications between air and ground, between human and machine, and between humans within the system.
6. To provide every controller with all the information needed and with means to access it readily, and to provide all the equipment needed for the whole range of tasks in forms that are easily identifiable an promote the efficient performance of each task and smooth transitions between tasks.
7. To reflect task structures and the relationships between tasks through the equipment, facilities and layouts.
8. To check that all items within the workspace meet the applicable ergonomic recommendations

9. To incorporate in the workspace design all practical means to proven foreseeable critical errors and omissions and to recover from any that are not prevented
10. To provide physical work conditions that are not obtrusive or distracting but pleasant and harmonious.
11. To check that all the information necessary for jobs and tasks is present in forms which are intelligible and that it can be manipulated to meet operational requirements and to harmonize with the needs of other tasks.
12. To ensure that no features of the workspace could have adverse effects of the well-being of those employed within it.
13. To foster interest, job satisfaction, morale and self-esteem within the workspace."

[Hopkin, 1995]

2.10 Similar Systems

2.10.1 An Automated TCA Monitor System for Air Traffic Control

A similar system to the proposed system has been developed by researchers in China referred to as "An Automated TCA Monitor System for Air Traffic Control" It is a real time monitor system that serves as an aid to air traffic controller in a terminal control area (TCA). The proposed monitor system is composed of a mathematical algorithms and a knowledge-based system to check real time aircraft data from radar data processor (RDP) with flight route constraints in a TCA. The flight route constraints are generated according to flight routes by different arrival and departure methods, TCA geographical conditions, real time weather conditions and other conditions which are significant to flight safety. Linear extrapolations of aircraft position data are calculated to examine constraint violations. The output of TCA monitor system in flashing mode or tone mode alerts the TCA controllers for hazardous conditions in advance. Using the proposed TCA monitor system, flight safety in a TCA can be improved, and ATC controller load can also be reduced." [Lin and Chen, 1994]

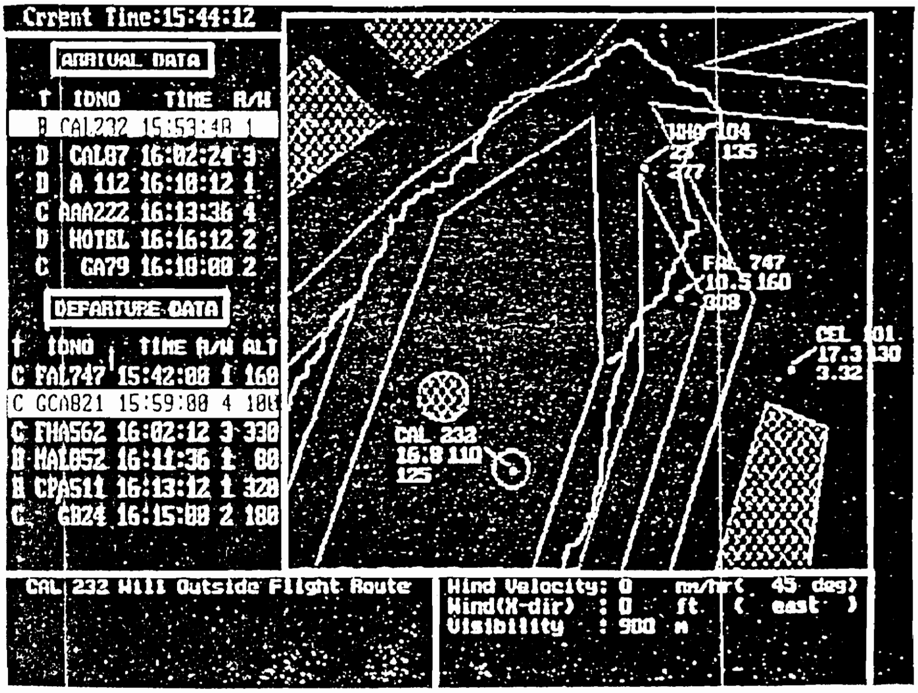

FIGURE 2.2: TCA Monitor System Screen Display

2.10.2 TATCA: Terminal Air Traffic Control Automation

"Automation is being developed by the FAA to assist terminal radar controller teams in efficiently merging and sequencing arrivals and precisely spacing aircraft on final approach during busy periods. To increase controller effectiveness and avoid operational errors, the techniques of human factors engineering are being applied in designing the human-system interface (HSI) for these automation aids."

"Preliminary real-time simulations have been conducted at Lincoln Laboratory using a relatively passive type of final-approach spacing aid known as a centerline slot marker. Centerline slot markers are similar to the passive "ghosting" aid currently being used by the FAA at St. Louis. The ghosting aid makes use of the display symbology available on existing terminal radar displays to assist controllers in achieving safely staggered spacings between aircraft landing on converging runways. The location of each ghost symbol is determined by performing (within the existing terminal radar display processor) a trigonometric transformation of the position of an actual aircraft approaching on the complementary converging runway. These symbols allow the controller to visualize the longitudinal spacing between aircraft as if they were arriving on a single runway."

"Using a computer external to the existing radar display processor to provide more flexibility in positioning the symbols on the screen, centerline slot markers indicated the desired position and ground-speed of each arrival on the final approach path to a given runway, rather than actual positions determined by reflecting other arriving aircraft. These markers exploit the controllers' natural use of spatial cues by translating the computer's recommended time schedule into a distance representation on the radar scope. They dynamically indicate the computer's planned outer-marker spacings for all arrivals. Appropriately separated from adjacent markers on the display, each marker moves along the extended runway centerline at its corresponding aircraft's desired ground speed as the aircraft approached the outer marker. The velocities and separations of the markers account for wind, aircraft performance characteristics, and wake vortex separation requirements.

These markers appear on the screen with abbreviated aircraft identification numbers to provide an early indication of the planned landing sequence. Then the controller vectors an aircraft to intercept its marker, the aircraft number is dropped from the marker, thereby giving positive feedback of target interception when using these aids." [Picardi, 1991]

3. Methodology

3.1 Introduction

The process of designing a new automated advisory system for use by air traffic controllers can be divided into four distinct phases as outlined in Human Engineering Guide to Equipment Design. Each step of the design process can be accomplished by answering a series of questions to steer the design in the proper direction. [Van Cott, 1972]

The questions in the preliminary design phase establish goals and objectives for the new systems. This phase also generates system specifications as well as possible alternative configurations.

Preliminary design phase

a) Why is this system being sought? What mission will the system be expected to fulfill? More particularly, what is this new system expected to do that existing systems are not doing or are not doing well enough?
b) How is the system to fulfill its mission? What are the stages of mission execution? What functions must be accomplished by the system at each stage?
c) In what environments must the system function? What particular hazards will obtain? What stresses or demands are likely to be placed on the system?
d) Who will benefit by system operation? Who will use the system? What kinds and numbers of operator and/or maintenance personnel are available?

e) What are the major technological options? What alternative configurations are feasible? What particular resource or class of resource is most crucial to prospective system effectiveness?

The advanced design phase consists of a series of questions aimed to identify the design conditions, the required information parameters that need to be presented as well as further specifying system requirements and characteristics. A task analysis is an integral part of this design phase.

Advanced design phase

a) What functions should be assigned to human operator and support personnel? What conditions will impose peak task loads on the operator or operators? What conditions (e.g., long periods of inactivity) will tend to degrade operator performance? What pattern of decision – action will occur at crucial mission stages?
b) What information is required by operators (and/or support personnel) in order to fulfill their functions? What is the probable pattern of channels and of flow rate for this information? In what form (i.e., code, mode, format) will the information be most useful to the operator?
c) How many humans are needed to man and support the system under normal and peak load conditions? What special skills, capabilities or attributes are needed for effective operator performance? What special training, if any, will be required? Is such training feasible? What resources will be required to implement the training?
d) How should the assigned functions be distributed among operator and support personnel? How should the work stations be arranged? What instrumentation is required at each work station? How should this instrumentation be laid out?

e) What specific devices tools, or controls are most appropriate to the pattern of task actions that will be imposed on operator and support personnel? What kinds of aids, guides, indicators, lock, interlocks, cover plates, etc. would be useful to facilitate correct actions and prevent operator errors? What means are available to allow quick recovery or to maintain the safety and integrity of the system in the event of operator error or failure?

The third step is the mock-up and prototype fabrication phase. By creating a prototype the system can be streamlined and altered in order to improve human performance and satisfaction with the system.

Mock-up to prototype fabrication phase

a) What options are available for eliminating, combining, or simplifying any of the instrumentation?
b) What will be the effect, if any, on human performance, safety, or morale of any proposed changes in configuration or instrumentation?
c) What safeguards, if any, are required to insure adherence to the design plan and functional requirements of the system? What quality control procedures are required to insure the validity of human factors considerations in the final product?

The final design stage is the test and evaluation phase. This step is used to ascertain a measure of the effectiveness of the system. The questions answered in this stage evaluate the prototyped system and provide direction to the implementation of the real system.

Test and evaluation phase

a) By what means can test and evaluation be made as realistic as possible in terms of the ultimate operator and support personnel and in terms of the operational conditions?
b) What criteria of system and operator performance are logical in terms of the mission and functions assigned? What measurement procedures will yield data which are valid with respect to such criteria? What test instrumentation is required?
c) What form of test design will yield unequivocal answers to questions of the effectiveness, operability and maintainability of the system? What is the most economical way of implementing the test design required?

3.2 User-Centered Approach

For systems with a complex human/computer interface it is important to concentrate on the user's role. Part of the user's job is to decide what to do and when to do it. The system must provide the information necessary to facilitate this process under varying conditions.

The goal is to understand the user's needs well enough to write a set of requirements and develop a user interface that allows the users to do their job effectively. To achieve this goal many facts and opinions must be collected, analyzed and synthesized. Many techniques may be used including, but not limited to: [Gutmann, 1991]

- Observation of current system operation
- Consultation with subject matter experts

* Analysis of operating procedures
* Recording upper level task descriptions
* Subject matter expert evaluation of system requirements
* Expert and user evaluation or prototypes
* Expert and user assessments during demonstrations

Obviously, a user-centered approach imposes a great demand on the user interface. In order to be effective, the system's functionality should be clearly revealed to the user. In addition, the application and the user must share a coherent vision and understanding of the system operation. [Schlater, 1994]

3.3 Observation and Task Analysis

In order to fully comprehend the user's needs, it is important to analyze their behavior under normal circumstances. To accomplish this goal, there are two important steps; 1) observation, and 2) task analysis.

The process of observing controllers in their regular routing is essential to the completion of an informative task analysis.

When developing a new system, a task analysis provides data for predicting the nature of the job activities that would be required to operate and maintain the projected system. This approach has two primary purposes: [McCormick, 1995]

1) To determine if there are any job activities that might be undesirable from a human factors point of view
2) To predict the nature of the jobs that would be required when the system becomes operational

The task analysis should answer the following questions: [Cardosi and Murhpy, 1995]

- What is the objective of the task that must be performed with this display? What other tasks will be performed concurrently?
- What information is needed by the controller at each stage of performing the task?
- What errors is the controller likely to make in conducting this task? What are the consequences of these errors?
- What other displays will the controller be working with? The symbology, layout, controls, and other characteristics of the new display must be compatible with those of other displays in use.
- How critical is it for this task to be completed immediately?

The task analysis is accomplished by gathering and organizing information related to:

- the psychological aspects of the indication to be observed (stimulus and channel)
- the action required (response behavior, including decision making)
- the skills and knowledge required for task performance
- probable characteristic human errors and equipment malfunctions

This information can be divided into two major parts; (a) subtask derivation and (b) skill and knowledge analysis. To find out which skills and knowledge are required involves an examination of the various steps or parts of the subtasks. This analysis results in a statement of the psychological requirements of the tasks, the kinds of discriminations that must be made, the decision-making, motor and other skilled responses required." [Van Cott, 1972]

"Task description consists of systematically describing, at successive levels of detail, what a user does when operating an existing system or what a user could do when operating a new system. A task description typically contains an identifier which indicates the level of description (e.g., activity, sub-activity, task, subtask), entry conditions, user information needs, user actions (including communication with other users), feedback from actions taken, timing considerations (time constraints, estimated durations, system response times), skills or knowledge required, classification of user action, potential for error or consequences of error, and exit conditions." [Gutmann, 1991]

3.4 Rapid Prototyping

As discussed previously, observation and task analysis are not the only methods used to determine the user's needs. Rapid Prototyping is a procedure used to develop new systems that have been found to have a high level of user acceptance.

The rapid prototyping process has five general steps:

1. Define Design Objectives
2. Create a Basic Interface Concept
3. Specify Information/Controllers for Each Display
4. Obtain Feedback from the Operators
5. Develop Actual Interface for First System

Step one traditionally consists of working with system operators to determine design objectives. Step two involves researching existing concepts, discussing alternatives with operators and developing a concept for application. Step three consists of extensive work with selective operators to obtain lists of necessary information and then prototyping the display via personal computer applications. The fourth step involves showing the developed prototype to operators to obtain user feedback – this process also encourages operators to become a part of the system development. Step five consists of developing the actual interface on the specified platform that will be used in actual practice. [Blackman, 1991]

3.5 Questionnaire

In order to ascertain the air traffic controller's input, a questionnaire was developed to gauge the controller's attitudes on various aspects of the user-interface. The questionnaire used in this research is shown in the appendix.

In research, questionnaires strive to obtain the following objectives: [Labaw, 1980]

1. "Gauge the depth of understanding of an issue or problem by determining the nearness of a respondent to it through actual experience or levels of experience. Those people who have actual experience are more likely to be conscious of their answers, because the experience has forced them to think more about the problem or feel more deeply about it.
2. Determine the respondent's ability to see an entire picture rather than random parts by asking a series of questions outlining the different facets of the issue, and then check answers to see that the respondent answered all the different questions logically and consistently.
3. Determine the respondent's framework within which he is answering questions by asking a series of questions to outline the framework, and by asking open-ended questions which allow the respondent to tell you more of what is inside his own head, and allow the respondent to explain to you what he means by his own answers.
4. Determine the respondent's ability to understand his own behavior by concentrating on the respondent's actual behavior: what he did, when he did it, what the circumstances surrounding his behavior were. Analyze his answers in terms of actual behavior. Do his stated reasons for his behavior correspond to his actual behavior, or do they seem unrelated?"

The following list describes the processes associated with questionnaire design and data analysis. [Oppenheim, 1992]

1. Decide the aims of the study
2. Review the relevant literature
3. Preliminary conceptualization of the study
4. Deciding the design of the study and assessing its feasibility
5. Deciding which hypothesis will be investigated
6. Designing the necessary research instruments
7. Doing the necessary pilot work
8. Designing the samples
9. Selection of the people / Drawing the sample
10. Doing the field-work
11. Processing the data
12. Performing the statistical analysis
13. Assembling the results and testing the hypotheses
14. Writing the report

3.6 Focus Groups

In many instances, a questionnaire does not point to all of the user-requirements for a new system. Focus groups have proven useful following the analysis of a qualitative survey. The focus group facilitates interpretation of quantitative results and adds depth to the responses obtained in the more structured survey.

"One of the strengths of focus group research is that it may be adapted to provide the most desirable level of focus and structure."

"The contemporary focus group interview generally involves 8 to 12 individuals who discuss a particular topic under the direction of a moderator who promotes interaction and assures that the discussion remains on the topic of interest. A typical focus group session will last from one and a half to two and a half hours."

"The moderator is the key to assuring that a group discussion goes smoothly. The focus group moderator generally is well trained in group dynamics and interview skills."

"Focus groups alone may be a sufficient basis for decision making in various cases. Especially in a situation in which there is reason to believe that the group of people – or population – of interest is relatively homogeneous, at least with respect to the issue at hand. In such cases, a small number of respondents is all that is needed to generalize to the larger population."

The success of focus group research depends largely on the effective planning and organization of the group and the research goals. The following is a list of the steps that should be accomplished when undertaking focus group research. [Stewart & Shamdasani, 1990]

1. Problem Definition / Formulation of the Research / Question:
2. Identification of Sampling Frame:
3. Identification of Moderator:
4. Generation and pre-testing of Interview Guide
5. Recruiting the Sample
6. Conducting the Group
7. Analysis and Interpretation of Data
8. Writing the Report

3.7 Authorware

Previous research has proven that PC applications can be very valuable in the initial design phases of a proposed user-interface. The use of a computer application enables operators to actually see the effects of their suggestions virtually immediately. "This not only provides a means of developing a quality interface, but operators really see their contribution being used." [Blackman, 1991]

Macromedia's Authorware 3.0 software is a platform that can be used to design multi-media presentations. This software facilitates the design of an interactive prototype. Although the prototype is not truly connected to the mathematical algorithms, it can be used to simulate the processes that the controllers complete when utilizing the advisory system. With this software, human factors issues can be explored more completely and the users can get a "feel" for the system and provide valuable feedback before a great deal of resources are invested into the project.

