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ANALYZING PASSENGER DELAYS DUE TO AIRPORT
CONGESTION: A SYSTEMS SIMULATION APPROACH

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James T. Low and Martin R. Warshaw

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ANALYZING PASSENGER DELAYS DUE TO AIRPORT CONGESTION: A SYSTEMS SIMULATION APPROACH

by

James T. Low
Marketing Department
School of Business Administration
Wayne State University
Detroit, Michigan 48202

and

Martin R. Warshaw
Marketing Department
Graduate School of Business Administration
The University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

After a period of relative slack, the demand for air travel has increased to the point that passenger congestion delays have become a serious problem at many major metropolitan airports. This article describes a system simulation approach for analyzing such delays. The use of a comprehensive GPSS and FORTRAN model of the entire airport system, including both the overall airside and landside sections, provides a view of passenger congestion delays unlike that provided by other approaches. Delays to passengers are considered to be equally important whether they occur to passengers in ground vehicles, in the terminal building, or aboard an aircraft. Because the discrete-event model allows the tracing of individual passengers through the airport system, the causes of interactive delays between parts of the airport system can be pinpointed and examined. These delays are likely to occur when the system is heavily loaded, and can seriously affect the operation of the overall system, even though they may be relatively short-lived.

Experiments with the large-scale simulation model were performed in which expected future passenger traffic loads were imposed on a specific major metropolitan airport in order to analyze the potential congestion delay effects under those loads. The results of those experiments

indicated that severe passenger congestion delays could be expected under the heaviest loads examined. The model pointed out the locations within the airport system where those delays would be expected to occur, as well as the expected severity and duration of the delays. Examples of interactive congestion delays shown by the model under heavy load conditions are discussed. Although these expected future delays are serious enough to cause passengers to miss flights, their causes are not of an obvious nature. The model can be used to examine such delays in order to anticipate future problems in the airport system. The system simulation approach described here could be of use to those concerned with airport planning in order to analyze the timing of changes to the configuration of the system, and to avoid immediate changes to the system which would be inconsistent with changes needed at a later date.

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Introduction

Although passenger delays due to airport congestion had reached serious proportions by the summers of 1968 and 1969, the slowdown in economic activity which marked the early 1970's reduced air travel to a level which could be handled without intolerable amounts of passenger delay. With phased deregulation of the airline industry beginning in the second half of the 1970's, the cost of air travel has declined markedly and demand for air passenger service has increased greatly. The resultant pressure on airport systems, many of which have been unable to expand capacity due to environmental constraints, has led once again to increased congestion in airports and the growing number of passengers who are delayed.

The research described in this article was undertaken to develop an improved approach for the analysis of passenger delays due to airport congestion. This approach provides a method by which airport planners and managers can examine passenger congestion delays on an overall, integrated system basis for given load conditions and configurations of the airport. Because this approach uses a comprehensive simulation model of the airport as an overall system, it can provide insights into the workings of major airports in ways that are not feasible with other approaches. Use of the model can provide a view of projected changes in passenger traffic loads, operating procedures and physical configurations of the airport, including identification of the factors which would cause passenger delays in those situations. Remedial measures designed to alleviate those delays can be tested in order to determine their effectiveness.

Previous Research

Prior research on congestion delays at major airports has concentrated on component parts of the overall airport system rather than on the total system. For example, research into airport congestion began with an examination of the runways by Galliher and Wheeler (1958), Carlin and Park (1969), Odoni (1969), Koopman (1970, 1972), and Harris (1972a,b,c). Research on taxiway problems was done initially by Dowe (1966, 1969), and later by Baran *et al*. (1973), D'Alessandro *et al*. (1975), and Hagerott (1975). The scope of work on airport problems was expanded to include both the runway and taxiways by Willis (1969), Gilsinn *et al*. (1971), Rinker (1971), Booth (1972), Research Triangle Institute (1972), and Gilsinn (1975). The ground access section of the system was studied by Baxter (1970), Parsons *et al*. (1972), Lu *et al*. (1972), and Cloverdale and Colpitts (1972). These parts of the total system were chosen for examination because it appeared that most of the congestion delays occurred there. However, some researchers concentrated their efforts on small parts of the terminal building. These included Reese (1967), Robinson (1969), and Nanda et al. (1972). This gradually gave way to examination of the terminal building as a whole by Chamberlain and Micka (1969), Chamberlain (1969), Braaksma (1973), and Parsons (1973, 1975).

