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AIRPORT SURFACE TRAFFIC CONTROL CONCEPT FORMULATION STUDY

VOLUME IV - ESTIMATION OF REQUIREMENTS

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16. Abstract

This four volume report presents system concepts for use in semi-automated airport surface traffic control at all positions in the tower cab of the major airports. The control functions and data requirements of a Ramp Control System, a Ground Control System, and a Local Control System are presented. The concept development process has been based upon an extensive study of cab operations at O'Hare Airport. This effort has included extensive delay analysis, study of communication tapes, and personal observations of the widely-varying situations that are faced by tower controllers. Following the Operations Analysis effort, a detailed study of requirements was performed and is presented in Volume IV of this report. This requirements effort provided an estimate of the performance requirements of a surveillance sensor that would be required in a TAGS (Tower Automated Ground Surveillance) system for use in both good and poor visibility conditions. Detailed studies were made of the complex type of conflicts to be solved by both the Ground and Local Controllers and operational levels and densities were developed. One particular TAGS system concept (employing an ATCRBS Trilateration Surveillance Subsystem) is described in Volume I and an estimate is made of its deployment potential at major airports. Backup material on this concept in the form of a working paper is held by TSC. This working paper also includes synthetic digital display concepts for the three systems which have been summarized in Volume I.

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PREFACE

At tower-equipped airports, the controllers in the tower cab are responsible for those aspects of Airport Surface Traffic Control (ASTC) requiring centralized management: issuing clearances for aircraft to land, taxi, or take off; establishing routing patterns for arriving and departing aircraft on the runway/taxiway network so as to minimize delays; sequencing aircraft movements on runways and taxiways and at critical intersections to ensure safety; and controlling the movements of service or emergency vehicles on the airport surface. Because of the expertise of the controllers and pilots, the ASTC system has worked well most of the time. However, the unfortunate incidents at Chicago-O'Hare (20 December 1972) and Boston-Logan (31 July 1973) have pointed out certain deficiencies; e.g., the system's surveillance capability when visibility is poor.

Initiated by the Federal Aviation Administration (FAA), the ASTC program is in the process of implementing several near-term system improvements. However, it is expected that these improvements, while adequate for the 1970's, will not be adequate to meet the more stringent long-term requirements of the 1980's.

The approach which has been taken in the present study is to concentrate on the Nation's most active and, in one sense, most mature airport; i.e., Chicago-O'Hare. In performing the study at O'Hare, the cooperation of the Airport Traffic Control Tower, the City of Chicago Department of Aviation, and the FAA Great Lakes Region was essential to the success of the effort. Mr. Paul S. Rempfer, of the Transportation Systems Center (TSC), acted as technical monitor for the Government. In addition, Messrs. Rempfer and L. Stevenson, also of TSC, performed the theoretical analysis of local area capacity which is presented in Section 5.3.3.1 of Volume III.

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SECTION 1 - INTRODUCTION

1.1 OBJECTIVES

General criteria for an ASTC system include (1) to be as simple and low in cost as possible while addressing the basic objectives and (2) to be equally applicable to all airports requiring it, which could be quite a few. The basic system objectives fall into three major areas of control as follows:

1. Local Control - To provide accurate and timely information to Local Control on the suitability of each inter-arrival space for a departure release. This assistance would offer benefits which could amount to a 20 percent increase in departure capacity for the more difficult to handle runway configurations with good visibility and a 30 percent increase for single mixed operations with bad cab visibility. Also, Local Control must be provided with positive assurance that the runway on which he is about to clear an operation is, in fact, clear of other vehicles. This latter requirement is critical to the basic safety of operation.

2. Ground Control - To provide the location and identity of each vehicle under control to Ground Control to reduce the excessive communications (work) load due to position reporting under bad visibility conditions. The average content of voice communications for Ground Control, indicates that these position reports represent 85 percent of the increased channel loading experienced under bad cab visibility. The identity could assist Ground Control in maintaining vehicle/identity correlation in good visibility.

3. Ramp Control - To provide a centralized system of ramp entry clearance to permit the most efficient use of those ramp areas which can only support one-way traffic flow. This implies operation in a batch or platoon mode (e.g., multiple "pushbacks" and taxiing aircraft within a ramp area).

The first two objectives are basically information presentation (surveillance) problems. In light of criteria (1), the initial ASTC concept will be surveillance only, without control automation. In addition, automation of control functions would make it much more difficult to maintain equipment commonality between airports. While the basic information needs at different airports may be the same, the control problems, especially for an automated Ground Control System, can be quite different.

The third problem is quite different from the first two. There is currently no centralized ramp control. The FAA is not responsible for the ramp area; there is no such control position. Staffing constraints and room in the cab make addition of a position undesirable. Such a system would have to be heavily automated and managed by the current complement of controllers, primarily Clearance Delivery. This automation would probably require the substantial tailoring of equipment to each airport. In addition, the participation of airline operations personnel would be required in the system and scheduling of pushbacks (a controversial item at best) would be involved.

The above considerations motivate the Tower Automated Ground Surveillance (TAGS) concept. TAGS is basically a surveillance system aimed at problems 1 and 2 above. Information retrieval, processing, formatting and display are automated. Control functions remain in the hands of the controllers. It is a simple system (conceptually), addressing the basic problems and permitting inter-airport equipment commonality. In the remainder of the report TAGS is described in terms of subsystems covering its major areas; a Local Control System (LCS) and a Ground Control System (GCS). In addition, to provide an understanding of what could be offered in the ramps, a Ramp Control System (RCS) is also described. Because of the problems enumerated above, RCS is considered an option and is not intended as part of the initial TAGS development.

The results of this working paper are expected to be used in the further development of concepts for each of the three major systems. Preliminary discussions of the system concepts are provided in this document in order to show how the requirements are related to the concept currently under development. It is expected that refinements to the requirements established in this working paper will take place as they are compared with the capabilities that can be achieved through various surveillance sensor techniques and/or data transfer methods. As such, therefore, they should be taken as representing a "first cut" in establishing the information required by the controller and the estimated performance requirements of the surveillance sensors that will serve to collect this information.

In performing this concept development, the system designer is faced with the problem of attempting to replace the information gathering capabilities of a visual surveillance method with other display or information presentation methods wherein the man/machine information transfer process will be completely different from that provided by visual means. Because of this, the design philosophy employed in the concept development process has been one wherein emphasis is placed on the use of data processing techniques as far as possible to perform as many portions of the control functions as possible; the basic premise, however, is that the control decisions will be made by the controller and not by the machine. Under this philosophy emphasis is placed upon the real-time, semi-automatic aspects of the control process wherein the information presented to the controller is specifically related to the function he is performing at a given time. Without this selectivity, it is believed that the controller's ability to perform the required functions at normal operational levels will be seriously hampered.

Another common aspect of the three portions of the ASTC system would be the use of data processing capabilities for controller cueing, or scheduling, of the functions he is to perform. This capability, of course, would be overridden by the controller when necessary.

The methodology employed to establish the several types of requirements is discussed later in this section; it essentially relies on the examination of aircraft movement profiles and the control actions currently employed by the cab controllers. The functions performed in each of the three major systems have been derived as a result of careful and extensive study of cab operations at the busiest commercial airport in the world, namely, O'Hare Field. It is recognized that at some other major airports all of the functions described in this report may not be necessary, and that in some cases other functions may be required. However, in our judgment these changes will be minor.

For each of the three systems the functions to be performed are described. The information transfer aspects of each function are examined and these are then translated into the performance requirements desired of the surveillance sensors. To determine the total load on the three systems, airport operational levels are estimated both during the busy hour as well as for short-term peaks. This operational requirement will impact on the data rates at various portions of the several systems and will, for example, be used in establishing surveillance sensor update rates, "refresh" rates of displays, etc.

A basic constraint used in the development of the three systems has been the reliance on voice rather than data link between the pilot and the controller. The availability of automated communications between these two individuals can, in the future, lead to the evolution of a more fully automated system from the concepts presented in this and subsequent documents.

In addition to investigating the three major systems described above, further material is presented on two other concepts which will impact on the Ramp Control System and Ground Control System, respectively. In the first area an Automatic Gate Status Equipment is included as part of the Ramp Control System. This subsystem could be expected to provide benefits to the airline operators by itself, and at some airports may be desirable as a separate module even though an automated or semi-automated Ramp Control System is not implemented.

With respect to the control functions performed as part of the GCS, a separate examination was made of potential benefits of a so-called STR (standard taxiway routing) module. This particular aspect is treated separately from the Ground Control System which, of course, does include as one of its functions that of Routing Control.

1.2 CHARACTERISTICS OF REQUIREMENTS

The establishment of system requirements is a complex process involving tradeoffs between design concepts, economics, and operational constraints. The conventional starting point is usually that of defining the problem(s) by means of a series of data collection experiments, or operations analysis. While many valuable inputs to the requirements establishment process are obtained in this manner, it should be recognized that an existing system or procedure in itself imposes constraints or limitations which a new system concept may not have to contend with.

The requirements to be set forth in this document are preliminary in nature; it is expected that system (module) synthesis efforts to be performed later in this program will result in some modification to the qualitative and quantitative values given in this report. We shall consider requirements as comprising three areas, namely Functional, Operational, and Performance requirements as defined below.

Functional requirements may be defined as those describing the tasks which a system or module is to accomplish. They answer the question "What must the system do?" and as such are a mixture of qualitative and quantitative statements. Representative examples of functional requirements include:

- Release of an aircraft for takeoff (or taxiing)
- Clearance for runway crossing
- Providing route information

Identification of system (subsystem) users and their characteristics will also be considered as part of the Functional Requirements definition. In most cases the primary users of the system are the controller(s) and the pilots; however, other potential users (or data sources) will be involved in the information flow process. A preliminary list of potential system users and/or personnel who may interface with the TAGS system is given in Table 1-1.

Table 1-1. Identification of Potential System Users

FAA - CAB	Flight Data Clearance Delivery Outbound Ground Control Inbound Ground Control North Local Control South Local Control Watch Supervisor
TRACON	Approach Control - North Approach Control - South Departure Control - North Departure Control - South Monitor Control
<u>Airlines</u>	
Pilot	Personnel
Ramp Area	Gate Attendant Cargo Supervisor Tow Vehicle Operator Ramp Supervisor (Gate Manager) Ramp Controller (Tower)
Airport	Vehicle Operator Duty Supervisor

To meet the Functional Requirements, the subsystem work flow may be considered as comprising machine-type process and human efforts. We shall attempt to use the term "job" to describe machine-type process and the term "task" to describe those functions performed by the controller, pilot, etc. Presentation of data, via a display, to the controller is therefore a "job" of the particular subsystem, while the interpretation of this data, as well as the voice communication process represent "tasks" performed by the controller.

Operational requirements represent parameters relating to the total situation under which the functional requirements are to be met. They include traffic considerations (load); environmental (weather) aspects; facility constraints (runway configurations, ramp areas, etc.); and the operational procedures and standards imposed for safety reasons. Representative examples of operational requirements include:

- Number of active aircraft in a particular geographic area at one time or during a particular interval of time
- Visibility level
- Separation standards

Performance requirements are a quantitative estimate of the acceptable capabilities of the module and its components required to meet the applicable functional and operational requirements. These are expected to vary in different portions of the TAGS system, i.e., the required position accuracy may be different in the ramp area as contrasted with the final approach area. Typical examples of performance requirements include:

- Data Rates/Response Times
- Accuracy of Position and/or Velocity Data
- Resolution

1.3 METHODOLOGY

1.3.1 General

The methodology employed to develop the ASTC (TAGS) performance requirements has been based upon a detailed examination of mission profiles (or scenarios). These scenarios are comprised of three major components, namely

Aircraft Movement Profile

Pilot Functions

Control System Functions

The information flow between the major components of the ASTC system is illustrated in Figure 1-1; the characteristics of these components will, of course, be different for the Ramp Control, Ground Control, and Local Control Systems.

The Aircraft Movement Profile component includes both aircraft parameters/constraints, as well as airfield/airspace characteristics. As representative of the former, one must consider aircraft equipment types, braking capabilities, etc.; the latter area essentially describes the characteristics of the facilities (taxiways, runways, etc.) that can be considered as providing "service" to the aircraft.

Functions expected to be performed by the pilot in the semi-automated system are listed in Table 1-2. These functions are relatively independent of the particular control system involved.

The Control Functions will be examined in detail for each of the three major subsystems. This investigation will consider first the estimated Data Requirements needed either by the Controller or a computer to adequately perform the Control System Functions. It is in this area that consideration must ultimately be given to man/machine interface or display characteristics.

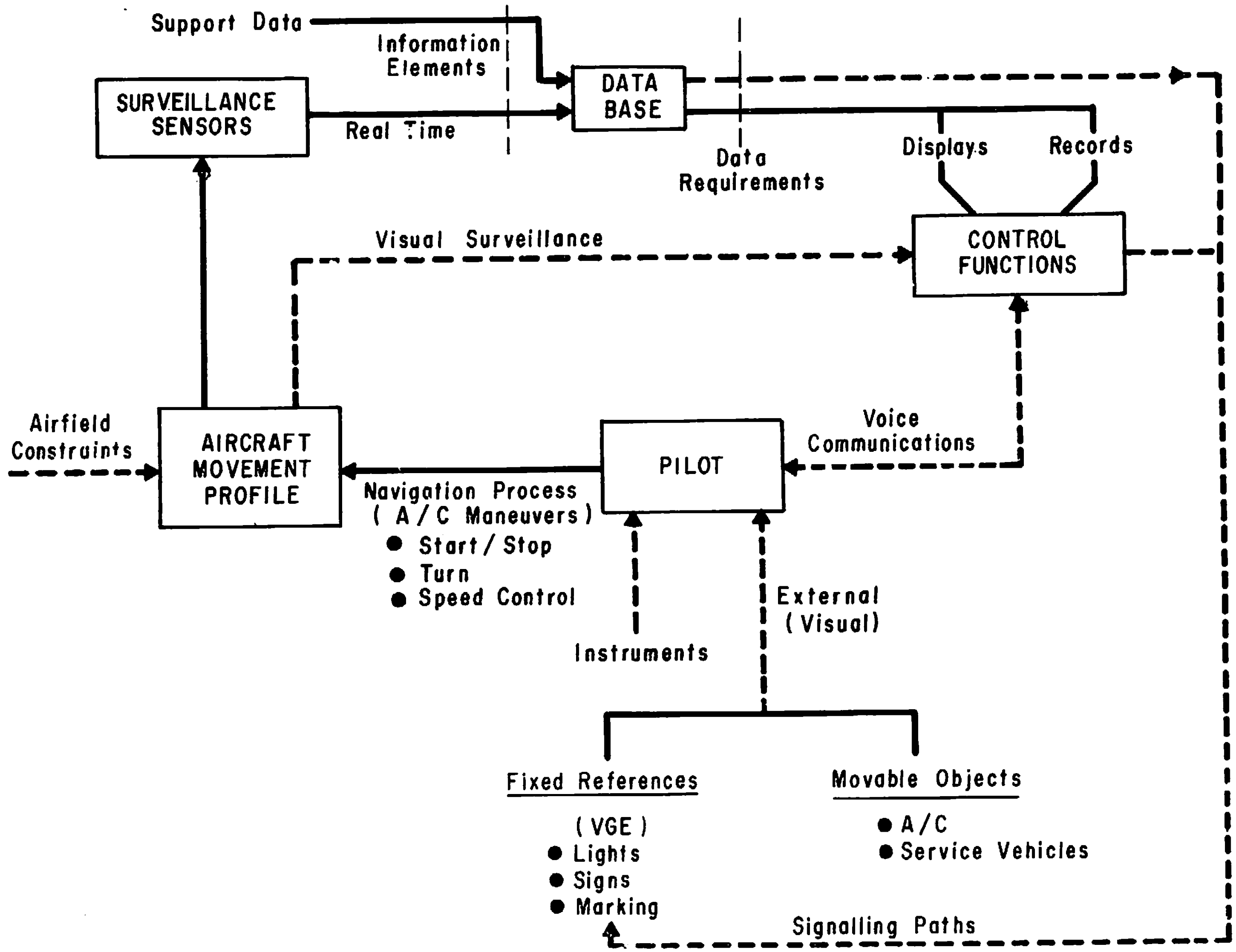


Figure 1-1. Information Flow Between Major Components of Airport Surface Traffic Control System

Table 1-2. Pilot Functions

Maintain separation from preceding aircraft on same link or "highway".
Determine partial identity (aircraft equipment type and airline) of nearby aircraft.
Maintain aircraft speed below safe limits consistent with taxiway constraints and flight phase.
Navigate aircraft using VGE references and aircraft instruments.
Maintain lateral (centerline) control.
Select appropriate R/W turnoff.
Stop aircraft clear of intersections, obey runway crossing hold lines.
Provide controller with aircraft status data as needed i.e., Ready-to-Taxi, Position Report, etc.

Inputs to the system Data Base--from which the control data is derived--will be classified as Information Elements. These fall into two classes: Real Time (or sensor-derived) data and Support data. The characteristics of the required Sensor or Real Time Information Elements are those of primary interest.

The communication processes for a semi-automated system may use present-day voice techniques or signaling methods which, for example, utilize FGE facilities, or possibly existing capabilities in the cockpit. Of major interest insofar as the communications portion of the control process is concerned is the System Response Time discussed in the next paragraph.

1.3.2 System Response Time Considerations

The major response time factors to be considered for a semi-automated surface traffic control system include

Sensor Response Time	Variable
Conflict Recognition (Detection) Interval	1.5-3 sec.
Conflict Resolution Time	1-2 sec.
Communication Duration (Controller-Pilot)	5-6 sec.
Aircraft Dynamics (including Pilot Response Time)	5.5-8 sec.

Preliminary values have been assigned to these various components of response time based upon rationale given below.

The Conflict Recognition process would be performed by a computer with negligible time delay. However, presentation of the results to the controller via some type of display, plus his interpretation of the display, will take a small amount of time. Moreover, it is expected that multiple conflicts may result in delay in the presentation of a small number of cases. These factors had led to an estimate of from 1.5 seconds to 3 seconds for this process.

The Conflict Resolution process is that wherein the Controller makes the decision to prevent the upcoming conflict. This decision, which may involve holding or sequencing an aircraft, may overlap the Conflict Recognition process. Time estimates of 1 second to 2 seconds have been used for this process.

Communications transactions (CT) between pilots and controllers average about 8 seconds to 9 seconds in duration. Control or decision-type CTs are expected to be shorter. Based upon voice communications this parameter has been estimated at from 5 seconds to 6 seconds.

The implementation by the pilot of a control instruction will be constrained by the pilot response time (0.5 second to 1.0 second) as well as the dynamics of the aircraft. At normal taxiing speeds it is estimated that 5 seconds to 7 seconds may be required for a normal aircraft "stop".

The sum of the above factors ranges from 13 seconds to 19 seconds. Sensor response times of from 1 second to 2 seconds represent durations which would not unduly penalize the overall system response time. This range of intervals permits the recognition of the various events to be handled in the control process, i. e., recognition of the time an aircraft enters the taxi system or new link.

These components of response time require of course further study of man/machine relationships in the actual system and represent, therefore, only very preliminary values. The limiting factors of voice communications and aircraft dynamics are readily apparent in the breakdown given above.

It is envisioned that the conflict estimation process to be performed by the computer would be organized so that several levels of potential conflict are defined based upon the prediction interval. For example, top priority would be given to prediction intervals of say 15 seconds to 22.5 seconds, second priority to conflicts expected to occur in time intervals of 22.5 seconds to 30 seconds in the future and lowest priority to a time interval of 30 seconds to 45 seconds. An example of the latter might be the prediction of an "Arrival" at the ramp entrance point.

SECTION 2 - COMPOSITE AIRPORT SURFACE TRAFFIC CONTROL SYSTEM OPTIONS

The integration of the three major systems into a composite ASTC system for a specific airport can result in a wide variety of hardware configurations. These configurations will be influenced by the airport layout, capabilities of existing hardware, weather considerations, etc. In some cases, it may be desirable to provde semi-automation capabilities for only some of the functions performed in one of the three major areas. For example, a subsystem providing R/W crossing management might be a desirable feature at an airport having visibility constraints but not requiring automation of other Ground Control functions. It is not the purpose of this document to put together all the possible means by which composite ASTC systems can be designed for a specific airport from the building blocks or systems described herein. The rationale by which the performance requirements are developed for each of the three systems can be used by the system designer to tailor a particular configuration meeting the needs of a specific airport. Later in this report a composite list of system performance requirements is developed based upon those established for each of the three separate systems. In some cases, therefore, only the performance requirements needed for one of the three systems might have to be specified for a given installation.

It is expected as more detailed design of the total ASTC concept is accomplished, specific recommendations for utilizing existing data processing hardware, centralizing data bases, etc. can be developed. These interface and specific airport-related aspects of the ASTC design are beyond the scope of the current study.

SECTION 3 - DEVELOPMENT OF A RAMP CONTROL SYSTEM (RCS) CONCEPT)

3.1 INTRODUCTION

This section investigates the possibility of an automated Ramp Control System. It is intended to show what might be done in the ramp area. As stated in the introduction, RCS is considered an optional subsystem of TAGS and will not be a part of the initial TAGS development.

The development of the Ramp Control System (RCS) (module) concept is directed toward improvement of the processes for coordination and control of operations in the ramp area(s) of the airport and for coordination of these operations with other airport surface traffic control operations. The development of the concept is based upon the integration of:

- Improved techniques of information exchange between the airport traffic control tower (ATCT), airline operations, and automated enroute and terminal ATC systems.
- Established basic procedures for flight operations coordination.
- Extension of positive control of flight operations to those ramp areas which justify such control.
- A systematic logic for automation of information exchange, flight operations management, and display of cue information to tower personnel.

3.2 REQUIREMENTS ESTIMATION

3.2.1 General

The RCS conceptual design incorporates the functional tasks associated with air traffic operations within or related to the airport ramp areas. This includes those functions now being performed by ATCT and airlines operations personnel as well as those additional functions necessary to more effectively and efficiently accomplish the specific performance objectives of the module.

These objectives include:

- To accomplish all information transfer related to acquisition, maintenance, and presentation of data for initiation of service to flight operations within the airport ramp areas.
- To accomplish all information transfer related to coordination of flight operations within the ramp area(s) and between the ramp area(s) and the airport taxiway network.
- To achieve an orderly flow of aircraft traffic within the ramp area that affords an optimum balance between delays (when necessary) to outbound and inbound traffic.

The areas of service of the RCS include all ramp areas associated with the airport passenger terminal(s), cargo terminal, and hangar facilities. To accomplish the necessary services within these areas the module must achieve operational interfaces between the ATCT and airline operations, NAS enroute system, and ARTS III. The system (module) must also achieve operational interfaces with other ASTC system modules, i.e., Ground Control System (GCS) and Local Control System (LCS). The interface with the Ground Control System is of primary importance because of the physical interface between the ramp area(s) and taxiway network and the requirement to coordinate the management of traffic operations at these physical interface points.

The Ramp Control System concepts described here represent, to a significant degree, modification of current procedures in airport surface operations. These concepts are dependent upon two underlying or subsidiary concepts and a number of assumptions regarding the manner of operations in the ramp areas. These subsidiary concepts are those of Positive Ramp Control and Gate Schedules Data Maintenance.

3.2.1.1 Definition of Positive Ramp Control

An essential element of the development of the RCS concept is the subsidiary concept of Positive Ramp Control.

In current operations at most airports, air carrier traffic may initiate their pushback when it is determined to be feasible by the aircraft crew and airline ramp operations and ground crew personnel.* Where the physical characteristics of the ramp area/terminal building configuration permit free movement of aircraft around another aircraft, this mode of operation does not cause any operational difficulties. However, where the physical characteristics of the ramp area/terminal building configuration does not permit this free movement, then significant operational difficulties may occur. For departures, this occurs when a flight which is ready to taxi cannot do so because of the pushback of another aircraft from a gate ahead of the first aircraft's gate. When this situation occurs, the delay may also result in the need for the ground controller to resequence the flight into the traffic stream. For arrivals, delays occur when the flight cannot enter the ramp area and taxi to its gate because its way is blocked by a departure taxiing out of the area or in pushback ahead of the arrival's destination gate. When this situation occurs, the ground controller may have to hold the arrival on the taxiway until the blockage is cleared, possibly resulting in delays to other aircraft following it or, to avoid such delays, issue instructions for additional taxiing of the arrival.

At some airports where this ramp constriction situation exists, individual airlines have constructed their own tower facilities (e.g., United Airlines and American Airlines at O'Hare) to afford their ramp controllers visual surveillance of the ramp areas in which they operate. This permits the ramp controller to determine when departure pushback should be delayed to avoid interference with their other flight operations or to avoid conflicts with the operations of other airlines sharing the same ramp area.

Even with these more advanced airline operations, and certainly where such facilities are not employed, the occurrence of delays to outbound as well as inbound flights is quite frequent. While ramp controllers can exercise management

*At some airports, flights operating at certain gates must obtain pushback clearance from the tower when pushback from their gates would temporarily block passage of other aircraft on the taxiway network (e.g., Continental Airlines operations on gates D-11 and D-12 at O'Hare International Airport).

of their own operations, they cannot directly exercise control of the operations of other airlines. Thus, another airline's flight may push back and block an outbound or inbound flight. At O'Hare, United and TWA have discussed the possibility of United providing pushback control of TWA flights. However, for several reasons no agreement was reached. The major deterrent was that the United tower afforded visibility of only the F-G ramp area which they share but not the G-H area in which TWA also operates, as shown in Figure 3-1.

The objective of the concept of Positive Ramp Control is to achieve and improve on the capabilities provided by the individual airline ramp control tower and to extend these capabilities to all ramp areas where it is required. At any given airport, the ramp area/terminal building configuration may incorporate areas in which Positive Ramp Control is not required and those in which it is. Those areas in which such control is deemed necessary are (and will be) referred to as Positive Ramp Control areas. The extent to which Positive Ramp Control is required will obviously vary from airport to airport. At airports such as O'Hare, LaGuardia, Los Angeles, and Atlanta, Positive Ramp Control may be the predominant mode of operation with some areas not under Positive Ramp Control At airports such as Logan, Kennedy, Philadelphia, and Newark, Positive Ramp Control may be a minor mode of operation for only one or two areas. At many other airports such as Cleveland, Dallas-Ft. Worth, San Francisco, and Baltimore, Positive Ramp Control may not be needed at all.

Thus, at each airport those ramp areas which will require Positive Ramp Control would have to be identified. These would include all areas in which:

- The outbound taxi of a departure flight (or aircraft moving from a terminal gate to another airport location) could be blocked by pushback of another aircraft

- The inbound taxi of an arrival flight (or aircraft moving to a terminal gate from another airport location) to its gate could be blocked by pushback of a departure flight

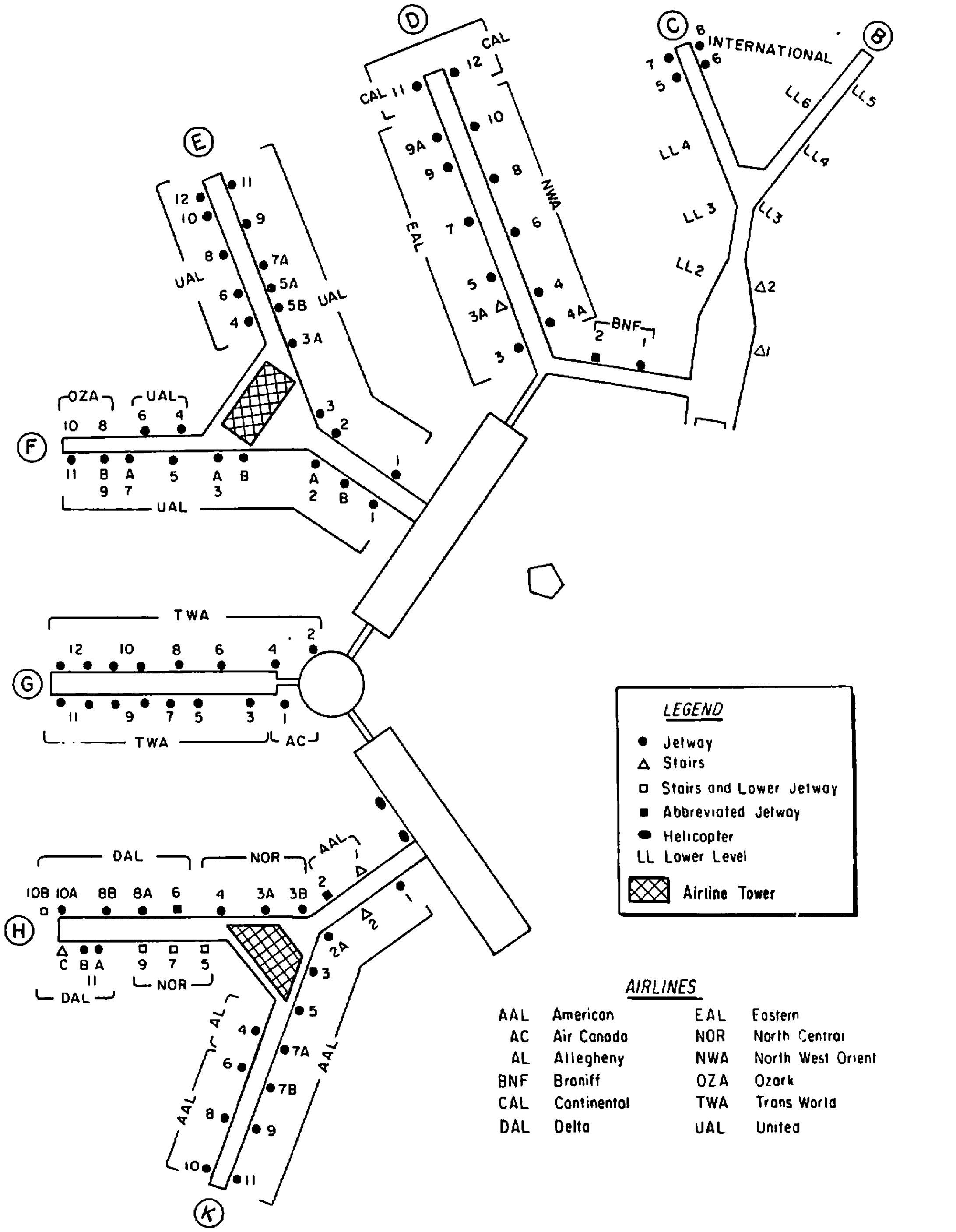


Figure 3-1. Ramp Area/Terminal Configuration - O'Hare International Airport

- The available space would permit simultaneous taxi (and passage) by two outbound aircraft or by both outbound and inbound aircraft under good visibility conditions but where this cannot be accomplished with a sufficient degree of safety when pilot visibility is impaired under poor weather conditions.

The application of these criteria to O'Hare for the passenger terminal ramp area is illustrated in Figure 3-2. The C-D, D-E, F-G, and G-H ramp areas are obvious candidates for Positive Ramp Control areas. The area to the east of K-wing is a candidate for Positive Ramp Control because the presence of blast fence limits the space available for aircraft movement. Moreover, based upon the airport management's indicated anticipation of construction of an L-wing in the future, this area would probably remain a candidate for Positive Ramp Control. The area to the north of the B-wing is not currently estimated to require Positive Ramp Control even with the presence of general aviation traffic at the Butler ramp. However, with the airport management's anticipated future construction of an A-wing (and a new general aviation terminal), Positive Ramp Control for this area may become necessary.

Therefore, the concept of the Ramp Control System provides for incorporation of Positive Ramp Control and non-Positive Ramp Control modes of operation for departure and arrival aircraft as a function of the origination/destination gate of the aircraft. Positive Ramp Control in designated areas would be applied to both normal aircraft departure/arrival flights as well as to flights moving between these areas and terminal facilities (i.e., cargo and hangar areas). Depending on the configuration of the airport cargo and hangar areas, these areas could also come under Positive Ramp Control.

As noted earlier, the concept of Positive Ramp Control is to improve on and extend the capabilities now achieved by the individual airline control tower. A number of approaches were considered in developing the Ramp Control System concepts described in this section. These included:

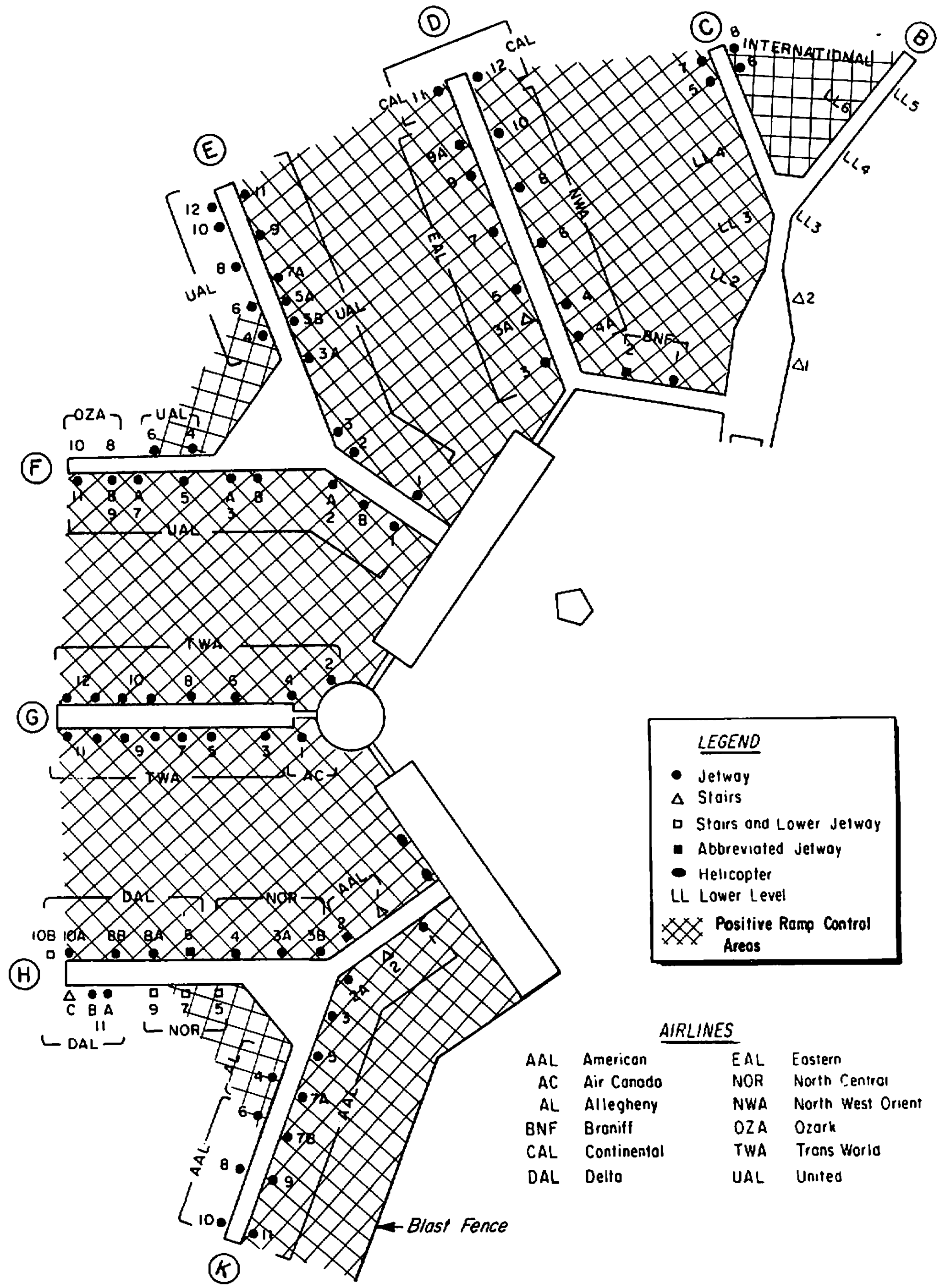


Figure 3-2. Positive Ramp Control Areas - O'Hare International Airport

1. Provision of Positive Ramp Control through the airlines with each airline provided with sufficient capability to control its own flights in relation to other flights operating in the same ramp area.

2. Provision of Positive Ramp Control through the airlines but where these responsibilities would be exercised by one or more airlines serving their own and other airlines' flights.

3. Provision of Positive Ramp Control by FAA personnel operating in suitable locations, such as existing airline towers.

4. Provision of centralized Positive Ramp Control by FAA personnel operating in a single location, i.e., the ATCT.

Each of these approaches has certain merits and disadvantages. At O'Hare, for example, the American and United towers could be readily used to provide control in the D-E, E-F, F-G, G-H, H-K, and K positive ramp areas within approaches 2 and 3 above. However, these locations are not adequate for control of the B-C and C-E Positive Ramp Control areas. It is recognized that an additional facility could be constructed to serve these areas or, in the case of 3 above, this could be accomplished from the ATCT.

After due consideration, approach 4 above was adopted as a preliminary approach. The primary factors in this determination included the following:

1. It is applicable to all airport configurations independent of the availability of airline control towers or other suitable locations.

2. Agreements between airlines over control of each other's operation may be potentially difficult to achieve.

3. Centralization of all required information, information processing, and display of conflicts at a single location for decision making appears more practical, both operationally and technically.

4. Vesting of control authority in a non-airline position would avoid potential disagreements over favoritism and provide more objective ramp area management.

Thus, it has been assumed the Positive Ramp Control as well as other functional responsibilities of the Ramp Control System would be exercised by the ATCT through Ramp Control positions. The extent to which these responsibilities could be exercised through expansion of the role of the existing Clearance Delivery position or would require an additional position in the ATCT would be determined by the volume of traffic and the degree of Positive Ramp Control required in proportion to other Ramp Control System operations. In either case the exercise of these functions will require data exchange with the airlines as discussed in the following section.

3.2.1.2 Gate Schedules Data Maintenance

The second subsidiary concept within the development of the Ramp Control System concept is the maintenance and application of gate schedules data. This concept is important for several reasons. First, knowledge of the ramp location (gate) from which a flight is departing or for which a flight is arriving will determine whether it will come under Positive Ramp Control. Second, knowledge of the ramp location of a departure is necessary for the ASTC system functions of routing to the runway, sequencing the flight in the taxi flow pattern, and determination of conflicts with arrival aircraft for the same ramp. Third, knowledge of the destination gate for arrivals and the availability of the gate is necessary for routing of the flight by ground control operations.

Currently, origination gate, destination gate, and availability are determined by direct communications between the ATCT and the flight. The objective of this subsidiary concept is to obtain and maintain this data in a more timely and efficient manner in order to reduce controller and pilot communications workload and more effectively manage system operations.

Discussions with airlines personnel during the preceding O'Hare Operations Analysis indicated that preplanned gate schedules are developed whenever major rescheduling of flight operations occurs. Temporary adjustments to these schedules are made when special flights are added to their schedule or when gate changes are necessitated by the operational situation (delays, equipment changes, etc.).

The concept incorporated here is based upon storage of the preplanned gate schedules in the Airport Surface Traffic Control (ASTC) system data base for reference by the Ramp Control System. This data base would be updated when temporary adjustments are made through direct communications with the airlines' flight operations. To maximize the efficiency of these communications it is anticipated that digital data transfer between flight operations and the ASTC system would be accomplished through suitable terminal devices (Automated Gate Status Equipment) in the airline flight operations facilities.

The concept further provides that this gate schedule data base be maintained on a dynamic basis by the internal processing of the Ramp Control System. The purpose of this is to maintain a reference of the current status of occupancy of gates (e.g., open, occupied, aircraft off gate but not yet departed). This information would be employed by the Ground Control System in determining whether an arrival can be routed directly to its gate or must be routed to an interim holding area (e.g., O'Hare's Penalty Box).

One of the basic requirements of this subsidiary concept as well as that of Positive Ramp Control is a positive data entry that the aircraft has docked or parked at its gate.

It is fully recognized that this concept, involving direct operational interface between proposed RCS and airline flight operations, is new to airport operations and that its implementation will require acceptance by the airlines. However, substantial benefits to both airline, ATC, and airport operations should result.

3.2.1.3 Basic Assumptions

The RCS concepts described here were developed to be generally applicable to a broad range of environments at major airports. The concepts provide for airport configurations including both positive and non-positive ramp areas as well as a mix of IFR and VFR traffic. To satisfy this objective, several assumptions were made relative to the nature of the ramp control services provided and to traffic procedures within the ramp areas. These assumptions are:

- Control of flight movements from/to/within the ramp area will be accomplished primarily as a scheduling function
- No real-time sensor surveillance for control of aircraft lineal (forward) and lateral (turning) movements will be performed
- No real-time guidance of aircraft lateral (turning) maneuvers will be provided
- Departure flights or flights to cargo/hangar areas will remain in pushback position until receipt of positive clearance to taxi from Ground Control; i.e., they will not move toward the outer edge of ramp area while waiting for such clearance
- Where sufficient ramp surface exists for an aircraft to hold (off the taxiway network) while waiting for the ramp to clear for taxi to its gate, Ground Control may clear a flight off the taxiways to the ramp area with instructions to "monitor Ramp Control". The flight would remain in the holding position until cleared by Ramp Control for taxi to its gate.

3.2.2 Functional Requirements

The major functions to be performed by the Ramp Control System have been derived from the detailed study of existing ASTC system procedures and flight operations during the period of service within the ramp areas. These functions are for the most part defined for implementation employing semi-automated control techniques to improve system effectiveness and efficiency. No provision for automated transmission of data to aircraft flight deck has been considered. Therefore, transmission of clearances, control instructions to aircraft, and pilot reports of flight status are by voice radio. Further improvements in the concepts outlined herein could be achieved in the future with the introduction of data links or by DABS.

3.2.2.1 Identification of Control Functions

The RCS functions may be divided into three categories, based upon whether they are required for departures (outbound) or arrival (inbound) flights or are common to both. These functions include:

Departures

A. Flight Clearance Delivery

B. Maintain Outbound Ramp Q

C. Pushback Clearance

D. Inter-Departure Conflict Management

E. Handoff to Ground Control Departure Q

Arrivals

F. Verify Gate Assignment

G. Monitor Inbound Ramp Q

H. Clear to Gate

Common

J. Outbound/Inbound Conflict Management

Each of these functions is examined in order to determine the information needed for data processing and decision making by the system computer equipment, controller, or airlines operations to perform the appropriate job (or task). There is a substantial amount of interaction between many of these functions. For example, Function C requires that: (1) Function A has been accomplished; (2) Function D (no conflict with other departures in the same ramp area) is satisfied; and (3) Function J (no conflict with inbound flights to the same ramp area) is satisfied. However, Function J also requires that Function G has been accomplished.

As another example, in current operating procedures the equivalent of Function E is accomplished as soon as a flight indicates it is ready to taxi. * Ground Control may contact the flight immediately for taxi or may delay contact because of other operational demands (e.g., another departure in the same ramp area which must taxi out first). Even after contact is established, compliance with Ground Control instructions could be blocked by the actions of another outbound or inbound flight. For the proposed RCS concept, Function E would be accomplished only when potential conflicts with the movement of the aircraft have been determined not to exist or have been resolved and, therefore, that the flight may move without delay when contacted by Ground Control. In effect, then, this function reserves the ramp area between the region of the departure's gate and the ramp/taxiway interface point for its exclusive movement.

Table 3-1 lists the major functions required in the Ramp Control System (module). The second column identifies where interface is required with the Ground Control and Local Control Systems, with airline flight operations, and with the NAS enroute and ARTS III systems. The third column lists (in order) the sequence of events or interacting functions which must be recognized or performed in accomplishing the function. In the case of Function D, Inter-Departure Conflict Management, the table shows an interaction with Functions B and C at the start of the sequence. These are essentially requests for the performance of Function D. However, if an inter-departure conflict is determined to exist, the sequence will return to the initiating functions. The return is not specifically indicated to avoid redundant listing of the interacting function. The same is true for Function J, Outbound-Inbound Conflict Management, in relation to Functions D and G. Where applicable the entries in this column have been classified as "Demand", "Start of Service", or "End of Service". These terms are intended to identify the entry of a demand

*Assuming that gate hold procedures have not been put into effect because of extensive operational delays.

Table 3-1. Ramp Control System - Functions and Requirements

Control Function	Interface Required With	Interacting Function	Data Requirements	Real-Time Data Input Requirements	Remarks
<u>DEPARTURES</u> A Flight Clearance Delivery	ARTCC TRACON Airline Operations	Receipt of Flight Clearance From ARTCC (For IFR Deps) Receipt of Call From Pilot (Start of Service) Issue Flight Clearance Function B Function F (VFR Dep)	Flight Route (Incl. First Fix), Cleared Altitude, Beacon Code Desired Direction of Flight & Altitude (For VFR Deps)	Flight Plan Modification Abbreviated Flight Plan (VFR)	
B Maintain Outbound Ramp Q	Ground Control Subsystem Airline Operations	Pilot Call-Ready to Taxi (Concurrent with Function A for VFR) (Demand) Function C Establish/Update Q List Function D Function J	Flight ID, Ramp Location, Status, Time of Demand	Flight Status (i.e., RTT, RTT/HO)	Interaction with Functions C and D only for ramp areas requiring Positive Ramp Control
C Pushback Clearance	Ground Control Subsystem Airline Operations	Receipt of Call for Clearance to Pushback (Demand) Update Q List Function D Function J Issue Pushback Clearance/Hold Function B	Flight ID, Ramp Location, Time of Demand	Flight Status (i.e., Pushback Clearance Request, Pushback)	Pushback clearance granted when Functions D and J requirements are satisfied Flight may be cleared to pushback "when previously conflicting flight is past."
D Inter-Departure Conflict Mgmt		Function B } Demand Function C } Display Inter-Departure Conflict Function J	Flight ID, Ramp Location, Status Competing Flight Ramp Location, Status Time of Demands		Checked against other departures in same Positive Ramp Control Area
E Handoff to Ground Control Departure Q	Ground Control Subsystem	Function A } Function B } Demand Function C } Pilot Instruction to Monitor Departure Ground Frequency (End of Service) Update Ground Control Departure Q List	Flight ID, Ramp Location	Flight Status (i.e., RTT/HO)	Interaction with Function C, only for flights in Positive Ramp Control Areas

Table 3-1. Ramp Control System - Functions and Requirements (Continued)

Control Function	Interface Required With	Interacting Function	Data Requirements	Real-Time Data Input Requirements	Remarks
ARRIVALS F Verify Gate Assignment	Local Control Subsystem Airline Operations Ground Control Subsystem	Receive Gate Verification Request Message (Demand) Retrieve Nominal Gate Assignment from Storage Transmit Verification Request Message to Airline Opns Receive Verification/Modification Message from Airline Opns Transmit Gate Assignment Message to G.C. Subsystem Update Gate Schedule	Flight ID Flight ID, Nominal Gate Assignment, Current Gate Status (i.e., Open, A/C on Gate) Flight ID, Assigned Gate No., Availability Delay	Gate # (change) Delay	Request received while flight decelerating for turnoff Gate No. Input required only if changed from nominal assignment
G Monitor Inbound Ramp Q	Ground Control Subsystem	Received Ramp Status Request Message (Demand) Function J Transmit Ramp Conflict Message to G.C. Subsystem Function H (No Conflict) Determine Flight Docked/Parked at Gate (End of Service)	Flight ID, Ramp Destination, Status, Time of Demand Flight ID, Status-Docked/Parked	Flight Status (i.e., Docked/ Parked)	
H Clear to Gate	Ground Control Subsystem	Function G Transmit Ramp Available Message to Ground Control Subsystem Transmit Clearance to Gate for Flight Holding in Ramp Update Inbound Ramp Q	Flight ID, Ramp Destination Status	Flight Status (i.e., Cleared to Gate)	Inbound may be cleared to Gate when Outbound has cleared ramp area
COMMON J Outbound-Inbound Conflict Management		Function D } Demand Function G } Display Conflict/No Conflict } For Departures Function B } Function C } Function G } For Arrivals Function H }	Outbound Flight ID, Ramp Location, Status Inbound Flight ID, Ramp Location, Status Time of Demands		Checked against competing flights for same Positive Ramp Control Area

for performance of the function, start of service to an individual flight, or end of service to an individual flight.

In general, "Demand" events involve the receipt of a request for performance of the function by an interacting function or from an external interface (e.g., NAS enroute system). The exceptions are the pilot's indication that the flight is ready to taxi for Function B, Monitor Outbound Ramp Q, and the pilot's request for pushback clearance for Function C, Pushback Clearance. In general, the flight will have already received service from the RCS under Function A, Flight Clearance Delivery. "Start of Service" events involve the initial radio contact with the flight awaiting service by the RCS. "End of Service" events are, as indicated, an end of service to the flight by the RCS and involve communications with the flight (or possibly airline operations when the flight docks or parks at its gate). Typically, "Start of Service" and "End of Service" events require a real-time data entry by ACTC or airline operations personnel. The "Demand" events for Functions B and C will also require real-time data entry by ATCT or airline operations personnel.

The fourth column in Table 3-1 indicates the data required for the performance of the function by the data processing equipments. These data requirements may be derived from ASTC system data bases or ATCT/airline operations personnel.

The fifth column indicates specific real-time data entries that must be accomplished by the ATCT or airline operations personnel to initiate the performance or within the performance sequence of the function.

The last column provides particular qualifying remarks pertaining to the performance of the functions or events with the performance sequence.

3.2.2.2 Organizational Interaction of Functions

The interaction of the Ramp Control System functions can be readily viewed as the logical and sequential processing of information within the ASTC system data base organization. This is illustrated in Figure 3-3.

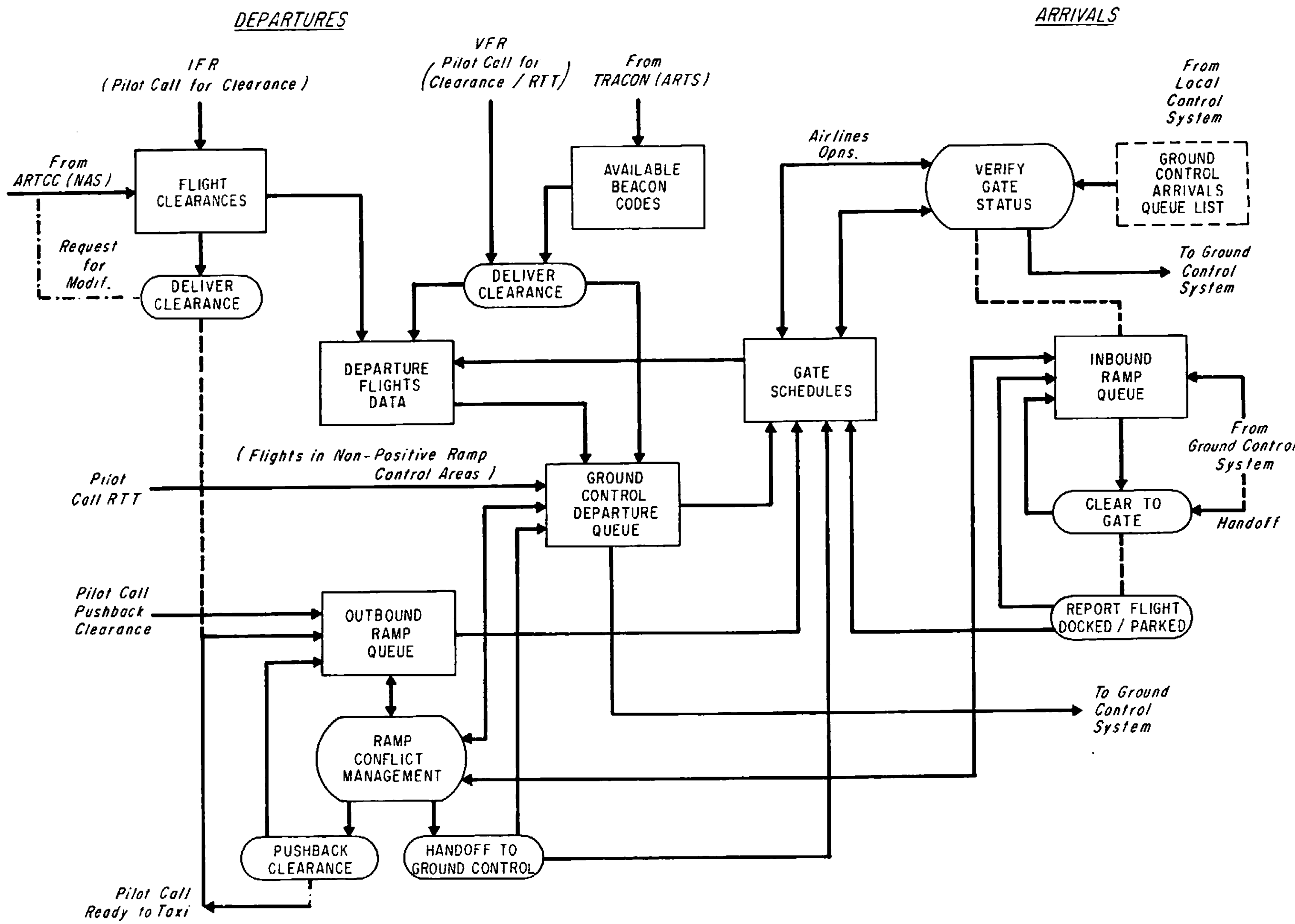


Figure 3-3. Possible Data Base Organization Concept for Ramp Control System

Flight clearances for IFR departures are received from the ARTCC. They are delivered to the pilots when they call for their clearances. As indicated, in the event that a change in the flight clearance is requested, it will be coordinated with the ARTCC. The data contained in the final clearance as well as the preplanned gate schedules may then be combined and stored in a Departure Flights Data file for ready reference when the flight is ready for departure.

