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Simulation of Alternative Airline Terminal Check-in Disciplines

Luis Alvero Lopez
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Luis Alvero Lopez entitled "Simulation of Alternative Airline Terminal Check-in Disciplines." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Frederick J. Wegmann, Major Professor

We have read this thesis and recommend its acceptance:

William L. Grecco, Airum Chatterjee

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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SIMULATION OF ALTERNATIVE AIRLINE TERMINAL CHECK-IN DISCIPLINES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee

Luis Alvaro Lopez
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ABSTRACT

Computer simulation has become a very useful and flexible tool in the planning process of passenger facilities. By this means the probability of queues, congestion and delays can be determined, and different design concepts and operational disciplines can be considered experimentally.

Within this thesis two different check-in disciplines, restricted flight system, and common system are compared. The stochastic simulation models developed to evaluate the performance of the alternative check-in systems examined the impact of 1) changes in the number of passengers boarding per flight, 2) reduction in the number of counters, and 3) different time value to the passengers. Input to the model including 1) service times, 2) passengers rate of arrivals, 3) characteristics of the passenger groups, etc. allowed for testing both alternatives.

Output from the model included 1) queuing times, 2) number of persons in queue, 3) density of crowds, and 4) counter utilization.

After calibrating the model with data gathered at Knoxville's airport, it was found that the common system has better performance than the restricted system. Also it was determined that the restricted system became inefficient

for a large number of persons checking in per flight. Finally, by assigning monetary value to the passenger time, it was possible to select the number of counters which represented the minimum cost to the airlines, the airport operator, and the passengers.

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CHAPTER I

INTRODUCTION

The principal object of an airport passenger building is to provide for the convenient and efficient flow of passengers and baggage from the airport entrance on the landside to the aircraft on the airside and vice versa. Since airport passengers are the most important customers, the passenger terminal should be planned to provide for their maximum comfort and convenience.

Passengers anticipate a uniform level of efficiency for all aspects of their trip between origin and destination. Any failure in the ground transportation system, terminal facilities or passenger processing system to attain a level of service commensurate with the air portion of the trip, will produce passenger dissatisfaction and inconvenience. Congestion, long queues, excessive delays at the terminal could cause adverse reaction to the whole air transportation system.

Consequently, although the planning of passenger facilities must fulfill the requirements of the different authorities, airlines and concessionaires, the final consideration should be to develop the "best" facilities for the passenger taking into consideration economical limitations.

The Development of the Passenger Facilities

There are three main stages in planning the passenger zone: 1) To define the facility required; 2) To define operational concepts; and 3) To define the dimensions of the facilities required.

The first stage is concerned with determining the type of facilities required given a particular type and quantity of traffic determined from a forecast. Among the most important factors which affect the type of facility required are: the proportion of departures, arrivals and transit passenger to the total traffic. For example, airports handling large volumes of diverse traffic need certain facilities which are unnecessary for airports with smaller amount of traffic, or with traffic only of a particular category.

In the second stage, optimum operational and flow concepts are defined. Alternative concepts are tested and experimentally considered, and for each one of the alternatives proposed, the particular advantages and disadvantages for the passengers, the airlines, or the government authorities must be analyzed considering economy and the level of service provided.

The final stage involves size estimation and the arrangement of all the elements in the system. Terminal size may vary not only according to the volume of passengers, but also with the nature of the operations, the type of aircraft operated, and the number of airlines and their proportional share of the total traffic. Thus, for a given volume of traffic, the smallest terminal would be required if only one airline had to be accommodated. The size of the facilities required increases with the number of airlines. This is due in part to the fact that airlines need fairly localized areas in order to be able to concentrate equipment and personnel for optimum utilization, and in part because of each airline having its own different views of the best passenger processing system. Emphasis on commercial competition and the consequent desire for separate public identity have encouraged airlines to seek allocation of specific spaces in the terminal building for their individual use. This means a reduction in the continuity of facility utilization and a consequent increase in the total size and cost. Minimum cost can only be achieved by continuous and homogeneous use of the facility.

Through all this process it must be kept in mind that the final terminal design will have to provide enough capacity to satisfy the demand within practical limits of economy and convenience. The capacity/demand analysis involved in the planning process is discussed in the next section.

Capacity and Demand

Capacity of an entire terminal building or its segments is usually expressed in terms of achievable rates of movements and in some cases, of actual population for a given area. The basic concept employed is number of movements (i.e., passengers, bags) per unit of time with the appropriate unit depending on the particular application. For some facilities the unit of time could be one hour, in others, a shorter time period such as five or ten minute-period may be used. For example, in determining the width of a facility such as a pier finger, it is necessary to consider that an arriving aircraft creates a substantial concentration of passengers in a relatively short period of time, the size of the surge being a function of the size and arrival schedule of the aircrafts and the number of doors being used. Therefore, in the consideration of space to be provided for this facility, it would not be adequate to use an hourly flow rate of passengers.

It is also necessary to define demand; although it would be desirable to satisfy a peak demand, the costs involved and space requirements make a value below this peak demand more realistic for implementation. Yet is is important that the capacities of different segments in the process be matched, so that adequate capacity in one operation does not restrict overall flow.

With respect to processing rates, the appropriate measurement of capacity is not the same for all individual facilities, and, the average time required to process one passenger at any specific facility depends on the nature of the procedure and the operational concept used. For instances, some airlines prefer to check-in all the passengers at one point, others check-in passengers with baggage at one point and passengers without baggage at another point, etc.

The period of delay or degree of congestion which is acceptable at any facility for efficient operation, is conditioned by the purpose of the space, and the nature of the passenger control procedure in question. For some facilities, delays and congestion only constitute temporary reduction of convenience which are acceptable (i.e., in concessions such as restaurants, etc.), but in other parts of the terminal such delays could produce excessive inconvenience. These are points where certain procedures have to be completed by a specific time in order to allow other operations to be accomplished. A typical example would consist of the check-in counters. Check-in process has to be completed within some specific period before flight departure time to permit airline's employees to complete aircraft documentation, compute load balance, etc. Therefore, any excess of demand over the check-in desk capacity would not allow some passengers to board within the specified time period, consequently either delaying the aircrafts or causing the passengers to miss their flight.

Finally, emphasis should be given to a final design that accommodating a given rate of passenger flow, provides acceptable level of service with the minimum cost to all interested parties (airport operator, airlines, passengers).

Use of Simulation Models

To ensure that a potential design satisfies requirements of both capacity and level of service, planners must be able to test alternative terminal concepts. The development of models is the most important analysis element of permitting performance of these tests. The complexity of the terminal problem previously described, with its many considerations and interrelated factors makes the use of analytical models almost impossible. Stochastic simulation, on the other hand, provides the benefit of a model that mirrors operations for all the facilities and functions in the airport. Thus, corrective planning and redesign can be executed in the light of a realistic evaluation of the terminal's layout.

Simulation models can produce detailed information about the probability of incurring queues, delays and congestion under a given set of conditions. They can be used to consider and test experimentally the relationships between space allocation and processing times, or to determine the effect of varying arrival patterns of either passengers or airplanes, changes in operational concepts, etc. Although the results are product of the model, they are also conditioned by the data and assumptions subjectively chosen by the planner.

A simulation model can serve, therefore, as a valuable tool in decision making for evaluating alternative design concepts and operating systems for optimum terminal design.

Objectives

The objective of this research is to evaluate through the use of stochastic simulation models, alternative concepts for processing airline passengers through a check-in area of a medium sized airport. One concept to be tested is a completely restricted or flight system, in which a group of counters (usually only one) is assigned to each flight. All passengers for a specific flight must check-in at the assigned counter, and no counter will handle passengers for more than one flight at the time. This system is used by some Latin American airports where airlines do not have computerized reservation systems.

The second concept to be tested is the common or fully availability check-in system in which passengers arriving to join any flight may check-in at any of the counters provided by the airline. This is the system currently used in American and European airports.

The models will estimate the actual performance of the system, and by comparing the requirements with the performance the level of service provided by the system can be established. Finally, by assessing the cost incurred by passengers, airlines and airport owner and operator, the economic implication of the system may be determined.

The simulation will be restricted to the activity in the check-in area, and therefore will consider only those passengers which by any reason (i.e., because of baggage) have to check-in at the main counters. It is also important to point out that the models only consider information about quantitative characteristics of the system such as congestions, waiting time and aircraft delays. They do not consider qualitative aspects such as competitive position of the airlines and their freedom over the use of the area.

CHAPTER II

LITERATURE REVIEW

The use of simulation models to aid in the design of transportation terminals has become common practice in recent years. Its use comprises the design of simple transit stations to very complex and sophisticated models to simulate the entire operation of major airports. In this chapter emphasis is placed on reviewing models developed to evaluate alternative terminal designs and operational concepts. Discussion of other simulation applications are not included since an exhaustive literature is available.

Transit Station Simulations

Fausch[1] developed a model for analyzing pedestrian flows through a transit station in order to determine the effect of changes of person and vehicular arrival patterns on space requirements. The simulation model is based on an interval-oriented method, in which examinations of the system's status are made at small consecutive intervals of time. The simulation is accomplished by generating events such as passenger arrivals, keeping track of consecutive

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[1]Peter Fausch, "A Transit Station Simulation," paper prepared for the PAST PRESIDENT'S AWARD, June 1971.

events, and then, determining the consequences of these events. The program includes four basic functions:

1. Generation of arrival events and service times based on a negative exponential distribution;
2. Generation of passengers, in which the number of passengers boarding or deboarding the bus is determined by a normal distribution;
3. Time accounting, or the internal clock of the model used to generate subsequent arrivals and to determine the time for printing statistics of the simulation; and
4. Determination of space requirements in which ten square feet per person is assigned to the number of persons present in the system at any one instant.

The output from the program is a listing of the activities within the station during each small time interval, including person and vehicular arrivals and departures, waiting times, and also the station area characteristics. Although the model was designed for a specific purpose, it could be used to simulate operations of any model interchange station, or simulate operation of entrance areas to buildings where the vehicle is an elevator or escalator.

Recently, Fausch, Dillar and Hoffmeister[2] developed a computer package for the U. S. Department of Transportation, UMTA. The model is used for evaluating transit station designs in terms of both efficiency, and comfort and convenience for the passengers using the system. This is accomplished by determining if the proposed layout achieves the design objective of providing sufficient service facilities and high quality pedestrian flow. Furthermore, the model not only provides pedestrian occupancy data, walking times, queue lines for specific areas of the station, but also the distribution of those variables for comparison with level of service standards.

One of the most interesting features of the model is the manner in which the layout of the station is represented by nodes, links, and areas. The nodes represent queue devices, decision points, or points where arrival or departures are created or destroyed. The links represent pedestrian paths between devices or points; and the areas are the spaces associated with the devices and paths.

The simulation is event-oriented, a technique in which each event produces a change in the system conditions, or the characteristics of the persons in the system. By accumulating information on these changes, the data

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[2]P. Fausch, D. Dillard, and J. Hoffmeister, "USS - An Evaluation Tool for Designing Pedestrian Facilities in Transit Stations," January 1974.

required to evaluate the station design is produced. This model is the most comprehensive and detailed model currently available for designing transit stations.

<u>Use of Simulation in Airport Planning and Design</u>

Hockaday and Madison[3] provide a general overview of the mathematical models representing aircraft movements at airports. This paper describes modeling techniques for five different classes of models: 1) Capacity models; 2) Delay models; 3) Air traffic control models; 4) Collision risk models; 5) Pollution models. However, the paper by its nature does not provide detailed information with respect to the way the models are applied or their results.

Low[4] also discusses potential use of simulation models, and suggested guidelines for their proper used. The four general uses of simulation models for planning and designing include:

1. Sizing design elements by gathering queuing, and traffic statistics;
2. Locating design elements in order to minimize walking distances;

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[3] S. Hockaday, and D. Maddison, "Modeling of Aircraft Movements at Airports," <u>Proceedings</u>, Fourteenth Annual Meeting, Transportation Research Forum, Vol. XIV, No. 1, 1973, pp. 469-482.

[4] Dana Low, "Use of Simulation in Airport Planning and Design," <u>Transportation Engineering Journal</u>, ASCE, November 1974, pp. 985-996.

3. Analyzing interdependent elements to examine their relationship with other elements of the complete system; and
4. Analyzing operating procedures as a tool for evaluating operational decisions.

An additional use suggested is that of testing proposed designs. This could be done in two different ways; testing the system as a whole, if it is assumed that the system and process are sensitive to the interaction of the component parts. However, for large systems, it would be impractical to model the complete system, and therefore, it is suggested that the subsystems be modeled and tested individually to determine their sensitivity to varying inputs from other subsystems.

The paper enumerates the following basic elements of airport operations which should be included for developing a fairly comprehensive simulation model: 1) Airfield subsystem to simulate processes occurring from airspace to gate positions; 2) Terminals, which would include operations within the terminal building such as check-in counters, baggage claim facilities, etc.; and 3) Ground access to represent highway, parking lot, transit and taxicab facilities, etc. Low's paper also provides an excellent set of guidelines concerning the degree of refinement of the models and the proper balance between time, budget, and output.

One of the earliest and most important examples in the field of airport simulation is the work of Reese[5]. The purpose of the study was to analyze the effect that increasing passenger flows and larger aircrafts would have on the passenger transfer systems linking the passenger terminal building and the aircraft. The model programmed in FORTRAN IV was used to simulate passenger movements, and passenger densities in each area of the "blocks" into which the system was broken. Each block corresponded to a homogeneous section of the system such as a section of a pier finger. Since it was not possible to determine a direct way of measuring the degree to which the model described the actual movement of persons within the system, Reese used an indirect test. Comparing simulated data with actual data collected at O'Hara Airport of the number of persons entering and leaving the system during a given time interval, the model could be tested by assuming: First, that if one model cannot describe the number of persons entering or leaving the system during a given time interval, it is logical, that the model cannot describe adequately the events happening within the system. Secondly, the rate at which persons leave the system is a function of the variables affecting the movements of the

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[5]Philip Reese, The Passenger-Aircraft Interphase at the Airport Terminal (Evanston, Ill., The Transportation Center, Northwestern University), 1968.

persons through the system. The relationship between these variables and the movement of persons through the system simulated is then correct if the model can describe the rate at which persons leave the system. Although this test did not show directly how well the model described activities within the system, it appeared to be the only way of testing this model given the limited amount of resources available.

Smith and Murphy[6] developed a computer simulation model for use in determining the flow of people in a pier finger of an airport terminal building. The model was intended to be used as an aid in designing and sizing this type of terminal facilities. The model consists of a main program and a set of subprograms that performs the flow generation and timing functions; the primary function of the main program being to control the sequence of steps in the simulation. Given as input are: flight data and test parameters such as duration of the test period, number of gates, and ratio of visitors to passengers. The model, then determines flow rate of persons through the time of simulation.

The generation of passengers coming from the land-side, is based on a cumulative arrival curve, closely

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[6] E. Smith, and J. Murphy, "Pier Finger Simulation Model," The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1968.

resembling an S-curve, starting on an hour prior to departure and terminating at departure time (EDT). This approach was suggested in an earlier study by Paullin,[7] while analyzing the passenger flow to departure lounges. On the other hand, the assumption of a linear relationship to describe the generating process of arriving passengers from the aircraft (in the airside), is similar to the model developed by Kaneko[8] in a study on passengers enplaning and deplaning characteristics. For the validation of the model, simulated data were compared with observations at the San Francisco Airport. The result of this validation showed that the generation of arriving passengers was not linear but that it could be better approximated by a two regime linear curve. Although the model also had some other limitations (i.e., the model did not provide the capability of simulating intermediate gate positions along the pier finger corridor), it still has more flexibility than a pure analytical approach can provide.

One of the most complex models developed was applied to evaluate the performance of the Dallas-Fort Worth

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[7] R. Paullin, "Passenger Flow at Departure Lounges," The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1966.

[8] E. J. Kaneko, "Passenger Emplaning and Deplaning Characteristics," The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1967.

Regional Airport plan.[9] The model developed by Tippets-Abbet-McCarty of New York was intended to simulate aircraft ground operations in order to evaluate the airfield layout. It was written in GPSS and not only records statistical measures of performance, but also provides a visual display of the simulation through creation of a motion picture from the computer simulation of selected portions of the aircraft traffic activity. In this motion picture each aircraft type was represented by a different symbol, and their movements observed about the airport's system of runways, taxiways, aprons, and intersections. Thus points of delays and queues build-up become evident.

The Dallas-Fort Worth model not only considers conventional efficiency input parameters such as flight data for passengers, cargo, and general aviation aircraft, and the physical and performance characteristics of the aircrafts, but also considers as a major input cost data (i.e., cost involved in aircraft taxiing, and passenger time cost). By determining queue lengths and delay times in the air and on the ground, minimum costs designs can be achieved and cost-benefit analysis performed.

Summary

Current research effort focuses on only one

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[9] A. E. Brant, and P. McAward, "An Evaluation of Airfield Performance by Simulation," Transportation Engineering Journal, ASCE, May 1974, pp. 505-522.

subsystem of the terminal, that of the passenger check-in area. As noted in the literature, previous applications of simulation models to airport terminal have considered components of the terminal building separately. In this manner simpler models can be developed while not sacrificing reliability of information. Efforts in developing this model could become elements of a much larger total terminal simulation model, or as suggested by the present application be used to test the effectiveness of alternative check-in procedures. The special characteristics of the check-in operation make it more suitable for analyzing by using simulation models than by applying complex analytical models. Queuing processes in which both the customers and the servers are human beings "face-to-face," do not behave in the way classical queuing models assume. Thus, it is reasonable to use simulation models which represent as close as possible the actual operations within the system.

CHAPTER III

MODELS FORMULATION

Objectives of the Models

The simulation models developed as part of this research are designed to be a realistic description and representation of the individual movements of passengers through alternative check-in procedures. The main element in the development of the models includes passenger group arrival characteristics and service times. The models determine length of queues, waiting times and space requirements in the system. The model also provides counter requirements in the case of the restricted system, and for both alternatives, the utilization of each counter expressed as the percentage the counter is used with respect to the time the counter remains open. By changing the degree of activity in terms of expected number of aircraft departures or passenger arrivals, it is possible to test the effectiveness these conditions on the performance of the system.

System Description and Operations

The check-in concourse is the area between the passenger building entrance and the check-in positions as noted in Figure 1. It may be an integral part of the main

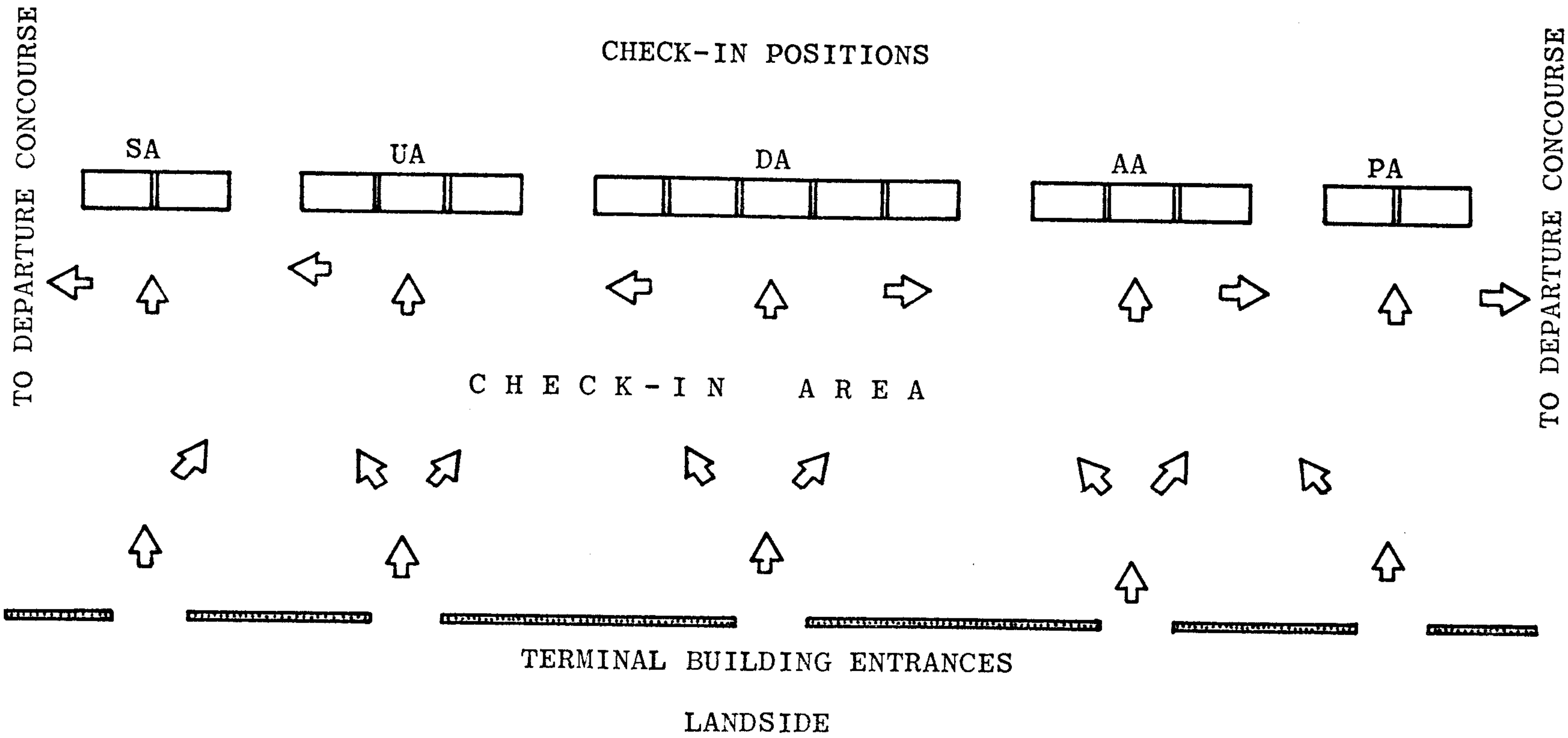


Fig. 1. Typical check-in area layout.

waiting room at airports in non-hub and small-hub communities, but generally at medium and large-hubs, check-in and waiting facilities are located in adjacent spaces to that enplaning and deplaning routes are separated from queuing lines forming at the check-in counters. The location of the check-in facility close to the building entrance enables passengers to check-in at the earliest moment possible, reducing the effect of delays at the initial stage, and allowing for the latest possible arrival arrivals at the airport before flight departure. This also enables passengers to be relieved of their baggage within the shortest walking distance.

Because of these considerations and in order to avoid increasing the complexity of the model, walking distances and passengers walking speeds are not considered. The system to be simulated is reduced to the simplest case in which the arrivals are considered when the passenger is close enough to the counter, so that walking time is negligible.

The check-in operation varies with the type of flight, and particularly with the operational concepts of each airline. For example, some airlines prefer to have passengers check-in at the departure lounges, and therefore only passengers with baggage have to go to the check-in counters. Other airlines prefer to check-in baggage at one place (i.e., at the curb) and passengers at different places. In some cases the employee must weigh the baggage and write the weight in the flight coupon (international flights), while for others only labeling the baggage is required before dispatching it to the baggage room (U.S. domestic operations).

In any case, check-in counters may be organized in different ways in order to provide an efficient service. Currently in use there are two basic systems as follows:

1. Completely restricted - under which one service position is assigned to each flight for a fixed period prior to the scheduled time of departure; and
2. Common check-in - where any of the desks provided by the airline may handle passengers for any flight before its close-out time.

Each system has its own advantages and disadvantages which must be considered carefully before implementation. For example, in the first system passengers arriving before flight open time cannot check-in and have to wait in the lounge, restaurants, etc., and return later when their flight opens. Also, passengers may frequently be found queuing at one counter when an adjacent counter assigned to another flight is idle. This would not occur with a common system since early passengers may check-in immediately. This system, however, has a serious disadvantage: a passenger arriving late to check-in just prior to departure might find himself waiting behind other passengers checking-in for later flights. The airline employee lacks information about the flight represented by the passengers queuing before him and he cannot readily anticipate this situation. The late passenger can be so delayed that when he finally reaches the front of the queue the flight might possibly have been closed and he would miss his flight.