As time passed, the research emphasis shifted to the airside section of the total system and to the overall landside section which includes both the terminal building and the ground access. Work on the airside section was done by Hosford and Lovitt (1970), Adarkar (1970,1971), Englander (1971), and Douglas Aircraft Company (1973). Problems in the landside section were addressed by Whorf (1970), the Transportation Research Board (1975), and McCabe and Carberry (1975). A study by Hiatt, Gordon, and Oisen (1976) examined the airport system on an integrated basis by using a continuous, rather than discrete-event, simulation model. The trends of research in airport congestion are outlined by Low and Warshaw (1978). There was a growing recognition that events taking place in many areas of the airport were influencing the aggregate passenger delay time in the total system. It was, however, quite clear that although researchers were expanding their view of the airport system, the boundary point for most work was the airline gate.

The Interactive Approach

The major contribution of the research reported here is that it crossed the boundary point to treat a metropolitan airport as a total transportation system in which delays to passengers are considered to have equal importance whether they occur while the passenger is in a ground vehicle, in the terminal building, or in an aircraft.

The use of a discrete-event time-oriented simulation model to represent the operation of the entire metropolitan airport system on an integrated basis has several important advantages. This approach avoids a narrow focus on specific parts of the system, so that delays to passengers are pointed out wherever they occur in the system. Also, a discrete-event simulation allows the measurement of delays for individual passengers along the paths they choose according to their individual characteristics. This can be important in analyzing interactive effects between parts of the system which occur under heavy load conditions, since these effects have a bearing on the operation of the system as a whole. This is especially true for interactive effects which are encountered by passengers following a particular path, but which do not appear for other passengers. Because statistics can be gathered on the total delays experienced by individual passengers following specific paths through the entire system, problems which are not of an obvious nature can be specifically pointed out and examined. It appears that these interactive effects, while serious enough to cause some passengers to miss their flights, may tend to be short-lived effects which would be difficult to examine under other methods of analysis, including the use of continuous, rather than discrete-event simulation models.

Because the focus of this approach is on the overall system, it provides a comprehensive view of the system unlike that seen by operating managers who must be concerned primarily with the operations under their own jurisdiction. This means that the overall effects of simultaneous changes to several parts of the system, all under separate management, can be examined to determine the overall impact on passenger congestion delays. This reduces the tendency to optimize parts of the system, while sub-optimizing its overall operation.

The Simulation Model

The key to implementation of the total-system interactive approach was the development of a discrete-event simulation model of a metropolitan airport system. This model was constructed by using a number of interconnected modules as shown in Figure 1. Each of these modules was developed separately and extensively tested to insure that it operated as intended. The interfaces with the other modules were carefully checked for each module and the results of deterministic runs were verified.