Flight clearances for VFR flights will also be delivered when the pilot calls for entry into the system. In this instance, the beacon codes to be employed by the flights will be assigned from a list of available codes obtained through the interface with ARTS. Flight clearance data and the assigned beacon codes may then be combined in the Departure Flights Data file. Since the flights are ready to taxi upon receipt of their clearance, they may be immediately entered into Ground Control Departure Q for service by the Ground Control System. The Ground Control Departure Q represents the list of aircraft waiting for service by the Ground Control System, i.e., waiting for instructions to enter the taxiway network from the ramp areas.

As general aviation flights with IFR clearances are also ready to taxi when they receive their clearance, they are also immediately entered into the Ground Control Departure Q.

After some time, air carrier flights are ready for pushback. Flights from non-Positive Ramp Control areas will push back and contact Ramp Control when ready to taxi. They may then be entered into the Ground Control Departure Q. Flights in Positive Ramp Control areas will call for their pushback clearance. They would be entered into the Outbound Ramp Q for service. The Outbound Ramp Q represents the list of aircraft in Positive Ramp Control areas awaiting or receiving service by the RCS in controlling their transition from pushback to the Ground Control Departure Q. Ramp conflict management processing would determine the status of other flights, if any, in the Ground Control Departure Q and Outbound Ramp Q for the particular ramp areas. If there is a conflict, the flights would be advised to hold at their gate and the process repeated in the next processing cycle. If there is no conflict with other outbound flights, the ramp conflict management processing would then determine the existence of any flights for the particular ramp areas in the Inbound Ramp Q established by the Ground Control System. The Inbound Ramp Q represents the list of aircraft, both still in the taxiway network approaching the turnoffs to the gates and holding in ramp areas, requiring service by the RCS in providing clearance to their gates. In the event of a conflict the flights would be advised to hold at their gates and the process repeated in the next cycle. If no conflicts are determined, then the flights are cleared for pushback and their status in the Outbound Ramp Q updated.

A short time later the flights' pilots will call for taxi. Their status will then be updated in the Outbound Ramp Q. The ramp conflict management processing will then be accomplished as previously described. If there is no conflict, the flight may then be entered into the Ground Control Departure Q.

Simultaneously with the updating of the flights' status data in the Outbound Ramp Q, the Gate Schedules data will be updated. The updating will reflect the availability of the gates for arrivals entering the system. This data may also be updated by airlines flight operations personnel when adjustments to the normal flight Gate Schedules are anticipated.

This data will be accessed in relation to flights entered into the Ground Control Arrivals Q list by the Local Control System. When necessary, the gate availability verification process will require interaction with airlines flight operations to determine a revised gate assignment and/or delay in the availability of the assigned gate for the flight.

At a later time the flights approaching the appropriate point of exit from the taxiway network for their assigned gates will be entered into the Inbound Ramp Q by the Ground Control System. Flights assigned to gates in non-Postiive Ramp Control areas will be cleared to their gates by Ground Control. For flights inbound to Positive Ramp Control areas, the ramp conflict management processing will determine whether the Ground Control Departure Q or Outbound Ramp Q contains conflicting departures for the appropriate ramp areas. When there are no conflicts, the flights will be cleared to the gates by Ground Control System and their status in the Inbound Ramp Q updated. When there are conflicts, Ground Control will retain control of the flights or, when possible, may clear flights off the taxiway network into a portion of the ramp area out of the way of the Positive Ramp Control area traffic until it is cleared to the gate by Ramp Control. In the latter event, the status of the flights in the Inbound Ramp Q would be updated. When ramp conflict management processing subsequently determines that a conflict situation no longer exists, such holding flights will be cleared to their gates and their status in the Inbound Ramp Q updated.

When the flights have docked or parked at their gates, they will be deleted from the Inbound Ramp Q. Simultaneously, the Gate Schedules data will be updated to reflect that the gate is now occupied.

3.2.3 Description of Information Transfer for Individual Functions

The logical processing requirements for the performance of each Ramp Control System function has been developed in detail. Flow diagrams and brief narrative descriptions of each function are given below.

3.2.3.1 Flight Clearance Delivery (Function A)

The functional flow for Flight Clearance Delivery is illustrated in Figure 3-4.

For IFR flights the process begins with the receipt of flight clearances and any applicable delay restrictions from the ARTCC. Currently the flight clearances are received and strips printed out at the FDEP in the tower. However, the Operations Analysis at O'Hare indicated that a significant degree of marking of the strips is then required by ATCT personnel. This includes:

- Annotating the equipment type for heavy aircraft and the first fix

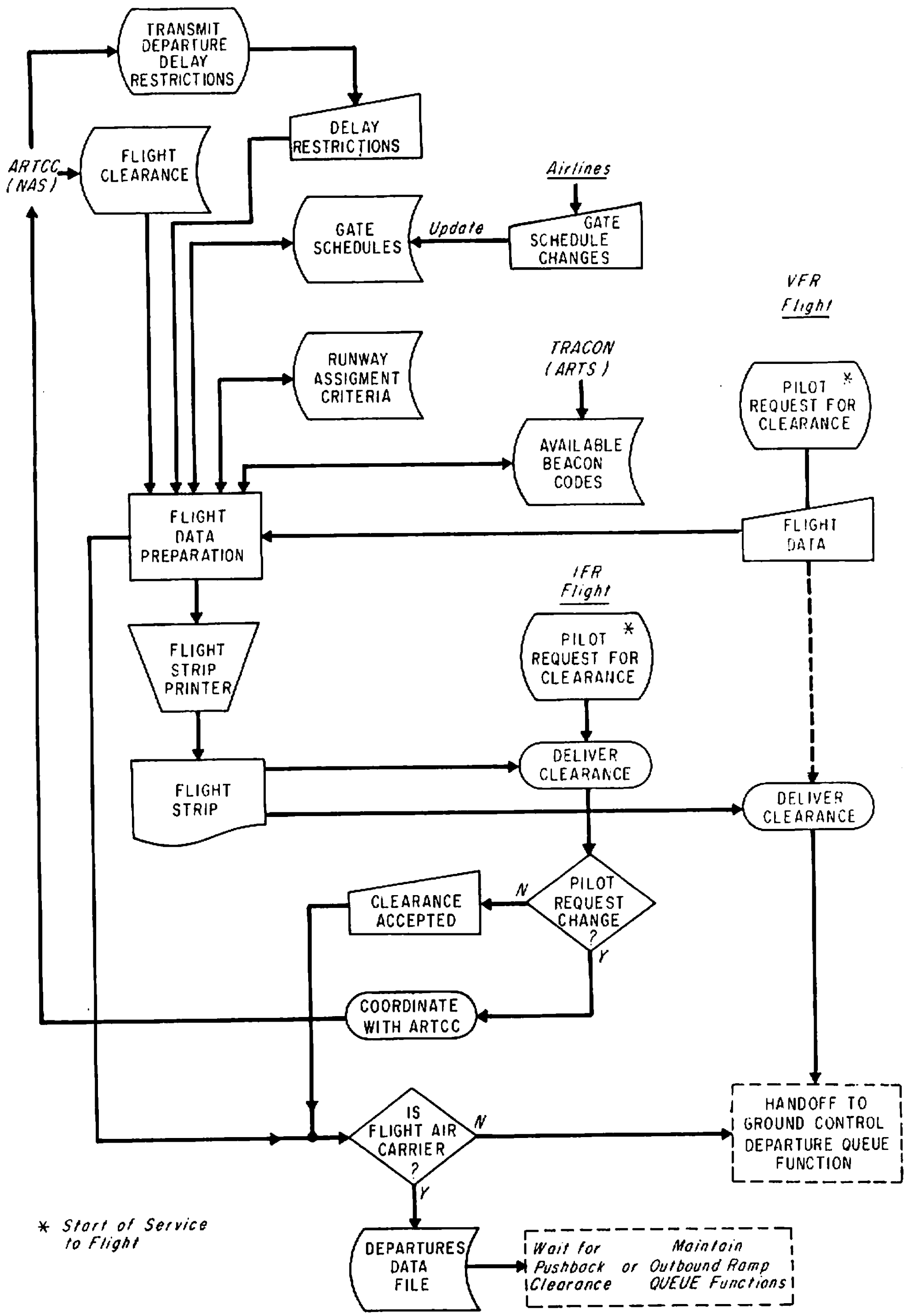


Figure 3-4. Flight Clearance Delivery - Functional Flow Diagram

- Correcting the cleared altitude to the clearance limit that can be issued for the tower/TRACON
- Entering the origination gate
- Entering the runway to which the flight is cleared for departure

In addition, Flight Clearance Delivery must manually prepare a flight strip for VFR departures.

It has been assumed that the use of flight strips will be retained to provide a means of manual backup in the event of system equipment failures. Therefore, the proposed concept for this function provides for a revised method of flight strip preparation which minimizes the need for the strip marking listed above.

The data contained in the flight clearances and delay restrictions provided by the ARTCC would be combined with the Gate Schedule data and the standard criteria for runway assignment to generate a composite flight clearance. The flight strip would then be printed with the appropriate altitude clearance limit (if applicable), flight originating gate, and nominally assigned runway. It is further assumed that improvements could be made to the flight strip printer to provide for special annotation of the flight equipment type for heavies and the first fix.

For VFR flights the ATCT personnel would enter the necessary data for the flight. This would include the flight call sign (ID), equipment type, beacon equipment type, and desired altitude and direction of flight out of terminal area. This data would be combined with a beacon code selected from a list of available codes provided by ARTS to prepare a flight strip.

For IFR flights the tower personnel would enter an acceptance of the clearance delivered. This effectively enters the flights into the system for further service. For air carrier flights this would involve establishment of the flight in the Departure Flights Data file until it is ready for further service by the ASTC system. This file is intended to contain only that reference data necessary for further service by the ASTC system. This data could possibly be displayed to ground controllers for planning purposes. It is estimated that this data would include:

- Call sign
- Equipment type or class
- Beacon code
- Computer number, if applicable
- Originating gate
- Departure fix (or direction of flight for VFRs)
- Nominal runway assignment
- Delay restrictions, if applicable

For VFRs and general aviation IFRs, upon delivery of the clearance the pilot would be directed to "taxi up to the taxiway and activate your beacon when ready-to-taxi". The ASTC system sensor (e.g., GEOSCAN) would automatically detect the beacon and transfer the aircraft to the Handoff to Ground Control Departure Q function for further processing.

3.2.3.2 Maintain Outbound Ramp Q (Function B)

The functional flow for the Maintain Outbound Ramp Q is illustrated in Figure 3-5. This function applies only to air carrier flights. These flights will enter the function for service from the other two functions depending upon whether they are originating from gates in Positive or non-Positive Ramp Control areas.

When the pilot indicates that the flight is ready for taxi, the ATCT personnel will enter this into the system. Flights in non-Positive Ramp Control areas will be transferred to the Handoff to Ground Control Departure Q function. The data for the flight will be transferred from the Departure Flights Data file.

For a flight in Positive Ramp Control areas, its status would be updated in the Outbound Ramp Q. The ramp conflict management functions would then be called for processing of the flight's request for taxi. If no conflicts are determined, the flight would be transferred to the Handoff to Ground Control Departure Q function. If a conflict is determined, the flight would be instructed to hold in position. The flight would be re-entered for the ramp conflict management functions in the next cycle.

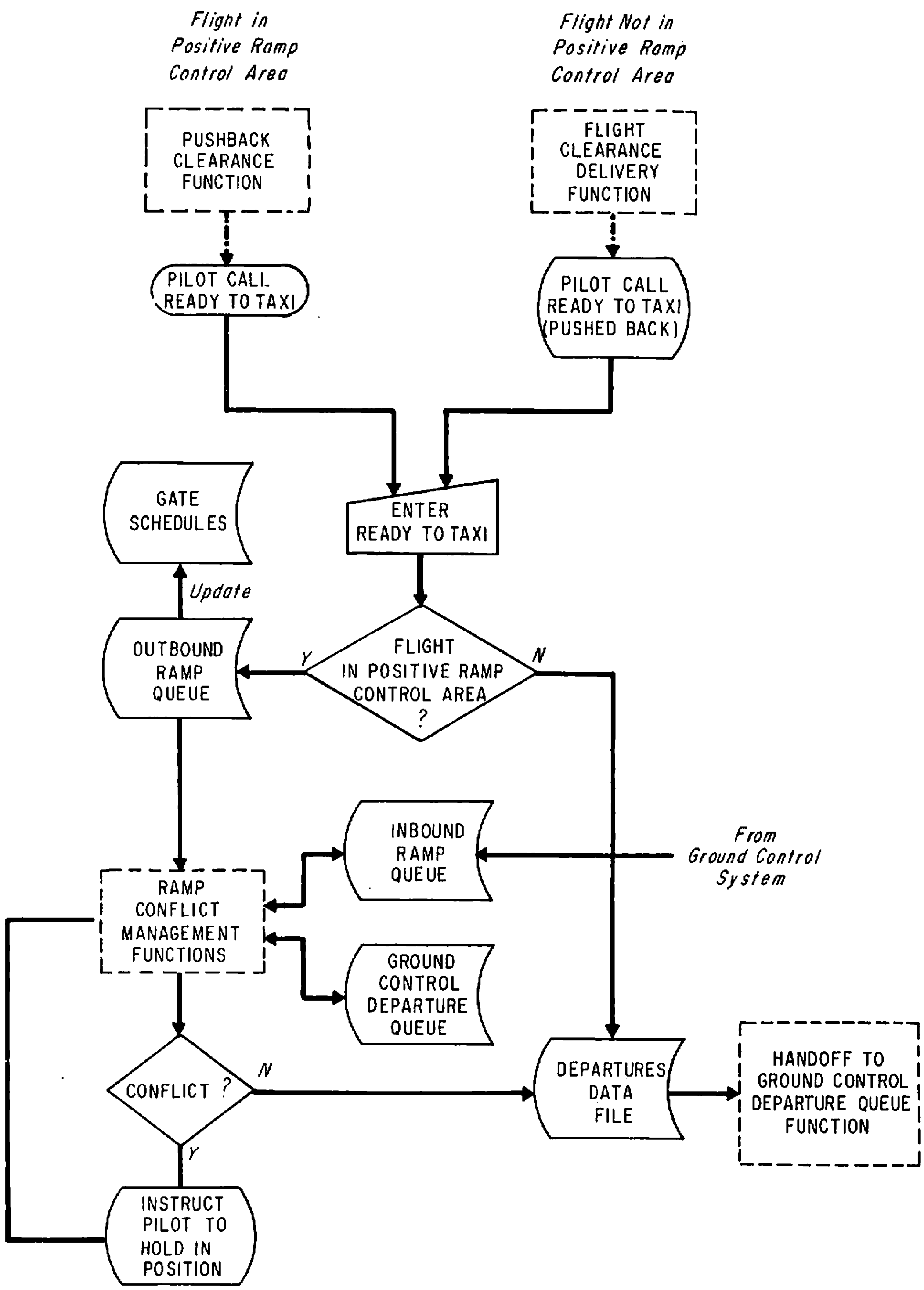


Figure 3-5. Maintain Outbound Ramp Queue - Functional Flow Diagram

3.2.3.3 Pushback Clearance (Function C)

The functional flow for Pushback Clearance is illustrated in Figure 3-6. This function serves only flights originating in Positive Ramp Control areas.

When the pilot requests Pushback Clearance the request would be entered into the system. There are two possible methods by which this process may occur. The pilot could directly contact the appropriate ATCT personnel (Ramp Control) requesting pushback and the entry made by the ATCT personnel (Ramp Control). As it is currently normal procedure for pilots to request an authorization to pushback from their own flight operations personnel, the request entry could be made by these personnel. The latter approach would be desirable from the point of view of minimizing ATCT (Ramp Control) personnel voice channel and data entry workload. However, it would require agreement by the airlines.

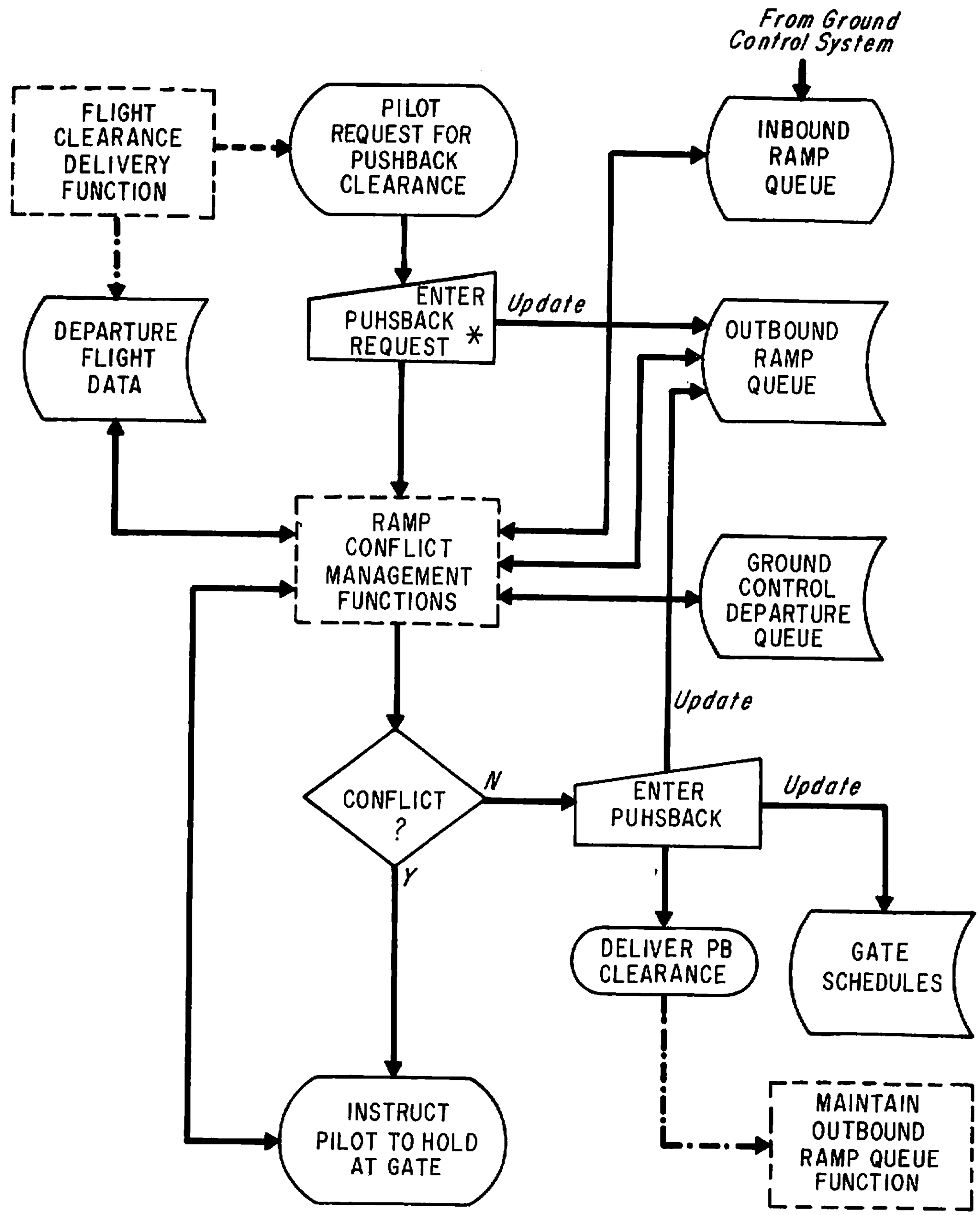
A third alternative is also possible but would require installation of data link/data entry equipment aboard aircraft. This approach might be considered for future system evolution.

The flight's status in the Outbound Ramp Q would be updated. The ramp conflict management functions would then be called for processing of the flight's request. If a conflict is determined the pilot would be instructed to hold at the gate and the flight scheduled for further ramp conflict management processing in the next cycle. If no conflict is determined the flight would be cleared for pushback. The ATCT (Ramp Control) personnel or airline flight operations would enter the pushback into the system updating the Outbound Ramp Q and Gate Schedules.

3.2.3.4 Inter-Departure Conflict Management (Function D)

The functional flow for the Inter-Departure Conflict Management is illustrated in Figure 3-7. This function applies only to outbound flights in Positive Ramp Control areas.

Flights will enter this function from either the Pushback Clearance or Maintain Outbound Ramp Q functions, depending upon their pre-taxi status.



Entry could be made by Tower or Airlines Flight Operations Personnel

Figure 3-6. Pushback Clearance - Functional Flow Diagram

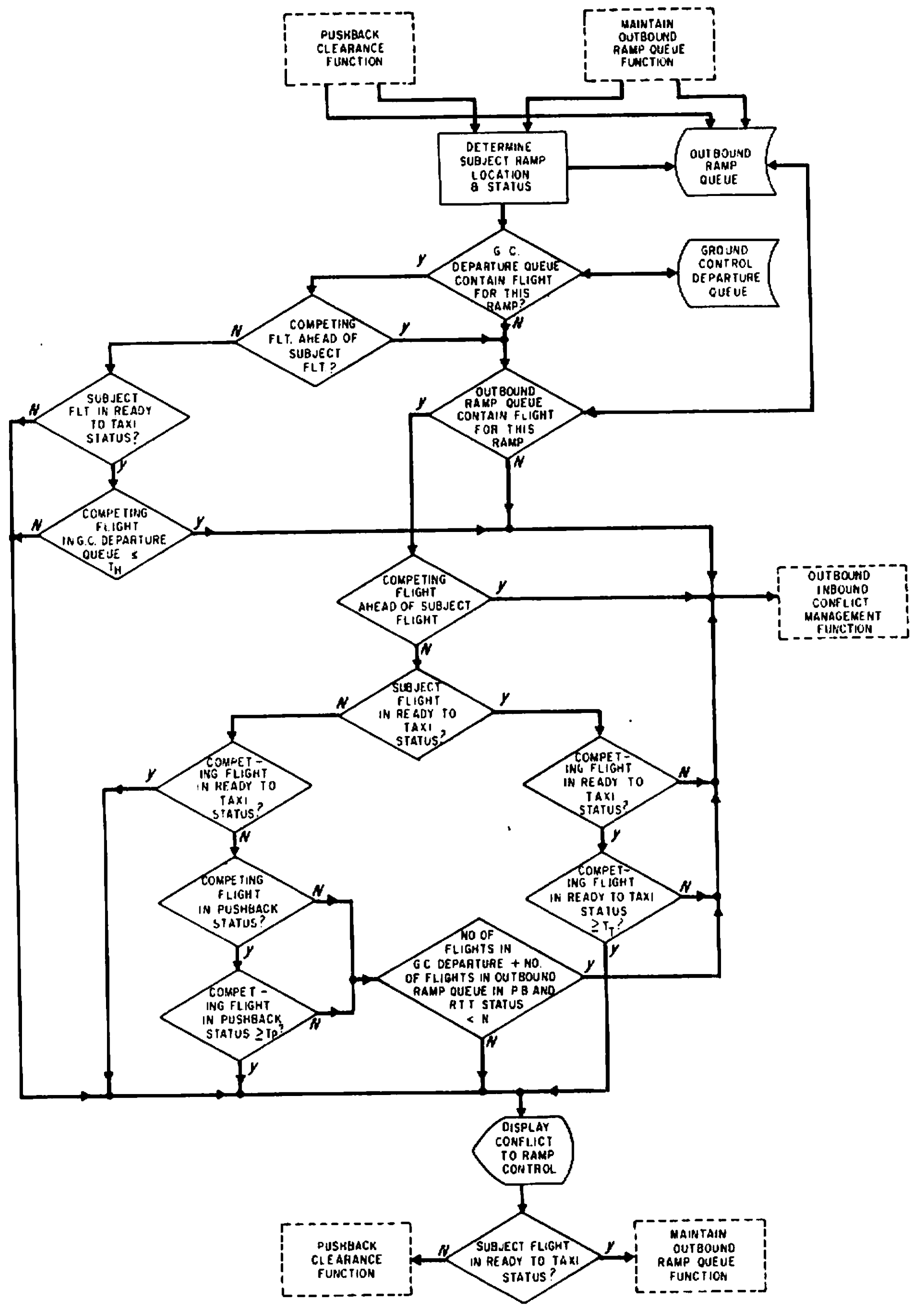


Figure 3-7. Interdeparture Conflict Management - Functional Flow Diagram

The logical flow of the process can be readily followed from Figure 3-7 once some of the basic concepts of the logic are understood. Therefore, it will not be followed in detail here. Rather, these basic concepts are defined.

The inherent rationale of this conflict management logic is that flights in a "higher" status of readiness to taxi are given priority over flights in "lower" readiness status. Proposed statuses would include:

- In (handed off to) Ground Control Departure Q
- Ready to Taxi (in pushback position)
- In Pushback (but not ready to taxi)
- Pushback Request

In addition, priority is dependent upon the relative locations (i. e., originating gates) of subject flights (i. e., flights requesting advancement to next higher status) and competing flights in the same ramp control area. In this context, a flight is termed to be ahead of another flight if its originating gate is literally farther out in the ramp area toward the taxiway network than the other flights. It is not ahead of another flight if their gates are effectively abreast of each other in the ramp area, i. e., the pushback of one flight would block the pushback of the other.

Therefore, when a subject (requesting) flight is not ahead of a competing flight in the same ramp area, it would be allowed to advance to the next higher status where there would be no conflict with the readiness status priority rationale. This would also be true if the subject field is ahead of a competing flight of a lower readiness status than the one requested. However, a subject flight would not be allowed to advance to the next readiness status if in doing so it would impede (delay) the movement of a competing flight in a higher status. The determination of whether its advancement would impede the competing flight is then made in terms of the status of the competing flight and, in some instances, the length of time competing flight has been in that status. This is further discussed below for each instance.

The first checks in the process are made to determine whether there are any competing flights in the Ground Control Departure Q for the ramp since they are in the highest priority. Where a subject flight is ahead of a competing flight in this status, it will normally be held in its current status. There may be one exception when the subject flight is ready to taxi and the competing flight has not been in the Ground Control Departure Q for a period of time equal to greater than T_H, where T_H is a parameter of the system. The rationale for this concept is that if T_H is established at a sufficiently low value, then it would be improbable that ground control had acted to clear the flight to taxi and enter the Ground Control system. Therefore, the subject flight could also be entered into the Ground Control Departure Q without significantly impeding the movement of the competing flight. A value of $T_H = 30$ seconds may be reasonable.

Similar approaches are proposed for the following situations:

- Subject flight is in ready-to-taxi status and the competing flight is also in ready-to-taxi status but has been in this status for less than a time T_T.
- Subject flight is in pushback request status and the competing flight is in pushback status but has been in this status for less than a time T_p.

Estimates of possible value for T_T and T_p may be determined on the basis of the observations of flight operations in the ramp areas during the O'Hare Operations Analysis. The observations indicated pushback times (i. e., from initiation of pushback to uncoupling of the tug tow bar) ranging from 10 seconds to 170 seconds, with an average of 73 seconds. The observations also indicated engine start times (i. e., from uncoupling to initiation of taxi ranging from 10 seconds to 175 seconds with an average 64 seconds. If T_p and T_T were set at appropriate fractions of the pushback time and engine start times, respectively, then only a portion of the competing flights might be slightly delayed in their total service time in the ramp area. If these fractions were set at one-half, then fifty percent of flights determined to be competing flights might be delayed one-half of the pushback or taxi delay times, i. e., 36.5 seconds or 32 seconds, respectively.

The incorporation of the above parametric decision approaches is based upon the following rationale. The most efficient utilization of the ramp area, system processing capacity, and controller flight handling capability will be accomplished when the ramp area is serving more than one departure at a time. Thus, it will be of advantage to allow as many flights as is practical to be active in the ramp area in various stages of readiness. To accomplish this some tolerances can be applied in possibly introducing a small amount of delay to a limited portion of all departures. The appropriate balance between system efficiency, degree of delays, and the portion of flights can be achieved by judiciously selecting the parameter values for T_H, T_p, and T_T.

However, it has been recognized that there is a practical upper limit to the number of departures that can be active in a ramp area in various stages of readiness. If too many departure flights are active in the ramp area, this could lead to an increased probability of the ramp being unavailable for use by arrivals with destination gates in the ramp. This in turn could result in increased probability of delays to flights or added workload on the Ground Control System.

A possible illustration of this situation is shown in Figure 3-8, extracted from an aerial photograph of O'Hare Airport. The figure shows four departures active in the F-G ramp area. The status of the B-747 at gate F-3A is not known with any certainty but, since the jetway is not connected, it could be preparing for pushback as well. The figure also indicates two arrivals taxiing on the Inner Circular taxiway. If either of these flights have a destination gate in this ramp there could be significant delay in the availability of the ramp for taxi to its gate. If the affected flight was the leading flight, then the second flight might also be significantly delayed if the lead flight held on the taxiway for the ramp to become clear. Observations made during the previous O'Hare Operations Analysis indicated that the average time for taxi out of the ramp area was 54 seconds. Thus, if it was assumed for simplicity that all the departures shown in Figure 3-8 are ready to taxi and that the aircraft on the Inner are held, then it

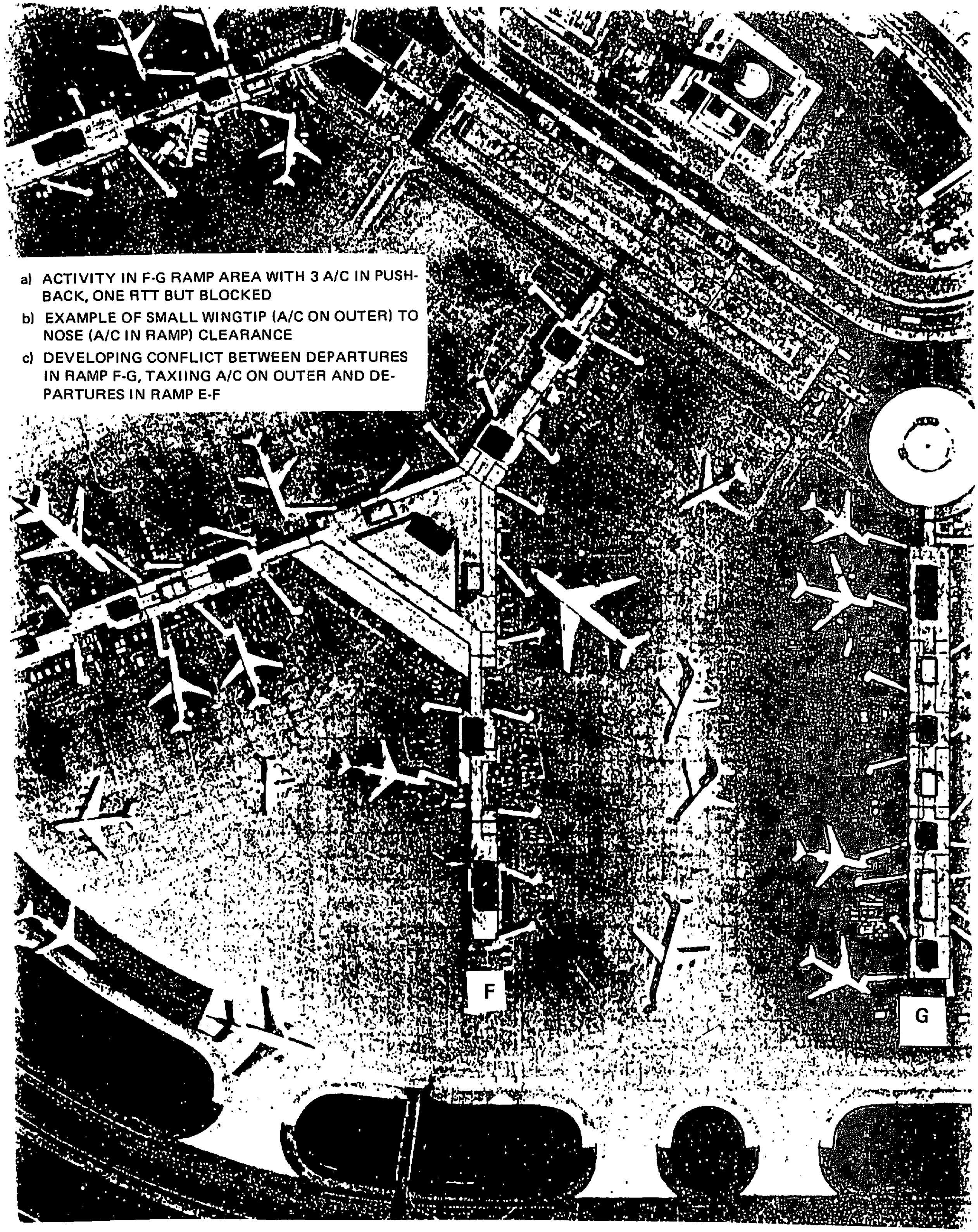


Figure 3-8. Example of Possible Ramp Area Congestion Problem

could require a minimum of 216 seconds (slightly over 3-1/2 minutes) before an arrival could enter the ramp area to taxi to an inner gate. If any of the departures were only starting their engines (observed engine start time = 64 seconds) this delay could be even longer.

To avoid this situation a final logical check on the total activity level of the ramp is proposed for flights requesting pushback for which no other inter-departure conflicts have been determined. If there are less than N departures active in the ramp, where N is a system parameter, , then it could be feasible to allow the pushback; if not, a conflict exists. An estimate of a practical value of this parameter N is derived as follows. It is assumed that on the average outbound flights are equally likely to have an origination gate in the outer or inner portion of the ramp area. Similarly, on the average, inbound flights are likely to have a destination gate in the outer or inner portion of the ramp area. Thus, on the average an inbound is likely to have a gate ahead of N/2 of the outbound flights. As will be noted in the description of the Outbound-Inbound Conflict Management function logic the inbound flight would be given priority. Therefore, it would be delayed only by those N/2 aircraft ahead of its destination gate (about N/2). If it is assumed these N/2 flights were just beginning engine start, then an inbound flight would face an average maximum delay (D_M) in seconds of

$$D_M = \frac{N}{2} (t_S + t_T)$$

where t_S and t_T are the average engine start and taxi out times. Similarly, if it is assumed that these N/2 flights were beginning to taxi out, then the inbound flight would face an average minimum delay (D_m) in seconds of

$$D_m = \frac{N}{2} t_T$$

Substituting the values for t_S and t_T observed at O'Hare then,

$$D_M = \frac{N}{2} (64 + 54) = 59N \text{ seconds}$$

$$D_m = \frac{N}{2} (54) = 27N \text{ seconds}$$

Table 3-2 lists the values of these delay extremes for several values of N.

Table 3-2. Potential Maximum and Minimum Inbound Delays for N Outbounds in the Ramp Area

N	D_M (sec)	D_m (sec)
2	118	54
3	177	81
4	236	108
5	295	135

From this table it can be seen that for N greater than 4 even the minimum potential delay (D_m) becomes excessive, i.e., over two minutes. Thus, it would appear that a value of N = 4 represents a practical parameter for limiting the number of active outbound flights in a single Positive Ramp Control area.

Before a flight may be cleared to advance to the next higher state of readiness, it is also necessary to determine whether this action would result in a conflict with flights inbound to the ramp. Thus, all subject flights satisfying the Inter-Departure Conflict Management criteria are transferred to the Outbound-Inbound Conflict Management function.

When an inter-departure conflict is determined, the conflict condition would be displayed to the tower (Ramp Control) personnel and the processing for the flight returned to the originating function.

3.2.3.5 Handoff to Ground Control Departure Q (Function E)

The functional flow for Handoff to Ground Control Departure Q is illustrated in Figure 3-9. IFR air carrier flights will enter this function from the Maintain Outbound Ramp Q function. VFR and IFR general aviation will enter this function from the Flight Clearance Delivery function.

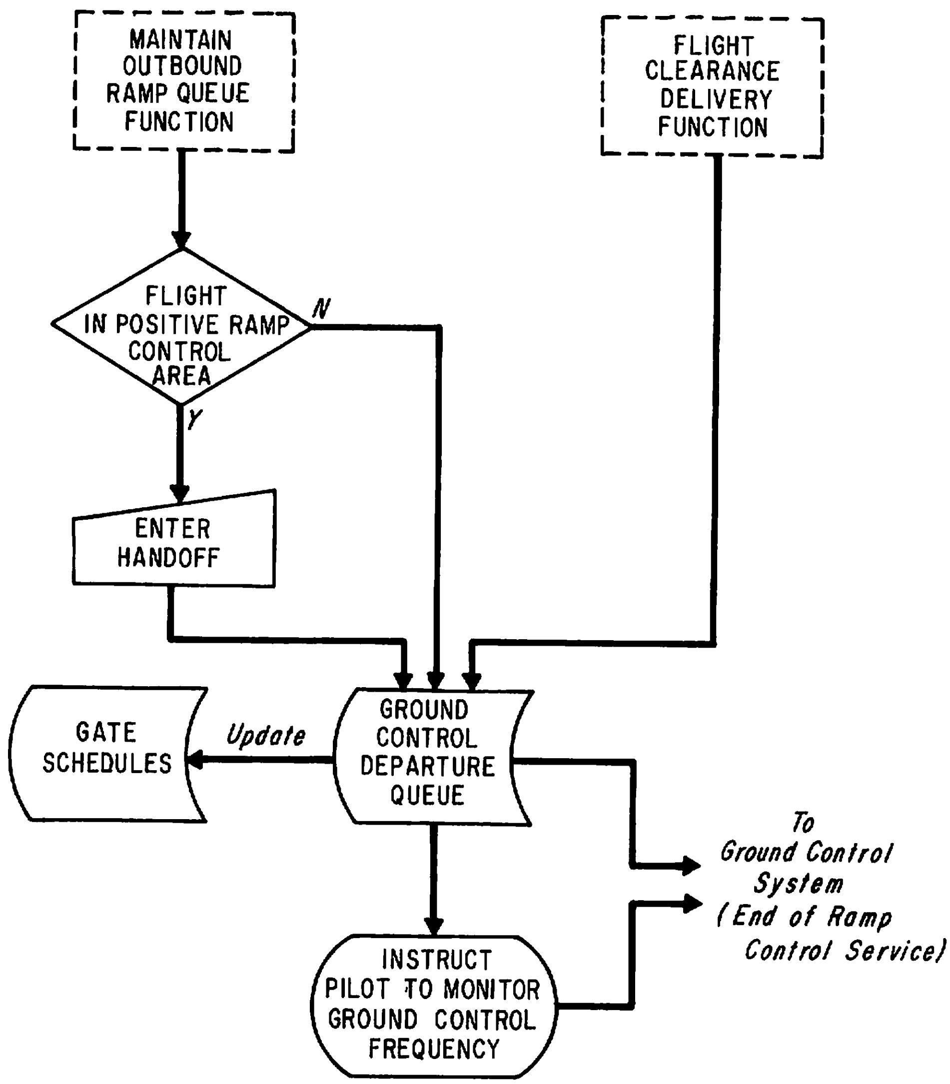


Figure 3-9. Handoff to Ground Control Departure Queue - Functional Flow Diagram

For flights in positive ramp control areas it will be necessary for the ATCT (Ramp Control) personnel to enter the handoff into the system for transfer of the flights to the Ground Control Departure Q. As air carrier flights enter the Q, the Gate Schedules data will be updated to indicate that the gates from which they departed are available for arrival flights.

3.2.3.6 Verify Gate Assignment (Function F)

The functional flow for Verify Gate Assignment, the first function for arrivals, is illustrated in Figure 3-10. This function and the following functions are applicable only to air carrier arrival flights.

An applicable flight will be entered into the Ground Control Arrival Q List by the Local Control System*. When this occurs, the Gate Schedule data will be accessed to determine the flight's assigned gate and the availability of the gate for the flight. The Gate Schedule data may have been updated for one or more flights when gate changes are known in advance by airlines flight operations.

If the flight's gate is available, the gate assignment and its availability will be transmitted to the Ground Control System for use in routing of the flight and communication to the pilot. A gate may be considered to be available if it is currently open (i.e., no flight on the gate) or if the flight at the gate is in an active status (i.e., in Pushback, Ready-to-Taxi, or Handoff to Ground Control Departure Q status). Airline decisions will also determine gate availability.

If the flight's gate is not available, a gate assignment/availability request message will be transmitted to the appropriate airline's flight operations. Flight operations will enter the revised gate assignment and/or delay in availability. This data will update the Gate Schedules Data and will be transmitted to the Ground Control System for use in flight routing and communication to the pilot.

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*Refer to Section 3.4

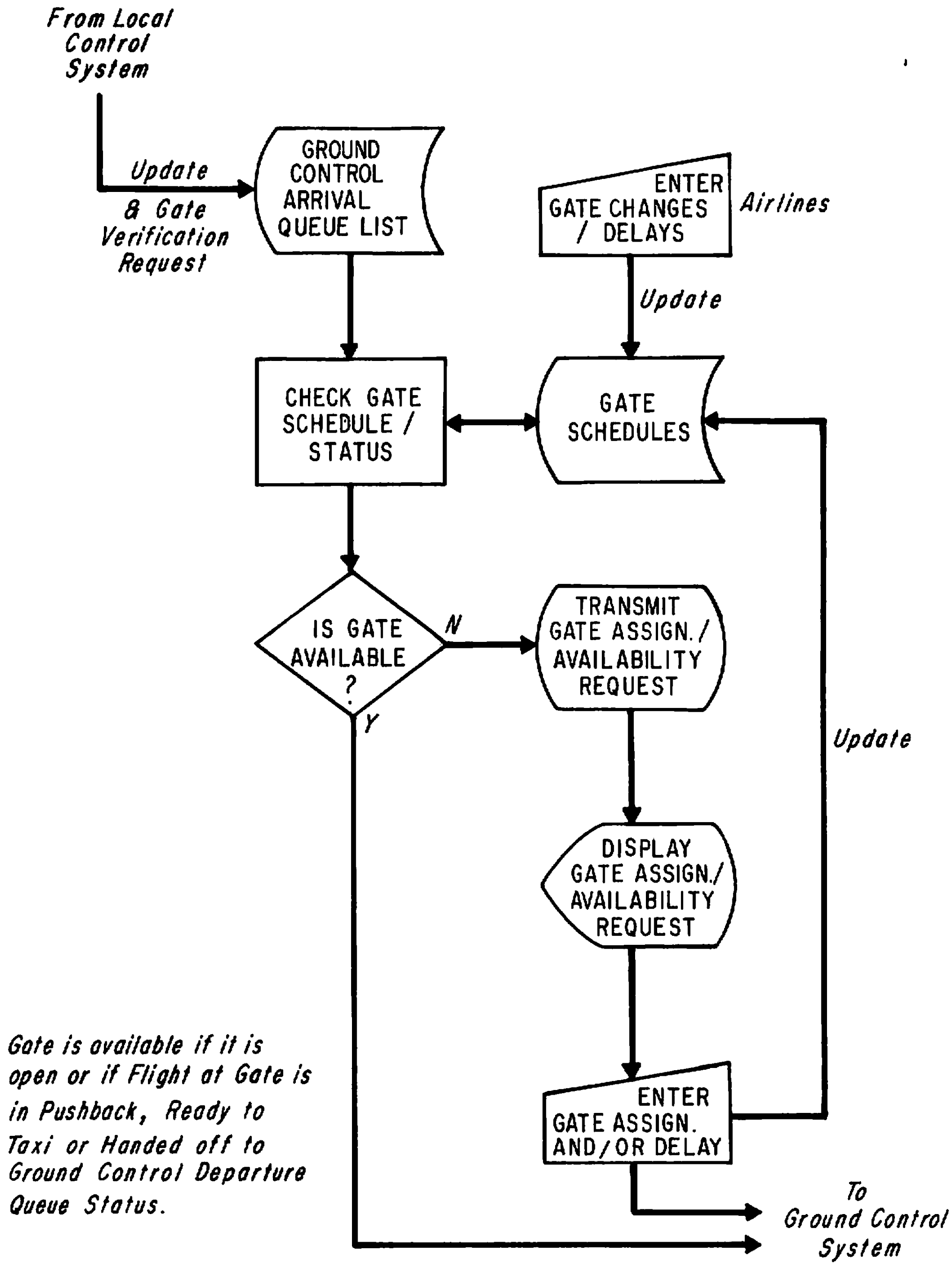


Figure 3-10. Verify Gate Assignment - Functional Flow Diagram

3.2.3.7 Monitor Inbound Ramp Q (Function G)

The functional flow for Monitor Inbound Ramp Q is illustrated in Figure 3-11. Flights will enter this function at some time after the performance of the Verify Gate Assignment function. This will be accomplished through the entry of the flight into the Inbound Ramp Q by the Ground Control. It is at this time that checks will be started for Ramp entrance conflicts (see GCS).

For flights scheduled for gates in non-Positive Ramp Control areas, no processing will occur until the flight docks or parks at its gate.

For flights scheduled for gates in Positive Ramp Control areas, the Ground Control System will also transmit a ramp status request. The Outbound-Inbound Conflict Management function would be called to determine whether a conflict exists. If a conflict is determined and the flight is still in the taxiway network, a ramp conflict message would be transmitted to the Ground Control System. If the flight is not on taxiway (i.e., it is holding in a portion of the ramp surface clear of the gate ramp traffic), then it will be re-entered for service by the Outbound-Inbound Conflict Management function in its next cycle.

If no conflict is determined, the flight would be transferred to the Clear to Gate function, i.e., Handoff by Ground Control System.

A short time later the flight will have taxied through the ramp area and docked or parted at its gate. When this occurs, it will be entered into the system. This will delete the flight from the Inbound Ramp Q and will update the Gate Schedules data to show the gate as occupied.

As in the case of the entry of a pushback request, the entry that the flight docked/parked could be made by the ATCT (Ramp Control) or airlines flight operations personnel. The latter approach would be more desirable from the points of view of minimizing tower controller communications and data entry workload and avoiding voice channel congestion in the ramp area. However, it would again require agreement by the airlines.

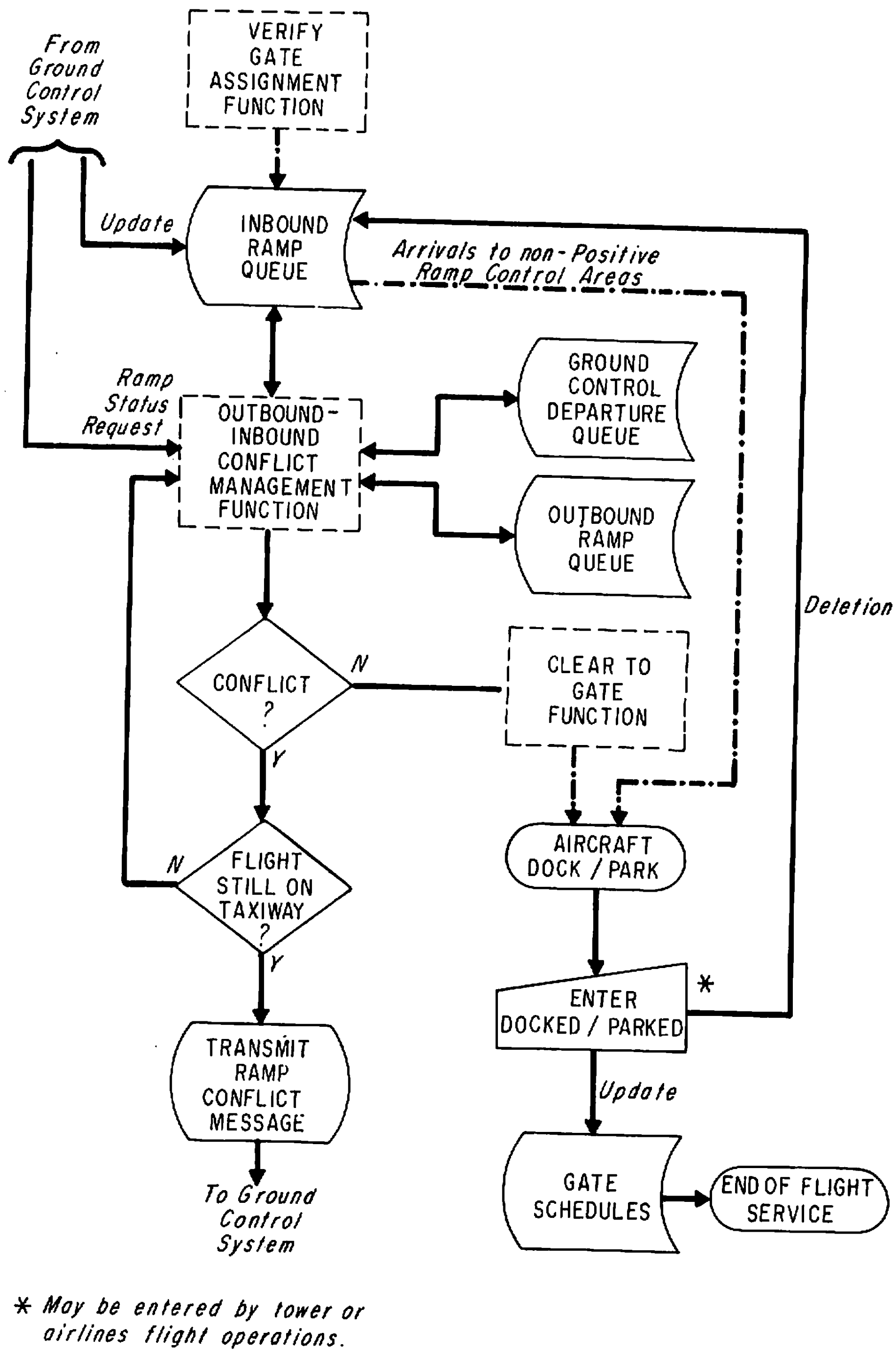


Figure 3-11. Monitor Inbound Ramp Queue - Functional Flow Diagram

3.2.3.8 Clear to Gate (Function H)

The function flow for Clear to Gate is illustrated in Figure 3-12. This function applies only to arrivals scheduled for gates in Positive Ramp Control areas. The flight will enter this function from the Monitor Inbound Ramp Q function when no conflict has been determined for the ramp area.

If the flight is still in the taxiway network, a ramp available message will be transmitted to the Ground Control System for use by Ground Control. If the flight is holding in an area of the ramp surface, the ATCT (Ramp Control) will clear the flight to its gate and enter this clearance into the system.

In either case the Inbound Ramp Q will be updated to show the flight status as cleared to the gate. This in effect reserves the ramp area from its entrance to the point of the destination gate for the exclusive use of the arrival flight.

The flight will then be transferred back to the Monitor Inbound Ramp Q to wait for the report of its arrival at the gate.

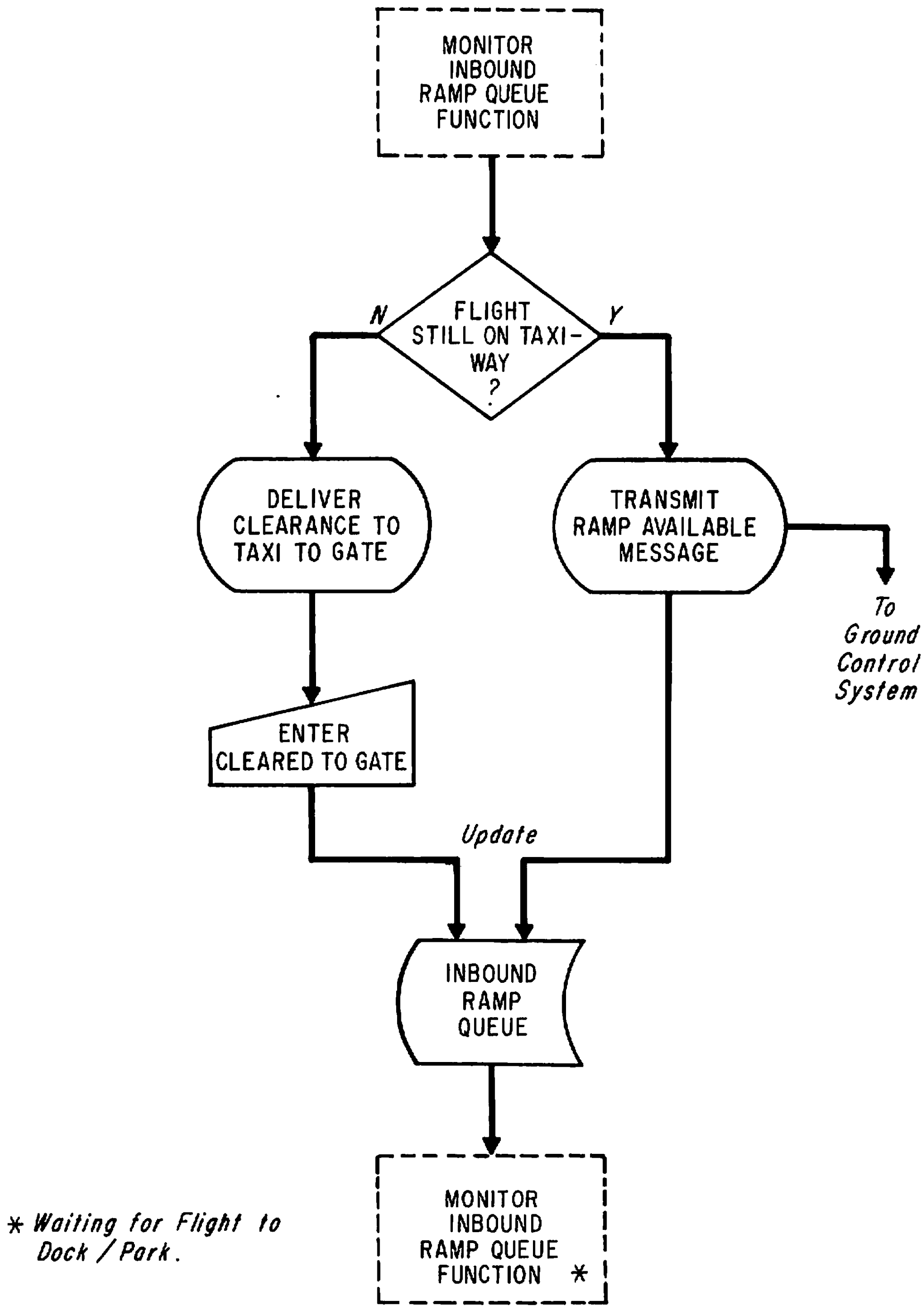


Figure 3-12. Clear to Gate - Functional Flow Diagram

3.2.3.9 Outbound-Inbound Conflict Management (Function J)

The functional flow for Outbound-Inbound Conflict Management is illustrated in Figure 3-13. This function applies to both outbound and inbound flights served by gates in Positive Ramp Control areas. Outbounds will enter this function from the Inter-Departure Conflict Management function. Inbounds will enter from the Monitor Inbound Ramp Q function.