In this decision-making process, it must be considered that from the passenger's viewpoint there exists a level of service associated with check-in operations. is measured by the time he must wait to be served plus the time taken to serve him. Since the airlines have the responsibility of pleasing passengers while operating at economic levels, the planning of check-in areas, must be based on operational concepts which provide an adequate level of service at least cost. The models developed in this research can be used to help in this process.

Models Characteristics

The basic structure of the simulation models is the scan-event method. In this technique a set of significant events are determined and stored in terms of times at which they will occur, and then the earliest is selected. To simulate each event a cycle of steps has to be completed as follows: 1) The events are scanned to determine which is the next potential event, 2) the activities that caused the event are selected and tested to see if they can be executed, 3) some records are changed to reflect the effects of the event, and 4) statistics for the simulation output are gathered. This cycle can be better visualized in the flow chart shown in Figure 2.

The passage of time is recorded by a number referred to as clock time. It is set to zero at the beginning of the simulation and subsequently indicates how many units of simulated time have passed since the beginning of the simulation. The method used for updating the clock is known as ASYNCHRONOUS TIMING in which the clock is increased by a variable amount each time. The basic idea is to keep the system running until an event occurs at which time the computer stops momentarily to record the change in the system. In the computer program this is accomplished by recording when the next events are scheduled to occur, updating the clock to the next imminent event and then recording the resulting state of the system. This process is repeated until it is considered that the simulation has run enough to produce reliable results.

The set of numbers that represent the system at any instant of time is called SYSTEM IMAGE, and in the models includes the following information: 1) Total number of persons actually present in the system; 2) number of persons in queue for each flight or counter; 3) number of passengers having arrived for each flight, and 4) pedestrian

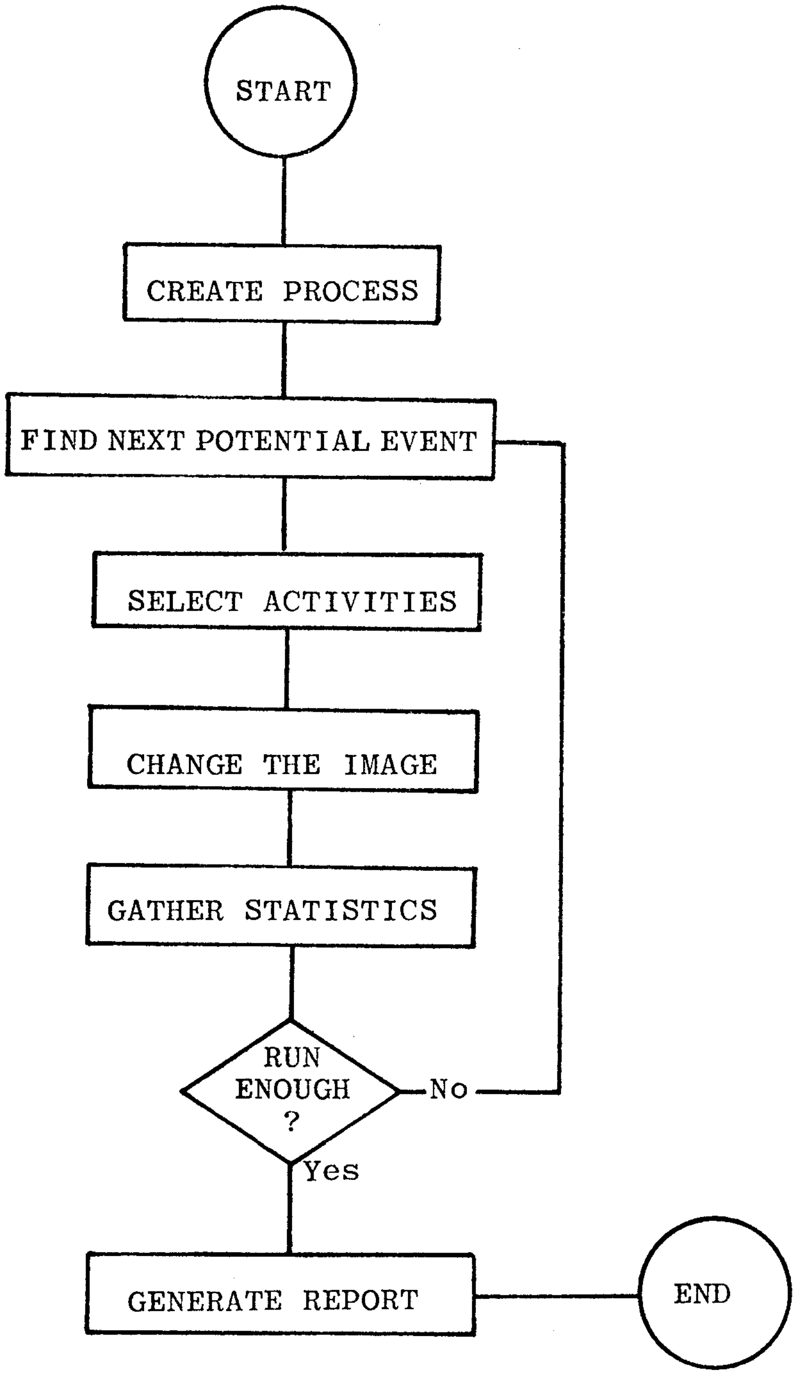
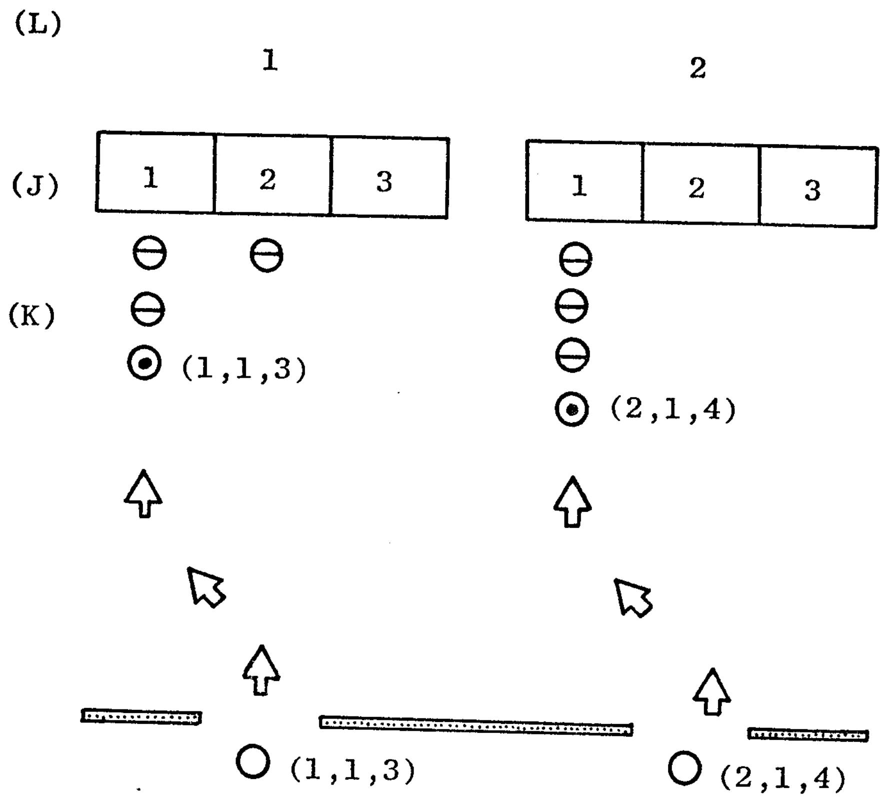


Fig. 2. Cycle of steps to simulate each event.

occupancy expressed in terms of available space (area) per person.

An event is represented by the change of state of an entity. The sequence of events ordered in time is called a PROCESS, and the collection of operations that transforms the state of an entity is referred to as an ACTIVITY. In the models, five basic events are considered adequate to represent the check-in process: 1) Flight open - the earliest time before departure at which passengers are allowed to check-in for the flight; 2) Passenger groups arrivals - the time when a new group of passengers and accompanying friends arrive in the system; 3) Passengers start check-in procedure; 4) Passenger service ends - the time when the passengers receive their boarding pass or flight coupon and leave toward the waiting areas or gate; and 5) Flight close-out - the time when no more passengers are allowed to check-in.

To facilitate the simulation, each event is defined in terms of the specific airline (L), the flight (J) and the particular passenger for the flight (K). In the case of common-counter system, in addition to the above characteristics, an event is also defined in terms of the counter used (M) and the order of arrival to this counter (N). All of these characteristics are called entity attributes. A schematic representation of the characteristics assignment to each passenger is shown in Figures 3 and 4.



Legend:

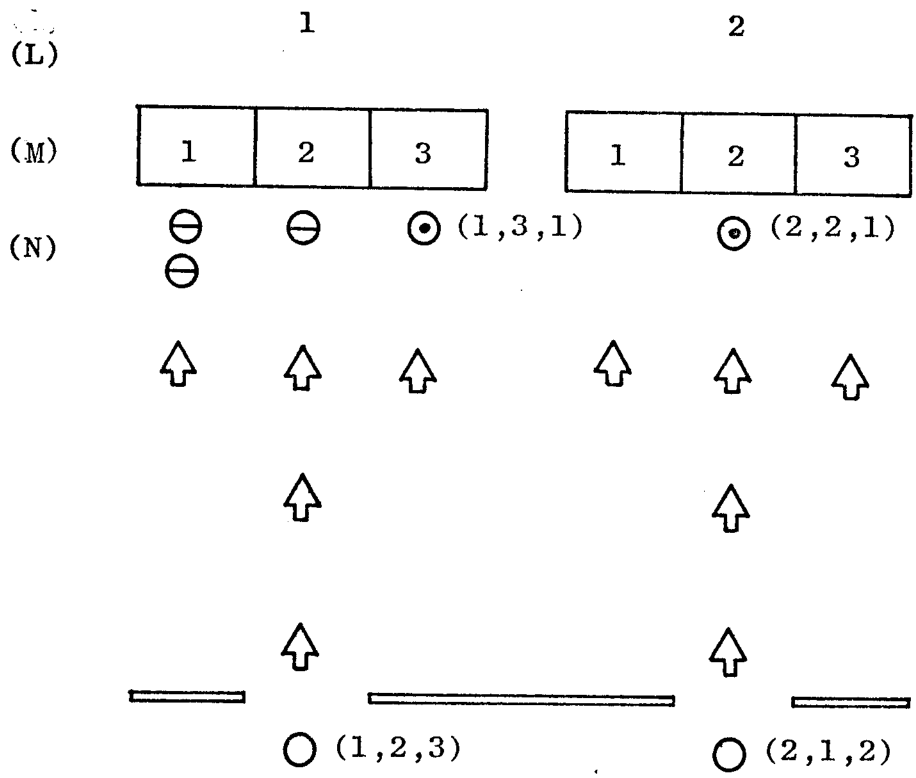
⊙ (L,J,K) = K^{th} passenger for the flight J of the airline L, assigned to the counter J.

○ (L,J,K) = K^{th} passenger generated for the flight J of the airline L.

⊖ = Passengers already in queue.

⇨ = Passenger's possible path.

Fig. 3. Passenger assignment to a specific counter - restricted system.



Legend:

⊙(L,M,N) = N^{th} passenger to select counter M, of the airline L.

○(J,K,L) = K^{th} passenger generated for the flight J of the airline L.

⇨ = Possible passenger's path.

Fig. 4. Passenger assignment to a specific counter - common system.

The following sections describe in detail each one of the operations used to represent the activities started or stopped by any event, the steps involved in the process, and the assumptions on which the model is used.

Flight open time. The time before departing flight is opened is especially critical in the case of restricted check-in system. In fact, the counter should begin to serve passengers in advance to be able to process those arriving early, and remain open long enough to allow all passengers to be processed before flight close-out. However, since one counter can handle only one flight at the time, the period of time the counter remains open must be kept to a minimum in order to permit the same desk to be used for the greatest possible number of flights. The period of time devoted to a flight is also a function of the type of flight (i.e., domestic, international or charter). For use in the models, the flight open time was assumed to be 90 minutes before time of departure.

Passenger group arrivals. The arrivals of passengers at airport terminals have specific characteristics which differentiate them from passenger arrival to other terminals. The arriving entity is not always a singular individual but a group of persons (i.e., passengers and friends) and must consider a distribution to reflect the number of passengers arriving per group.

Furthermore, the interarrival time cannot be expected to be completely random in form. This is true in part because: 1) The arrival process is made up of passengers from a finite number of sources (different flights); 2) each flight generates arrivals at different times and at different rates; and 3) arrival rates of passengers are not constant but vary with time because of the impending flight deadline. Passengers begin to arrive at a slow rate at the time the flight is open, reach a peak about the deadline time, and then taper off at, or shortly before, departure time. Rate of arrival curves vary between flights and may depend upon the predominant type of traveler (i.e., business, pleasure, etc.), and the hour of the day the flight is scheduled (i.e., in the morning, evening, etc.).

To analyze the pattern of arrivals to be used in the model data was collected at McGhee Tyson Airport in Knoxville. Information was gathered for those airlines which did not have flights scheduled so close together that passengers for the different flights might arrive at the same time. The data collected for the flights noted in Table 1 had flight departure separated by ninety minutes or more.

Kolmogorov-Smirnov test for goodness of fit showed that the hypothesis that observed arrivals are Poisson distributed had to be rejected at the 5 percent significance level. The Kolmogorov-Smirnov test for goodness of

Table 1. Flights Observed for Check-in Passengers

Airline	Flight	Days of the Week	Departure Time	Date
United	495	Wed., Sat.	09:20	XI-13,16-75
United	550	Fri., Sat.	10:10	XI-15,16-75
United	826	Fri., Sat.	12:40	XI-15,16-75
United	815	Fri., Sat.	15:15	XI-15,16-75
American	610	Fri., Sat.	17:49	XI-15,16-75

fit for the passenger arrivals is noted in Appendix A. Given that Poisson arrivals cannot be used in the model, a different approach had to be used to describe the passenger arrival rate curves. By determining the expected number of arrivals for each time interval before departure, and normalizing it in terms of percent, the number of passengers arriving at any time "t" can be determined for a specific total number of passengers to be boarding a given flight.

Assuming that each class interval (10-minute intervals) is independent, and assuming that a frequency distribution exists for each interval, then an estimate of the expected value of each of the observed frequencies may be obtained from:

$$\eta = \sum_{i=1}^{n} Yi/n \qquad (3.1)$$

where η is the expected value; Yi is each one of the observed number of passenger arrivals during the 10-minute interval for each one of the n flights. Tables 2 and 3 give the results of these calculations.

Having determined the expected number of arrivals for each time interval a cumulative flow curve can be obtained from the cumulative percentages to represent the pattern of passenger group arrivals (Figure 5). The slope of the line between any two points represents the rate of 'ow of passengers expressed as a percentage of the total

Table 2. Normalized Frequency of Arrivals

Time Before	Flight EDT	AA 495	UA 550	UA 826	UA 815	UA 610	AA 495	UA 550	UA 826	UA 815	UA 610	
-90	-80	0	0	0	1	0	0	1	2	2	0	0.60
-80	-70	0	0	1	2	1	1	0	4	2	1	1.20
-70	-60	1	2	4	4	1	3	3	6	4	0	2.80
-60	-50	1	7	3	5	3	2	6	5	8	3	4.30
-50	-40	7	10	5	5	6	6	8	6	7	5	6.50
-40	-30	7	12	3	6	4	9	11	3	16	6	7.10
-30	-20	11	6	2	6	3	10	7	4	5	4	5.80
-20	-10	3	0	1	3	3	4	4	1	5	3	2.70
-10	0	3	1	1	1	2	2	2	1	2	0	1.50

Table 3. Accumulation of Passengers

Time Before Flight	Expected No. of Arrivals	Cumulative	Cumulative % of Passengers
90			0.0
	0.6	0.6	
80			0.0185
	1.2	1.8	
70			0.0554
	2.8	4.6	
60			0.1415
	4.3	8.9	
50			0.2738
	6.5	15.4	
40			0.4738
	7.1	22.5	
30			0.6923
	5.8	28.3	
20			0.8708
	2.7	31.0	
10			0.9538
	1.5	32.5	
0			1.0

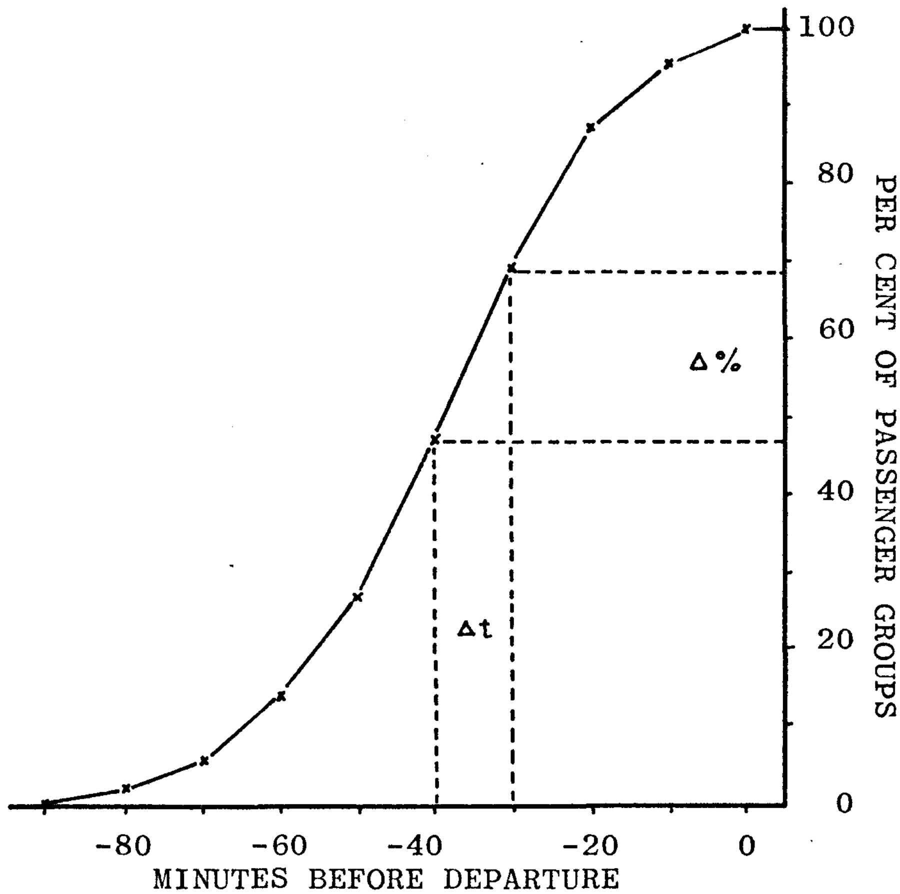


Fig. 5. Accumulation of passenger group flow.

number of passengers to check-in for any given flight. Thus, if NPB is the number of passengers to check-in, the expected number of passengers arriving in a t interval is given by:

$$\hat{\lambda} = (\Delta\%) \cdot (NPB)/\Delta t \quad \text{(Arrival/min.)} \qquad (3.2)$$

and the mean interarrival time:

$$T_a = 1.0/\hat{\lambda} \qquad \text{(Minutes)} \qquad (3.3)$$

The assumption that arrivals are random within each time interval cannot be validated statistically because of the size of the sample used to calibrate the model (10 flights). However, if the rate of arrivals can be assumed constant for the interval and the arrival of a passenger group is completely independent of the arrivals of the other ones, the hypothesis of Poisson arrivals within each time interval does not seem too absurd.

An additional consideration is given to the number of passengers arriving in each group. A passenger group consists of a number of passengers traveling together with common baggage and the persons accompanying them. From data collected at Knoxville Airport, the distribution of number of passengers per group is shown in Figure 6.

Passengers initiate and complete check-in process. The time a passenger starts checking in depends on whether or not a desk is available at that moment, and the time he finishes depends on the duration of service time. An

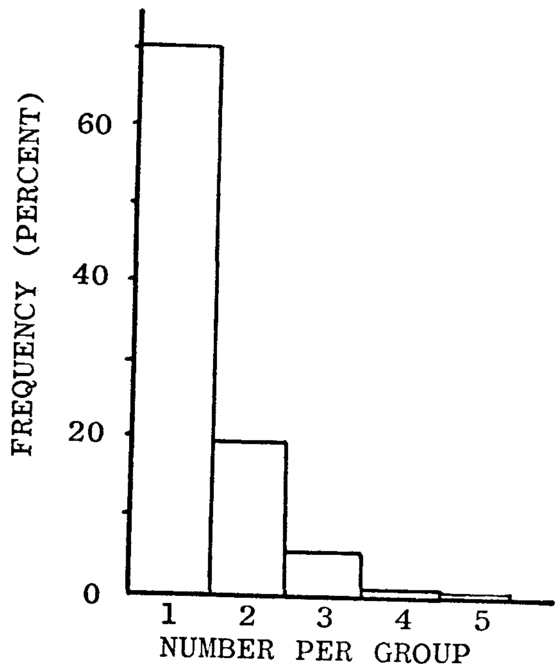


Fig. 6. Distribution of number of passengers per group observed at McGhee Tyson Airport.

analysis of service times gathered at McGhee Tyson is shown in Appendix B. The exponential distribution did not adequately describe the empirical data. From Figure 7 it is evident that the observed data are close to the mean value, with the exception of a few low and high values. Based on the coefficient of variation and the Kolmogorov-Smirnov test results, an Erlang distribution with k = 3 was used to represent the data. The analysis of the service time data collected is given in Appendix B.

Flight close-out. Flight close-out time has been defined previously as ninety minutes after a flight opens. This value is taken arbitrarily and it does not correspond to any airline practice but rather to empirical observations. From the passengers' arrival pattern observed at Knoxville, this value seems reasonable.

Description of the Models

The programs, written in FORTRAN IV, comprise a main program in which the events are created and stored and ten subroutines which provide the values of the stochastics variables and the means for ordering these events in time. The main program is divided into five elements which correspond to each one of the events previously defined. A verbal description of the operations, and activities in each one of the elements, as well as the construction logic of the program, are given in the following sections.

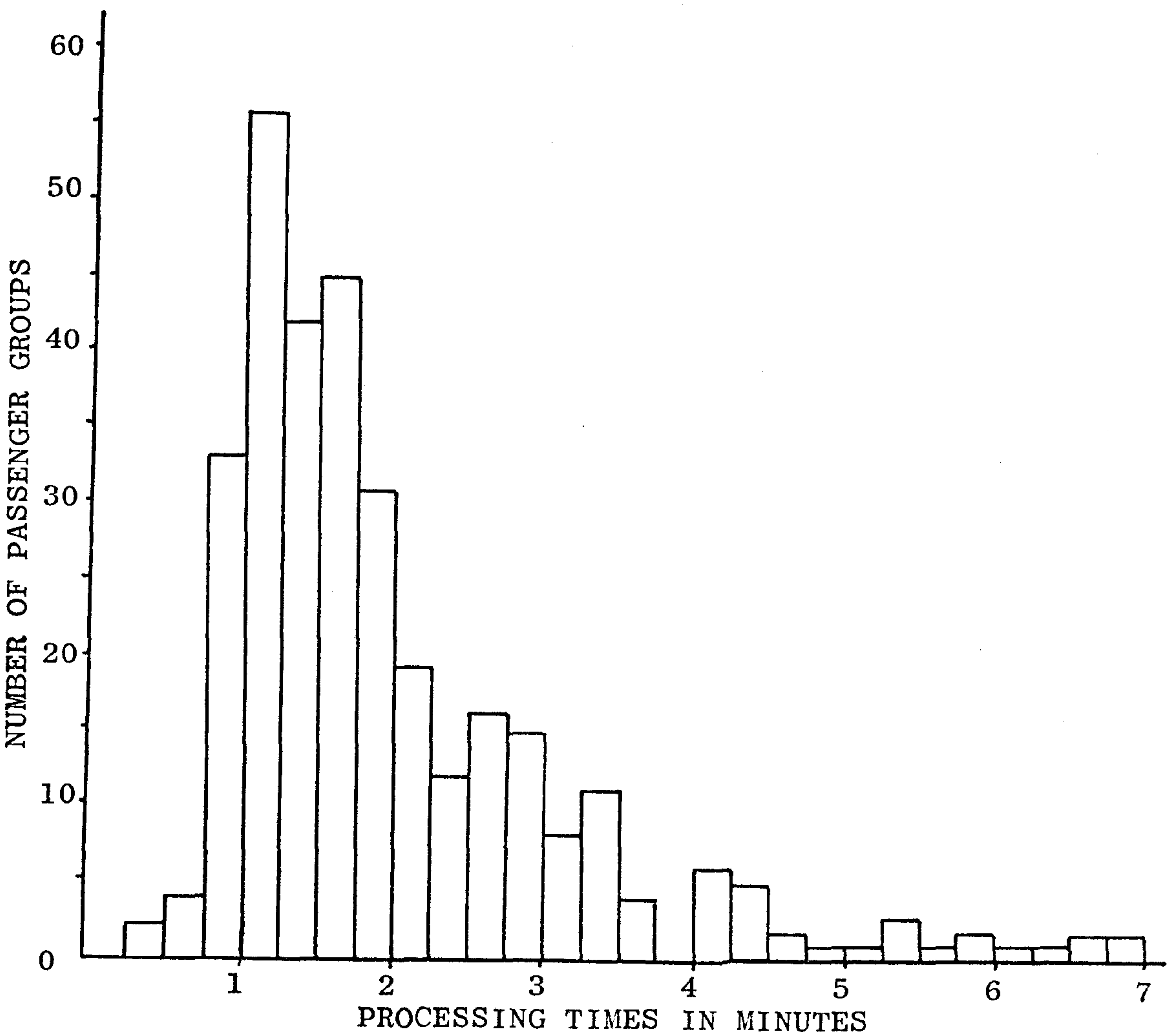


Fig. 7. Distribution of processing times.