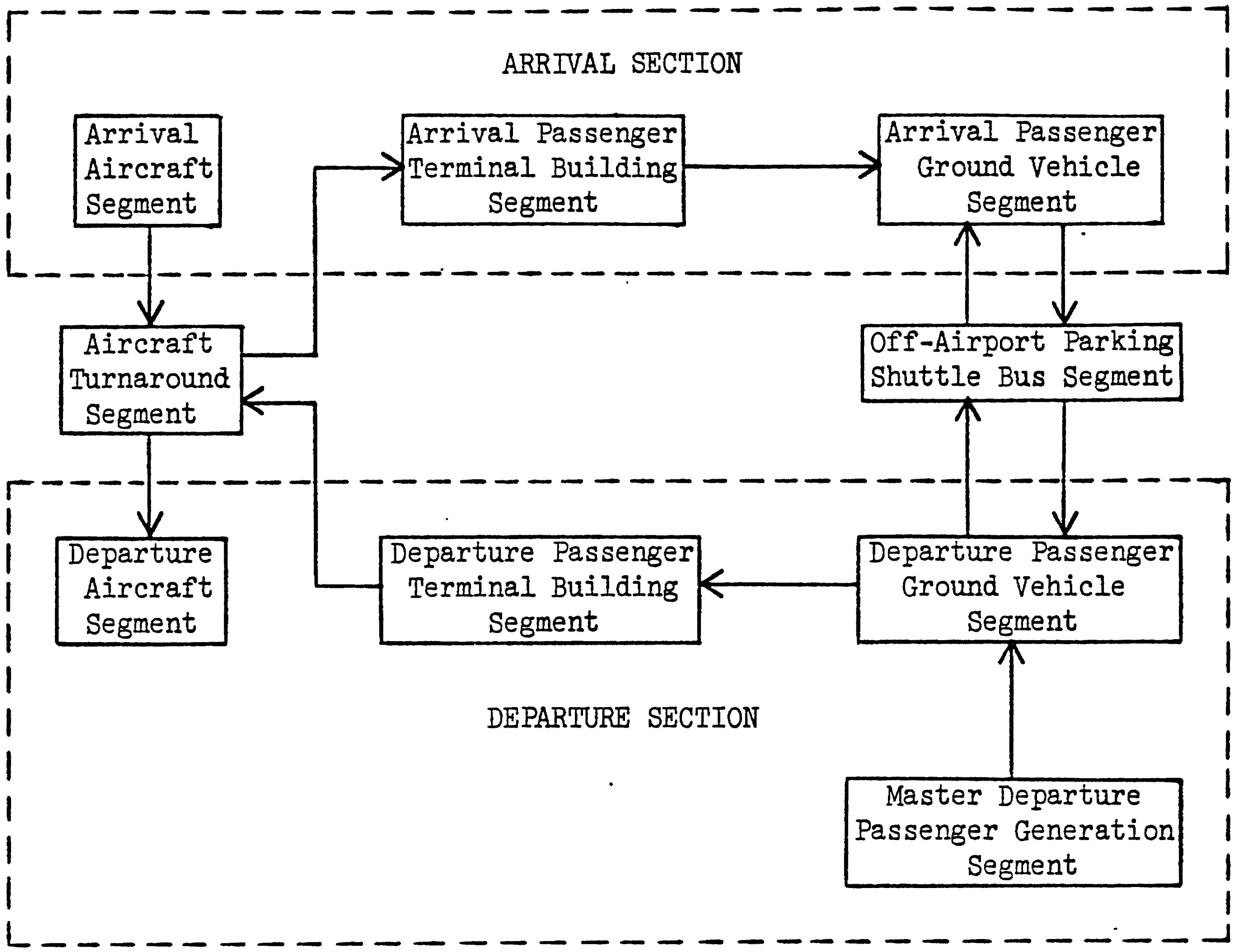

Fig. 1.--Flow Diagram of Airport Simulation Model

The model was patterned after Detroit Metropolitan Wayne County Airport, and was written in GPSS/360 and FORTRAN IV. The model includes 900 GPSS blocks and uses three FORTRAN HELP subroutines to input data and to perform calculations necessary for the operation of the model. Under the heaviest load conditions imposed on the system for the year 1980, the model performed 2.6 million block executions to simulate one 24-hour day of operations at Detroit Metropolitan Airport.

Included in the model are the movements of ground vehicles, passengers, and aircraft within the ground access, landside, airside, and terminal airspace sections of the airport system. These sections of the model interface with each other so that interactions occur between parts of the model as they would in the actual airport system. Taking these interactive effects into account is crucial in assessing correctly the overall passenger congestion delays in the airport system.

In general, the simulation model represents the layout and operating conditions at Detroit Metropolitan Airport. However, in order to keep the complexity of the model within manageable bounds, it was necessary to make several simplifying assumptions. These assumptions tend to reduce the required complexity of the model while still retaining most of the characteristic behavior of the actual system. Most of the assumptions made allow the elimination of small details of vehicle or passenger movement which do not contribute importantly to the measurement of passenger congestion delays.

Arrival Section

The overall arrival section of the airport model includes passengers arriving aboard incoming aircraft and takes them through the system until they leave the airport in ground vehicles. This section of the model consists of several interconnected model segments, as shown in Figure 1.