As in the case of the Inter-Departure Conflict Management function, the logical flow can be readily followed once the basic concepts for the process are understood. Therefore, these concepts are described here rather than the detailed functional flow sequence.

The concept of one gate ahead of another discussed previously in connection with the Inter-Departure Conflict Management function applies here as well. In this case, it applies to the destination gate of the inbound flights in relation to the origination gate of outbound flights.

In addition, the basic approach of defining a conflict as a situation that would impede the flow of a flight in a higher priority status applies here as well. For arrival flights the priority statuses defined here, in highest order first, include:

1. Cleared to Gate
2. Within T_A seconds of arrival at the appropriate turnoff from the the taxi network - second attempt at ramp entry*
3. Holding in ramp area for clearance to taxi to gate
4. Entering last link in taxi network prior to approaching the turn-off intersection (more than T_A seconds from intersection) - Second attempt at ramp entry

*T_A is a system parameter which is a highly reliable prediction of the flight's arrival at the turnoff intersection. The estimation of the value of T_A is discussed in the Ground Control System section.

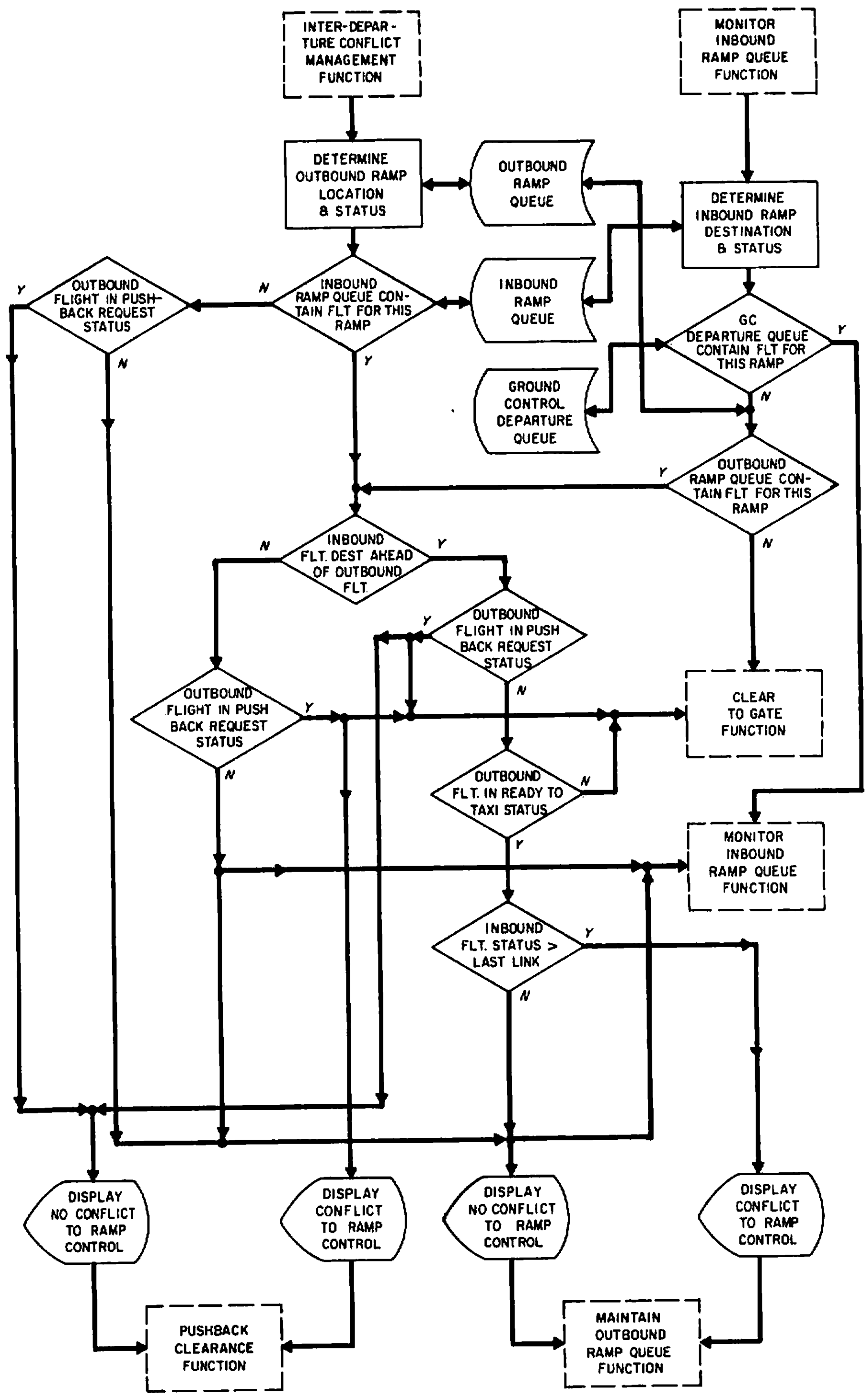


Figure 3-13. Outbound-Inbound Conflict Management - Functional Flow Diagram

5. Within T_A seconds of arrival at the appropriate turnoff intersection - first attempt at ramp entry

6. Entering last link prior to approaching turnoff intersection - first attempt at ramp entry

Departure flights are compared against the status of flights in the Inbound Ramp Q. Arrival flights are compared against the existence of flights in the Ground Control Departure Q and the status of flights in the Outbound Ramp Q.

Flights in the Inbound Ramp Q for a given ramp would be acted on by this function in the order of their priority status.

Flights in the Ground Control Departure Q are given priority over flights in the Inbound Ramp Q.

When the gate for an active departure in the Outbound Ramp Q (i.e., the flight is in pushback or ready-to-taxi status) is ahead of the gate for the arrival, then a conflict exists. The arrival would be returned to the Monitor Inbound Ramp Q function and transmission of ramp conflict message to the Ground Control System, as applicable.

When the gate for a non-active departure is ahead of the arrival's gate (i.e., flight is in pushback request status), the arrival is given priority. The arrival is transferred to the Clear to Gate function for transmission of the clearance. A conflict message is displayed to Ramp Control and the flight is returned to the Pushback Clearance Function to be re-entered into the next conflict processing cycle. However, when the destination gate for the arrival is ahead of the gate for a departure in this status, then no conflict exists and both flights may be cleared to proceed (the arrival to taxi to the gate and the departure to pushback).

When the destination gate for the arrival is ahead of the gate for an active departure, the arrival is normally given priority. The exception occurs when the arrival is in the lowest priority status and the departure is in the ready-to-taxi status. In this situation, priority would be given to the departure. The rationale for this priority is based upon these considerations:

1. It is most desirable to keep the outbound traffic flowing in a reasonably constant stream to the runways in order that the optimum capacity of runways can be achieved.
2. Delay of competing departures may also result in delays to other departures in the ramp.
3. During busy periods there may be another arrival with the competing departure's gate as its destination and the gate should be cleared as rapidly as possible.

In all situations, Ramp Control would be given a positive display of the conflict or no conflict exists for each ramp and flights within the ramp.

3.2.3.10 Controller Intervention/Override of Capabilities

The descriptions of the performance of the various RCS functions provided in the preceding paragraphs represent the basic logical flows for these functions. As in any other semi-automated real-time control system, especially an air traffic control system, the capabilities for intervention in or override of system logical decisions must be inherent in the system design. In the case of the Ramp Control System concepts the ATCT (Ramp Control) personnel must have the functional capabilities to review the results or cues of system processing in relation to the overall situation to determine when such intervention is advantageous. This intervention could take the form of decisions:

1. To deny a clearance to pushback or, conversely, to authorize pushback in contradiction to control cues presented by the system.
2. To accomplish a handoff of an outbound flight to ground control in contradiction to control cues (or, conversely, to delay a handoff).
3. To deny a clearance (or, conversely, to issue a clearance) for an inbound flight to taxi to its gate.
4. To emphasize service to outbound or inbound flights in general based upon the traffic situation.

Accomplishment of these capabilities must be afforded in the nature of the information (control cues and other situation data) displayed to the Ramp Control position by the RCS as well as the data entry/retrieval features of the system.

As an example, consider a situation where a flight indicates it is ready to taxi and the flight on a gate ahead of it is in pushback but not yet ready to taxi. In this situation, the logic of Inter-Departure Conflict Management function would determine that a conflict exists and this information would be displayed to Ramp Control. However, depending on the types of aircraft involved and the existence or absence of aircraft on gates opposite to that of the pushback, it might actually be possible for the requesting flight to safely taxi around the pushback. In the observation of operations and analysis of the communications of ground control personnel at O'Hare it was noted that these personnel may ask a pilot if he has room to pass a blocking flight. If the pilot responded affirmatively he would receive the appropriate taxi instructions. This was observed for both the outbound and inbound Ground Control positions. Therefore, if the RCS provided sufficient information, Ramp Control could be capable of determining whether such a situation exists or to coordinate with the requesting flight on the situation in order to decide whether to accept or override the displayed control cue.

The nature of potential information display features that could provide the required capabilities for controller intervention/override will be discussed in paragraph 3.3.4.

3.2.4 Operational Requirements

Implementation of an RCS will be influenced by the operational environment of potential airports. This includes the physical configuration of the airport facilities, traffic volume, and environmental conditions under which operations are conducted.

3.2.4.1 Physical Configuration of Airport Facilities

In general, Positive Ramp Control would primarily apply to the passenger terminal ramp area. The most predominant physical characteristic of a terminal configuration that would tend to necessitate Positive Ramp Control is one involving wings or fingers along which gates are located. Where these wings or fingers are basically parallel and are sufficiently close to prohibit movement of more than one flight at a time past aircraft parked at gates on both wings, then Positive Ramp Control is likely to be required. In addition, when the wings are long, i.e., more aircraft gates in a given ramp area, Positive Ramp Control becomes more desirable to avoid conflicts between flight operations. The amount of separation between parallel wings at which Positive Ramp Control would not be required is also dependent on the types of aircraft operating at an airport. Airports having a significant volume of wide-bodied aircraft traffic would require wider separation between parallel wings than those where the traffic is primarily non-heavy aircraft.

Other terminal area configurations in which Positive Ramp Control may be required include cases wherein:

- A physical structure (such as a building or fence) is parallel or opposite to the terminal gates.
- An aircraft parking area, for non-air-carrier aircraft, e.g., general aviation or military aircraft, opposite to the terminal gates.
- A terminal building configuration other than parallel wings where the ramp area entrance/exit throat does not permit simultaneous passage of two aircraft.

- A multiple terminal building configuration (e.g., J. F. Kennedy and Los Angeles International Airports) where the distance between the terminals does not permit simultaneous movements of two aircraft.

A ramp area configuration involving a Y configuration of the terminal wings represents a special situation. Depending on the length of the wings and the angle between them, there may be sufficient space for independent aircraft movement at the outer portion of the ramp area. However, it is almost a certainty that Positive Ramp Control would be required in some portion of the inner ramp area up to a point where the distance between the wings permits multiple aircraft movements.

At some airports Positive Ramp Control might even be required in cargo or hangar areas. Delays in the operation of aircraft in these areas may not be as critical as delays for aircraft in the passenger terminal. However, depending on the interface of these areas with the taxiway network, delays in the movement of aircraft into or out of the areas could cause delays in the taxiway network. Such situations could exist when access/egress from these areas to a portion of taxiway network is by single taxi ramp and where the cargo/hangar traffic mixes with the other airport traffic in that portion of the taxiway network. Examples of such situations at O'Hare include:

1. The intersection of taxiway referred to as Hangar Alley with the Scenic Taxiway, which carries departure traffic to runway 14L, northwest of the ATCT.

2. The intersection of the same hangar area taxiway with the runway 14R/32L parallel taxiway, which carries departure traffic to 14R or arrival traffic from 32L, southwest of the ATCT.

3. The intersection of cargo area ramp with the cargo taxiway, which carries departure traffic for 22L or 27L or arrival traffic from 9R, southeast of the ATCT.

During the O'Hare Operations Analysis it was observed that traffic movement to or from the cargo or hangar required coordination between Inbound Ground and Outbound Ground to control traffic flow at these intersections.

Similar situations may exist at other airports, necessitating Positive Ramp Control for the ramp areas to avoid traffic flow problems in the taxiway network.

3.2.4.2 Ramp Area Traffic Volume

The airport ramp area configurations discussed above give rise to potential ramp area traffic conflicts. However, the requirement for implementation of Positive Ramp Control in such areas is also dependent on the volume of traffic served by the area. Obviously the higher the traffic operations rate the greater the potential for traffic flow conflicts. An assessment is made of the traffic conditions for which Positive Ramp Control is required as well as the capacity requirements for the Ramp Control System.

Table 3-3 provides a summary of ramp congestion associated delays observed at O'Hare. The table indicates the number of arrivals and departures to various ramp areas during twelve observation periods, the computed hourly operations rate for the ramp areas, the ratio of arrivals to departures for the observation period, and the percent of aircraft operations experiencing delays.

The percentage of arrivals delayed included aircraft which were held momentarily within the ramp area as well as those which were held on the taxiways for access to the ramp areas. The former group represents holds noted during the observation periods. The latter represents an estimate of the number of aircraft held based upon the results of taxi hold analysis performed utilizing the ASDE films taken by TSC and CSC. This analysis indicated that approximately 20 percent of the arrival aircraft holds were due to ramp congestion; i.e., the arrival was held on the inner or outer taxiway or at an intersection of the outer and crossing taxiways.

The percentage of departure flight delays represents momentary holds of aircraft in the ramp area after they had begun to taxi from their pushback position. It does not include delays in flight pushback by airlines (United or American)

Table 3-3. Summary of Estimated Ramp Congestion Delays at O'Hare International Airport

Observation Period	No. of Arrivals	No. of Departures	Operations Per Hour	Arrival/ Departure Ratio	% Arrivals Delayed	% Departure Delayed	% All Flights Delayed
3&5	7.0	13	10.0	0.54	20.0	0.0	7.0
11	15.0	18	19.0	0.83	26.7	0.6	15.2
9	18.0	20	14.2	0.90	53.3	20.0	35.8
10	21.0	23	22.0	0.91	33.8	21.7	27.5
4&6	17.0	17	14.1	1.00	24.7	29.4	27.1
7	11.0	11	19.0	1.00	20.0	36.4	27.7
8	21.0	20	16.4	1.05	24.3	0.0	12.4
12	21.0	20	19.7	1.05	20.0	15.0	17.3
1	15.0	12	13.5	1.25	20.0	0.0	11.1
2	20.0	16	18.0	1.25	30.0	0.0	16.7
Average Observation Period	16.6	17	16.6	.98	25.3	12.3	19.8

ramp control personnel due to competing traffic or delays in issuing of taxi instructions because Outbound Ground was aware that the flight could not taxi due to competing traffic. These delays could not be determined due to limitations of data collection and/or analysis.

The limited amount of data available in Table 3-3 does not permit analytic determination of any parametric relationships. However, a number of significant observations can be made from examination of this data:

1. The percent of operations delayed tends to be greater as the Arrivals/Departure ratio is less than or approaches 1.0. The ramp area service times observed in the O'Hare Operations Analysis (i.e., average times of 200 seconds for departures and 75 seconds for arrivals) would tend to support this observation.

2. The major exception to this observation occurs for the first entry in the table. However, the traffic level for these observation periods is significantly lower than for other periods.

3. For periods when the Arrivals/Departure ratio exceeds 1.0 the percentage of all flights delayed increases with the traffic operations rate.

4. The percentage of traffic delayed exceeds ten percent for all but the one period with the low traffic operations rate.

Based upon this data two conclusions are drawn regarding the requirements for the Ramp Control System:

1. The system should be designed for a capacity of 20, and possibly up to 25, operations per hour for each terminal building ramp area.

2. Positive Ramp Control should be implemented, when the traffic volume is equal to or exceeds 14 operations per hour in a ramp area with a configuration offering a potential for traffic flow constriction.

3.2.4.3 Environmental Factors

Earlier in this section one of the criteria cited for classification of a ramp area as requiring Positive Ramp Control was the lack of sufficient space for simultaneous independent operations of two outbound aircraft or an outbound and an inbound aircraft with a sufficient degree of safety during periods of poor operating conditions. This is based on the assumption of reduced pilot capability for visual reference to other aircraft, or physical structures. This factor suggests some qualifications of the discussions in the preceding paragraphs.

Consider first the potential impact in areas where the terminal/ramp configuration would not normally require Positive Ramp Control. This would be because the terminal/ramp area configuration does not include any physical features tending to constrain traffic movement (e.g., terminal fingers, narrow throat for ramp area entrance/exit) or because the distance between constraining features is sufficient to permit multiple flight operations. Under Category II and lower operating conditions pilot visibility may be sufficiently reduced so that wing tip clearance requirements would have to be increased to assure an adequate safety margin. Thus a ramp area that was not a candidate for Positive Ramp Control under good visibility conditions might require Positive Ramp Control under poor operating conditions. In addition, reduced pilot forward visibility under these conditions may necessitate greater care at the ramp area interface with the taxiway network, particularly where outbound and inbound aircraft paths might cross due to their points of entrance to or exit from the taxiway network.

Consider next the potential impact on areas which would not normally require Positive Ramp Control because of a low traffic operations rate. Reduced pilot visibility under poor operating conditions would require greater care in controlling the movements of aircraft into and out of the ramp area. As an example, the O'Hare Operations Analysis included a period of Category II conditions during which visibility dropped briefly to effectively Category IIIa conditions. Throughout this period, visibility of the low level of aircraft operations in the terminal ramp areas from the ATCT was non-existent. Therefore, neither Outbound nor Inbound Ground had any visual references to the relationship between departure and arrival traffic for the same ramp area on which to control flight movements for the area.

During the brief period in which visibility dropped to effectively Category IIIa conditions a pilot in one ramp area was given his taxi clearance by Outbound Ground. Just prior to that another departure flight from the same ramp area had been given his taxi clearance by Outbound Ground. The pilot of the later departure informed Outbound Ground that he did not have sufficient visibility to determine the location of the previous departure ahead of him and that he would not taxi until Outbound Ground could advise him of the position of the previous departure. Outbound Ground had to contact the previous departure to determine that it was clear of the ramp area and convey that information to the concerned pilot, who then indicated that he was starting to taxi.

From the above discussion it would appear that under poor visibility conditions it could become necessary or desirable to implement Positive Ramp Control in areas that would not normally be controlled under good visibility conditions. Therefore, the design of the ASTC system should permit the flexibility and capacity to accomplish Positive Ramp Control in nominally Non-Positive Ramp Control areas when operating visibility is sufficiently reduced to make such control necessary.

3.3 PRELIMINARY DESCRIPTION

This section describes the RCS elements, data requirements, data transmission across system interfaces, and information display and data entry requirements for the performance of the RCS functions.

3.3.1 Overall Characteristics

The overall configuration of the proposed Ramp Control System is illustrated in Figure 3-14. The RCS components include:

- ARTCC (NAS) Interface Equipment
- TRACON (ARTS) Interface Equipment
- Central Data Processing Equipment
- Ramp Control Input/Output Equipment
- Automatic Gate Status Equipment
- Control Communications Equipment

The ARTCC (NAS) Interface Equipment would provide for automated data exchange with NAS for receipt of IFR flight clearances and delay restrictions. The TRACON (ARTS) interface provides for receipt of available beacon codes for VFR departures. Other coordination communications between the Ramp Control, NAS, and ARTS personnel would be via voice landline facilities.

The Central Data Processing Equipment would be used for:

- Reception and integration of data received from ARTS and NAS into the system data base.
- Maintenance of the data base required for the performance of the Ramp Control System functions.
- Management of the interface with airlines flight operations, including reception and integration of data entered via the Automatic Gate Status Equipment (AGSE) and transmission of data requests to the AGSE.
- Processing of system data to accomplish the functions of the system, including the determination of ramp area traffic flow conflicts.

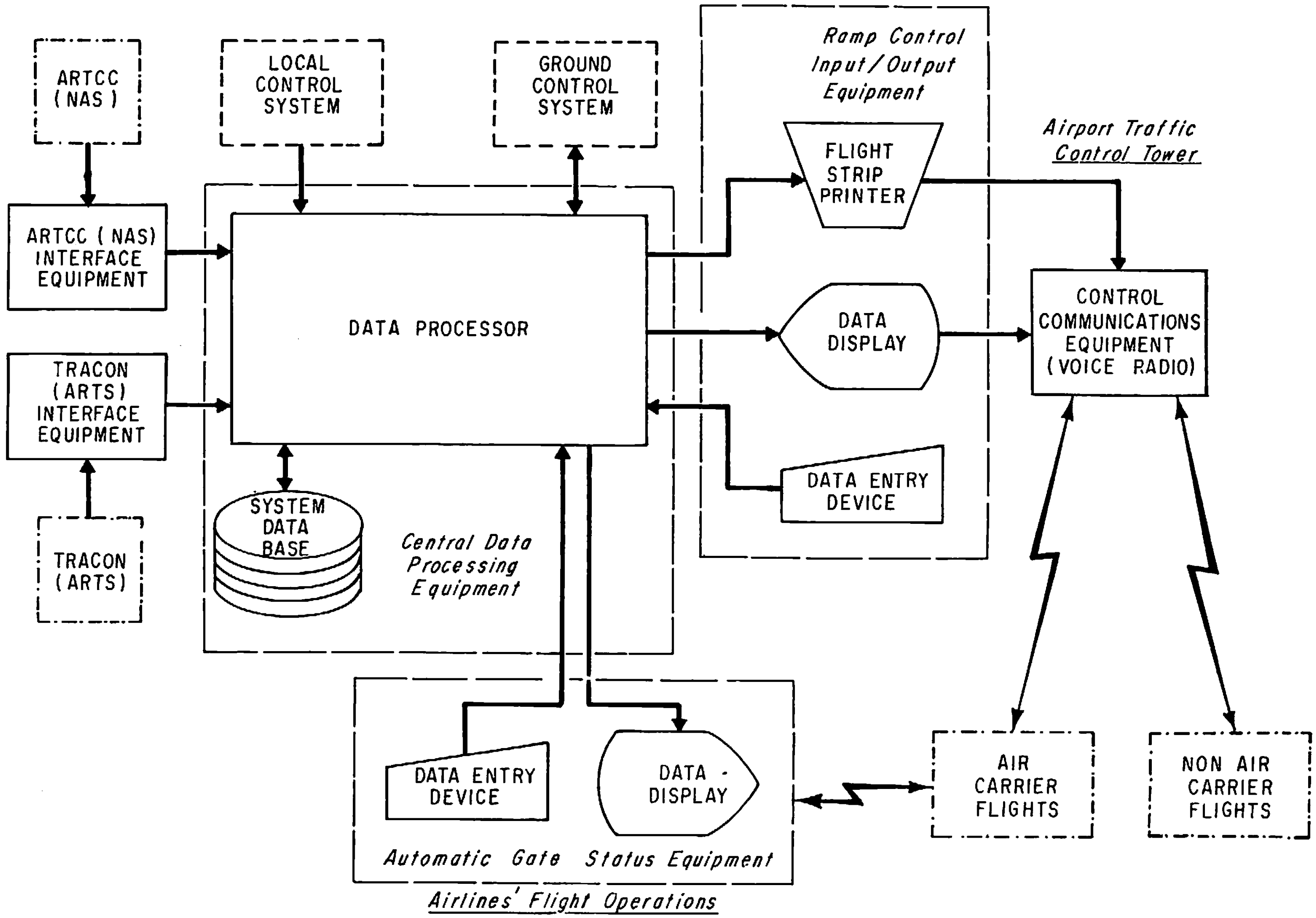


Figure 3-14. Ramp Control System Functional Configuration

- Management of the interface with the Ramp Control Input/Output Equipment, including reception and integration of data entered via that equipment and generation of control information/cue displays.

The Central Data Processing Equipment is shown in Figure 3-14 as an element of the RCS. It is probable in the total ASTC system configuration that it would be shared among the Ground Control and Local Control Systems as well.

The Ramp Control Input/Output Equipment would provide the functional capabilities for the man-machine interface between Ramp Control personnel and the system processing features. This would include:

- Preparation of flight strips (in an improved format as discussed earlier) for use in delivering flight clearances to IFR flights and for use by ATCT personnel in a backup manual mode of operations.
- Presentation of the appropriate operational situation data and control cues information for use by Ramp Control personnel in assessing and controlling ramp area operations.
- Entry of flight description, status, and control data as necessary.

The AGSE would provide the capabilities for the man/machine interface between the airlines' flight operations personnel and the system data processing to accomplish the coordination between airlines' flight operations and the ATCT. This would include:

- Presentation of status information on flights under control of the ASTC system.*
- Presentation of requests for information on the availability of gates for arrival flights.
- Entry of data on anticipated changes in gate schedules (assignments), to be used in response to requests for gate availability from arrival flights.

*It is considered probable that airlines' acceptance of some of the proposed RCS concepts will be dependent on the benefits they might receive through availability of data on the status of their flights for their own utilization.

- Entry of flight status data necessary for initiation of service to departures in Positive Ramp Control areas and termination of service to arrivals.*

It should be noted that, although not specifically shown in Figure 3-14, airlines communications facilities also constitute an element of the RCS. This is based on the assumption that pushback clearances and reporting of aircraft docking/parking will be accomplished through airlines flight operations.

3.3.2 Data Requirements

Table 3-4 summarizes the data requirements for the performance of the control functions of the Ramp Control System. The required data items are grouped by category:

- Data pertaining to a particular flight.
- Data pertaining to the status of terminal gates (ramp locations).
- Data pertaining to departure delay restrictions.
- Data specific to the operational environment of the airport.

The control functions to which the various data items apply are indicated on the table. Data items which may be utilized for information display purposes are also indicated.

Operations data would be maintained in the system data base in a number of working files. These include:

- Departure Flights Data File
- Outbound Ramp Q
- Ground Control Departure Q
- Inbound Ramp Q
- Gate Schedule File

*Based on the assumption that entry of pushback clearance requests and flight docking/parking status is made by the airlines to minimize voice channel loading and controller workload.

Table 3-4. Summary of Data Requirements for Ramp Control System Functions

DATA ITEMS	RAMP CONTROL SYSTEM FUNCTIONS: FLIGHT DELIVERY CLEARANCE	MAINTAIN OUTBOUND RAMP Q	PUSHBACK CLEARANCE	INTER-DEPARTURE CONFLICT MANAGEMENT	HANDOFF TO GROUND CONTROL DEPARTURE Q	VERIFY GATE ASSIGNMENT	MONITOR INBOUND RAMP Q	CLEAR TO GATE	OUTBOUND-INBOUND CONFLICT MANAGEMENT
FLIGHT DATA									
CALL SIGN	✓	✓	✓	✓[1]	✓	✓	✓	✓	✓[2]
AIRCRAFT EQUIPMENT TYPE	✓	✓[3]	✓[3]		✓[4]		✓[3]		
BEACON EQUIPMENT TYPE	✓				✓[4]				
ASSIGNED BEACON CODE	✓								
CLEARED ALTITUDE (IFR)	✓								
DESIRED (CLEARED) ALTITUDE OUT OF TERMINAL AREA (VFR)	✓								
FIRST FIX (IFR)	✓				✓[4]				
DESIRED DIRECTION OF FLIGHT OUT OF TERMINAL AREA (VFR)	✓				✓[4]				
CLEARED ROUTE (IFR)	✓								
ORIGINATION GATE (RAMP LOCATION)	✓[5]	✓	✓	✓[1]	✓		✓[3]		✓
DESTINATION GATE (RAMP LOCATION)						✓[5]	✓		✓
CURRENT RAMP DEPARTURE (READINESS) STATUS		✓	✓	✓[1]			✓[3]		✓
CURRENT RAMP ARRIVAL STATUS							✓	✓	✓
TIME OF DEMAND (ENTRY INTO CURRENT STATUS)		✓	✓	✓[1]	✓	✓	✓	✓	✓[2]
TERMINAL GATE (RAMP LOCATION) DATA									
GATE (RAMP) SCHEDULES	✓					✓			
CURRENT GATE (RAMP LOCATION) STATUS		✓[3]	✓[3]			✓	✓[3]		
GATE (RAMP LOCATION) AVAILABILITY DELAY						✓			
DEPARTURE RESTRICTIONS DATA									
RESTRICTED DIRECTION(S) OF FLIGHT	✓								
DELAY RESTRICTION FOR EACH DIRECTION OF FLIGHT	✓								
AIRPORT OPERATIONS DATA									
IFR ALTITUDE CLEARANCE LIMIT(S)	✓								
DEPARTURE RUNWAY ASSIGNMENT CRITERIA	✓[6]				✓[4,6]				
AVAILABLE (VFR) BEACON CODES	✓								

NOTES

1. Required for Subject (Requesting) Departure flight and Competing departure flights in same Positive Ramp Control area.
2. Required for Subject departure (Arrival) and Competing Arrival (Departures) for same Positive Ramp Control area.
3. May be utilized in generating display for Ramp Control to permit intervention/override in system operations.
4. Required for inclusion in Ground Control Departure Q data for use by Ground Control System.
5. Derived for this function from Stored Gate (Ramp) data.
6. Reflected in inclusion of nominal runway assignment in flight related data storage and outputs.

The anticipated data contents of these files are summarized in Table 3-5.

3.3.3 Interface/Data Transfer Considerations

The Ramp Control System requires data transfer with the external ATC system (ARTCC and TRACON) as well as with the Ground Control System and Local Control System components of the total ASTC system.

The data transfer associated with the ARTCC interface would be uni-directional from the ARTCC (NAS) to the Ramp Control System. This data transfer would include specific flight and general operations contraints, i.e., delay restrictions. The data items included in each transfer are given below.

Specific Flight Data

Call Sign
Proposed Departure Time
Aircraft (and Beacon) Equipment Type
Assigned Beacon Code
Cleared Altitude
Departure (First) Fix
Standard Instrument Departure (SID) Identification
Cleared Route (all components)

General Operations Data

Restricted Direction of Flight (or Departure Fix)
Applicable Delay Restriction
} For each restricted direction (or fix)

Cancellations

The data transfer associated with the TRACON interface would be uni-directional from the TRACON (ARTS) to the Ramp Control System. This data transfer would include a list of beacon codes available for assignment to VFR departures.

Table 3-5. Summary of Proposed Data Contents of Primary Ramp Control System Working Files

Data Items	Departure Flights Data File	Outbound Ramp Q	Ground Control Departure Q	Inbound Ramp Q	Gate (Ramp) Schedules Data File
Flight Call Sign	✓	✓	✓	✓	
Aircraft Equipment Type (or Class)	✓	✓[1]	✓	✓[1]	
Assigned Beacon Code	✓		✓		
Computer Number	✓[2]	✓[2]	✓[2]	✓[2]	
Origination Gate (Ramp Location)	✓	✓	✓		
Destination Gate (Ramp Location)				✓	
Departure (First) Fix or Direction of Flight (for VFRs)	✓		✓		
Nominal Runway Assignment	✓		✓		
Departure (Delay) Restrictions (if any)	✓		✓		
Current Departure (Readiness) Status		✓	✓		
Current Ramp Arrival Status				✓	
Time of Demand (Entered Status)		✓	✓	✓	
Scheduled Flight					✓[3]
Nominal (Scheduled) Departure Time					✓[3]
Nominal (Scheduled) Arrival Time					✓[3]
Current Gate Status					✓

Notes

1. Could be included for use (display) in controller intervention/override capability.
2. If utilized in system (as in NAS and ARTS).
3. For each flight scheduled for use of Gate (Ramp Location).

The data transfer associated with the LCS interface would be unidirectional from the Local Control System. This data transfer would include the call sign of flights entering the Ground Control Arrivals Q as well as requests for verification of Gate Assignment in the Ramp Control System.

The data transfer associated with the GCS interface would be bidirectional between the Ramp Control and Ground Control Systems. These data transfers will occur as entries to the Ground Control Departure Q, Verify Gate Assignment, and Monitor Inbound Ramp Q functions. The data items included in each transfer are given below.

1. Handoff to Ground Control Departure Q (From Ramp Control to Ground Control)

   Flight Call Sign
   Aircraft Equipment Type (or Class)
   Assigned Beacon Code
   Computer Number
   Origination Gate
   Departure (First) Fix or Direction of Flight (for VFR)
   Nominal Runway Assignment
   Departure (Delay) Restrictions (if applicable)
   Time of Demand

2. Verify Gate Assignment (From Ramp Control to Ground Control)

   Flight Call Sign
   Destination Gate (Ramp Location)
   Gate (Ramp Location) Availability Delay (Zero or applicable delay in minutes)

3. Monitor Inbound Ramp Q (From Ground Control to Ramp Control)

   Flight Call Sign
   Destination Gate (Ramp Location)
   Ramp Arrival Status
   Time of Demand (Entered Status)
   Request for Ramp Area Availability

4. Monitor Inbound Ramp Q (From Ramp Control to Ground Control)

   Flight Call Sign
   Destination Gate (Ramp Location)
   Ramp Area Available or Unavailable (conflict)

3.3.4 Display Considerations

The data which would be displayed to Ramp Control personnel in the ATCT in connection with the performance of the various Ramp Control System functions are described below.

The data for Clearance Delivery would be displayed in the form of a flight strip prepared by the FDEP flight strip printer. The data that would be included in either IFR or VFR flight strips are listed below.

IFR Flight Strip

Call Sign
Aircraft (and Beacon) Equipment Type
Assigned Beacon Code
Proposed Departure Time
Cleared Altitude or Altitude Clearance Limit (if appropriate)
Departure (First) Fix
Standard Instrument Departure Identification
Cleared Route (all components)
Origination Gate (Ramp Location)
Nominal Runway Assignment
Departure (Delay) Restriction (if applicable)

VFR Flight Strip

Call Sign
Aircraft (and Beacon) Equipment Type
Assigned Beacon Code
Cleared Altitude (out of terminal area)
Cleared Direction of Flight (out of terminal area)
Nominal Departure Runway Assignment
Departure Delay Restriction (if applicable)

The data display necessary for control of flight operations associated with the Maintain Outbound Ramp Q, Pushback Clearance, Handoff to Ground Control Departure Q, and Monitor Inbound Ramp Q functions of the RCS are similar in most respects. The required data and supplemental data items which could be displayed are summarized in Table 3-6. Supplemental data includes that information which would be displayed to Ramp Control for evaluation of the ramp activity situation and determination of the appropriateness of intervention in the operations to override system recommended control cues.

It may be noted that in each case the supplemental data is related to:

- The type (or class) of equipment of the subject requesting flight.
- The identity, origination/destination gate (ramp location), and status of the conflicting outbound/inbound flight(s)
- The status of "opposing gates".

"Opposing gates" are defined as those gates on the opposite side of the ramp area from that of the origination/destination gate of conflicting outbound/inbound flight(s).

The intent of the supplemental data would be to allow the Ramp Control personnel to determine whether the potential exists for the subject (requesting) flight to maneuver around the conflicting flight. If such a potential exists Ramp Control could contact the pilot of the subject (requesting) flight to determine his assessment of the potential. If the pilot indicated that such a maneuver was possible, then Ramp Control would clear the pilot to proceed under his own responsibility. This process (representing shared responsibility in flight operations control as noted in the O'Hara Operations Analysis) is maintained in the Ramp Control System, as well as in the Ground Control System, in order to achieve operational flexibility and to avoid unnecessary delays.

Table 3-6. Summary of Data Display for Flight Operations Control Functions of Ramp Control System

Data for Display	Maintain Outbound Ramp Q	Pushback Clear-ance	Handoff to Ground Control Depar-ture Q	Maintain Inbound Ramp Q
Flight Call Sign	R	R	R	R
Aircraft Equipment Type (or Class)	S	S	S	S
Origination Gate (Ramp Location)	R	R	R	A
Destination Gate (Ramp Location)	A	A		R
Current Departure (Readiness) Status	R	R	R	A
Current Ramp Arrival Status	A	A		R
Time of Demand (Entered Status)	R, A	R, A	R, A	R, A
Outbound Conflict (Hold in Position)	R	R		
No Outbound Conflict	R	R		
Inbound Conflict (Hold in Position for Flight Holding in Ramp Area) or				R
No Inbound Conflict - Clear to Gate				R
Conflicting Flight(s) Call Sign	S	S		S
Opposing Gates Status	S	S		S

R = Required Data Item

S = Supplemental Data Item

A = Available, if needed

3.4 BENEFITS ASSESSMENT

The benefits assessment considers the impact of the RCS on aircraft traffic delays as well as controller functional activities, i.e., communications and flight strip marking. The assessment is made with respect to values obtained during the O'Hare Operations Analysis. The impact is first determined for each control function of the Ramp Control System. The total benefit is then determined as the sum of the benefits associated with each control function.

3.4.1 Flight Clearance Delivery Function

The potential areas of impact of the Flight Clearance Delivery function are listed below.

Delays

None

Controller Communications

- Eliminate communications transactions (CTs) related to obtaining departure gate from pilots.

Manual Activity

- Eliminate marking of clearance limit by Flight Data position.
- Eliminate marking of departure gate by Clearance Delivery (Ramp Control in system concept).
- Eliminate need to obtain available beacon codes via ARTS keyboard entry by Flight Data.
- Eliminate marking of departure runway assignment by Ground Control.
- Manual preparation of a flight strip for a VFR departure by Clearance Delivery will be replaced by entry of flight data into the system for use in the proposed improved flight strip preparation.

Based upon the measurements of controller activity at O'Hare, the above CTs accounted for approximately 15 percent of the communications of the Clearance Delivery position. Therefore, communications channel occupancy for the Clearance Delivery (Ramp Control) position could be reduced by this amount.

Based upon the controller manual activity analysis the above activities represent approximately

- 27 percent of the manual activity of Flight Data
- 5 percent of the manual activity of Clearance Delivery
- 16 percent of the manual activity of Outbound Ground

Therefore, the manual activities workload of these positions could be reduced by these amounts.

3.4.2 Maintain Outbound Ramp Q

The potential areas of impact of the Maintain Outbound Ramp Q function are listed below.

Delays

None

Controller Communications

None

Manual Activity

- Addition of need to enter flight status (ready to taxi) for air carrier departures into system would be balanced by elimination of controller recording of time of request since this recording would be automatically accomplished by the system.
- Elimination of need to record time of request for general aviation flights since this would be automatically accomplished at the time the flights are entered into the system under Flight Clearance Delivery Function.

Based on the controller activity analyses the marking of ready-to-taxi time for general aviation departures represented approximately 3.5 percent of the manual activity of the Clearance Delivery Position. Thus, the manual activities for Clearance Delivery (Ramp Control) could be reduced by this amount.

3.4.3 Pushback Clearance

Delays

None

Controller Communications

Elimination of CTs related to pilot request for pushback clearance as these would be entered by airlines.

Manual Activities

Elimination of recording of time of request for pushback clearance as this would be automatically recorded at the time of airline request entry.

Based on controller communications activities the above CTs represented approximately 1 percent of the communications of the Clearance Delivery position at O'Hare. Therefore, communications channel occupancy for Clearance Delivery (Ramp Control) could be reduced by this amount.

Based upon the O'Hare Operations Analysis, flights requiring pushback clearance represent less than 4 percent of the total operations. The time spent in marking of request times for these flights, represents approximately 1 percent of the manual activities of the Clearance Delivery and could be eliminated by the proposed system concept.

3.4.4 Interdeparture Conflict Management

The areas of impact for this function by the nature of its definition is limited to reducing delays for outbound flights (in relation to other outbound flights).

The O'Hare Operations Analysis indicated that approximately 13 percent of the air carrier departures experienced a delay in the ramp area, for an average of 67 seconds. Most of these were caused by blockage by other departures. It is estimated that this situation accounted for 75 percent of the delays (the remainder are due to ramp area arrivals).

For the purposes of this analysis the parameters employed in the previous O'Hare system effectiveness analysis are used here: 120 operations per busy hour; 85 percent air carrier traffic; arrival/departure ratio of 1.0. Based upon these parameters and the above estimates the number of departure flight delays which can occur may be computed as

$$(0.85)\ (60)\ (0.13)\ (0.75) = 5 \text{ per busy hour.}$$

This represents 335 seconds (5.6 minutes) of flight delay per busy hour.

3.4.5 Handoff to Ground Control Departure Q

Due to the nature of the definition of this function its potential impact would be limited to the area of manual activity for the Ramp Control position.

In the description of the logic flow of this function in paragraph 3.2.3.5 it was indicated that flights would be entered into the Ground Control Departure Q through a system data entry by Ramp Control when no conflicts are determined for the flight. If it is estimated that this entry would take approximately two seconds, this would represent an increase of approximately 16.5 percent in the manual activities of the Clearance Delivery (Ramp Control) position. Note, however, the system could be designed to automatically accomplish this transfer to the Ground Control Departure Q when no conflicts are detected for a flight and to cue Ramp Control to accomplish the frequency change (handover) instruction.

3.4.6 Verify Gate Assignment

Due to the nature of the definition of this function its impact would be limited to the area of controller communications activity. This function would eliminate the communications between flights and airlines flight operations because the flights' destination gates would be transmitted to the pilots by (inbound) Ground Control as part of the flights' taxi clearance. However, the communication of destination gate and availability information was observed for approximately 60 percent of all arrivals in the analysis of controller communications. Since, for the most part, these communications involved a request from Ground Control and a response from the pilot, a reduction in communications activity would be achieved by a one-way transmission from the Controller.

The net benefit is derived using the results of the (inbound) Ground Control Communications analysis, namely

- Gate assignment communications for 60 percent of traffic.
- Gate assignment communications representing approximately 15 percent of all CTs.
- Average CT time of 9.3 seconds.

It is assumed that the one-way transmission of gate assignment would involve one half of the time for the previous two-way communications. Therefore, the net change in gate assignment communications time could be computed as

$$\left[\frac{+0.40\ (4.65) - 0.60\ (4.65)}{0.60\ (9.3)} \right] 0.15 = -0.025$$

That is, a net reduction of approximately 2.5 percent of the channel occupancy of the (inbound) Ground Control would be accomplished.

3.4.7 Monitor Inbound Ramp Q

Within the proposed functional concept the reporting of arrival at a gate would be accomplished through a system data entry by airlines flight operations.

This reporting is occasionally performed, usually on request from Inbound Ground Control, during low visibility conditions when flight operations in the ramp area cannot be observed by Inbound Ground. However, such situations were not explicitly measured during the O'Hare Operations Analysis. Therefore, no quantitative assessment of this impact can be derived here.

3.4.8 Clear to Gate

The areas of potential impact for this function are listed below.

Delays

None

Controller Communications

Addition of a Ramp Control communications transaction to clear a flight that has been holding off the taxiway network in a portion of the ramp area.

Manual Activity

Addition of controller (Ramp Control) flight status data entry--Cleared to Gate--into the system when the flight is so cleared.

When a flight is instructed by Ground Control to hold in the ramp area, Ground Control must also transmit the instruction to taxi to its gate at a later time. Thus, the effect of this function would be to transfer this communication from Ground Control to Ramp Control.

With respect to controller manual activity it is estimated that the required data entry would take approximately 2 seconds for each occurrence.

Holding of arrival flights off the end of terminal building fingers is accomplished occasionally at O'Hare but only for B-727 and smaller aircraft because of the limitations of the space between the terminal fingers and the inner taxiway. However, no explicit measurements of such situations were achieved during the O'Hare Operations Analysis. Therefore, no quantitative estimates of the impact of this function can be derived here.

3.4.9 Outbound-Inbound Conflict Management

The benefits of this function would be limited to reduction of delays for both outbound aircraft and inbound aircraft. The specific effects anticipated would be:

- Reduction of delays to outbound flights due to blockage by inbound flights on the taxiways.
- Elimination of delays to inbound flights within the ramp area due to blockage by outbound flights.
- Reduction of delays, to inbound flights outside the ramp area, i.e., holding on the taxiway network, due to blockage by outbound flights.

The effects of this function are assessed using the results of the O'Hare Operations Analysis.

With respect to outbound flights, it was estimated in paragraph 3.3.3 that 13 percent of outbound flights were delayed in the ramp area and that 25 percent of these delays were due to inbound flights. The average outbound delay was noted in paragraph 3.4.4. to be 67 seconds.

With respect to inbound flights, delays within the ramp area were observed to affect 8.4 percent of the arrivals and to have an average duration of 90 seconds. The O'Hare analysis indicated that approximately 20 percent of arrivals experienced delays on the taxiway network due to ramp congestion. The average taxiway "hold" delay was measured as 67.5 seconds.

For the purposes of this analysis the parameters employed in the previous O'Hare system effectiveness analysis are used here: 120 operations per busy hour; 85 percent air carrier traffic; arrival/departure ratio of 1.0. Based upon these parameters and the above estimates the number of flight delays which can occur may be computed as:

$$(0.85)\ (60)\ \left[(0.13)\ (.25) + (0.084) + (0.20)\right] =$$

$$51\ \left[0.033 + 0.084 = 0.20\right] = 16.2 \text{ flights per busy hour}$$

The delay time may be computed

$$51\ \left[0.033\ (67) + 0.084\ (90) + 0.20\ (67.5)\right] =$$
$$1187 \text{ seconds per busy hour}$$

3.4.10 Composite Benefits

The results of the preceding analyses may be combined to provide an estimate of the total (net) benefits of the proposed Ramp Control System. These results indicate:

- A reduction of approximately 16 percent of the communication channel occupancy (workload) of the Clearance Delivery (Ramp Control) position.
- A reduction of approximately 2.5 percent of the communication channel occupancy (workload) of the Inbound Ground Control position.
- A reduction of approximately 27 percent of the manual activities workload of the Flight Data position.
- An increase of approximately 7 percent of the manual activities workload of the Clearance Delivery (Ramp Control) position.
- A reduction of approximately 16 percent of the manual activities workload of the Outbound Ground Control position.

While there is a net increase in the manual activity workload of the Clearance Delivery (Ramp Control) position, this does not seriously detract from the overall benefits of the system concept. During the O'Hare Operations Analysis the manual activity workload of this position was determined to account for 16.9 percent of the controller's time during a busy hour. In addition, it was noted that these activities occurred, for the most part, simultaneously with his communications activities. This situation is expected to continue in the proposed Ramp Control System. Therefore, the reduction of approximately 16 percent of the controller's communications activity more than than compensates for this increase in manual activity.

The estimated aircraft delays represent an extremely important factor. The total estimated delay for all flights is 1522 seconds (25.4 minutes) per busy hour. Using the weighted average cost of $11.23 per aircraft operating minute derived in the O'Hare system effectiveness analysis, this delay represents costs of:

- $285 per busy hour
- $4564 per day
- $1,665,860 per year

Estimates of actual savings due to the proposed RCS have not been made; however, the above figures demonstrate the substantial costs incurred by the airline operators which could be reduced through application of positive Ramp Control concepts.

SECTION 4 - DEVELOPMENT OF A GROUND CONTROL SYSTEM (GCS) CONCEPT

4.1 INTRODUCTION

Control of aircraft on the surface of an airport is a substantially different control process from that performed at other ATC control positions. In general the route structure of the airport is more complex than that in the airspace; the number of aircraft sources (ramps, for example) are larger and the interactions between surface traffic movement and the interacting local and ramp areas more complex. Pilot options are more diverse since the aircraft can hold at almost any location and the navigational aspects, relying heavily on VGE equipment, are appreciably different from those followed by the pilot when airborne.

The concentration of traffic in the vicinity of a major terminal is significantly higher than that existing at other control positions. The relatively slow speeds used by aircraft in taxiing, the unique aspects of aircraft turning (either at intersections or at runway turnoffs), and the pavement constraints of most airports, coupled with the recent advent of heavies, are some of the factors that make the ground controller's job indeed a difficult one even in conditions of excellent visibility. The experience of the pilots is believed to be a major factor in the "workability" of the existing GCS. Aircraft taxiing on "highways" such as the Outer Circular or some of the parallels at O'Hare maintain headway with respect to each other. This type of conflict, therefore, is not something that a controller must be concerned with since he knows that the pilots will exercise this function. At intersections, however, no such "rules of the road" exist because of the single lane nature of the existing pavements. Scheduling of the pavement facilities, which must serve a wide variety of runway configurations, is by no means a simple task. An idea of the complexity of the control functions may be obtained from the discussion of the individual functions set forth under the performance requirement section. The manner in which these interact with each other will be shown on a composite operational logic figure. The required amount of functional activity in the present manual system is compared in the benefits analysis section with those anticipated in a semiautomated GCS.

4.2 REQUIREMENTS ESTIMATION

4.2.1 General

The area of responsibility of the Ground Control System includes all taxiway links and intersections exclusive, however, of ramp, cargo, and hangar areas. This system must interface with other pavement areas (facilities) which are under the control of other systems. These interface areas include the ramp entry/exit areas, runway turnoff links, departure Q nodes serviced by Local Control, and the cargo and hangar areas from which aircraft may also wish to enter the GCS. Runway crossings represent a facility managed on a time-shared basis by both the Local Control system as well as the Ground Control System. During some active runway configurations, inactive runways may be used (4L/22R at O'Hare for example) for taxi purposes. These will be considered as part of the taxi system for the particular runway configuration in use. The above description, supplemented by the taxi network analysis of Appendix A, defines the required coverage area of the Ground Control System. Special mention should be made of staging areas (such as the Penalty Box at O'Hare) which are portions of the taxiway network wherein an aircraft is delayed because of the unavailability of a facility (i.e., a gate for example) outside of the ground controller's area of responsibility. Non-paved areas, service roads, fuel depots, and all areas closed to aircraft traffic are excluded from the coverage area of the GCS.

4.2.2 Functional Requirements and Operational Logic

The major functions to be performed by the GCS have been derived from a detailed study of existing control procedures and examination of aircraft scenarios and maneuvers during their use of the various ground control facilities. It is expected that some of these functions can be improved materially by use of semi-automated control techniques; other functions, however, will still be performed in a manner similar to the present-day system.

The control functions may be divided into three categories, based upon whether they are required for Departures, Arrivals, or both.

These Control Functions are as follows:

Departures

A. Release of Departure A/C (from Ramp Areas) (including monitoring status of Ground Control Departure Q)

B. Handoff to Local Control Departure Q.

Arrivals

C. Formation and Monitoring of Ground Control Arrival Q

D. Acceptance of Arrival A/C (into Taxi System)

E. Penalty Box/Staging Area Management

F. Interface/Handoff to Ramp Control

Common

G. Routing Control (Selection and Verification)

H. GCS Conflict Management

Each of these functions is examined in order to determine the information needed by the data processing subsystem (or controller) to perform the appropriate job (or task). There is a substantial amount of interaction between many of these Control Functions; for example, Function A requires (1) that Function H (no Ramp Exit Conflict exists) is satisfied; (2) that Function G (Routing Control) has been performed. In the present system the logic used is that if Function H is not satisfied (i.e., a Ramp Exit Conflict exists) then no contact is made by the Ground Controller with the Departure A/C.

Table 4-1 lists the major Control Functions required in the Ground Control System. This table also indicates where interface is required with the associated Local Control or Ramp Control systems. The next heading of this table lists (in order) the sequence of events or interacting functions which are to be recognized or performed during the designated function. These entries may be used to identify the demand (or request) for service; the actual initiation of service and the completion of service for each function of the aircraft control process are parts of a series of tandem queues managed by the controllers.