4. Model Development

4.1 Introduction

Three different scenarios have been considered during the design of the Ground Control Advisory System. Although future applications may include other additional scenarios, for research purposes, three of the most typical have been evaluated. First, the touch-and-go maneuver has been investigated, followed by applications involving simultaneous intersecting runway operations and standard bank operations. Diagrams illustrating the three scenarios can be found following the descriptions of the operations.

4.2 Touch-and-Go Operations (TGO)

A touch-and-go clearance allows an aircraft to land on a given runway, but to take off again before actually coming to a complete stop. This maneuver is usually used by students practicing takeoffs and landings. An aircraft performing a touch-and-go is considered an arriving aircraft until actually touching down, then is considered a departure.

Touch-and-Go operations are normally found at small and medium facilities because they are primarily performed by student pilots. These operations can be somewhat disruptive to the normal traffic flow and air traffic control routine. Because the aircraft partially circles the airport during the maneuver, it restricts other arrivals and departures for a period of time. Some flexibility, however, is available to the controller in terms of the third, or base, leg of the touch-and-go operation.

When intersecting runways are present at a facility, one runway is often reserved for the touch-and-go operation, while the other runway is used for the regular air traffic. In the scenario where an aircraft is on final approach on one runway and the touch-and-go aircraft is approaching the facility, it is important to accommodate the arriving aircraft. In this situation, the touch-and-go operation should be scheduled to touch down after the other arriving aircraft.

Air traffic control rules state that the second landing aircraft (in this case, the touch-and-go) must be sequenced so as to not cross the landing threshold until at least one of the following conditions exists:

- An aircraft landing on the intersecting runway has taxied off the landing runway
- An aircraft landing on the intersecting runway has crossed the runway intersection
- An aircraft landing on the intersecting runway has completed the landing roll and advised the local controller that the aircraft will hold short of the intersecting runway.

"When approved in the facility directives, the local controller may authorize an aircraft to land on a runway that intersects the departure runway when all of the following conditions can be met:

- VFR conditions exist at the airport and it is between sunrise and sunset.
- The aircraft has been instructed to hold short of the intersecting runway, and has acknowledged the instruction.
- The departing aircraft has been advised that the other aircraft will be holding short.

- Both runways are clear and dry with no reports that the braking actions is less than "good."
- The aircraft restricted to hold short has no tailwind.
- If requested by the pilot, the distance from the landing threshold to the intersection has been issued by the local controller." [Nolan, 1990]

In order to ensure that the touch-and-go operation meets the outlined conditions, the base leg of the maneuver can be specified by the air traffic controller. The touch-and-go aircraft can follow one of three paths assigned by the controller. A short base leg means that the aircraft turns close into the airport, an extended base leg means that the aircraft extends the turn away from the facility, and a normal base leg is in the middle.

The Ground Control Advisory System is designed to advise controllers on turning paths to minimize conflicts. The advisory system is designed with the assumption that differential global positioning systems (DGPS) can provide the system with continuous position updates for both aircraft at the rate of one update per second.

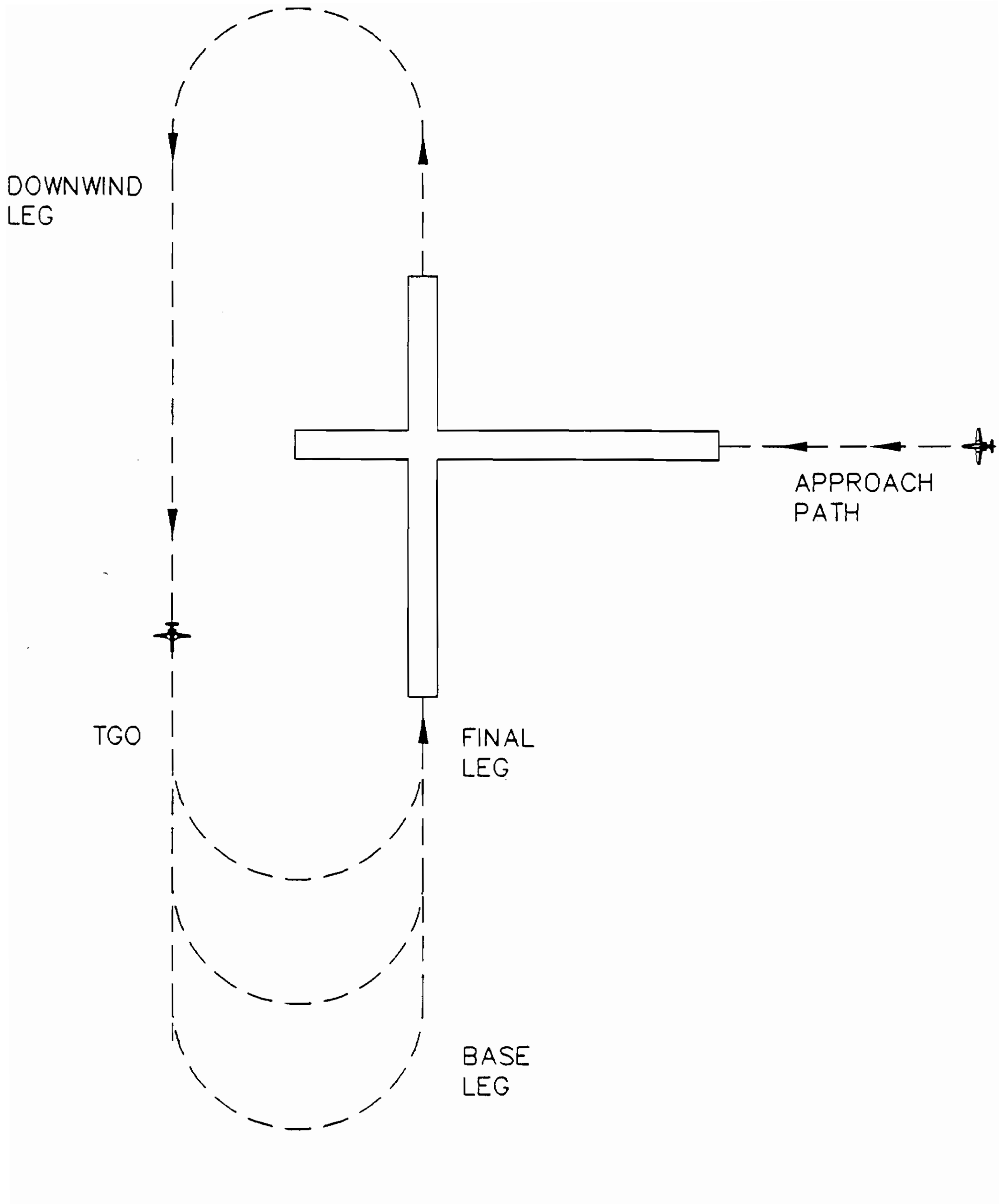

FIGURE 4.1: Diagram of Touch-and-Go Operations

4.3 Simultaneous Intersecting Runway Operations (SIRO)

"Many airports have two or more runways in different directions crossing each other. These are referred to as intersecting runways. Intersecting runways are necessary when relatively strong winds come from more than one direction, resulting in excessive crosswinds when only one runway is provided. When winds are strong, only one runway of a pair of intersecting runways can be used, reducing the capacity of the airfield substantially. If the winds are relatively light, both runways can be used simultaneously. The capacity of two intersecting runways depends a great deal on the location of the intersection (i.e., midway or near the ends); the manner in which runways are operated for takeoffs and landings, referred to as the runway-use strategy; and the aircraft mix. The farther the intersection is from the takeoff end of the runway and the landing threshold, the lower the capacity. The highest capacity is achieved when the intersection is close to the take-off and landing threshold." [Horonjeff & McKelvey, 1994]

When both runways are used simultaneously, it is important for the air traffic controllers to coordinate takeoffs and landings. The air traffic control rules that govern the described scenario are outlined in the previous section.

When an arrival is approaching the facility and a departing flight is awaiting clearance, it is essential that the advisory system provide various information parameters to the controller on duty. When the arriving flight touches down, the controller needs the advisory system to estimate the landing roll trajectory and predict whether the arrival will cross the runway intersection. If this information is provided, it can shorten the departure occupancy time for the departing aircraft. In other instances, the controllers need to know the approximate point of lift-off for the departing aircraft. This can also shorten the interval of time allowed for intersecting operations.

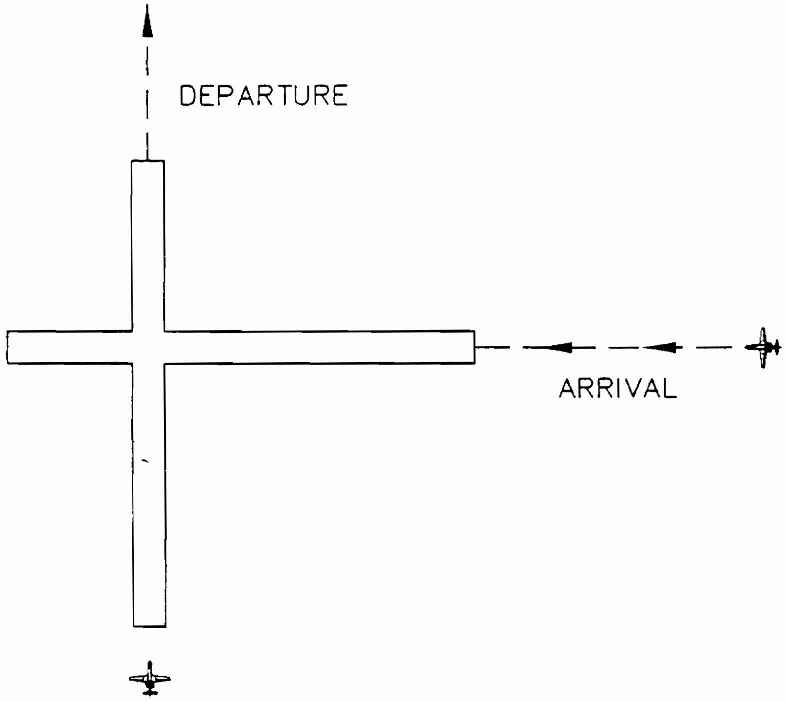

FIGURE 4.2: Diagram of Simultaneous Intersecting Runway Operations

4.4 Standard Bank Operations

Parallel runways are one of the most popular runway configurations. The capacities of parallel-runway systems depend a great deal on the number of runways and on the spacing between them. Runway spacing can be classified as close, intermediate, and far, depending on the centerline separation between two parallel runways.

Close parallel runways are spaced from 700 feet to less than 2,500 feet. Under instrument flight rules (IFR), the operation of close runways is *dependent* upon the operation on the other runway. Under visual meteorological conditions (VMC) close parallel runways allow simultaneous arrivals and departures; i.e., arrivals may occur on one runway while departures are occurring on the other runway. When simultaneous operations are being allowed, wake vortex avoidance procedures must be used.

Intermediate parallel runways are spaced from 2,500 feet to less than 4,300 feet. In IFR conditions, an arrival on one runway is *independent* of a departure on the other runway(s). In addition, in a radar environment, simultaneous departures or simultaneous arrivals can be allowed if the runways are separated by at least 3,400 feet and in the presence of a Precision Runway Monitor (PRM).

Far parallel runways are spaced at least 4,300 feet apart. Under IFR and VFR conditions, the two runways can be operated independently for both arrivals and departures.

There are numerous air traffic control rules associated with conducting operations on parallel runways. The first step to analyzing operations at a given facility is to understand the various categories of aircraft. The following is a description of the three existing categories.

CATEGORY I: Light-weight, single-engine, propeller-driven general aviation aircraft. This category includes the Cessna 152 and 172, Piper Cherokee, and Bellanca Viking. It does not include high-performance single-engine aircraft such as the T-28.

CATEGORY II: Light-weight, twin-engine, propeller-driven aircraft weighing 12,500 pounds or less. This category includes aircraft such as the Piper Navajo, Piper Seneca, and Cessna 330 but does not include larger aircraft such as the Convair 580 or most turbo-prop commuter aircraft.

CATEGORY III: All other aircraft not included in either Category I or II. This category includes high-performance single-engine, large twin-engine, four-engine propeller-driven, and turbojet aircraft. Category III includes aircraft such as the Cessna Citation, Boeing 727, and McDonnell Douglas MD-80. [Nolan, 1990]

Dependent Parallel Runways

When operations on parallel runways are dependent on one another, it is the same as using only one runway, in terms of air traffic control. For consecutive departures, the local controller must ensure that an aircraft does not begin its takeoff roll until at least one of the following conditions exist:

- The preceding departing aircraft is airborne and has crossed the departure end of the runway or has turned to avoid any conflict.
- If the local controller can determine runway distance using landmarks or runway markings, the first aircraft need only be airborne before the second aircraft begins its takeoff roll if the following minimum distance exists between the aircraft involved.
    - If both aircraft are Category I, a 3,000-foot separation interval may be used.
    - If a Category II aircraft precedes the Category I, a 3,000-foot separation interval may be used.
    - If the succeeding or both of the aircraft are Category II, a 4,500-foot separation interval must be used.
    - If either of the aircraft is a Category III aircraft, a 6,000-foot separation interval must be used.

When dependent runways are being used, the following rules apply when consecutive arrivals are expected. The controller must ensure that the arriving aircraft does not cross the landing threshold until at least one of the following conditions exists:

- The preceding arrival has landed and taxied off of the runway.
- Between sunrise and sunset, the preceding aircraft need not have taxied off of the runway if the distance between the two aircraft can be determined using landmarks or runway markings, and the following minimum can be maintained:
    - 3,000 feet, if a Category I aircraft is landing behind either a category I or a Category II aircraft.
    - 4,500 feet if a Category II aircraft is landing behind either a Category I or a Category II aircraft.

If dependent runways are being used, and an arrival is following a departure, it must have already crossed the departure end of the runway. This minimum can be disregarded if the departing aircraft is airborne an is at least the following distance from the landing threshold:

- 3,000 feet if a Category I aircraft is landing behind either a Category I or a Category II aircraft.
- 4,500 feet if a Category II aircraft is landing behind either a Category I or a Category II aircraft.
- 6,000 feet if either of the aircraft is a Category III aircraft.

If, under dependent conditions, an arrival is followed by a departure, the landing aircraft should have taxied off of the runway before the departing aircraft begins its takeoff roll.

Independent Parallel Runways

When the parallel runways are functioning independently, different air traffic control rules apply. Under non-radar conditions, if two aircraft are departing from parallel runways separated by at least 3,500 feet, the controller may authorize simultaneous departures if the aircraft's courses diverge by at least 45° immediately after takeoff. The controller must ensure separation between these departures and from succeeding departures. If two aircraft departing from parallel runways will not diverge immediately after takeoff, the controller must act as if both aircraft are departing from the same runway and use the separation rules outlined below.

- If the two aircraft will fly diverging courses immediately after takeoff, the aircraft must be separated by at least a 1-minute interval.
- If the two aircraft will not diverge immediately but will diverge within 5 minutes after departure, they must be separated by at least a 2-minute interval.
- If the two aircraft will diverge within 13 miles of the departure airport, they must be separated by at least a 3-mile interval.

Under radar conditions, the course divergence requirement is a minimum of 15° and the parallel runways must be separated by at least 2,500 feet. If the departing aircraft will diverge immediately after takeoff, a 1-mile separation interval must be maintained – otherwise the normal longitudinal, vertical, or visual separation rules apply.

The Ground Control Advisory System aims to reduce the buffer times between arrivals and between arrivals and departures. The advisory system should predict optimal spacings of arrivals when departures queue at departing points both when parallel runways are spaced far enough apart to allow for mixed arrivals and departures and when they are spaced closely, allowing for single-use runways only.