Input variables to the models. In order to use the simulation models developed, it is necessary to include information about those variables which have effect on the check-in operations which are as follows:

A. Passengers:

1. The expected number of passenger groups per flight and its standard deviation
2. The distribution of number of passengers per group
3. The distribution of visitors per passenger group
4. The points which define the cumulative passenger flow curve, and the time interval used for defining those points

B. Airlines:

1. The name of the airlines to use the facilities
2. The percentage of total air traffic (considered as number of flights) shared by by each airline
3. In the case of the common check-in system the number of counters to be provided by each airline

C. The system as a whole:

1. The number of departures during the busiest hour

2. The average hour activity
3. A Kurtosis factor to simulate the peak activity
4. The area provided for check-in procedures

The Main Program

The structure and principles followed in both models are similar and therefore only those activities specific of any of the models will be described separately. The major differences between the two models are shown in Figure 8. As explained before, the major function of the main program is to create and store the events that will take place in the system during the simulation time. This is accomplished by means of "chains" of events in which the time of occurrence and the characteristics of the entity to produce the event are stored. There is one chain for each of the events, and a matrix of "next potential events," where the earliest event of each chain is placed in a specific position (i.e., flight open time will be located in the first row; the passenger group arriving time in the second row, etc.). The characteristics associated with each event, recorded in the matrix include the airline and the flight for all the events, and also the number of the group for the arrival and the initiation or finalization of services. In addition to these characteristics, the matrix of potential events in the common system model must include

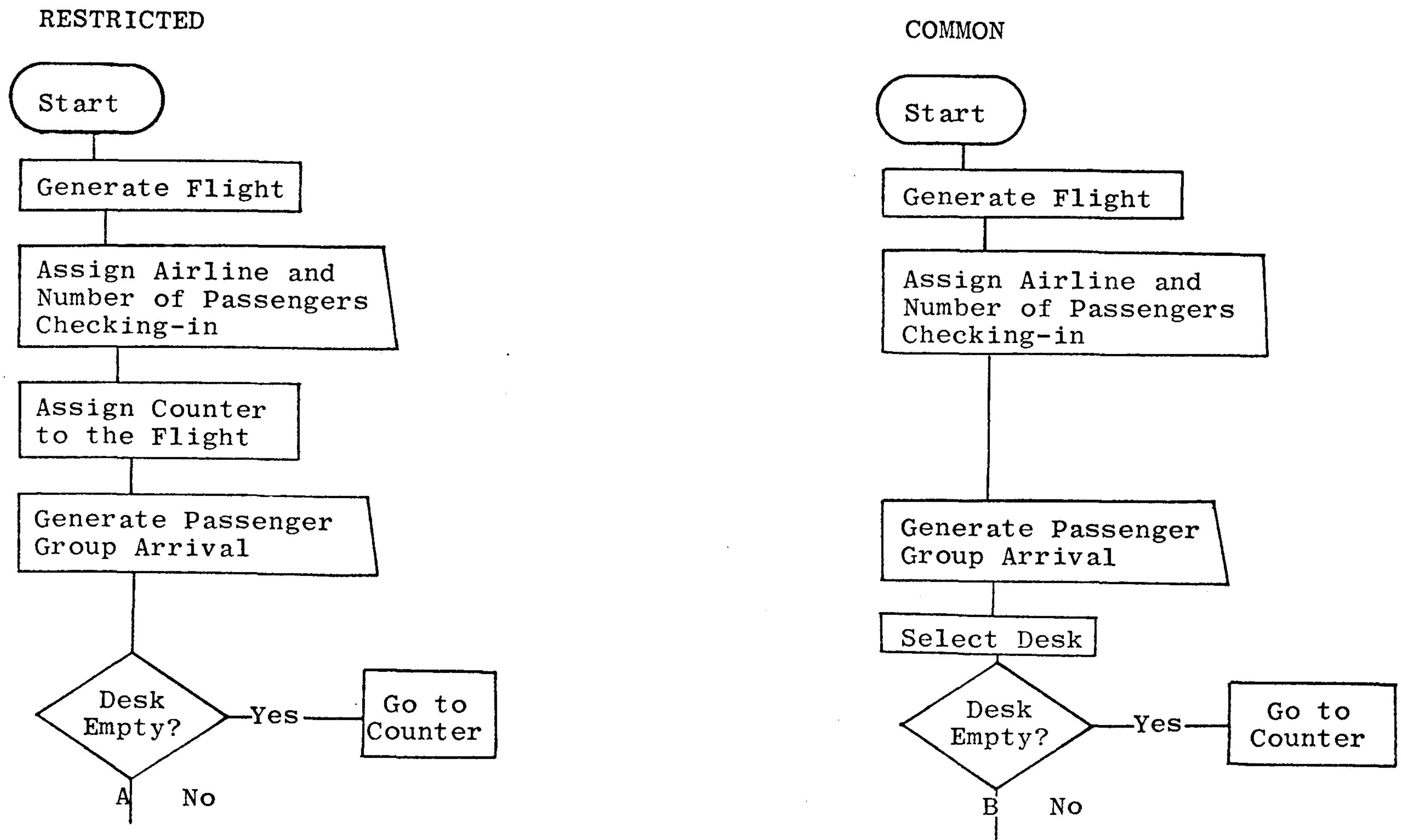


Fig. 8. Major differences in the simulation models - restricted vs. common check-in systems.

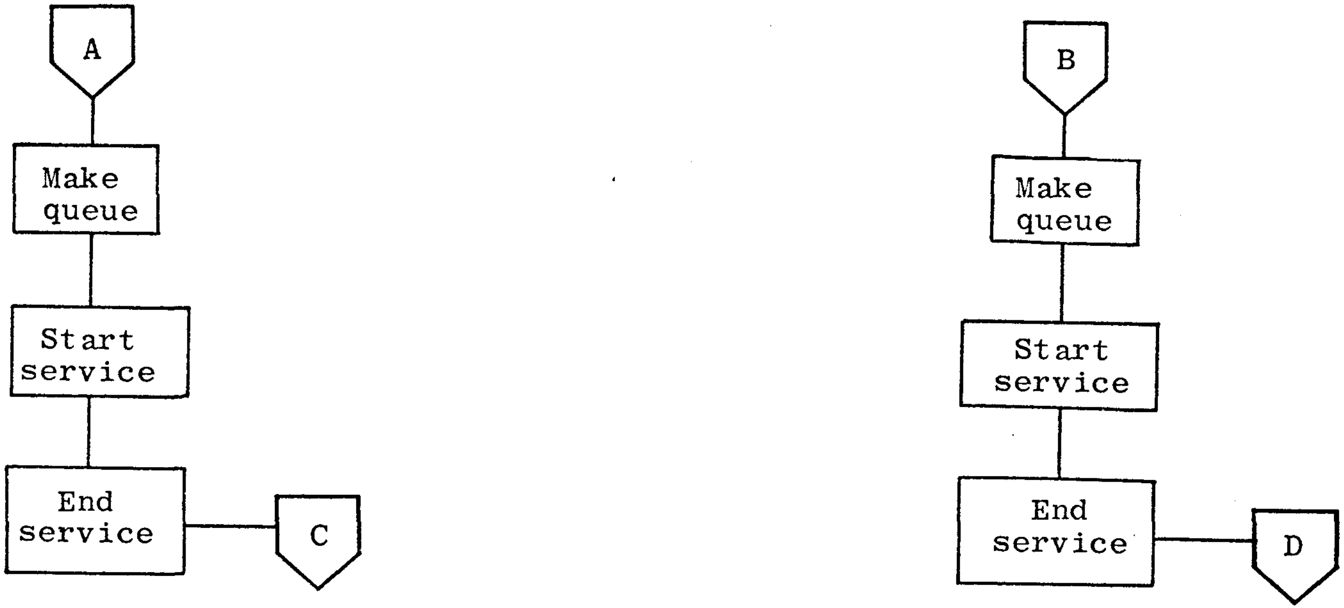


Fig. 8. (continued).

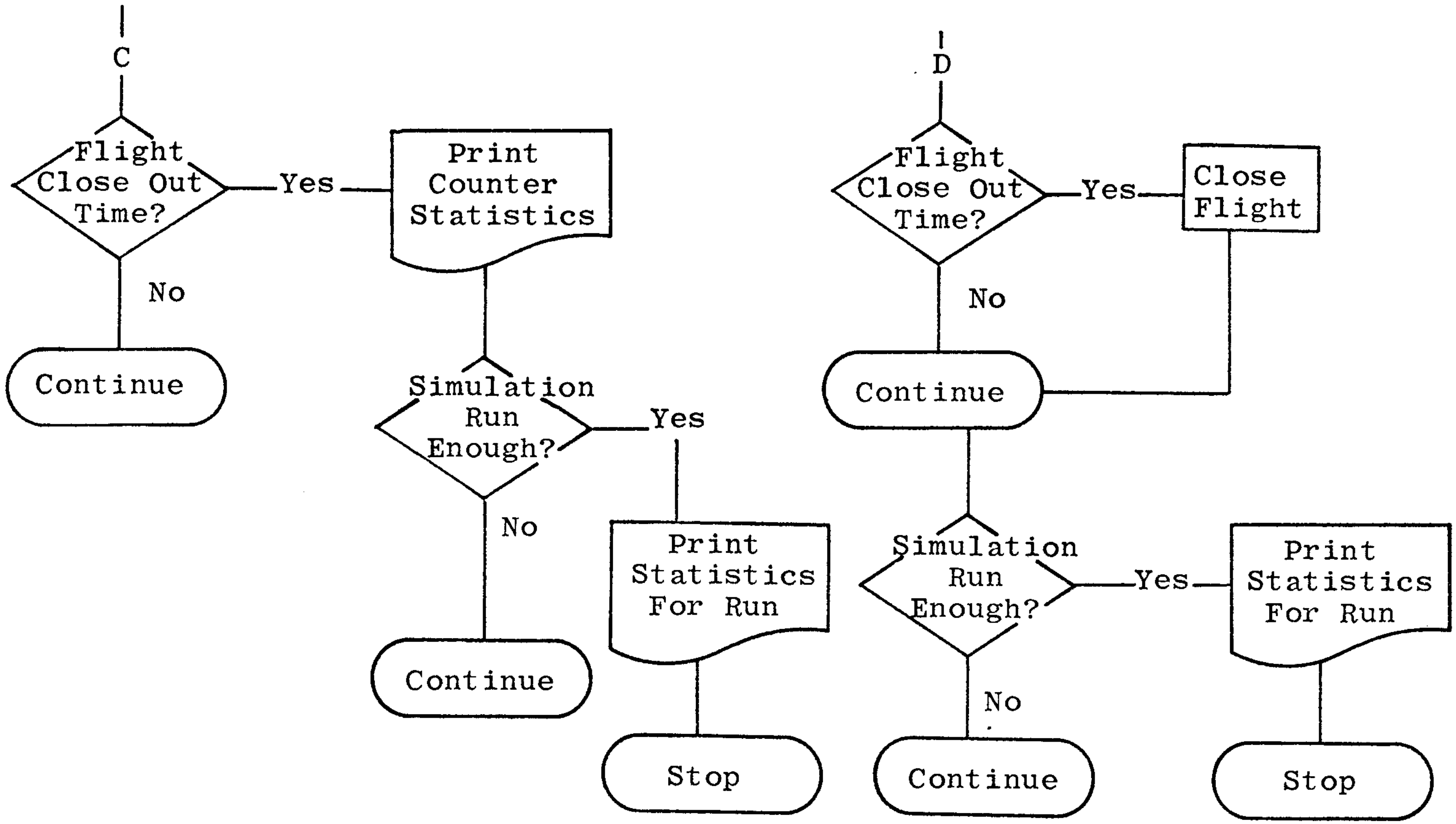


Fig. 8. (continued)

the number of the counter associated with the event and the order of arrival of the passengers to the counter. By using a subroutine, the smallest time (the earliest event) is selected and then the element of the program corresponds to that event is executed. After one event has already occurred, a new event of the same type has to replace it in the matrix and the selection process is repeated again.

A. Flight open time. The function of this element of the program is to create the flights that will generate the arrivals. The flight is assigned to one of the airlines and the number of passenger groups to arrive for the flight are determined. For the restricted system, the model searches to find if any of the counters previously assigned to other flights could be used; if so, the flight is assigned to that desk. If no desks are available a new counter is provided. The time of opening a new flight is given by the time between aircraft departures. In the models, aircraft activity is simulated considering the rate of operations per unit of time as a function of time (Figure 9). The curve follows a Gaussian distribution and is expressed by the equation:

$$N = (MAX - MIN) \exp (- 1/2 ((T-90)/KF)^2) + MIN \quad (3.4)$$

where:

N = Number of departures per unit of time (60 minutes)

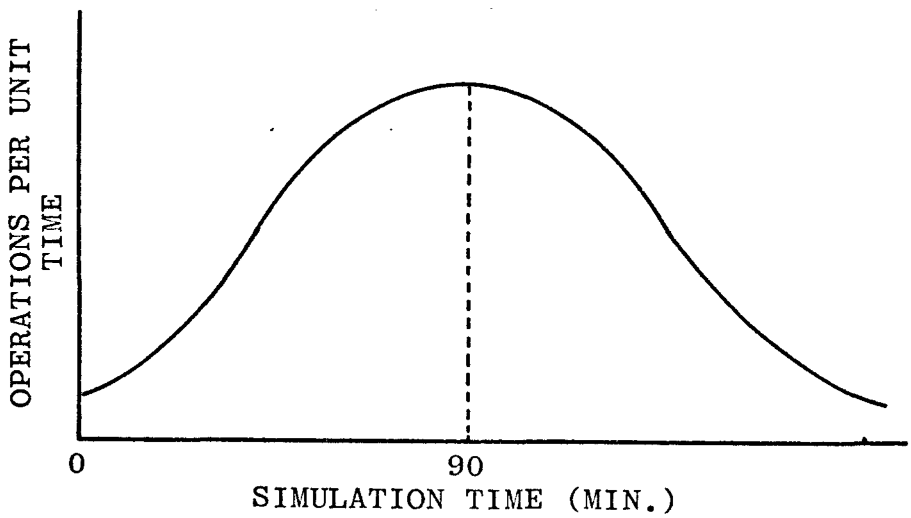


Fig. 9. Simplified departure rate.

MAX = Number of departures during the busy hour

MIN = Number of departures during the average hour

T = Time in the simulation of the previous departure

KF = Kurtosis factor. This number must be such that for T = O, the first term in the equation be close to zero, and at the same time gives an acceptable "peakedness" to the departures.

If N is the number of departure per unit of time for this moment, the interdeparture time will be given as:

$$Td = 60/N \qquad (3.5)$$

B. Passenger group arrival. The second element in the program generates the flow of passengers into the system. If there is more than one flight for which passengers are checking-in the model generates one time of arrival for a passenger group for each flight, assigning to each of them the number of passengers in the group and the expected service time at the counter. Once the earliest of these arrivals is selected, the next operation defines the time of initiation and finalization of the check-in process for the group. In order to accomplish this, the model has to select the desk where the group will be served. Each model uses a different approach for the selection of the check-in counter. In the restricted system model, the program assigns the passenger group to the designated flight. If the passengers are the first ones to check-in for a flight or the desk is empty (the time of arrival of the group is greater than the service time of the previous group), the time for beginning service is the time of arrival of the group. In other cases the starting time is the time the previous group terminates service.

The common or free system model involves a more complex operation. The program determines the state of the counter of the airline to which the group is assigned. If all of them are empty or in equal conditions (the same number of persons in queue) the passengers are assigned to any of the counters (each counter will have the same probability of being selected). On the other hand, if all of them are occupied, the program assigns the group to the counter which has the smallest number of persons in queue. Finally, if only some of the counters are empty, the group is assigned to any of the counters not occupied, based on the assumption of equal probabilities for selection. Service initiation and termination time are the determinates for the group in a similar manner to the restricted method described previously.

C. Initiation of service at counter. The function of this element is to control the state of the counters, determine how long the passenger has remained in queue, reduce the size of the queues and advance all the persons in queue one position.

D. Finalization of service at counter. This fourth element of the model removes the entities from the system. Once the passengers finish service at the counter, the facility is placed in an empty status permitting calculation of the time the counter has been in use. Finally the net number of people in the system is reduced by the size of the group leaving and the number of visitors accompanying them.

E. Close-out time. The final element in the program is used to represent the activities taking place when the flight is said to be closed. This element has different operations for each model. The common system program places the status of the flight as "closed" and any passengers arriving at a later time to any counter will be included in the list of passengers that missed the flight. The restricted system model, on the other hand, must determine the number of passengers in the queue and the time required to process them, based on the service time previously assigned. This time will be reported in the output as the expected delay for the flight. Since under this system all the passengers remaining in queue at close-out time have to be processed, delaying the departure of the flight. The counter is next set to "free" so that a new flight of the same airline can be assigned. Finally, both models remove the flight from the chain where it is stored so that no more passengers are generated for the flight.

The subroutines. The main purposes of the subroutines was previously explained. The function of ordering the events on time is carried out by four different subroutines: GONEXT, FOLLOW, WHOBGN, WHOEND, each one of which is associated with one of the chain of future events, and the matrix of next potential events. The subroutines determine the smallest time and the position of the event, so that the characteristics of the entity associated with the event (i.e., airline, flight, counter, etc.) can be easily defined. Some of the subroutines provide the stochastic variables used in the simulation and include: 1) the subroutine RAND which generates pseudo random numbers to be used through the simulation, 2) subroutine GAUSS, which generates the number of passenger groups to check-in for a flight follows a normal distribution, 3) subroutine SERVE, determining the service time for each one of the groups following an Earlang distribution with k = 3, 4, subroutine GENPAS, which generates the passenger interarrival time. This is done by determining the time interval before departure time in which the last arrival took place, obtain the expected number of groups to arrive during that interval and the mean interarrival time. Finally, this mean value is used to generate a Poisson arrival.

The functions of the last two subroutines can be described briefly as follows: the subroutine STATUS assigns to each passenger group generated, the number of passengers in the group and the number of associated visitors. For these two variables, the probability of a number of passengers per group or visitors per group is obtained by converting the relative frequency into a probability scale ranging from zero to one. Considering this function as a "generating function" a random number between zero and one will define the random variable. The subroutine AIRLN utilizes this approach to assign an airline to each one of the flights generated in the main program. Each airline is represented by one number which corresponds to the class interval. The percentage of traffic shared by each airline is assumed to the relative frequency, and the cumulative frequency is used as a generating function. A random number will define a class interval for the random variable and therefore an airline for the flight.

Output from the Model

The output from the model provides information at two different levels, information of performance of the system as a whole, which is obtained at the end of each run and includes the following information:

1. Number of passengers that entered the system

2. Number of persons remaining in the system
3. Pedestrian occupancy and density
4. Maximum number of persons in queue
5. Average number of persons in queue
6. Number of persons with zero waiting time
7. Maximum time spent in queue
8. Average waiting time
9. Average waiting time for passengers in queue
10. Counter utilization

Also available is information about the individual performance of each counter which varies with the model. For the restricted system model, the counter performance output is obtained whenever a flight is closed. In addition to the items enumerated above, information is also provided on the expected delay for the flight as previously discussed. In the common system model, information about the individual counters is obtained at the end of the run, and includes information similar to the items listed above, except for items 1. and 2. This model provides information concerning the individual flights, their schedule, number of passenger groups per flight, and the number of passengers that could not check-in on time before close-out time.

The output information facilitates examination of alternative operating concepts. The output then makes it possible to examine the results of imposing a restricted versus a common check-in system which will be discussed in the next chapter.

CHAPTER IV

APPLICATION OF THE MODEL AND RESULTS

Introduction

The simulation models developed in Chapter III can be applied to the planning of terminal areas, specifically the evaluation of alternative check-in disciplines. For example, given a selected operational policy, restricted or common check-in, flight loading and number of counters in operation, the model can identify such passenger level of service parameters as average queue length, average waiting time, etc. Delay parameters form an important component in assessing level of service and also are of value to airlines in defining operating procedures and number of counters to operate. The terminal planner would also be interested in space parameters such as minimum space per person (density of crowd) and maximum queue size which will determine the extent of concourse area to devote to check-in operations.

Cost provides a common denominator and permits definition of a minimum cost design by assigning a monetary value to flight delays and passenger times. This minimum cost, of course, will be subjected to constraints of achieving a minimum level of service.

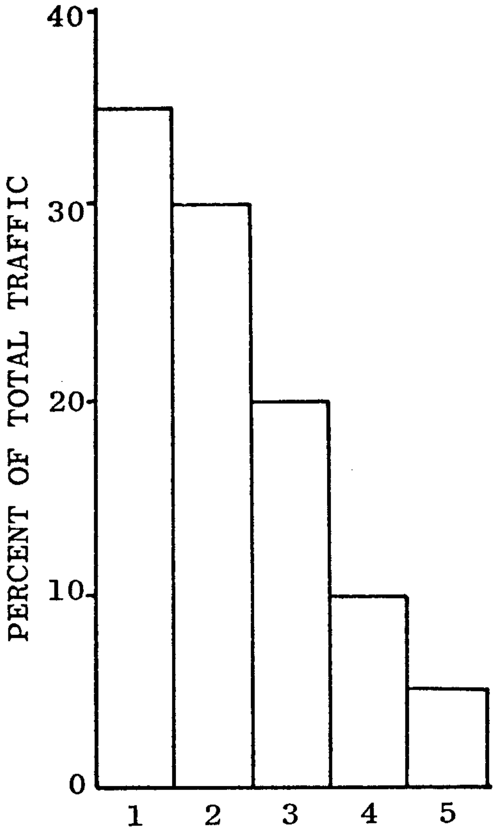
Restricted vs. Common Operating Policy

The first run of the simulation models compared the restricted vs. the common check-in disciplines for 180 minutes of activity. Defined as input into the simulation run were:

1. Average number of passengers to check-in per flight = 32 (480 ps./hr.)
2. Maximum number of flight over 90 minutes = 15
3. Average service time per passenger = 92 sec.
4. Number of counters in operation = 13

The value and other internal parameters such as proportion of traffic shared by each airline, and size of the passenger group, are shown in Figures 10 and 5 (p. 35) respectively. The relationships were derived from flight schedules and passenger loads observed at Knoxville-McGhee Tyson Airport. The number of counters corresponds to the summation of the average number of counters assigned to each airline during the simulation of the restricted system. As previously explained, airline counter assignment to a flight is a stochastic process and for each simulation run, a different number of counters would be required by an airline. Thus, the number of counters used may not necessarily correspond to the existing facilities at the Knoxville Airport.