The arrival aircraft are specified as to airline, flight number, number of passengers, type of flight (through vs. terminating/originating), scheduled arrival time, and scheduled departure time from the gate. The flight schedules are determined in advance and represent realistic schedules for Detroit Metropolitan Airport. An incoming flight is scheduled for its designated runway, waits for any other aircraft in its way, achieves the proper wake turbulence separation from any preceding aircraft, and then turns onto final approach for that runway. If any conflict develops over the use of the runway, the incoming flight executes a missed approach and waits its turn again. Otherwise, the arrival plane uses the runway, turns off and taxis to its gate. The incoming aircraft may be required to wait prior to reaching its gate, if the gate is still occupied by a departure aircraft which is late in leaving, or if the taxiing path it must use to reach its gate is blocked by another arrival or departure aircraft using the same path.

Once the plane reaches its gate, it discharges its passengers to the Arrival Passenger Terminal Building Segment and the plane continues through the Aircraft Turnaround Segment. The arrival passengers proceed through the terminal building to the Arrival Passenger Ground Vehicle Segment where they choose ground vehicles by which they leave the airport.

Aircraft Turnaround Segment

The turnaround activities include those necessary to prepare an aircraft for its departure from the airport. These include deplaning the arrival passengers, cabin cleaning and boarding of arrival passengers. Also included are refueling and checkout activities. A third set of tasks includes baggage and cargo unloading upon arrival, and baggage and cargo loading prior to departure. The aircraft is not allowed to leave at its scheduled departure time unless all of the turnaround tasks are complete. For example, it is possible for a departing flight to be held because the passenger gate check-in point does not close on time.

Departure Section

The overall departure section of the airport includes departure passengers entering the airport boundary in ground vehicles and takes them through the system until they leave the airport aboard an aircraft. The model segments which comprise this section of the model are shown in Figure 1.

Passengers for specific airline flights are released from the Master Departure Passenger Generation Segment at appropriate times before their scheduled flights, and are assigned ground vehicle paths by which they proceed to the terminal building. The Departure Passenger Ground Vehicle Segment accomplishes the movement of the passengers to the terminal. The Departure Passenger Terminal Building Segment assigns passengers to appropriate paths through the terminal building facilities of their airline. If everything is on schedule, the passengers board the aircraft as scheduled and the flight departs on time. If the flight departs late, the delay is recorded. At the time the flight is ready for departure, control over the flight is shared between the Departure Passenger Terminal Building Segment and the Aircraft Turnaround Segment. As soon as all passengers have boarded, control over the departure flight is transferred to the Aircraft Turnaround Segment, and then to the Departure Aircraft Segment. This segment includes checking for any conflict with other arrival or departure aircraft over the use of the common taxiing path, pushing back the aircraft from the gate, taxiing to the assigned runway, and using the runway for takeoff. The aircraft leaves the model as soon as wake turbulence separation would have been attained for any following departure aircraft.

Data Sources

A great deal of the data regarding the airport layout, current and future traffic loads, and other information was obtained from the Master Plan Study conducted at Detroit Metropolitan Airport in 1972. As part of this study, an Airport Activity Survey was performed which provided a great deal of other valuable data. Further, the Civil Aeronautics Board conducted a study in 1970 which provided data on specific flights which were later adapted to drive the model. On-site observations at the airport and interviews with operating managers at the airport were made by the senior author.

Model Checkout Procedures

The fact that the overall model was built in a modular fashion aided in the verification of each of the modules. Extensive testing of each module was performed, using sets of test data to run each module separately in a deterministic (non-random number) fashion so that the results of these runs could be compared with hand calculations. Extensive use was also made of tracing procedures available in both GPSS and FORTRAN to insure that the logic of each module was correct. Following this, the model and its output were examined by individuals familiar with the operation of Detroit Metropolitan Airport. This was done in order to determine the reasonableness of the model in representing the behavior of the actual system. It was the consensus of these individuals that the model appeared to be valid.

Congestion Measurement

In this study, delay was defined as an increase beyond the usual time required to move from one point to another because of congestion interference. The airport simulation model used in this study has over 100 separate congestion measures, not counting queues at each individual gate check-in point. If each gate check-in is counted as well, the total rises to over 150 separate measures of congestion delays. These measures include waiting time statistics for passengers in ground vehicles, in the terminal building, and in aircraft. Each point at which passengers may encounter congestion delays has a separate queue which can measure the delays incurred. At many of these locations, the distribution of waiting times is collected, as well as the average delays during each clock hour. This provides additional information regarding the extremes of delay conditions occurring during a given hour. It is quite possible for average delays at a location during a given hour to mask the effects of severe congestion occurring during the hour, but which dissipated before the end of the hour. It could happen that delays serious enough to cause passengers to miss their flights may occur during an hour, but that the effects would clear up before the clock hour is completed. In that case, the statistic for average waiting time during the hour would not indicate that anything worthy of notice had occurred. However, the distribution of waiting times encountered by individuals at that location would conclusively point out that serious delays had occurred. This is particularly important when dealing with interactive delays between parts of the airport system, since these delays tend to be short-lived even though they can be serious enough to cause passengers to miss their flights.