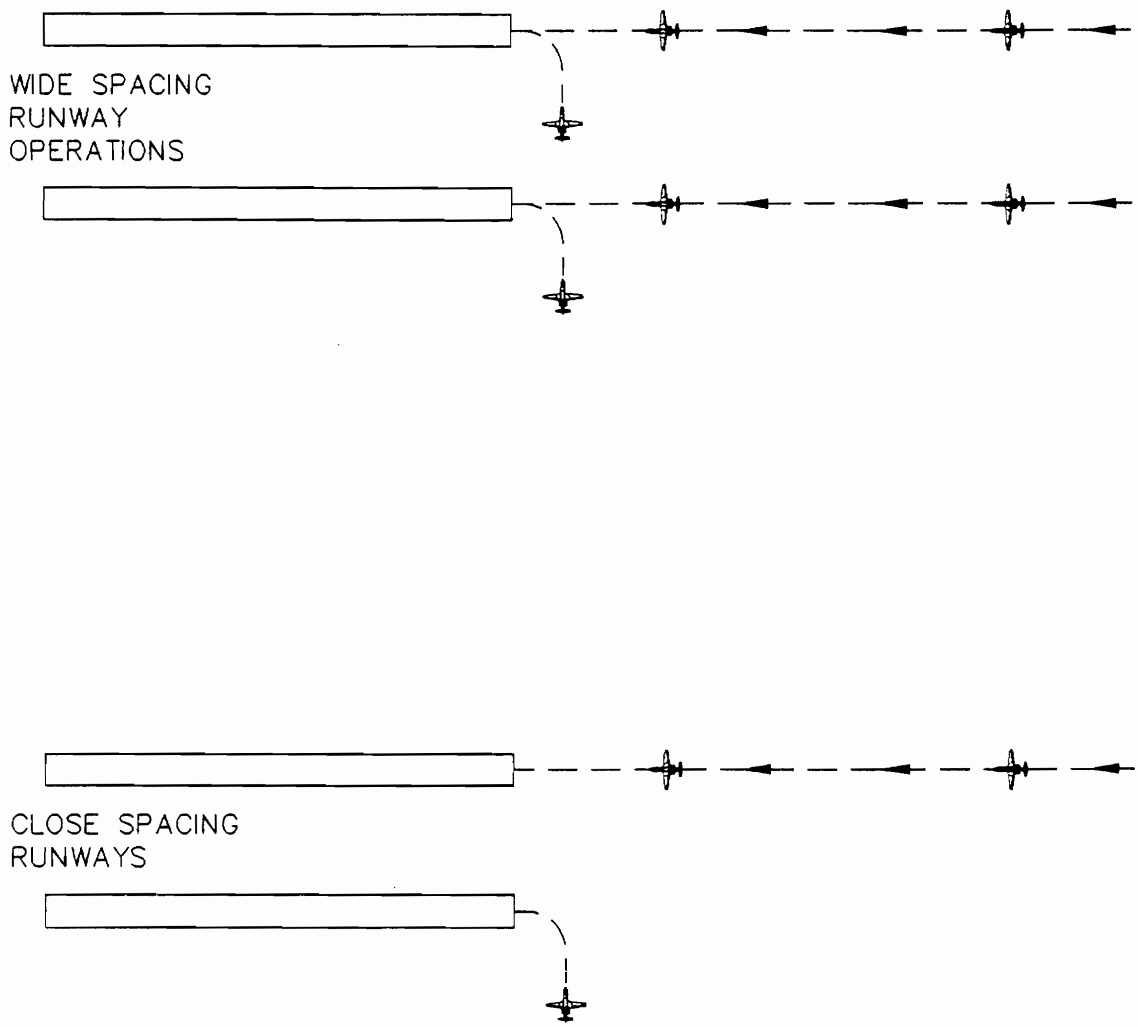

FIGURE 4.3: Diagram of Standard Bank Operations

5. Model Description

5.1 Introduction

The graphical user-interface for the Ground Control Advisory System has been designed to optimize the relationship between the human and the machine based on human factors research. The advisory system is designed to provide optional assistance to the terminal air traffic controller. The display has been designed to help the controller to easily identify the important flight characteristics, to aid comprehension of the current air traffic, and to help the controller to establish plans, predict problems and resolve conflicts.

5.2 General Display Characteristics

5.2.1 Situational Awareness Display

The situational awareness display is provided to aid the controller with perception and comprehension of the air traffic. This display is designed to complement the controller's mental picture of the air traffic. The aircraft are displayed by small colored circles and superimposed onto a map of the airport facilities and surrounding area. The display offers the controller two viewing options: "zoom-in" and "zoom-out." The "zoom-out" display shows surrounding airspace while the "zoom-in" display provides details including taxiways and apron areas.

In terms of comprehension, the display is periodically updated to illustrate the current separation of aircraft. When a change is made to the flight characteristics, the change is reflected on the display. More investigation and input from the targeted users is needed to determine the optimal timing of display updates. Some latency may be incorporated in order to avoid controller confusion.

This situational awareness display can be seen in the figures throughout this chapter.

5.2.2 Automated Flight Progress Strips

The automated version of the traditional paper flight progress strips is presented on the right hand side of the display. The arriving and departing flights are listed on buttons in chronological order in color-coded columns. Currently, the button displays only the flight number, but customization should be made available with the actual display. "Clicking' the flight button causes a "pop-up" display in the format of a traditional flight progress strip. The display can be suppressed at any time by choosing the cancel button.

The automated flight progress strips can be seen in the figures located throughout the chapter.

5.2.3 Clock

A clock displaying the current time in hours, minutes, and seconds is located immediately beneath the columns of flight progress strips. The clock is provided so that the air traffic controller can immediately perceive the current time and its relationship to the advisory.

5.2.4 General Advisory Format

When the system determines that an advisory is necessary, the advisory is displayed to the controller in a "pop-up" window that appears in the lower left corner of the screen.

The user, after reading the advisory, can choose to accept or reject the advisory, or in other instances, search for more information. The Accept, Reject, and More Information buttons are provided at the bottom of the "pop-up" window.

If the user chooses to accept the advisory, the system will graphically display the steps necessary to complete the procedure and give the user the opportunity to verify that the change is correct.

If the user chooses to reject the advisory, the "pop-up" window disappears, and the system continues to monitor and evaluate the air traffic as before.

If the user finds it necessary to request more information, another "pop-up" window appears in the lower right and provides the controller with details about how the decision was reached. Once the controller has evaluated the information, the controller can cancel the window by choosing the button at the bottom of the display. The system then reverts back to the original window, allowing the controller to their accept or reject the advisory.

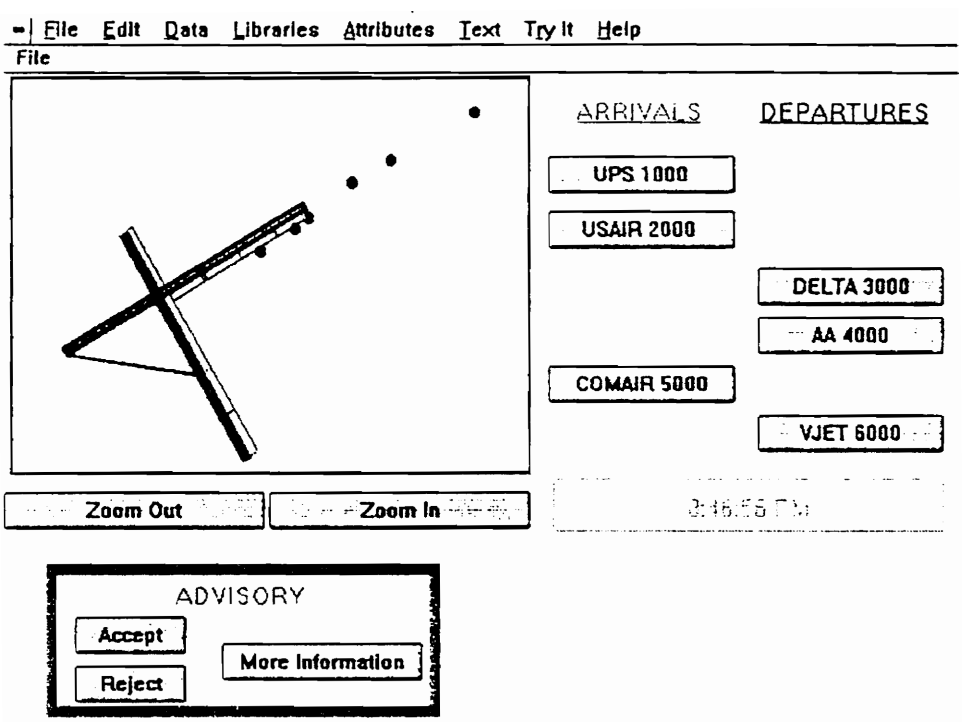

FIGURE 5.1: General Advisory Format

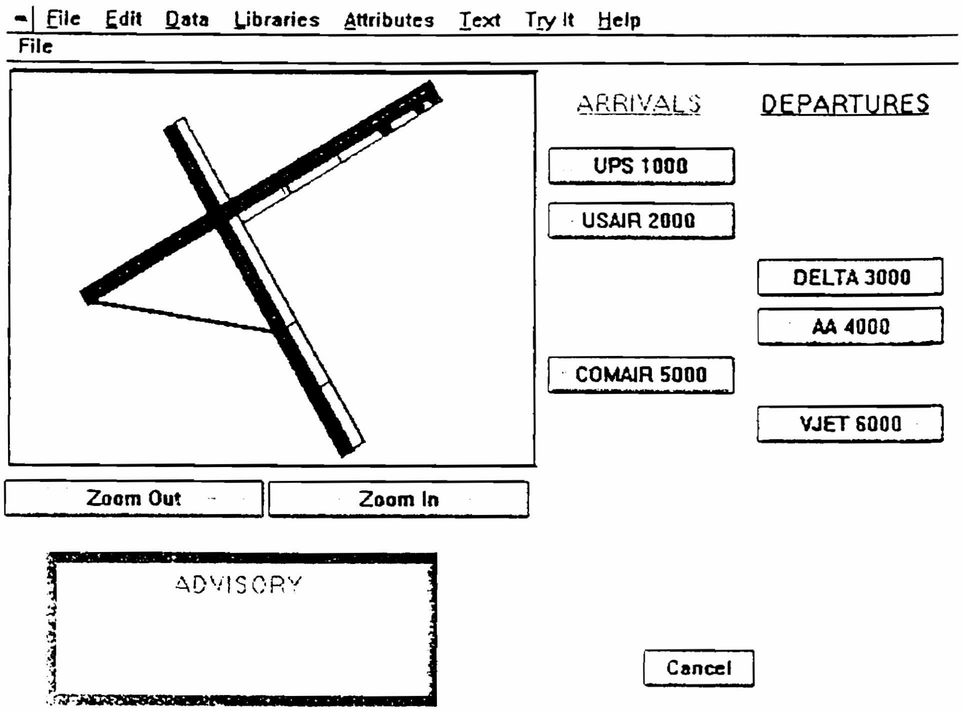

FIGURE 5.2: General Advisory Screen showing the "More Information" pop-up display

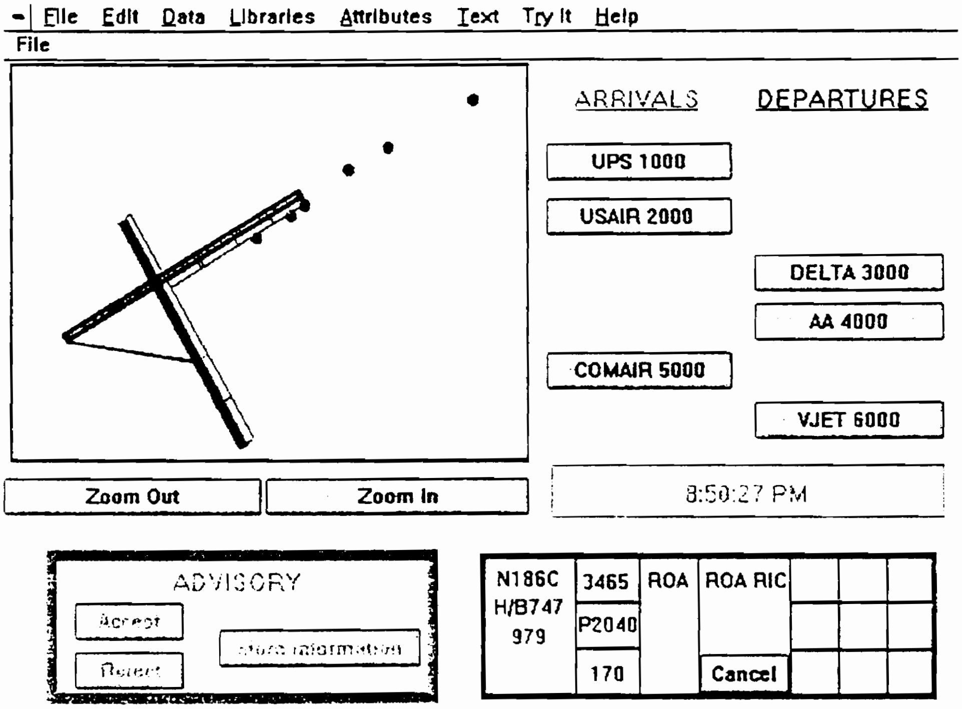

FIGURE 5.3: General Advisory Screen showing the detailed Flight Progress Strip

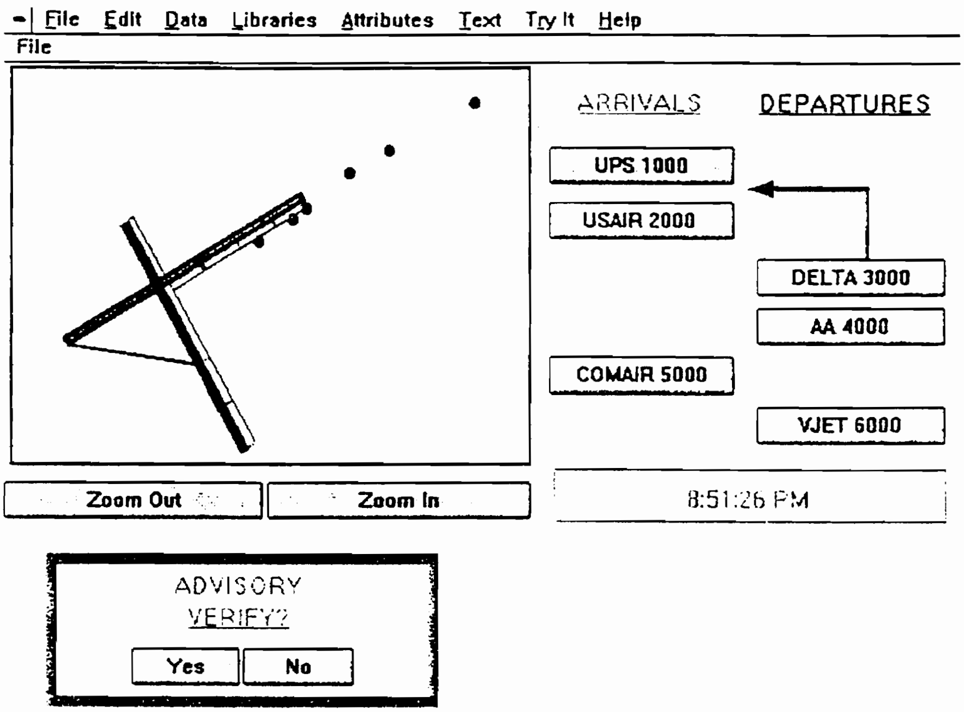

FIGURE 5.4: Screen prompting the controller for flight schedule verification

5.3 Touch-and-Go Operations Advisory

When a touch-and-go operation and an arrival are being accommodated on converging runways, the controller will receive an advisory suggesting the optimum base leg for the touch-and-go maneuver.

The advisory system first alerts the controller that a conflict exists. The system then alerts the user that the incoming flight will not be able to taxi past the runway intersection before the returning Touch-and-Go flight crosses the threshold during arrival. The system then takes the controller through a series of advisories that will optimally alter the base leg. The instructions include both directional as well as velocity instructions for the flight. Finally, a disappearing bar shows the time remaining for the controller to safely inform the Touch-and-Go pilot of the required maneuver.

The sequence of displays can be viewed throughout the following Figures 5.5 through 5.11.