Partly for this reason and because of a lack of empirical observations it was not possible to conduct a formal verification test. However, Appendix C reports the results of an internal verification check concerned with



1. Delta Airline
2. United Airline
3. American Airline
4. Southern Airline
5. Piedmont Airline

Fig. 10. Proportional share of total traffic - airlines serving McGhee Tyson.

testing if stochastic results have stabilized on a set of reliable values.

A summary of the simulation results is presented in Table 4. It is evident that for a given number of counters the common system provides a superior level of service over the restricted system. By allowing all the passengers to check-in at any counter, regardless of their boarding flight, reduction in queue lengths and waiting time can be achieved. For example, the average time spent in queue (1.3 minutes) under the restricted system, can be reduced to about half the time (0.65 minutes) under the common system. However, the common system does not provide as great efficiency in the utilization of the counters as does the restricted system.

In order to evaluate the performance of the system, use can be made of standards provided by previous studies. It has been found by Lee[10] in a study for the London Airport, that an optimal system should provide an average waiting time of less than 0.5 minute during the peak hours. In the same way, Fruin[11] suggested 13.0 square feet as the minimum average area per person to be provided in queuing space. The standard, however, is related to passengers

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[10] A. M. Lee, Applied Queuing Theory (New York: St. Martin's Press, 1966), Chap. 10, p. 116.

[11] J. Fruin, Designing for Pedestrians - A Level of Service Concept, Doctoral Dissertation, Politechnique Institute of Brooklyn, January 1970, p. 34.

Table 4. Summary of Simulation Results, Restricted vs. Common Check-in Systems

Evaluation Parameters	Restricted System	Common System
1. Maximum number of persons in queue	4.31	2.40
2. Number of persons with zero waiting time	5.47	18.05
3. Average number of persons in queue	0.73	0.42
4. Maximum time spent in queue (min.)	4.74	3.36
5. Average time spent in queue (min.)	1.29	0.65
6. Average waiting time for persons in queue (min.)	3.53	1.74
7. Maximum number of persons/sq. ft. of space	0.036	0.027
8. Minimum space per person provided (sq. ft.)	27.59	36.70
9. Counter utilization (percentage)	0.436	0.290

Note: Number of counters considered 13.

without baggage. Therefore at least 20.0 square feet per person should be provided to ensure unrestricted circulation through the queue. Based on the criteria of standard space per person both the common and restricted systems exceed the stated standard. However, a comparison with average waiting time standard indicates that for all passengers the delay is very high in the case of restricted system (1.3 minutes) and for the common system (0.65 minutes). Particularly for passengers in a queue the times are excessive (3 minutes for the common system and 1.74 for the restricted system).

In summary, for the conditions specified as input, the simulation model has provided estimates of level of service in terms of queue length, waiting time and average area per person. For all the parameters of evaluation, the common system presents a better performance than the restricted system. Furthermore, under the common check-in discipline the passenger is more likely to encounter an idle desk.

Sensitivity of Passenger Loading

Airline passenger traffic is expected to increase at most airports with time. Therefore, the planning of terminal areas must be aware of increased loadings. The simulation model can, then, aid the planner by performing the function of evaluating the alternative check-in procedures under variable passenger loading. The simulation of the restricted check-in discipline was repeated for the following average number of passengers checking-in per flight: 42 (equivalent hourly volume of 630 pass./hr.). The results of these simulation runs are noted in Table 5. As expected, with an increase in the number of passengers the service level provided by the restricted system will decrease. For example, the minimum space per person, which measures crowd density, was reduced to less than half of the space required when the expected number of passengers was increased from 32 to 62 passenger/flight. The significance of this is that the restricted system is very likely to produce excessive congestions for increasing number of passengers. It is evident from the results in Table 5, that the restricted system with 13 counters cannot provide adequate levels of service for large numbers of passengers checking-in. The only solution available to the planners would be to assign more than one counter to each departing flight, which is an uneconomical situation.

When considering the system as a whole average values are obtained for all the counters. However, by analyzing the simulation results for each individual flight, the effect of increasing the number of passengers on the level of service provided by each counter can be easily determined. The results comparing changes in the level of service parameters with number of passengers

Table 5. Summary of Simulation Results - Restricted Check-in System

Evaluation Parameters	Expected Number of Passengers To Check-in per Flight			
	32	42	52	62
1. Maximum number of persons in queue	1.31	4.95	6.32	10.63
2. Number of persons with zero waiting time	5.47	3.72	3.26	2.85
3. Average number of persons in queue	0.73	1.96	3.71	5.49
4. Maximum time spent in queue (min.)	4.74	5.23	6.86	10.72
5. Average time spent in queue (min.)	1.29	1.83	2.00	2.94
6. Average waiting time for persons in queue (min.)	3.53	4.01	4.22	4.67
7. Maximum number of persons/sq. ft. of space	0.036	0.045	0.058	0.079
8. Minimum space per person (sq. ft.)	27.59	27.22	17.24	12.66
9. Counter utilization percentage	0.436	0.563	0.648	0.702

Note: Number of counters considered 13.

checking-in per flight are shown in Figures 11 through 16. The results represent a simulated sample of 440 observations. While the average number of persons in a queue (Figure 11) is likely to remain relatively low, less than two persons for values up to 35 passenger groups, the average number in queue increases very rapidly far in excess of that value. The same can be said with respect to waiting time (Figures 12, 13, 14). Given a standard of 0.5 minutes, the average time spent in queue for all the passengers exceeds acceptable levels of passenger delay, even for low number of passenger groups. It seems, therefore, that the standard value for waiting time can not be achieved with the restricted system when the airport is to be used by medium or large size aircraft.

On the other hand, counter, utilization which measures how efficiently a facility has been used (Figure 15) does not increase uniformly with the number of passenger groups, but provides only small improvements for large numbers of groups. For example, if the number of passengers increases from 10 to 40, the utilization of the counter improves 40 percent (from 20 percent to 60 percent, approximately), but if the number increases from 40 to 70, the utilization achieved is only 75 percent (an increase of 15 percent). This means that if by selecting a restricted system, the planner is seeking a better utilization of the facilities, a real benefit may not be realized. Arriving

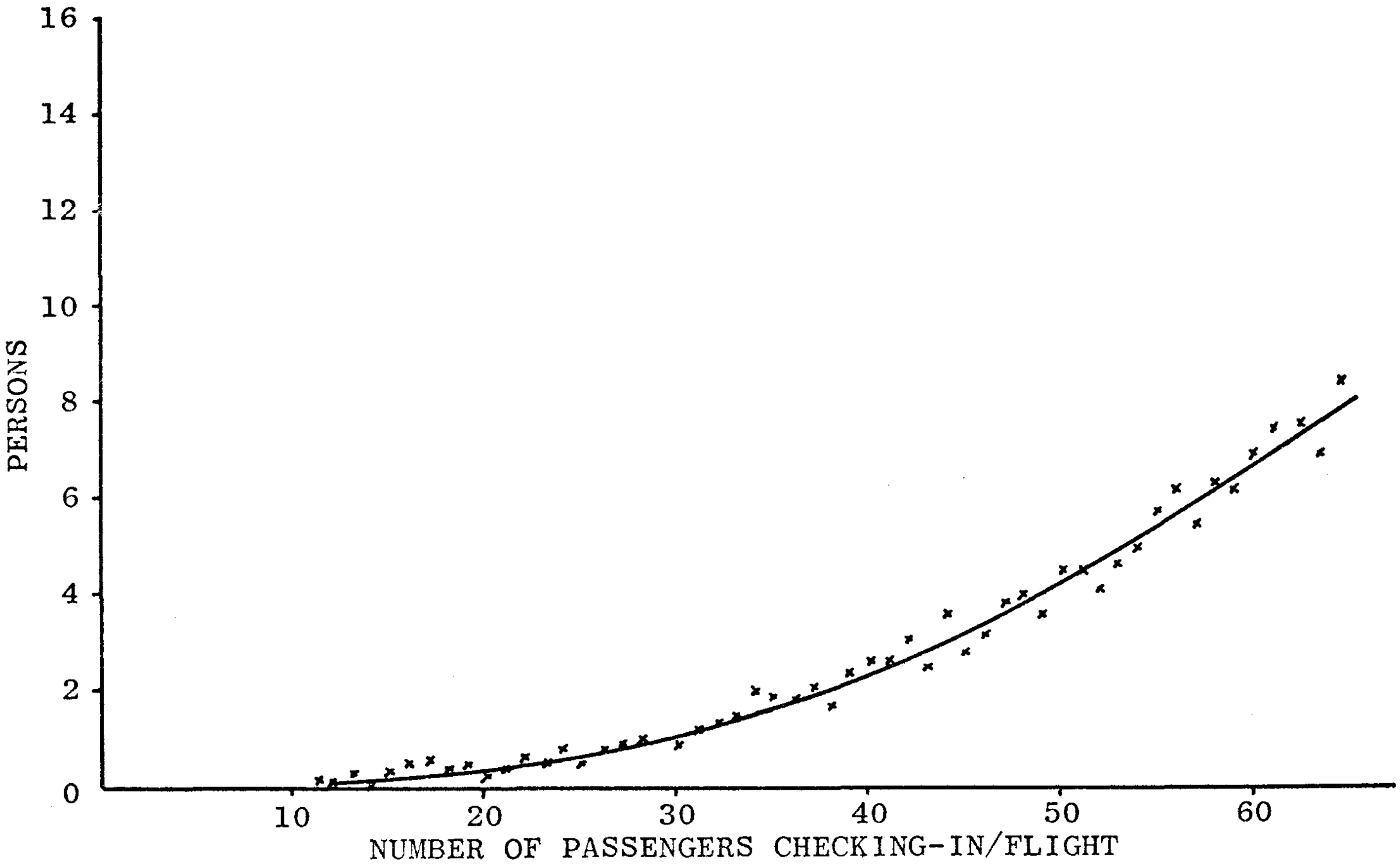

Fig. 11. Average number of persons in queue - individual counter performance.

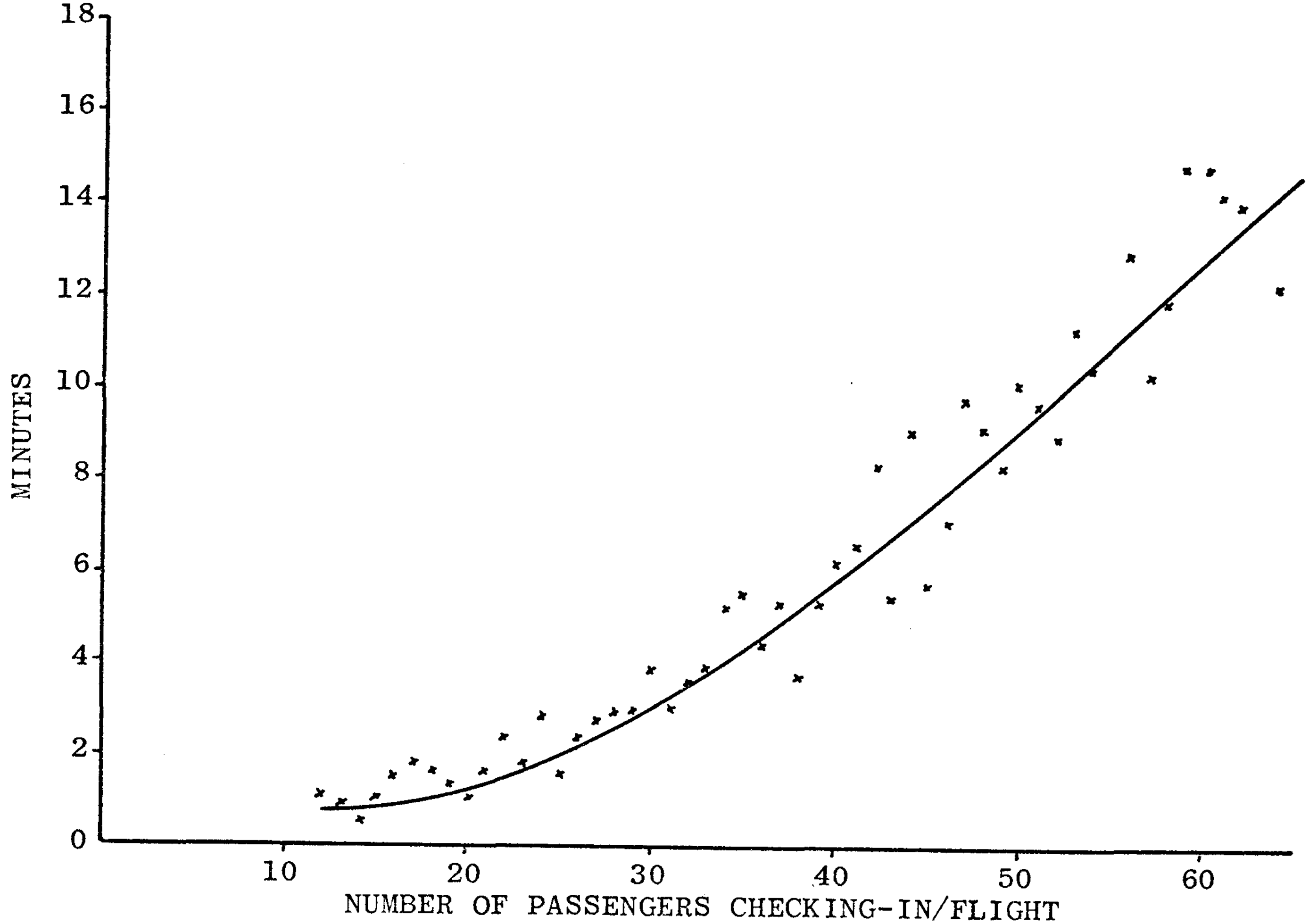

Fig. 12. Average waiting time for persons in queue - individual counter performance.

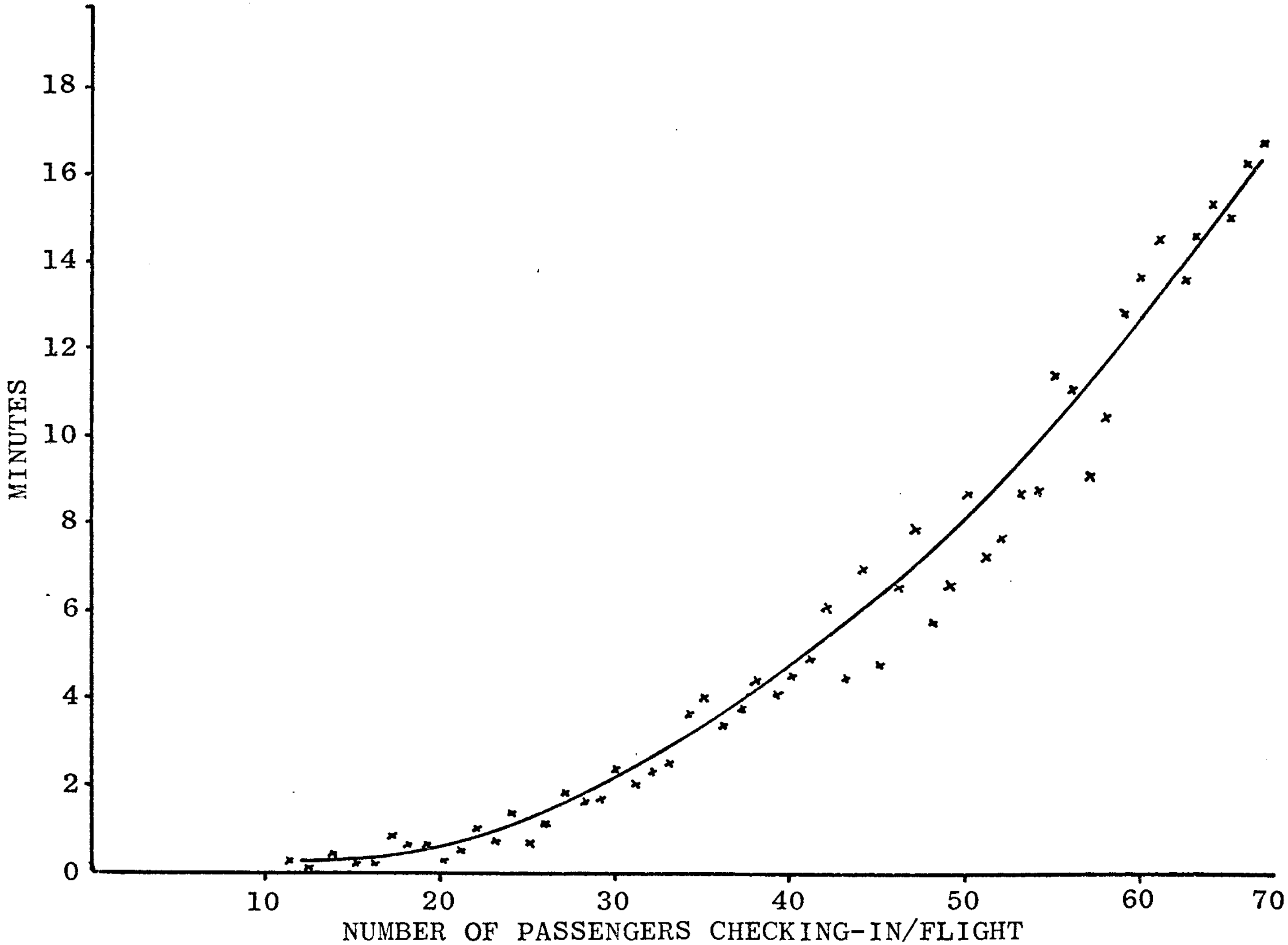

Fig. 13. Average time spent in queue - individual counter performance.

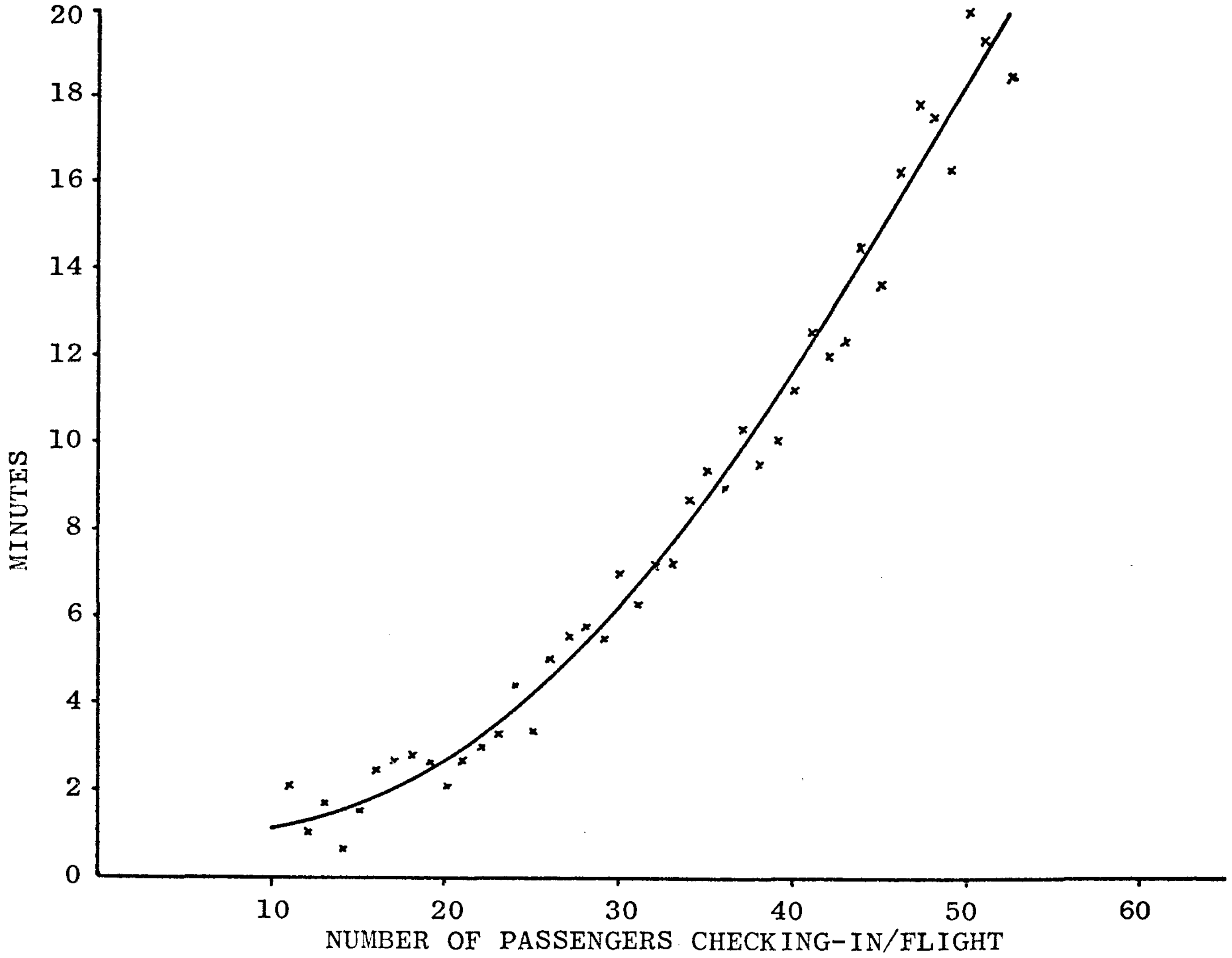

Fig. 14. Maximum time spent in queue - individual counter performance.

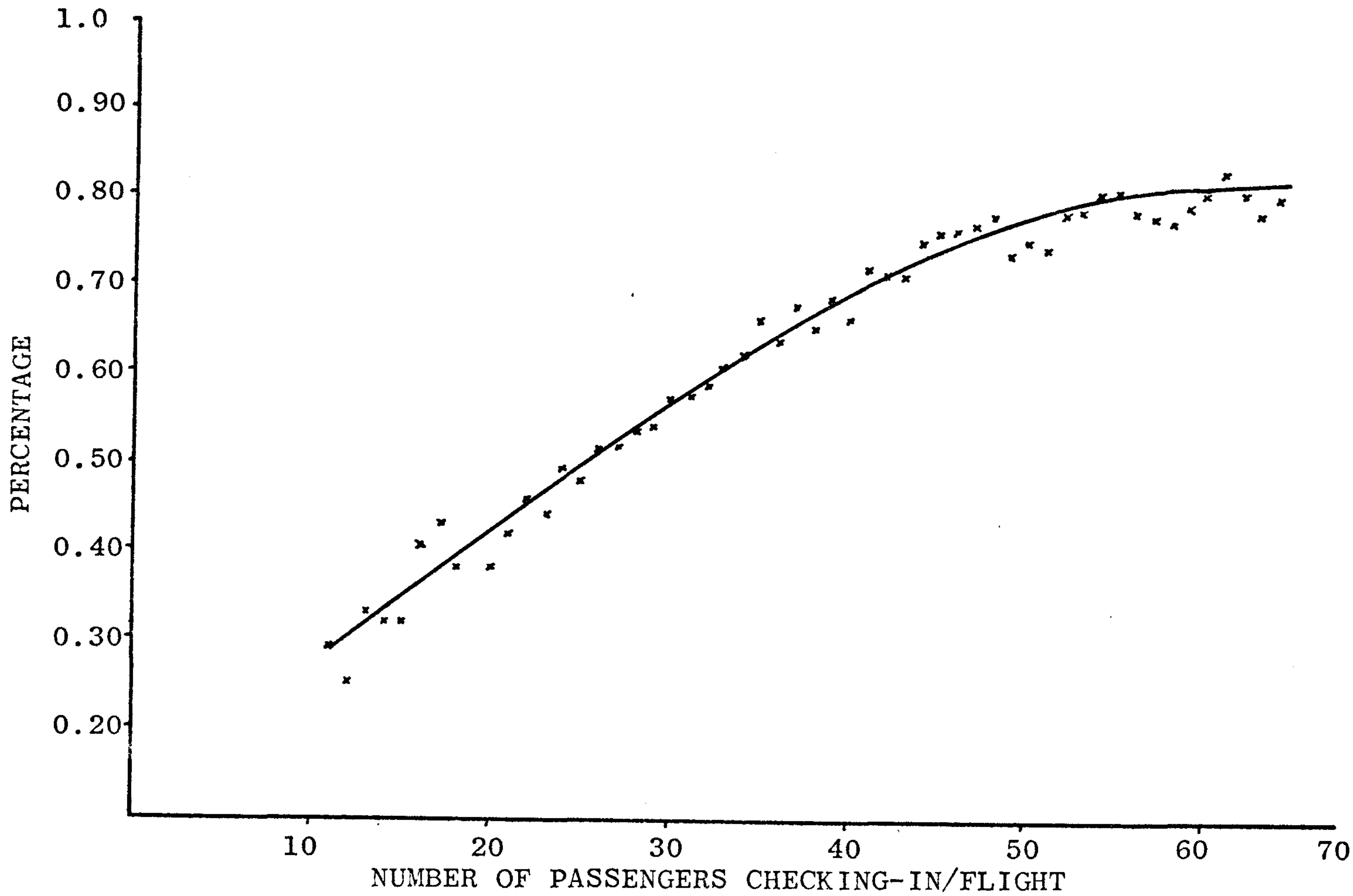

Fig. 15. Check-in counter utilization - individual counter performance.