While some "Demand" events may be defined solely in terms of aircraft location (and possibly other physical parameters), other "Demand" events must be specified by the users (i. e., a pilot indicating he is ready to taxi). On the other hand, the events identifying Start and End of Service (or activity) are essentially recognizable from surveillance information, i. e., an aircraft has left the Ramp Area, is about to turn off the runway after landing, or is "near" the Local Control Departure Q. It is these events which must be examined for each function in order to determine the performance requirements of the surveillance sensor(s).

The next column on Table 4-1 provides an estimate of the information (or data requirements) needed by the controller or data processing system. The various types of data requirements (Link Occupancy, Movement Detection, etc.) are discussed in the Appendices wherein estimates of the performance requirements of the sensors are given (and included in Table 4-1). Changes in these data requirements are expected as refinements are made in the development of the GCS concept.

The interaction between these Control Functions is described by an Operational Logic diagram as shown in Figure 4-1. Aircraft wishing to enter the taxi system are designated as being in the Ground Control Departure Q or the Ground Control Arrival Q. Upon entry, these aircraft "move" into an "Active" A/C status, i. e., service is being provided by the taxiway facilities. Termination

Table 4-1. Ground Control System Functions and Requirements

Control Functions	Interface Required With	Sequence of Events/Interacting Functions	Operational Data Requirements (Controller and/or Computer Needs)	Sensor Requirements Estimated Accuracy: Position σ_x – ft	Velocity σ_v – fps	Directional	Response Time-Sec	Remarks
DEPARTURES								
A Release of Departure A/C	RCS	A/C "In" Ground Control Departure Q Function G (Routing Control) Function H-1 (Ramp Exit Conflict) "OK"-to-Release" (FLAG) Entry Verification	ID (Flight, Code, Equipment Type) Origin/Destination (Ramp/R/W)	– –	– –	– –		Input from RCS
			See H-1					
			Link Occupancy; Movement Detection (Alternate - Passage Detection)	N/A 10(25)	N/A 3	N/A Binary	4-7	Acquisition + Track Initiation (A/C "Active")
B Handoff to Local Control Departure Q	LCS	A/C on "Last" Link (FLAG) Initiate Handoff (Data Entry)	Link Occupancy; Route Assignment	35	–	Binary	7-10	H-3 used for L.C. Departure Q input, suspension of track (A/C "Inactive")
ARRIVALS								
C Formation/Monitoring of Ground Control Arrival Q (GCAQ)								
• Landing A/C (GCAQL)	LCS	A/C Past R/W Threshold or "Down"	ID; R/W Approximate Position from LCS	See LCS			2-3	R/W configuration in use
• Hangar/Popups (GCAQH)		Pilot "Callup"; Data Entry by Controller	ID; Origin/Destination	100/200	–	–	7-10	For acquisition by surv. sensor
• Penalty Box (GCAQP)		See Function E (Penalty Box Management)						A/C ready to leave Penalty Box
D Acceptance of Arrival A/C	LCS RCS	A/C in GCAQ (Function C) Function H-4 (Turnoff Gen. Conflict Check) Function G (Routing Control) "OK-to-Accept" (FLAG)	See Function C					
			Turnoff (T/O) Prediction/Recognition Origin/Destination (Penalty Box or Ramp) Special Action Required?	? –	? –	? –	2-3 –	Needed for both GCS and LCS Gate information from RCS
		Pilot Call-in (Data Entry by Controller) Verification of Entry (FLAG)	T/O Recognition; Link Occupancy Movement Detection	25	–	Binary	2-3	A/C now "Active" Transfer of track to GCS
E Penalty Box/Staging Area Mgmt	 RCS?	Entry Recognition (into P.B.)-Temp End of Service Pilot Callup or Input from RCS (FLAG)	Link Occupancy; Route Ready to Leave Penalty Box; ID	25 100/200[a]	– N/A	Binary Binary[a]	7-10 7-10	Change A/C to "Inactive" [a]For multiple staging areas
	 RCS	Function G (Routing Control) Function H-5 (Ramp Entrance Check) Function H-3 (Taxiway/Taxiway Conflict Check)	Per Function G Per Function H-5 Per Function H-3	None None See H-3				
		Issue Clearance (Data Entry by Controller) Function D (Acceptance of Arrival A/C)	Per Function D (Verify Entry)	10(25)	3	Binary	4-7	Change A/C to "Active"
F Handoff To Ramp Control	RCS RCS	A/C within "X" seconds of Ramp (FLAG) Function H-5 (Ramp Entrance Conflict Check)	Link Occupancy; Movement Detection Ramp Availability	50-100 N/A	– N/A	Binary N/A	4-7	Provide input to RCS
	 RCS	Issue Handoff (Data Entry) Verification of Entry into Ramp	Link Occupancy or Beacon "OFF"	25	–	Binary	7-10	Terminate A/C Track

Table 4-1. Ground Control System Functions and Requirements (Continued)

Control Functions	Interface Required With	Sequence of Events/Interacting Functions	Operational Data Requirements (Controller and/or Computer Needs)	Sensor Requirements Estimated Accuracy: Position x - ft	Velocity v - fps	Directional	Response Time-Sec	Remarks
COMMON								
G Routing Control	LCS/RCS							
Route Selection		(Provides input to most Functions)	Origin/Destination; Equipment Type	None			Not crit.	R/W configuration needed
Route Verification		On Link/Link Basis - (FLAG Possible Errors)	Assigned Route; Link Occupancy	20	-	Binary	4-7	"Lost" A/C
			Possibly Turn Recognition					
H GCS Conflict Management								
H-1 Ramp Exit Conflicts		Function A	Link Occupancy (Active A/C); Route Data	10(25)	3	Binary	2-3	Merge type conflict usually
			Predicted Position of Taxiing A/C		(2)			t_p = 15-30 sec (Pred. Time)
H-2 R/W Crossing Control	LCS	Status of R/W - Taxiway Crossing	From LCS (Estimated/Predicted Crossing Time)	See LCS				Of A/C using R/W
(may be performed for		Status of Taxiing A/C (FLAG)	Route; Link Occupancy; Movement Detection	10(25)	3	Binary	2-3	Initiate conflict evaluation
either Arrivals-Deps.)		Issue Clearance or Hold		Per Above				
		Verify A/C Across R/W (FLAG)		Per Above				
H-3 Taxiway/Taxiway Conflicts		Detection of "New" Conflicts (FLAG)	Assigned Route; Link Occupancy	10(25)	3	Binary	2-3	Active A/C only
			Movement Detection; Turn Recognition?			(10-20°)		If turn recognition is used
		• Verify "Hold" Compliance (FLAG)		10(25)	3	-	2-3	
		Monitoring of "Old" Conflicts (FLAG when over)	Per above plus	10(25)	3	Binary	4-7	One A/C in "Hold" status
			Turn Recognition	?	?	10-20°	4-7	To distinguish "turns" from conflicts
		• Verify "Start-up" (FLAG No "Start-up")	Per above	10(25)	3	Binary	4-7	A/C changes to "Active" status
H-4 Turnoff-Generated Conflicts	LCS	Function D	A/C Landing on R/W	See LCS				
		Status of A/C Near R/W (FLAG)	Link Occupancy; Movement Detection	10(25)	3	Binary	2-3	
		Verify "Hold" Compliance (FLAG)	Movement Detection	10(25)	3	-	2-3	
H-5 Ramp Entrance Conflict	RCS	Function F	Ramp Availability Data	As Per Function F				

NOTES

1 RCS = Ramp Control System; LCS = Local Control System

2 Velocity used for movement detection; for prediction, standard values are to be used

3 Sensor requirements are for modest data rates (e.g., 1 sample/2 seconds) except the (25) position estimate which is at a fairly high rate (e.g., 10 samples/second)

(or suspension) of service to "Active" aircraft will occur when they are "handed off" to the Local Control Departure Q, the Penalty Box, or the Ramp Control System. All "Active" aircraft are "continually" examined for conflict recognition purposes. Where necessary (as determined by the Controller) certain aircraft may be "Held" in order to resolve a potential conflict. These A/C (in the "Held" A/C List) are reactivated by the Controller at some later time. In Figure 4-1 GCS activated "flags" to the Controller are indicated wherever controller intervention is required, i.e.,

Clear departure A/C into taxiway system
Cleared departure A/C has not entered taxiway system
Provide route to cleared aircraft
A/C is "lost", i.e., not following route
Conflict resolution, i.e., "Hold" A/C, etc.
Clear "Held" A/C to move
R/W crossing clearance
Acceptance of arrival aircraft
Resolution of turn-off generalized conflicts
Ramp entrance conflicts
Penalty box routing
Time for Handoff

Five types of conflict have been identified for GCS Conflict Management (Function H). These are:

H-1	Ramp Exit Conflicts
H-2	R/W Crossing Conflicts
H-3	Taxiway/Taxiway Conflicts
H-4	Turn-off Generated Conflicts
H-5	Ramp Entrance Conflicts

With the exception of taxiway/taxiway conflicts, all others are deterministic in nature, i.e., they must only be evaluated at or near the time of

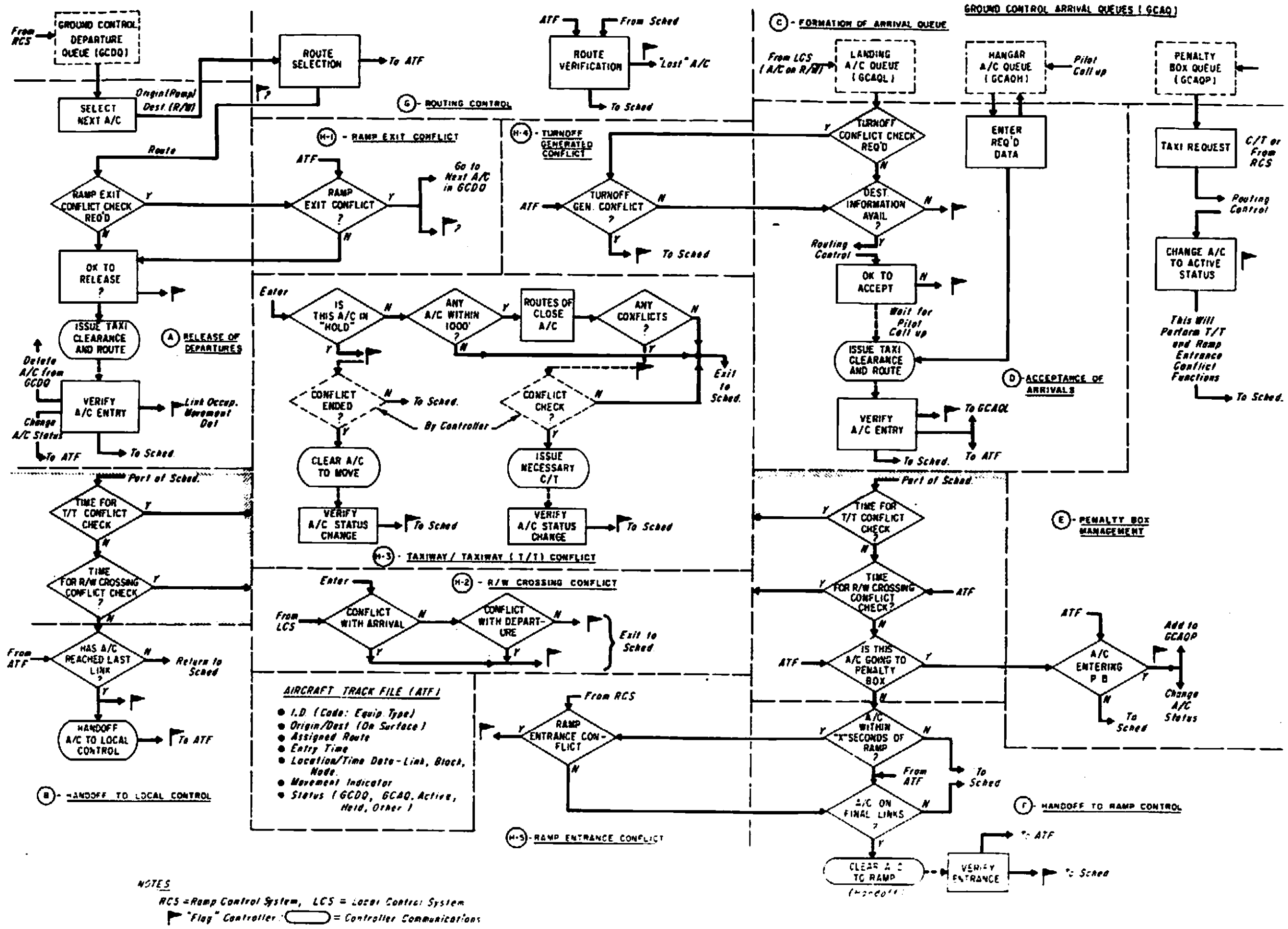


Figure 4-1. Operational Logic for Ground Control System (GCS) Functions

demand. The turn-off-generated conflict is defined as that caused to aircraft in the vicinity of landing aircraft turning off the runway (and having priority).

4.2.3 Performance Requirements

4.2.3.1 General

Each of the eight control functions to be performed by the GCS represents an activity involving the interaction of a data acquisition system, a data processing system, and data inputs to and from the controller with the controller directing aircraft movement by voice via a standard radio link.

Most of the Control Functions involve the provision of advisory notices (Flags) to the controller and controller-to-machine indication of action taken. However, a need for function verification has been identified, i.e., an aircraft is indeed following instructions as given by controller. This verification can be performed as at present, i.e., visual verification by controller or by machine process, viz A/C does not move with "T" seconds, A/C moves after "Hold" instruction, etc.

The performance requirements of all eight control functions are discussed with technical analyses of certain aspects of requirements provided in the Appendices. These aspects are estimates of required accuracies for the DAS sensors, the minimum GCS response time for recognition of conflicts, etc.

The GCS response time represents the interval between the time an event actually happens and the time it can be recognized by the controller. This will vary with the particular type of indication used, i.e., it is expected to be different for Movement Detection as contrasted with Link Occupancy. Transition of an A/C from a "stopped" condition to a "moving" condition may be easily recognized almost immediately under visual conditions. Using surveillance sensors, algorithms must be established to define "movement"; the approach taken has been that an aircraft moving at less than a specified threshold speed is considered as "stopped". The GCS response time for this component would then be defined as from the time the aircraft speed actually dropped below this threshold value to the time this data element was available to the controller. In general, GCS response times of from 2 seconds to 3 seconds have been specified since overall system response time considerations indicate prediction intervals of from 15 seconds to 30 seconds are of most significance in the control process. Where non-critical functions are involved, the GCS response time may be relaxed to 4 seconds to 7 seconds. Tradeoffs can be made between GCS response time and sensor performance requirements; these should be considered in the examination of specific sensor and display approaches.

4.2.3.2 Release of Departure Aircraft (Function A)

This function includes monitoring the status of the Ground Control Departure Q, i.e., those aircraft "demanding" entry from the ramp area into the taxi system, as well as the processes actually involved in release of A/C into the taxi system.

Acquisition by the sensor system may be desirable for those aircraft at the "head" of each sub-queue although this may pose special resolution problems. An alternate method would rely on acquisition after the aircraft starts to move out onto its first link.

Interface with the Ramp Control System is necessary to establish A/C ID, ramp areas, and time of entry into the GC Departure Q. Monitoring of the GC Departure Q is essentially a "housekeeping" function which can readily be performed by a computer in a manner that should simplify the current handling and monitoring of flight strips by the Outbound Ground Controller and Clearance Delivery position.

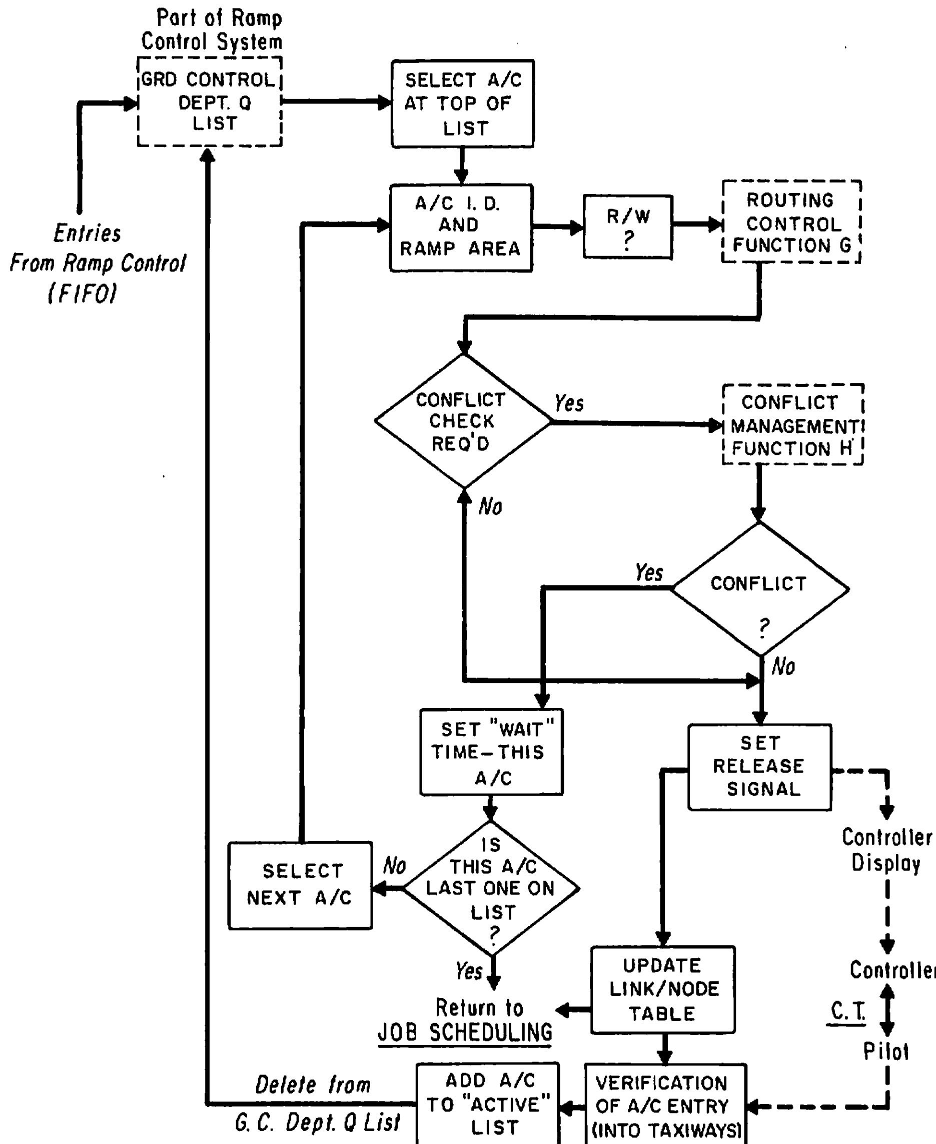
Release of a Departure A/C from the Ground Control Departure Q into the taxiway system is a function interacting with several other functions, namely G and H. Function G (Routing Control) requires the controller to assign a departure R/W as well as a taxi route to the departing aircraft. The performance of this function is not very time sensitive, i. e., it could be performed before (one minute to two minutes perhaps) the actual release of the aircraft. On the other hand, performance of Function H (GCS Conflict Management) must be done in real time with a minimum of delay. Accomplishment of this "merging" of aircraft with nearby traffic will be examined under Function H; this type of conflict will be defined as a "Ramp Exit Conflict". Successful completion of Functions G and H permits the controller to release the aircraft into the system. It is now the "job" of the sensor data processing equipments to recognize (i. e., begin track) entry of this particular aircraft into the taxi system. A logic flow diagram representing activities to be performed during this function is shown in Figure 4-2.

Recognition of A/C entry onto the taxiway could be accomplished in a variety of ways. These include:

- A "passage" detector at the ramp exit
- Movement detection on the designated R/I link
- Position detection on the R/I link (Link Occupancy)
- Combination of some of the above

As shown in the Appendices, the R/I links are short at O'Hare and aircraft exit speeds are expected to range from 5 knots to 10 knots. The time available for acquisition and recognition of entry does not appear critical; a response time of 4 seconds to 7 seconds for an individual Departure should be acceptable for verification of entry. It should be noted, however, that in many cases aircraft are released from a ramp area in "batches" and that this factor will play a role in the update interval.

After permission to taxi has been given, the sensor system must verify entrance of the aircraft into the taxi system. After initial acquisition of the target, position information of sufficient accuracy should be available to recognize that the aircraft has indeed moved out onto the designated R/I Link. If an aircraft standing clear of the R/I link accelerates at 0.1g to 7.5 knots (estimated ramp taxi speed) and then maintains that velocity, it will cover 38.3 feet in five seconds. If a link



NOTES:

1. FIFO Service to Various Ramp Areas
2. Multiple Departures from One Ramp Area may Affect G C. Dept Q Order
3. Ramp Areas with Dual Nodes Expected to have Slightly Different Logic

Figure 4-2. Logic Flow Diagram for Release of Departures into Taxiway System (Function A)

occupied test is defined as measured position (x_s) $\geq$ 19.2 feet and the position error is normal with zero mean and standard deviation of 9.6 feet, then an aircraft at 38.3 feet (i.e., five seconds into the link) will indicate link occupancy with 97.5 percent certainty and an aircraft clear of the link will indicate link occupancy (i.e., false alarm) only 2.5 percent of the time. With a modest sample rate (e.g., two seconds) worst case detection time is seven seconds satisfying the 4-7 second specified. If position is sensed every 0.1 seconds and measured position is computed each 25 samples with a first order filter (see Appendix D) then the single sensed position accuracy requirement can be relaxed to 25 feet (9.6/.38) and the worst case detection time is 7.5 seconds.

If Movement Detection of this aircraft (rather than Link Occupancy) is used, similar position accuracy and detection time as above is required (see Appendix D).

4.2.3.3 Handoff to Local Control Departure Q (Function B)

Under present procedures the Outbound Ground Controller will "handoff" a Departure aircraft after it has passed the last node before the Local Control Departure Q area. Since these links are relatively long for most Department Q areas, the "handoff" time is not critical. It should of course take place sufficiently before the Departure Q area so that Departures can be handled expeditiously by Local Control if no Departure Q exists. This method of operation is based upon the premise that no further taxiing conflicts can arise.

For the South runways at O'Hare these "last" links are as follows:

Runway	Final Link	Approx. Link Length
4R	S16/Y18	> 1000'
9R	S14/Y12	> 1000'
14R	S1 or S2/Y1	900/>1000'
22L or 27L	S11/Y17	> 1000'
32L	S15/Y12	900'

Similar lengths exist on the North side except for 9L where the "last" link is about 500 ft long after the intersection of the New Scenic and the 9L/27R parallel. Using a minimal estimated taxi speed of 12.5 knots, an aircraft will have moved onto the last link by 150 feet in seven seconds. With position detection rationale as in paragraph 4.2.3.2 a standard deviation on measured position of 37.5 feet would provide 97.5 percent probability of detection, 2.5 percent probability of false alarm, and a worst case detection time of $7 + T_S$. A 7-10 second detection time requirement could be met with modest data rates (e.g., $T_S = 2$ seconds).

4.2.3.4 Formation and Monitoring of Ground Control Arrival Q (Function C)

The Inbound Ground Controller has responsibility at O'Hare for two categories of aircraft. One category consists of aircraft at hangar areas wishing to taxi to the ramp areas or those in the Penalty Box and are now ready to leave. The other category is landing aircraft which are handed off to the Inbound Ground Controller from either one of the two Local Control positions. It is this latter category which must be handled rapidly. Operational factors involved in the "handoff" process from Local Control which must be considered include:

1. Selection of a particular R/W turnoff is the pilot's responsibility, not the controller's.
2. In the present system it appears that the Local Controller will perform the handoff on an anticipatory basis, i.e., while the plane is still partially on the runway or near a turnoff which the Local Controller believes will be used by the pilot. While this approach is desirable for minimizing "handoff" delays, it could possibly result in runway conflicts.
3. Communications between pilot/ground controller must be confirmed at handoff. A position report is usually given by the pilot at this time.
4. A "landing" aircraft takes from 30 seconds to 40 seconds from runway threshold to turnoff. During most of this period this particular aircraft must be considered as demanding "service" at all R/W turnoffs (except of course those already passed). Measurement of aircraft position and velocity data for prediction purposes during R/W deceleration can permit reduction in the number of potential "turnoffs" that could actually be used by the landing aircraft.

5. Potential conflicts between aircraft entering turnoffs are most likely to occur with the preceding landing aircraft which is taxiing down the associated parallel taxiway (turnoff-generated conflicts).

6. Both "high speed" and "low speed" R/W turnoffs must be considered. The former intersects the runway with turnoff angles as low as 30 degrees while the latter have intersecting angles near 90 degrees. This factor can be significant in detecting "Turn Recognition" as a means of formation of the Ground Control Arrival Q for landing aircraft. Aircraft velocity at turnoff is expected to vary somewhat for these two cases.

7. The responsibility for runway status monitoring, or recognition that the runway is clear or occupied, belongs to the Local Controller.

8. For some runways (primarily on the North side of O'Hare) the Local Control does not "handoff" the aircraft to Inbound Ground Control at or near the R/W turnoff point. He will actually perform taxi control until the landing aircraft has been brought across other active runways.

To perform Function C it is recommended that "Arrival" aircraft from hangars be handled as "popups" and entered into the Ground Control Arrival Q on a manual basis since in many cases beacon codes must be assigned and temporary (not flight numbers) aircraft IDs are employed. Aircraft reentering the taxi system from the Penalty Box are simply reacquired as they leave the staging area. Entry of landing aircraft, on the other hand, into the Ground Control Arrival Q may be performed manually (as at present) or automatically. In the automatic case a sensor system would recognize perhaps an aircraft turning at a particular R/W turnoff (Turnoff Recognition) or occupancy of the turnoff link (Link Occupancy).

A logic flow chart for this function and the succeeding one (Function D - Acceptance of Arrival A/C) is shown in Figure 4-3; this also depicts the interfacing functions of Routing Control and GCS Conflict Management. The results of the Operations Analysis effort at O'Hare showed that in almost no cases (8 out of over 700 arrivals) is an aircraft "held" at the turnoff link. It is believed that this policy

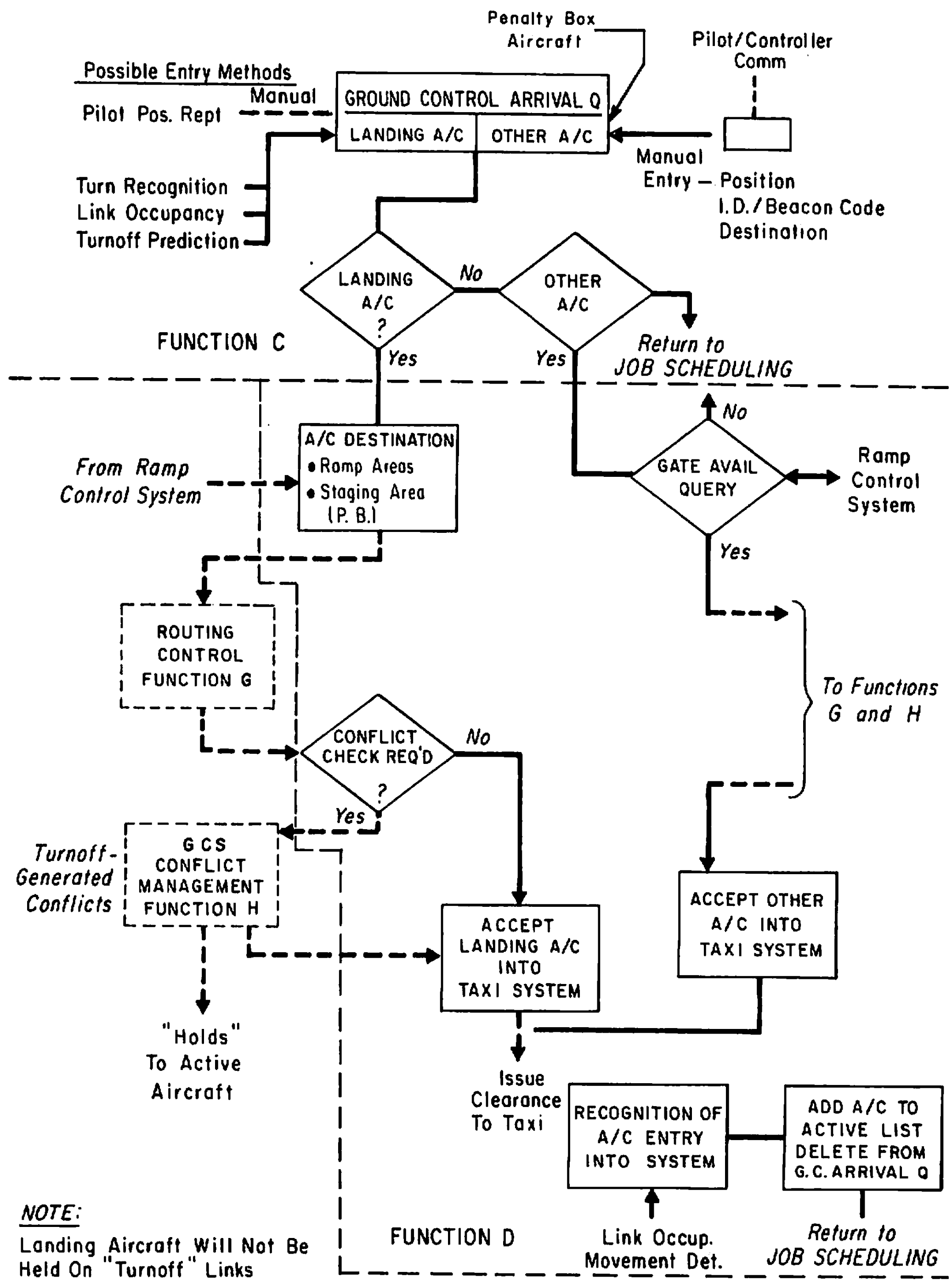


Figure 4-3. Logic Flow Diagram for Entry of Arrival Aircraft (Functions C and D)

is followed in order to expedite the aircraft off the runways. The Inbound Ground Controller, therefore, if a conflict does exist with an aircraft taxiing on the associated parallel, must issue a "Hold" instruction to this aircraft in order to clear the landing aircraft into the taxi system at turnoff as soon as possible. It is therefore highly desirable to recognize entry into the Ground Control Arrival Q (GCAQ) as soon as possible. Turnoff Recognition or Turnoff Prediction, therefore, appears more desirable as a recognition of this event than does occupancy of the turnoff link.

After the Inbound Ground Controller has issued taxi clearance (and routing) to the landing aircraft, the sensor system should confirm (as was done for ramp area departures) actual entry into the taxi system; i.e., the aircraft becomes an "Active" user of the taxi network.

If Turnoff Prediction is used as a method for early recognition of "demand" for taxiway service by landing aircraft, the estimation techniques of Appendix E may be used to obtain required position and velocity accuracy of sensor data when the aircraft is braking on the runway. Using pre-turnoff speeds of 30 knots to 60 knots (50-100 fps) the error in Turnoff estimate due to Position error is

$$\sigma t_1 = \frac{\sigma_x}{V}$$

while that due to the velocity error is

$$\sigma t_2 = t \frac{\sigma_V}{V}$$

where t is the prediction time interval. If σt_1 and σt_2 are taken as 2 seconds, then $\sigma_x = 50\ (2) = 100$ ft for V = 30 knots and $\sigma V/V = 2/15 = 0.13$ or $\sigma_V = 0.13\ (50) = 6.5$ fps. These values represent performance requirements imposed on the Local Control System because of its interaction with the Ground Control System and are not shown on Table 4-1.

4.2.3.5 Acceptance of Arrival Aircraft (Function D)

As described in the previous section landing aircraft must be immediately accepted into the taxi system. The sensor system to verify entry may be used to recognize aircraft heading change (Turn Recognition) near the turnoff point. Alternately, position data may be used to determine link occupancy on the Runway/Taxiway Turnoff Link. The former technique may offer certain advantages in a position measurement system having unequal errors in the two coordinates although higher sampling rates may be required. The Turnoff links are longer than the R/I links and higher taxi speeds will be used. If Link Occupancy is used as the verification criteria and the exit velocity is estimated at 30 knots then using position detection rationale as in paragraph 4.2.3.2 a standard deviation on measured position of 25 feet will provide 97.5 percent probability of detection, 2.5 percent probability of false alarm, and a detection time of 2-3 seconds with modest data rates (e.g., T_S = 2 seconds). It is estimated that the GCS response time for this function should be two seconds to three seconds.

4.2.3.6 Penalty Box/Staging Area Management (Function E)

Arrival aircraft which must be "held" in the Penalty Box or other staging areas because of gate unavailability or related reasons are handled somewhat differently by the Inbound Ground Controller than aircraft which are "held" because of conflicts. In the latter case the controller and/or the Ground Control system will be able to determine the end of a conflict and therefore the need to change the aircraft from a "Hold" condition to an "Active" or moving status. The time at which an aircraft is ready to leave the Penalty Box or staging area must be furnished to the controller either via communications with the pilot or possibly via the Ramp Control system.

The Penalty Box at O'Hare is approximately 500 feet long and therefore can be used as a staging area for perhaps two to four aircraft depending on equipment type. It has two entrance/exit nodes and is located fairly close to the ramp areas.

The staging areas may be considered as the initial destination of those landing aircraft which do not have a gate and the designated (by the controller) taxi route is given on this basis. Recognition of aircraft entry into the Penalty Box by the sensor/data processing system essentially completes the initial handling of this aircraft; at this time the aircraft may be considered as moving into a non-active status, i.e., into the Penalty Box Q.

Demand by the pilot for release from the Penalty Box necessitates that the Inbound Ground Controller (and Ground Control system) perform a release function similar to that of Function A, i.e., both Conflict Management and Routing Control will be involved. If these are satisfied, permission to depart from the Penalty Box can be given via the voice link. It may be desirable, because of the relatively short distance between the Penalty Box and the ramp area, to interpose one additional step before permission to taxi is given. This step would be a check of the status of the particular ramp area to determine that it is not blocked by several departure aircraft.

Recognition of aircraft departure from the Penalty Box must next be performed by the sensor/data processing system in order to verify that the control function has been complied with. Control of aircraft within the Penalty Box area is not currently envisioned as a semi-automated function.

For those delayed aircraft which are placed in staging areas other than the Penalty Box (such as the cargo taxiway for certain runway configurations) recognition of the entry to and exit from this condition can be most readily performed by movement detection (start/stop) in the designated "Hold" area. Application of this method within the Penalty Box may impose more stringent resolution requirements on the sensor system than at most other points in the taxi network. Link (or node) occupancy at the two Penalty Box transitions possibly supplemented by route history data or movement detection should be sufficient to support the Penalty Box Management function.

The exit/entrance dimensions near the Penalty Box as well as anticipated aircraft speeds are expected to be similar to those of the Ramp Exit Function A. Entrance verification response times of 7-10 seconds to temporarily end service should be adequate. In seven seconds an aircraft moving at a typical ramp speed of 7.5 knots will travel 90 feet into the penalty box. With position detection rationale as in paragraph 4.2.3.2 a standard deviation of 25 feet would provide 97.5 percent probability of detection, 2.5 percent probability of false alarm and a detection time of 7-10 seconds with modest data rates (e.g., $T_S = 2$ seconds). Exit verification response times and accuracy requirements are similar to those of verifying entry into the taxiways from the ramps (Function A).

Figure 4-4 illustrates the operational logic for this function.

4.2.3.7 Interface/Handoff to Ramp Control (Function F)

Arrival aircraft entering the ramp area at O'Hare currently do not "sign off" the Inbound Ground Control channel; it appears that the entrance event is visually recognized by the controller and the aircraft is crossed out on the scratch pad he uses to keep track of "Inbounds". Arrival aircraft, in many cases, cannot enter most ramp areas if a "Departure" is in "pushback". This type of scheduling conflict is one of the most prevalent at O'Hare and explains why so many of the "Holds" occur in the vicinity of the Inner and Outer Circulars. While under the present day system the Tower Controllers do not have responsibility for the ramp area, it can readily be seen that they cannot perform their function of taxiway management unless they are cognizant of the status of the various ramp areas, i.e., their availability for a particular arrival.

A preliminary logic diagram for this function is shown in Figure 4-5 wherein "Arrival" aircraft within "X" feet (or a certain time - perhaps 20 seconds to 30 seconds) of ramp entrance may be considered as requesting usage of the particular ramp. This information probably should be supplied to the Ramp Control system for scheduling control of "pushbacks" and other "Arrivals". Initial check of ramp area availability may be made by checking the status of the Ground Control

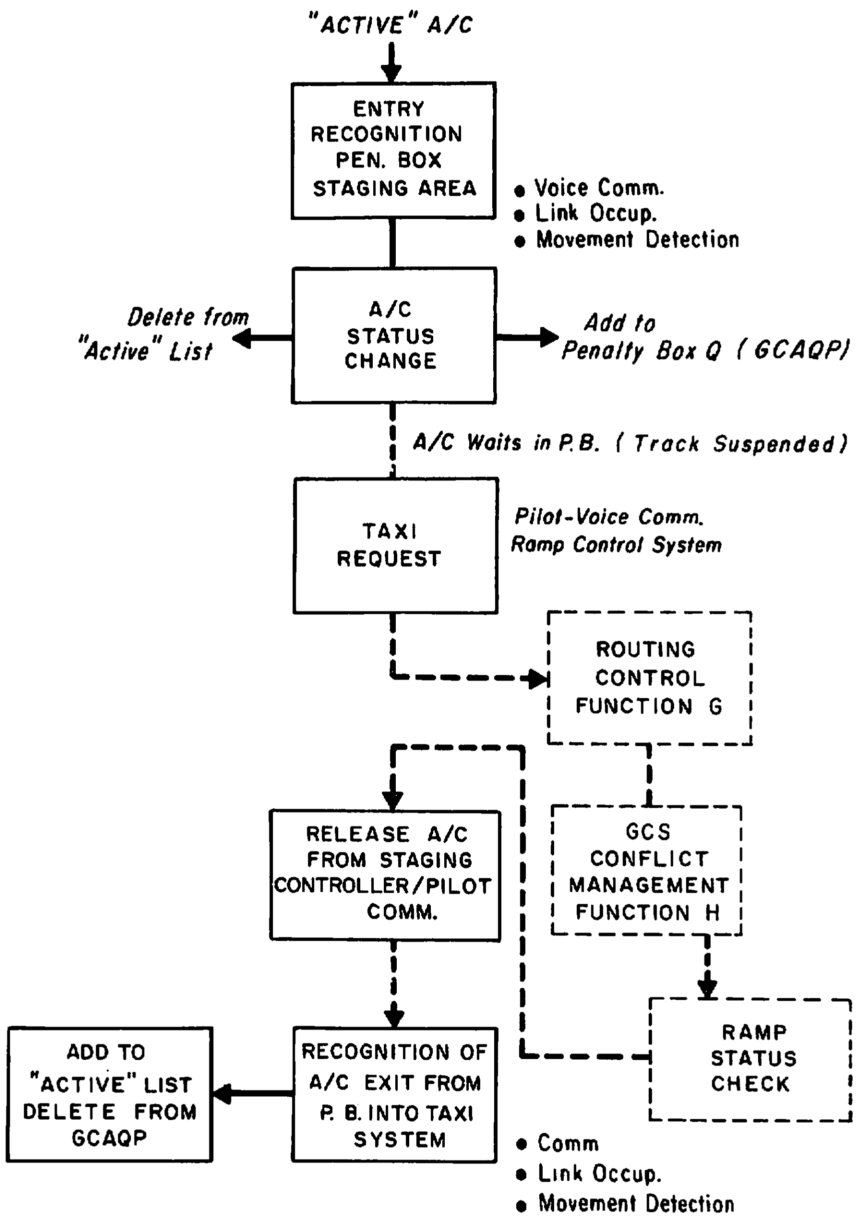


Figure 4-4. Logic Flow Diagram Penalty Box/Staging Area Management (Function E)

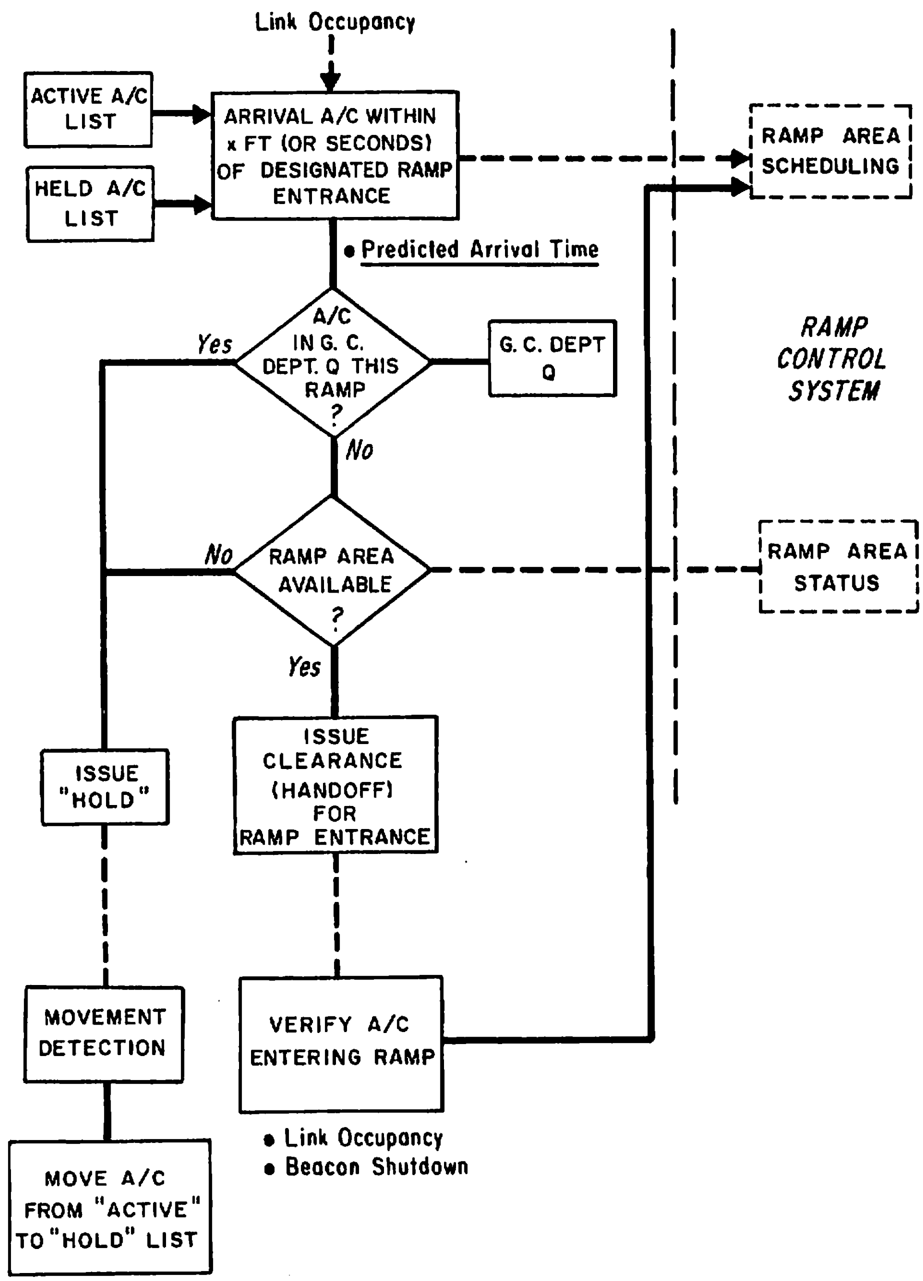


Figure 4-5. Logic Flow Diagram for Interface/Handoff to Ramp Control (Function F)

Departure Q. However, this is not sufficient to establish ramp area availability and it is envisioned that the Ramp Control system should have the capability of providing status information to the Ground Control system that will permit an availability decision to be performed.

If the ramp area is unavailable a "Hold" instruction must be issued and the sensor system should recognize compliance with this instruction. If the ramp area is available, a clearance/handoff may be issued or the lack of a "Hold" instruction can be interpreted by the pilot (as is done at present) that the ramp area is available. Verification of the event that the arrival aircraft is proceeding into the ramp area should be made prior to the last location at which the arrival aircraft can be "held". This location might be on one of the Inner Links immediately preceding the R/I link to be used by the "Arrival", or possibly the I/O link directly outside of the ramp entrance. The occurrence of this situation should be furnished to the Ramp Control system for scheduling purposes.

While taxiway routing requirements for "Arrivals" are such that only the ramp area must be specified, the handoff function can be most expeditiously performed if specific gate information is available. For example, departure aircraft close to the main terminal buildings and in "pushback" would not block "Arrivals" with gates farther out on the concourse fingers. It appears, therefore, that the interface/handoff function may impose on the Ramp Control system the necessity of some type of "block" or space availability estimation within the narrow, and often crowded, ramp areas.

Sensor requirements for recognition of entrance demand, since prediction of entrance time is desired, are not stringent in terms of position.

We have chosen a value between 50 feet and 100 feet which should have only a small impact upon the estimated ramp arrival time. Measurement of the existing velocity of the aircraft, except for movement detection purposes, cannot be really used for prediction purposes due to time variations arising from "turns," "braking," etc.

4.2.3.8 Routing Control Function G

The operational logic for the Routing Control function is shown in Figure 4-6. The three major components of this process are those of Route Selection, Route Issuance, and Route Verification. Route Selection depends upon the particular runway configuration in use, the origin and destination of the taxiing aircraft, and, in some cases, the aircraft equipment type. Standard routes are used in most cases by the Inbound and Outbound Ground Controllers; these have been described in the previous working paper on this contract. Issuance of the route (and confirmation by the pilot that he understands it) takes place via voice communications.

While it is desirable that verification of the specified route be performed by the Ground Controllers, this in many cases is extremely difficult because of the aircraft load; therefore, extensive reliance is placed upon the fact that pilots are quite familiar with the taxiway network at O'Hare. It should be noted that, as part of our survey effort of visual guidance equipment at O'Hare, there are only a limited number of signs that actually indicate to a pilot where he is; most signs provide destination type rather than location information.

The designated route for a particular aircraft can serve a major role in the conflict management function; specifically it would be used for conflict detection purposes. Without this data, appreciably more data processing would be required for the conflict detection "job".

In the semi-automated system it can be seen that a major problem in inputing route data will exist if it is required that the controller enter this data at the time it is issued to the pilot. An alternate approach, whereby the information in the data base is presented to the controller for a particular operation and he then selects one of perhaps two computer-displayed routes via a binary entry device, appears to be a more desirable mode of operation which is compatible with the needs of a semi-automated ground control system.

It is envisioned that the surveillance sensor data will be utilized for monitoring the actual route followed by either the Arrival or Departure aircraft.

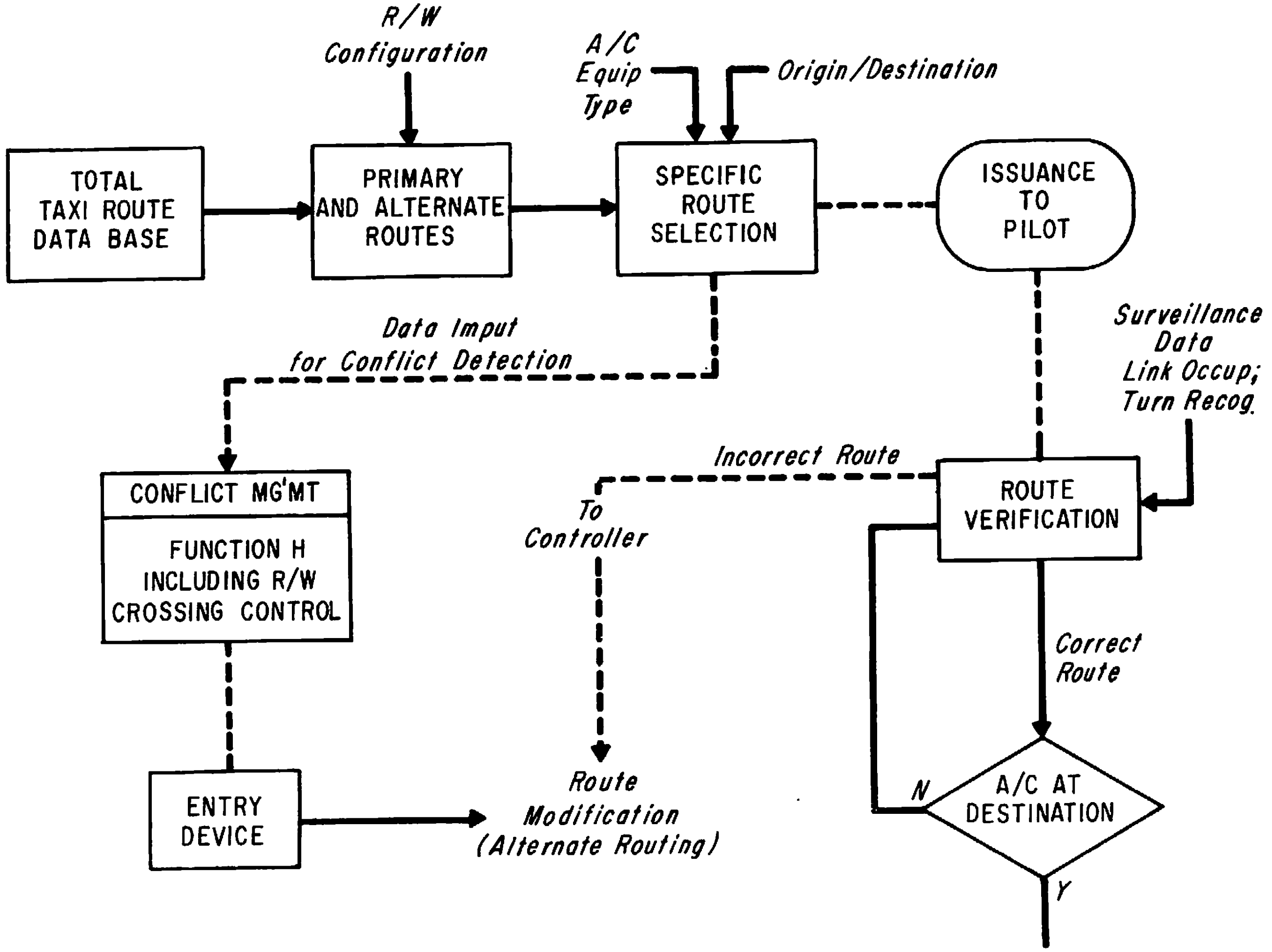


Figure 4-6. Logic Flow Diagram for Routing Control (Function G)

Upon recognition that an incorrect route is being followed by an aircraft, a flag of some type will call this event to the attention of the controller. At this time he will then take the appropriate action which may involve a keyboard entry device of some type for route modification purposes. Moreover, since the specific turnoff of an arrival from a runway cannot be firmly established until effected, this may impact on the route to be followed by Arrival aircraft. Such a situation may require an input either by the controller or from the data processing system of the actual turnoff exercised by the incoming aircraft. The "Turnoff Recognition or Prediction" function performed here as part of the Local Control System (at handoff), or as part of the Ground Control System, can then serve as an input to the route selection process for arrivals.

In estimating the positional accuracy required by route verification, the criteria used is to assure link detection (clear of the intersections at both ends) for most of the links for which sole link occupancy is possible. These links are represented largely by the O/O and S/O taxiways (see Appendix A). The O/O are largely over 600 feet long and the S/O range from 400-700 feet. If a length of 550 is chosen as representative then an accuracy of 20 feet (see Appendix C) is adequate with modest sampling rates.

4.2.3.9 GCS Conflict Management (Function H)

Conflicts may be defined as those situations wherein there is an apparent demand for the same facility (i. e., link or node) by two or more aircraft overlapping in time. Actual conflicts, of course, will almost never occur; while in most cases they are resolved by the controller, the pilot of either aircraft can be expected to take the necessary evasive action, i. e., stop, slow down, request instructions, etc.

Conflicts for use of taxiway facilities may occur between two taxiing aircraft or may arise between a taxiing aircraft and aircraft "in" the interfacing Local Control and Ramp Control Systems. R/W Crossing Control, wherein the crossing node is time shared by both the Local and Ground Controller, is an example of the latter. Other examples may occur due to Ramp Area activity, i.e., the release of aircraft from the Ground Control Departure Q (or Ramp Area) must consider nearby taxiing aircraft. A similar situation exists for Function F (Interface/Handoff to Ramp Control) wherein Ramp Area availability may necessitate a taxiway "Hold".

The Conflict Management function may be considered to comprise several subfunctions as follows:

- Conflict Search and Recognition
- Presentation of Situation to Controller
- Resolution Verification
- Monitoring of Ongoing Conflicts

We have previously identified five types of conflicts which occur in the Ground Control System. Of these only the Taxiway/Taxiway conflict is non-deterministic in nature; all other conflicts can occur only because an aircraft is demanding a specific type of service. A summary of these conflict types is given in Table 4-2. The semi-automated system concept is based upon the premise that Conflict Resolution is performed in all cases by the controller. The accomplishment of the other component of Conflict Management will depend upon the particular conflict involved. These factors are discussed separately below for each of the five conflict types.