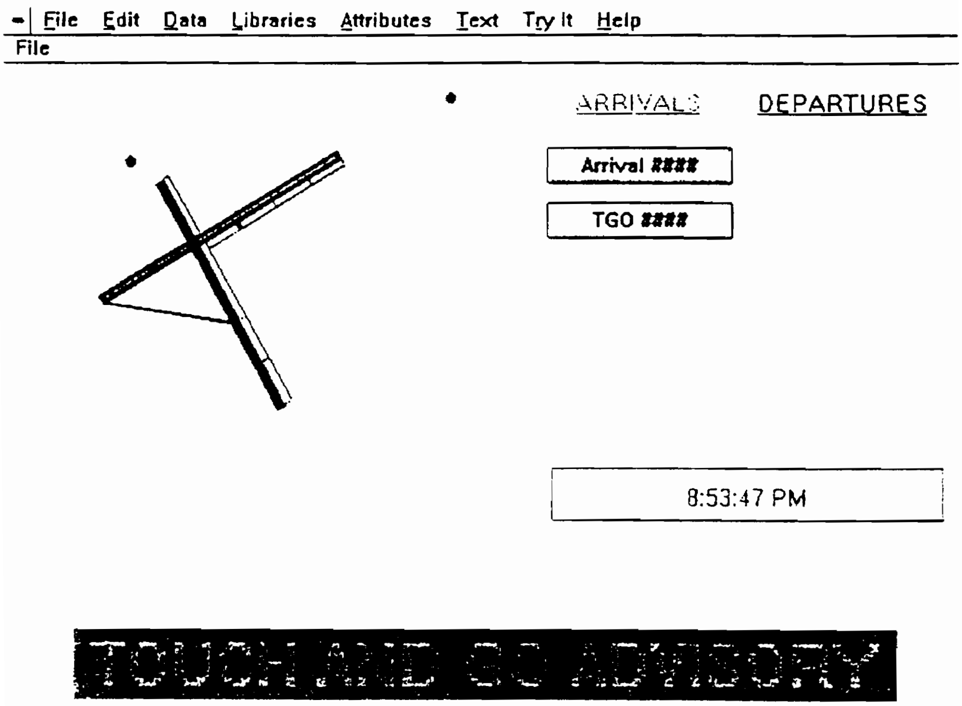

FIGURE 5.5: Initial Touch-and-Go Advisory Screen

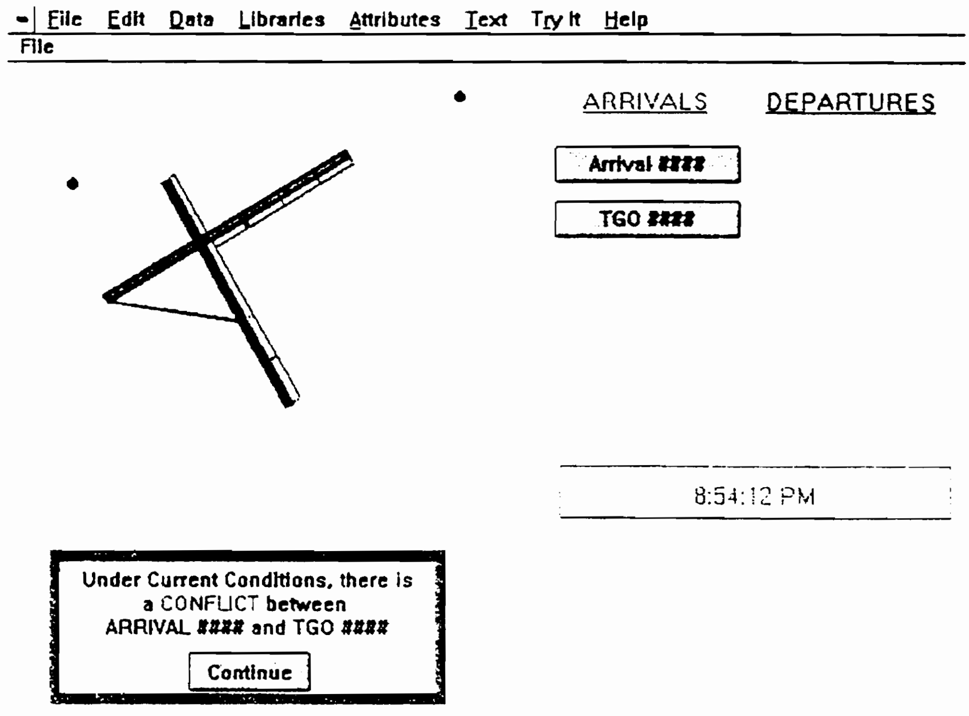

FIGURE 5.6: Touch-and-Go Advisory Screen alerting the controller of the conflict

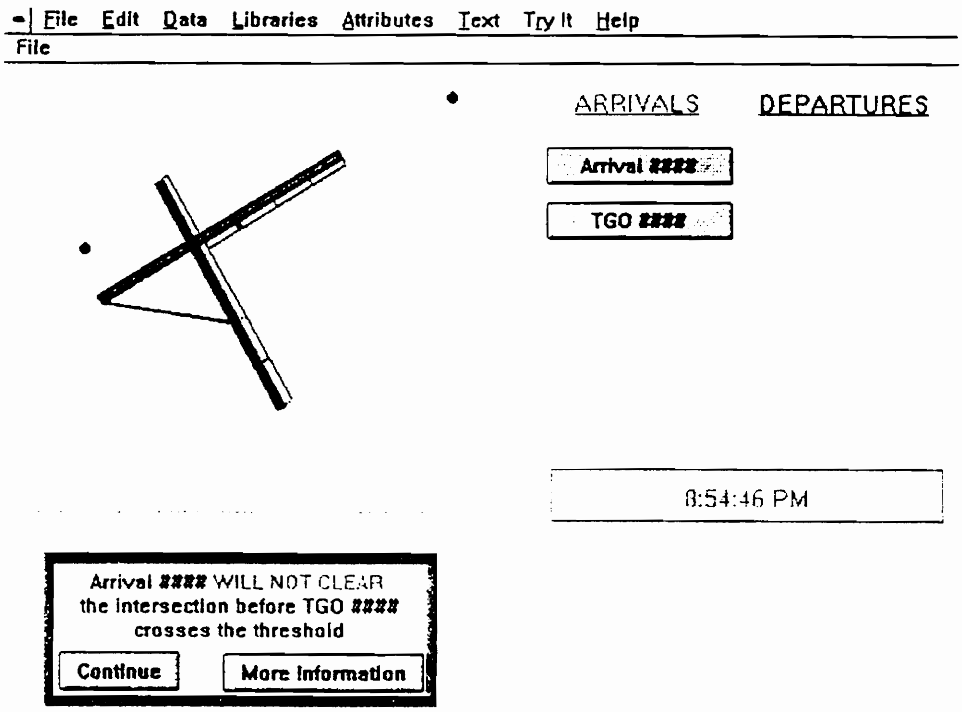

FIGURE 5.7: Touch-and-Go Advisory Screen alerting the controller of the problem

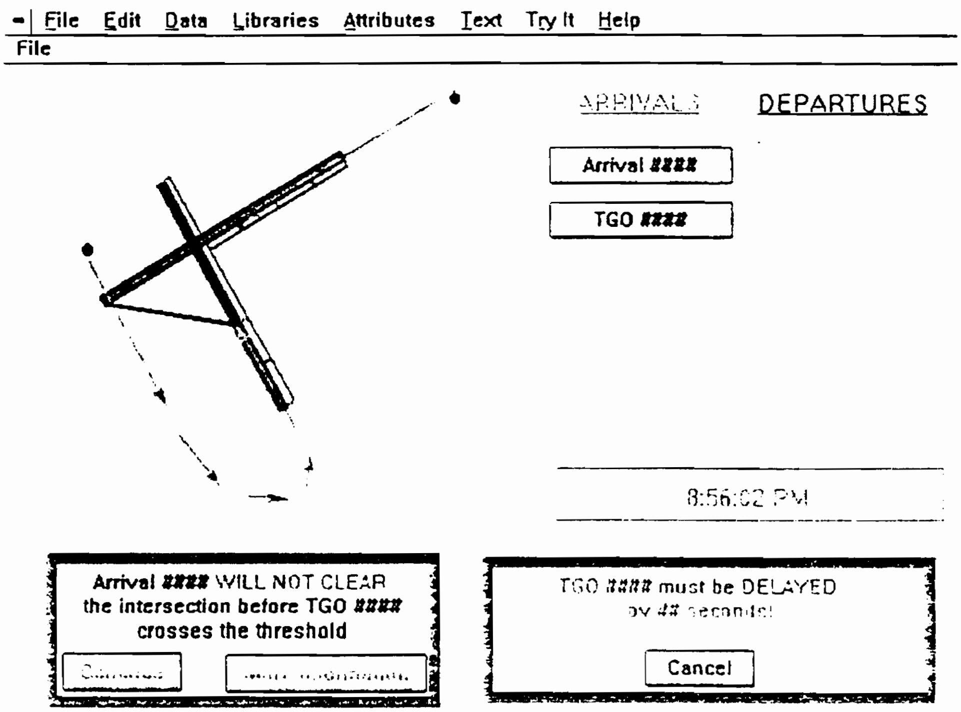

FIGURE 5.8: Touch-and-Go Advisory Screen showing the "More Information" box

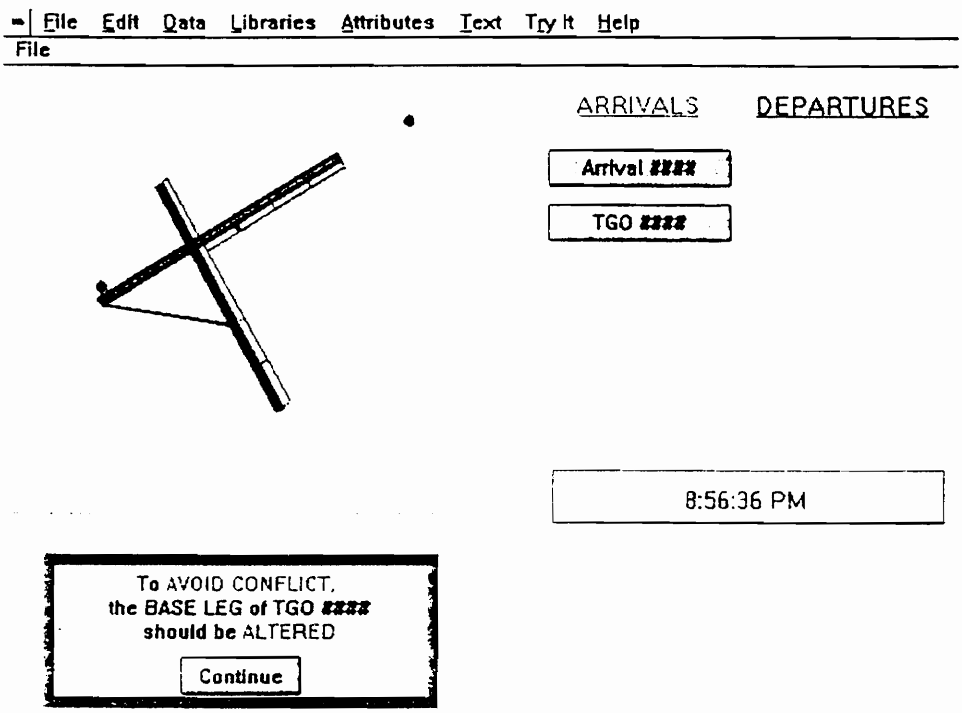

FIGURE 5.9: Advisory Screen instructing the controller to alter the TGO base leg

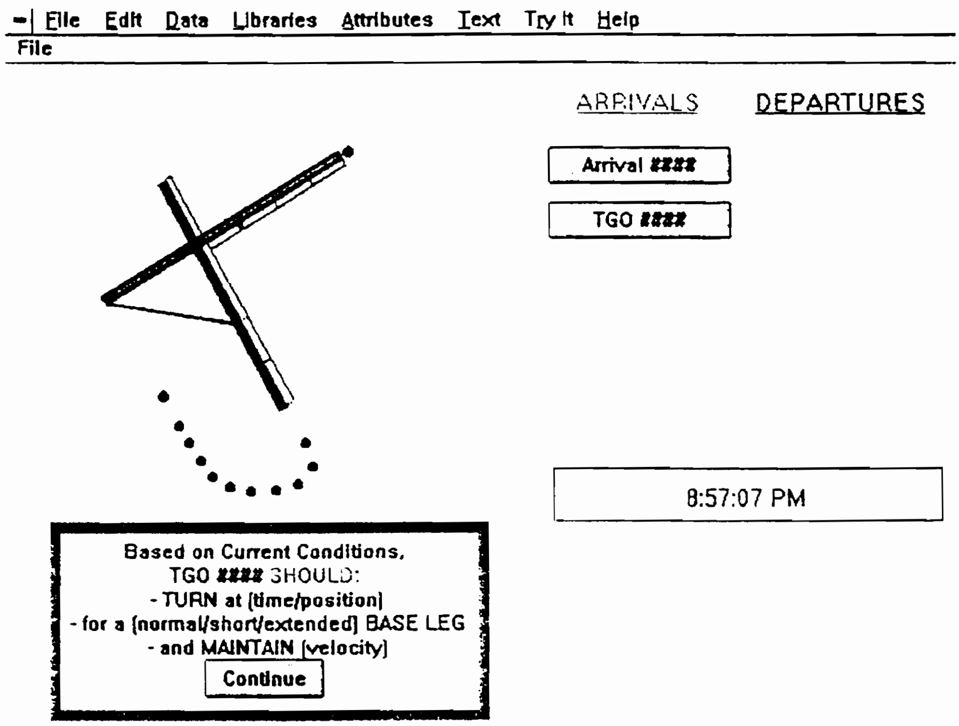

FIGURE 5.10: Advisory outlining the optimal base leg

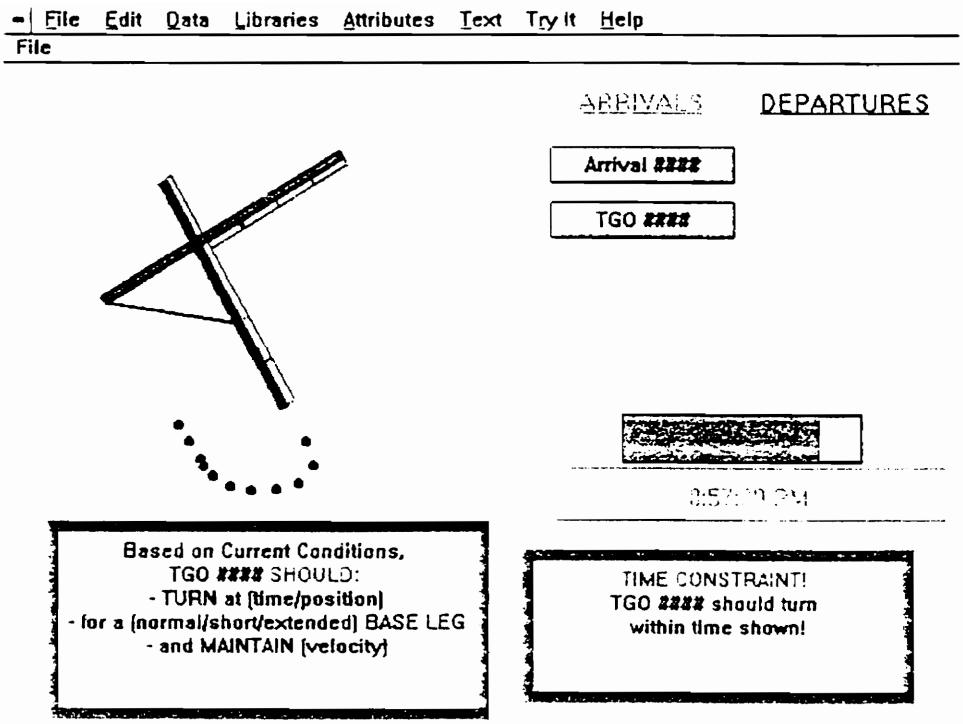

FIGURE 5.11: A disappearing bar shows time remaining to safely execute the command

5.4 Simultaneous Intersecting Runway Operations Advisory

When an arrival and a departure are being accommodated on intersecting runways, two scenarios are possible when the arrival has priority.

The advisory that the controller receives will be based on the predicted landing roll length. The advisory system chooses the appropriate path through the decision processes outlined below.

If the system determines that the anticipated arrival ***can*** taxi off the runway before the scheduled departure roll is to begin, the controller is advised to instruct the departure that the incoming flight is expected to taxi off of the runway before the intersection. Then, the controller is prompted to clear the flight for immediate departure.

If the system dctermines that the incoming flight ***cannot*** taxi off the runway before the departure roll is scheduled to begin, another decision must be made by the system.

The automated advisory system next determines if the anticipated arrival can hold short of the intersection.

Again, two scenarios are possible. If the system determines that the arrival ***can*** hold short of the intersection, the following advisory sequence is activated. First, the controller is asked to verify the runway pavement and wind conditions. If they are acceptable, the system next advises the controller to instruct the arriving aircraft to hold short and inform the arrival of the scheduled departing traffic. Then the system prompts the controller to inform the departure of the arrival that is holding short. Finally, the controller is advised to clear the flight for departure.

If it is found that the incoming aircraft ***cannot*** hold short, the controller is presented with an advisory explaining that the arrival cannot hold short and that the controller must reschedule the pending departure. The system then advises the controller of the optimal amount of time to hold back the departure.

One scenario is shown in the following Figures 5.12 through 5.19.