The missed flight is probably the most dramatic measure of passenger congestion delays. All passengers who miss flights in the simulation model are counted, and the information regarding their airline, time of entry into the model, and paths taken through the system are recorded. This is done so that the exact reason for the missed flight can be identified. All departure passengers introduced into the model have enough time to make their flights if they are not delayed unduly at one or more points in the system. Passengers who have missed their flights by the time they reach the terminal building door are intercepted and counted, as are those who miss their flights at the gate check-in. In all, the measurement of congestion delays in the model is rather extensive.

Experiments With the Model

The principal reason for experimentation with a simulation model of an actual system is to examine the behavior of the system under differing sets of circumstances. These would usually include a heavier operating load on the system, alternative ways of accomplishing tasks, or some combination of these. Although the careful examination of the actual system needed to build a model yields many insights into the behavior of that system, experimentation yields even more.

The basic idea is that insights can be gained through the simulation model into the likely behavior of the actual system under those changed sets of circumstances without the necessity of experimenting with the actual system itself. Such experimentation with the actual system is usually difficult or even impossible because of cost, manpower limitations, or risk of upsetting operation of the system. Simulation models are useful in predicting the probable effect of changes which could be made to the actual system. Simulation thus provides a way to determine the best manner in which to use an actual system most efficiently.

The experiments performed with this airport simulation model serve one major purpose. That goal is to demonstrate the usefulness of a large-scale integrated simulation model of the overall airport system in evaluating potential passenger congestion delays within the airport system, and in evaluating the relative attractiveness of different means of dealing with passenger congestion delays which might arise. The experiments are designed to indicate the potential passenger congestion delays which might be expected under an assumed set of circumstances which could occur in the future.

Projected Future Loads

Future passenger load conditions were simulated by increasing the passenger loads imposed on the model. These passenger loads represented those which might be experienced in the year 1980 under three different growth rate assumptions. These assumptions were a pessimistic three percent, a most likely six percent, and an optimistic nine percent growth rate per year in passenger traffic from 1975 levels to 1980. Using these three different levels provided a picture of conditions likely to occur in the future under any reasonable growth rate assumptions.

Analysis of Operational Changes

In order to view the effects of changes which operating managers would likely apply to deal with congestion effects, increased capacity was applied to those points in the model where it was needed to alleviate congestion delays under the heavier loads. In this fashion, the model could be used to evaluate the probable success of specific operational changes in reducing passenger congestion delays.

Experimental Results

The results of the experiments indicated that heavier passenger loads on the airport system studied are very likely to cause severe congestion delays to occur. It is expected that these delays will occur in the following locations:

1. On-airport parking entrance
2. On-airport parking check-out
3. Upper terminal curbside roadway
4. Curbside baggage check-in facilities*
5. Airline ticket counter facilities*
6. Airline express baggage check-in facilities*
7. Airline security check facilities*
8. Airline gate check-in points*

*Note: Delays at these points were specific to certain of the airlines, but not others. Severity and duration of these delays varies by time of day.

The experimental findings indicated that it will be necessary to make changes in the configuration of the airport in order to deal with the expected levels of congestion delay. These changes would include the expansion of capacity for all of the congested locations listed above. The experimental results also indicated that alternative methods of passenger handling can be examined by using the simulation model and that the "best" alternative can be chosen by use of the simulation model.

Lobby Check-in

An example of the examination of alternatives is the set of experiments conducted to determine the relative attractiveness of increased capacity at the airline gate check-in as opposed to issuing boarding passes to passengers at the airline ticket counter and express baggage check-in. The results of these experiments indicated that the "lobby check-in" may have several benefits as well as some higher costs. The simulation model output could be examined by airline management in order to determine the required man-minutes of personnel staffing under each alternative. This indication of the relative costs could be weighed against the benefits for each alternative.