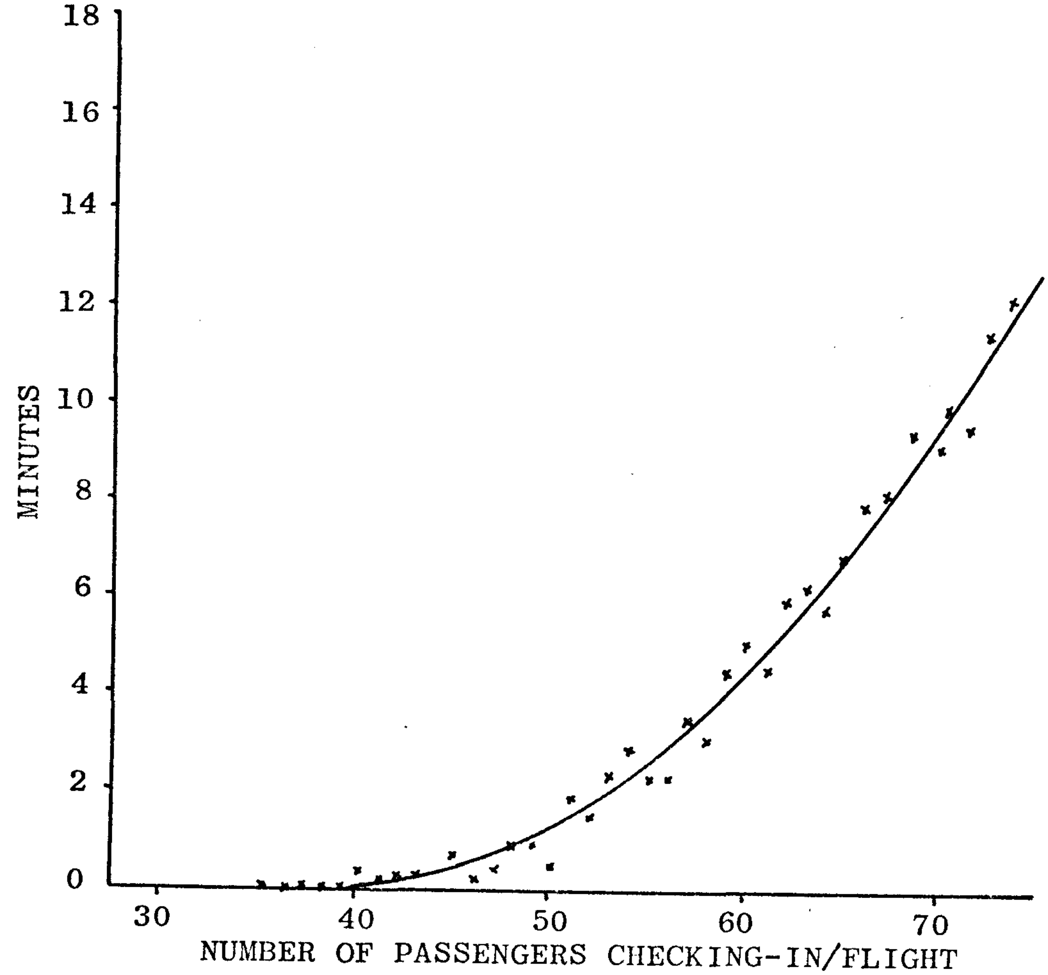

Fig. 16. Expected delay for the flight.

passenger flows is not constant, and even for a large number of passengers, peak arrivals are likely to occur.

In evaluating alternative check-in procedures, consideration must also be given to delays imposed on flights due to insufficient check-in procedures. The cost and inconvenience of late departures is so great that check-in systems which might substantially increase the likelihood of delays cannot be accepted. The simulation results (Figure 16) indicated that for less than 40 groups delays are not likely to occur, but when more than 40 passenger groups are checking-in for a flight delay increases considerably. For the simulation runs the delay increased by 10 minutes for 70 passengers/flight.

These results indicate that from the point of view of passenger convenience and efficient airline operations, a completely restricted check-in system can only provide acceptable performance when the number of passenger groups checking-in for a specific flight is relatively low (less than 35).

Sensitivity to Number of Counters

The number of counters required under the restricted system must be constant for a given number of departures and flight schedule. Therefore only the common system model was used in the analysis of variable counters. Sets of runs were made with different numbers of counters to test the effects of these changes on the evaluation parameters. The results of the simulation runs are presented in Table 6. As noted previously, by using the common system the number of counters can be reduced over the restricted system and while maintaining a similar level of service. This factor is important when considering the cost involved in implementing each alternative. A brief discussion of the models' application, including costs for each alternative is presented in the next section.

Cost as Criterion

Until now, most of the discussion has been devoted to one aspect of the system, performance as it relates to convenience for the passenger and airlines. However, in the selection of alternatives, cost must be considered prior to implementation. Costs can be traded off against convenience and therefore it is necessary to establish a proper balance between both factors. As noted in Figure 17, for an increasing number of counters (and therefore increasing costs), the passengers delays and their associated costs decreases. The proper balance between convenience and cost can be accomplished by determining the alternative which imposes minimum total system costs. Cost then becomes the common denominator. Airport operator cost can be represented by capital and maintenance costs incurred in providing the basic facilities. Airline costs

Table 6. Summary of Simulation Results - Common Check-in System

Evaluation Parameters	Expected Number of Passenger-Groups to Check-in per Flight				
	32 (a)	32 (b)	32 (c)	32 (d)	32 (e)
1. Maximum number of persons in queue	1.80	2.40	2.80	3.76	5.04
2. Number of persons with zero waiting time	20.03	18.05	16.21	15.77	13.54
3. Average number of persons in queue	0.21	0.42	0.77	1.31	2.54
4. Maximum time spent in queue (min.)	1.93	3.36	5.63	6.95	9.58
5. Average time spent in queue (min.)	0.38	0.65	1.15	1.68	2.34
6. Average waiting time for persons in queue (min.)	0.80	1.74	2.13	3.29	3.88
7. Maximum number of persons/sq. ft. of space	0.022	0.027	0.041	0.043	0.069
8. Minimum space per person (sq. ft.)	45.46	36.70	24.39	23.26	14.49
9. Counter utilization (percentage)	0.241	0.290	0.359	0.442	0.475

Note: Number of counters: a=14, b=13, c=12, d=11, e=10.

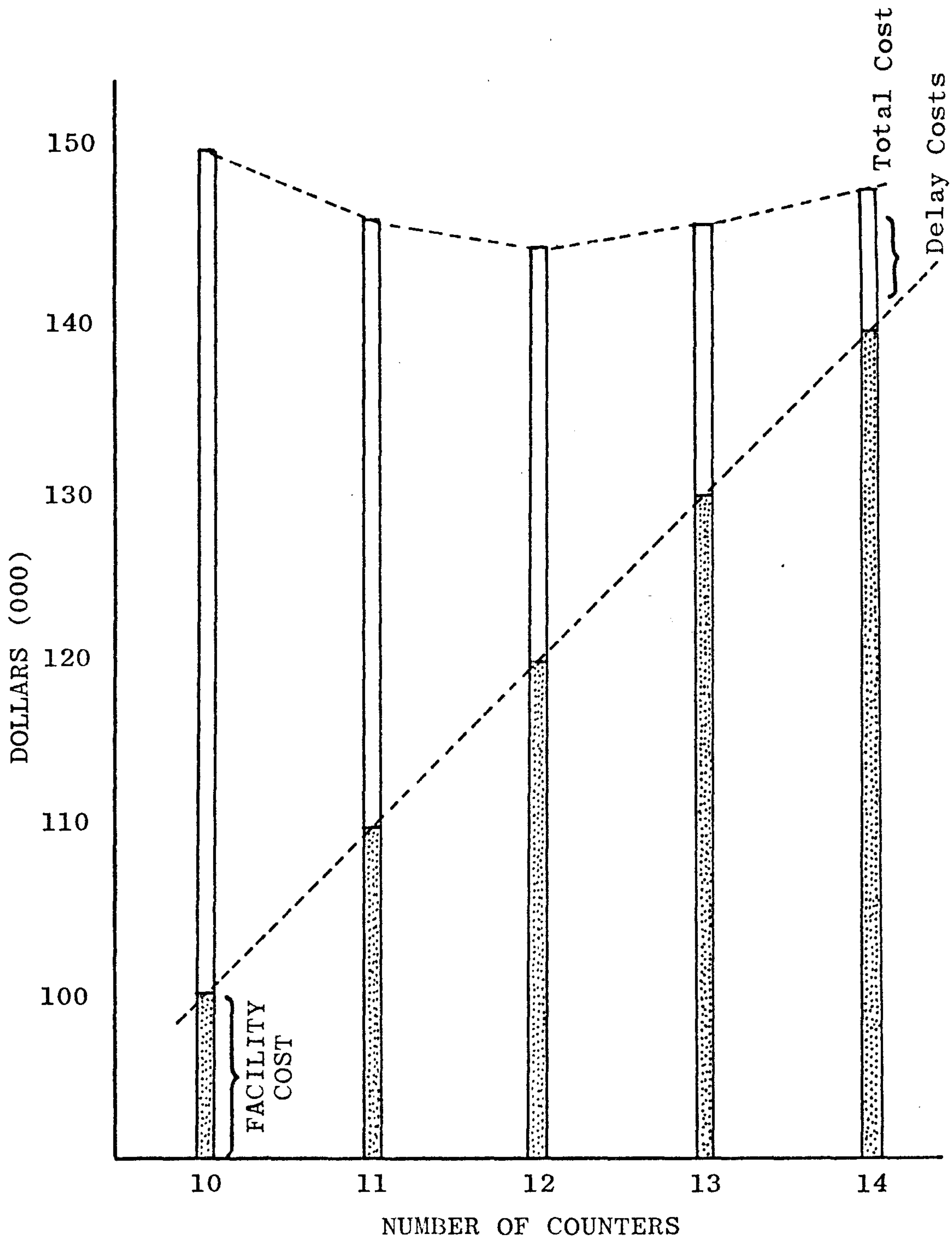

Figure 17. Annual cost of counters and passengers delay - common check-in system.

are represented by personnel and space rent and passengers' cost are reflected as inconvenience expressed in monetary terms.

User convenience has been defined as quality of service and therefore it is difficult to express it numerically in dollar terms. Value of time for the passenger, although subjective, has been conventionally used and appears to be an adequate measure of convenience. Unfortunately, no agreement exists with respect to the value assigned to passengers' time. It is known that this value is relative to the passengers' income.[12] Values previously assigned to passengers' time for delays vary between two and 15 dollars per hour,[13, 14] but there are no references with respect to pricing inconveniences such as queuing times or congestion. In the following section the analysis is carried out for different values of time between two and five dollars per hour.

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[12]N. J. Asher, et al., The Demand for Intercity Passenger Transportation by VTOL Aircraft (Washington, D. C., Institute for Defense Analysers, Program Analysis Division, August 1968), Appendix J, pp. 149-159.

[13]P. Beinhaker, and A. Elek, "Passenger Terminal Planning and Design," Readings in Airport Planning, University of Toronto, Centre for Urban and Community Studies, Toronto, Canada, 1972, p. 370.

[14]R. Waldo, and P. Tilton, An Economic Analysis of Commercial VTOL and STOL Transport Aircraft (Washington, D. C., 1965, Aircraft Development Service, 1965), pp. iv-27, iv-28.

Value of Time Sensitivity

For this analysis the number of departures in the peak hours was expressed in equivalent annual departures assuming that 30 percent of the daily operations occur during the peak hour. Thus, 15 departures in the hour are equivalent to 16,440 annual departures and 326,125 passengers. In the calculation represented by Figure 18, the cost assigned to the value of passengers' time varies between two and five dollars per hour. It was assumed that the annual cost of providing one counter, for the airlines and the airport operator is $10,000.

As the cost of counters increases the delay cost decreases. However, by increasing the value of time, the number of counters which must be provided to obtain minimum total cost will increase. For example, by assigning two dollars to the passengers' time, minimum cost will be achieved by providing 10 counters. But if the value of time is increased to five dollars, the number of counters required will be 13. Now, it is possible for the planner to make reasonable judgments about the alternatives presented in Figure 18. The proper number of counters will be given by the value of time which is felt on the average reflects the passengers' value of the inconvenience of standing in a crowded terminal. Considering four dollars as appropriate value, the number of counters selected would be 12.

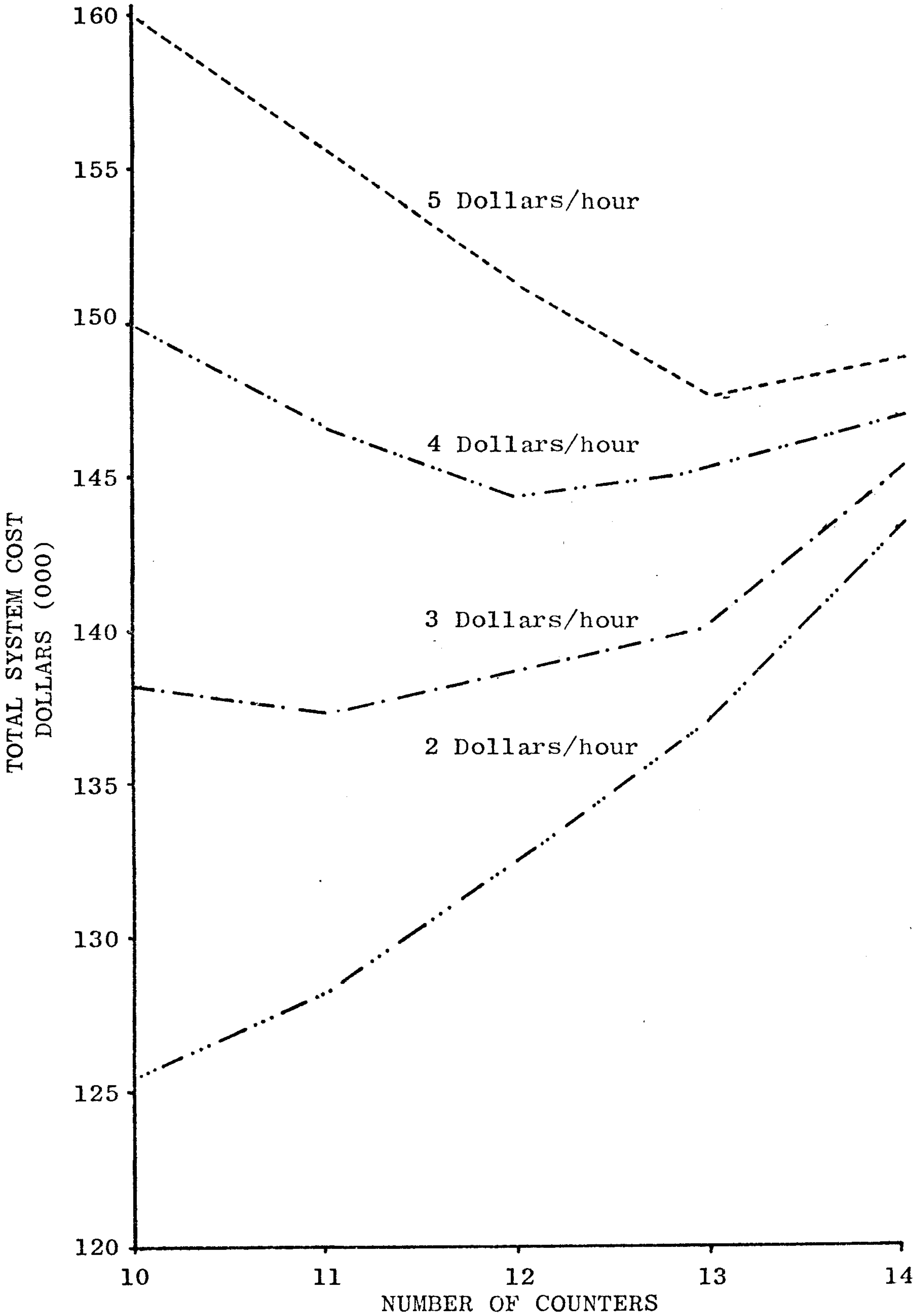

Fig. 18. Annual total cost for different values of time.

Applications

The type of analysis described above are only a few of the possible studies which can be carried out by applying the common or restricted simulation models. Changes in the number of flights permit the planner to evaluate the system under different conditions of airline traffic. Also passengers arrivals can be varied to test the effect of different ground transportation concepts such as greater reliance on buses, rapid transit systems, etc. In the same way, the effect of improving check-in service time on time savings and space requirements can be determined. The simulation model then permits the planner to test efficiently alternative scenarios which permit him to incorporate suitable flexibility into his designs. Airport terminal designs no longer need to be based on arbitrary standards as suggested by the FAA[15] but can now be established by a set of unique parameters describing the performance of the airport under assumed conditions. For these reasons, simulation models can become very flexible and powerful tools in the airport decision making process.

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[15] Federal Aviation Agency, Airport Terminal Buildings (Washington, D.C., September 1960).

CHAPTER V

CONCLUSIONS AND SUGGESTED FUTURE RESEARCH

Conclusions

A computer simulation of a check-in system has been developed and as shown, it may yield the air terminal data in a form readily available for detail analysis of design and operational concepts. By reviewing each element or parameter of an existing or proposed system, it will be possible to choose the optimum configuration for determined level of service. Although the results of the simulation were not validated due to time and resources limitations, the analyses of the common and restricted check-in system indicated the following benefits expected from implementing any system, as listed below.

1. For a given number of counters a common check-in procedures provides better level of service than assigning each counter to a specific flight.
2. Since convenience can be expressed in monetary terms, as a value of time for the passenger, the restricted system is a more expensive alternative (even for the same number of counters) than common system, due to the increase of waiting time that the check-in concept produces.
3. It is then evident that in order to provide a

determined level of service, fewer counters are required under the common check-in system than under the restricted system.

4. The restricted system not only requires the maximum number of counters for a given number of flight departures but also it becomes inefficient for large numbers of passengers checking-in. In this case, flight delays are most likely to occur.

Future Research

In order for the model to provide a more useful service to the air terminal planners and designers, the following suggested modifications should be investigated for possible future implementation.

1. The output from the models describes the performance of the system in terms of average values. These numbers, by themselves, do not describe the performance of the system completely because they do not provide the proportion of people who would experience levels of service equal or better than the minimum acceptable. In the same way, average values do not indicate the percentage of people subjected to unacceptable conditions. Therefore, it would be appropriate to restructure

the model so that the distribution of the parameters be part of the output.
The specification of a single value (i.e., averages) as requirements must be accompanied by the percentage of passengers that has to attain at least the specified level of service.

2. In the simulation model a very simple approach was used to estimate the mean waiting times by accumulating the waiting time of n successive passengers and then dividing by n. Waiting times measured in that way are not independent because obviously waiting time of each passenger depends on the waiting times of his predecessors. In this case, the data obtained are "auto-correlated" and this characteristic must be considered when analyzing the population variance. However the mean values obtained are satisfactory estimates of the mean value of the distribution. The same sort of problems occurs when estimating mean queue length.

3. Another problem present in the model is that the simulation runs are started with the system at an idle condition, and therefore sample means, including early arrivals, will be biased. To solve these two last problems, the length of the simulation run can be extended so that the

effect of the increased sample size counteracts the effect of the bias. In the same way, by repeating the experiment with different random numbers a set of independent determinations of the sample mean is obtained. Even though the distribution of the sample means depends on the degree of autocorrelation, those independent determinations can be used to estimate the variance of the distribution easily.

4. To save computer time, rather than extending the simulation, a more appropriate method of removing initial bias is to eliminate an initial section of the run. Instructions required to stop the program after a certain period of time and to wipe out the statistics gathered up to the point of restart must be added to the program. On the other hand, if the models are restructured so that observations are made at unit time intervals, rather than at the end of the run, Time Series Analysis may be made to obtain variance of sample mean from a single run with the initial bias removed.

5. Finally, changing the subscripts of some of the variables, the model developed for the common system can be used to simulate any element or part of the terminal in which queuing devices

are present, such as security counters, government frontier controls (i.e., immigration), etc.

BIBLIOGRAPHY

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Blankenship, E. The Airport: Architecture-Urban Integration-Ecological Problems, Preager Publishers, New York, 1974.

Brant, A. E., and McAward, P. "An Evaluation of Airfield Performance by Simulation," Transportation Engineering Journal, ASCE, May 1974, pp. 505-522.

Fausch, Peter. "A Transit Station Simulation," paper prepared for the PAST PRESIDENT'S AWARD, June 1971.

Fausch, P., Dillard, D., and Hoffmeister, J. "USS -- An Evaluation Tool for Designing Pedestrian Facilities in Transit Stations," January 1974.

Federal Aviation Agency, Airport Terminal Buildings, Washington, September 1960.

Fishman, G. Concepts and Methods in Discrete Event Digital Simulation, John Wiley and Sons, Inc., New York, 1973, Chap. 8, pp. 197-241.

Gordon, G. System Simulation, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1969, Chap. 7, pp. 105-119.

Hockaday, S., Maddison, D. "Modeling of Aircraft Movements at Airports," Proceedings, Fourteenth Annual Meeting, Transportation Research Forum, Vol. XIV, No. 1, 1973, pp. 469-482.

Horonjeff, R. The Planning and Design of Airports, McGraw-Hill Book Company, 1962.

International Civil Aviation Organization, Manual on Airport Master Planning, First Edition, 1969, Doc. 8796-AN/891.

Kaneko, E. J. Passenger Enplaning and Deplaning Characteristics, The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1967.

Lee, A. M. Applied Queuing Theory, St. Martin's Press, New York, 1966, Chap. 10, p. 116.

Low, Dana. "Use of Simulation in Airport Planning and Design," Transportation Engineering Journal, ASCE, November 1974, pp. 985-996.

Paullin, R. Passenger Flow at Departure Lounges, The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1966.

Reese, Philip. The Passenger-Aircraft Interface at the Airport Terminal, The Transportation Center, Northwestern University, Evanston, Ill., 1968.

Smith, E., and Murphy, J. Pier Finger Simulation Model, The Institute of Transportation and Traffic Engineering, University of California, Berkeley, 1968.

University of Toronto, Readings in Airport Planning, Centre for Urban and Community Studies, 1972.

APPENDIXES

APPENDIX A

STATISTICAL ANALYSIS OF PASSENGER GROUP ARRIVALS

When the arrivals are completely random, the probability that n arrivals will occur during an interval of time t follows the well known Poisson Distribution given by the equation:

$$An(t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}.$$

(The basic assumption is that the time of the next arrival is independent of the last arrival.)

In the above equation:

$$\lambda = \frac{\text{Number of Arrivals}}{(\text{Number of Intervals}) \times (\text{Time/Interval})}$$

In this case of the observed data:

$$\lambda = \frac{325 \text{ Arrivals}}{(90 \text{ Intervals}) \times (10 \text{ Min./Interval})}$$

$\lambda = 0.361$ Arrival/Minute.