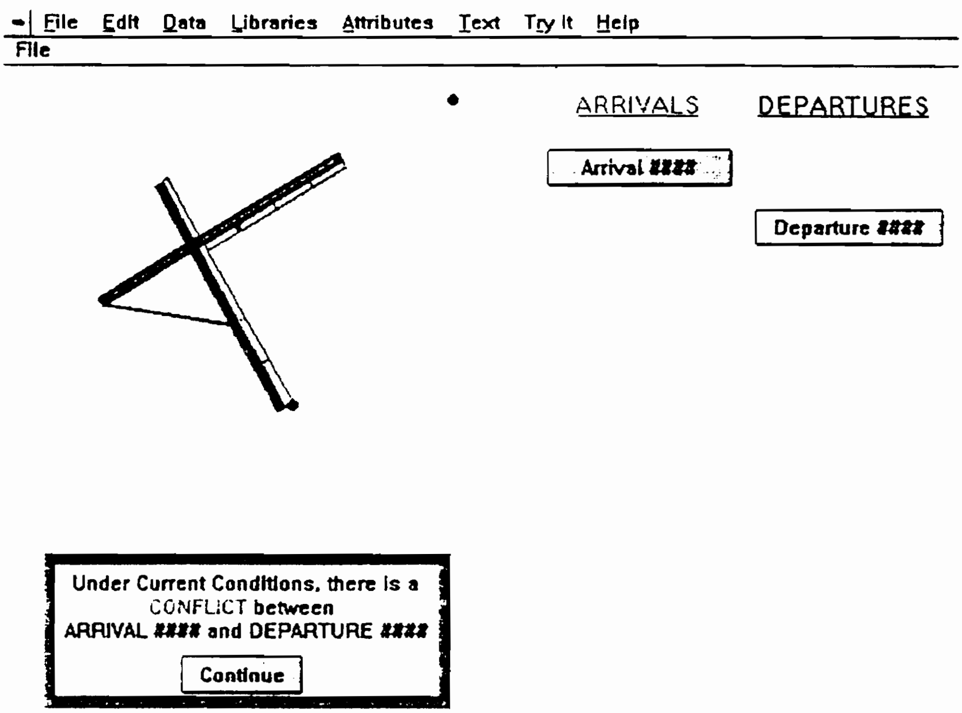

FIGURE 5.12: Initial Simultaneous Intersecting Runway Operations Advisory Screen

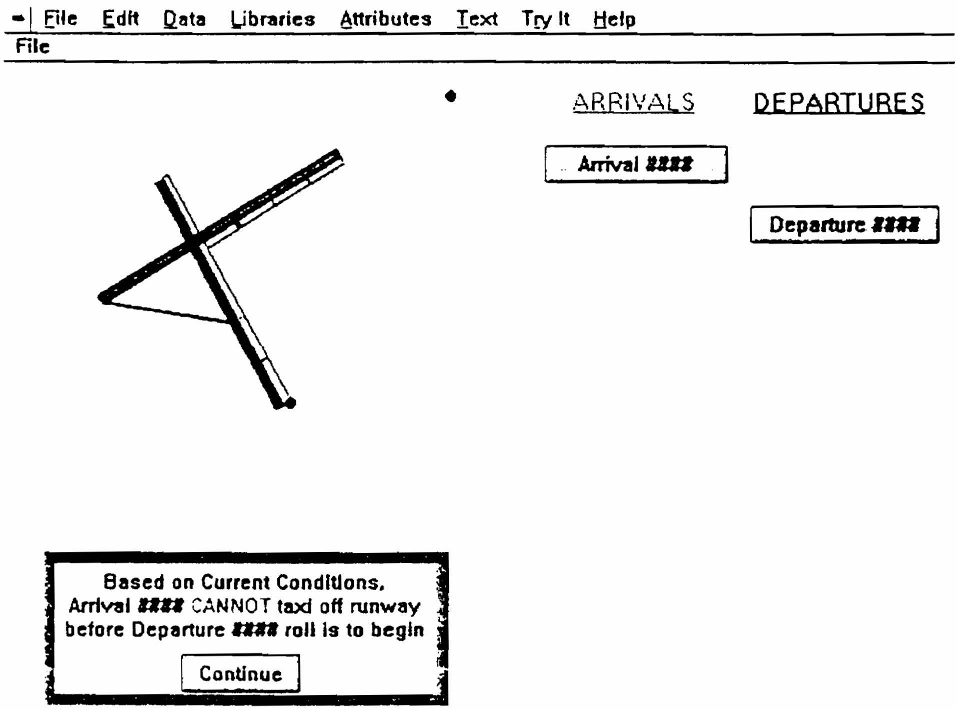

FIGURE 5.13: Advisory Screen warning the controller of the impending conflict

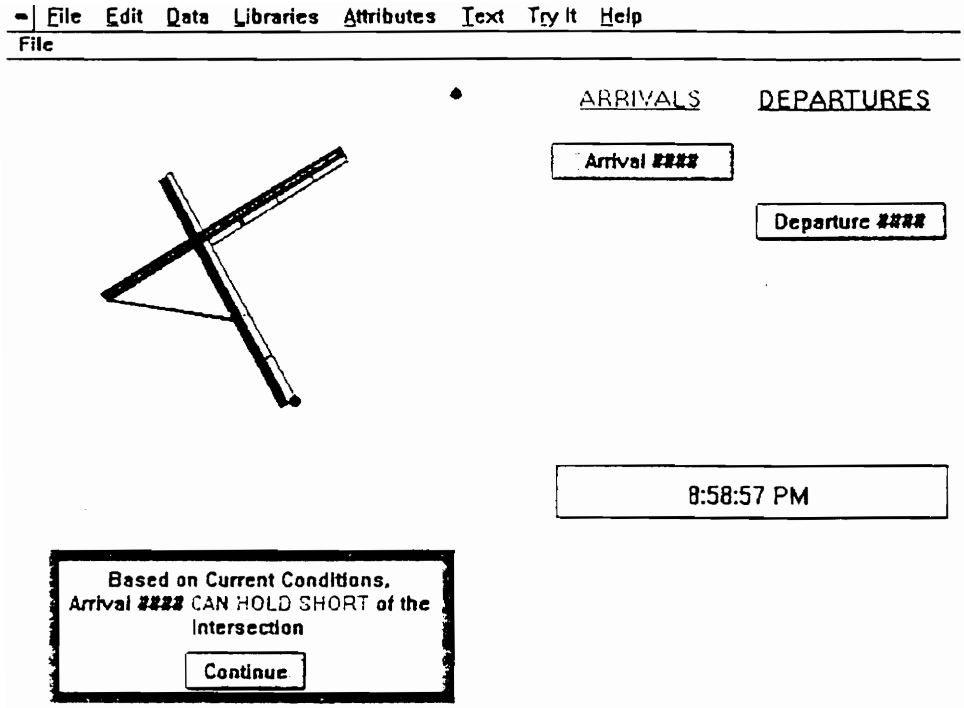

FIGURE 5.14: Display showing that the arrival can hold short

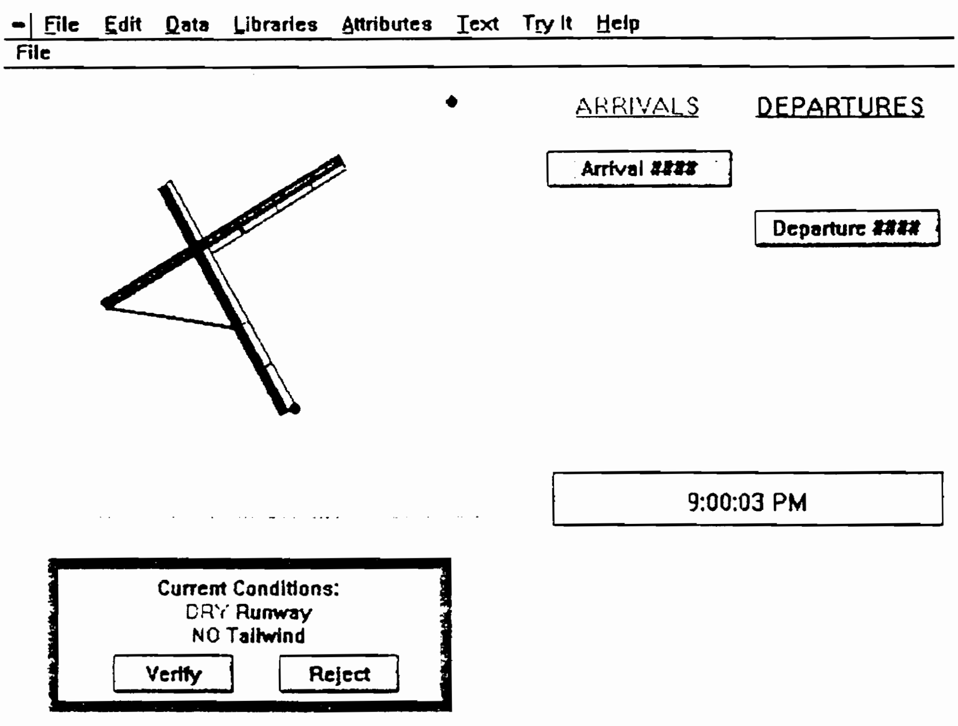

FIGURE 5.15: Display asking the controller to verify the current conditions

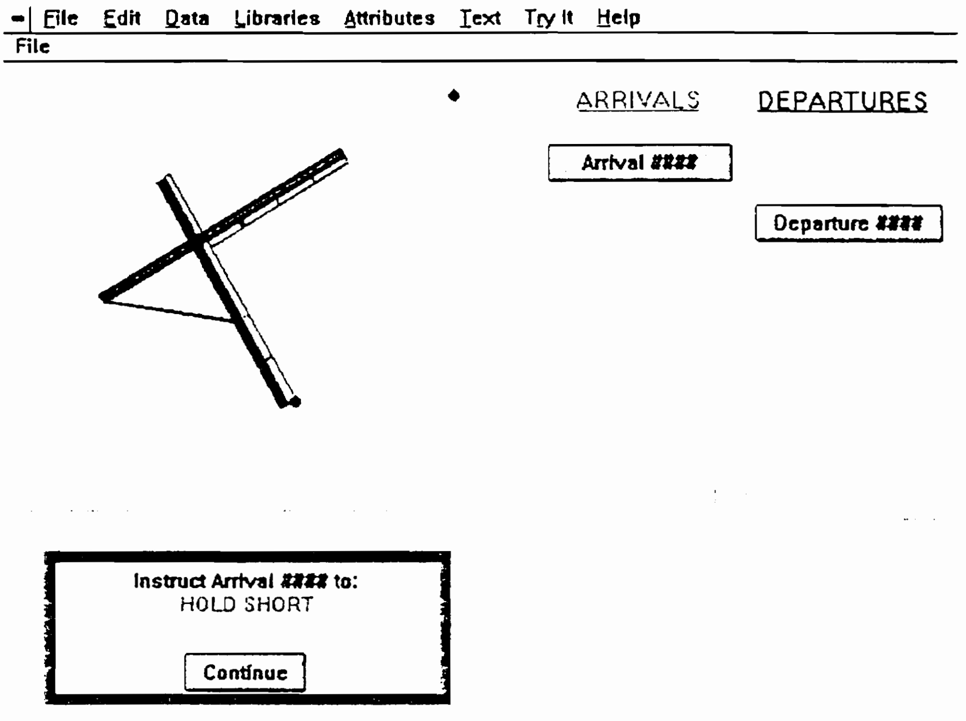

FIGURE 5.16: Screen showing Hold Short instructions to the controller

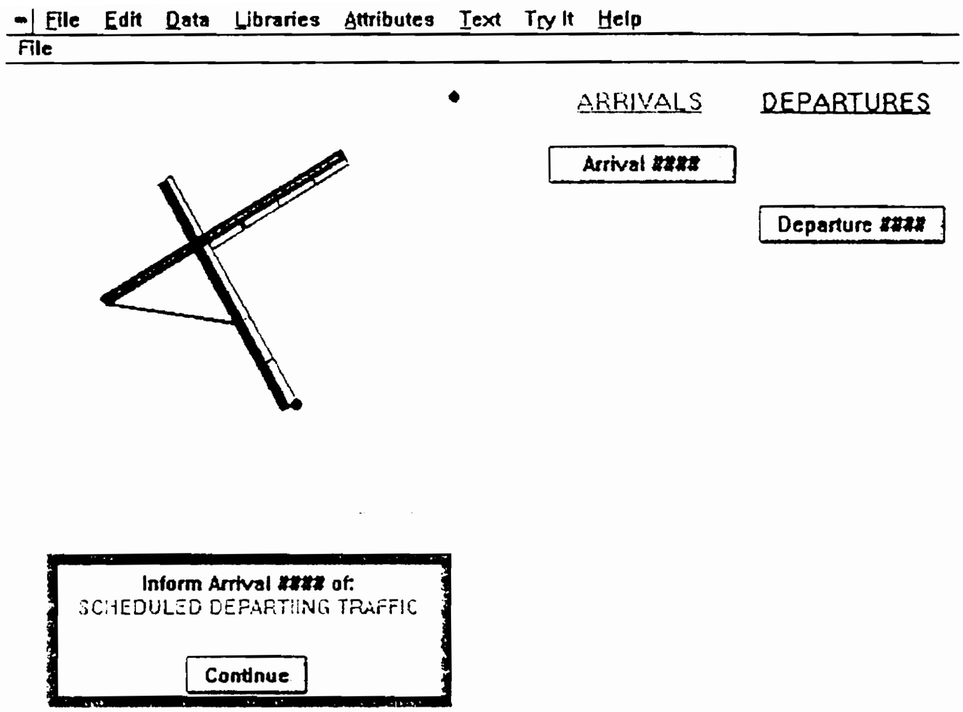

FIGURE 5.17: Screen prompting controller to inform arrival of departing traffic

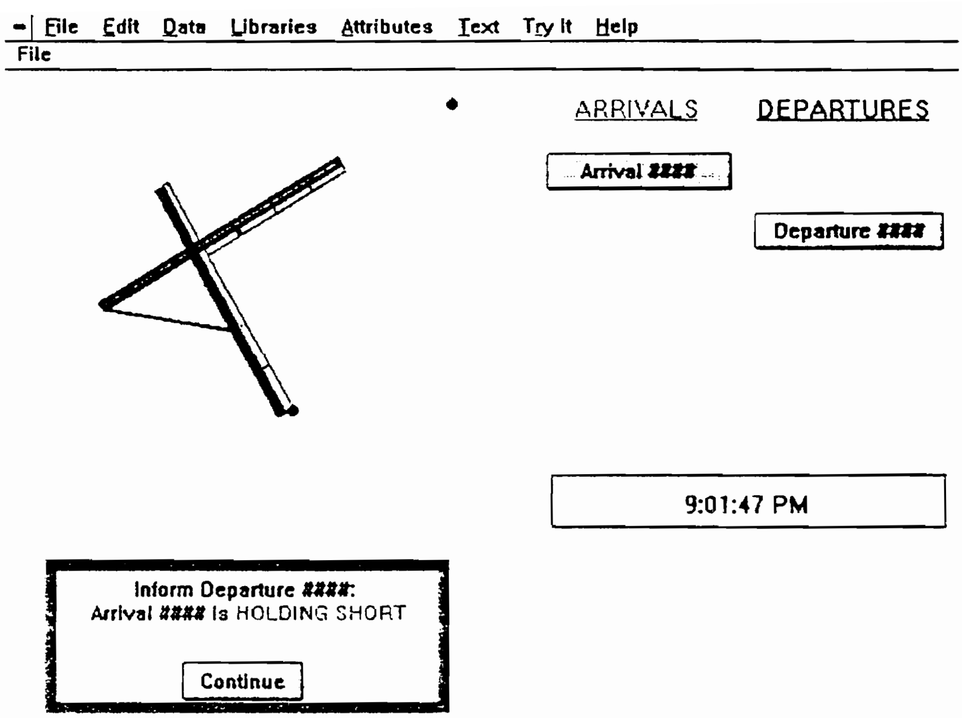

FIGURE 5.18: Display advising controller to inform departure of arrival's actions

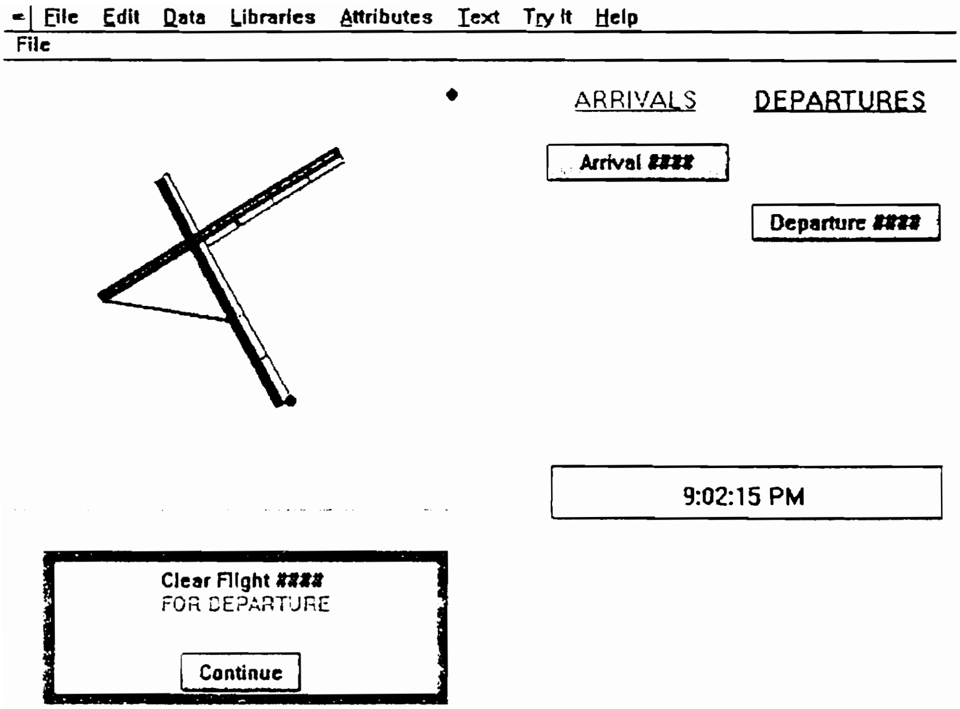

FIGURE 5.19: Display advising controller to clear flight for departure

5.5 Standard Bank Operations Advisory

During standard bank operations on parallel runways, the advisory system can be utilized to predict optimal spacings of arrivals when aircraft wait at departure queuing points.