Departure Flight Delays

One of the most interesting of the experiments with the airport simulation model was the effect on departure flight delays of increased capacity at other queueing locations than the airline gate check-in points. While the capacities of the airport roadway segments, airline ticket counters, security check stations, express baggage check-ins, and curbside baggage check-ins were increased, the capacities of the gate check-in points to handle passengers were not changed. The results shown in Figure 2 indicate the dramatic nature of the congestion delay reductions achieved for departure flights by changing service capacities elsewhere in the airport system. Before the expansion of

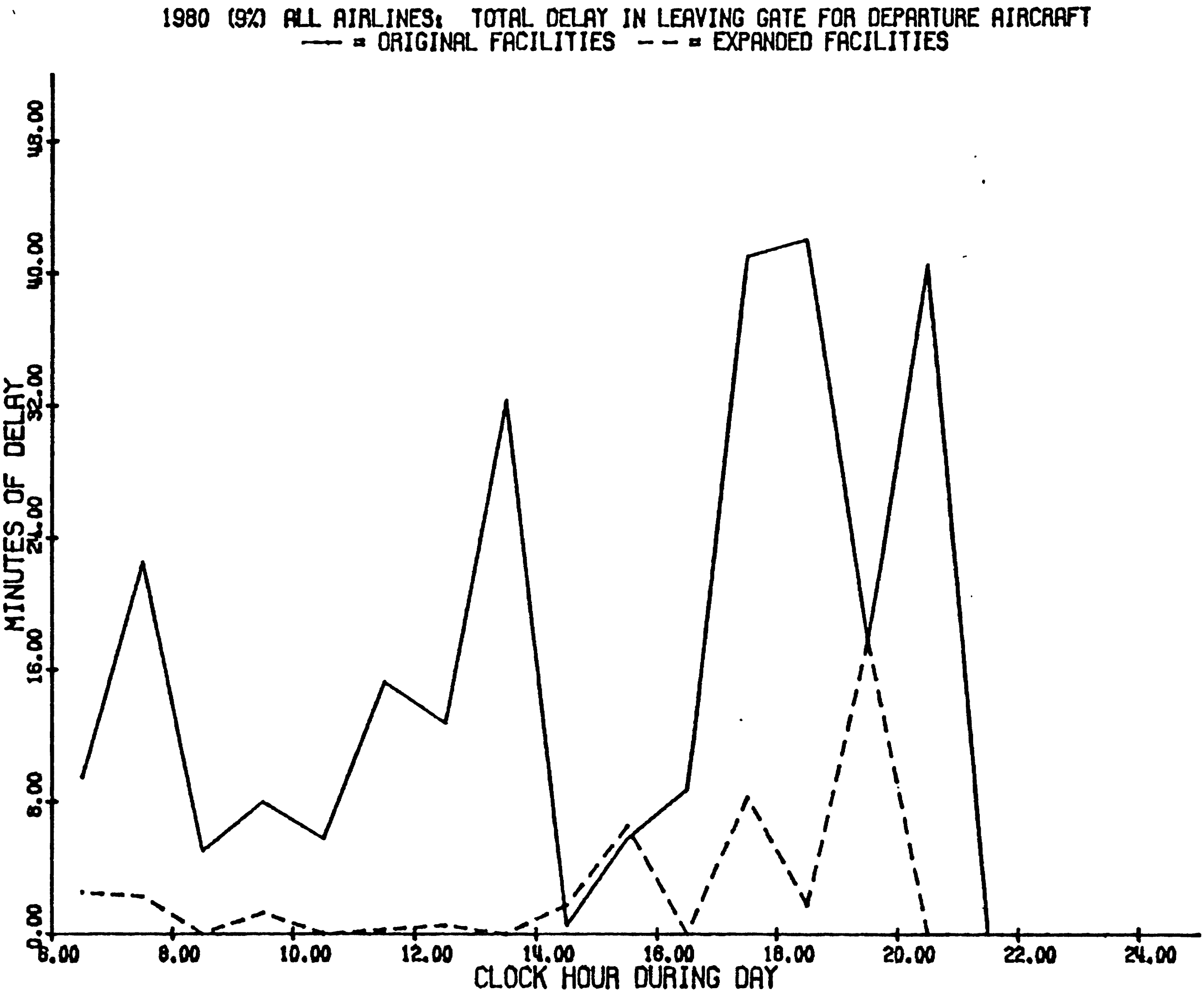

Fig. 2.--1980 (9%) All Airlines: Total Delay in
Leaving Gate for Departure Aircraft
for Original, Expanded Facilities