Having observed 100 time intervals, the theoretical frequency for a Poisson Distribution is given by:

$$Ei(5) = (90)\ (3.61)\frac{^n e^{-3.61}}{n!}$$

To measure the discrepancy existing between observed and expected frequency the Kolmogorov-Smirnov test is used since it treats individual observations separately, and thus, unlike the Chi-Square test need not lose information through the combining of categories. Briefly the test involved specifying a cumulative frequency distribution which would occur under theoretical distribution and comparing it with the observed cumulative frequency distribution.

If $F_o(x)$ is the theoretical cumulative distribution under H_o; $S_N(x)$ the observed cumulative frequency, then

$$D = \left| F_o(x) - S_N(x) \right|$$

where D is the point at which these distributions show the greatest divergence is compared against a theoretical value to determine if the difference is significant.

Table 7 shows the results of this test.

For N = 90 and = 0.05 any value greater or equal to

$$\frac{1.36}{\sqrt{N}} = 0.1434$$

will be significant. Since the maximum deviation is 0.1754, then our decision is not to accept H_o. We do not have enough evidence to prove that arrivals are random, or that they follow a Poisson Distribution.

Table 7. Arrivals During 5-Minute Intervals

n	Observed	N	Expected	$S_N(x)$	$F_o(x)$	D
0	12	0	2.43	0.8667	0.9730	0.1063
1	15	15	8.78	0.7000	0.8754	0.1754
2	11	22	15.86	0.5778	0.6992	0.1214
3	13	39	19.09	0.4333	0.4871	0.0538
4	9	36	17.23	0.3333	0.2957	0.0376
5	7	35	12.44	0.2556	0.1574	0.0982
6	9	54	7.49	0.1556	0.0742	0.0814
7	5	35	3.86	0.1000	0.0313	0.0687
8	2	16	1.74	0.0778	0.0120	0.0658
9	1	9	0.70	0.0667	0.0042	0.0625
10	3	30	0.25	0.0333	0.0014	0.0319
11	2	22	0.08	0.0111	0.0006	0.0105
12	1	12	0.02	0.0000	0.0003	0.0003
	90	325	89.97			

APPENDIX B

STATISTICAL ANALYSIS FOR SERVICE TIMES

In any queuing study, the following properties of service times are required:

1. Each service time should be subject to the same set of random variation
2. Service time of any particular passenger should not depend in any way on the service times of the preceding passengers

These requirements are known as stability and statixtical independence of the service time.

The assumption that service times are "random" is equivalent to saying that each service time has a constant probability of termination during the next increment of time regardless of how long service has already been taking place. It is said then that service time has an exponential distribution.

The results of the times required to serve the passengers are shown in Table 8. The mean service time is 92.6 seconds, and as a result the mean service rate is 0.0108 service per second. Therefore, the probability that a service operation will last longer than t is:

$$S_o(t) = e^{-0.0108^t}$$

Table 8. Processing Times Frequency Distributions

t	Observed Frequency	Observed Cumulative Frequency	Theoretical Exponential	(D)	Theoretical Erlang k = 3	(D')
0 - 14.99	0	1.0	1.0	0.0	1.0	0.06
15 - 29.99	2	0.9938	0.8505	0.1433	0.9867	0.0071
30 - 44.99	4	0.9815	0.7233	0.2582	0.9248	0.0567
45 - 59.99	33	0.8800	0.6151	0.2649	0.8193	0.0607
60 - 74.99	56	0.7077	0.5231	0.1846	0.6919	0.0158
75 - 89.99	42	0.5785	0.4449	0.1336	0.5619	0.0166
90 - 104.99	45	0.4400	0.3784	0.0616	0.4423	0.0023
105 - 119.99	31	0.3446	0.3218	0.0228	0.3394	0.0052
120 - 134.99	19	0.2862	0.2737	0.0130	0.2550	0.0312
135 - 149.99	12	0.2492	0.2327	0.0167	0.1883	0.0609
150 - 164.99	16	0.2000	0.1979	0.0021	0.1370	0.0630
165 - 179.99	15	0.1538	0.1638	0.0100	0.0984	0.0554
180 - 194.99	8	0.1292	0.1432	0.0140	0.0699	0.0593
195 - 209.99	11	0.0954	0.1217	0.0263	0.0492	0.0462
210 - 224.99	4	0.0831	0.1035	0.0204	0.0343	0.0462
225 - 269.99	0	0.0831	0.0881	0.0050	0.0238	0.0593
240 - 254.99	6	0.0646	0.0794	0.0184	0.0164	0.0482

Table 8 (continued)

t	Observed Frequency	Observed Cumulative Frequency	Theoretical Exponential	(D)	Theoretical Erlang k = 3	(D')
255 - 269.99	5	0.0492	0.0637	0.0145	0.0112	0.0380
270 - 284.99	2	0.0431	0.0542	0.0111	0.0076	0.0355
285 - 299.99	1	0.0400	0.0461	0.0061	0.0052	0.0348
300 - 299.99	1	0.0369	0.0392	0.0023	0.0035	0.0334
315 - 329.99	3	0.0277	0.0333	0.0056	0.0023	0.0254
330 - 344.99	1	0.0246	0.0283	0.0037	0.0016	0.0230
345 - 359.99	2	0.0185	0.0241	0.0056	0.0010	0.0175
360 - 374.99	1	0.0154	0.0205	0.0051	0.0006	0.0148
375 - 389.99	1	0.0123	0.0174	0.0051	0.0005	0.0118
390 - 404.99	2	0.0002	0.0148	0.0086	0.0003	0.0059
405 - 419.99	2	0.0	0.0126	0.0126	0.0002	0.0002

According to the Kolmogorov-Smirnov test, a difference greater than 0.0754 will be significant at 0.005 alpha level. Since the maximum difference between the observed frequency and $S_o(t)$ is $0.2649 > 0.0754$, the decision is to reject the null hypothesis that observations in the sample can be reasonably be thought to have come from a population having exponential distribution.

This result is not surprising since service time distributions even in the classic telephone theories are not exponential.

The exponential distribution is a special case of the Erlang Distribution when k = 1. For this distribution the standard deviation is given by $1/\Theta k$, and the mean $1/\Theta$. It is possible to vary k, and in this way to reduce the variation in t and "fit" a particular Erlang Distribution. Then, the probability that the service operation will last longer than t is given by:

$$S_o(t) = e^{-k\theta t} \sum_{n=0}^{k-1} \frac{(k\theta t)^n}{n!} \; ; \; t > o$$

In this study, the standard deviation is 58.5 and since it is given by

$$SD = \sqrt{V(t)} = T_S/\sqrt{k}$$

therefore

$$K = (T_S/SD)^2$$

$$K = 2.51$$

For K = 3, the probability that the service will last longer than t is given by

$$So(t) = e^{-0.0324t} \sum_{n=o}^{2} \frac{(0.0324t)^n}{n!} \quad t > 0$$

The maximum difference between the observed frequency and So(t) is 0.0630 which is less than 0.0754. The hypothesis that the sample comes from an Erlang distribution of k = 3, can not be rejected at 0.05 level of significance.

APPENDIX C

VERIFICATION OF SIMULATION RESULTS

In a stochastic simulation the variables used to measure the performance of the system are random variables. The value obtained as output are no more than a sample and they are subject to the question of statistical reliability. In order to estimate parameters from observations on random variables, one of the statistical methods commonly used is the confidence interval method. In this approach it is considered that the estimate of the parameter is located between an upper and a lower limit with a certain probability. If $1 - \alpha$ is the confidence level (usually 90 percent), the confidence interval is given by:

$$\bar{X} \pm (t\ \alpha/2,\ n-1) \cdot S/\sqrt{n}$$

The difference between the estimate ($\bar{X}$) and the quantity it is supposed to estimate (μ) represents the magnitude of error of estimate (E). The expression

$$E < (t\ \alpha/2,\ n-1) \cdot S/\sqrt{n}$$

says that if we estimate u by means of a random sample of size n, we can assert with a probability of $1 - \alpha$ that the error E is less than $(t\ \alpha/2,\ n-1) \cdot S/\sqrt{n}$. Therefore, the larger the number of observations, the smaller the confidence interval and the error of estimate.

The final decision on whether or not the results, after a given number of runs, are reliable will depend upon the confidence levels and the maximum tolerable error chosen. These two values are selected subjectively, and therefore additional analysis of the simulation results is carried out. Figures 19 through 24 note the average values of the evaluation parameters from repeated runs as each run was made. As expected by increasing the number of runs, the results show a steady state condition. All figures present four different curves, each one corresponding to a different number of expected passengers checking-in per flight. It is also important to point out that for the last runs the vertical distance between any two curves remains relatively constant. This factor and the assumption of an equlibrium condition suggest that the results obtained are reliable, and therefore the conclusions that were drawn in the simulation can be trusted. In addition to the previous analysis the confidence intervals of the evaluation parameters for the first 10 runs are given in Table 9. The confidence interval is given by:

$$CI = 2(t\,\alpha/2,\ n-1)\ S/\sqrt{n}$$

and for $\alpha = 0.10$ and $n = 10$.

The equation becomes:

$$CI = 1.15\ (S)$$

The confidence intervals noted in Table 9 appears to be reasonable and therefore it was assumed that the estimates of the evaluation parameters were accurate enough for the research purpose.

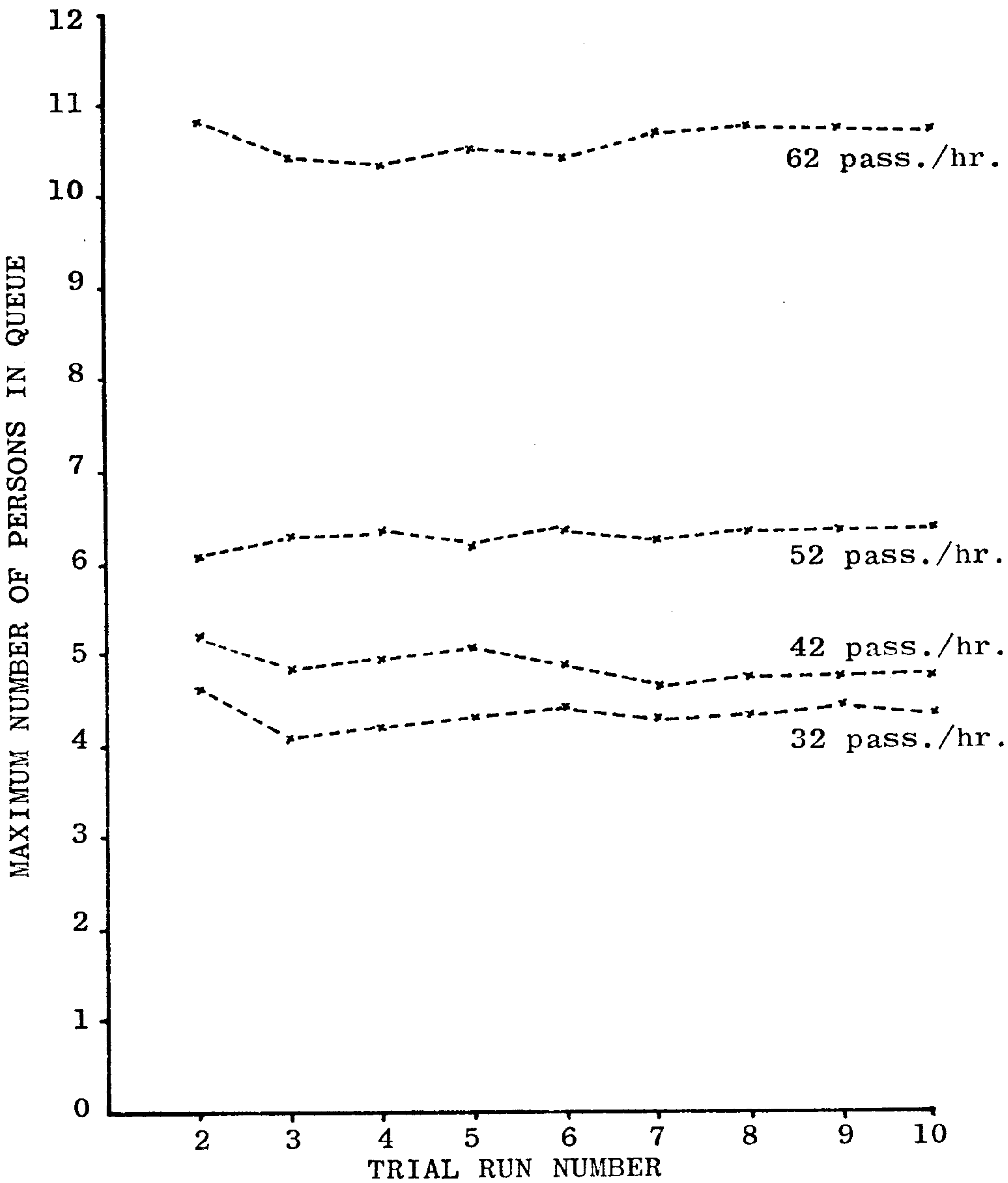

Fig. 19. Variation of results for maximum number of persons in queue.

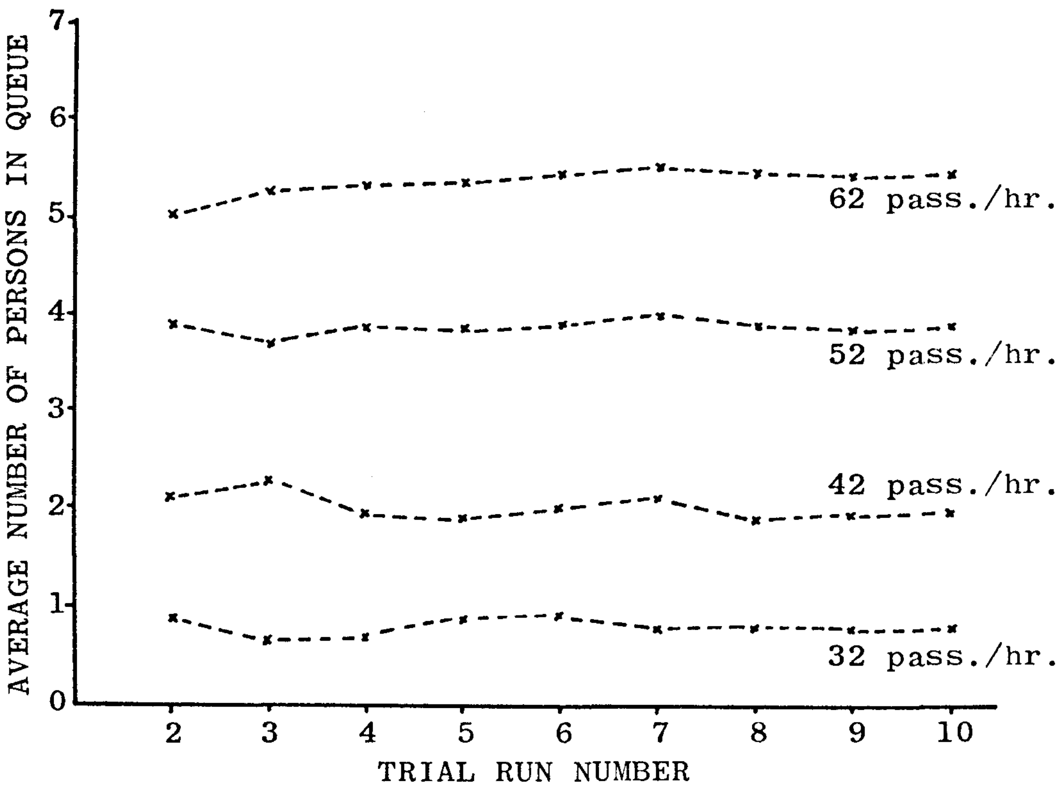

Fig. 20. Variation of results for average number of persons in queue.

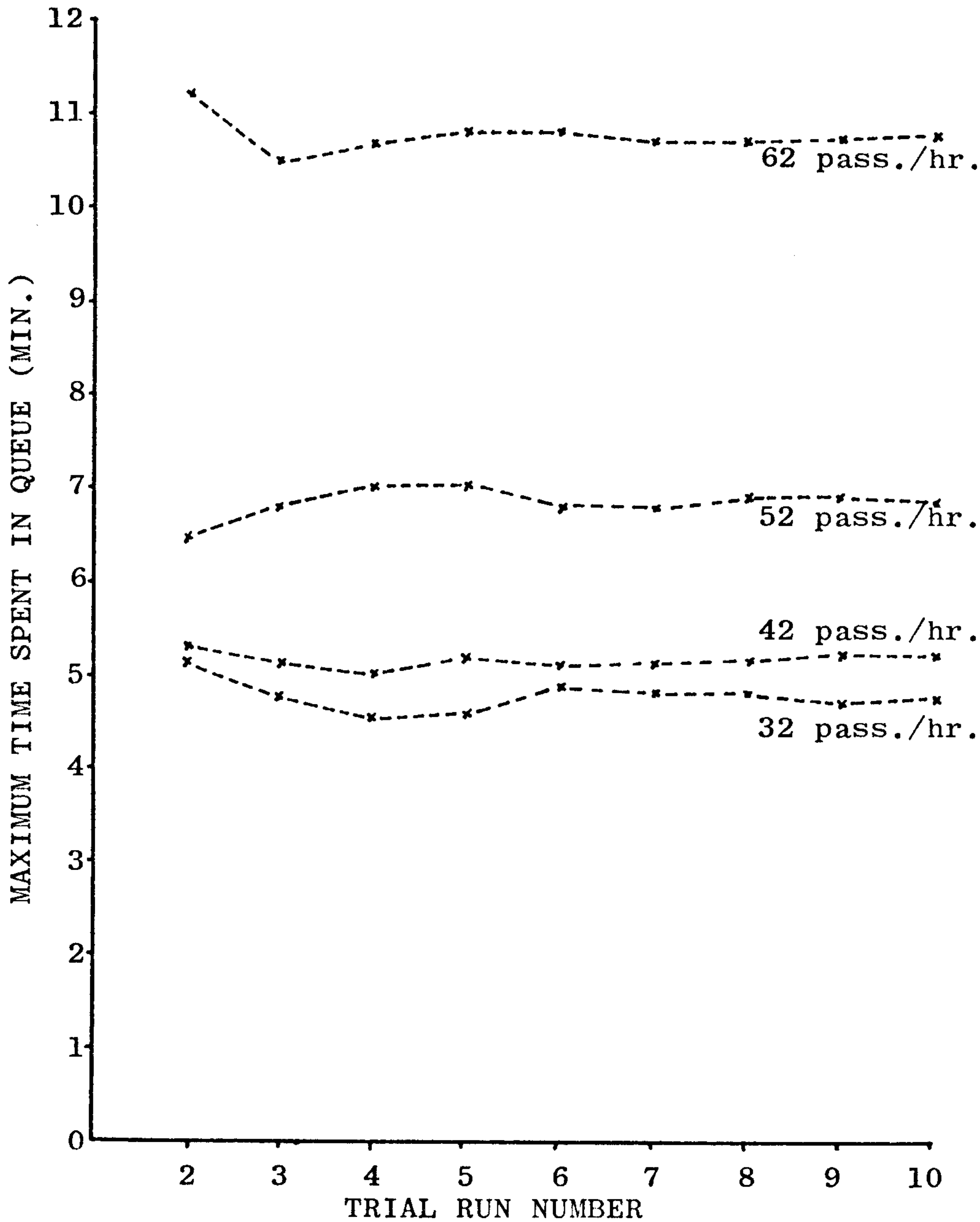

Fig. 21. Variation of results for maximum time spent in queue.

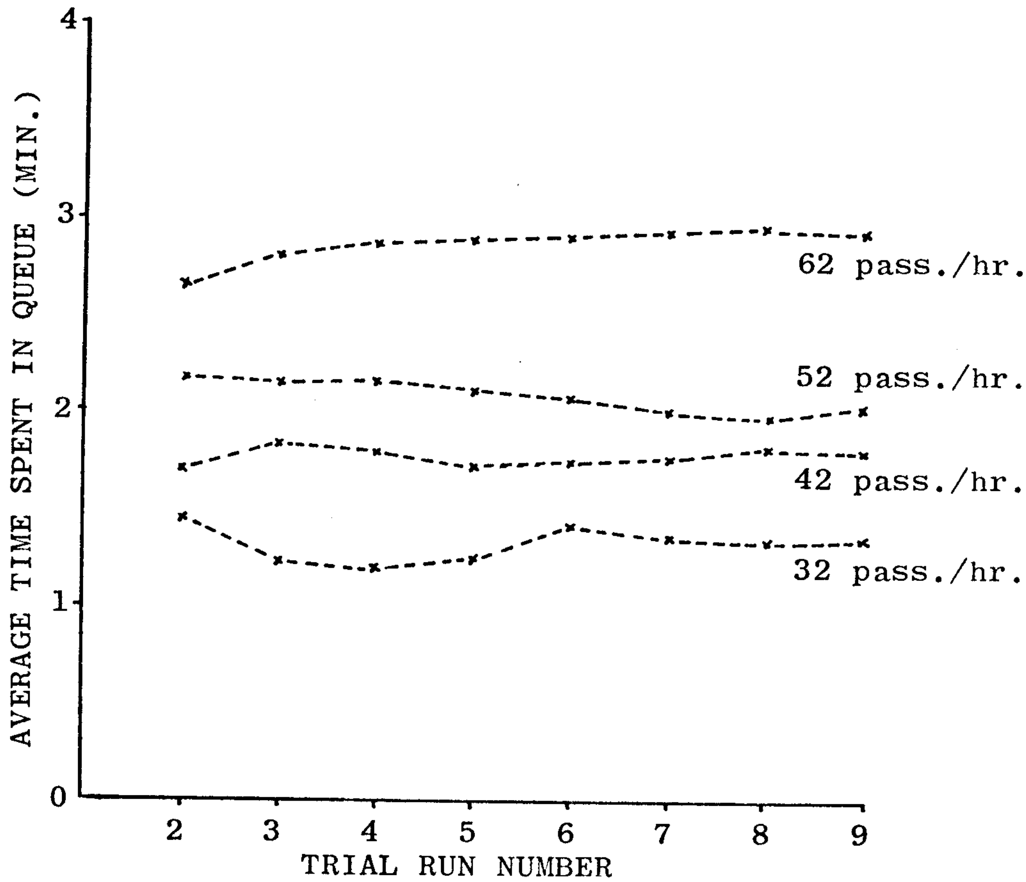

Fig. 22. Variation of results for average time spent in queue.

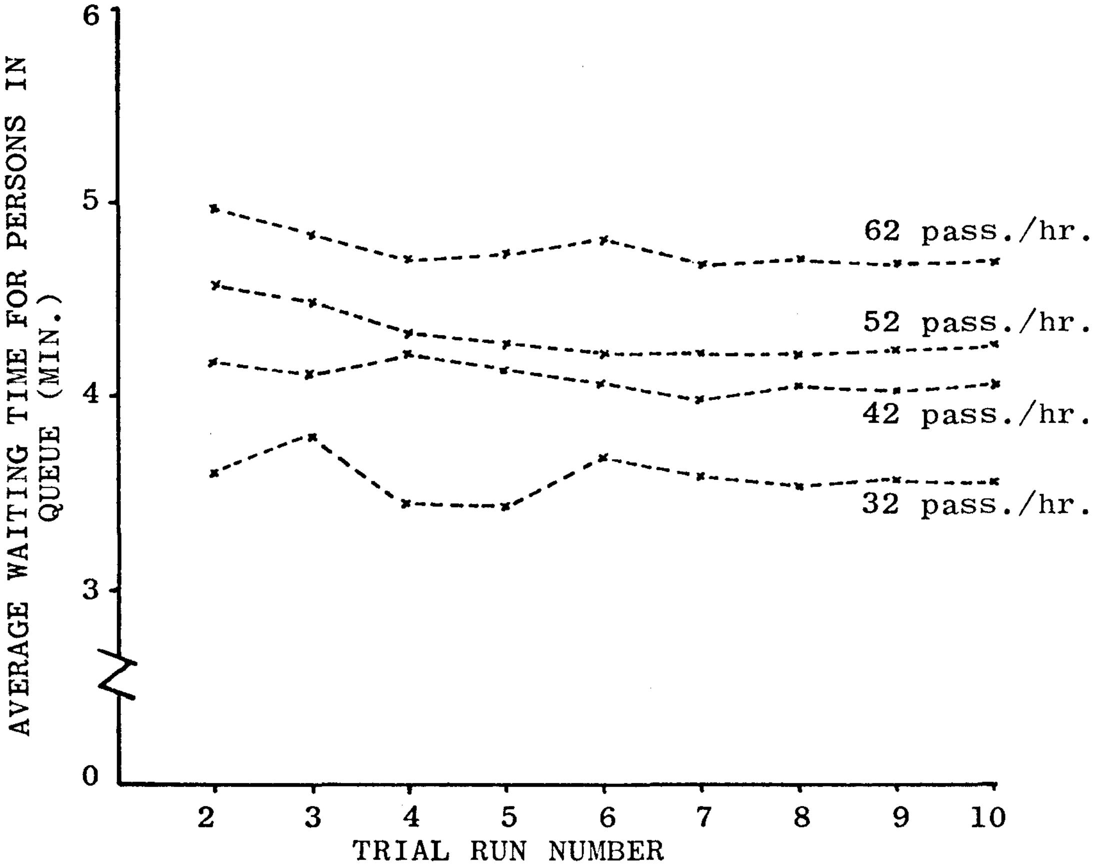

Fig. 23. Variation of results for waiting time for persons in queue.