The controller receives an advisory when it is determined that arrivals are spaced too closely to release departures and the queue is growing to unacceptable levels. The controller then receives an advisory concerning the minimum gap requirement for the aircraft in question. The controller can choose to increase the gap by vectoring or by requesting the flight to enter a holding pattern.

If vectoring is chosen, the controller is prompted to instruct the flight to vector at a given heading for a set time. Then the system guides the controller through the required steps to return the flight to it's original path by vectoring at another set heading for a given amount of time.

If a holding pattern is selected, the system prompts the controller to instruct the flight to enter the standard holding pattern.

In many instances, a holding pattern will not be an option given the close proximity of the terminal area boundary. Realistically, the advisory system should operate up to a range of 20 to 30 nautical miles which will provide the controllers with an adequate amount of situational awareness to effectively control the air traffic.

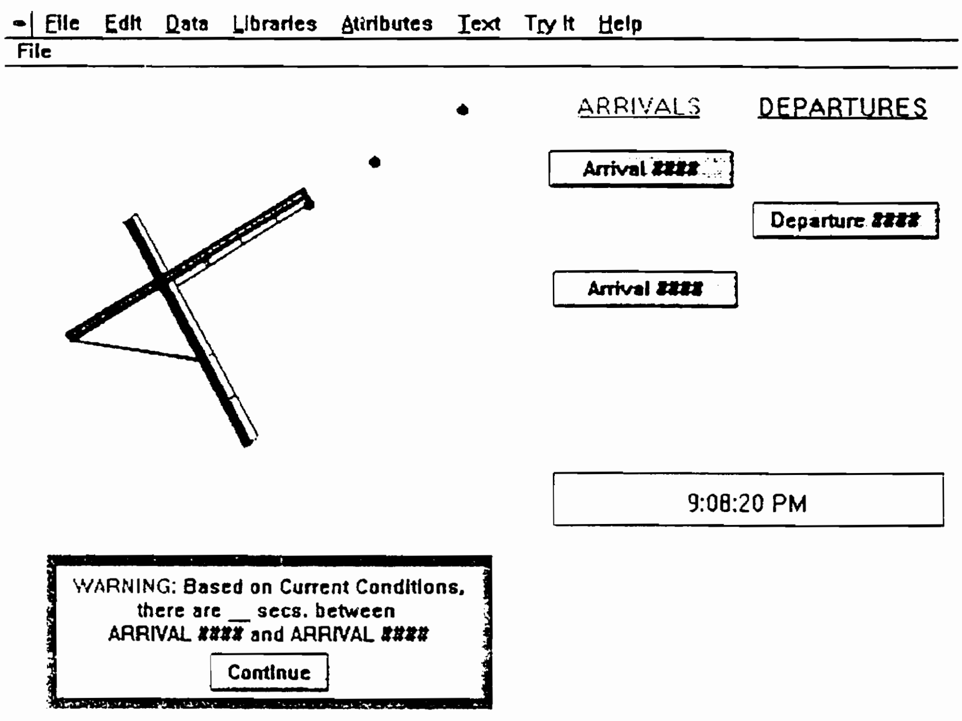

FIGURE 5.20: Standard Bank Operations Advisory warning the controller of a conflict

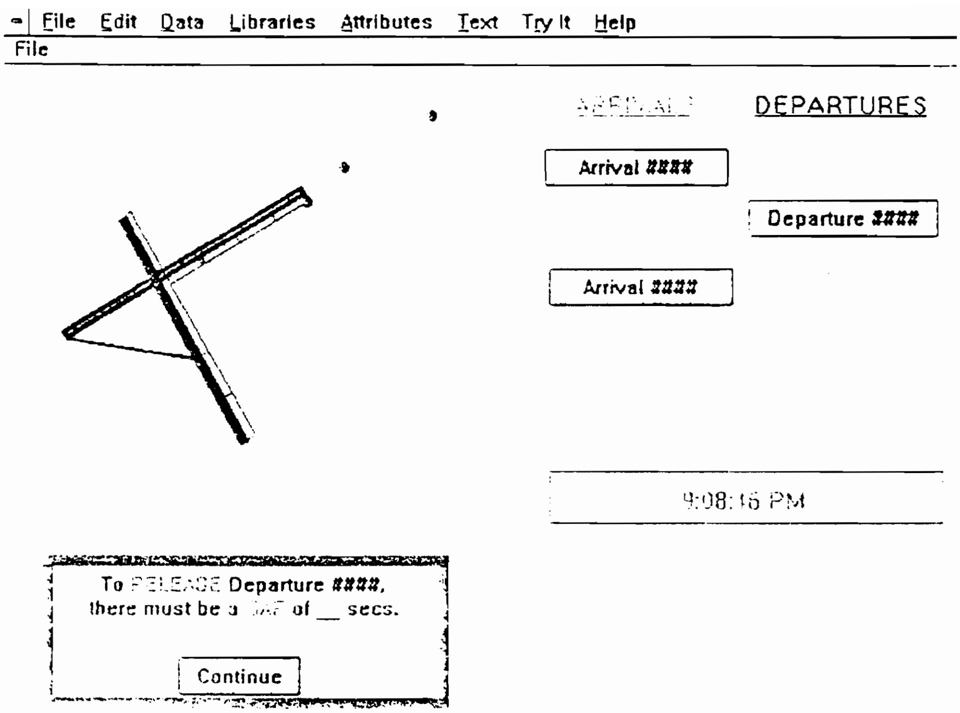

FIGURE 5.21: Advisory alerting the controller of the required gap between arrivals

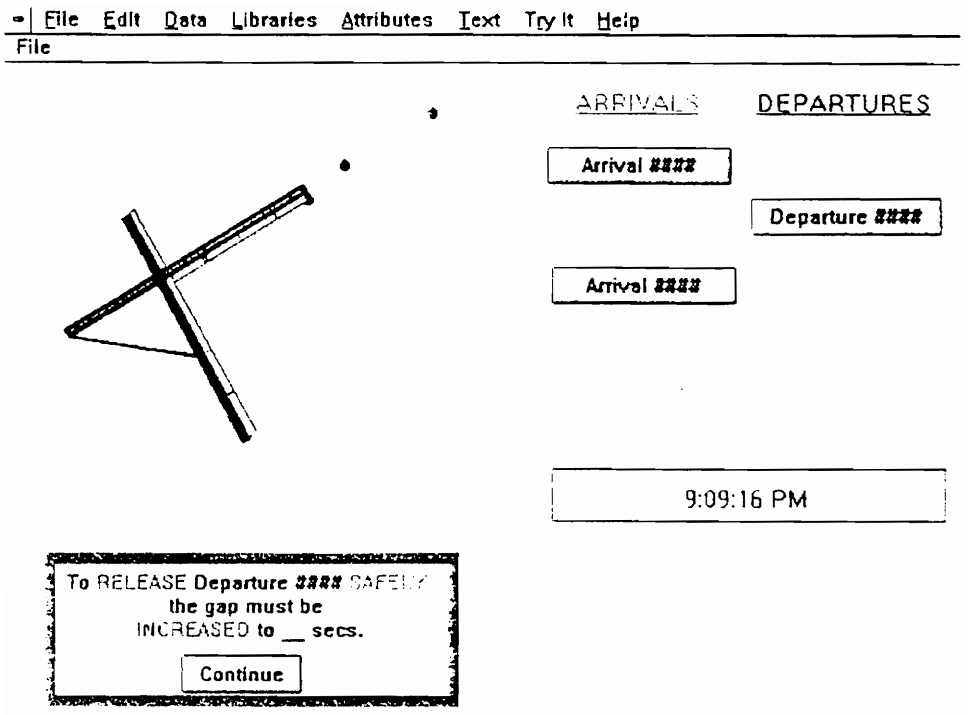

FIGURE 5.22: Screen showing the necessary gap increase

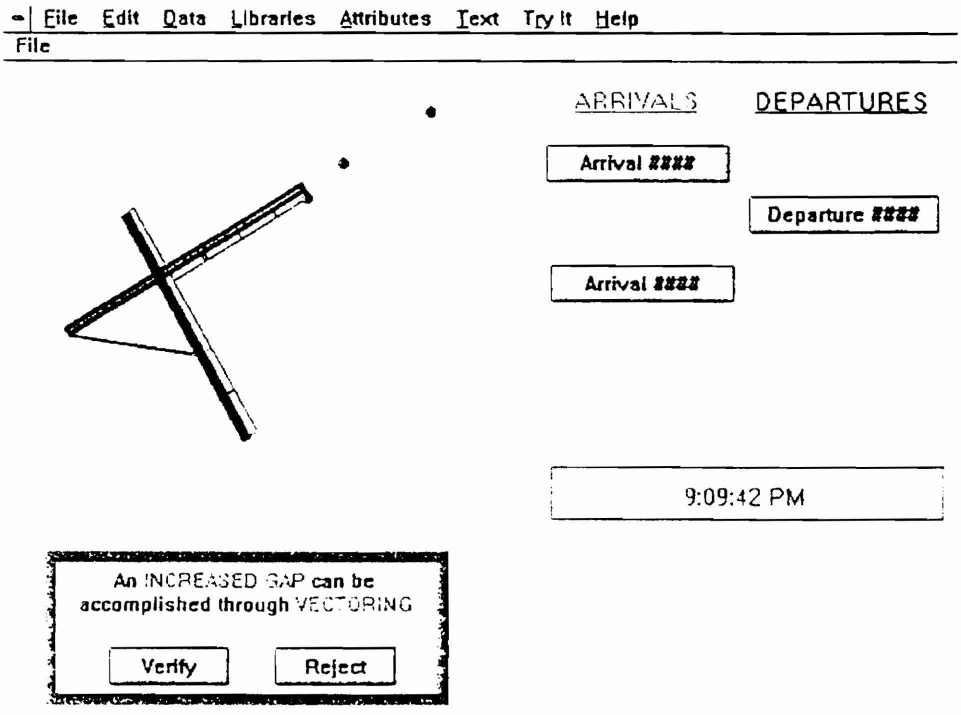

FIGURE 5.23: Advisory suggesting a method to increase the gap

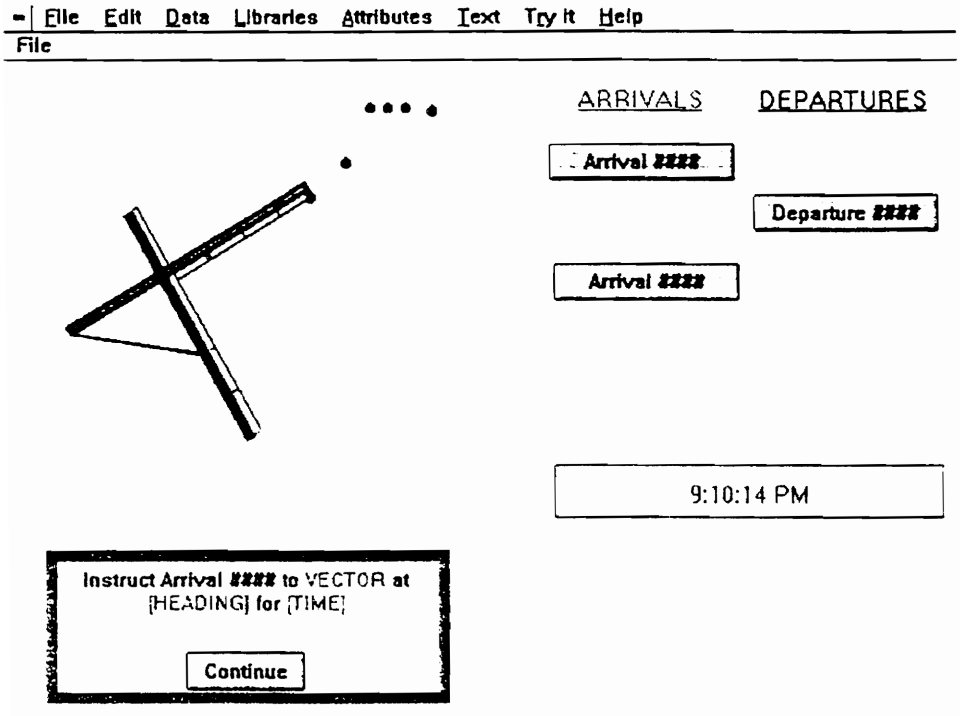

FIGURE 5.24: Screen displaying initial vectoring instructions

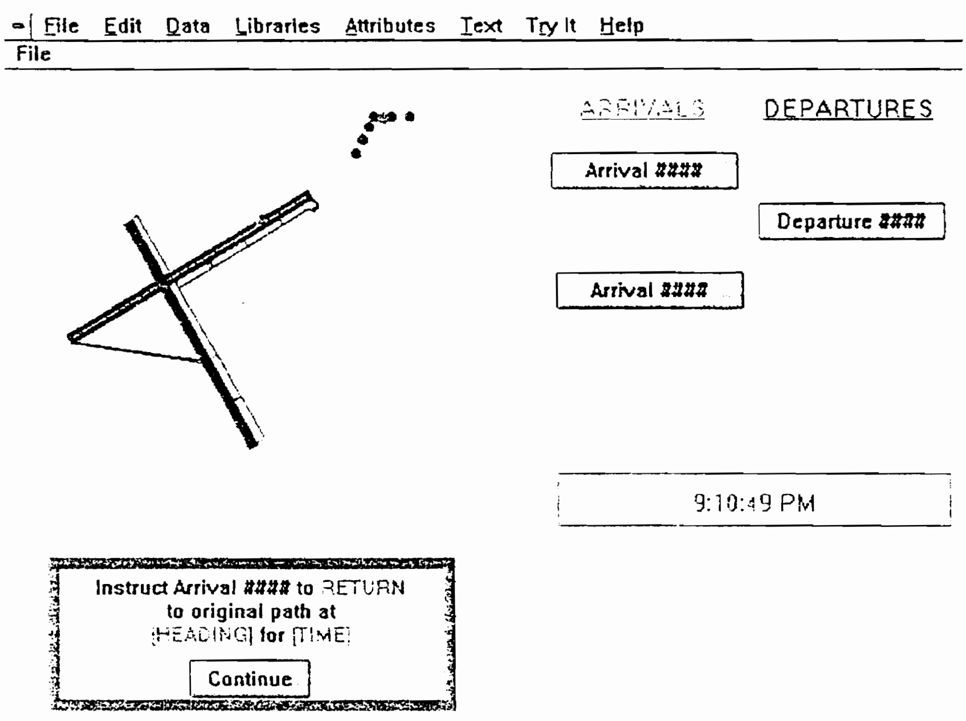

FIGURE 5.25: Screen displaying the instruction for the return to the original path

5.6 Potential Benefits

In addition to decreased controller workload and stress level, it is anticipated that the proposed advisory system will allow the proposed facility to realize an increased capacity, decreased delay and therefore an associated monetary benefit.

A time-space approach is used to illustrate the time-savings associated with the implementation of the advisory system. Capacity improvements can then be easily deduced by studying the provided diagrams.

Figure 5.26 illustrates a time-space diagram that illustrates mixed operations without position error.