capacity at those other facilities, passengers were released very slowly from those locations and arrived at the gate check-in points for some flights in a long drawn-out stream. This meant that the gate check-ins were held open for an inordinately long time in many cases, delaying the departure of those flights. The improvement occurred because the passengers arrived at the gate check-in point in a timely manner, since they were no longer delayed so long at the other service locations, once the capacities there were expanded.

Missed Flights

The need for a method of analyzing airport congestion delays on an overall system basis is dramatically pointed out by the 1980 nine-percent growth rate runs which showed the effects of roadway congestion. In this situation, many departure passengers using off-airport parking were delayed enough that their flights had departed by the time they reached the door of the terminal building. The reason for this was not obvious, but a careful tracing of the model's operation showed that the temporary peaking of congestion at the upper terminal curbside roadway unduly delayed the shuttle buses used by passengers using off-airport parking. Furthermore, the same temporary peaking of congestion at the upper terminal curbside roadway used up the extra "cushion" of time for many passengers being dropped off at the curbside by private autos. This meant that any further

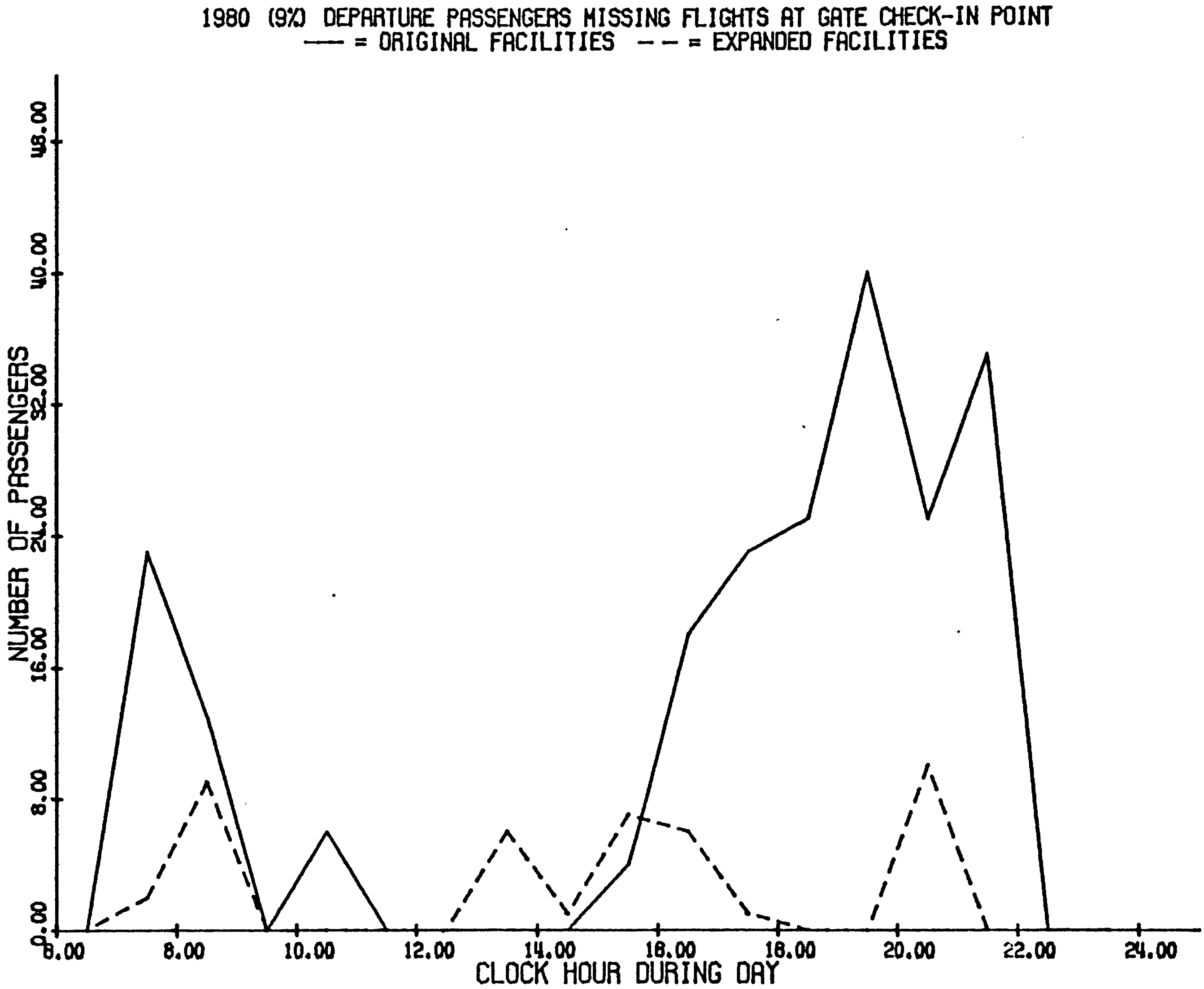

Fig. 3.--1980 (9%) Departure Passengers Missing Flights at Gate Check-in Points for Original, Expanded Facilities

delays in the terminal building caused them to miss their flights by the time they reached their gates. Thus the roadway congestion delays contributed to the number of passengers missing their flights at the gate check-in points, as shown in Figure 3. This kind of interactive delay effect indicates the crucial importance of examining passenger congestion delays on an overall system-wide basis, rather than examining each part of the system separately. Through the use of the discrete-event system simulation approach developed here, the reason for departure passengers missing their flights at the gate can be identified. The ability to trace individual passenger movements provides a means for discovering interactive effects through which congestion in one part of the airport system causes delays in another part. Without using an overall integrated simulation model of the airport system, findings of this sort would most likely be overlooked. Their importance would certainly not be pointed out to those with the ability to make corrective changes to the system.

Conclusions

The use of an overall system simulation model is an effective approach to the analysis of passenger congestion delays at a metropolitan airport under different passenger traffic loads and operating configurations. It is apparent that interactive effects between different parts of the airport system become more important in analyzing congestion delays as the loads on the system become increasingly heavier. These interactive effects appear to be short-lived for the most part, but they can often be serious enough to cause passengers to miss their flights. It is expected that these interactive effects will become longer-lasting and more serious as traffic loads on the system increase.