Table 4-2. Summary of Conflict Types (Ground Control System)

Conflict Type	Priority Aircraft	Conflict Effect	Relative Occurrence
Ramp Exit	Taxiing A/C	Delay to Departure	Medium
Taxiway/Taxiway	-		Low
R/W Crossing	Landing A/C	Delay to Taxiing A/C	Medium (R/W Configuration Dependent)
Turnoff-Generated	Landing A/C	Delay to Taxiing A/C	Low
Ramp Entrance	Ramp Departure	Delay to Arrival	High

4.2.3.9.1 Ramp Exit Conflict (Function H-1)

Upon recognition of "demand", i.e., an A/C in the Ground Control Departure Q, it is necessary to perform a Conflict Search of the "Active" Aircraft in the immediate vicinity of the particular Ramp Area. If there are "Active" aircraft (moving) in a manner that would conflict with the Departure aircraft, this situation could be presented to the controller so that he would recognize the end of the conflict and release the Departure. Alternately, a "denial" signal could be presented to the controller which would change to a "Go" signal upon end of the conflict. Prediction of future position of the taxiing aircraft (causing the scheduling type conflict) would be required.

4.2.3.9.2 R/W Crossing Conflict (Function H-2)

This conflict can only occur if two events are satisfied, i.e., an aircraft is "close" to crossing a R/W and an aircraft (under Local Control) is within "X" seconds of the R/W Crossing. Conflict search and recognition based upon runway surveillance data need only be performed when necessary. This particular type of conflict involving only two aircraft appears readily suitable for a GO/NO-GO type display.

4.2.3.9.3 Taxiway/Taxiway Conflict (Function H-3)

While this type of conflict seldom occurs it does impose the greatest surveillance load upon the controllers in the present system. Being non-deterministic it is necessary to continually perform a search for potential conflicts for all "Active" aircraft. This search rate should be such that it does not unduly penalize the system response time. If a one-second search rate is employed and there are, say, 15 Active aircraft "in" the Ground Control System, then all possible pairs of conflicts, i.e., $\frac{15(14)}{2} = 105$ would have to be examined every second in a system without other control logic. This number, of course, can be substantially reduced by using location algorithms, etc., so that only pairs of aircraft within a certain distance of each other or at a given location are evaluated. In fact, this criteria should probably be employed in controlling the surveillance activities. Upon recognition of a conflict of this type, the situation may be displayed to the controller in a manner perhaps showing the predicted position of each aircraft involved in the projected conflict over the next 15 seconds to 25 seconds. Upon the controller taking action, i.e., "holding" an aircraft, it is envisioned that the surveillance system would recognize that one of the aircraft has stopped (Movement Detection).

Monitoring of on-going conflicts is essentially a subfunction directed toward recognition of the end of a conflict (scheduling or otherwise) so that an indication may be given to the controller that a "Hold" aircraft must be changed into an "Active" status.

While further effort is required in this area to define the necessary surveillance requirements, the results given in Appendix E indicate that values of σx of 50 ft will result in prediction time errors of about 2 seconds. Measurement of present velocity of the aircraft does not appear to be a significant parameter for prediction of future A/C position because of acceleration/deceleration effects over the prediction period of 15 seconds to 30 seconds. It is currently believed that, if the aircraft is recognized as "moving", estimated taxi velocities can be assigned to the aircraft depending upon its location. For example, in the Inner/Outer area a nominal taxi speed of perhaps 12 knots would be used for conflict estimation purposes. On links closer to the runways values of taxi speed of 20 knots to 25 knots might be used.

Aircraft on the same highway, i.e., maintaining headway between each other, would not be considered to be in conflict since this is the pilot's responsibility. This should substantially reduce the number of apparent conflicts.

4.2.3.9.4 Turnoff-Generated Conflicts (Function H-4)

These are very similar to those of the R/W Crossing type with the exception that the actual turnoff cannot be positively estimated in advance. "Turnoff Recognition", i.e., change of heading of the landing aircraft, may be an event which could trigger this conflict recognition process. Aircraft on the parallels in the vicinity of the turnoffs would then be presented to the controller who would inform them to "hold" if necessary. It is not expected that this conflict will occur often. Alternately, the situation existing on the runway/parallel could be presented to the Ground Controller when the landing aircraft's speed had dropped below, say, 60 knots. This would indicate whether any action was required. Acceptance of the landing aircraft into the taxi system (Function D) and recognition thereof would indicate the "end" of this type of conflict.

4.2.3.9.5 Ramp Entrance Conflict (Function H-5)

This conflict is caused by Departure A/C in the Ramp Area essentially making it unavailable for an Arrival aircraft that is within perhaps 30 seconds to 45 seconds of entry. It is primarily a scheduling problem which occurs often and has been discussed under Function F. It is not envisioned that this type of conflict will impose stringent requirements upon the surveillance needs of the Ground Control System. However, it will impose additional requirements on the Ramp Control System, i.e., the need to distinguish between Arrivals and Departures and possibly the desirability of recognizing approximate location (in the Ramp area) of Departures in the Pushback mode.

4.2.4 Operational Requirements

The principal operational requirements that have to be satisfied by the semi-automated, real-time Ground Control System are:

1. Compatibility with the current Tower Ground Control procedures and methodology.

2. Output indications to aid and augment Ground Controller performance and reduce Ground Controller workload.

3. Output indications to permit safe and efficient control of aircraft under visibility conditions in which the pilot can see to taxi but controller's visibility is limited.

4. Output indications are to be in the form of displays oriented to the specific function to be performed, i. e., selective vs all inclusive.

5. "Job" scheduling primarily arranged by the Ground Control System, not Controller. Controller to have override capability.

6. The Ground Control System must operate satisfactorily with the maximum peak aircraft traffic load.

During normal (daytime) weekday hours under good weather conditions the hourly aircraft load on the total GCS at O'Hare has been found to range from 8 to 12 (aircraft-hours per hour) although a peak value of 15. 4 was observed during the survey efforts. These values occurred during airport operational rates of 120-140/hour. These values do not include A/C awaiting entry into the taxi system (at the R/Ws or Ramp areas) nor do they include A/C in the Local Control Departure Q area. Previous studies have shown that the ratio of short term "peaks" over a 5-minute interval with respect to the hourly load may range from 1. 5 to 2. 0. Translation of the above to an operational level of 200 operations/hour gives hourly "load" values of $\frac{300}{100}$ x 13 (an estimate) or 20; in peak 5-minute periods, 30-40 aircraft would be "in" the system either taxiing to or from the ramp. in the Penalty Box, or in a "Hold" condition. As a check on the above conclusions the following analysis may be compared with the above.

If it is assumed that A/C movement on the airport past fixed points or segments can be modeled by a Poisson distribution, then at 99. 6 percent probability no more than 4 A/C (or a queue of 3) will be attempting to pass at one instant of time.

If also the airport is working fairly smoothly at maximum capacity (probably no more than 200 operations/hour at O'Hare) the above conditions can be expected to occur over all major elements of A/C movement, i. e., expected A/C densities are:

Ramp Departure Queues	3	
Departures, Inner/Outer	4	
Departures, Taxiways	8	(2 RW)
RW Departure Queues (Local Control Departure Q)	6	(2 RW)
RW Effective Occupancy	4	(4 RW)
Arrivals, Taxiways	8	(2 RW)
Arrivals, Inner/Outer	4	
Arrivals, Staging Area	3	
Total	40	

For individual controller positions, these totals relate to:

Arrival Ground Control	15
Departure Ground Control	15
Local Control North	5
Local Control South	5

From the above it is estimated that the GCS should be capable of maintaining "track" on about 50 aircraft (25 percent margin) at one time.

In addition we are interested in the rate at which tracks must be established. Tracks must be initiated for:

A/C Entering from Ramp Area	90-100/hr.
Arrival A/C	
Landing/Turnoffs	90-100/hr.
Hangar/Popups	10-20/hr.
Penalty Box Exits	10-20/hr.
Total	240/hr.

Special needs (other vehicles, reacquisition, etc.) may be expected to increase this by 25 percent or to 300/hr. In a peak minute this would be $\frac{300}{60} \times 20$ or 10 track initiations/minute.

4.3 MODULE DESCRIPTION

4.3.1 Overall Characteristics

The GCS Module involves a Data Acquisition System (DAS), a Data Processing System (DPS) and inputs/outputs to and from the Controller via Displays and simple keyboards as shown in Figure 4-7.

The DAS can be a single scheme such as GEOSCAN or an integration of separate elements. However, it should respond to "Job" scheduling demands of the DPS and provide A/C data as required.

The DPS provides all the machine elements of the Control Functions and data for displays to the Controllers and accepts Controller Action indications. In addition, the DPS interfaces with the RCS and the LCS by maintenance of A/C files as the A/C moves between control of the three modules.

Controller displays are to be based upon the discrete requirements of the controller position, i.e., Arrival vs Departure. Typically two displays are envisioned, one an alpha-numeric display indicating A/C awaiting entry from the LCS or RCS together with a simple A/C file of A/C in the system; and a schematic display for conflict situation presentation. A highly simplified controller entry device is required to indicate controller actions: A/C entry acceptance, "Hold" instruction, handover, etc., plus features for overriding the "Job" scheduling feature of the DPS to obtain a display of any specific airport surface area.

While this description of the Ground Control System has been based upon the use of a single data processor, integration of this system with the similar LCS may be feasible permitting the use of a single processor for use of both systems.

4.3.2 Interface Considerations

The GCS must interface with the RCS and the LCS. Interfacing with the LCS will involve the interchange of A/C data for computing safe conditions for Runway Crossing Control, and Handoff A/C file data for A/C transferring under control between the two systems.

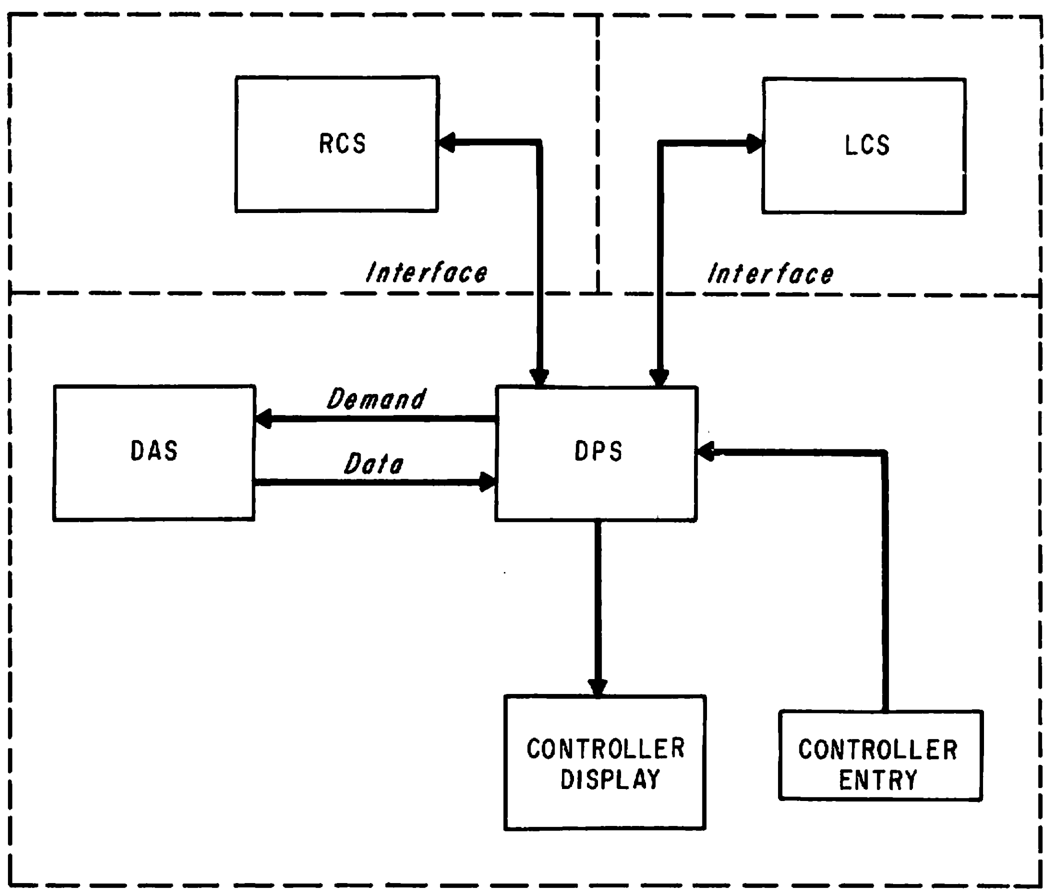


Figure 4-7. GCS Module

Similarly an interface is required between the RCS and the GCS. In this instance arrival A/C files require data from the RCS as to whether the destination is clear or whether routing to the Penalty Box is required. For this feature the GCS processor must supply the RCS with expected time of the arrival A/C at its destination.

For departure aircraft the RCS must enter RTT A/C files into the Departure Q of the GCS.

4.4 BENEFIT ANALYSIS

4.4.1 General

The major benefits derived by the GCS are keyed to controller workload especially under poor visibility conditions. By reducing controller workload through the implementation of a semi-automatic system the controller can:

1. Devote more time (judgment) to individual conflicts requiring his attention.
2. Maintain alertness for potentially dangerous situations.
3. Work under high stress conditions with reduced mental fatigue.

The above factors probably will produce situations of reduced aircraft delay under peak traffic load and certainly improve safety and efficiency.

Under poor visibility conditions controller workload will be further reduced as the controller will not have to continually call A/C for position reports as is currently done. In addition, the feature of automatic A/C route verification produces a level of safety not available in the current system.

Under poor visibility conditions, the current controller workload increases because:

- Departure queues become extensive, causing blocking of Inner and Outer Links.
- Controllers increase use of "Holds" for safety purposes and resolution of taxi conflicts due to long departure queues.

- Controllers may not have normal visual access to A/C and may have to resort to Pilot Position Reports and/or ASDE interpretation.
- Normal traffic disruption interfering with Gate Scheduling causes increased Penalty Box Staging of arrival aircraft.

In addition the visual displays currently under consideration for the GCS will be functionally oriented (i. e., selective) so that only that information needed for the particular function is displayed. This selective process is envisioned as providing capabilities for display of portions (ramp exit/entrance area; R/W crossings area, turnoff area, etc.) of the airport as the need arises. This selective process coupled with the availability of A/C ID should permit substantial improvement in the control process under poor visibility conditions. As will be shown later in this section, the controller workload is expected to be reduced by about 30 percent in conditions of good visibility; the reduction in poor visibility should be even greater.

The current extensive controller requirements of A/C position reports by radio communication transactions will no longer be required with the semi-automatic system, and "lost" aircraft situations will be automatically reported to the controller.

The compatibility requirement intimates that operations with the GCS will incorporate much of the same methodology, radio communication discipline and protocol, and flight strip handling (for departure aircraft) as is in use at present.

Controller performance augmentation is to be achieved through a display system that automatically alerts the controller to:

Potential taxiing conflicts

R/W turnoff conflicts

Lost aircraft situations

R/W crossing requirements

Handover situations

Presence of aircraft in Ground Control Departure Q and status of Ramp Exit Areas (Ramp Exit Conflict)

4.4.2 Workload Reduction

While controller/pilot communications represent a substantial part of the controller's work load (and is readily measurable), the data collection (primarily visual surveillance) and interpretation portion of the controller's activities are of primary significance in establishing how well he can perform the various control functions. The controller can do some scheduling, or selection, of which function is to be done next, i.e., he can defer a "Handoff" if a higher priority function needs his attention. However, the scheduling of his activities is most strongly influenced by the random nature of aircraft maneuvers and the use of the communication channel. This scheduling process is supported also by pilot actions; if the controller cannot "handle" an aircraft at a particular time, the pilot may slow down or wait for the controller's actions.

An attempt has been made to establish the total functional load on the overall GCS under conditions of good visibility. This estimate is given in Table 4-3. In periods of poor visibility, this functional load will increase with the present system due to lack of surveillance capabilities, decreased A/C speeds, etc. The functional activity or load on the controller is then estimated in Table 4-3 for a semi-automated system which not only provides surveillance inputs for the controller but provides conflict detection capabilities for assisting the controller in scheduling his activities.

The functional activity estimate in the present system has been based upon the hourly operations rate shown in the table (180 operations/hour). The second column, labeled "Conflict/Repeat Factor", represents the estimated increase in the number of times the particular function has to be performed because of conflicts, lack of data, or controller unavailability. This will not be readily apparent from analysis of communications; for example, a controller when seeing a ramp exit conflict simply goes on to another function without talking to the pilot, then reevaluates the situation again, etc. Translation of the modified hourly activity rate to the load occurring in a "peak" minute has been based upon factors

Table 4-3. Functional Activity Comparison - Present and GCS Approaches

Assumptions: Total Airport
90 Departures/Hour; 90 Arrivals/Hour; 10 Hangar or "Popups" per Hour
20 Penalty Box/Staging Area Operations/Hour

Control Function	Present System (Good Visibility)					Semi-Automatic System Peak Minute Operations
	Hourly Rate	Conflict/ Repeat Factor	Modified Hourly Rate	Peak Minute Factor	Peak Minute Operations	
A Release of A/C from GC Departure Q	90	1.2	108	2.0	3.6	2.9
B Handoff to LCS	90	1.0	90	1.2	1.8	1.8
Subtotal					(5.4)	(4.7)
C Formation of GC Arrival Q	120	1.0	120	1.5	3.0	3.0
D Acceptance of Arrival A/C	120	1.0	120	1.5	3.0	3.0
E Penalty Box Management	20	1.0	20	1.2	0.4	0.4
F Handoff to RCS	100	1.3	130	2.0	4.5	3.3
Subtotal					(10.9)	(9.7)
G Routing Control						
Selection	210	1.0	210	1.5	5.2	5.2
Verification	2100[1]	1.0	2,100[3]	1.1	39	0
H GCS Conflict Management						
H-1 Ramp Exit Conflicts	90	1.2	108	2.0	3.6	0.6
H-2 R/W Crossing Control	90	1.5[2]	135	1.5	3.4	1.1
H-3 Taxiway/Taxiway Conflicts (120 per A/C)[4]			12,000	1.0	200	0.1
H-4 Turnoff-Generated Conflict	90	1.03[2]	93	1.3	2.0	≈ 0
H-5 Ramp Entrance Conflict	100	1.3	130	1.5	3.2	0.75
Subtotal					(17.4)	(7.75)
Taking Sum of All Peak Loads - Total					33.7	22.15
More Probable Peak Load					15-20	10-15

Notes:
1 Based on 10 checks during taxi time
2 Values shown indicative of conflict occurrence
3 Values in ▭ not included in totals
4 Based upon 240 sec taxi interval; check made every 2 sec (50%); 5 sec (50%)

determined in previous studies for the FAA where the ratio of "peaks" in a 5-minute period to the hourly load was found to range from 1.3 to about 1.7. The values of functional activity in the "peak" minute have been summed for "Departures" (Functions A and B), "Arrival" and Common Factors (Functions G and H). The total peak load of 34 functions per minute has then been adjusted downward by a factor of between 0.5 and 0.6 since all functions will not "peak" at the same time. The resulting functional activity of 15-20 per peak minute does not include the functions of route verification (part of Function G) and the rapid and continuing surveillance of all aircraft for random conflicts (Function H-2). It is believed that heavy reliance is placed upon the pilot for accomplishment of these functions.

One significant aspect of the functional activity analysis are the apparent larger load on the Inbound Ground Controller although no "weighting" of the complexity of the various functions has been attempted. The GCS conflict load represents primarily the need to "check" or detect conflicts and should not be interpreted as actual conflict occurrence. This conflict load (Function H) is comparable to the sum of the Departure plus Arrival Loan (Functions A through G excluding Route Verification).

One may well ask how the controller can handle such a load. Possible factors contributing to this capability include delay of non-critical functions; knowledgeable pilots familiar with O'Hare (low G. A. levels); and, perhaps most important, the ability of a controller to remember, select, collect, and interpret visual data (A/C orientation, markings, movement, etc.).

In periods of low visibility when the benefits of a semi-automated system would be greater, the data processing system and displays must provide as much support to the controller as possible. This support is envisioned as providing extensive capability for conflict detection and function scheduling so that controller attention may be directed toward the highest priority functions. With such an approach functions will not disappear. Their need will instead be determined within the computer (with controller override) so that repeats of functions or surveillance for conflicts can be substantially reduced. For example, in the R/W crossing conflict the controller needs simply a GO/NO-GO indication; with proper surveillance data and processing the need for controller surveillance of all R/W crossing situations may be substantially reduced. This rationale has been used to develop an estimate of the functional activity required of the controller with a semi-automated system and is shown in the last column of Table 4-3. It has been concluded that such a system could reduce the functional activity load to approximately 2/3 of that in the present system under good visibility. Comparison with the present system under poor visibility conditions cannot readily be made; however, it is believed that the workload reduction benefits will be even more substantial.

SECTION 5 - DEVELOPMENT OF A LOCAL CONTROL SYSTEM (LCS) CONCEPT

5.1 INTRODUCTION

The semi-automated Local Control System (LCS) will provide the Local Controller(s) with improved data surveillance, data processing, and display capabilities for increasing runway capacities, reducing his workload, and providing additional safety margins under both VFR and IFR conditions. The proposed concept is one wherein measurement of both position and velocity information is used to predict future aircraft position. This prediction capability is then used within a computer to satisfy a variety of functions such as conflict detection, spacing control, R/W crossing control, etc. The outputs to the controller in this semi-automated concept are expected to range from simple GO/NO-GO types to available time indications as well as recommendations for specific action (speed change for second arrival, etc.).

The proposed concept of this real-time system is still under development; the emphasis of this working paper is therefore directed primarily toward the requirements dictated by the semi-automated concept.

The LCS system is that described in the Statement of Work as the RASE (Runway and Approach Surveillance Equipment). It should include, however, all components necessary for a complete system from sensors to displays.

5.2 REQUIREMENTS ESTIMATION

5.2.1 General

The Local Control System differs from the Ground Control System (GCS) in that the traffic is more "ordered" and predictable. In addition, the number of possible aircraft routes is appreciably smaller than in the GCS. These differences may therefore permit, and for some functions require, that the information presented to the controller is more than a GO/NO-GO type of indication.

Specifically, the apparent needs for Spacing Control (Function F) are such that a computer-derived recommendation for a speed change would appear desirable.

As in the GCS, an Aircraft Movement Profile has been used to estimate the required prediction intervals and sensor performance requirements. A summary of these profile characteristics is presented in Table 5-1. It should be noted that this table is by no means complete; additional data is highly desirable if proper algoithms are to be developed for the actual system.

To illustrate the several decision-making functions which could be expedited by a semi-automated LCS, four separate cases may be cited. These are:

Case 1 - Taxiway/Runway Crossing Control - Input to GCS from Function J

Case 2 - Arrival/Departure Sequencing (Separate Crossing Runways) - Functions L-1 and L-2

Case 3 - Control of Arrivals on Intersecting Runways - Function L-3

Case 4 - Arrival/Departure Sequencing during mixed operations on the same runway - Function K

The functional identification of these cases are set forth later in this section under the several types of possible conflicts. It should be noted that other cases also exist.

Examples of the above four control situations are shown in Figures 5-1, 5-2, 5-3, and 5-4 for O'Hare Airport. All have been observed during our work for TSC. In Case 1, the Departure Ground Controller must decide when to release an aircraft across the active runway. Cases 2 through 4 involve only the Local Controller.

In Case 2 the release of Departures (Clear to Takeoff) by Local Control is based upon the status of the Arrival runway AND the intersection. The most common method of release appears to be based upon visual recognition of

Table 5-1. Aircraft Movement Profile Data (Local Control System)
(Based primarily on air carrier jet aircraft)

Aircraft Maneuver	Time Duration-Sec Avg	Time Duration-Sec Std Dev.	Time Duration-Sec Range of Values	Distance (ft) (O'Hare)	Velocity-fps Avg	Velocity-fps Std Dev.	Velocity-fps Range	Remarks
DEPARTURES								
R/W Entrance Time[1]	33	12.6	12-73	200-400			25-35E	O'Hare measurements-All R/Ws
R/W Hold Time (T_{ldh})			0-120	0	0		-	Dependent on R/W configuration and Arrival load
Takeoff Time (STR-"OFF")								Heathrow data (74+139 AC)
Heavies/Large Jets	38	10	20-56	5000 E			200-300	Takeoff speeds 120-180 knots
Medium Jets	35	4	23-50	8000 E				
Takeoff - To Initial Heading			0-180	>1500				Dependent on "vector" given
ARRIVALS								
Approach Time (OM-2nmi)	54-100*			13,500/ 25,000	250E			150 knot velocity assumed
Landing Control Interval (2 nmi to MM)	30-40*			7,500/ 9,000	240E			
MM to R/W Threshold	15-18*			3,300/ 4,000	220E			
Threshold/Touchdown	15-3*			2,900/ 700[2]	210 195	13 20	1.95-238 1.57-233	Heathrow velocity data (21 + 59 AC)
Threshold/Turnoff	38-52	6-19	20-100					O'Hare data - 210 A/C; R/W dependent
Touchdown/Turnoff				3,000/ 6,000 E				

Notes: 1 From LC Departure Q to "In Position on R/W" (T_{ldt})   * ±2σ range
2 Calculate values from estimated velocity

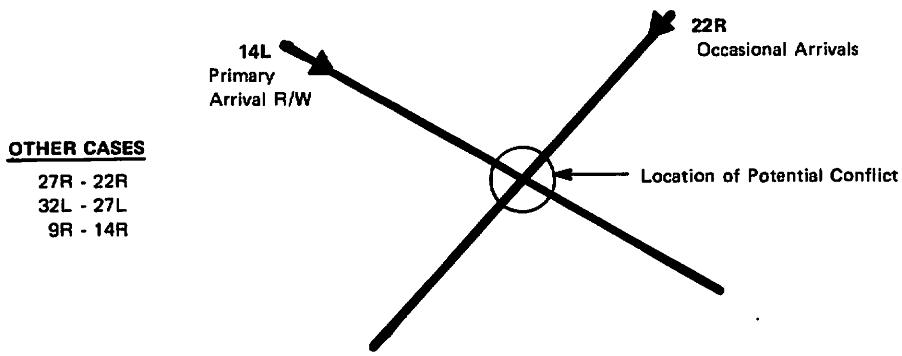


Figure 5-1. Arrivals on Intersecting Runways

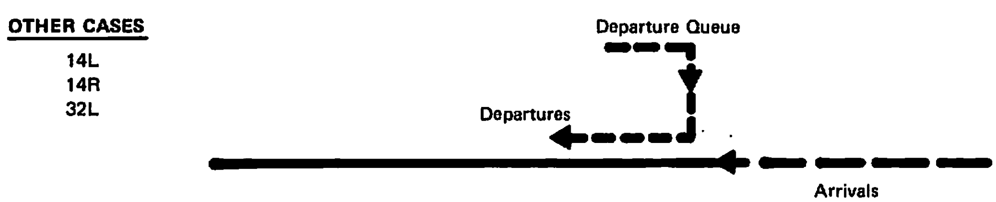


Figure 5-2. Arrival/Departure Sequencing Mixed Operations on Same Runway

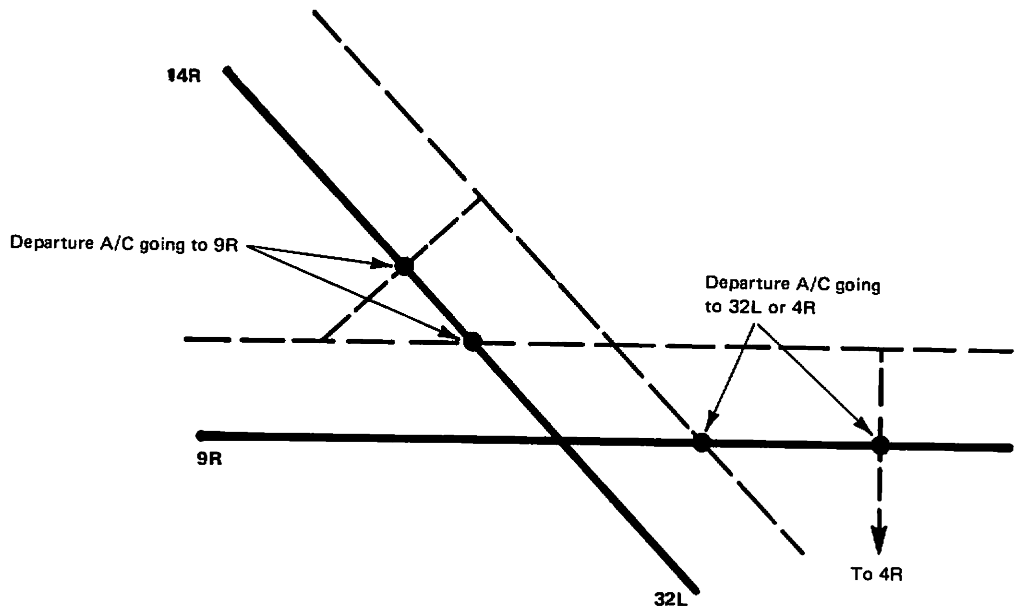


Figure 5-3. Typical Taxiway/Runway Crossings

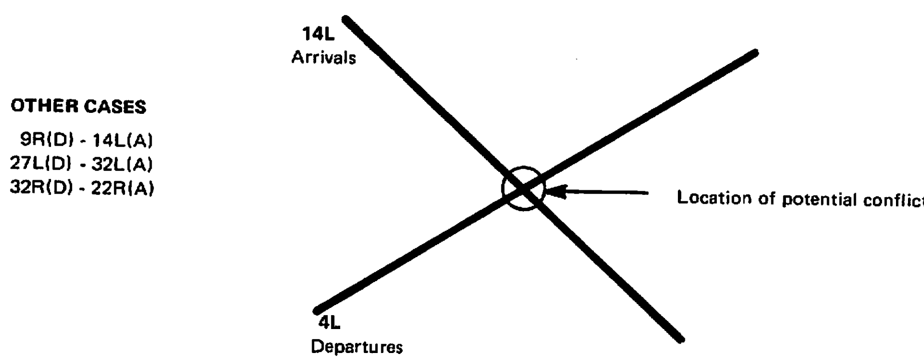


Figure 5-4. Arrival/Departure Sequencing Separate Crossing Runways

an Arrival passing through the intersection, * or "marking" the time when the release command can be given. This method of release of a Departure after an Arrival works well in good visibility; release of a Departure before an Arrival is not as efficiently accomplished with visual cues.

In Case 3 we have observed situations where occasional Arrivals will use a runway other than the primary Arrival runway. The Controller must prevent conflicts at the intersection of the two runways. The prediction of this possibility cannot be made to a high degree of accuracy and can represent a high risk situation.

In the mixed operations of Case 4 (Arrivals and Departures on a single runway) the Local Controller must release or clear an aircraft from the LC Departure Q to the runway (Function A) and then clear it to takeoff (Function B). These instructions may in some cases be combined in a single "contact". The Local Controller follows a similar procedure in performing this function to that described in sequencing Arrival/Departures on intersection runways except that the margin for error is reduced and the effect of pilot response time becomes more significant.

The common parameter in these Controller decisions is the need for a prediction of a "time" at which an event will occur--for example, an Arrival reaching an intersection. In the absence of any significant tools to make this prediction, the capacity of the runways must suffer in order to maintain adequate safety levels. If simple and accurate prediction methods are available to assist the Controller, both capacity and safety can benefit.

*A "Heavy" Arrival may restrict usage of some intersections to 2 minutes after passage of the "Heavy" due to wake turbulence effects.

To predict aircraft future position, velocity accuracy is appreciably more important than position accuracy for runway surveillance purposes. The velocity parameter becomes of even greater significance when periods of deceleration or acceleration occur. From rough position and accurate velocity data, a prediction may be made of the earliest possible time an aircraft can be at a future location, i.e., an intersection. Continuous computation of this minimum predicted Arrival time can then be used to establish a "denial window" (or control red lights) for the particular operation involved.

The wide range of variables (aircraft type, pilot differences, turnoff locations, weather, etc.) produce a wide range of runway occupancy values which cannot be readily estimated by the controller.

In Appendix F, the aircraft movement profile for landing aircraft has been examined. Theoretical and experimental results indicate that substantial benefits could be obtained through the use of prediction techniques for Runway Crossing control purposes. Sensor performance requirements for the above conflict as well as other conflict types are developed in paragraphs 4.2.3 and 5.2.3.

In the proposed LCS, velocity measurements are of major importance. What is even more important is the use made of this data--in many cases it must be processed within a computer to produce a "time" parameter since the use of speed values by themselves or even with position data is highly questionable.

5.2.2 Functional Requirements and Operational Logic

The functions to be performed by the proposed semi-automated Local Control System have been derived from a detailed study of existing operational procedures and problems. The control functions have been classified into those performed for Departures, those performed for Arrivals, and those Common to both of the above types of operations. Four major functions have been identified for Departure aircraft. These are:

A. Clearance of aircraft from Departure Q to runway

B. Clearance of aircraft for takeoff

C. Departure routing control

D. Handoff to TRACON

Four control functions have also been defined for Arrival aircraft. These are:

E. Acceptance of handoffs from Approach Control

F. Spacing control

G. Landing control

H. Handoff to Ground Control

The Common control functions are as follows:

J. Runway status monitoring

K. Single runway conflict management

L. Intersection runway conflict management

These control functions are summarized in Table 5-2; in addition, the interfaces required with the other portions of the ATC system are indicated. The sequence of events and/or interacting functions have also been indicated in order for each of the functions. A qualitative identification of the type of data required by the controller is indicated in this table. In addition the estimated performance requirements which are developed later in this section have been summarized on this table.

The operational logic or interaction between the 11 required control functions of the semi-automated Local Control System is depicted in Figure 5-5. On the left side of this figure are those control functions dealing with Departures while the right side of the figure shows the control functions performed for Arrival aircraft. In the center of this figure the conflict management functions (K and L) and their associated sub-conflict types are shown to illustrate the manner in which they interact with the functions performed for Arrivals and Departures respectively.

Table 5-2. Control Functions and Requirements Local Control System (Sheet 1 of 3)

Control Functions	Interface Required With	Sequence of Events and/or Interacting Functions	Data Requirements/Characteristics	Estimated Performance Requirements: Position σ_x – ft	Velocity σ_v – fps	Directional	Response Time-Sec	Remarks
DEPARTURES								
A Clear A/C From Dep Q to R/W (Dep Q Mgmt)	Ground Control	A/C ID at Head of L.C. Dep Q (A_q)	Order of Entry into Q; Equip. Type	No	No	No		Dependent on GC ordering
		R/W Takeoff Area Available	Previous Dep Rolling	N/A	N/A	N/A		
		Single R/W - A/D Conflict Check (Function K-1)		[See Function K-1]				
		Recognition of Exit from Dep Q (A_s)	Link Occupancy & Movement Detection		3	No	4-7	
B Clear A/C For Takeoff (Release of Deps)		A/C at R/W Takeoff Point (A_t and B_q)	Node Occupancy, Movement Detection	40-50	5	20° (O)	2-3	Heading information desirable
		Single R/W Conflict Check Previous Dep (K-2) Wake Turbulence (K-3) Previous Arrival (K-4)	A/C Equipment Type; Wind	[See Function K]				
		Intersecting R/W Conflict Check Arrival (L-1) Departures (L-2)		[See Function L]				
		Dep Routing (Assignment) - Function C		[See Function C]				
		Recognition of "Start to Roll" (B_s)	Movement Detection	N/A	5-10	No	2-3	
C Dep Routing Control (Assignment and Verification)		Functions B and D	Dep Route Measurement - For last 2-3 deps + "OFF" Time	200-400	15-20	10° (O)	4-7	From "OFF" to ARTS acquisition
D Handoff to TRACON	Dep Control	A/C "OFF" R/W or Abort Takeoff (B_t and D_q)	Takeoff Recognition/Prediction	[See Function K-4]			2-3	To Function J
		Dep Routing (Verification) - Function C (D_s)		As Per Function C				
		Handoff (D_t)	None Critical	200-400	No	No	4-7	

NOTE:

1. Subscripts q, s, and t indicate start of demand, start of service and termination of service for the indicated control functions.
2. (O) indicates optional requirement for confirmation.
3. ☐ Values are measurement made while aircraft is on surface.
4. Acceptable prediction error taken as 5 sec (one sigma) at R/W threshold and aircraft is at OM.

Table 5-2. Control Functions and Requirements Local Control System (Sheet 2 of 3)

Control Functions	Interface Required With	Sequence of Events and/or Interacting Functions	Data Requirements/Characteristics	Estimated Performance Requirements				Remarks
				Position σ_x – ft	Velocity σ_v – fps	Directional	Response Time-Sec	
ARRIVALS								
E Accept Handoffs from Approach Control	Approach Control	Pilot Report		No	No	No		
		Recognition of Target on BRITE (Outer Marker or Beyond)	A/C ID	600/1800	No	No	4-7	Based on ARTS "BRITE"
F Spacing Control	Approach Control	Separation From Preceding Arrival (F_s) Predicted Separation						Based on ARTS "BRITE"
G Landing Control		Single R/W Conflict Management (K-5) Dep on R/W Previous Arrival on R/W		See Function K-5				From 1.5 nm to MAP or middle marker
		Intersecting R/W Conflict Management (L-3)		See Function L-3				
		Issue Clear to Land or Missed Approach		N/A	N/A	N/A		
		Recognize A/C at Middle Marker (G_t and H_s)	Airborne Location	100-300	No	No	2-3	
H Handoff to Ground Control	Ground Control	R/W Status Monitoring (J) Deceleration Phase	Data for Conflict Management (K&L) and R/W Crossing Control	See Function J				From 2.5 nm to R/W turnoff
		Handoff to Ground Control (H_t)	Turnoff Recognition/Prediction	See Function K				

Table 5-2. Control Functions and Requirements Local Control System (Sheet 3 of 3)

Control Functions	Interface Required With	Sequence of Events and/or Interacting Functions	Data Requirements/Characteristics	Estimated Performance Requirements: Position σ_x – ft	Velocity σ_v – fps	Directional	Response Time-Sec	Remarks
COMMON								
J R/W Status Monitoring								
Arrivals		For Input to Functions K&L	Airborne Location; Predicted Time Over Threshold	See Values in Functions K & L			2-3	Coverage out to 2.5 nm
		For R/W Crossing Control and Functions K&L	Predicted Time at Crossing; Estimated Time at Crossing (Arrivals); Turnoff Recognition/ Prediction	See Values in Functions K & L				
Departures		For Functions K and L	Estimated Time at Crossing (Deps); Takeoff Recognition/Prediction	See Values in Functions K & L				
"Pop-ups"/Service Vehicles			Runway Occupancy; Turnoffs?	Presence Only				
K Single R/W Conflict Mgmt								
K-1 R/W Entrance Delay (Next Arrival)		Function A	Predicted Time Over Threshold	167	8.3	No		Coverage out to 5 nm
K-2 Takeoff Delay (Previous Departure)		Function B	Takeoff Recognition/Prediction	No	[10]	No		$\sigma_a = 1.6$ fps^2
K-3 Takeoff Delay (Wake Turbulence)		Function B	From Wake Turbulence Sensors	— Special Input Required —				Position vs time data of some benefit
K-4 Takeoff Delay (Previous Arrival)		Function B	Turnoff Recognition/Prediction	[20-30]	[4-5]	[5-10°]		Rough estimate
K-5 Arrival (Previous Operation)		Function G	Predicted Time Over Threshold	— As Per K-1 —		10-15°(1)		(1) For Dep entering R/W Hdg of A/C at R/W Start
			Turnoff Prediction/Recognition	— As Per K-4 —				
L Intersecting R/W Conflict Mgmt								
L-1 Takeoff Delay (Arrival)		Function B	Predicted Time at Crossing (t + 60)	167	8.3	No		
			Estimated Crossing Time of Arrival	—	—	No		After R/W Threshold
L-2 Takeoff Delay (Departure)		Function B	Estimated Crossing Time of Departure	[100-200]	[8-10]	No		$\sigma_a = 1\text{-}2$ fps^2
L-3 Arrival (Previous Operation)		Function G	Estimated Crossing Time of Departure; Predicted Time at Crossing; Estimated Crossing Time of Arrival	See L-1 and L-2				

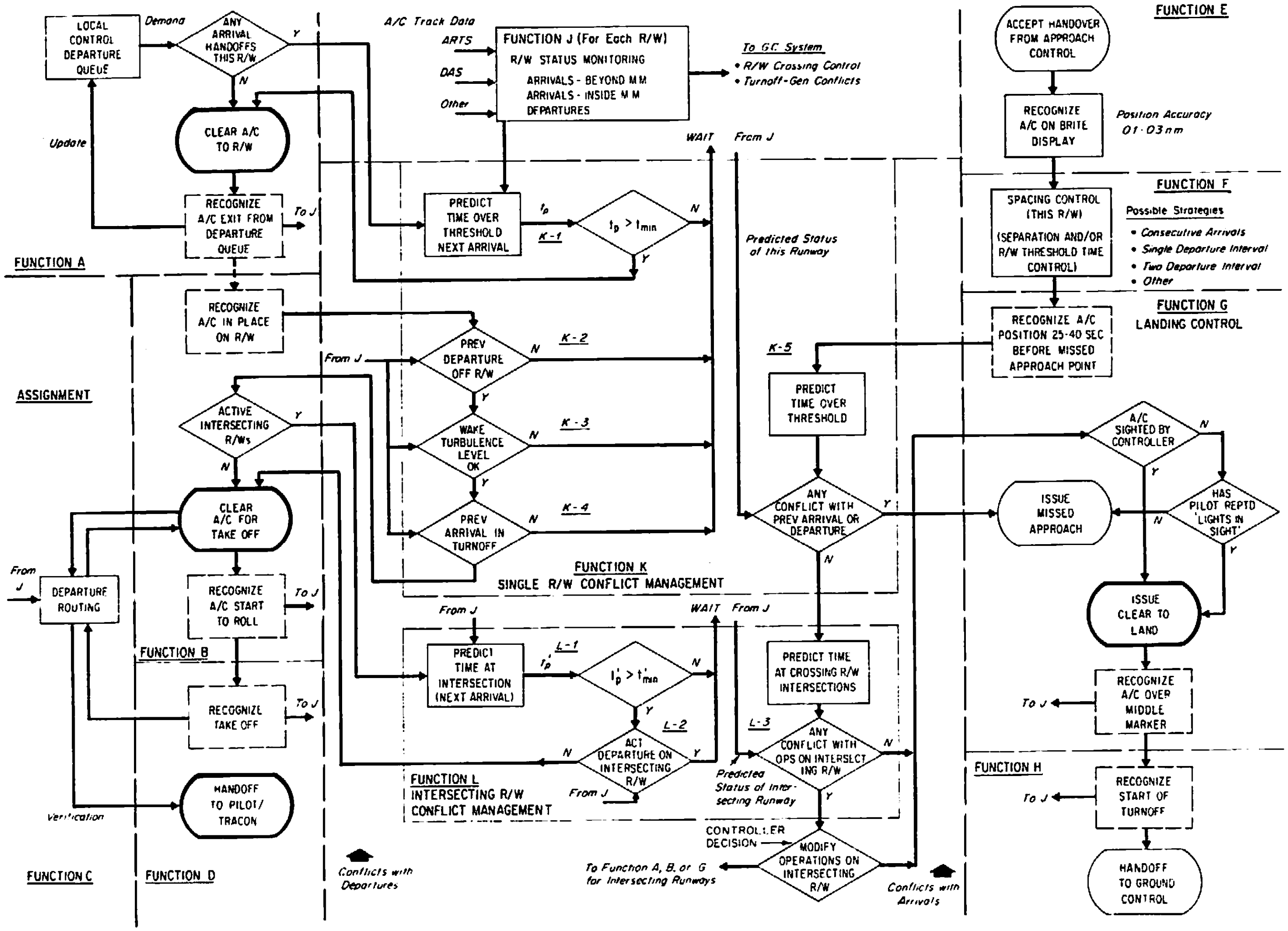


Figure 5-5. Preliminary Functional Logic For Local Control System

This figure depicts the overall logic between the various control functions; the detailed examination of each function provides further breakdown of the operational logic in the section on Performance Requirements.

It should be noted that the function of dual approach monitoring currently performed in the IFR room has not been included in the proposed system.

5.2.3 Performance Requirements

5.2.3.1 General

The following sections examine each of the functions to be performed by the LCS in order to determine the performance requirements or characteristics of the data needed by the Controller and/or data processing system to properly perform the specified function. Primary emphasis is on the desired characteristics of the surveillance sensor(s), recognizing that there will, of course, be other inputs to the data processor. The information required is set forth in operational terminology; these terms must then be related to the physical parameters or maneuvers of the aircraft which will be determined by the surveillance sensors. For the 11 functions of the LCS the information needed is:

OPERATIONAL DATA	INPUTS FROM SURVEILLANCE SENSOR(S)
Link Occupancy/Binary Heading	Position
Movement Detection	Velocity
Turn Recognition/Heading	Heading or Position Velocity
Airborne Position	Position
Airborne Velocity	For Heading Computation
Airborne Heading	
"OFF" or Predicted "OFF" Time	Position, Velocity, Acceleration
Turnoff Recognition/Prediction	Position, Velocity, Heading
R/W Occupancy	Presence
Predicted Time Over Threshold	Airborne Position/Velocity
Predicted Time at Crossing	Airborne Position/Velocity
Estimated Time at Crossing	Ground Position, Velocity Acceleration

Only a few of these operational data elements are needed for each function; the ones selected are those believed to be of primary significance for replacing or supplementing the process where applicable. Current prediction capabilities based upon position vs time (for example, "location above the horizon" vs time for an incoming Arrival) are believed to be quite limited in the present system.

Resolution performance requirements have not been discussed in the specific sections which follow since aircraft under Local Control are well separated except at their entry into, and exit from, the area of responsibility of the Local Controller. No need is seen at this time to resolve or track the individual aircraft in the Local Control Departure Q. However, resolution of an aircraft leaving this Q will require resolution capabilities of perhaps 100 ft to 200 ft from those in the Q area. Moreover, tracking of aircraft on the runway must be achievable with adjacent A/C on the parallels (approximately 400 ft between centers).

5.2.3.2 Clear Aircraft from Departure Q to Runway (Function A)

The movement of an aircraft from a "stopped" condition in the Local Control Departure Q to the point where the aircraft is on the runway and pointed in the take-off direction has been found to take about 33 seconds. * An indication of "demand", or that this function is to be performed by the Local Controller, is usually based on the fact that there is one or more aircraft in the Local Control Departure Q. However, it should be noted that in certain cases of bad weather some aircraft may be pushed to the side of the Local Control Departure Q area (while they are waiting for weather to reach company minimums) and other departures in the Q will bypass these waiting aircraft. However, in general the order of aircraft in the Departure Q is established by the hand-off process of the Ground Controller and, unless the special situation as described above takes place, the

*Reexamination of the data collected at O'Hare, based on a sample of 88 aircraft and most of the runways, indicated a value for this parameter of 33 seconds with a standard deviation of 12.6 seconds. The range of values was from 12 seconds to 73 seconds.

Local Controller knows which aircraft is at the head of the Local Control Departure Q. Before releasing the aircraft from the Departure Q to the runway takeoff location, a Local Controller must also know that the runway takeoff area is available, i.e., usually by simply noting that the previous departure has left.

Prior to issuing the clearance to the runway, Function K-1 must be performed, i.e., a single runway conflict check must be made if the particular runway is also being used for Arrival aircraft. If such is the case (i.e., an Arrival aircraft for example has been accepted by the Local Controller on this runway), it will be necessary to estimate whether sufficient time is available to clear the Departure to the runway and to release it for takeoff, while maintaining adequate separation between the Departure and the incoming Arrival. This conflict check is discussed more fully under Function K-1.

After the aircraft has been cleared to enter the runway it will be necessary for the surveillance and data processing system to recognize aircraft start-up from the Departure Q and movement out onto the takeoff end of the runway. It is proposed that Link Occupancy and Movement Detection processes will be satisfactory to verify that Function A is underway. The performance requirements are expected to be similar to those discussed under the Ground Control System, namely, one sigma values are about 3 fps in velocity. If velocity is obtained from position, it is estimated that σ_x = 10 ft to 25 ft depending upon the sampling rate employed.

5.2.3.3 Clearance of Aircraft for Takeoff (Function B

While under some conditions aircraft can be cleared for takeoff at the same time they are released from the Departure Q to the runway, the more prevalent mode of operations is to release the aircraft for takeoff after they have moved to the runway end point. The time at which this function is to be performed can therefore be recognized by the fact that the aircraft is indeed at the runway takeoff point. Function B may be considered to have been completed when the aircraft has begun its takeoff roll. Depending upon the runway configuration in use, various types of conflict checks must be made by the Local Controller before the Departure is released for takeoff. One set of checks involves those dealing with the operations on the particular runway to be used by the Departure; these have been classified as single runway conflict checks and are described later under Function K. The other type of conflict checks (and these appear to be more prevalent in the operations at O'Hare) are those dealing with operations on intersecting runways. These are more fully described under Function L.

Recommended heading, or Departure Routing information, will be given by the Local Controller to the pilot (often in the same contact that is used for "clear to takeoff"). It can be seen, therefore, that Function B interacts with Functions C (Departure Routing Control), K and L. The performance requirements of Function B, insofar as recognition of the aircraft being at the takeoff point, are approximately the same as those set forth for Function A, with the exception that rough indication of aircraft heading information appears to be desirable. It is estimated that most aircraft will take between 10 seconds to 15 seconds to make a 90 degree turn such as that required when an aircraft turns onto the runway. If all other criteria have been satisfied, it can be seen that the Local Controller could release the aircraft for takeoff during the time that the aircraft was completing its turn onto the runway; such a process might save 4 seconds to 6 seconds in the runway occupancy time of a Departure. We have estimated that aircraft heading information to perhaps 20 degree accuracy would be useful for this purpose. The velocity accuracy requirement is established by the fact that the Controller might wish to have information showing that the particular aircraft has indeed stopped, i.e., not started to take off before the release signal has been given. The accuracy requirement here is established by the need for Movement Detection or recognition and is estimated to be of the order of 5 fps. The position accuracy (exclusive of that required to estimate velocity) is less demanding than that of Function A; a value of perhaps 40 feet to 50 feet should be sufficient.

Position information is not needed for recognition of the "start-to-roll" process; the velocity information requires an accuracy comparable or slightly higher than that previously discussed. The more accurate this process the faster will be the response time in recognizing the beginning of the takeoff process.

5.2.3.4 Departure Routing Control (Function C)

Since one of the major functions of the Local Controller is to provide separation between successive departures, it is desirable to assign different headings or vectors to successive departure aircraft. The information needed by the Controller, therefore, is the departure (vector) heading followed by the previous 2 to 3 departures as well as the "off" time of these aircraft. From this information the Controller may then select a different vector/heading in order to increase departure separation as much as possible early in the takeoff process. When "heavy" aircraft are involved, wake turbulence effects are, of course, a separate constraint on this routing process. Accurate position and velocity information is of less importance in this departure routing and control function than is the measurement of aircraft heading in order to verify that the departure is indeed following the assigned vector heading. Estimates of position accuracy of between 200 feet and 400 feet, velocity accuracy of 15 feet to 20 feet per second (about 10 knots) should be sufficient for routing verification. Aircraft heading information to a one sigma value of perhaps 10 degrees represents a preliminary estimate of the directional data desired for this function.

Pilot verification of departure route assignment is currently used; handoffs are often made during the time that the aircraft is turning to its assigned heading. This procedure may be acceptable in the semi-automated LCS. However, data entry of route followed by the aircraft, if needed, then must be done manually.

5.2.3.5 Handoff to TRACON (Function D)

We may consider that Function B has been completed when the aircraft lifts off the runway and that Function D begins at this time. Handoff of the Departure to the IFR room or TRACON does not usually take place, however, until the Local Controller has verified that the assigned departure routing is indeed being followed by the aircraft. Function C therefore will interact with this function for a period of from perhaps 20 seconds to 60 seconds depending upon the aircraft equipment type as well as the assigned departure routing. No accurate sensor information is required at the time of handoff insofar as the Local Controller is concerned since the evaluation that separation standards are being maintained is part of Function C. Information on aircraft "Off" time, but not position or velocity, is needed to provide an input to Function J, Runway Status Monitoring. This information can be used by the Local Controller in performing the single runway conflict check or to assist him in specifying the release time of the next departure. The recognition of "off" time or "predicted off" time for a departure has been discussed in Function K-5.

5.2.3.6 Acceptance of Handoffs from Approach Control (Function E)

Handoff of arrival aircraft from Approach Control position usually takes place in the vicinity of the outer marker, 4 nmi to 6 nmi from runway threshold. The ARTS BRITE display in the cab is the tool used by the Local Controller to recognize aircraft position and identity at the time of handoff. Performance of this function, therefore, simply requires sufficient position accuracy for the Local Controller to readily detect the incoming arrival at the time of handoff. A value of between 600 feet and 1800 feet has been estimated for this function; velocity information is not needed until Spacing Control is to be performed.