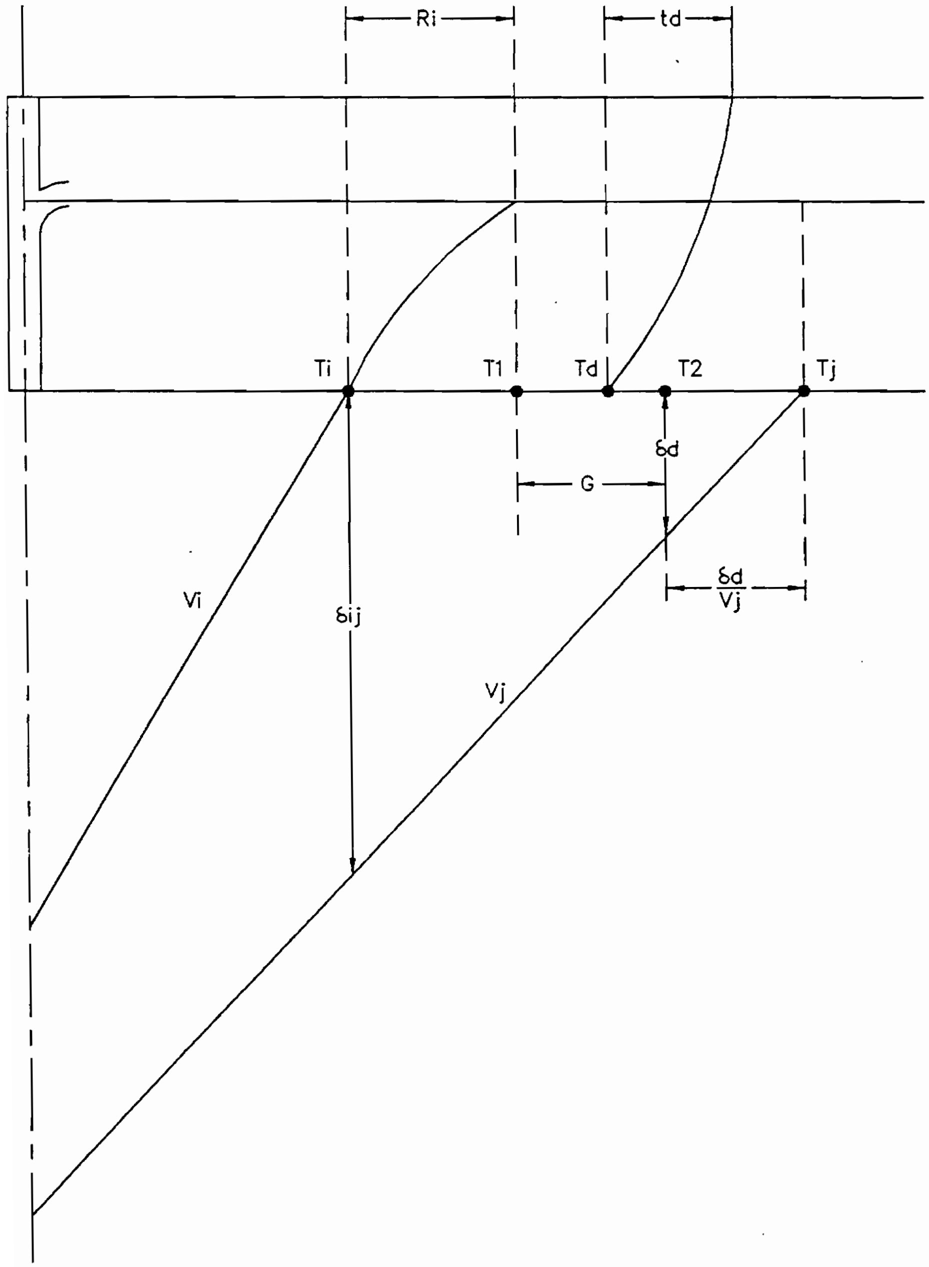

FIGURE 5.26: Baseline Time-Space Diagram

In the diagram,

T_i = time arrival i passes over the arrival threshold
T_j = time arrival j passes over arrival threshold
δ_{ij} = minimum separation between arrivals
T_1 = time when arrival i clears the runway
T_d = time departure begins take-off roll
δ_d = minimum distance that an arrival must be from the threshold to release a departure (usually 2 nmi under IFR)
T_2 = last instant a departure can be released
Ri = runway occupancy time for arrival i
G = time gap in which an aircraft can be released
t_d = departure service time or minimum separation requirement

From the diagram, it can be seen that the inter-arrival time (ΔTij) to release n departures in a sum of the following expected values.

$$E(\Delta T_{ij}) \geq E(R_i) + E\,(\delta_d / V_j) + (n-1)\,E\,(t_d)$$

If position error is to be included in the calculations, a term is added to provide the operations with a safety buffer

$$E(\Delta T_{ij}) \geq E(R_i) + E\,(\delta_d / V_j) + (n-1)\,E\,(t_d) + \sigma q$$

Where, σ = standard deviation of inter-arrival times
q = 1 - Pv
Pv = probability of violation

Obviously, decreasing the inter-arrival times allows more flights to be processed in the same amount of time. This increases the capacity of the facility and reduces the deletes realized by the flights. The monetary benefits are realized in two manners. Increased capacity allows the facility to accept more flights, which can result in increased landing fees as well as other revenues contributed by the facility customers. Decreased delay can make the airlines more profitable by reducing costs incurred while the aircraft are not airborne.

A quantification of the benefits achieved for a facility utilizing the proposed system can be found in Figure 5.27. Using a single runway and aircraft mix of 50% large, 40% small, and 10% general aviation, benefits can be achieved as shown. Under manual control, the standard deviation of interarrival times is approximately 22 to 24 seconds. Under normal IFR conditions, the saturation capacity is 42 to 43 total operations per hour. Under arrival priority conditions, this is comprised of 32 to 33 arrivals and 10 departures. With the assistance of the advisory system, the interarrival time standard deviation can be reduced. Until further tests of the system can be performed, the new standard deviation can only be approximated. The figure shows the saturation capacities associated with various standard deviations. For instance, if the standard deviation can be reduced by 50%, the new saturation capacity would be 49 to 50 operations per hour.

Assuming a \$6000, \$3500, and \$800 per hour cost associated with operating large, small, and general aviation aircraft, respectively, a monetary benefit of approximately \$35,000 per hour can be realized.

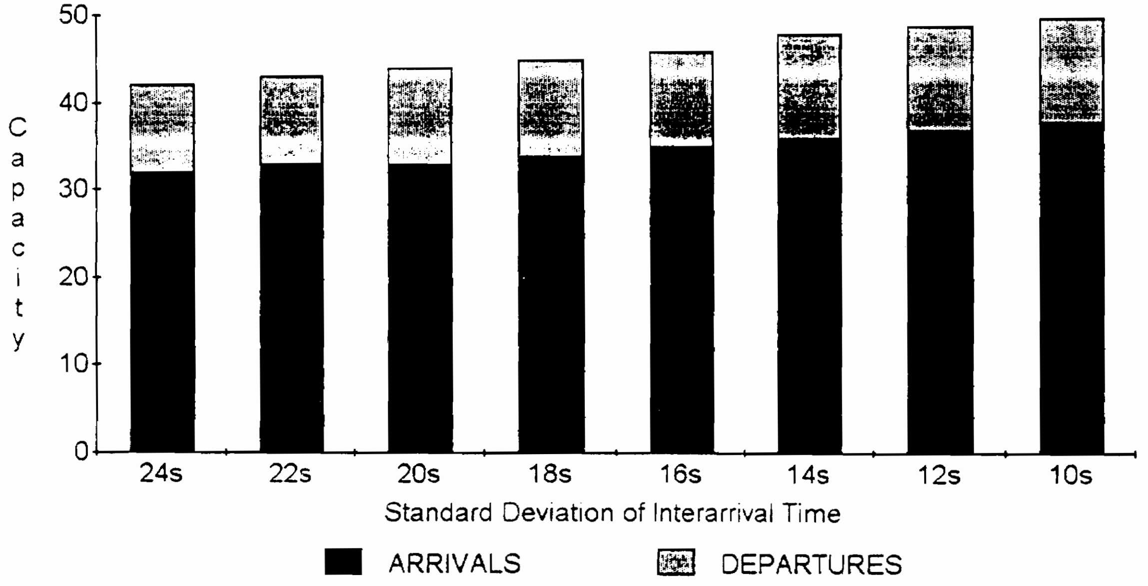

FIGURE 5.27: Saturation Capacity as it relates to Interarrival Time Standard Deviation

5.6.1 Touch-and-Go Operations

In the scenario where a facility consists of intersecting runways and touch-and-gos as well as arrivals are being accommodated, the scenario can be viewed as described in the previous chapter.

The touch-and-go on runway one can cross the landing threshold if:

- the arrival on runway two has taxied off of the runway
- the arrival has crossed the intersection
- the arrival has completed the landing roll and will hold short

During VFR, the touch-and-go can cross the landing threshold if

- wind and runway conditions are favorable
- the arrival on runway two has been instructed to hold short and has agreed.

With the implementation of state of the art positioning systems, the position error can be greatly reduced. Although not eliminated entirely, with the proper tools and update rates, the combination of the system and a skilled controller strives to eliminate the position error.

Since the system will be able to accurately predict the length of the landing roll for the arrival on runway two, the inter-arrival time can be reduced in any of the following ways, depending on the situation. The time-space diagram is illustrated in Figure 5.28.

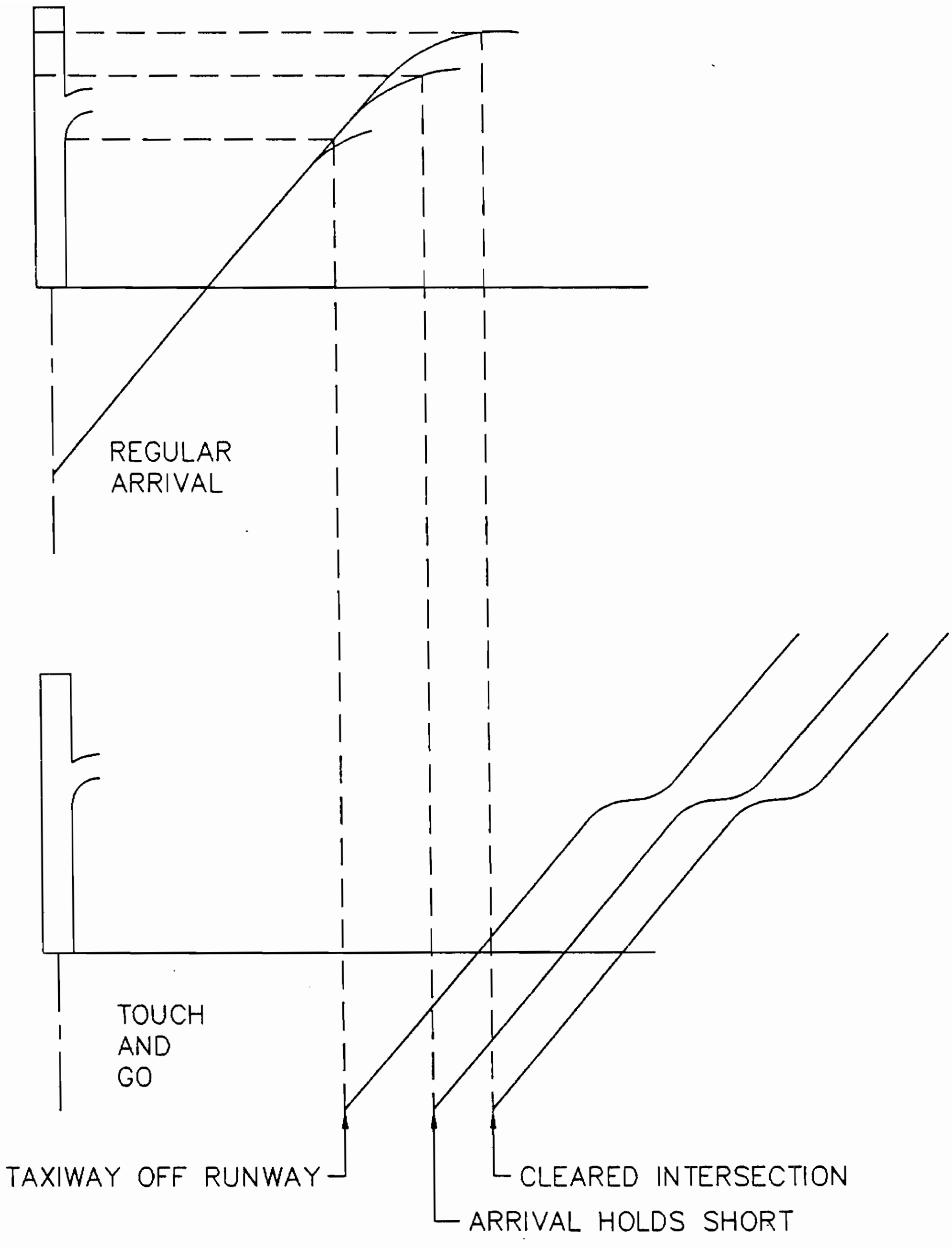

FIGURE 5.28: Time-Space Diagram for accommodating both TGOs and arrivals

5.6.2 Simultaneous Intersecting Runway Operations

In the scenario where a facility consists of intersecting runways that accommodate both arrivals and departures, the scenario can be viewed as shown in the previous chapter.

The departure on runway one cannot begin its takeoff roll until:

- the arrival on runway two has taxied off of the runway
- the arrival has completed its landing roll and can hold short
- the arrival has passed the intersection

This scenario is very similar to the one previously described. Again, some of the inter-arrival time is eliminated by the reduction in position error.

Armed with information relating to the length of the landing roll, the air traffic controller can optimize the departure, again reducing the inter-arrival time. The scenarios are illustrated in Figure 5.29.

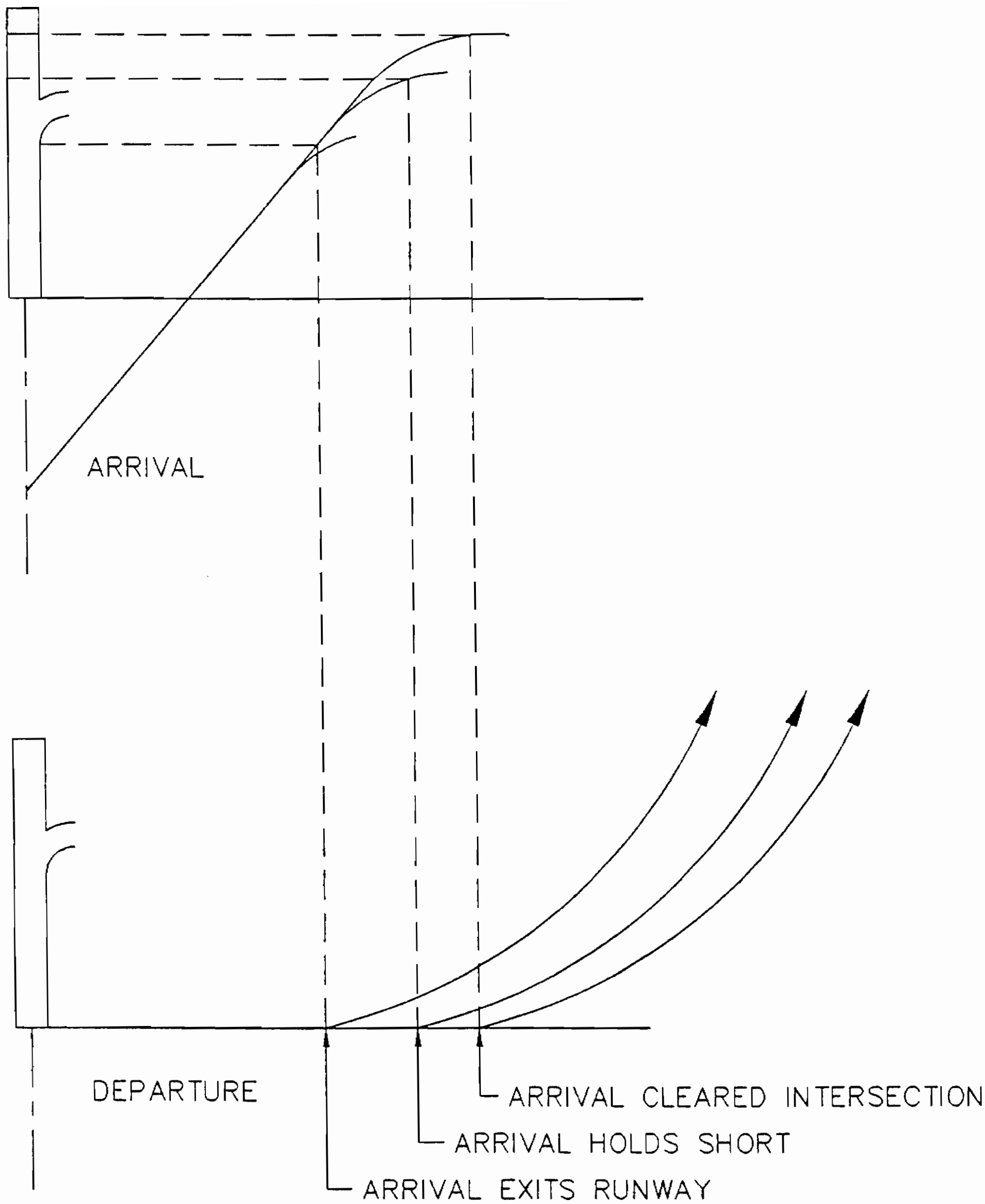

FIGURE 5.29: Time-Space Diagram for Simultaneous Intersecting Runway Operations

5.6.3 Standard Bank Operations

During standard bank operations on parallel runways, the timing of arrivals and departures is of utmost importance. It is important to ensure that departures do not queue unnecessarily at the end of the runways and that arrivals are spaced tightly, but safely.