The experiments with the model demonstrated that the ability to track the activities of individual passengers as they move through the airport system is important in isolating the causes of interactive delays in the system and determining effective measures to deal with these delays. This is especially important where potential future loads are imposed on the model in order to determine the likely effects on the actual system. An important advantage of the simulation model in its comprehensive form is the ability to analyze the effects of combined solutions to more than one congestion delay problem. In this way, it is possible to avoid situations in which solution measures merely shift delays from one location to another. It is also possible to avoid solutions which treat the symptoms rather than isolating and dealing directly with the causes of congestion.

A real advantage of using the simulation model is that the timing of changes to the airport system can be scheduled so that changes needed in the future can be planned in advance, rather than as reactions to crisis situations. Contingency planning would thus be made much more effective because the likely results of such plans could be seen in advance, with the result that the plans could be improved or modified as needed.

A further benefit is that the examination of future conditions through the use of the overall airport simulation model could avoid the choice of immediate changes to the system which would be inconsistent with changes needed at a later date. This applies particularly to the case where the choices to deal with congestion delays include the modification or construction of fixed facilities or the acquisition of special equipment. For example, it might seem desireable to build large passenger lounges at the departure gates to accomodate large numbers of airline passengers waiting to board wide-bodied jets. However, the construction of such lounges could be made unnecessary by changes to the system in which passenger check-in at the gate was eliminated.

It was not a simple task to construct a model of the size described above. Approximately three man-years of effort were required plus several thousand dollars worth of computer time. Although it is difficult to quantify the benefits of reducing passenger delay time in an airport system, it seems obvious that the payoff in alleviating these delays is very high. The availability of a simulation model approach to the analysis of airport passenger congestion delays should greatly improve the ability of airport planners and managers to examine current operations and to plan for the future in order to reduce and to avoid these delays.

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