5.2.3.7 Spacing Control (Function F)

Normal procedures call for minimum separation between Arrivals of three nautical miles while under radar control. In poor visibility conditions, when visual approaches are not possible, the Local Controller is responsible for longitudinal separation via the ARTS BRITE in the cab. For the purpose of this study, that mode of operation will be assumed to continue with no change due to ASTC equipments.

5.2.3.8 Landing Control (Function G)

Issuance by the Local Controller of the "clear-to-land" instruction under current day practices and in visual conditions appears to occur over a wide range of time intervals. In some cases the aircraft is at the middle marker while in others it might be 2 miles to 3 miles out. If the Local Controller does not have the aircraft in sight by the time it is close to the missed approach point, the Controller must issue missed approach instructions unless the pilot has reported that the runway lights are in sight. In any case, the termination of an approach by the issuance of the "clear to land" message cannot take place any later than when the aircraft is at the middle marker or the missed approach point. During the Landing Control function, conflict checks must be made on a single runway basis (see Function K-5), as well as possible conflicts arising due to usage of intersecting runways (see Function L-3).

No special sensor requirements have been established for Landing Control except those dictated by the two conflict management functions K and L. Aircraft location at the middle marker will, of course, terminate the time at which Landing Control can be exercised. However, during the last 20 seconds to 30 seconds of the pre-touchdown phase of the arrival aircraft, it is anticipated that the conflict management jobs performed on the computer may still be in process so that special instructions may be given to other aircraft on the surface if necessary.

5.2.3.9 Handoff to Ground Control (Function H)

Landing aircraft may occupy a runway from periods of between 40 seconds and perhaps 60 seconds. Were it not for the scheduling and conflict management of other aircraft the handoff process to the Ground Controller could take place any time during the period that the aircraft is decelerating on the runway. In practice, however, handoff to the Ground Controller is performed at a time close to aircraft turnoff from the runway. The Local Controller in many cases recognizes A/C Heading Change and gives an anticipatory "handoff".

The sensor requirements, therefore, for the handoff process are primarily those established for conflict management purposes to be certain that the runway is indeed clear for other operations. Estimates of the performance requirements for this function are set forth under the conflict management functions K and L, discussed later.

5.2.3.10 Runway Status Monitoring (Function J)

The function of this computer job is primarily one of providing inputs to the conflict management functions K and L. However, it is also required to provide inputs to GCS Conflict Management (H-2). In order for the ground controller to release a departure to cross an arrival runway there should be sufficient time for the crossing aircraft to clear the runway before the next arrival approaches the crossing intersection. The time elements for crossing are estimated as follows:

	Duration (Sec)
Communication to Pilot	5-7
Pilot Reaction Time	0.8
Runway Crossing Time*	20-40
Totals	25.8-47.8

If the taxiway crossing point is at the mid-rollout point (i.e., about 20 seconds after the arrival crosses the threshold) and 20 seconds of safety buffer is allowed between the crossing aircrafts clearing and the arrivals reaching the intersection, a crossing should be withheld if an arrival is within 50 seconds of the threshold. Allowing 5-10 seconds latitude in the decision making, the predicted-time-over-threshold should be available 60 seconds out from threshold. At appraoch speeds of up to 150 knots the GCS coverage of 2.5N miles from threshold is established.

*Reexamination of the data collected at O'Hare indicated a mean of 30 seconds with a standard deviation of 6 seconds. The range of values was from 18 seconds to 38 seconds.

5.2.3.11 Single Runway Conflict Management (Function K)

Operations conducted on a single runway make it necessary for the Local Controller to evaluate five types of conflicts on a regular basis. These five conflicts are listed in Table 5-3 which also provides an indication of which aircraft will normally be given priority (A/C #1) as well as a qualitative estimate of the information needed by the Controller for decision-making purposes. The three main decisions made by the Controller under normal conditions are:

For Departures

Clear to enter runway - part of Function A

Clear for takeoff - part of Function B

For Arrivals

Clear to land - part of Function G

Accomplishment of these decisions in an optimum manner requires information on both surface as well as airborne aircraft. Each of the five conflicts will be discussed in detail below.

1. Conflict K-1 R/W Entrance Delay/Next Arrival

In order for the Local Controller to release a Departure from the Local Control Departure Q onto the runway there should be sufficient time for the outgoing aircraft to be clear of the runway ("OFF") before touchdown of the next Arrival. The time elements involved are estimated as follows:

	Duration (Sec.)
Communication to Pilot	5-7
Pilot Reaction Time	0.8
A/C Movement Time (to R/W)	25-35
Communication to Pilot (Clear to R/W)	5-7
Pilot Reaction Time	0.8
Start-to-Roll/"OFF" Interval	30-50
Total	67.6-101.6

Table 5-3. Summary of Potential Single R/W Conflicts and Information Requirements

Conflict Type		A/C#1 (Priority A/C)	Required Sensor Data	A/C #2	Required Sensor Data
K-1	R/W Entrance Delay (Next Arrival)	Airborne Arrival	Predicted Time Over R/W Threshold	A/C in LC Departure Q	Location
K-2	Takeoff Delay (Previous Dep)	"Rolling" Departure	"OFF" indication or Predicted "OFF" Time	Departure A/C at R/W Start	Location
K-3	Takeoff Delay (Wake Turbulence)	Previous Operations	Special	Departure A/C at R/W Start	Location
K-4	Takeoff Delay (Previous Arrival)	Arrival on R/W	Turnoff Recognition Turnoff Prediction	Departure A/C at R/W Start	Location
K-5	Arrival/Previous Operation	(1) "Airborne" Arrival	Predicted Time Over R/W Threshold	Departure A/C at R/W Start	Location/Hdg
		(2) "Rolling" Departure	Predicted "OFF" Time	Airborne Arrival	Predicted Time Over R/W Threshold
		Arrival on R/W	Turnoff Prediction Turnoff Recognition	Airborne Arrival	Predicted Time Over R/W Threshold

NOTES

1. This conflict may be caused by a "slow" departure.
2. This conflict cannot exist unless departure "aborts" takeoff since Airborne Arrival must be beyond MAP for "waveoff", i.e., more than 20 seconds from R/W Threshold; this conflict can exist for intersecting R/Ws.

Rounding off these values we may estimate that between 70 seconds and 100 seconds are needed with the present voice system; this possibly could be reduced by 10 seconds if a "signaling" approach (red/green light) was employed.

If "t_p" is the predicted "Time over R/W Threshold" for the Arrival and $\sigma^2(t_p)$ is the variance associated with t_p, then the decision can be made as long as

$$t_p - 2\sigma(t_p) \geq 70\text{-}100 \text{ seconds.}$$

It has been estimated* that the ability of a pilot to control his speed from the Outer Marker to Threshold is such that the standard deviation of his time over threshold is about 5 seconds. If this value is also used for $\sigma(t_p)$ and the upper value of 100 seconds is selected from the above relationship, then

$$t_p \geq 110 \text{ seconds}$$

Since landing speeds of aircraft range from 100 knots to 150 knots (167 fps to 250 fps) the arrival aircraft must be no less than 18, 370 (110 x 167) or 27,500 (110 x 250) feet from threshold for these two speeds (three nmi to five nmi out). This essentially defines the required coverage area for prediction of "time over threshold".

Using the prediction accuracy formulas of Appendix E, we have

$$\sigma t_1 = \frac{1}{V} \sigma_x \qquad \text{due to position error}$$

$$\sigma t_2 = t \; \frac{\sigma_V}{V} \qquad \text{due to velocity error}$$

where these are the two components of $\sigma(t_p)$ and it is assumed that no appreciable braking or acceleration takes place during the last 80 seconds to 100 seconds before threshold crossing. If σ_{t_1} is taken as one second then, for the slowest aircraft, we have $\sigma_x = 167$ ft. Taking $\sigma_{t_2} = 5$ seconds and $t = 100$ seconds the required velocity accuracy is $\sigma_v = 5(167)/100 = 8.3$ fps.

*Astholz, et al., "Increasing Runway Capacity", Proceedings of IEEE, March 1970

2. Conflict K-2 Takeoff Delay due to Previous Departure

Since R/W occupancy time for a departure will range from 20 seconds to 56 seconds, and the time required to move a Departure from the LC Departure Q to the takeoff point averages 33 seconds (range 12 seconds to 73 seconds) (see time estimates in Table 5-1) it is expected that "rolling" departures will cause takeoff delays until the first aircraft is clear ("OFF") of the runway. An indication of this status can be obtained by a pilot report. Measurement of this change in aircraft status appears difficult to accomplish. On the other hand, prediction of "OFF" time based on aircraft velocity and possibly acceleration measurements while on the runway may be desirable. Assuming that the second departure can be cleared-for-takeoff no sooner than 6 seconds to 8 seconds before the first aircraft is actually "OFF", the prediction interval of interest is of the order of 10 seconds. Ignoring for the moment wind effects (which will be minimal in most low visibility conditions), the requirement becomes one of prediction of the time at which normal takeoff velocity is reached. Since

$$t = \frac{v}{a} \qquad \text{for linear acceleration}$$

we may define the two components of prediction error (due to velocity and acceleration errors) in the same manner as for the position/velocity relationship $t = \frac{x}{v}$. This, of course, assumes independent Gaussian processes for "a" and "v". The two components of error are

$$\sigma_{t1} = \frac{1}{a}\sigma_v$$

$$\sigma_{t2} = t\frac{\sigma_a}{a}$$

Values of σ_{t1} and σ_{t2} equal or less than 1 second appear desirable. With a = 16 fps^2 (0.5g) a value of σ_v = 10 fps would result in σ_{t1} = 0.8 second. Acceleration measurement uncertainty of 1.6 fps^2 (σ_a) would result in σ_{t2} = 1 second $\left(\frac{10 \times 1.6}{16}\right)$ at the 10-second prediction interval. This prediction capability could result in perhaps 6 seconds to 8 seconds time saving for departures. The impact of aircraft equipment type on the variations in takeoff characteristics need further investigation.

3. Conflict K-3 Takeoff Delay/Wake Turbulence

Separation between departures must consider wake turbulence effects due to "heavy" aircraft. Wake turbulence measurement sensors can plan a significant role, it is believed, in reducing departure delays due to this phenomena. No special requirements on the aircraft position, velocity, or acceleration sensors can be defined at this time. While wake formation may possibly be correlated with aircraft equipment type and velocity, wake dissipation takes many seconds and may not be readily predictable. Data from wake turbulence sensors should be integrated into the Local Control System for use in this function.

4. Conflict K-4 Takeoff Delay/Previous Arrival

Immediately after an Arrival has crossed the runway threshold, the controller can perform Function A (release of aircraft from Local Control Departure Q to runway). Runway occupancy time by Arrivals is longer than that of Departures and ranges from about 38 seconds to 52 seconds at O'Hare except when aircraft use the R/W for taxiing (R/W 22L). Under present procedures Departures are not cleared for takeoff until the Arrival is clear (or almost clear) of the runway; the Controller in visual conditions does give anticipatory clearances. Ideally, a "runway available" signal to the Controller perhaps 6 seconds to 10 seconds prior to the Arrival being actually clear of the runway appears desirable to reduce departure delays. Relaxation of the rule that only one aircraft can be moving on the runway at any instant of time could increase this interval to perhaps 10 seconds to 15 seconds since the minimum total time from release to takeoff will be of the order of 40 seconds. Prediction of the aircraft turnoff maneuver of the Arrival could perhaps be accomplished by recognition of change in aircraft heading in many cases. For low angle turnoffs (where the angle is perhaps 30 degrees) a standard deviation of heading change of perhaps 5 degrees to 10 degrees (σ_Θ) is believed to be desirable.

This "Turn Recognition" process wherein

$$\Theta = \tan^{-1} \frac{x}{y}$$

and

x = Position component orthogonal to runway

y = Position component along runway

will be influenced by the statistical characteristics of the sensor geometry with respect to the runway as well as the turnoff geometry. Additional study and/or simulation will be required to ascertain the ability to recognize "turns" with a minimum of time delay.

At this time the safer criteria appears to be one of recognizing aircraft occupancy of the turnoff link (and clear of runway); i.e., Link Occupancy plus Movement Detection. The latter process is desirable since the turnoff links are short and, unless the aircraft is detected as "moving", the system cannot be sure that the arrival aircraft is completely clear of the runway. It should be recognized, however, that this criteria will hamper overall response time.

5. Conflict K-5 Arrival with Previous Operation

The preceding four conflicts, K-1 through K-4, have dealt with delays to Departures. Under conflict K-5 we shall consider the possible impact of the preceding operation on an incoming Arrival. While under most circumstances the incoming Arrival must be given priority, there may be situations where "permission to land" should be denied.

Three situations will be examined under this conflict. In the first, a conflict may exist between an Arrival and a Departure at the runway start point but not moving. This has been observed in the data collection effort. In this case, the Departure was instructed to continue across the runway to clear the threshold for the Arrival. The information needed by the Local Controller is the Predicted Time over Threshold for the Arrival while for the Departure aircraft he needs heading information, i.e., is the Departure pointed along the runway or can it quickly "exit" the runway if necessary. This latter option is not possible at all takeoff points, i.e., it can be done on 27L and 32R, for example, but not on 32L and 9R unless the aircraft is moved onto the grass. * The information needed by the controller is the "Predicted Time over Threshold" (for the Arrival) similar to that needed for Conflict K-1, except that the prediction interval will probably be of the order of 50 seconds to 70 seconds rather than the higher values required in K-1. We shall use the same position and velocity accuracy estimates for this conflict as in K-1, recognizing that somewhat better prediction capabilities will be achieved. The information required on the other aircraft is its relative heading with respect to the runway and that a potential runway exit is available. This requirement appears to imply "Turn Recognition" capabilities when the aircraft moves out onto the runway.

In the other two examples of K-5 wherein a "rolling" Departure or Arrival is on the runway with an Airborne Arrival near the Missed Approach Point (MAP) it is believed that the former cannot take place unless the Departure aborts its takeoff (see Note 2 on Table 5-3). When the previous Arrival is slow in clearing the runway it may be necessary to issue a Missed Approach instruction to the incoming Arrival or to inform it to "hold short" of a particular point on the runway. It is recognized that priority should be given to the airborne Arrival; however, in certain situations this may be impossible. "Predicted Time over Threshold" is required data for the airborne Arrival; for the "rolling" Arrival on the runway it is desired to have a "Turnoff Recognition" or prediction as soon as possible.

5.2.3.12 Intersecting Runway Conflict Management (Function L)

Most operations conducted at O'Hare use intersecting runway configurations. The location of the intersection of the runways with respect to the threshold for Arrivals and the start of takeoff point for Departures is a major factor in the decision process performed by the Local Controller. Figure 5-6 illustrates four types of intersections based upon Arrivals on one runway and Departures on the other. These four cases (Case I through IV) are identified as Near/Near; Near/Far; Far/Near; and Far/Far with the first designation indicating the Arrival runway and the second the Departure runway.

*The control flexibility offered by this pavement design at the runway ends appears to be a desirable feature for incorporation in future runway designs.

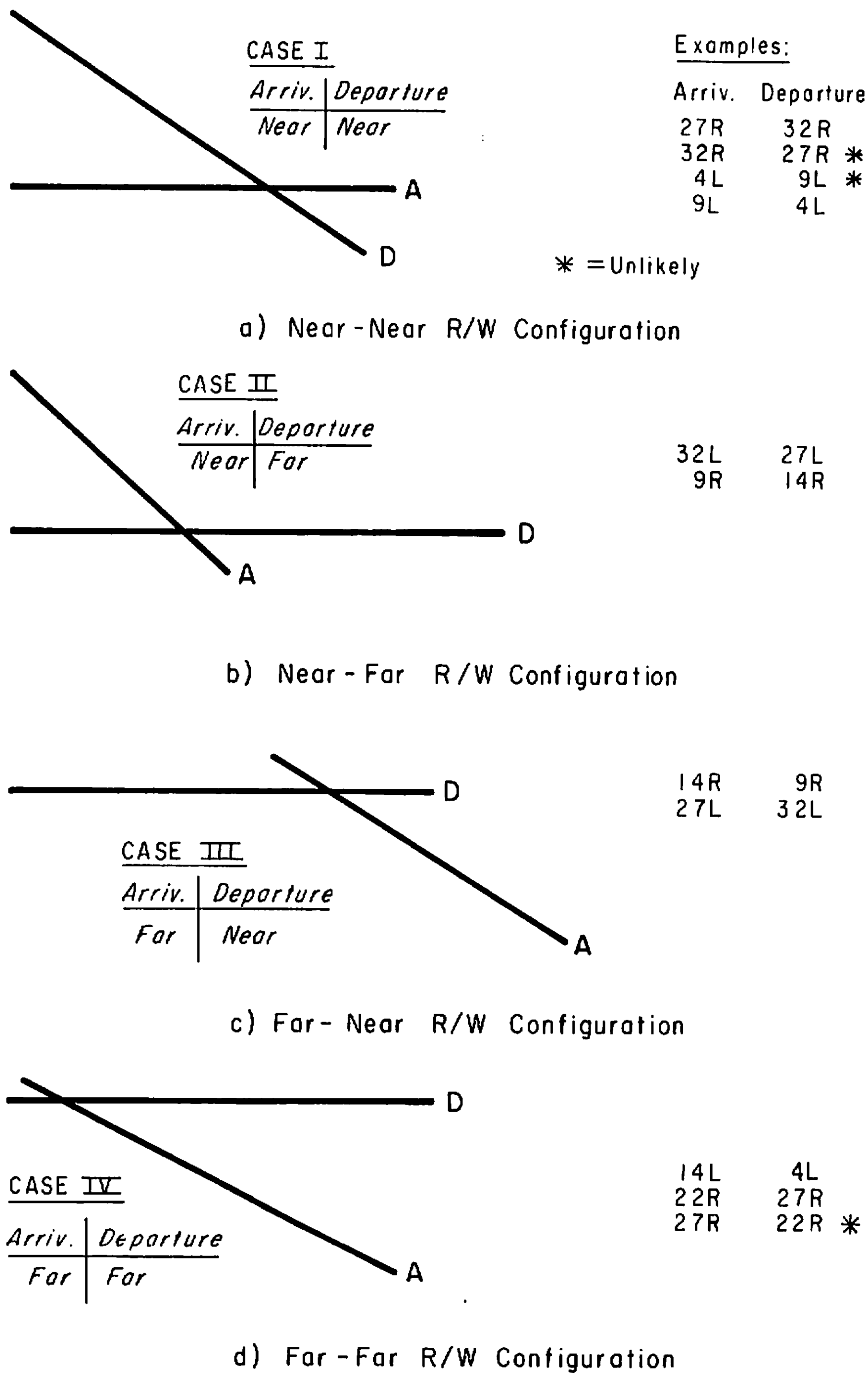


Figure 5-6. Intersecting Runway Configurations

Three types of potential conflicts have been identified as shown in Table 5-4 for operations on intersecting runways. In the first, L-1, a Departure on one runway must be released so as to avoid a conflict with either an incoming airborne Arrival or an Arrival rolling on the runway but not yet past the intersection. In the second case, L-2, the Departure must avoid a conflict with a "rolling" Departure (on the other runway) which is not yet past the intersection (wake turbulence may also be a factor in this situation). These two conflicts (L-1 and L-2) represent "Takeoff Delays" which can be minimized by the use of prediction or estimation techniques for establishing the time availability of the intersection (or crossing). We shall use the term "predicted" to indicate the estimated time that an airborne aircraft will reach a particular crossing while the term "Estimated Crossing Time" will be applied to aircraft (either Arrivals or Departures) which are "down" on the runway.

The third type of conflict, L-3, is that occurring between two moving aircraft and as such represents the most stringent safety requirement. In the first example of this type of conflict a "rolling" Departure, because of delay in starting to roll, may be in conflict with an incoming Arrival beyond the MAP. The priority aircraft in this case is probably the Departure. The Near/Far Configuration (Case II) is the most stringent situation. Information on the Estimated Crossing Time (of the rolling Departure) can permit the acceptance or rejection of the incoming Arrival. Another example of the L-3 conflict would be between an airborne Arrival and a "rolling Arrival" on another runway which has not yet reached the Crossing. Here the Airborne A/C has priority and the other aircraft must be given a "stop" instruction rapidly. This situation is most likely under the Near/Far or Far/Near runway configurations. The data needed by the Controller is the Estimated Crossing Time of the ground Arrival as well as the Predicted Time at Crossing for the airborne aircraft.

From the above discussion it can be seen that three types of data are required for either control of the runway crossing or release of Departures. These are:

Table 5-4. Summary of Potential Intersecting R/W Conflicts and Information Requirements

Conflict Type		A/C#1 (Priority A/C)	Required Sensor Data	A/C #2	Required Sensor Data
L-1	Takeoff Delays (Arrivals)	Airborne Arrival	Predicted Time at Crossing	Departure A/C at R/W Start	Location
		Arrival on R/W	Estimated Crossing Time	Departure A/C at R/W Start	Location
L-2	Takeoff Delays (Departures)	"Rolling" Departure	Estimated Crossing Time	Departure A/C at R/W Start	Location
L-3	Arrival/Previous Operation	"Rolling" Departure	Estimated Crossing Time	Airborne Arrival	Predicted Time at Crossing
		Airborne Arrival	Predicted Crossing Time	Arrival on R/W	Estimated Crossing Time

1. Predicted Time at Crossing - of Airborne Arrivals
2. Estimated Crossing Time - for "Rolling" Departures
3. Estimated Crossing Time - for "Braking" Arrivals

Since the prediction interval for the first data item above is expected to be no more than 60 seconds, the required position and velocity accuracy can be satisfied by the criteria established under Function K. The performance requirements for the second data item above can be satisfied with the criteria established under Function K-5.

The third data item, i.e., the Estimated crossing time of a "braking" Arrival at a future intersection is needed not only for Function L-3 at intersection of runways but also needed for input to the runway Crossing Control function performed by the Ground Control System. Based upon measurement of the position and velocity of the "braking" Arrival, several estimates can be made. For a slow moving Arrival, an estimate based on the assumption that no acceleration takes place in the future can be made of the minimum time at which the Arrival will reach the intersection. If this time is more than say 20 seconds to 30 seconds, then there is sufficient time to stop the Arrival if necessary. Fast moving Arrivals, say at 60 knots (about 100 fps) or that are within 1000 feet of the intersection, probably must be considered as positive users of the upcoming intersection. The estimate of time past the intersection, or Estimated Crossing Time, in this case must be delayed until the Time-to-Go of the Arrival is perhaps 10 seconds or less.

5.2.4 Operational Requirements

The operational requirements for the Local Control System will be specified in terms of the responsibilities of a single Local Controller recognizing that at O'Hare for example there are essentially two almost independent sets of runways. Of primary interest is the maximum traffic that a single Local Controller will handle both during the "busy" hour as well as during the short term (3-minute to 5-minute) peaks. This traffic load will be dependent upon runway configuration. For a single runway serving just arrivals it is estimated that four aircraft could be simultaneously under control, three airborne (OM, OM-MM, near threshold), and one on the ground near turnoff. A separation value of 2 nmi has been used as an estimate of possible future standards. Similarly there may be four simultaneous departures for a single runway, one entering the runway, one "rolling", and two airborne (prior to handoff). From these estimates and the fact that 2-3 runways may be active at one time we can estimate the number of simultaneous operations in progress. This represents a short term peak load.

While the present hourly quota system of 135 A/C for O'Hare implies about 70 operations/hour for each side of the airport, the tower is currently (summer 1974) handling from 140-170 ops/hr. It is recommended that the LCS be sized to handle 100 ops/hr per Local Controller. We may summarize the traffic load as follows:

Number of Active Runways	3
Number of Simultaneous A/C under Control	10-12
Busy Hour Ops Rate (Future)	100/hr

The LCS must be capable of operating in a variety of runway configurations. Mixed operations on each of the three active runways must be achievable. In addition the system must be capable of handling a variety of crossing-runway situations.

5.3 PRELIMINARY MODULE DESCRIPTION

5.3.1 Overall Characteristics

The major components of the proposed semi-automated LCS are Surveillance Sensors, Data Processor, and Displays plus Input/Output devices. These components must be connected via dedicated communication facilities of either a "hardwire" and/or radio nature. Independent displays are provided for the two Local Controllers. The set of surveillance sensors may or may not be geographically independent. This gross representation of the total LCS does not imply that some pre-processing of surveillance data cannot be done in the sensors themselves.

While the description of the LCS has been based on the use of a single data processor, integration of this system with a similar Ground Control System might result in a single processor for use by both systems.

Three types of surveillance sensors have been shown feeding into the data processor. The first type of sensor would be one wherein aircraft in the ground environment are kept under surveillance; the second would be devoted toward surveillance of airborne aircraft on both the approach and departure flight paths; the third sensor would be used for determination of "runway occupancy" checks on non-cooperating vehicles. While three independent sensor systems have been shown, it may be possible for one sensor system to perform the three types of surveillance functions illustrated in Figure 5-7.

It is anticipated that the data processor will also perform scheduling functions to activate on the displays the proper information for the specific function to be performed by the Local Controller. It is recognized that a large amount of information is currently acquired by the Local Controller by means of visual surveillance techniques over a large area of coverage. Condensation of this information, as well as proper selection of the data elements, will be a prime goal in the concept development of the displays. It is envisioned that there will be multiple displays/data inputs available for the Controller with cueing assistance provided from the data processing.

5.3.2 Interface Considerations

The LCS must interface with the Ground Control System as well as the ARTS system. In the latter area, it is currently envisioned that interface will be required only for Arrival aircraft and that Departures from the LCS will be handled no differently than the acquisition process currently performed by the Departure Controller in the TRACON. On the other hand, arrival information from the ARTS data base will serve to ease the acquisition problem for the airborne surveillance sensors and also provide coarse position information for use in some of the Local Control System functions (for example, Spacing Control).

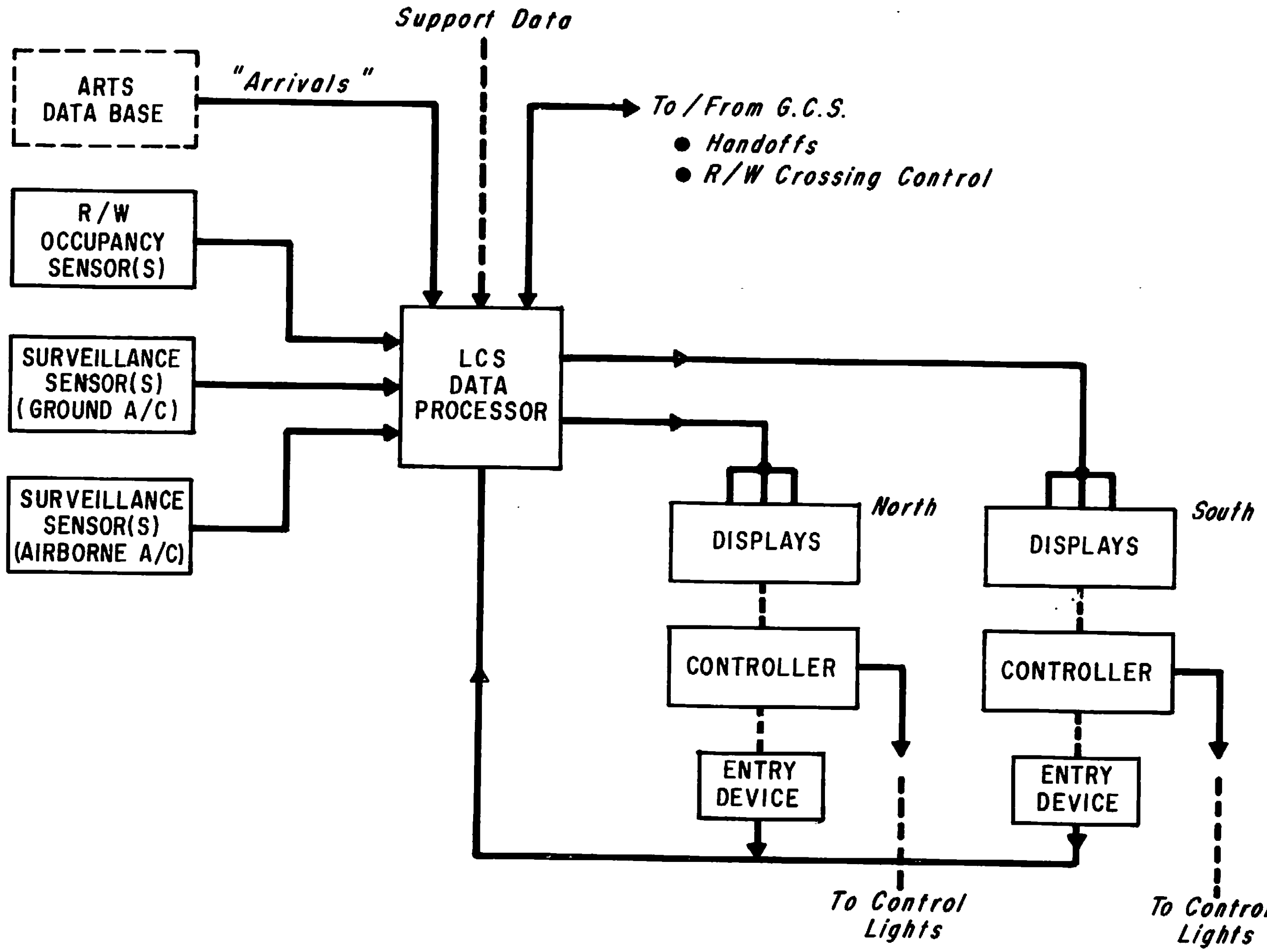


Figure 5-7. Major Components of Semi-Automated Local Control System (LCS)

The LCS must supply information to the Ground Control System for handoff purposes as well as runway occupancy or prediction data to be used by the Ground Control System in performing the Runway Crossing control function. In the latter area, conversely, it is expected that the GCS will provide information on taxiing aircraft that might impact upon the operations of the runways. Aircraft that have been handed off by the Ground Control System to Local Control automatically will be entered in the Local Control System data processor at the time this event occurs. These departure aircraft essentially will be in an inactive status as they move toward the top of the Local Control departure queue.

The block diagram of the LCS also shows possible alternate communication paths between the Controller and aircraft; these paths are of a signaling nature and would be via control lights for such diverse purposes as releasing aircraft onto the runway entrance, clearing aircraft for takeoff, etc.

Additional interface requirement between LCS and other portions of the ATC system will necessitate the inputting of support data to the LCS data processor. This may include such parameters as the runway configuration in use, inputs from wake turbulence detector sensors, weather data, etc.

5.4 BENEFITS ANALYSIS

5.4.1 Capacity Improvement and Delay Reduction

While the present quota system at O'Hare is 135 ops/hr., there are numerous occasions when the ATCT will handle between 140-170 aircraft. These peak hourly loads are most prevalent in the summer period; the busiest hour at O'Hare was 208 aircraft moved in 1968. Weather is the primary cause of long delays. Such factors as local thunder storms forcing larger separations as well as conditions of poor visibility represent two different weather conditions affecting operations. In good weather, airport operational levels of 120-140 aircraft/hour result in average delay per departure between 6.2 minutes to 8.5 minutes. These results are for periods when essentially "no delay" would be reported by the ATCT. These delays have been found to be sensitive to the active runway configuration. It is believed that other factors such as individual differences between controllers may also play an important role in these delay variations.

The data inputs to the Local Controller come either from the position information on the BRITE (Airborne Arrivals only) or from visual surveillance. These limited data inputs do not provide much prediction capability for decision-making purposes by the Controller. It is in this area that the proposed semi-automated LCS can provide substantial assistance to the functional activities of the Local Controller.

This assistance would take the form of providing "flags" or signals to the Controller as to the acceptability of a particular decision (Clear to Takeoff; Clear to Enter Runway, etc) as well as furnishing "scheduling" recommendations. The benefits from the LCS would consist of improvements in

Arrival/Departure Sequencing

Landing Control

Runway/Runway Crossing Control

Interfacing with Ground Control for

- Taxiway/runway Crossing Control and
- Indication of when Turnoff-Generated Conflicts can exist

These improvements should reduce good weather delays and significantly increase the airport operational levels under conditions of poor visibility when it normally falls between 10 percent and 25 percent of normal operations.

If a reduction of 2 minutes could be achieved in the departure delays in good weather conditions this would result in a daily saving of about 700 x 2 = 1400 minutes based upon 700 departures taking place during busy hours. Over the year this translates into cost savings (at $11.23/minute) of $4.7 million (1400 x 300 x 11.23).

5.4.2 Safety Benefits

The proposed LCS can provide substantial safety benefits by performing many "housekeeping" and estimations functions for the Local Controller, thereby releasing additional time for the exercise of human judgment. Such safety benefits become of greater significance in periods of low visibility if reasonable operational levels are to be achieved in these periods.

The operational areas wherein safety will be improved have been described earlier in this section as well as in the discussion on the Conflict Management function. Provision of additional information on operations in these areas on a timely basis (when needed) can also minimize differences between controller decisions and task scheduling. These factors should further reduce safety incidents in the most vulnerable portion of the tower operations, i.e., Local Control.

5.4.3 Workload Reduction

The workload of the Local Controller can be only partially estimated from the communication traffic. When delays exist the Controller must in most cases wait; during this interval he is continually reevaluating the situation. Table 5-5 provides an estimate of the functional activity of a Local Controller for departures (represented by "d") and Arrivals (represented by "a") under the present system as well as in the proposed semi-automated real time control system. It is estimated that appreciably more effort is necessary for Departures than Arrivals under the current system. Using the values shown of 8d and (5.5-7)a given in this table, an operations rate of 60/hr would require the performance of 405-450 functions per hour. In a peak minute perhaps 10-12 functions would require service. This functional load does not appear tractable by a single individual. The Controller therefore adapts to the situation (estimates Spacing Control, performs less monitoring of Departure Routing, and maintains further separation to ensure no possible conflicts can occur). Under the semi-automated concept, the functional activity level can be substantially reduced, primarily since the computer will be

Table 5-5. Functional Activity Comparison - Present and LCS Approaches

Control Function	Inter-acting Function	Estimated Required Functional Activity of Controller: Current System	Semi-Automatic System	Remarks
DEPARTURE A/C		5d	3.5d	
A Clear A/C to R/W	K-1	d	.25d	With signaling
B Clear A/C for Takeoff	K-2; K-4 L-1; L-2	d	.25d	With signaling
C Departure Routing				
Assignment		d	d	
Verification		d	-	
D Handoff to Departure Control		d	d	
ARRIVAL A/C		(3.5-5)a	(3.5-5)a	
E Accept Handoff from TRACON		a	a	
F Spacing Control		(0.5-2.0)a	(0.5-2.0)a	Remains with ARTS
G Landing Control	K-5; L-3	a	a	
H Handoff to Ground Control		a	a	
COMMON FUNCTIONS				
K Single R/W Conflict Management		2d + a	.25d+0.1a	
K-1 R/W Entrance Delay		d*	.15d	Primarily controller override
K-2/ K-4 Takeoff Delay/Previous Operation		d*	0.1d	
K-5 Arrival/Previous Operation		a	0.1a	
L Intersecting R/W Conflict Management		d + a	.2d + .1a	
L-1/ L-2 Takeoff Delay/Arrival or Departure		d*	.2d	
L-3 Arrival/Previous Operation		a	.1a	
TOTAL		8d* (5.5-7)a	4.0d (3.7-5.2)a	

Notes: d = Departure A/C a = Arrival A/C *Value may be appreciably higher if several evaluations are required per aircraft operation.

performing the calculation of "release" times, detecting potential conflicts, and providing spacing control assistance to the Controller. The application of "signaling" for Departures (release onto runway, release for takeoff) is also a significant possible source of workload reduction.

With the LCS, therefore, it is estimated that the Controller's workload would be reduced to between 50 percent to 60 percent of the present workload (on a functional basis).

SECTION 6 - RELATED SUPPORT CONCEPTS

6.1 AUTOMATIC GATE STATUS EQUIPMENT (AGSE) CONCEPT

6.1.1 Introduction

The Automatic Gate Status Equipment (AGSE) concept is relatively new to airport surface traffic control. The AGSE provides a means of coordination between the ATCT and airlines flight operations in the management and control of aircraft movements, which heretofore has not existed.

The AGSE concept has been discussed to a large extent in Section 3 as an integral element of the Ramp Control System concept. It plays an important role in the Ramp Control System for the implementation of Positive Ramp Control at airports requiring this capability. However, the AGSE concept can be quite useful at those airports for which Positive Ramp Control is not required. This importance derives from the reduction of controller-pilot communications workload which may be achieved.

This section is devoted to a discussion of the AGSE concept in this latter context. Reference to previous discussions in Section 3 will be made where applicable to avoid unnecessary repetition.

6.1.2 Information Requirements Estimation

In an airport environment in which Positive Ramp Control is not required, the requirements for AGSE stems from three basic information needs of aircraft ground control. These are:

- Identification of the point of origination (terminal gate or other portion of the airport ramp area) for departures and other flights outbound from the passenger terminal(s).

- Identification of the destination (terminal gate or other portion of the airport area) for arrivals and other aircraft inbound to the passenger terminal(s).

- Information on the availability of the destination gate for arrivals and the extent of any delay in its availability.
- Information that the arrival aircraft arrived at and docked or parked at their destination gate.

Knowledge of the point of origination is required for determination and transmission of the routing of the departure to the appropriate departure runway by (Outbound) Ground Control. The second data element is needed for determination and transmission of the routing for other outbound flights to the appropriate cargo/hangar area by (Inbound) Ground Control. The third is determination of the position of the flight for reference in sequencing (controlling) the entry of the flight into the traffic flow on the taxiway network. The fourth element (position of the flight) would be useful for initiation of automatic surveillance and tracking of its movements in order to reduce the time for search and acquisition by the surveillance subsystem.

Knowledge of the aircraft destination is similarly important for routing of Arrivals or other traffic to the terminal building. Depending on the airport runway-taxiway surfaces configuration and associated routing patterns this data element may also be important in sequencing of these flights into the traffic flow pattern.

Availability status of aircraft destination gates is also important in the aircraft routing. When a flight's gate is not available it may be necessary to route it to a holding area (e.g., the Penalty Box at O'Hare). In addition, since there may be several holding areas, the usage of these is dependent on the destination gate of the flight and/or the amount of gate delay anticipated. This, therefore, will also affect the routing of the aircraft.

Knowledge that aircraft have arrived at and docked/parked at their destination gate is important for two reasons. The first is that when this occurs the aircraft no longer represents any potential need for service by the ATCT. Under certain conditions where the controller cannot visually observe this event, explicit action to indicate its occurrence becomes neceessary. These conditions could exist when controller visibility of the terminal ramps is blocked due to the physical configuration of the terminal or other physical structure with respect to the location of the ATCT. They could also exist under low visibility operating conditions.

The second reason is that aircraft gate arrival data is a useful element in maintaining gate availability status. This could eliminate the need for direct coordination with airline flight operations for each arrival.

6.1.3 Functional Flow Description

The functional flow of the AGSE in airports not requiring Positive Ramp Control is illustrated in Figure 6-1.

As in the previous Ramp Control System discussions the pre-filed gate schedules and updates by airlines' flight operations personnel would be maintained in the Gate Schedules File. This information would be utilized in the generation of improved flight strips as previously discussed.

When an arrival flight is added to the Ground Control Arrivals Q List by the Local Control System, a request for a gate availability for the flight is received. The Gate Schedules file will then be accessed to determine the assigned gate and its availability. A gate could be defined as available if it was open or a departure on the gate has pushed back and called for taxi.

If the assigned gate is found to be available, the assigned gate number and its availability would be transmitted to the Ground Control System.

If the assigned gate is not available a gate verification request would be displayed to the appropriate airline's ramp controller. A revised gate assignment and/or gate availability delay would be entered by the airline's ramp controller. This data would be transmitted to the Ground Control System and would update the Gate Schedules data.

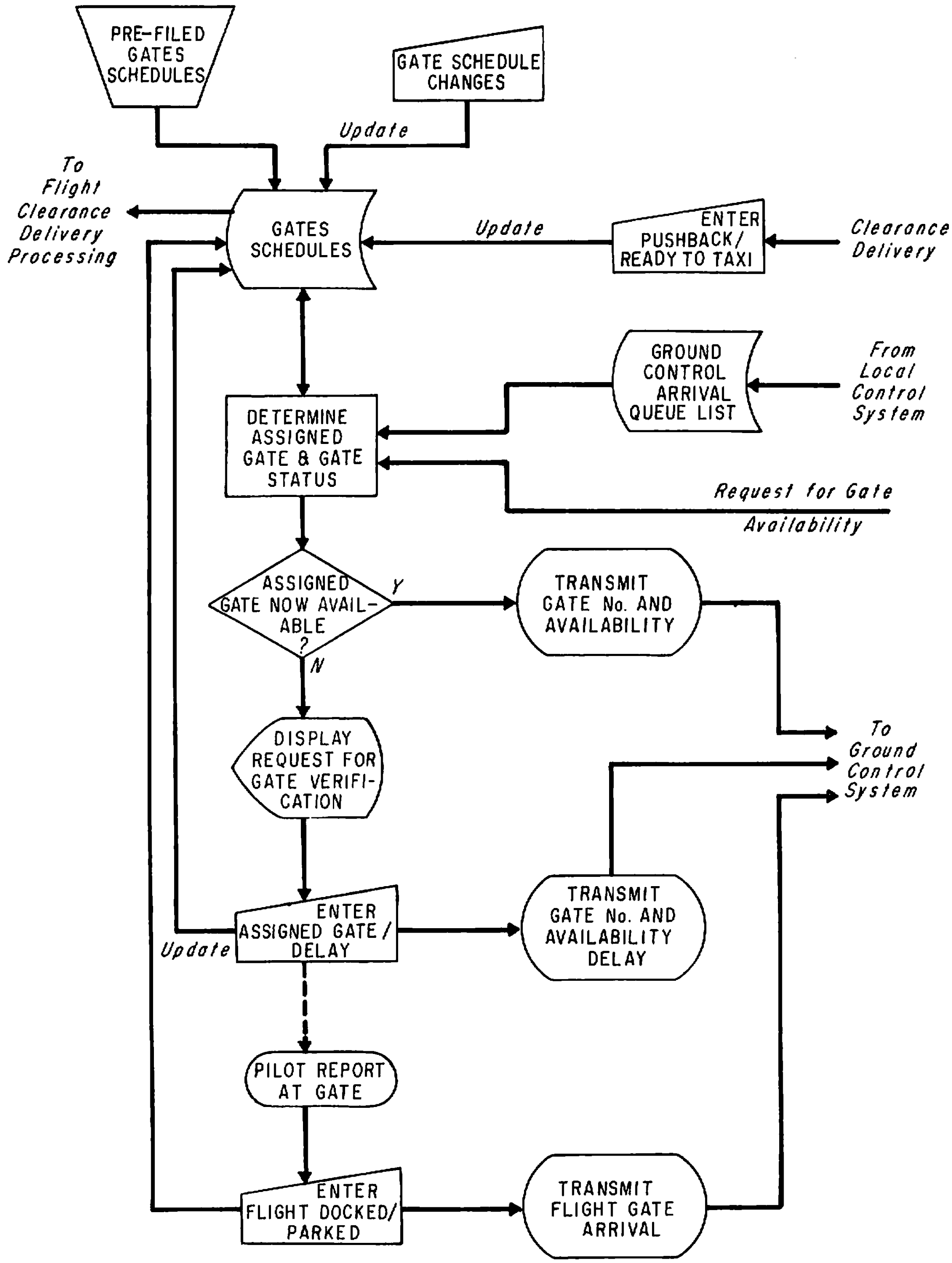


Figure 6-1. Functional Flow for AGSE in Airports Without Positive Ramp Control

At a later time the flight's arrival at its gate would be reported by the pilot to the airline's ramp controller (or observed by the ramp controller, where the airline operates its own operations tower). This status report would be entered by the airline's ramp controller. This would result in transmission of an indication of gate arrival to the Ground Control System in order that the flight could be deleted from the Active Aircraft List. It would also update the Gate Schedules data.

6.1.4 Operational Requirements

The AGSE should possess sufficient capacity to meet the requirements for:

- Storage of Gate Schedules data
- Processing of all inputs updating this data base
- Display of gate availability requests at all airlines installations
- Receipt, processing and transmission of response to gate availability queries.
- Generation and transmission of gate arrival status to Ground Control System.

At a minimum, sufficient capacity should be provided to meet all requirements at the peak operations rate of the airport to avoid any delay in the receipt, processing, and response to gate availability requests from the Ground Control System. Under low visibility operating conditions it is likely that changes to gate assignments and/or gate availability delays would increase. The AGSE should possess sufficient capacity to handle the increased number of data entries and display of gate verification. However, as the volume of traffic operations is likely to be lower under these conditions the capacity for operation at the peak operations rate of the airport may be sufficient.

6.2 STANDARD TAXIWAY ROUTING MODULE

6.2.1 The Routing Communication Problem

Ground control procedures at O'Hare require that the Outbound Ground issue to every departing aircraft a taxi route to the current departure runway. Presently, this routing data is communicated to the pilot by the Outbound Ground Controller as part of Function B (Release of Departure A/C into the taxi system), i.e., during the initial taxi clearance instruction. An example might be:

> "Eastern 114. Your runway is going to be 14 Right. Turn right onto the Outer behind that DC10 coming from your left. Follow to the New Scenic and then up the Bypass to the North West Parallel taxiway."

During busy traffic hours, communications are issued from Outbound Ground to the pilot in a more abbreviated format. This format permits the controller to handle more aircraft without saturating his communication channel. Thus the clearance example above is shortened to:

> "Eastern 114, 14R, Outer behind the 10 to Scenic, Bypass to North West taxi"

This abbreviated format requires greater pilot attention , since there are fewer redundant words. He must know the O'Hare taxiway layout better, since the route requires greater interpretation. Finally, the rapid message rate can increase pilot misunderstandings of the selected route and control instructions. Not all misunderstandings are pilot errors. In the above example, the Northwest taxiway and the Northwest Parallel taxiway are at opposite ends of O'Hare. Should the pilot take the "Old Scenic" instead of the "New Scenic" in the abbreviated format example, runways 4L and 9L may be crossed before the Outbound Ground detects the error.

A similar routing scenario occurs with arrival aircraft and the Inbound Ground Controller. Here Inbound Ground must issue a taxi route to each arrival aircraft. This routing data is communicated to the pilot by Inbound Ground on the initial communications with the pilot after handoff from Local Control (at start of Function E, Acceptance of A/C into Taxi System). Again, as traffic increases, Inbound Ground will issue route and control instructions in an abbreviated format in order to prevent saturating his communications channel.

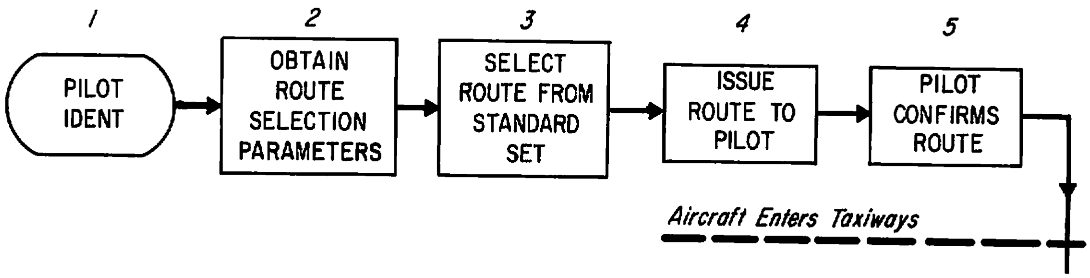
Safety incidents can occur when routing misunderstandings result in aircraft crossing active runways or competing simultaneously for the same piece of taxi pavement. The Standard Taxiway Routing module (STR) is proposed to reduced this safety hazard as well as increase the Ground Controller's workload capability (number of aircraft handled).

6.2.2 Standard Taxiway Routing Considerations

At O'Hare, most departure taxi routing schemes are procedurally established by parameters that are independent of Outbound Ground Controller actions. These parameters such as gate position, departure runway, etc., are usually fixed and known well ahead of taxi clearance time. As such, detailed departure routing can be correctly established, for most aircraft, minutes before taxi clearance requests are to be issued.

Similarly, arrival aircraft have established routing parameters that are independent of Inbound Ground action. Again, these parameters such as landing runway or gate/penalty box destination can be determined well ahead of Local Control handoff. Thus, detailed arrival routing can also be established several minutes before handoff.

The Standard Taxiway Routing module is proposed to perform the establishment and issuance of standard taxi routing for all aircraft entering the taxiway system. These are the five steps of the initial routing sequence outlined in Figure 6-2. The STR module will eliminate the burden of detailed routing responsibility on the two ground controllers and their communications channels. Pilots could then receive their routing instructions in some other



STEP	METHOD	PROCESS
1	RADIO	PILOT IDENTIFIES HIS CALL SIGN. THIS IMPLIES A REQUEST FOR ROUTING INSTRUCTIONS FROM THE APPROPRIATE GROUND CONTROLLER.
2	RADIO VISUAL FLIGHT STRIPS OTHER	GROUND CONTROLLER GATHERS PARAMETERS FROM VARIOUS SOURCES. EXAMPLES ARE AIRCRAFT TYPE, RUNWAY CONFIGURATION, IN-FLIGHT RESTRICTIONS, GATE SOURCE OR DESTINATION, AND SO FORTH.
3	MEMORY PRO-CEDURAL CRITERIA	GROUND CONTROL SELECTS ROUTES AND ALTERNATES FROM MEMORY OF THE STANDARD ROUTES. THIS IS PREVIOUSLY ESTABLISHED PRO-CEDURE.
4	RADIO	GROUND CONTROLLER ISSUES A DETAILED ROUTE TO THE PILOT FOR HIS WHOLE TAXIWAY ROUTE.
5	RADIO	PILOT ACKNOWLEDGES BRIEFLY THE ROUTE BY EITHER REPEATING THE LAST WORDS OF THE ROUTE OR HIS CALL SIGN.

Figure 6-2. Initial Routing Sequence of Inbound and Outbound Ground

manner and most likely prior to taxi clearance requests. Using STR, the pilot and the Ground Controllers will both know the detailed routing scheme assigned to the aircraft. By adding a phonetic such as, "I've got STR Alpha", to the initial Step 1 call, the pilot has performed Step 5, confirmation of the route. The Ground Controller will only issue changes to the STR route (rare) as required for conflict resolution or required recent changes due to the runway, taxiway, or terminal traffic control configurations.

6.2.3 STR Module Development Concepts

The STR module will develop in stages from an initial primitive form until it is finally integrated into a fully automated taxiway routing control system of later years. The initial stages of STR may be implemented with just procedural changes. As such, the STR system will handle the bulk of the predictable routing now burdening the Inbound and Outbound Ground controllers. The intent is to offload this burden onto the as yet unspecified STR techniques.

Possible methods of communicating the routing information to the pilot include

1. The use of data links.

2. Issuance during the clearance delivery process. This may require that confirmation of enroute clearance is handled in a different manner than at present.

3. Use of billboard type signs at the gates.

4. ATIS type channels.

The STR module is not associated with a specific piece of developmental hardware, but is part of the taxiway routing function (Function H) and can be implemented by various methods. As the developmental hardware items of the ASTC modules are installed, the STR module may be implemented with this hardware and in later years it could be integrated into a fully automated taxiway routing control system. Various stages of STR implementation will result.

A criteria for the STR module design is to maximize payoff in terms of increased safety, increased aircraft throughput rates, ability to operate effectively at lower weather minimums, and reduced controller communications workloads. Events of lower probability, such as "pop-ups" or Cat IIIC capability, may be excluded from STR unless their payoffs justify the increased costs and complexity. It may be that some STR methods cannot implement satisfactory taxi routing of arrivals since arrival routing is less predictable. For instance, early or late runway turnoffs of arrival may result in different standard taxi routes. Also, a gate status change or ramp pushback congestion can dynamically alter arrival routing.

6.2.4 Functional Requirements Estimation

The following is an estimate of the functional requirements of the Standard Taxiway Routing Module. As indicated in the previous paragraph, STR is primarily a procedural module not associated with a specific hardware item. The STR module is part of the taxiway routing function that deals with the issuance of standard routes to all aircraft entering the taxiway system. Its elements will be undergoing change as hardware is added, obsoleted or upgraded in the ASTC systems. Thus, the STR module requirements, the resulting benefits, and actual implementation may be affected by each change in the total ASTC system.

The functional requirements or elements of the STR module are tabulated below and outlined in Figure 6-2.

1. Aircraft Identity
2. Acquisition of Route Selection Parameters
3. Route Selection Algorithm
4. Route Issuance
5. Pilot Confirmation

The necessity for aircraft identify depends on the particular type of STR module. The ATIS broadcast type of STR Module would not require initial aircraft identity. The advanced data link STR module would require aircraft identify if it is to perform individual route selection and issuance.

The Route Selection parameters are the information inputs used by Inbound and Outbound Ground Controllers to select a particular taxiway route for arrivals and departures. Table 6-1 lists the major Route Selection parameters used by the O'Hare Inbound and Outbound Controllers in early 1974. The list changes periodically as the airport layout and traffic control procedures are changed.