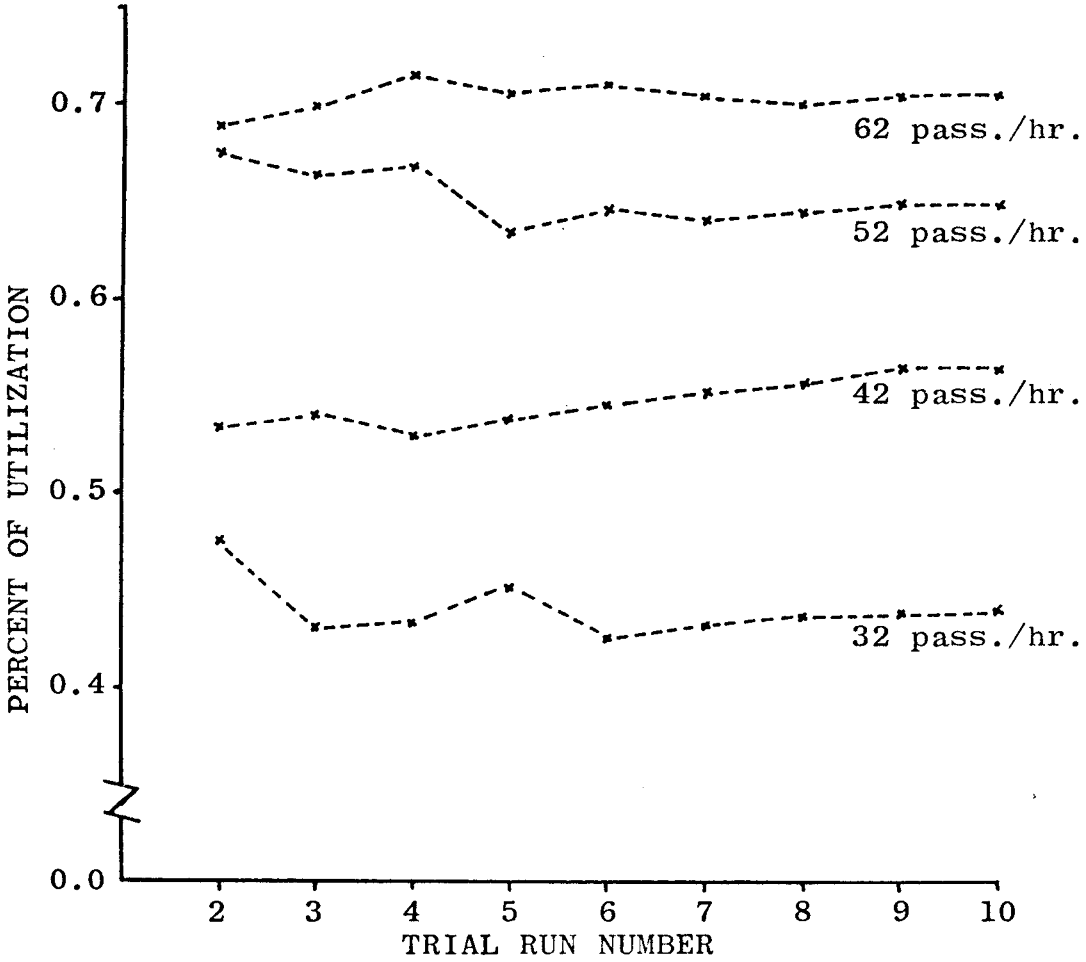

Fig. 24. Variation of results for counter utilization.

Table 9. Expected Values and Confidence Interval for the Evaluation Parameters - Initial Runs

	Evaluation Parameters	Average Value	Confidence Interval
1.	Maximum number of persons in queue	4.31	0.58
2.	Number of persons with zero waiting time	5.47	1.38
3.	Average number of persons in queue	0.73	0.20
4.	Maximum time spent in queue (min.)	4.74	1.09
5.	Average time spent in queue (min.)	1.29	0.43
6.	Average waiting time for persons in queue (min.)	3.54	0.77
7.	Minimum space available per person	27.58	5.69

APPENDIX D

SIMULATION MODELS FLOWCHART

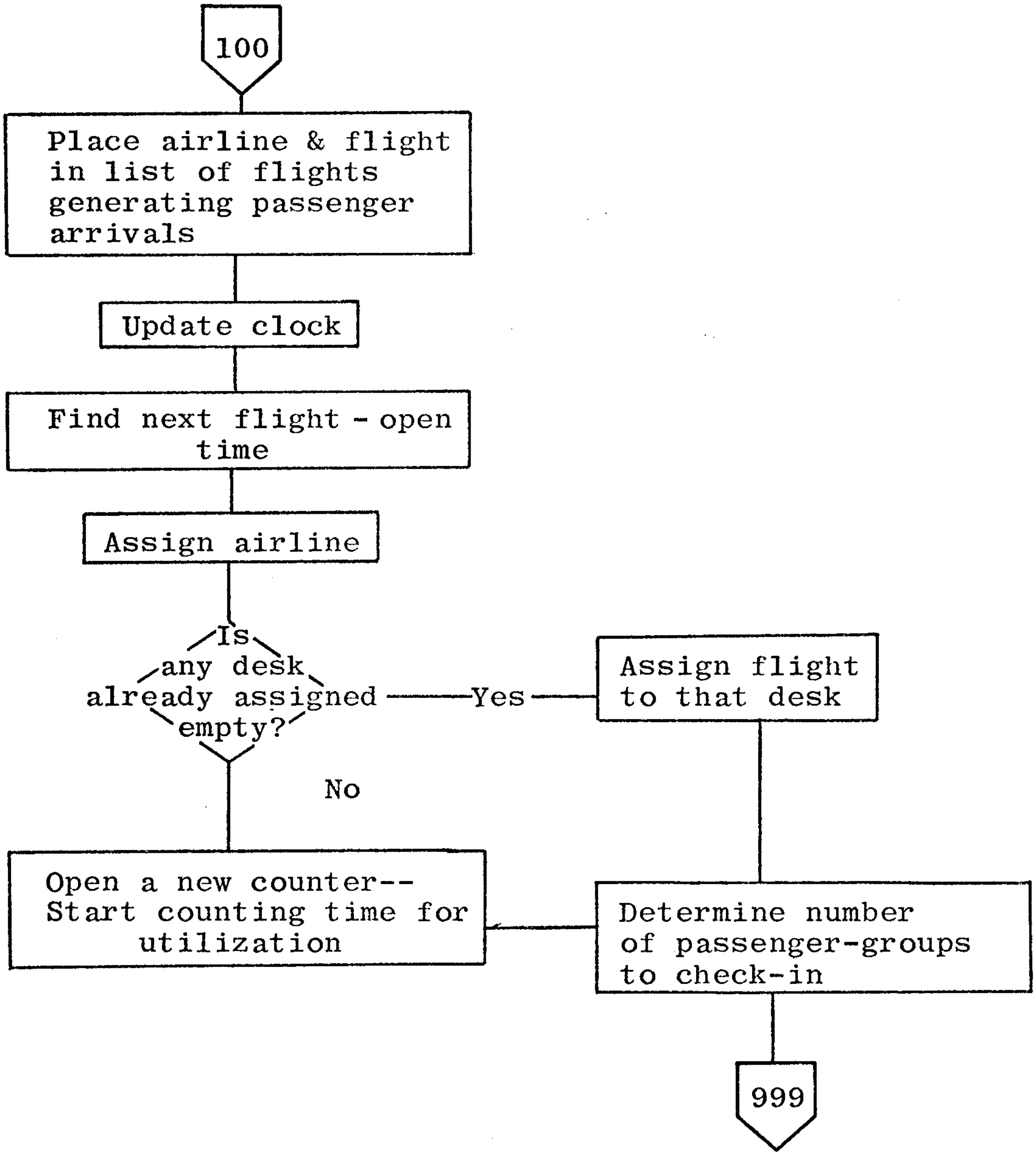

Fig. 25. Flight generation element - restricted system.

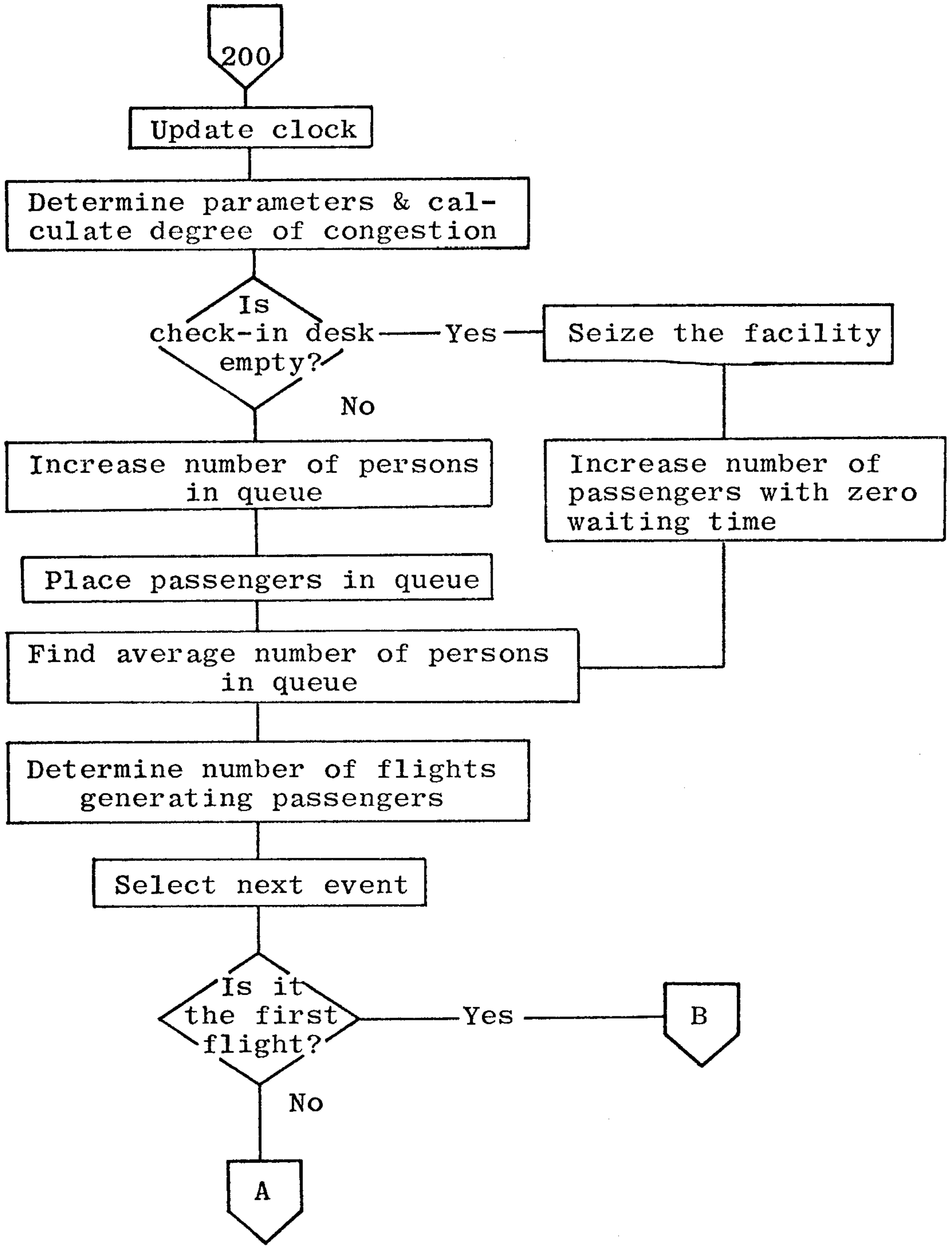

Fig. 26. Passenger-group arrival element - restricted system.

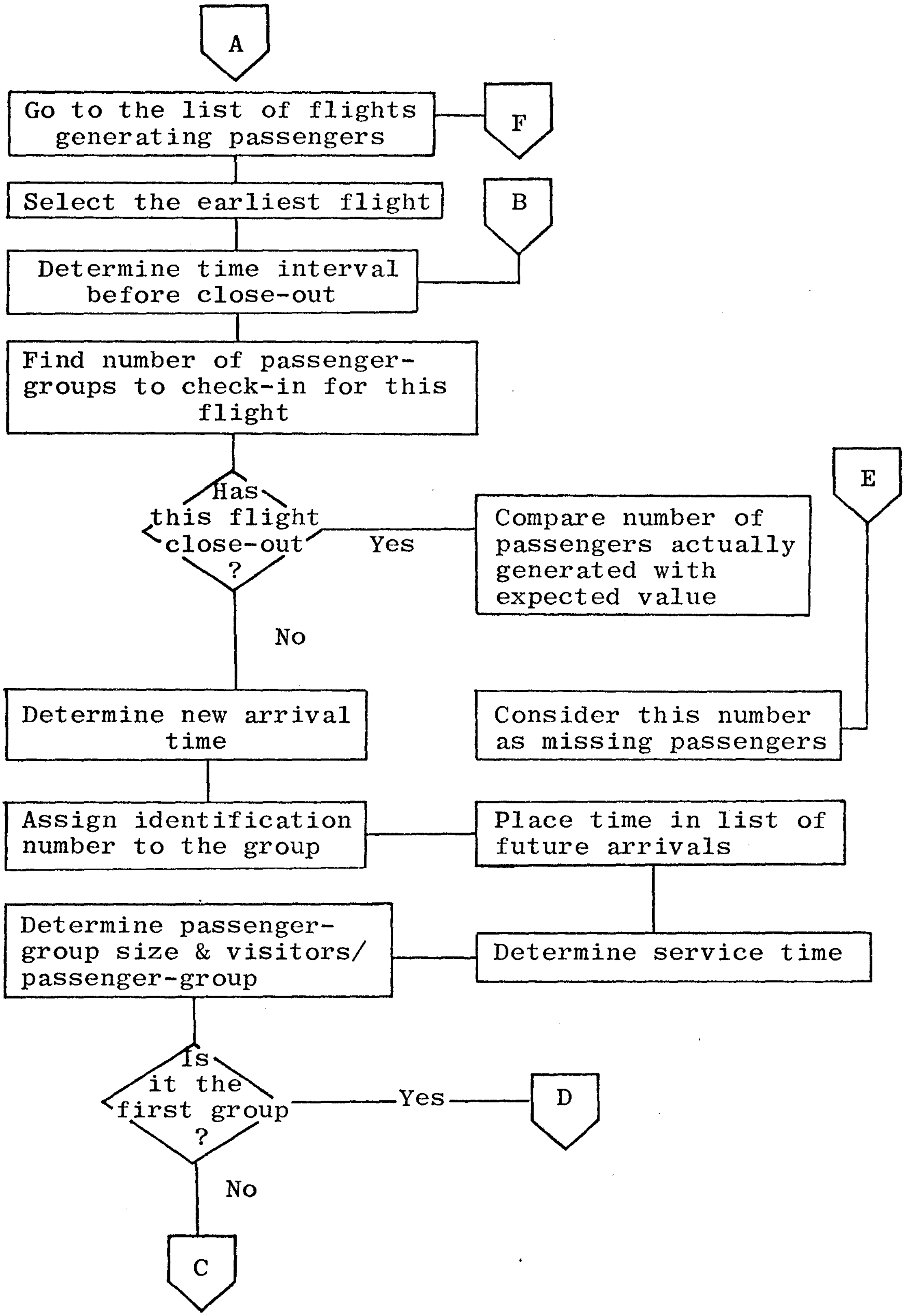

Fig. 26. (continued).

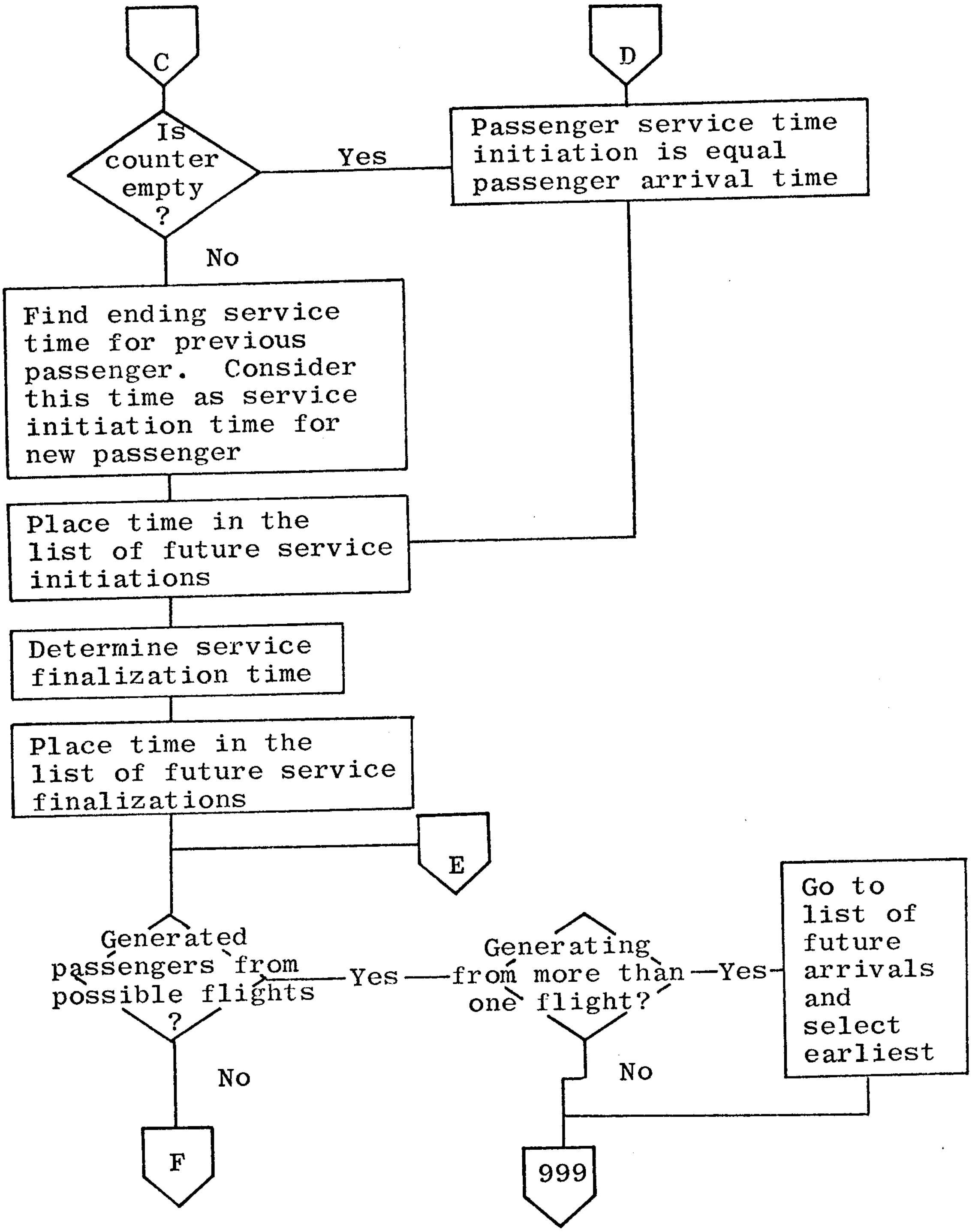

Fig. 26. (continued).

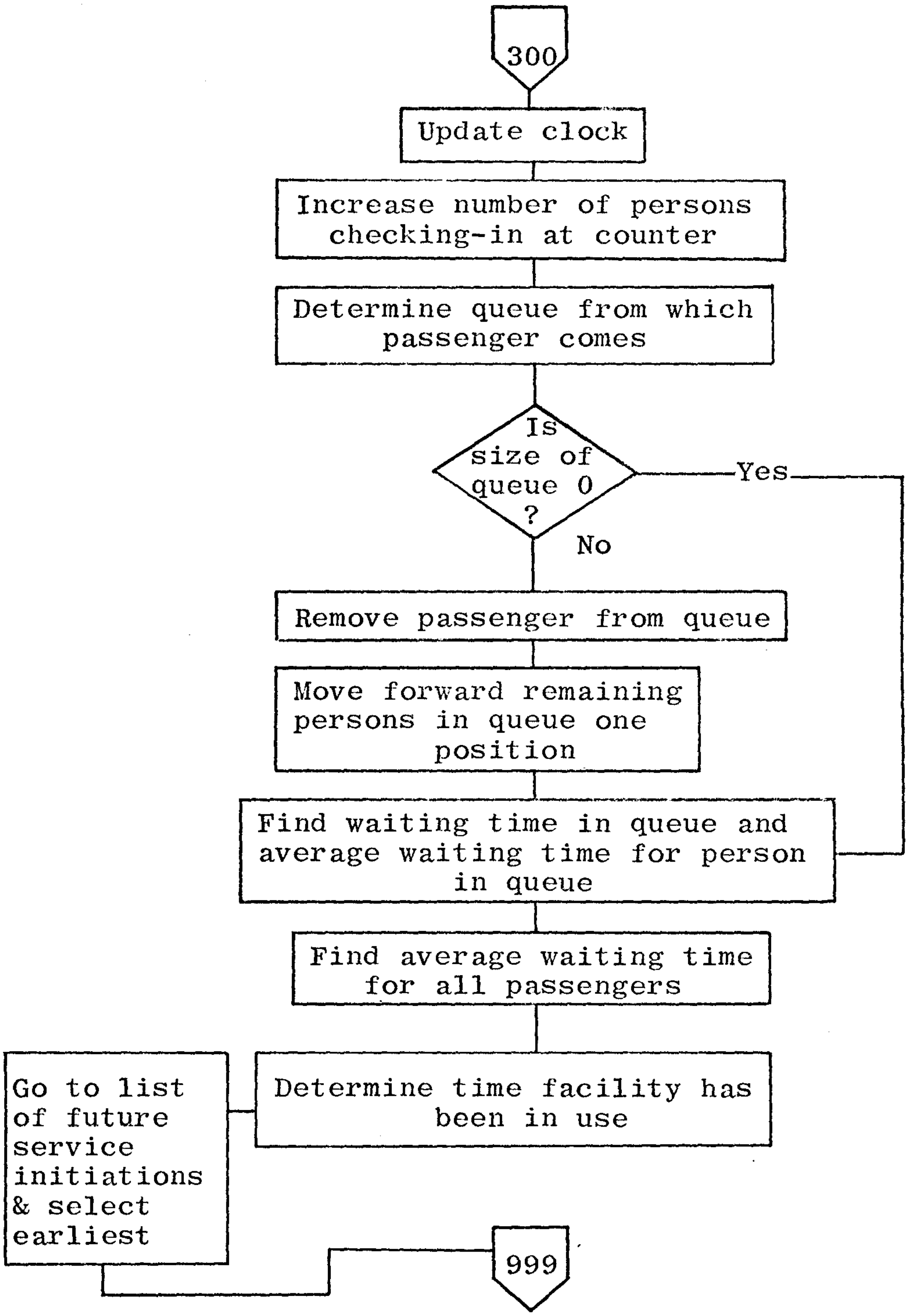

Fig. 27. Service initiation element - common and restricted systems.