As with the other scenarios, position-error is reduced by the advisory system, improving the spacings between successive aircraft. In addition, the system advises the controllers on the appropriate actions necessary to optimize the flight schedule. This "tightens the pack" and allows maximum capacity to be achieved with minimal delays.

6. Direction for Further Investigation

6.1 Introduction

This research effort has only just begun the development process for the proposed graphical user-interface. In order for the advisory system to have an appropriate user-interface, the prototyping process must be completed completely and thoroughly. This section outlines the remaining steps necessary to design an acceptable interface.

6.2 Rapid Prototyping

The thrust of this research effort has been to complete the first steps of the rapid prototyping process of an advanced ground control ATC Advisory System. The goals and information requirements of the system have been identified through extensive research into the role of the air traffic controller. The fundamental characteristics of the interface have also been identified through investigation of the human factors issues related to air traffic control and to display design.

The next step of the rapid prototyping process has also been completed. A basic prototype has been developed in order to convey the system attributes to the actual system users – the air traffic controllers. The basic prototype was developed using Macromedia Authorware and can be used to demonstrate how sample scenarios would be handled by the advisory system.

6.3 Task Analysis

In order for the interface to be designed optimally, it is necessary to analyze the tasks that the air traffic control personnel complete regularly. This is the next step in the display development process. The task analysis should be accomplished through several hours of control tower observation in order to fully understand the role of the controller. An upper level task analysis should be performed in order to identify the scenarios that controllers face and the necessary actions taken to process the flights. The task analysis should include the type of job completed, the specific tasks associated with job completion, and the time associated with each event.

By understanding the controller's tasks, the interface can be tailored so that the job of the controller is complemented, not interrupted, by the advisory system. Special attention needs to be given to the role of the flight progress strips since these are currently perceived as central to the job of the air traffic controller.

6.4 Questionnaire

Although the task analysis is necessary to identify the jobs of the controller from the designer's point of view, it is also important to gather data based on the controller's point of view. The questionnaire stage is another essential part of the prototyping process. A proposed questionnaire is contained Appendix A.

Questionnaires need to be distributed to a reasonable number of controllers in order to achieve an adequate sample size. The data should then be analyzed in an appropriate fashion and the results used to contribute to the design of the advisory system.

6.5 Focus Group

As described previously, focus group research can be used to supplement the previous data gathered thorough the task analysis and the questionnaire. In this situation, a focus group can be used in two distinct ways.

The first meeting of the focus group should concentrate on furthering the usefulness of the results of the questionnaire. For example, if results were mixed in a particular data area, the focus group can be used to find out more information on the various controller's opinions and perspectives.

Perhaps more importantly; however, is the focus group after the initial prototype has been developed. The designer can present the initial prototype to the controllers, and the focus group can provide critical feedback to the designer about the various characteristics of the advisory system. For example, the members of the focus group can provide suggestions for additions, deletions or alterations to the interface. The designer can then incorporate the changes into the prototype and return to the controllers for additional feedback. This process is what makes rapid prototyping so valuable. It not only allows for a well-designed interface, but it also encourages user-acceptance by obtaining controller feedback during the development process.

7. Conclusions and Recommendations

7.1 Conclusions

This research effort has aimed to prove that the proposed advisory system could help the air transportation industry achieve a variety of benefits. In terms of air traffic benefits, a given facility using this system can realize increased capacity, decreased delay, and as a result, an associated monetary and time savings.

In terms of air traffic control, the use of an automated system decreases the probability of violations, and in particular, reduces the instances of controller error. In addition, the controllers should benefit from a decreased work load and stress level. A decrease in the interarrival time standard deviation can result in a saturation capacity increase of approximately ten operations per hour resulting in a monetary benefit of approximately $35,000.00.

However, the most important conclusions that should be drawn from this research is the importance of human factors in the development of a user-interface. Without proper attention to human factors, an interface could be designed inadequately. For example, the advisory could interfere with other air traffic control tasks, could not meet the information requirements of the controller, or could fail to be user-friendly. It should be obvious that if human factors issues are not addressed and user needs met, the system will not be used by the attending air traffic control personnel. If the system is not used, none of the benefits outlined above can be realized and the system is a waste of time and resources.

7.2 Recommendations

As outlined in the previous chapter, this research effort has only begun the design process for a graphical user-interface. The process of rapid prototyping should be continued until a satisfactory design is achieved. The final prototype should meet the needs of the user, be acceptable to the focus group of air traffic controllers, and meet all human factors requirements and recommendations set forth by government agencies such as the FAA.

The next step is to program the interface on a platform that is compatible with the programming of mathematical algorithms developed in a separate research effort. Following the programming of the interface, further study should be undertaken to address the following issues:

- How the interface will be incorporated into the existing facilities; keeping in mind that each facility is unique and has different requirements
- How the system will be implemented – for example, how many interfaces will be installed, how the transition to automation will take place, etc.
- How the air traffic controllers will be trained to use the new system

In summary, this research effort has developed a framework for the development of the user-interface portion of the proposed advisory system. Although not exhaustive, this effort outlined the major areas of emphasis in human factors and has provided a step-by-step approach to the design. In addition, a sample design has been provided to form a foundation for further research.

Literature Cited

1. Billings, Charles E., "A Concept of Human-Centered Automation," *Challenges in Aviation Human Factors: The National Plan.* Vienna, Virginia, January 15-17, 1991.

2. Blackman, Harold S., "Introduction of Digital Control Systems to Operating Environments," *Challenges in Aviation Human Factors: The National Plan.* Vienna, Virginia, January 15-17, 1991.

3. Cardosi, Kim M., and Murphy, Elizabeth D., *Human Factors in the Design and Evaluation of Air Traffic Control Systems*, DOT-VNTSC-FAA-95-3.

4. Debelack, A.S., Dehn, J.D., Muchinsky, L.L., Smith, D.M., "Next Generation Air Traffic Control Automation." *IBM Systems Journal.* Volume 34, No. 1, 1995, pp. 63-77.

5. Endsley, Mica R, Rodgers, Mark D., "Situation Awareness Information Requirements Analysis for EnRoute Air Traffic Control." *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 1994.

6. Gutmann, James C., "An Alternative View of Task Analysis and System Design." *Challenges in Aviation Human Factors: The National Plan.* Vienna, Virginia, January 15-17, 1991.

7. Hopkin, V. David, "Automated Flight Strip Usage: Lessons from the Functions of Paper Strips." *Challenges in Aviation Human Factors: The National Plan.* Vienna, Virginia, January 15-17, 1991.

8. Hopkin, V. David, *Human Factors in Air Traffic Control.* Taylor and Francis; Briston, Pennsylvania, 1995.

9. Horonjeff, Robert and McKelvey, Francis X., *Planning and Design of Airports, 4th Edition.* McGraw Hill, Inc.; Washington, 1994.

10. Hunt, Valerio R., and Zellweger, Andres, "Strategies for Future Air Traffic Control Systems." *Computer*, February, 1987, pp. 19-32.

11. Labaw, Patricia J., *Advanced Questionnaire Design.* ABT Books; Cambridge, 1980.

12. Lin, Chin E. and Chen, K.L., "An Automated TCA Monitor System for Air Traffic Control." *IEEE Proceedings for the National Aerospace and Electronics Conference, Volume 2*: IEEE, 1994.

13. McCormick, Ernest J., *Job Analysis: Methods and Applications*. AMACOM: New York, 1979.

14. McCormick, Ernest J., and Sanders, Mark, *Human Factors in Engineering and Design, 5th Edition*. McGraw-Hill: New York, 1982.

15. Nolan, Michael S., *Fundamentals of Air Traffic Control*. Wadsworth Publishing Company: California, 1990.

16. Oppenheim, A.N., *Questionnaire Design, Interviewing and Attitude Measurement, New Edition*. Pinter Publishers: New York, 1992.

17. Picardi, Maria C., "Real-Time Simulations of Slot Markers for Terminal ATC: Implications for Automation and Training." *Challenges in Aviation Human Factors: The National Plan*. Vienna, Virginia, January 15-17, 1991.

18. Pozesky, Martin, "Air Traffic Control Automation Challenges." *Challenges in Aviation Human Factors: The National Plan*. Vienna, Virginia, January 15-17, 1991.

19. Reynolds, Linda, "Colour for Air Traffic Control Displays." *Displays*. Volume 15, No. 4, 1994.

20. Schlatter, Urs R., "Real-Time Knowledge-Based Support for Air Traffic Management." *IEEE Expert*. June, 1994.

21. Sommerville, Ian, Rodden, Tom, and Sawyer, Peter, "Cooperative Systems Design." *The Computer Journal*. Volume 37, No. 5, 1994.

22. Stewart, David W., and Shamdasani, Prem N., *Focus Groups: Theory and Practice*. Applied Social Research Methods Series, Volume 20. Sage Publications, Inc.; Newbury Park, 1990.

23. Thackray, Richard I., "Controller Vigilance and Monitoring Performance." *Challenges in Aviation Human Factors: The National Plan*. Vienna, Virginia, January 15-17, 1991.

24. Tobias, Leonard, "Development of Workstation-Based Automation Tools." *Challenges in Aviation Human Factors: The National Plan.* Vienna, Virginia, January 15-17, 1991.

25. Van Cott, Harold P., and Kinkade, Robert G., *Human Engineering Guide to Equipment Design, Revised Edition.* American Institutes for Reasearch; Washington, 1972.

26. Vortac, O.U., et al., *Automation and Cognition in Air Traffic Control: An Empirical Investigation.* DOT/FAA/AM-94/3.

27. Vortac, O.U., Edwards, Mark B., Manning, Carol A., "Sequences of Actions for Individual and Teams of Air Traffic Controllers." *Human-Computer Interaction.* Volume 9, N3-4, 1994.

28. Wickens, Christopher D., Miller, Sonia, Tham, Mingpo, "The Implications of Date-Link for Representing Pilot Request Informatin of 2D and 3D ATC Displays." *Proceedings of the Human Factors and Ergonomics Society, 38th Annual Meeting,* 1994.

Appendix A

Questionnaire
for the
Advanced Advisory System for Air Traffic Control

Here at Virginia Tech, we are working to develop an Advanced Advisory System for Air Traffic Control in the terminal area. In simple terms, we are working on mathematical algorithms that will determine the optimal sequencing of arrivals and departures. We want the optimal sequencing to be presented to the controller in the form of an advisory that appears on a display that is situated in the control tower.

The mathematical algorithms are currently being developed at Virginia Tech; however, this research doesn't benefit you, the air traffic controllers, unless you can receive the information in real time and in a usable format. This is where we need your help!

To complete our project successfully, we need to know how you – "real" air traffic controllers – operate on a daily basis. We want to know what equipment you use regularly and the procedures you complete when processing flights. We also want to find out what you like (and don't like) about your current facility. We need this information in order to make our graphical interface as user-friendly as possible.

Through the questionnaire portion of our research we hope to gather information concerning current equipment used, tasks that you perform, time spent on each activity, and your opinions on what information should be displayed on the new system.

Thank you for agreeing to complete the questionnaire. We truly appreciate your help with our research efforts. Please answer the following questions to the best of your ability. You should be able to complete the questionnaire in approximately 30 minutes. If you have any additional comments, please feel free to use the space at the end of the questionnaire. Again, thank you for your time and cooperation.

Demographics Section

How long have you worked as an air traffic controller?

How long have you worked with terminal area / ground control?

How long have you worked at this facility?

General Information

We envision the graphical-user interface as a display that will be present in the control tower and will provide a list of flights in the area and advisories to the controllers concerning the optimal processing times for the arrivals and departures. In the development of this system, we are assuming that aircraft position transmitters will be present in each aircraft that uses the facility.

A sample display is shown below. Please refer to this when completing the questionnaire.

The first series of questions is somewhat open-ended. Feel free to make as many comments as you would like. We appreciate any and all comments that you provide.

The proposed system will permanently display a flight list to aid the controller with traffic assessment and advisory evaluation. Some of the flight attributes will be permanently displayed, while others will be available through "pop-up" windows. With this in mind, please respond to the following questions.

Flight Progress Strips:

How many flights should be shown on the display simultaneously?

Which flight progress strip information parameters should be permanently displayed?

Which flight progress strip information parameters should be available when the flight icon is "clicked"?

One common use of the Advanced Advisory System could be to alert the controller that a departure can be safely released between two arrivals. Given this hypothetical situation, please answer the following questions.

Advisory:

How far in advance should an advisory occur?

When an advisory is displayed, three options are provided: *Accept, Reject, and More Information*. What information should be provided in the *More Information* area?

With any given advisory, there is an associated time during which the action must be completed for safety purposes. For example, "time remaining to release departure." How would you like to see this time displayed? *Some choices may include a clock or a disappearing bar, etc.*

Should the pop-up advisory be signaled with an auditory cue?

Should an auditory cue be associated with the "time remaining" display described above?

The proposed display will contain an area known as the "situational awareness display." Please refer to the above diagram for details. This portion of the display can be used by controllers to obtain an overview of the surrounding traffic.

Situational Awareness Display:

The situational awareness section of the display has two views: *Zoom In and Zoom Out*. What *information / topographical features / airport facilities* would you like to see on each display?

Zoom In:

Zoom Out:

How would you like the flight depicted on the situational awareness display? For instance, color coded dots, triangles, etc.?

What provisions should be made to account for intersecting runways? For example, a "ghosting" of one flight stream can be superimposed on the other flight stream so that the true separation of aircraft can be easily discerned. Would this be helpful?

Additional Information:

How frequently should the computer update the display?

How large would you like the display to be?

Would you like this as an additional display or would it replace a device currently in place?

Would you prefer a head-up display that is projected onto the glass or a traditional display?

Where would you like the display to be located in your facility?

How would you like to input data? For example, touch-screen, keyboard, mouse, etc.

Information Parameter Evaluation

Please let us know, to the best of your ability, which of the following information parameters would be helpful/necessary.

Please base your answers on a scale from 1 to 7. A score of 7 indicates that this information parameter is very helpful and/or necessary on the new display.

A Clock displaying the current time would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful

1 2 3 4 5 6 7

When presented with an advisory, a window pops up and describes the situation to the attending controller (see example). In this situation, the Opportunity to Reject the Advisory would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful

1 2 3 4 5 6 7

In the same situation, the Opportunity to Verify your action before you Accept the Advisory would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful

1 2 3 4 5 6 7

In the same situation, the Opportunity to Gather More Information on the Advisory would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful

1 2 3 4 5 6 7

If the "More Information" button is chosen, another window is shown (see example). Under the "More Information" window, viewing the Runway Occupancy Times of the aircraft in question would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful

1 2 3 4 5 6 7

Under the "More Information" window, viewing the Time Difference between the aircraft in question would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

The proposed system will permanently display a flight list and selected information about the flights (similar to the traditional flight progress strips). On the permanent display, the Airline associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

Other flight attributes, while not permanently displayed, will be available in a "pop-up" window by "clicking' the strip. On the "pop-up" display, the Airline associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the permanent display, the Flight Number associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the "pop-up" display, the Flight Number associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the permanent display, the Aircraft Type associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the "pop-up" display, the Aircraft Type associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the permanent display, the Aircraft Category associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the "pop-up" display, the Aircraft Category associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the permanent display, the ETA to FAF associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the "pop-up" display, the ETA to FAF associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the permanent display, the ROT associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the "pop-up" display, the ROT associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the permanent display, the Gate associated with a given flight would be:

NOT necessary or helpful ←——————→ VERY necessary and/or helpful
1 2 3 4 5 6 7

On the “pop-up” display, the <u>Gate</u> associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the permanent display, the <u>Destination Airport</u> associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

On the “pop-up” display, the <u>Destination Airport</u> associated with a given flight would be:

NOT necessary or helpful ←——→ VERY necessary and/or helpful

1 2 3 4 5 6 7

Task Analysis Section

This portion of the questionnaire is intended to discover what you perceive as your regular actions while processing a flight at your facility.

Please use the following hypothetical scenario: Releasing a departure between two incoming flights. The first arrival is still several minutes out.

Please list the task that you complete, the time spent at each task, and the equipment used to complete each task.

Sample task headings could include: controller command, controller query, pilot request, team communication, look, write, manipulate, obtain computer information, etc. Please be as specific as possible.

TASK	TIME SPENT	EQUIPMENT USED

Vita

Ms. Courtney A. Beamon was born October 24, 1973, in Richmond, Virginia. She received her Bachelor of Science in Civil Engineering in May, 1995, from Virginia Polytechnic Institute and State University. She began her graduate studies during the Summer of 1995. As a graduate student, she served as a Teaching Assistant for Dr. R. Sivanandan in the Introduction to Transportation Engineering course. She completed her Master of Science in Civil Engineering with a specialization in Transportation in August, 1996. She currently works as an engineer/planner for Delta Airport Consultants, Inc. in Richmond, Virginia.

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August, 1996