Table 6-1. Route Selection Parameters

Selection Parameters	Routing Affected	Controllers Source
Runway Configuration in Use	Both	ATC, local
Taxiway Configuration (Maintenance/Obstructions)	Both	Visual, radio, other
Surface Origin and Destination	Both	Radio, visual, surveillance sensors
Aircraft Type (747 Heavy)	Both	Part of A/C identity
Gate Status	Arrival	Visual, radio from Ramp Control System
Penalty Box-Hold Points Status	Arrival	Visual, other
In Trail Restrictions*	Departure	Flight strip
First Fix*	Departure	Flight strip

*May impact on Surface Origin and Destination.

Eleven major runway configurations are identified in the Operational Analysis report for O'Hare in 1974. Each configuration results in two or more standard departure routes plus alternates. An STR functional requirement is to select the correct routes from these 70 or so standard routes. The selection process or algorithm is based on the selection parameters. This requirement can be a simple Flight Data Controller Table Look-up procedure or it may be a program within a computerized automated routing control system.

The functional requirement for route issuance will be the STR communication link to the pilot. At present, the Ground Controller half duplex party line radio channel performs this function. Any effective STR module will have to develop a different link or method of communicating detailed routing to the pilots. For the semi-automated ASTC system, it appears that VHF radio-voice communications will be used exclusively. In the more advanced ASTC systems of later years, STR communications may be assisted by automated CGE and/or VGE systems. As an example, a CGE cockpit/tower data link with automatically switched control signs and lighting systems may be used for route issuance. Costs and responsibilities for CGE and VGE systems will spread across the airport authority, the air carriers, and the FAA causing great inertia on speedy implementation. The present controller partyline single-channel communications may be unacceptable for STR purposes due to such hazards as a "stuck-mike" button or simultaneous transmissions by two or more channel users. Discrete address-handshaking roles over a multichannel communication link may be required for STR communications.

The pilot confirmation of the route is considered a necessary feedback control requirement. Without confirmation, the ground controller has no positive assurance that the pilot has received the correct route. The present use of partial confirmation is hazardous. Full confirmation by the pilot reporting back the detailed route may be necessary. This could be automated with CGE items such as the Cockpit-Tower data link, but would saturate the present Ground Controller communication channels.

SECTION 7 - SUMMARY OF SENSOR PERFORMANCE REQUIREMENTS

This section summarizes the estimates of performance requirements made in the preceding sections of this report. In addition, the independent estimates made by our subcontractor, Bendix, are also discussed.

If the Ramp Control System option is selected, it is recommended that no attempt be made to obtain aircraft maneuver data (position, velocity, etc.) on aircraft within the ramp area except for automatic transfer of VFRs and general aviation IFRs to the Handoff to Ground Control Departure Q function (see paragraph 3.2.3.1). Such automatic transfer will require resolution capabilities on the order of 100 feet from aircraft center to aircraft center. In general, however, information on aircraft position within the ramp area will be obtained via procedures using AGSE (gate) data, estimates made from empirical data (using measured values of pushback time, entry time, etc.) and inputs from the GCS.

The semi-automated GCS must provide surveillance data on all aircraft on the taxiways and runways since the latter are sometimes used for taxi purposes when they are not in use for landing or departing aircraft. Surveillance data is not required on aircraft entering staging areas or the Local Control Departure Q; aircraft "track" will be suspended at these locations and reinstituted at a later time. We estimate that the surveillance sensor(s) should provide the following capability (all values shown except response time are one-sigma)

Position Accuracy	20-30 ft
Velocity Accuracy	2-3 fps
Directional Accuracy	10 degrees (for Turn Recognition)
Response Time	2-3 seconds

with a sample period of the same magnitude as the Response Time.

If velocity data is to be derived from position measurements, it is estimated that a more stringent position accuracy will be required. This is estimated to be about 10 feet. However, an alternative of higher sample rates (e.g., 10 samples/second) will relax this requirement back to 20-30 ft.

The estimates made by our subcontractor, Bendix, for the GCS are

Position	±50 feet
Velocity	±5 percent (about 2.5 fps for V = 30 knots)
Directional	±20 degrees

No response time values have been provided by Bendix.

Resolution requirements for the GCS are based upon physical characteristics of the airport with the ability to resolve an aircraft on the Inner Circular from one on the Outer as a limiting case. Resolution capabilities of about 200 ft, from aircraft center to aircraft center, appear necessary.

The estimated sensor performance requirements for the semi-automated LCS must be given for airborne aircraft and for surface aircraft. The LCS must provide airborne coverage out to 5 nmi from runway thresholds and ground coverage of all runways as well as the entrance and exit links interfacing with the runways. Resolution capabilities of the airborne area of the LCS are estimated as 1000 ft in order to separate aircraft on parallel approaches and to distinguish aircraft on different altitudes. In the ground position of the LCS, resolution capabilities of about 200 ft should permit recognition of aircraft exiting the Local Control Departure Q area as well as resolution of aircraft on the runways from those on the parallels.

The estimated performance requirements of the ground position of the LCS (one-sigma values except for Response Time) are as follows:

Position Accuracy	20 ft
Velocity Accuracy	2-3 fps
Directional Accuracy	5-10 degrees
Acceleration Accuracy	1.6 fps^2
Response Time	1-2 seconds

with a sample period of the same magnitude as the Response Time. As with the GCS, if position is used to estimate velocity either a greater positional accuracy (10 ft) or a higher position sample rate (10 samples/second) is required.

For surveillance of airborne aircraft, the estimated accuracy requirements of the LCS are

Position Accuracy	150 ft
Velocity Accuracy	8 fps
Directional Accuracy	15 degrees (Departure Routing)
Response Time	1-2 seconds

with a sample period of the same magnitude as the Respone Time.

The estimates provided by Bendix for the LCS are as follows:

	Ground Aircraft	Airborne Aircraft
Position Accuracy	±30 ft	±100 ft
Velocity Accuracy	±2 percent	3 fps
Directional Accuracy	±10 degrees	±20 degrees

No response times have been provided by Bendix at this time.

The independent estimates of CSC and Bendix given above do not differ significantly. Both companies recognize the significance of velocity for such purposes as Movement Recognition as well as prediction. The need for some type of "heading" (aircraft fuselage direction) or "course" (velocity vector orientation) is recognized for such diverse purposes as Turn Recognition, Turnoff Recognition, Departure Routing, Turn onto Runway, etc. The achievement of this capability from a series of position measurements must be further investigated if the necessary algorithms are to be developed and evaluated.

Combining the requirement of the GCS and the ground portion of the LCS (since these can possibly be provided by one sensor subsystem) results in the following composite requirements for surface aircraft:

Position Accuracy	20 feet
Velocity Accuracy	2–3 fps
Directional Accuracy	5–10 degrees
Acceleration Accuracy	1.6 fps
Response Time	1–2 seconds

with a sample period of the same magnitude as the Response Time.

If position is to be used for derivation of velocity and/or directional data either a position accuracy of the order of 10 feet or a sample rate on the order of 10 samples/second will be required.

APPENDIX A - CHARACTERISTICS OF THE TAXIWAY NETWORK AT O'HARE

The taxiway network at O'Hare will be described in terms of links and nodes (or intersections); it serves traffic primarily between the ramp exit/entrance nodes and the runway nodes (Departure Q areas and runway turnoffs). The control of port surface traffic (i.e., the management of these taxi facilities) will be strongly influenced by such physical characteristics of the network as link size (length) and network connectivity. Other factors such as the active runway configuration, aircraft equipment characteristics, and traffic loads must also be considered in the control process.

The nodes at O'Hare, considering primarily the South side of the airport, may be considered to fall into one of the following classes:

Ramp Nodes (R)
Inner Circular Nodes (I)
Outer Circular Nodes (O)
South Taxiway Nodes (S)
Runway Turnoff Nodes (Y)

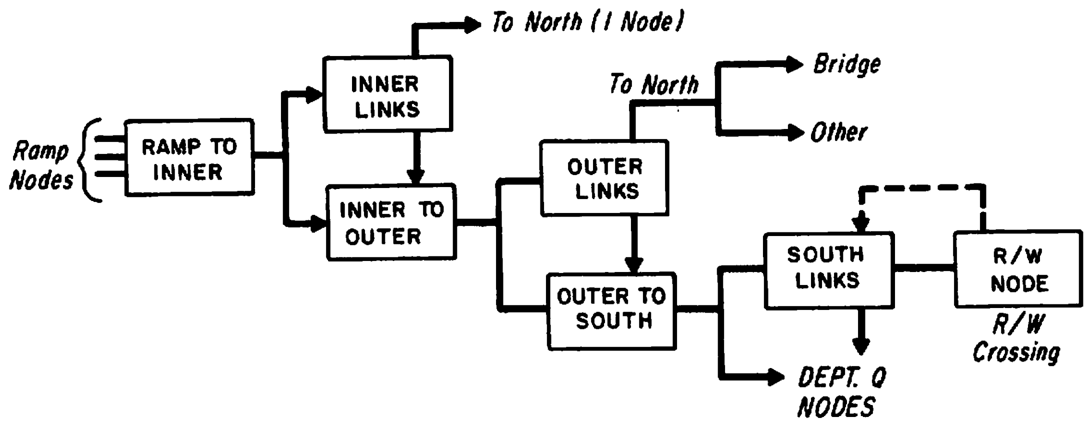
The connectivity between these classes of nodes may be described in matrix format as shown in Figure A-1; note that connectivity may exist only between certain classes (i.e., no single link exists between any Inner Circular and South Taxiway nodes). The diagonal entries in this matrix (I/I for example) represent "highways" while the off-diagonal entries represent interconnecting links between the "highways", or between the entry/exit modes and highways.

A representation of the flow of aircraft through these links and nodes is shown in Figure A-2 for both Departures and Arrivals. Figure A-3 shows the taxiing process for Departures in finer detail. The number of links traversed on the major arteries varies from aircraft to aircraft; however, only a single interconnecting link (I/O, O/S) of each category will normally be used in the taxiing process at O'Hare.

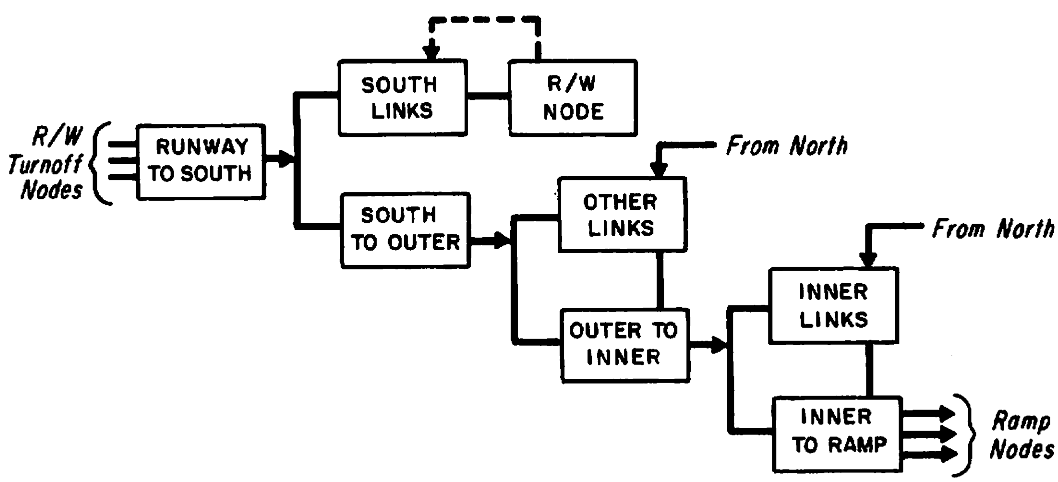
NODE (INTERSECTION) CLASSES

	Ramp Nodes (R)	Inner Circular Nodes (I)	Outer Circular Nodes (O)	South Taxiway Nodes (S)	Runway Turnoff Nodes (Y)
R	-	R/I	-	-	-
I		I/I	I/O	-	-
O			O/O	O/S	-
S				S/S	S/Y
Y					-

Figure A-1. Connectivity Matrix for Node Classes O'Hare Airport (South Side Only)



a) DEPARTURES



b) ARRIVALS

Figure A-2. Aircraft Flow Through Taxiway Network (O'Hare)

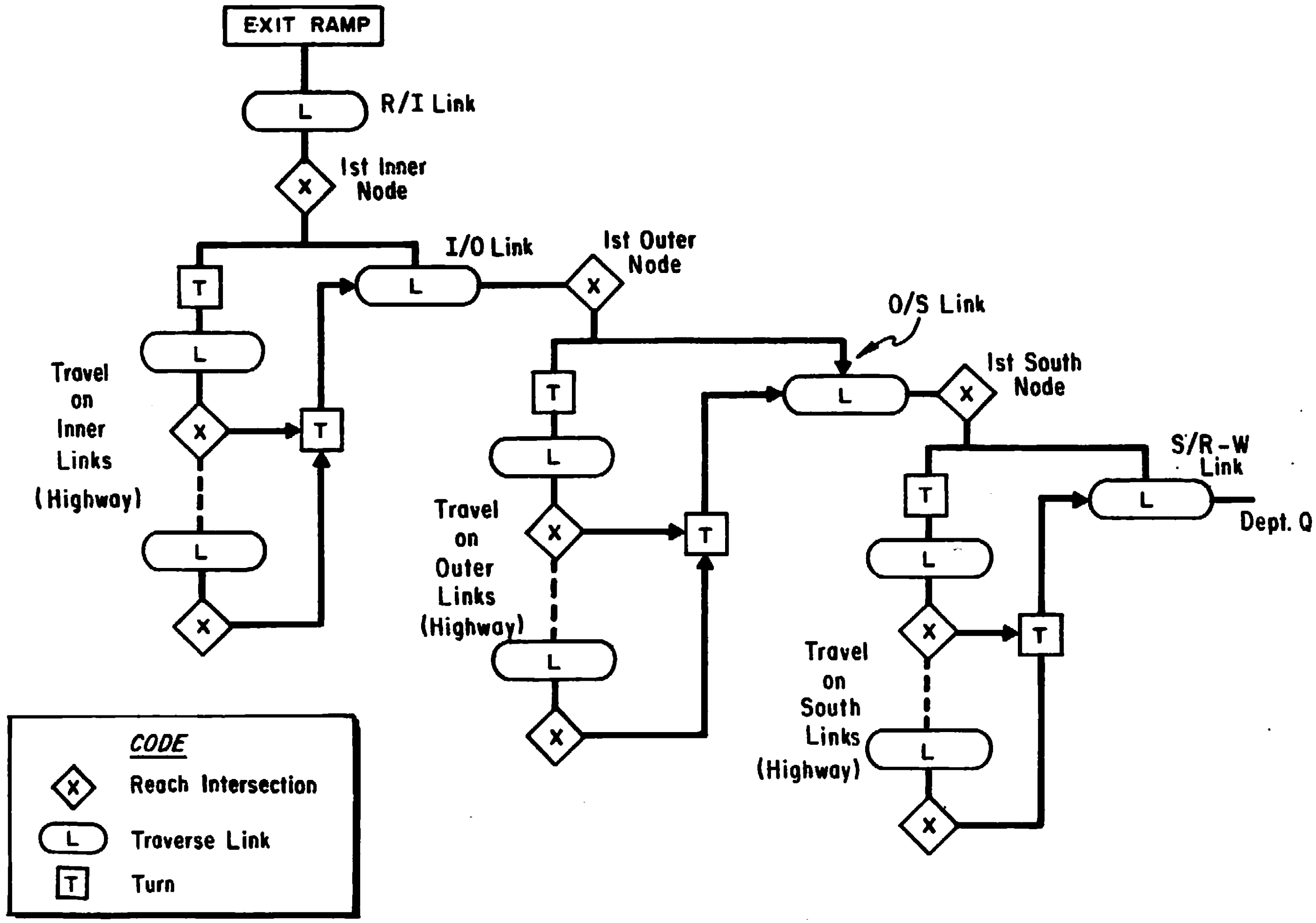


Figure A-3. Individual Aircraft Movements on O'Hare Network (Departures)

Aircraft movement involving cargo, hangar, or penalty box areas have not been considered at this time.

The detail portions of the connectivity matrix are examined below; Figure A-4 illustrates the numbering scheme employed. The nine ramp areas (B-C has been included, although seldom used) have been considered as having 12 nodes, since several ramp areas appear capable of handling two operations simultaneously (A-B, E-F, and H-K). The adjacent Inner Circular nodes will define the permissible Ramp/Inner (R/I) links; these are indicated in the upper left section of Figure A-5 which provides the details on the R/I portion of the connectivity matrix previously described. While only one entry is shown for each link, this submatrix may of course be expanded to include traffic direction by defining columns as "sources" and rows as "sinks" as has been done for the INNER, OUTER, and South highway links (I/I; O/O; S/S).

The center of the intersection has been used at this time for evaluation of link distance. The R/I links are quite short, averaging about 175 feet. The I/I and O/O links are also relatively short; we estimate that 7 of the 15 I/I links are less than 350 feet long and, therefore, cannot serve as aircraft holding locations without interfering with adjacent nodes and/or links. The O/O links average over 600 feet in length and are relatively equal in size; each appears capable of a "Hold" without hampering adjacent node and crossing link usage.

The interconnecting links between the Inner and Outer (I/O) are also short (around 275 feet in length) and should not usually be used for holding. It is not until aircraft reach the S/O links that sufficient length exists for implementing non-interfering "holds". These seven links range from 400 feet to 700 feet in length, excluding the bypass and 0-10/0-13 link.

A summary of the links, nodes, and the associated center/center link distances is given in Table A-1. The common taxi area serving both the North and South sides of the airport includes about 3,150 linear feet of R/I links, an INNER highway of 7,000 feet, an OUTER highway of 8,000 feet, and the short I/O links comprising about 4,000 linear feet.

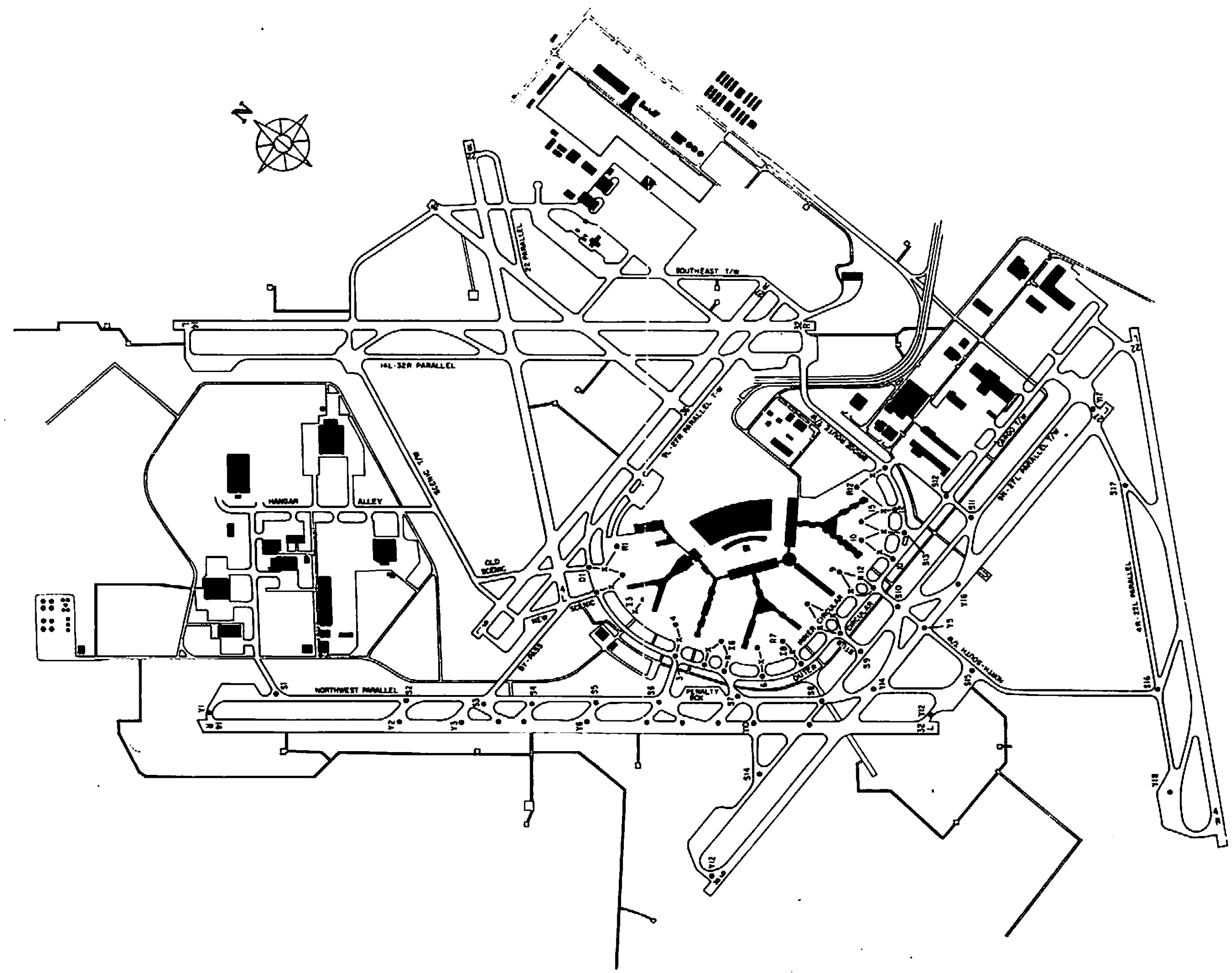


Figure A-4. Node Identification - O'Hare Airport

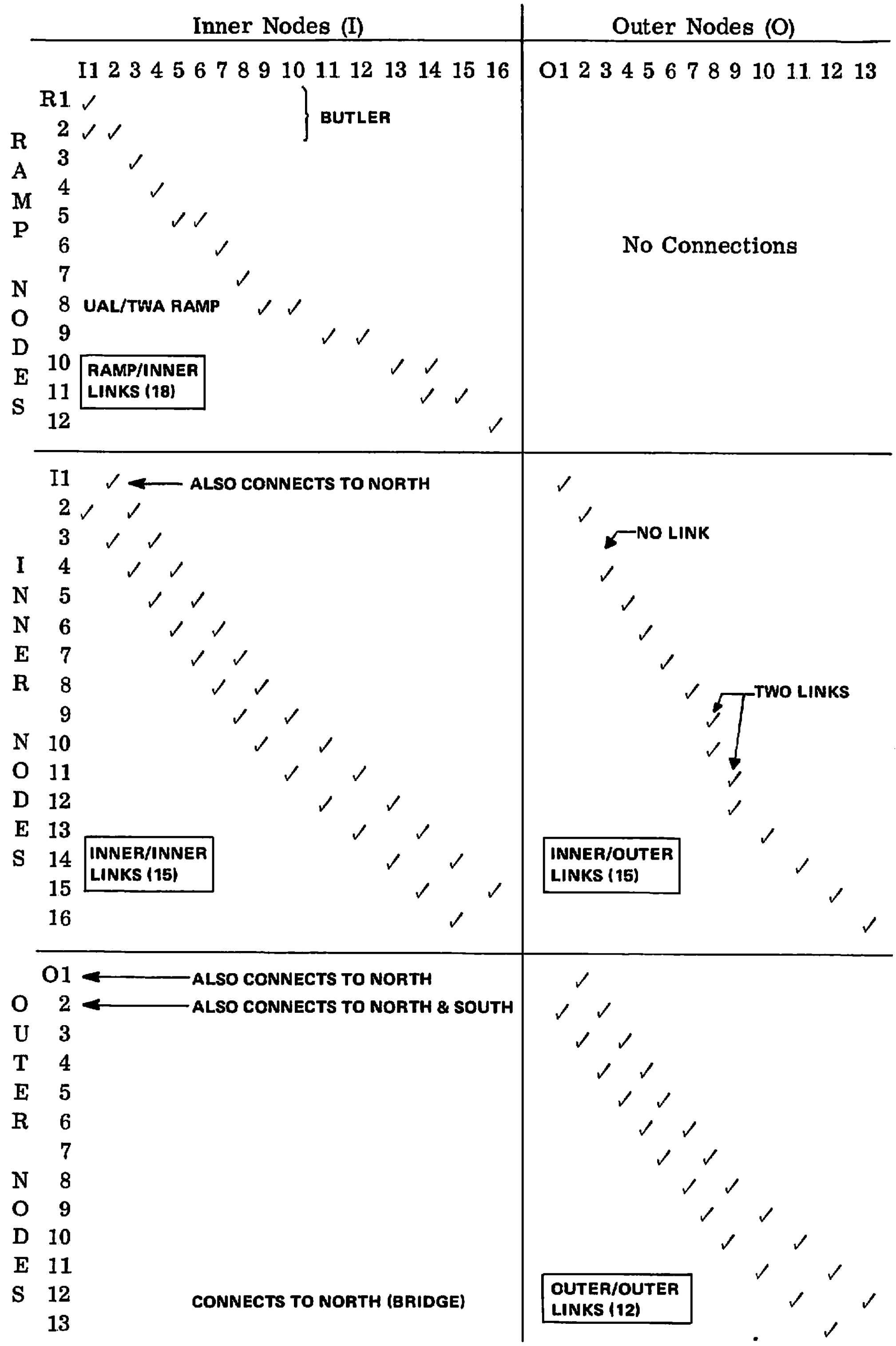


Figure A-5a. Detail Connectivity Matrix O'Hare Airport

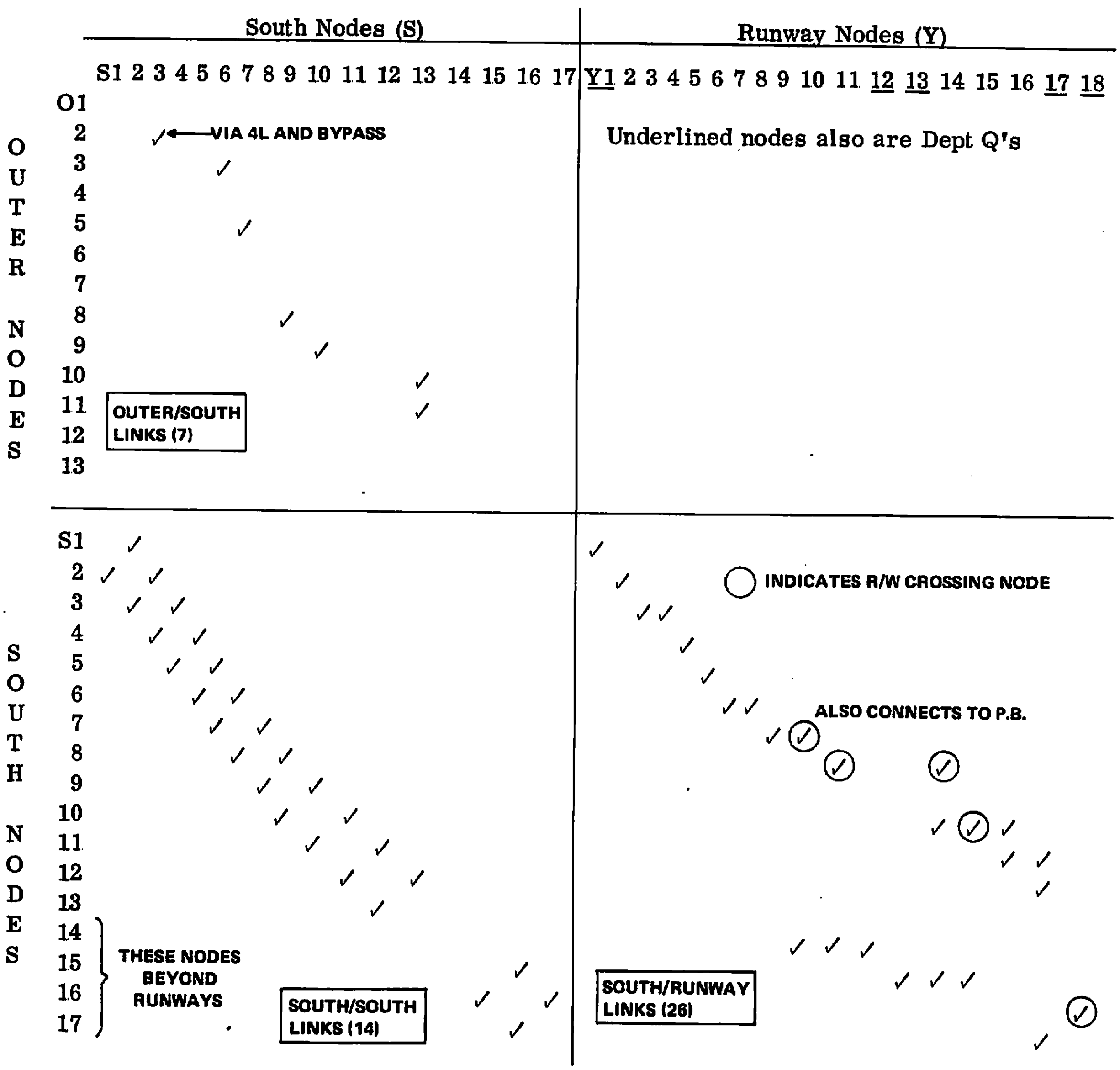


Figure A-5b. Detail Connectivity Matrix O'Hare Airport

On the other hand, the South taxiways north of the runways offer about 14,000 feet of pavement; note, however that the seven S/O links (of which only part are used depending on the runways in use) offer about 3,500 feet of taxi surface.

Runway nodes include both "turnoffs" as well as Departure Q locations (which may also be used for turnoffs when the runway direction is reversed). R/W crossing nodes have been separately identified in Figure A-6 which portrays the common and South side taxi structure on a "flow", or logical basis. This type of display presentation may be desirable for some of the control functions.

Excluding ramp entry/exit nodes the South side of O'Hare has 64 nodes or intersections including 9 which are runway turnoffs only. Of the total of 98 links on the South side (excluding turnoffs), 40 are less than 350 feet in length.

Table A-1. Summary of Common and South Taxiway Facilities - O'Hare

Ramp Area (R)	
Number of Ramp Areas with Single Node	6
Number of Ramp Areas with Dual Nodes	3
Inner Circular Highway (I/I)	
Number of Nodes	16
Number of Links	15
Total Length of Inner Circular	7000 ft
Number/Identification of Links less than 350 ft long	7 (Links 1-2, 4-5, 5-6, 9-10, 11-12, 13-14, 14-15)
Ramp/Inner Circular Links (R/I)	
Number of Links	18
Link Distance	
Maximum	225 ft
Average	175 ft
Minimum	140 ft
Outer Circular Highway (O/O)	
Number of Nodes	13
Number of Links	12
Total Length of Outer Circular	8000 ft
Inner/Outer Links (I/O)	
Number of Links	15
Link Distance	275 ft (little variation between links)
South Taxiway (S) - Parallels - Highway	
Number of Nodes	13
Number of Links	12
Total Length (S-1 to S-13)	8850 ft (S-1/S-8) 3800 ft (S-8/S-11) 550 ft (S-11/S-12) 850 ft (S-12/S-13)
South/Outer Links (S/O)	
Number of Links	7
Link Distance (excluding Bypass and 0-10/S-13 Link of 200 feet)	400-700 ft

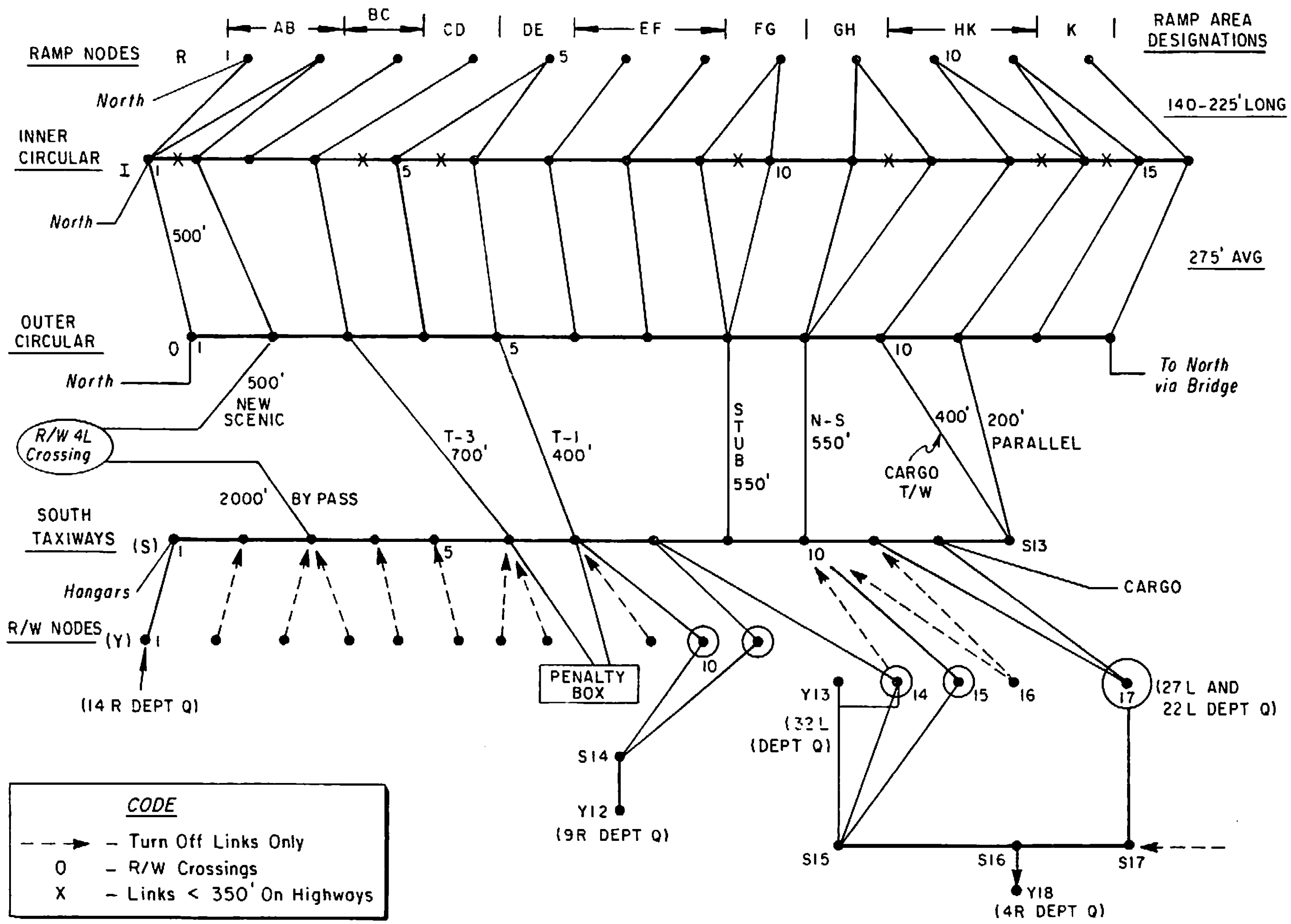


Figure A-6. South Taxiway Network - O'Hare

APPENDIX B - AIRCRAFT MOVEMENT PROFILE CHARACTERISTICS

INTRODUCTION

Aircraft maneuvers on the airport surface will be of importance in the requirements establishment process. These maneuvers will be a function of the aircraft equipment type as well as the constraints imposed by the taxiway network. In general, aircraft speed will vary directly with distance from the terminal since links are longer farther out from the terminal. In the following sections, estimates of velocities for various aircraft maneuvers will be used with the geometrical values of the taxiway network (Appendix A) to obtain estimated time parameters for the various maneuvers.

Links have been considered as extending from node-center to node-center since in many cases an aircraft moving on a short link must be considered as occupying the upcoming intersection, i.e., there is insufficient room to stop without blocking the intersection. The rationale for link and node control is not discussed in this section.

Aircraft acceleration and deceleration have been considered as constant values between the initial and final velocities. Figure B-1 present the velocity and distance variations vs time for accelerations of 0.1 to 0.3 g's which are those expected on the taxiway surface. It is assumed that, after an aircraft reaches the desired speed, its acceleration will drop to zero. These relationships have been used in developing the estimates described below. Aircraft length has been taken as 250 ft (a 747 is about 232 ft.) and as 80 ft for small aircraft.

RAMP/INNER (R/I) LINKS

Three types of situations will be examined. Departure aircraft may transit R/I links either after having come to a full stop at the ramp exit or may move directly out (i.e., cleared to taxi instruction already received) without stopping. Arrival

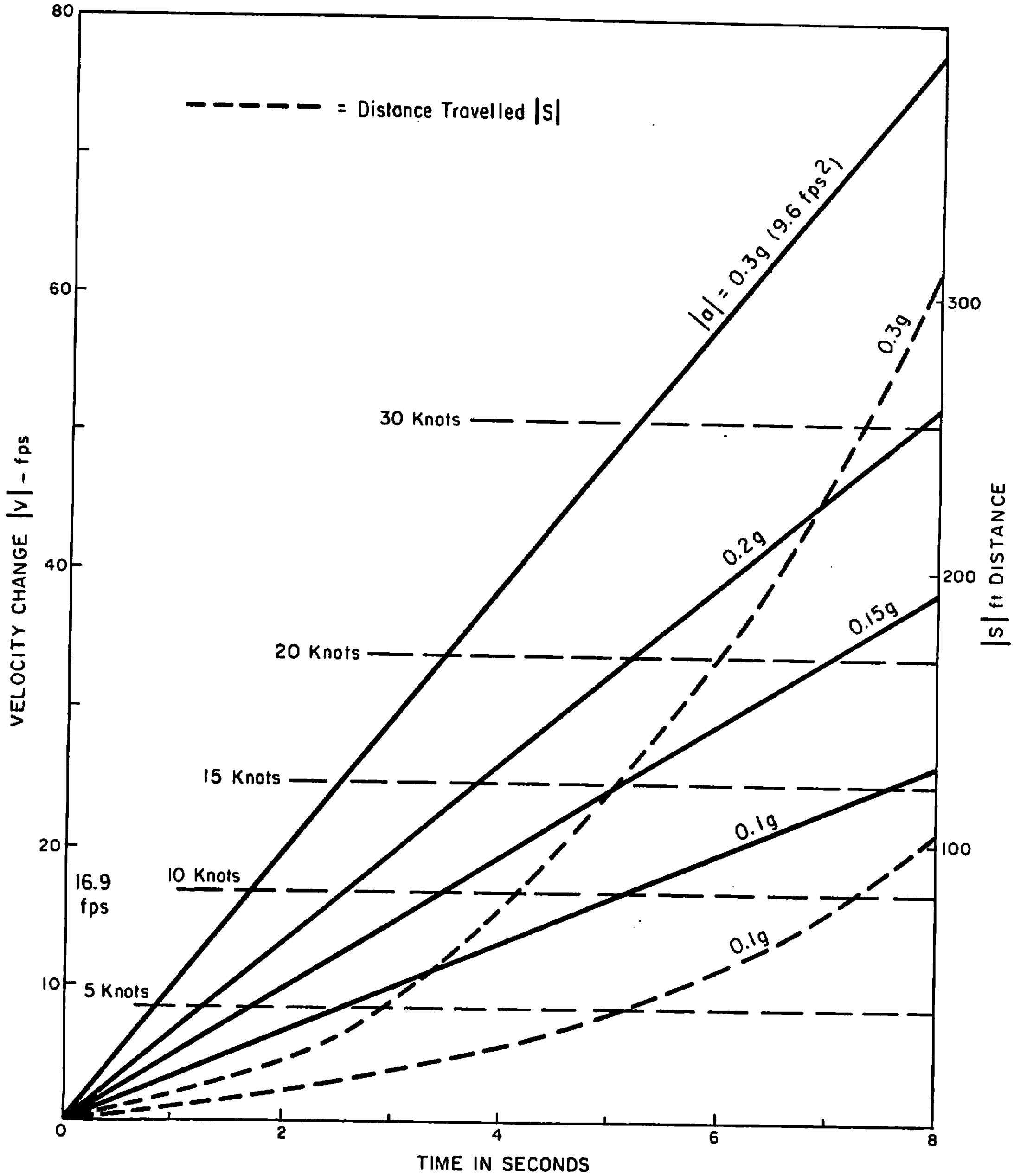


Figure B-1. Distance and Velocity Change for Constant Acceleration Levels

aircraft will not be held on R/I links and will move directly into the ramp area. While Appendix A describes R/I distances on a straight line basis, in many cases some aircraft turning is involved in the ramp exit/entry maneuver.

Measurements of Arrival aircraft movement in the ramp area indicate an average time from entrance to docking of 76 seconds. Allowing 40 seconds to 45 seconds for the turn-in and docking phase of this operation, it is estimated that the average aircraft travels straight in for about 400 ft. in a period of 31 seconds to 36 seconds, i.e., an average speed of 11 fps to 13 fps (around 7 knots to 8 knots).

To estimate the R/I parameters we shall use final velocities of 5 knots to 10 knots (8.5 fps to 17 fps) and accelerations of 0.1 to 0.15 g's (3.2 to 4.8 fps^2). Using the minimum and maximum R/I distances of 150 ft. and 250 ft. we may estimate the occupancy time of the R/I links under various departure aircraft situations, or

	R/I Link Occupancy Time - seconds			
	R/I = 150 feet		R/I = 250 feet	
	V = 5 knots	10 knots	5 knots	10 knots
After Stopping for a = 0.1 g	19	11.6	31	17.4
for a = 0.15 g	18.5	10.2	30.2	16.5
Without Stopping	17.5	9	29.5	15

These occupancy times are measured with respect to a common point on the aircraft, i.e., the nose, for example.

Link occupancy time is relatively insensitive to start-up acceleration and the entry mode (with or without a stop). Distance and taxiing velocity appear to be the most significant parameters. On longer R/I links it is believed that higher aircraft velocities (10 knots rather than 5 knots) would be used. We shall consider the normal range of R/I occupancy times for Departures to be 10 seconds to 20 seconds for distances of 150 feet to 250 feet and speeds of 5 knots to 10 knots.

Similar values will be used for Arrivals recognizing that the lower time intervals are more likely.

COMMON LINKS - (I/I, O/O, O/I)

These links involve both the Inner and Outer highways as well as the O/I links between them. It is estimated that taxi speeds of from 10 knots to 15 knots are most likely in these areas with link occupancy times of from 15 seconds to 25 seconds for distances of 300 feet to 700 feet when approximately uniform speed is maintained.

TRANSITION AND SOUTH LINKS (O/S and S/S)

These links include both the South parallels as well as the O/S interconnections and (because of the longer lengths involved) it is expected that average taxi velocity will range from 15 knots to 25 knots. For the distances set forth in Appendix A, it is estimated that occupancy time of between 15 seconds to 30 seconds will be normal. Only slight changes in acceleration are expected on these links.

TURN DURATION

For 90 degree turns it is estimated that between 10 seconds and 15 seconds will be required from the entrance of the undercarriage into the intersection until it enters the next link. These values may be used as additional time factors to be added to the normal link traversing (occupancy) times.

TURNOFF LINKS

Runway turnoffs vary from 90 degree turns to high speed exits; in general, the latter are larger. An exiting aircraft must be prepared to stop before entering the taxiway system at the adjacent parallel. Using deceleration values of from 0.1 to 0.3 g's, and turnoff velocities of from 20 knots to 35 knots, it is estimated that turnoffs will be occupied between 5 seconds to 8 seconds when no stopping is involved.

NODE CROSSINGS

Two situations are of interest here. In one, the node or intersection is traversed by the aircraft without stopping. In the other the aircraft has been stopped and must accelerate to cross. We have used 400 ft. as the maximum distance to be traveled by the crossing aircraft. This is based upon 75 foot taxiways, 75 foot clearance before crossing, and the selected length of the 747 (250 ft.) For smaller aircraft (80 ft. in length) the distance has been taken as 230 ft. The crossing values of 10 seconds to 24 seconds (without a stop) and 15 seconds to 26 seconds after stopping represent estimates and not exact computations.

RUNWAY CROSSING

Estimates for time required to cross runways have been made in the same manner as for node crossings, except higher accelerations and final speeds have been assumed. A runway width of 200 ft. has been used and only the stop and go values are shown since this is the more common situation. Two to three seconds could be eliminated from the 15 second to 25 second estimates of runway crossing time if a non-stopping situation was involved. It may be noted that duration of aircraft "Holds" as measured at O'Hare averaged from 40 seconds to 90 seconds for the various runs.

AIRCRAFT STOPPING PARAMETERS

Two estimates have been made of the time required for an aircraft to stop at decelerations of 0.2 to 0.3 g's. Initial velocities of 30 knots and 20 knots have been assumed in these two estimates. Stopping time ranges from 4.5 seconds to 6 seconds in the latter case and from 6 seconds to 9 seconds in the former; the associated distances range from 90 ft. to 250 ft. including pilot reaction time of 0.5 second to 1.0 second. These values are of use in establishing minimum desired aircraft separation ("headway") on highways or longer links.

SUMMARY

A summary of the above parameters is presented in Table B-1. As a check in their applicability, a hypothetical departure route involving the following segments may be compared to actual measured taxi times (without stops).

Table B-1. Estimates of Aircraft Maneuver Parameters

	Est Velocity Range	Distance ft (4)	Acceleration Range fps(2)	Occupancy Time (Est) Sec
Ramp/Inner Links	5-10 knots (8.5-16.9 fps)	150-250	0-4.8 (0-0.15 g)	10-20
Common Links (W/O Stop) I/I; O/O; O/I	10-15 knots (16.9-25.5 fps)	300-700	0	15-25
Transition and South Links O/S and S/S	15-25 knots (25.5-42 fps)	400-1000	0-3.2 (0-0.1 g)	15-30
Turn Time (90°)				10-15
Turnoff Link (Arrivals)	20-35 knots (34-60 fps)	250-500	3.2-9.6 (0.1-0.3 g)	5-8
Node (90°) Crossing From Stop W/O Stop	 0-15 knots 10-20 knots	230-400 (1)	 0-4.8 0	 15-27 10-24
R/W Crossing (After Stop)	0-25 knots	380-550 (2)	0-6.4	15-25
Aircraft Stopping Parameters	30 → 0 knots 20 → 0 knots	180-250 (3) 90-120 (3)	6.4-9.6 6.4-9.6	6-9 4.5-6

NOTES

1. Based on 75' T/W, 75' Clearance, 70' or 250' Aircraft Length.
2. Based on 75' + 200' + 250' (or 70') + 25' Clearance.
3. Includes pilot reaction times of 0.5-1.0 seconds.
4. Link distances defined from node center to node center.

R/I Link (1)	15 seconds
Turn	12
I/I Links (2)	40
Turn	12
I/O Link	15
Turn	12
O/O Links (3)	50
Turn	12
O/S Link	18
R/W Crossing	20
S/Y Link	20
	226 seconds

Average departure taxi times measured on the South side of O'Hare ranged from 209 seconds to 235 seconds for Runway 9R; this configuration is similar to the hypothetical model evaluated above.

APPENDIX C - LINK/NODE OCCUPANCY CONSIDERATIONS

The logic for use of position information must consider the constraints imposed by the characteristics of the facilities (links and nodes), aircraft dimensions, and clearance requirements. Figure C-1 shows the geometry of a sample link between nodes A and B. We shall assume that a position sensor can provide an estimate of X, the distance from the centerline of the intersection to the center of the aircraft. The lengths of various types of aircraft are shown in Figure C-2.

If the error in the position sensor is considered a normal distribution with mean of zero and standard deviation σ_x and the test for link occupancy (i.e., Node A clearance) is sensed position $(X_s) \geq X_1$, then the minimum value of X that will indicate the aircraft is clear of the intersection with 97.5 percent certainty is $X_1 + 2\sigma_x$; and the value of X_1 which will guarantee with 97.5 percent certainty that an aircraft within the intersection will indicate intersection occupancy (i.e., Node A occupancy) is

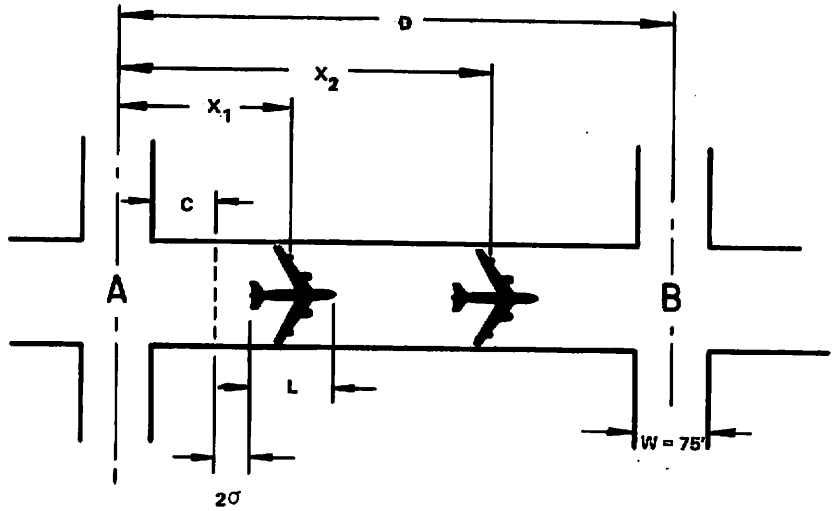
$$X_1 = C + \frac{L}{2} + \frac{W}{2} + 2\sigma_x.$$

Similarly, if the test for link occupancy on the other end (i.e., Node B clearance) is $X_s \leq X_2$, then the maximum value of X that will indicate the aircraft is clear of the intersection with 97.5 percent certainty is $X_2 - 2\sigma_x$; and the value of X_2 which will guarantee with 97.5 percent certainty that an aircraft within the intersection will indicate intersection occupancy (i.e., Node B occupancy) is

$$X_2 = D - C - \frac{W}{2} - \frac{L}{2} - 2\sigma_x.$$

The difference between the two values of X within which detection on the link (i.e., not in either intersection) is assured (with greater than 97.5 percent certainty) is given.

$$\Delta X = (X_2 - 2\sigma_x) - (X_1 + 2\sigma_x) = D - 2C - L - W - 8\sigma_x.$$



$$X_1 = \frac{75}{2} + C + 2\sigma_x + \frac{L}{2}$$

$$X_2 = D - \frac{75}{2} - C - 2\sigma_x - \frac{L}{2}$$

WHERE

- W = TAXIWAY WIDTH (75' NOMINAL)
- L = A/C LENGTH
- D = LINK LENGTH
- C = REQUIRED CLEARANCE (75')
- σ_x = POSITION SENSOR ERROR STANDARD DEVIATION
- X_1 = TEST VALUE OF X TO INDICATE A/C IS CLEAR OF INTERSECTION A
- X_2 = TEST VALUE OF X TO INDICATE A/C HAS NOT ENTERED INTERSECTION B

Figure C-1. Representative Link/Node Geometry

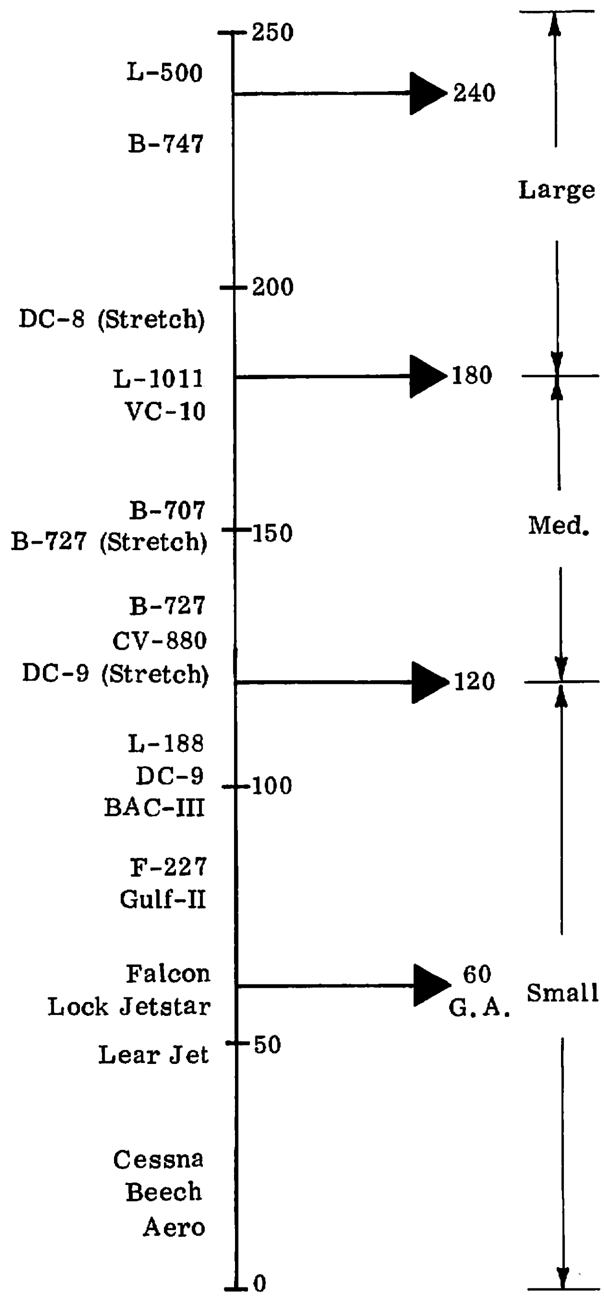


Figure C-2. Aircraft Size Categories

If the parameters are such that $\Delta X \leq 0$, then detection of the aircraft on the link clear of both intersections cannot be assured.