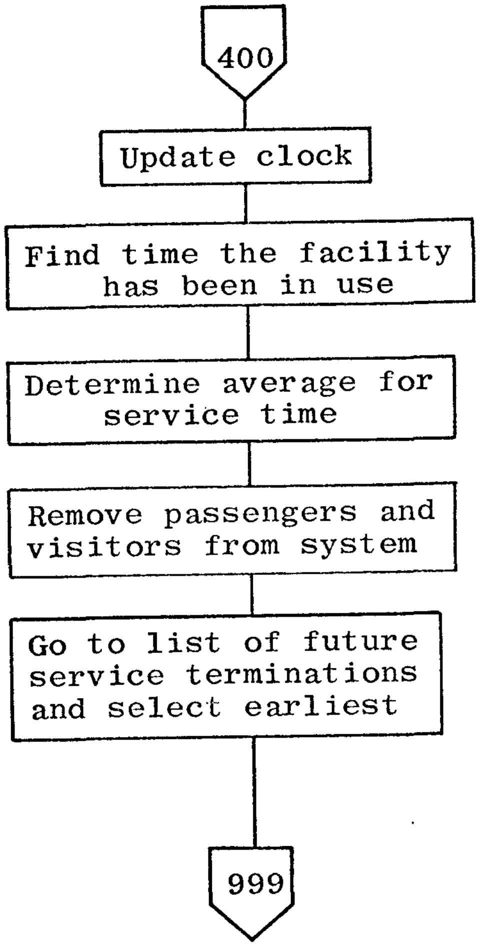

Fig. 28. Service finalization element - common and restricted systems.

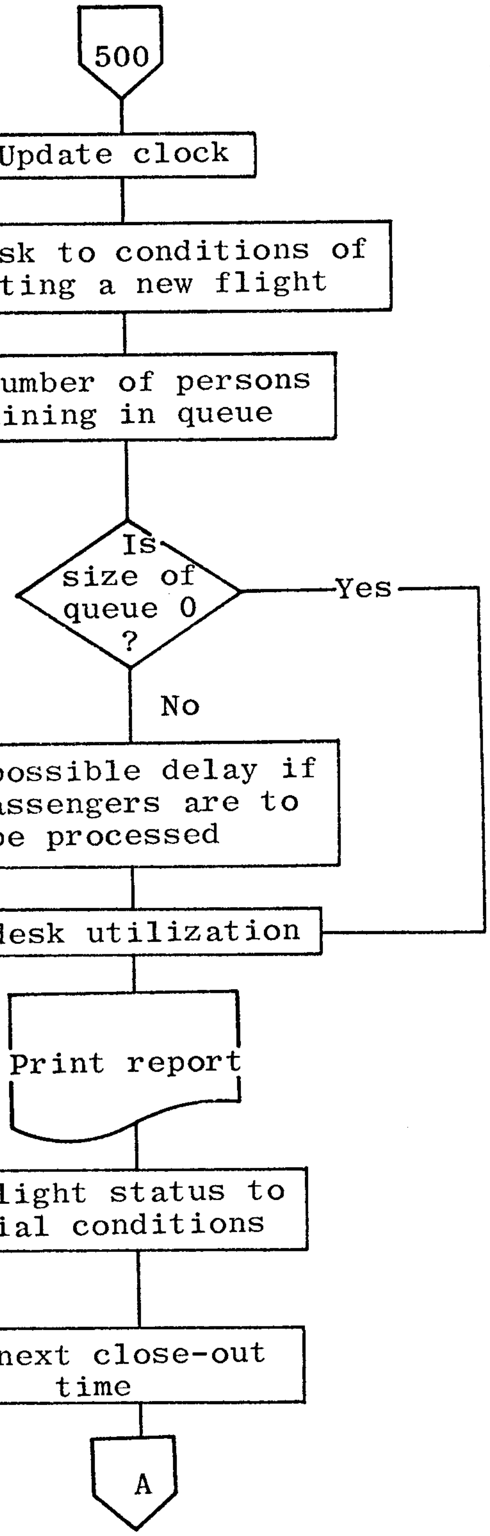

Fig. 29. Flight close-out time element - restricted system.

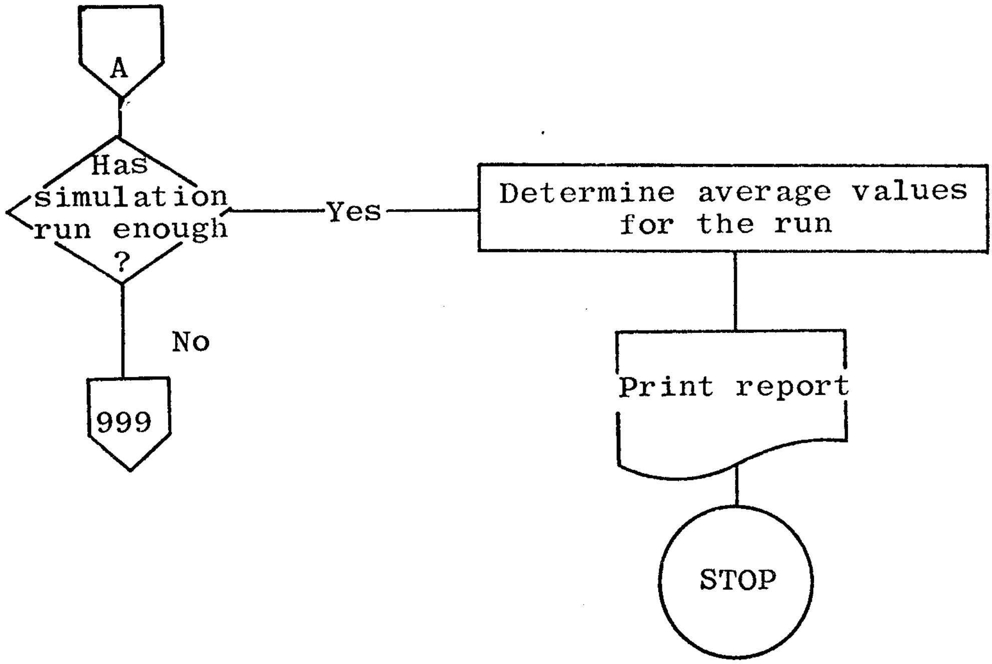

Fig. 29. (continued).

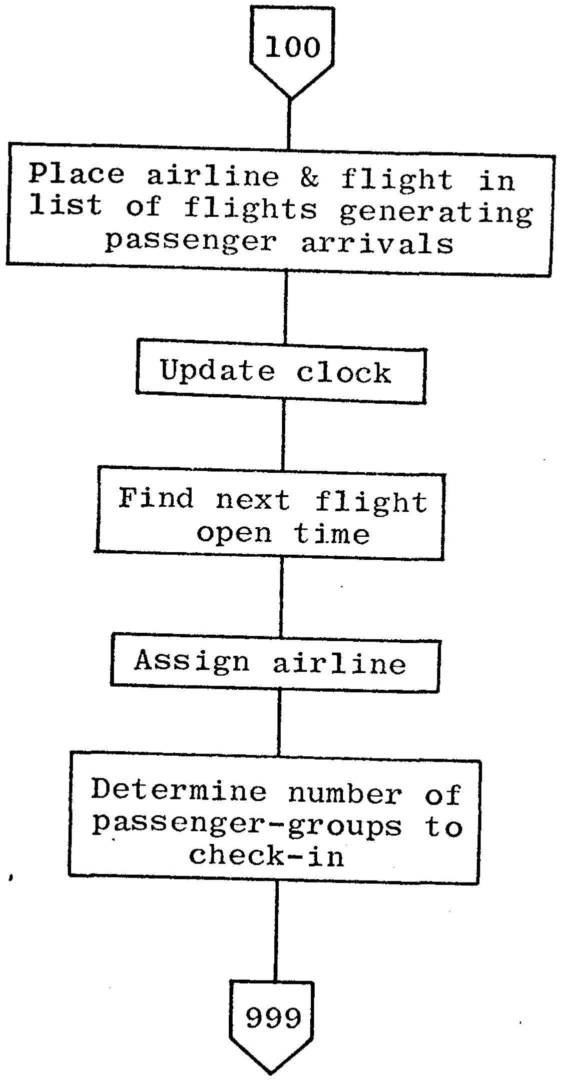

Fig. 30. Flight generation element - common system.

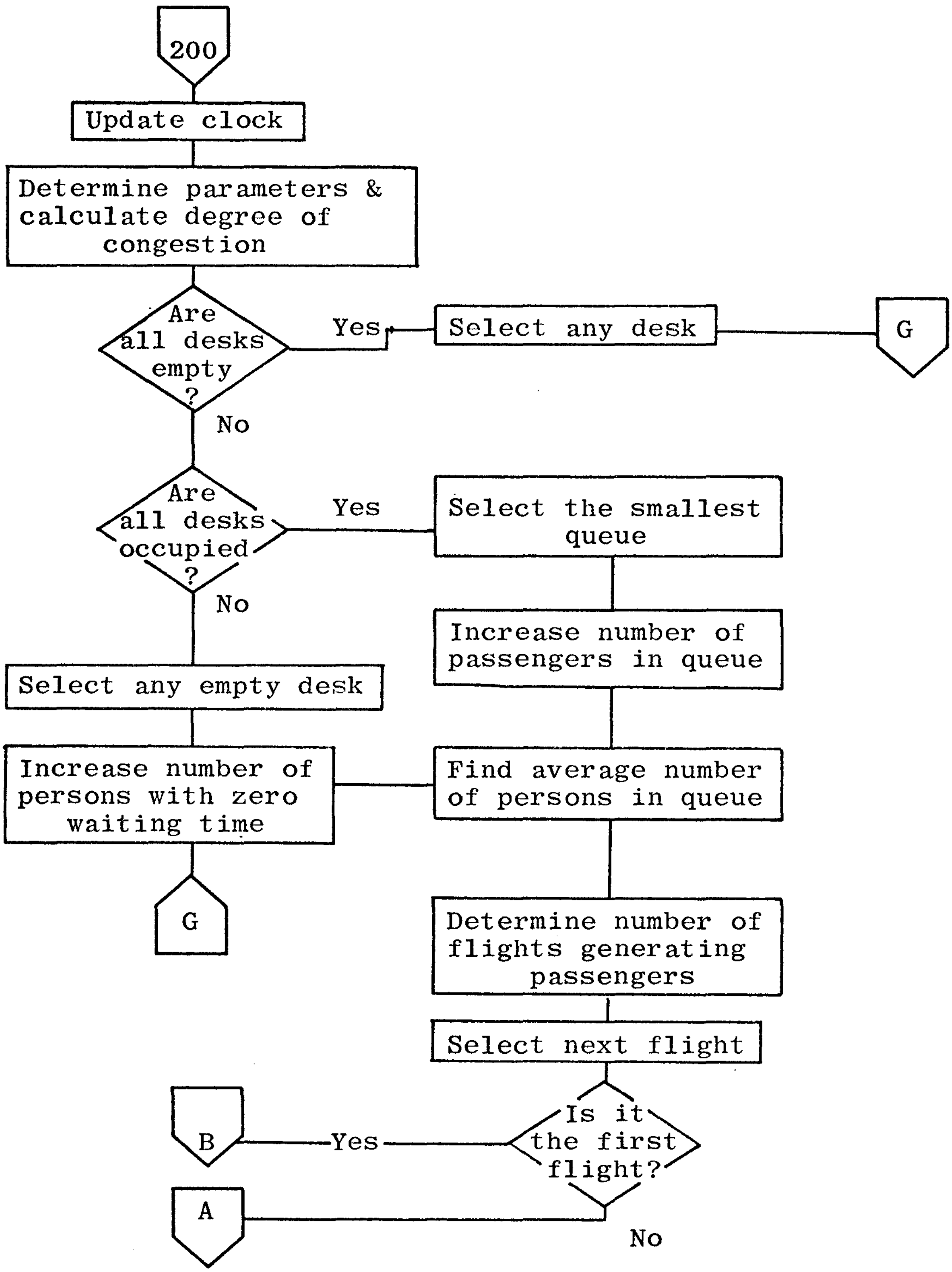

Fig. 31. Passenger-group arrival element - common system.

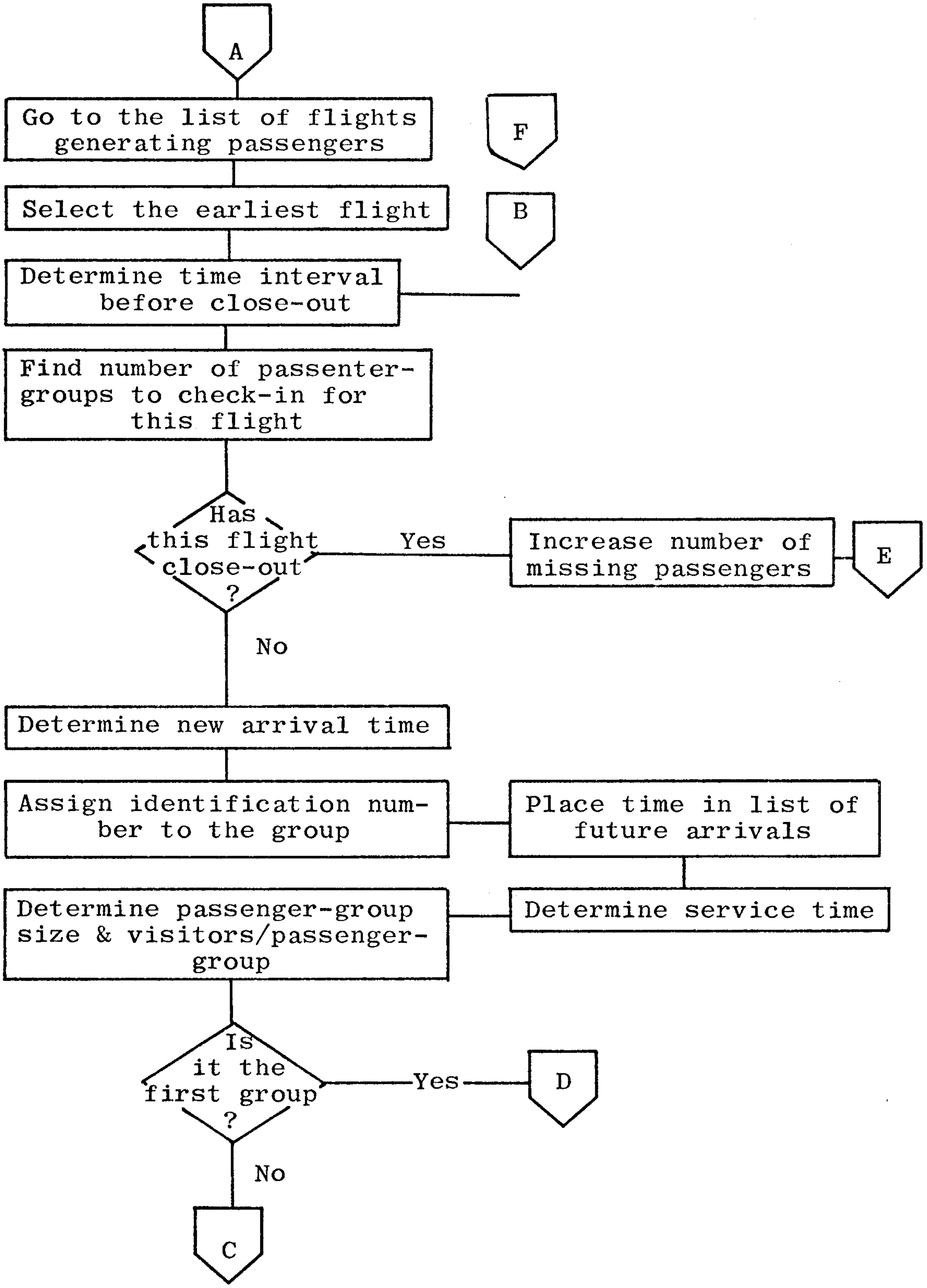

Fig. 31. (continued).

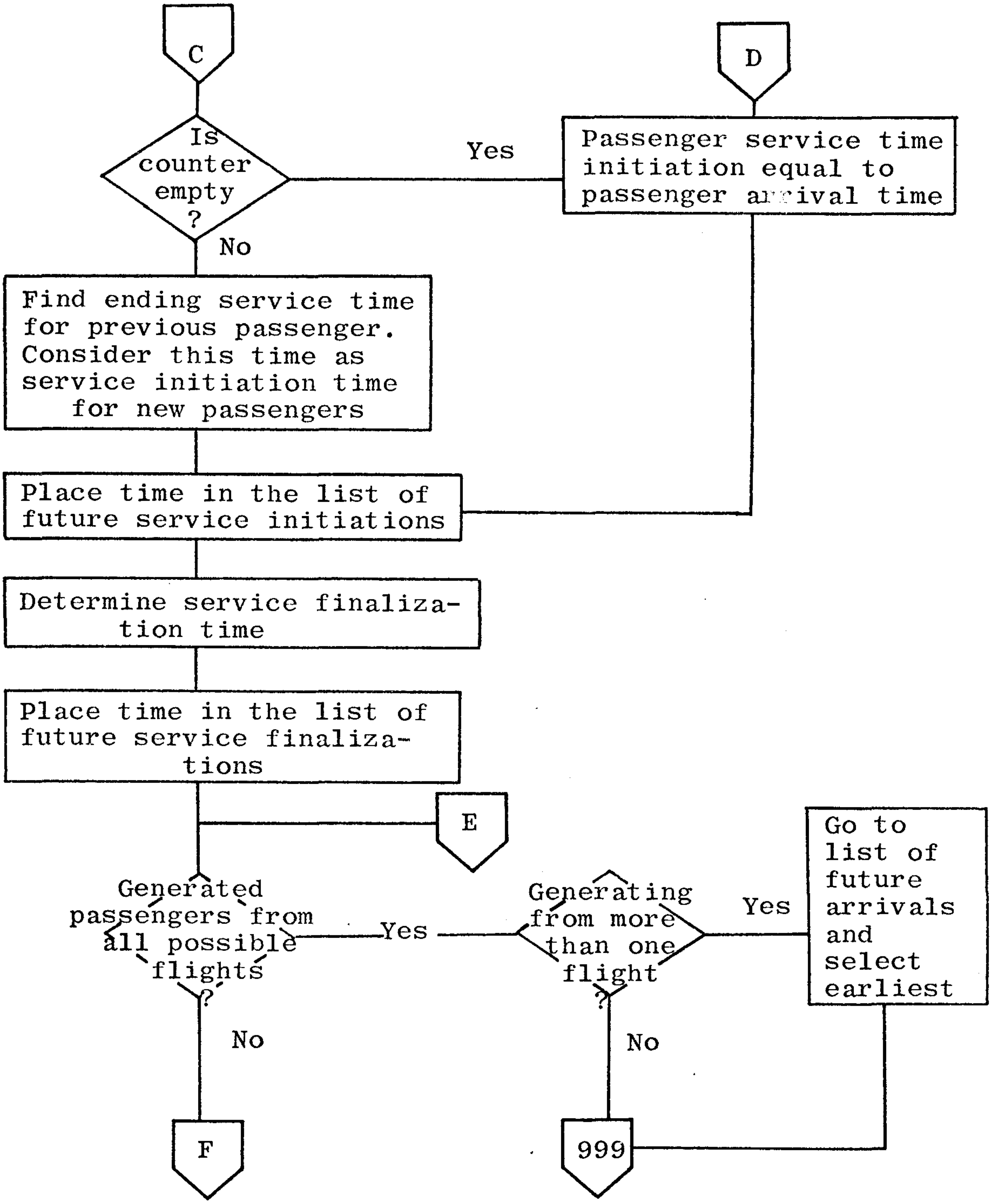

Fig. 31. (continued).

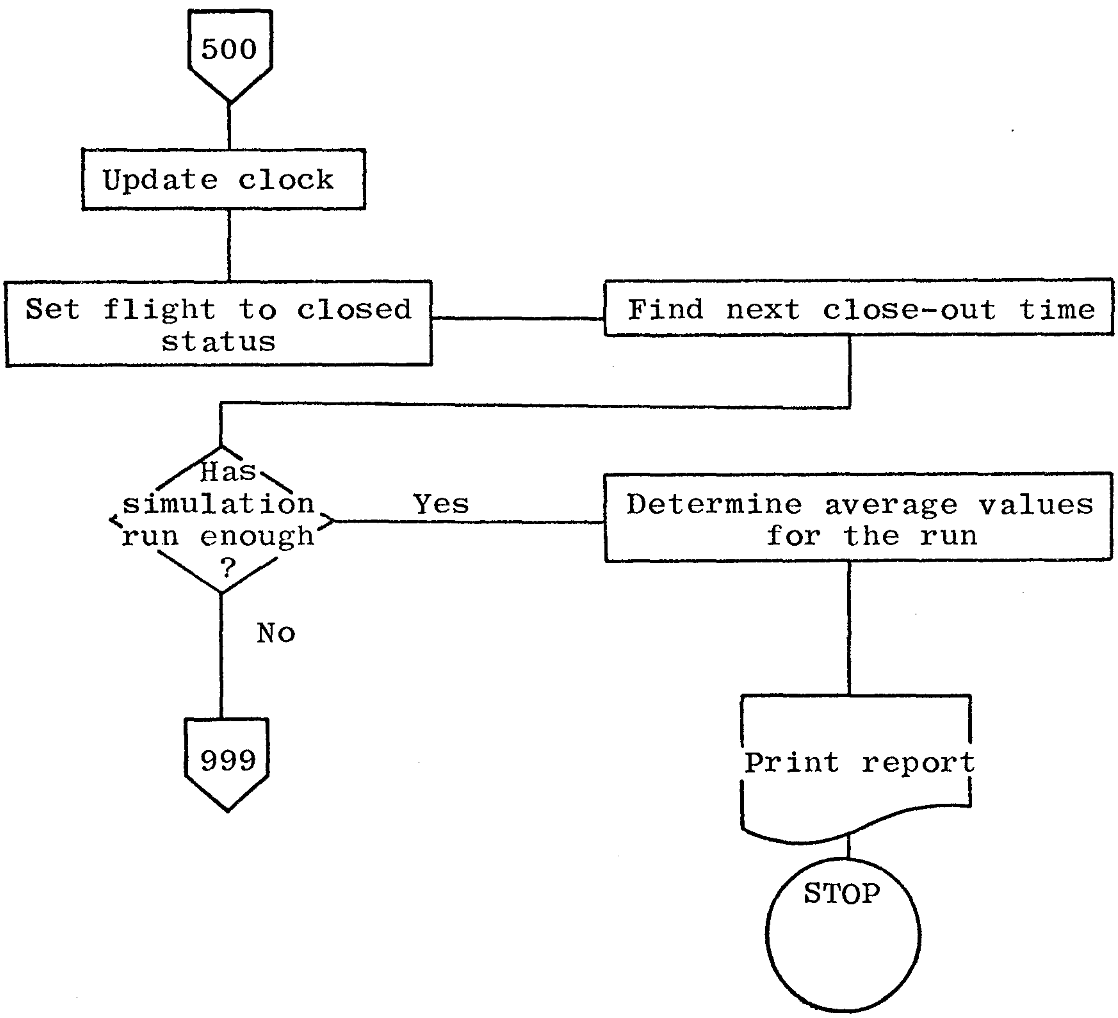

Fig. 32. Flight close-out time element - common system.

VITA

Luis Alvaro Lopez was born in Bogota, Colombia on December 13, 1947. He attended Universidad Pedagogica y Technologica de Colombia and received a Transportation Engineer degree in 1970. After completing undergraduate studies he was employed by the Transportation Engineering Department of the UPTC until May 1973. His master's study at the University of Tennessee was conducted under the auspices of a LASPAU Scholarship, awarded by the Latin American Scholarship Program of American Universities. Mr. Lopez received the Master of Science degree in Civil Engineering in August 1975.