Consider a B747 aircraft and the parameters L = 235 ft, C = 75 ft, W = 75 ft. With perfect sensing ($\sigma_X = 0$) the link must be longer than 460 ft to hold a B747 clear of both intersections. Evenfor a more common aircraft length (L = 150 ft) the required length is 375 ft. As shown in Appendix A, many links will not meet this criteria.

As can be seen from the ΔX equation, position error will require a longer link to assure detection of an aircraft clear of both intersections than is actually required. For an aircraft of 150 ft length the link length required for position errors (σ_X) of 10, 20, and 30 ft are 455, 535, and 615 ft, respectively. This is in contrast to the 375 ft actually required. The span of these lengths exceeds commonly used holding links (e.g., the Stub and Outer/South, North/South taxiways; see Appendix A) and may cause serious system problems.

APPENDIX D - MOVEMENT DETECTION

As part of the control process it will be necessary to have the capability for recognition of a change in aircraft status between a moving and non-moving condition as well as to distinguish a moving and stopped aircraft. In the simplest case no acceleration is present and a velocity measurement must have sufficient accuracy to separate the two conditions. If the error in the velocity measurement is considered a normal distribution with mean of zero and standard deviation σ_v and the test for movement is $V_m \geq V_{min}$ (V_m being the velocity measurement), then the minimum value of V that will indicate the aircraft is moving with 97.5 percent certainty is $V_{min} + 2\sigma_v$; and the value of V_{min} which will guarantee with 97.5 percent certainty that a standing aircraft will not indicate it is moving is $V_{min} = 2\sigma_v$. Before applying these relationships in determining the σ_v requirement, the impact of sampling is examined.

In the worst case, an aircraft can accelerate from a stopped condition and attain the velocity assuring detection ($V = V_{min} + 2\sigma_v$) just after a sample was taken. In this instance the delay in movement detection will be

$$T_{DW} = \frac{V_{min} + 2\sigma_v}{a} + T_S$$

where a is the acceleration, T_S is the sample period and T_{DW} is the worst case delay.

On the average, aircraft will be detected as moving at $V = V_{min}$ and will reach V_{min} half way into a sample period. In this instance the average delay in movement detection (T_{DA}) will be

$$T_{DA} = \frac{V_{min}}{a} + \frac{T_S}{2}$$

To illustrate possible ranges of the various parameters, Table D-1 has been prepared for a = 0.1g, and V = 7.5 knots or 12.5 knots respectively;

Table D-1. Estimates of Velocity Accuracy and Sampling Rates for Movement Detection Based on Velocity Measurement

V (fps)	σ_v (fps)	V_{min} (fps)	T_S (sec)	T_{DA} (sec)	T_{DW} (sec)
12.7 (7.5 knots)	3.2	6.4	2 4 6	3.0 4.0 5.0	6.0 8.0 10.0
21.2 (12.5 knots)	5.3	10.6	2 4 6	4.3 5.3 6.3	8.6 10.6 12.6

the former value represents an average velocity estimated in the Ramp/Inner area while the latter represents a velocity estimate expected to be exceeded by most aircraft outside of this area. V_{min} was chosen such that the velocity values equalled the minimum value of V which would indicate the aircraft was moving with 97.5 percent certainty, $V_{min} + 2\sigma_v$. Since $V_{min} = 2\sigma_v$ would give less than 2.5 percent probability of false alarm (i.e., indication a standing vehicle is moving), equations for σ_v and V_{min} were

$$\sigma_v = \frac{\text{velocity estimate}}{4}$$

$$V_{min} = 2\sigma_v = \frac{\text{velocity estimate}}{2}$$

This table indicates that a sampling interval of four seconds would satisfy the four to seven second detection requirement on the average; however, the required velocity accuracy would be set by the Ramp/Inner taxi speeds at 3.2 fps. If detection in the Ramp/Inner area was compromised with respect to probability of detection a less strict velocity accuracy of 5.3 fps could be adopted with a sampling period of two seconds. However, this should be avoided.

The measured velocity can be obtained from some sensors directly. More relevant to this study is a velocity estimate based upon position information.

If a single position measurement is taken at the end of each velocity sample period, X_E, and the beginning of each sample period (i.e., the end of the last sample period), X_B, a simple velocity estimate would be

$$V_m = \frac{X_E - X_B}{T_S}$$

If the positional error is assumed to be uncorrelated and normal with zero mean and σ_x standard deviation, the velocity measurement deviation is

$$\sigma_v = \frac{\sqrt{2}}{T_S}\ \sigma_x$$

Using $T_S = 4$ seconds and $\sigma_v = 3.2$ fps or $T_S = 2$ seconds and $\sigma_v = 5.3$ fps the positional accuracy would be, respectively

$$\sigma_x = \frac{\sigma_v T_S}{\sqrt{2}} = 9.1 \text{ ft and } 7.6 \text{ ft}$$

It can be seen that no apparent advantage exists in opening up the velocity error since the effect of reducing the sample period more than offsets it.

The position estimates X_B and X_E can represent smoothed values of M measurements based upon an observation interval equal to (M-1) t_o where t_o is the interval between samples.

If σ is the smoothed value of these measurements and σ_x is the standard deviation of individual measurements the curves of Reference 1 may be used to determine σ/σ_x vs M for a first order filter, or

M =	26	11	6	points
σ/σ_x	0.38	0.57	0.75	

excluding truncation effects. For example, if (M-1) t_o is fixed at 2.5 seconds, t_o would range from 0.1 (10 samples/sec) to 0.5 seconds for the values of M shown.

The required single measurement position accuracy required for movement recognition for M = 26 would then be

$$\sigma_x = \frac{\sigma}{0.38} = \frac{9.1}{.38} = 24 \text{ ft}$$

Note that this relaxation of position accuracy is bought at the price of increased data (sampling) rate by a factor of 40. In addition, the time delay is increased by the position sample interval $(M-1)\ t_o$ resulting in an average delay of 6.5 seconds and worst case delay of 10.5 seconds. The four to seven second criteria is just satisfied on the average.

So far velocity measurement and position change have been examined as movement detection devices. A "passage" detector can provide movement recognition at a particular point since it essentially recognizes entry into a particular area. Such devices may have application in ramp entrance/exit areas, possibly at R/W turnoffs, and on the link preceding the Local Control Departure Q. The advantage is the lack of vehicle identification.

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[1] Blum, M., "Long Range Trajectory Prediction Errors for Least Squares Smoothing," AES, March 1971.

APPENDIX E - PREDICTION ERRORS

To develop a rationale for an airport surface traffic control system consideration must be given to the various types of conflicts that can occur. We shall consider "conflicts" as those combinations of events which can lead to overlapping demands from two or more aircraft for the same facilities (i. e., links or nodes). An existing conflict is relatively easy to recognize since the location of one aircraft on a link or at an intersection is either preventing the second aircraft from moving or causing it to slow down. An example of the former case might be denial of entry to the taxiway system for an aircraft leaving the ramp area because of traffic on the Inner or Outer directly in front of the Ramp Exit. The second case might be that at an intersection wherein one aircraft has previously been instructed to give way to another aircraft.

Recognition of future conflicts (i. e., conflict prediction) is a much more difficult process requiring in many cases a priori knowledge of the route to be followed by each of the aircraft involved, as well as other aircraft movement parameters. At any instant of time these data elements permit an estimation by the controller of the entry and exit times into each of perhaps the next several links and nodes. Longer prediction intervals, of course, will have higher uncertainties; most control decisions in the Ground Control System are expected to be based upon prediction intervals of from 15 seconds to 30 seconds. In the Local Control System prediction intervals as long as 2 minutes to 3 minutes may be feasible because of the relatively constant aircraft speeds during approach.

The controller decisions are based upon an estimate of future aircraft position at a particular time or, from another viewpoint, an estimate of the time an aircraft will arrive at a particular location. The controller is essentially therefore predicting the start and completion times that an aircraft will be using a certain facility, i. e., a section of pavement. This prediction process is currently based primarily upon a controller's experience (knowledge of pilot/aircraft operations), plus the inputs he obtains from his visual surveillance activities.

To illustrate the relative contributions of position and velocity errors to the prediction process, the relationship given in Reference 1 may be used to estimate the error in arrival time caused by uncertainties in velocity and/or initial position of an object moving on a straight line path. This relationship

$$\sigma_t^2 = \frac{1}{V^2}\,\sigma_x^2 + \left(\frac{x}{V^2}\right)^2 \sigma_V^2 = \sigma_{t1}^2 + \sigma_{t2}^2 \qquad (1)$$

assumes independent Gaussian errors for x and V. If future velocity is known exactly, the predicted time error will depend solely on the first term, i.e.,

$$\sigma_{t1} = \frac{1}{V}\,\sigma_x \qquad (2)$$

or on the accuracy of the present position estimate and the speed of the taxiing aircrafts during the prediction interval. On the other hand, if σ_x is zero, the accuracy of the predicted occurrence of arrival at a designated point will be a function of time, as well as velocity magnitude and its error, i.e.,

$$\sigma_{t2} = \frac{x}{V^2}\,\sigma_V = t\left(\frac{\sigma_V}{V}\right) \qquad (3)$$

The predicted time error, σ_{t1}, due solely to position inaccuracy has been plotted in Figure E-1 as a function of average velocity, V, during the prediction interval. For low value of velocities the prediction error becomes, as expected, quite large since of course it is impossible to predict the future time/location of a non-moving object. The range of estimated aircraft velocities in the various portions of the taxiway system described in Appendix A is also indicated on this figure. An interpretation of this plot might be as follows. If σ_x, the uncertainty in present aircraft position is 25 feet, and the aircraft is expected to maintain exactly 10 knots in the future, there will be an 1σ uncertainty of about ±1.4 seconds in the prediction of the aircraft's arrival at a future point due solely to σ_x. Therefore, if a particular link

[1] Astholz, et al., "Increasing Runway Capacity", Proc. of IEEE, March 1970

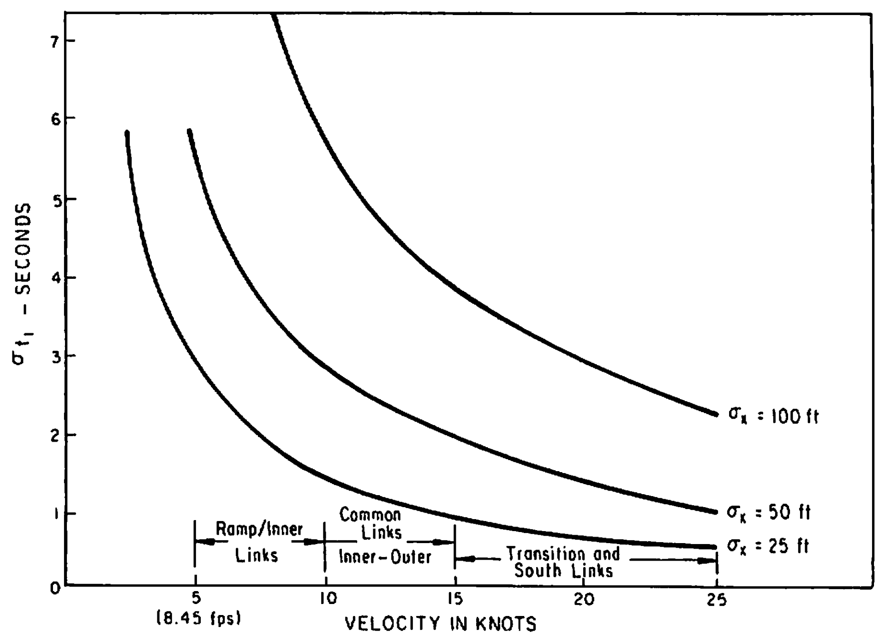

Figure E-1. Prediction Time Error Due to Initial Position Errors was to be scheduled for use by this aircraft and the aircraft nominally occupied the link for 15 seconds, the controller would have to reserve the link for a larger interval of time. Allowing 2σ at the beginning and end of the nominal 15-second occupancy interval, the link would have to be reserved for 15 + 2 (2.8) or 20.6 seconds.

The prediction errors, σ_{t2}, due to velocity variations <u>during</u> the prediction interval has been plotted in Figure E-2 vs prediction interval, "t_p" for several values of $\sigma_{V/V}$. These latter values have been estimated has follows. Assume the aircraft is moving in a known area of the airport (on the South links, for example) and its velocity will normally lie between 15 knots and 25 knots. For a rectangular distribution we may use $\sigma_V = \frac{25-25}{3.5} = 2.85$ knots or $\sigma_{V/V} = 0.142$. Closer to the terminal the velocity range might normally be expected to be from 5 knots to 15 knots or $\sigma_{V/V} = 0.282$. If closer estimates of σ_V are possible--say to a 5 knot range between 10 knots and 15 knots--$\sigma_{V/V}$ might be as small as 0.12 for this range of velocities.

As shown above, the uncertainty in prediction time is a function of <u>present</u> position accuracy <u>and</u> the variation in aircraft velocity that occurs <u>during</u> the prediction interval. To minimize the contribution of position error to the prediction uncertainty, the basic relationship may be expressed as

$$\sigma_t = \sigma_{t2} \left[1 + \left(\frac{\sigma_{t1}}{\sigma_{t2}}\right)^2\right]^{1/2}$$

If

$$\frac{\sigma_{t1}}{\sigma_{t2}} \leq 0.5$$

then

$$\sigma_{t2} \leq \sigma_t \leq 1.1\, \sigma_{t2}$$

i.e., the position error will contribute no more than 10 percent to the prediction uncertainty.

With

$$\sigma_{t1} = 0.5\, \sigma_{t2}$$

$$\frac{\sigma_x}{V} = 0.5t\, \frac{\sigma_V}{V}$$

or

$$\sigma_x = 0.5t\, \sigma_V \qquad (4)$$

Using 20 seconds as a prediction interval and $\sigma_V = 4.8$ fps (2.85 knots) the required present position accuracy to meet the above criteria would be

$$\sigma_x = 0.5\ (20)\ (4.8) = 48 \text{ feet}$$

If the position accuracy is equal or better than this value the prediction uncertainty can then be estimated solely from the σ_{t2} vs t curves of Figure E-2.

Considering the various prediction intervals ranging from 15 seconds to 45 seconds set forth in the section on System Response Time it is estimated that position accuracy equal to

$$\sigma_x = 0.5\ (15)\ (4.8) = 36 \text{ feet}$$

would be acceptable for those areas of the airport where $\sigma_V = 4.8$ fps (2.85 knots). For areas where larger velocities will occur the value of σ_x may be relaxed from that given above.

In those cases where position accuracy is relatively insignificant the accuracy of the prediction process may also be estimated from Figure E-2. For σ_V/V of 0.15 the value of σ_{t2} is 2.3 seconds at 15 seconds. At the end of an additional fifteen seconds this value rises to 4.6 seconds. The predicted occupancy time of a link, for example, which is normally transversed by an aircraft in 15 seconds would have to take into account 2σ (4.6 seconds) at the beginning of the interval and 2σ (9.2)

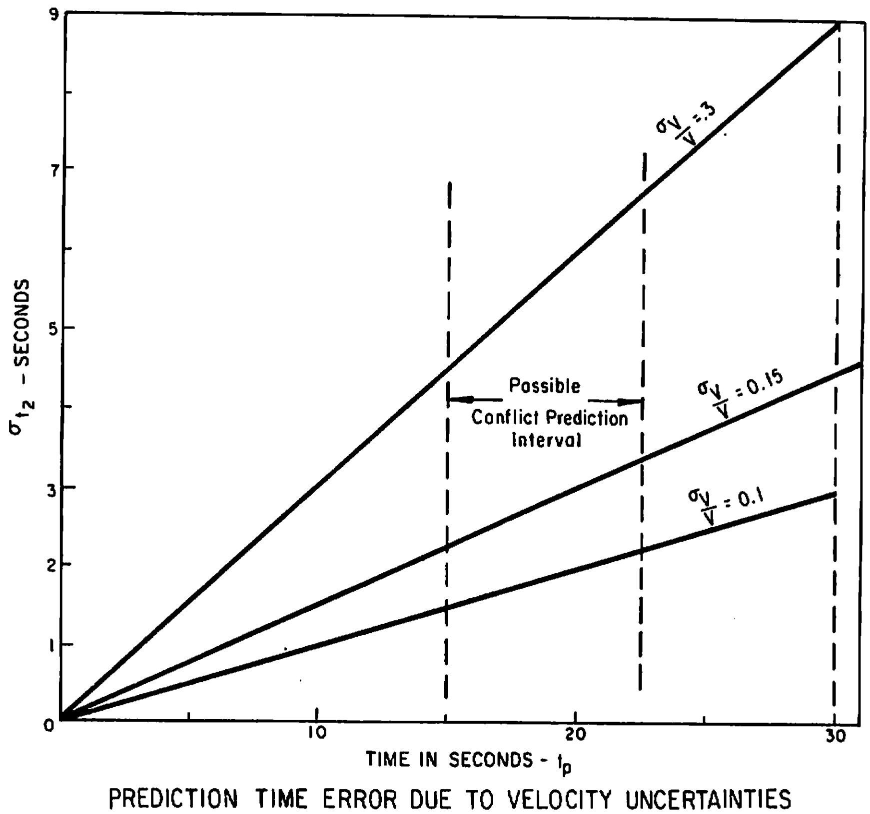

Figure E-2. Prediction Time Error Due to Velocity Uncertainties

seconds at the end of the interval. This inaccuracy in prediction results in almost doubling the time for which a link (or node) must be reserved and illustrates the difficulties in attempting to predict beyond 30 seconds in the future to any degree of accuracy within the boundaries of the Ground Control System.

APPENDIX F - AIRCRAFT MOVEMENT PROFILE CHARACTERISTICS FOR RUNWAY/TAXIWAY CROSSING CONTROL

1.0 LANDING CONSIDERATIONS

Arriving aircraft may be considered to be in one of three phases while handled by the Local Controller. These are:

1. Tracking Phase
2. Pretouchdown Phase
3. Runway Occupancy Phase

Figure F-1 illustrates these phases and the definitions to be used in the following discussion; the distance parameter "S" is taken as zero at runway threshold and negative prior to this point. Since the distances must be related to time we may note that representative landing speeds range from 125 mph (183 fps) for the 737 to about 165 mph (242 fps) for the 707 and 747.

Considering first the Tracking Phase, the ARTS computer updates aircraft location every 4 seconds and displays this information to the Local Controller until the "track" is dropped. This occurs at slightly different times for various runways; for discussion purposes we shall use a value of S_2 (the track drop point) equal to 7500 ft. The estimated maximum width of the track drop interval is 4 x 242 = 968 ft, i.e., approximately ±500 ft from the nominal center. The "BRITE" display provides half-mile range lines separated by half-mile spaces as a scale on which the aircraft location is seen during the Track Phase. If the controller wished (and had the available time) he might estimate the aircraft positions to about 1/5 of the range line, i.e., to a precision of about 500 ft.

The Pretouchdown Phase occurs over the distance $S_2 + S_1$ where S_2 has been taken as 7500 ft. The distance S_1 depends upon many parameters; average values of 1000 ft (Category B aircraft landing at 164 fps) and 1500 feet (Category C and D aircraft landing at 202 and 237 fps, respectively) are cited in FAA Publication AC 150/5335-1A. With $S_1 + S_2$ ranging from 8000 ft to 9000 ft the Pretouchdown Phase may take from 33 seconds to 50 seconds for velocities of 183 fps and 242 fps.

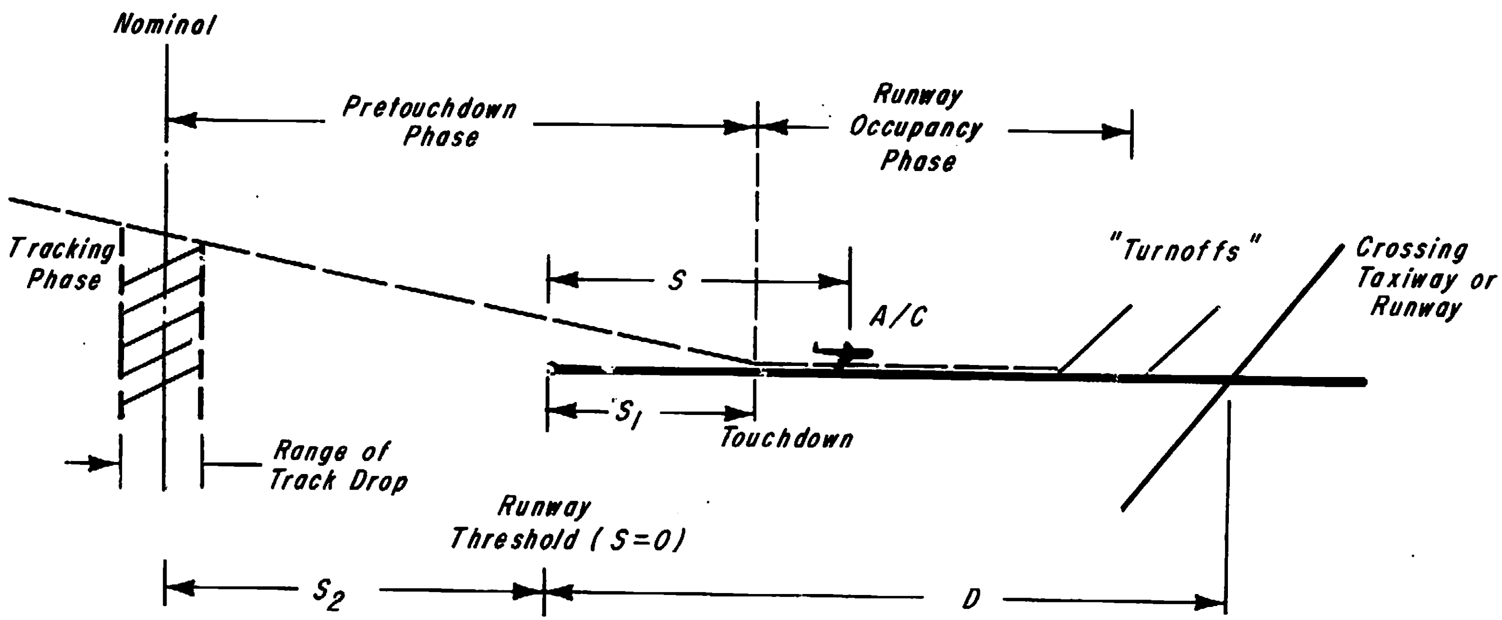

Figure F-1. Landing Aircraft Phases

During this interval, while the aircraft is 1.5 miles to 3 miles from the tower, the Local man must rely solely on visual observations for any decision he may wish to reach.

Following "touchdown" we may define the actual Runway Occupancy Phase which lasts until turnoff. During this phase substantial aircraft deceleration must take place. The amount of "braking" and the time at which it is applied depends upon the location and type of "turnoffs", surface conditions, aircraft type, actual touchdown point, etc. Actual measurements on 210 aircraft on most of the runways at O'Hare gave average values of time from threshold to turnoff ranging from 38 seconds to 52 seconds depending upon the runway used (standard deviation of each runway ranged from 6 seconds to 19 seconds). Allowing about 6 seconds from threshold to "touchdown" (1250 ft ÷ 200 fps), runway occupancy time varies from 22 seconds to 40 seconds.

Observations made by Peat, Marwick & Mitchell in April 1973 on a small number of aircraft at other airports provided the following results:

Airport	No. of Observations	R/W Occupancy Time (secs)	Standard Deviation (secs)
TPA	6	43-68	11.2
Houston	7	46-75	9.7
New Orleans	13	48-73	8.1

These wide variations in runway occupancy may increase the total runway crossing time (including delay time).

2.0 SIMPLE THEORETICAL BRAKING MODEL

Prediction of the arrival time of a moving object at a point on its trajectory can be made based upon knowledge of its present position and velocity in conjunction with assumptions regarding its future behavior. These assumptions might include a constant future velocity equal to that at the measured point. The predicted arrival time, or "time-to-go" would then be conservative, or smaller, than would actually be experienced by an aircraft, for example, rolling on a runway and influenced by "drag" and frictional components.

Consider a moving aircraft with constant velocity, V_o, which at $t = 0$ a distance D from a remote point (such as an intersection).

Then

$S = V_o t$ is the distance traveled by the aircraft in "t"

$T_g(t) = \frac{D-S}{V_o}$ is the minimum predicted "time-to-go", or time to reach D based on $V(t) \leq V_o$.

$= T_{go} - t$

where

$T_{go} = \frac{D}{V_o}$ is the "time-to-go" at $t = 0$.

For this constant velocity case, the "time-to-go" decreases with time from the T_{go} point.

A landing aircraft will apply deceleration, or braking, to reduce its runway occupancy time. This deceleration rapidly reduces the aircraft velocity and therefore increases T_g as will be shown below. While the shape of the applied deceleration function is variable (dependent upon aircraft type and pilot actions) we shall assume a constant deceleration of value "a" lasting for a time interval t_1 and starting at $t = 0$ when $v = v_o$. We then have

$v = v_o - at$ ("a" taken as positive for deceleration)

$$S = v_o t - \frac{at^2}{2}$$

$$T_g(t) = \frac{D-S}{v} = \frac{D - v_o t + at^2/2}{v_o - at}$$

$$= \frac{\frac{D}{v_o} - t + \frac{at^2}{2 v_o}}{1 - \frac{a}{v_o} t} = \frac{T_{go} - t + \frac{at^2}{2 v_o}}{1 - \frac{a}{v_o} t}$$

The above relationships hold only during the interval, t_1, during which the deceleration is applied. The range of values of the several parameters are as follows:

v_o - 66 fps (45 mph) to 242 fps (165 mph)

a - 0 to 12 fps^2 (about 0.4 g's)

t_1 - 0 to 6 seconds

Assuming an initial value of T_{go} at 30 seconds (for example D = 7200 ft and V_o = 242 fps) the expression for $T_g(t)$ may be approximated below, by noting that the maximum value of the "$at^2/2 V_o$" term is

$$12 (6)^2 \div 2 (66) = 3.3 \text{ seconds}$$

which is small compared to $T_{go} - t$.

Therefore

$$T_g(t) \approx \frac{T_{go} - t}{1 - \frac{a}{V_o} t}$$

This equation for minimum predicted arrival time has been plotted in Figure F-2 for a constant T_{go} in order to show the non-linear deceleration effects of the a/v_o ratio.

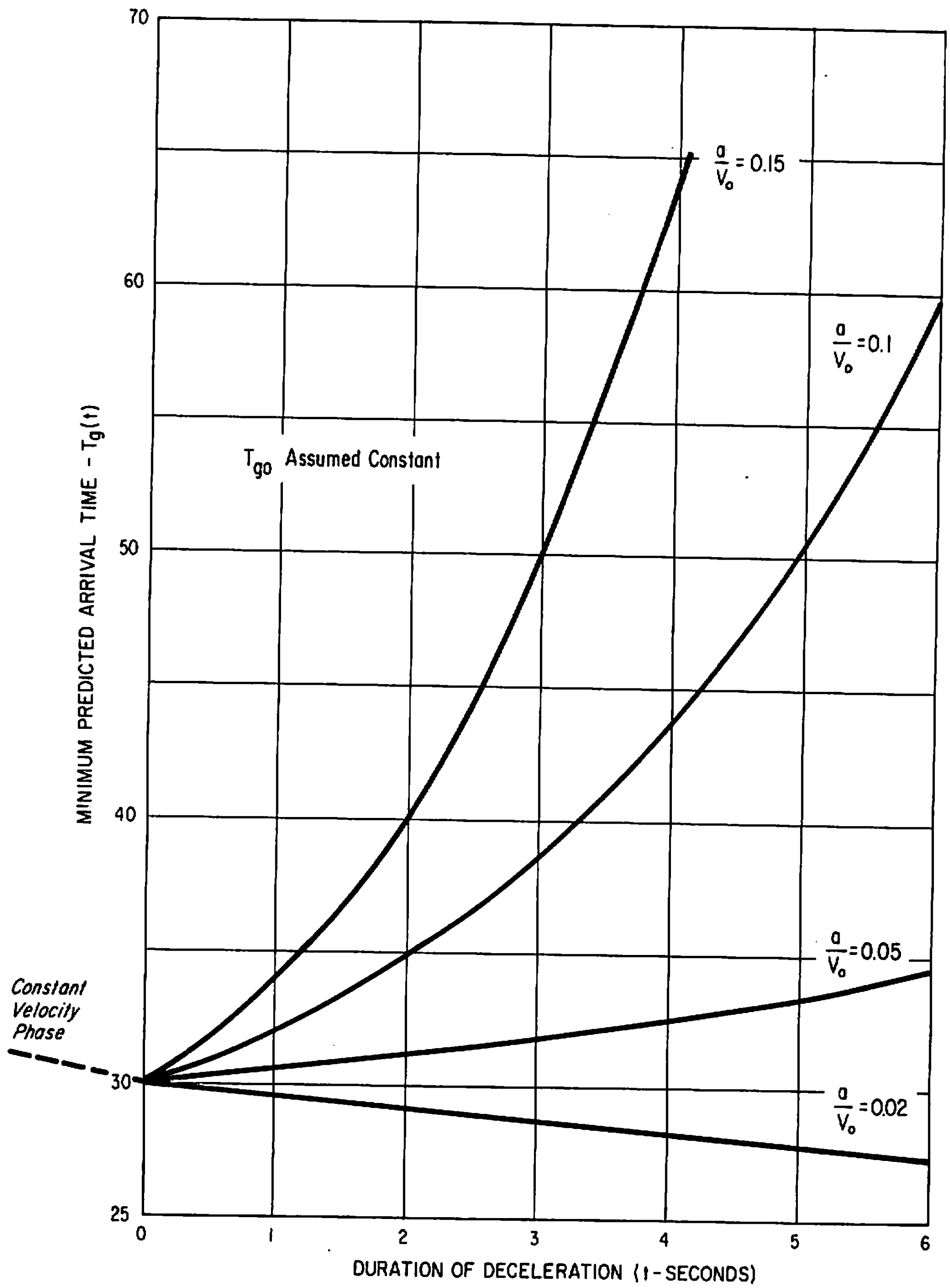

Figure F-2. Deceleration Effects on Minimum Predicted Arrival Time

Applying the above to a specific example with two deceleration phases we might have

- First constant velocity phase

  $v_o = 200$ fps

  T_{go} (at end = 35 sec. i.e., D = 7000 ft)

- First braking phase

  $a = 10 \text{ fps}^2; t_1 = 6$ sec.

  Then

$$v\ (6\ \text{sec}) = 200 - 60 = 140\ \text{fps}$$

$$\frac{a}{v_o} = \frac{10}{200} = .05$$

$$T_g(6) = \frac{35 - 6}{1 - .05(6)} = 41\ \text{sec.}$$

- Second Constant Velocity Phase lasting 5 seconds

  $T_g(11) = 41 - 5 = 36$ seconds

- Second Braking Phase

  $a_o = 10 \text{ fps}^2 \quad t_1 = 6$ sec

Then

$$V(17\ \text{sec.}) = 140 - 60 = 80\ \text{fps}$$

$$\frac{a}{v_o} = \frac{10}{140} = .071$$

$$T_g(17) = \frac{36 - 6}{1 - .071(6)} = 52.3\ \text{seconds}$$

The results of the above example are plotted in Figure F-3. This curve of minimum predicted arrival time, $T_g(t)$, could be applied to establishment of a "denial" window wherein an aircraft at the intersection would not be permitted to cross. If, for the above example, 45 seconds were necessary for crossing (including response time and suitable margins for safety) the duration of the "denial" window (red light) would be 25 seconds for the example cited.

3.0 EXPERIMENTAL RESULTS

To further examine the benefits of the prediction technique, landing profiles were developed (from ASDE films) for a few aircraft arriving at runways 9R, 32L, 14R, and 27R. The position vs time measurements permitted a rough estimate of velocity vs time to be developed; sample velocity curves are given in Figures F-4 and F-5. The differences in start of deceleration as well as the magnitude of the deceleration can readily be seen.

From the profile data, computations of minimum predicted intersection arrival time, T_g, at a hypothetical intersection 8000 ft from runway threshold were computed as a function of time. The results for the nine aircraft are given in Figures F-6 and F-7.

If the criteria for releasing an aircraft across the intersection is selected as $T_g \geq 45$ seconds, the values of time after threshold crossing at which the intersection could be activated are as shown in the first columns of Table F-1. For aircraft 8 and 9 the criteria is not met until turnoff; for the other seven aircraft time savings of from 5 seconds to 30 seconds appear possible.

The right hand column of the table shows the additional "denial time" as developed from the profile existing prior to runway threshold time. The average of the total "denial" window (based on these nine aircraft and using the 45 second criteria) is 31 seconds.

It has previously been noted that threshold to turnoff interval ranges from 28 seconds to 46 seconds. Using an average of 37 seconds (probably low) and adding the average

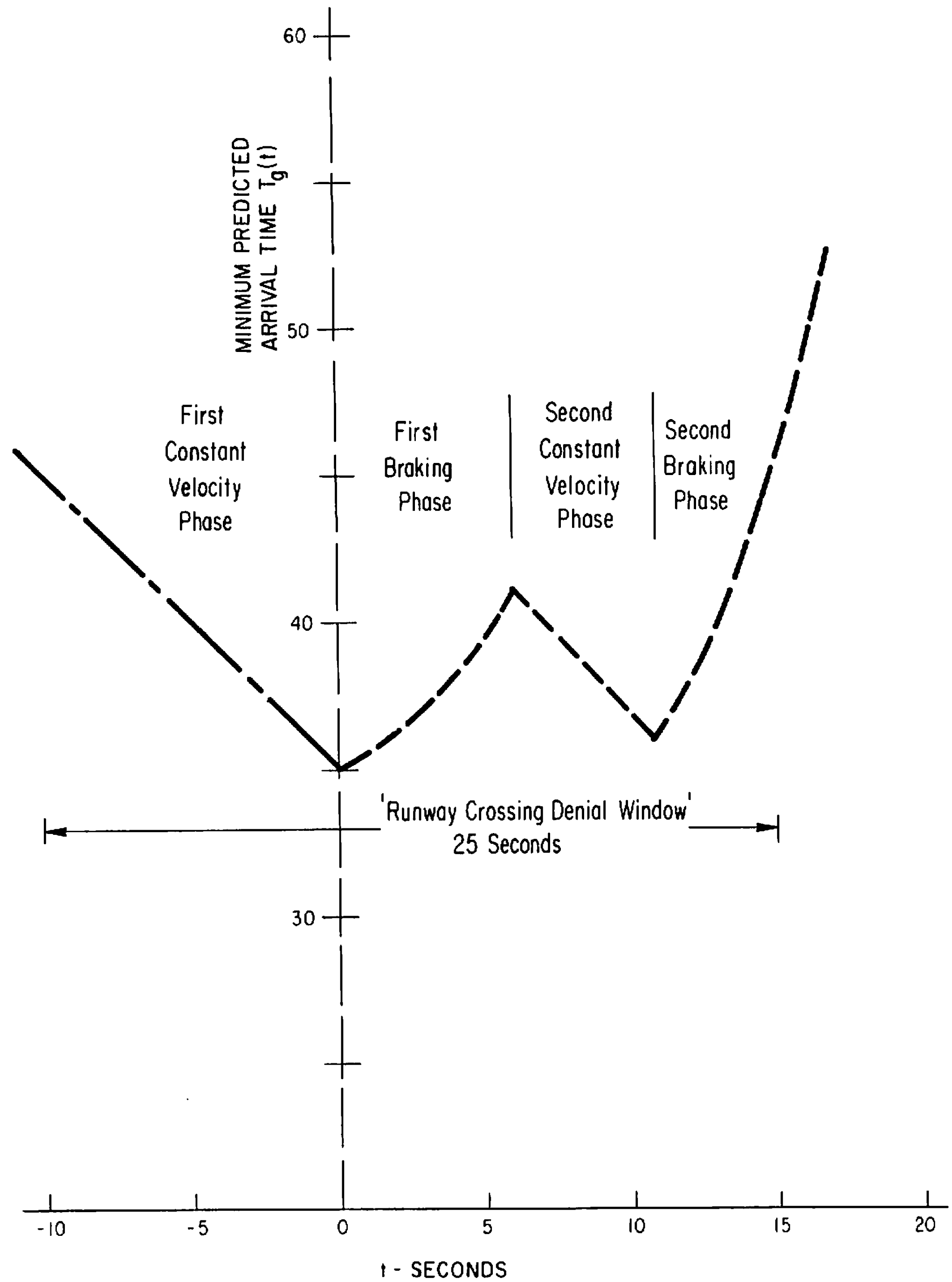

Figure F-3. Sample Aircraft Deceleration Process

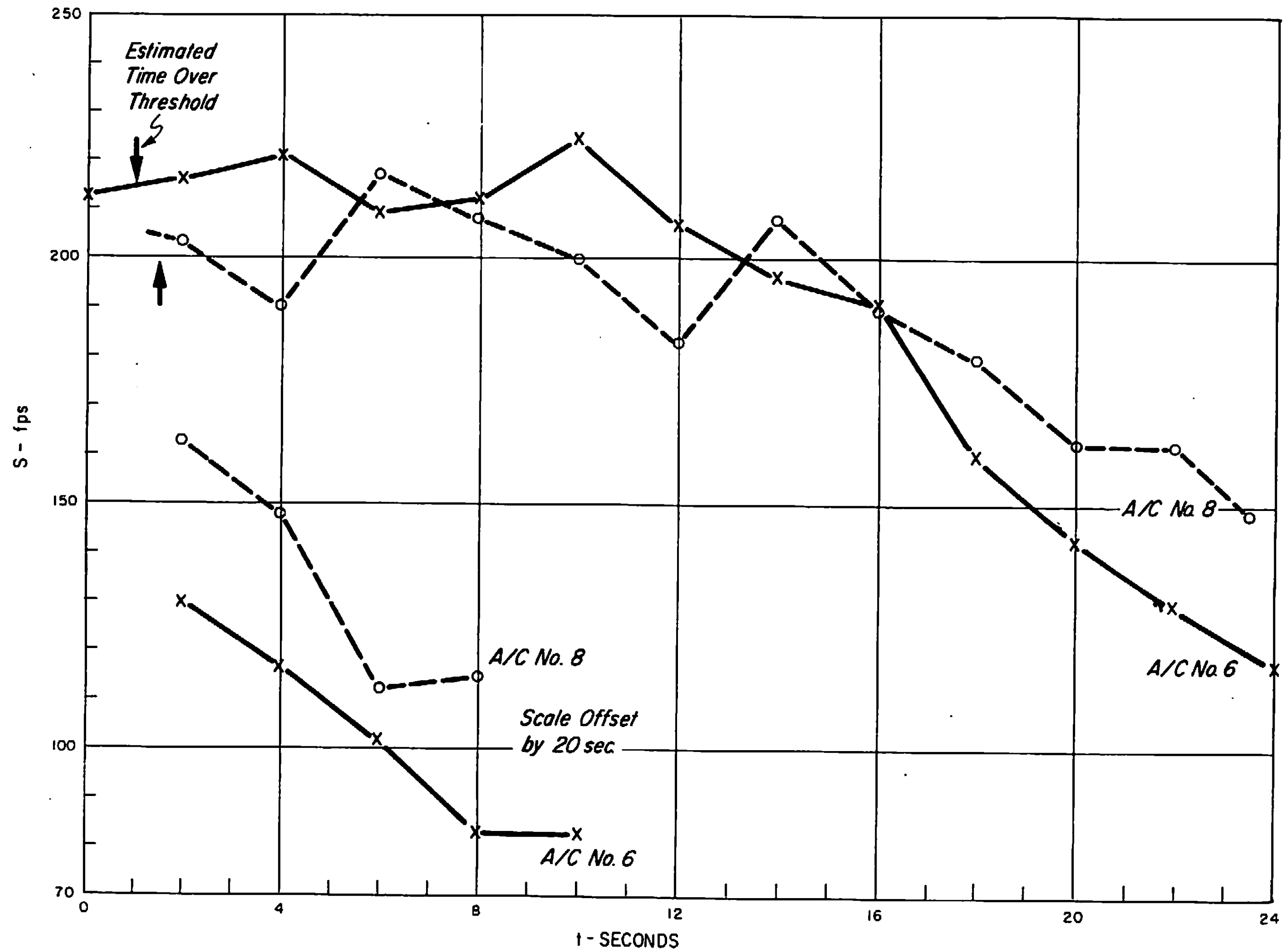

Figure F-4. Estimated Velocity vs Time During Landing - Runway 32L

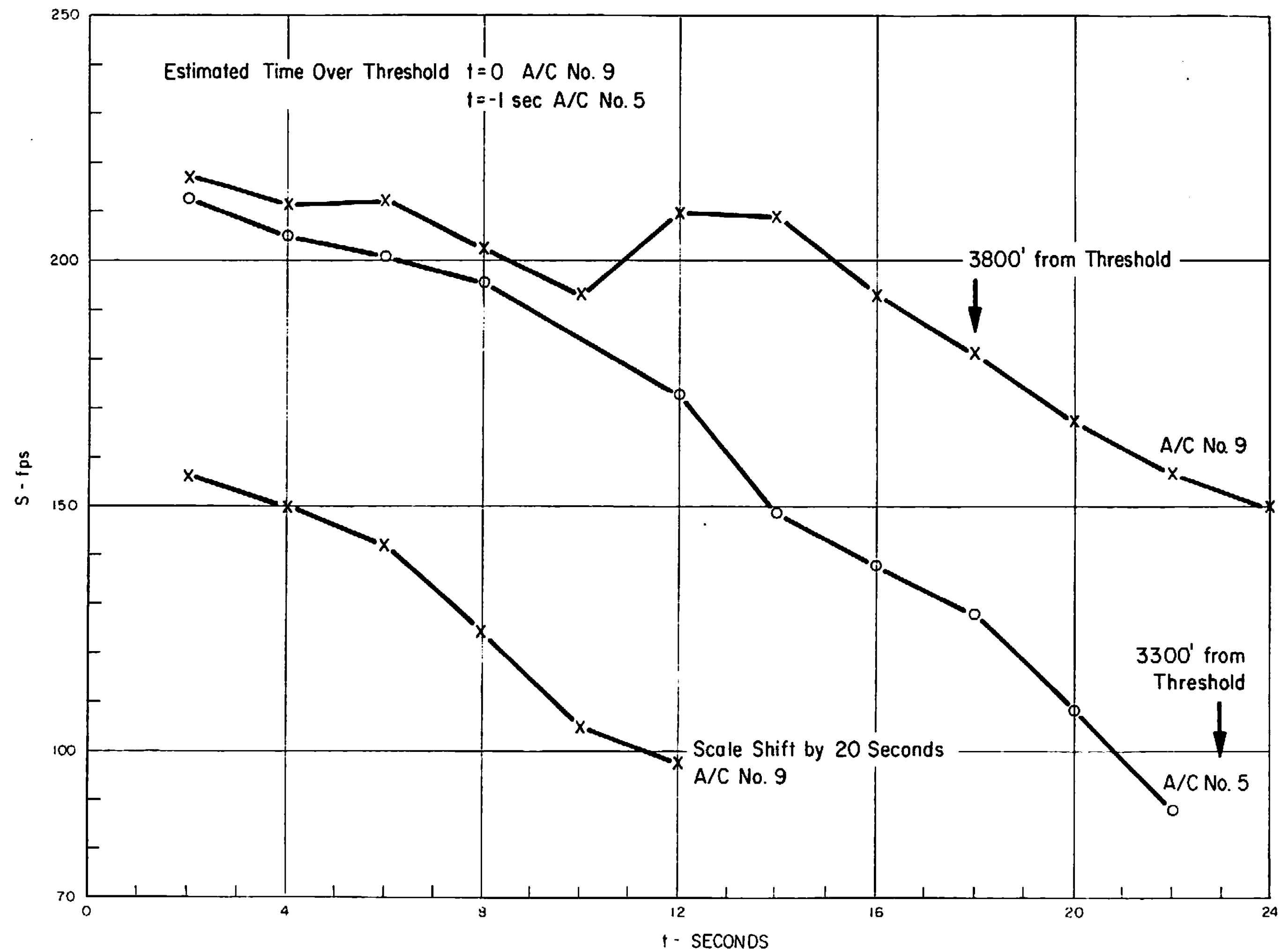

Figure F-5. Estimated Velocity vs Time During Landing - Runway 9R

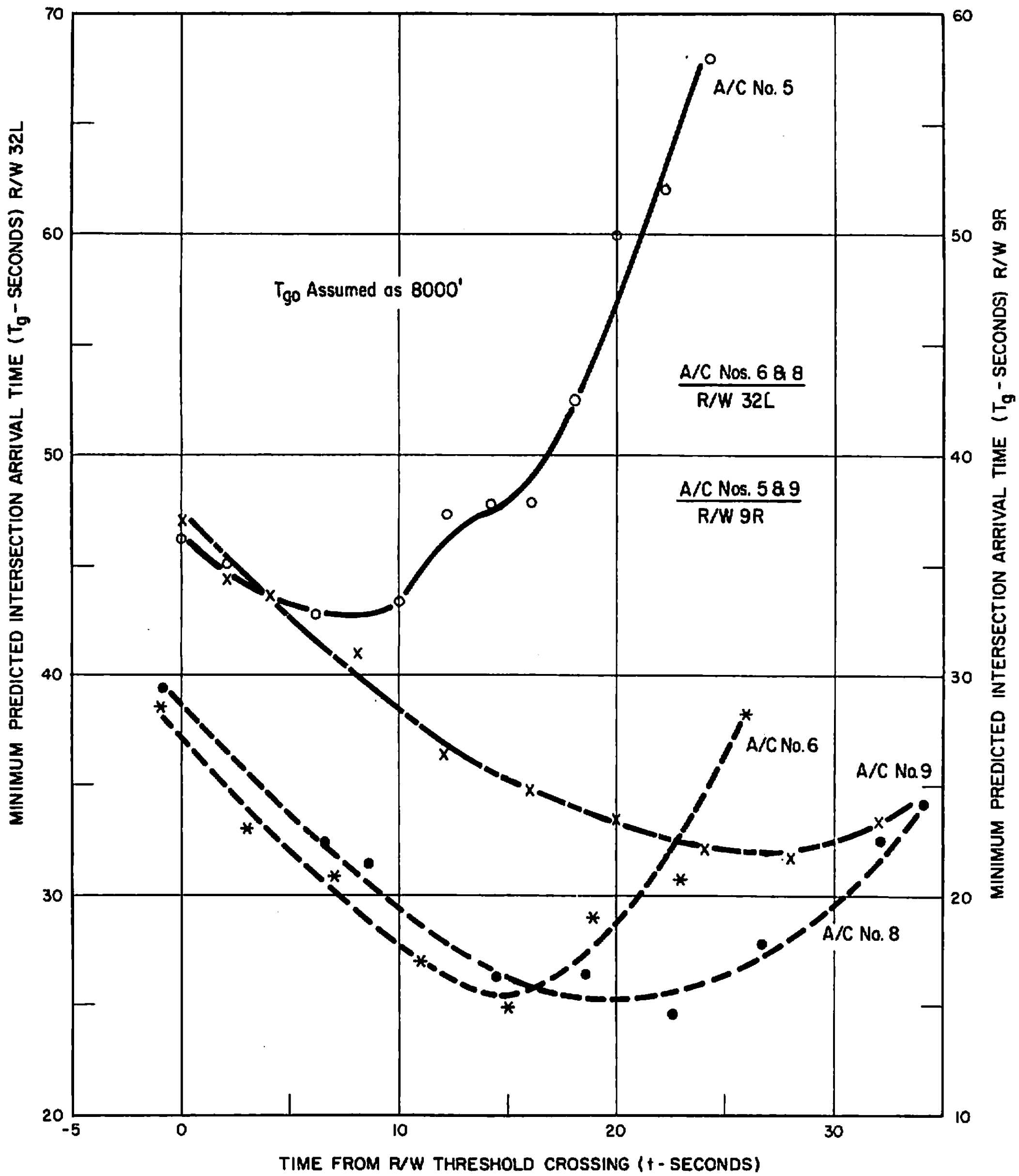

Figure F-6. Minimum Predicted Intersection Arrival Time - 4 Aircraft

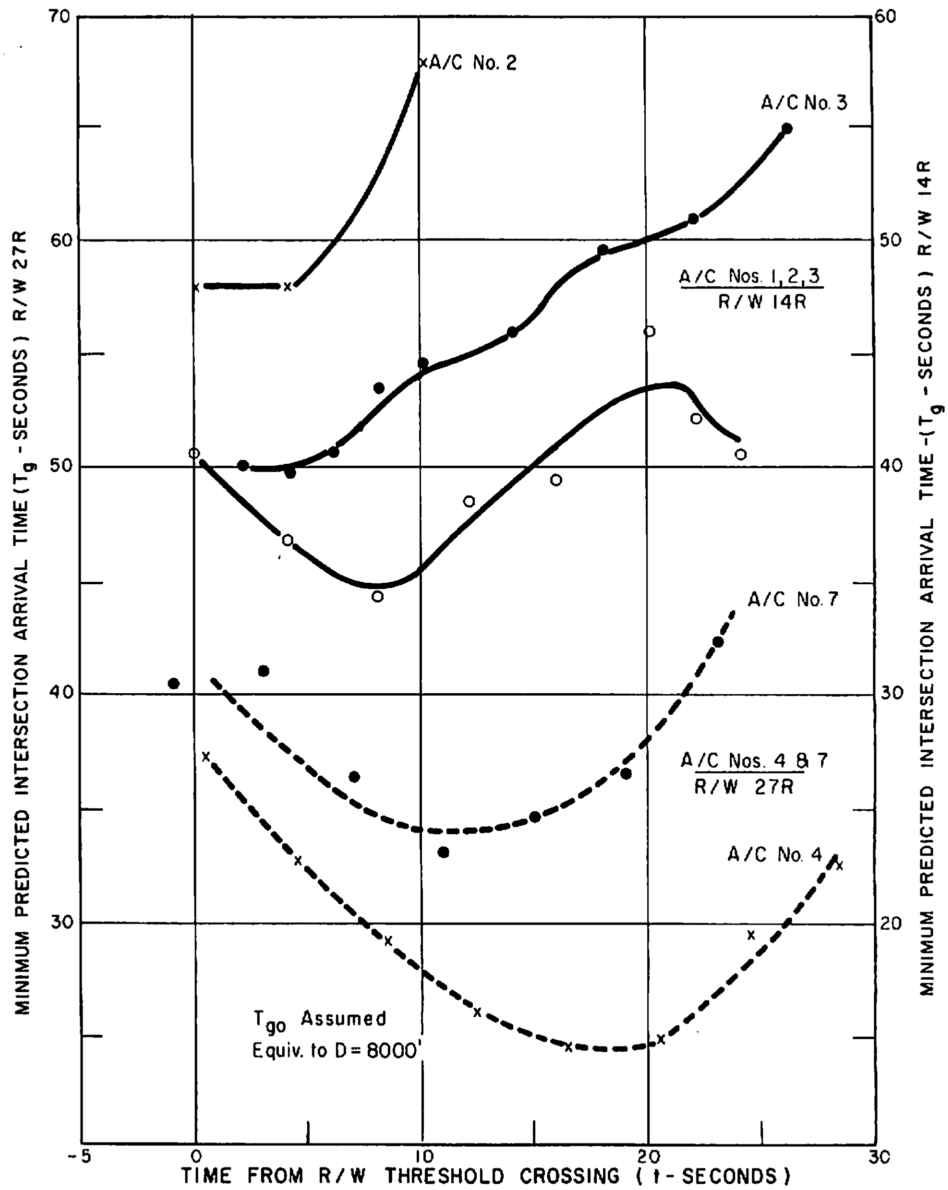

Figure F-7. Minimum Predicted Intersection Arrival Time - 5 Aircraft

Table F-1. Experimental Results

Aircraft Number	Permissible Release Time (Seconds after Runway Threshold)	Additional Denial Time Prior to R/W Threshold (seconds)
1	>30	5.0
2	0	0
3	12	5.0
4	33 Estimate	8.0
5	20	9.0
6	28	8.0
7	24	4.0
8	Turnoff at 35 secs	4.0
9	Turnoff at 40 secs	8.0
		5.7 Avg

of 5.7 seconds, the mean denial window based upon visual or similar observations of a clear runway for release of a crossing aircraft would be 42.7 seconds. The increase in crossing efficiency (decrease in number of holds) may be estimated by considering arrival rates of 30 and 36 per hour (for one side of the O'Hare airport). The average inter-arrival interval of 120 seconds and 100 seconds may be used to compute the percent of time the crossing would be denied. For example, at 30 arrivals/hour using the clear runway criteria, the crossing would be unavailable $\frac{42.7}{120}$ = 35.5 percent of the time.

The unavailability of the crossing for the two operational rates and two decision-criteria described above are as follows:

Arrival Rate	Unavailability of Crossing - % Clear Runway Criteria	Predicted Arrival Technique
30/hr	35.5%	25.6%
36/hr	42.7%	31.0%
Avg. Denial Window Duration	42.7 sec	31 sec

The above results represent, of course, only a limited example selected, however, from what are believed to be representative and conservative estimates. Detailed studies of aircraft deceleration profiles and other landing/turnoff variables should be made to obtain adequate statistical distributions.