Passenger Terminal Impedances

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Conventional transportation network analysis requires the estimation of the times necessary to complete three portions of a typical intercity trip. Although the times associated with the line-haul and access portions have been studied extensively, the time required for transfer between access and line-haul modes has not been handled adequately. These times, or impedances, occur at any intercity passenger terminal for air, rail, and bus modes. This paper identifies each of the major components of the passenger terminal system and develops the respective impedance methodology for each as well as a technique for combining them into a single value representative of the total impedance level for a particular terminal. Data were collected at several intercity terminals in the Washington, D. C., area; and the impedance levels were determined for each terminal. The methodology and many of the component values are directly transferable to other terminals. In addition, the methodology may be used as an aid in evaluating alternative functional arrangements of the various terminal facilities.

•A CONVENTIONAL network simulation model distributes transportation flows across the network as an inverse function of the difficulty, or "impedance," of travel along each link. For a regional network, at least three major categories of impedance may be defined:

1. Link impedance is the measure of the average "line-haul" travel times, costs, or distances associated with travel along the major links of the regional network.
2. Access impedance is the measure of the average "access" times, costs, or distances involved in traveling from a typical origin or destination point to the nearest access/egress point on the regional network.
3. Terminal impedance is the measure of the average transfer (or "terminal") times, costs, or distances involved in transferring from the access system to the line-haul system.

For a typical air journey from Washington, D. C., to Boston, the link impedance might be represented by the average air travel time between Washington National and Logan International Airports; the access impedance, by the respective travel times from the original starting point in Washington to Washington National Airport and from the airport in Boston to the final destination; and the terminal impedance, by the respective times spent within the airports in Washington and Boston.

To date, the attention of model-builders has focused on estimates of link impedances and, more recently, access impedances. Little or no attention has been devoted to estimates of terminal impedances. This paper describes a first attempt to develop a system of terminal impedance measures for incorporation into the existing Northeast Corridor network simulation model(s).

In this study, attention is directed primarily toward time measurements, covering the period between the arrival of the passenger in the line-haul terminal to his departure by either the line-haul or the access/egress mode. The estimates are based on the output of a series of simple queueing models embedded in a matrix of estimated walking times. Data for the study were developed from "as built" plans of existing Corridor

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terminals and were supplemented by limited field studies of walking speeds and terminal process times developed in the Washington, D. C., area.

In addition to providing terminal time estimates as inputs to a simulation model system, the materials developed in this study also serve as a framework within which to evaluate the operational efficiency of alternative functional arrangements within the terminal and as a convenient empirical device for identifying current focal points of delay.

IMPEDANCE METHODOLOGY AND DEFINITIONS

Three separate measures of terminal time were initially developed for possible inclusion in the network model system. The first, termed "average elapsed time," represents the total time spent by the average traveler within the terminal system, measured from his instant of entry to his time of exit. This measure was rejected for a variety of reasons. First, such a measure would include time spent in various nonterminal activities such as eating a meal or shopping in gift shops. Second, such a definition does not lend itself readily to mathematical modeling. Finally, data collection would require passenger contacts, a technique to be avoided in crowded terminals.

A second, more meaningful definition, termed "average terminal time," is used extensively in the following analysis. The average terminal time is made of three separate elements: the "processing time," the "engaging/disengaging time," and the "movement time." Processing time represents the average time taken by a passenger to perform specific, travel-related terminal functions, such as ticket purchase or baggage checking. Engaging/disengaging times are the times at which a passenger may be assumed to have transferred between two of the terminal subsystems discussed in a following paragraph. The difference between an engaging/disengaging time and the time when a specific event occurs (e.g., the time of the traveler's arrival at the boarding area before scheduled departure time) is used as an element of the average terminal time. Finally, the movement time is simply the time required to move from one process or engaging/disengaging point to another.

The third measure, "minimum essential processing time," represents the least amount of time that a typical passenger must spend within the terminal system. This value differs from the average terminal time in that the engaging/disengaging times are replaced by the equivalent processing times associated with the engaging/disengaging activity.

For departing passengers, separate average terminal time and minimum essential processing time estimates are developed for each of the terminals studied. For arriving passengers, however, the two definitions produce essentially the same results; thus only one estimate is required and is computed for the average passenger. For passengers transferring from one line-haul vehicle to another, a minimum essential processing time may be estimated for assumed typical interchanges.

The operation of a passenger terminal may be generalized as shown in Figure 1. Three types of flows are indicated: line-haul departures, line-haul arrivals, and line-haul transfers. For analytical convenience, the terminal has been broken down into three subsystems; an access mode transfer system, a terminal processing system, and a line-haul transfer system. As the three types of flows have somewhat different needs in each of three subsystems, a matrix of nine subsystems is formed. For all practical purposes, the termination of the line-haul mode system will be the same for both line-haul arrivals and line-haul transfers, and the initiation of the line-haul mode system will be the same for line-haul departures and line-haul transfers. A total of seven different subsystems thus may be examined.

Each of these subsystems may be broken down into many separate components. The example shown in Figure 2 illustrates the operation of the terminal processing system when used for line-haul departures. This chart is applicable for use in determining both average transfer times and minimum essential processing times. Passengers are received from the termination of the access mode system either with or without baggage. Each group may be further broken down into these who are preticketed and those who must acquire their tickets at the terminal. A further breakdown of those groups with

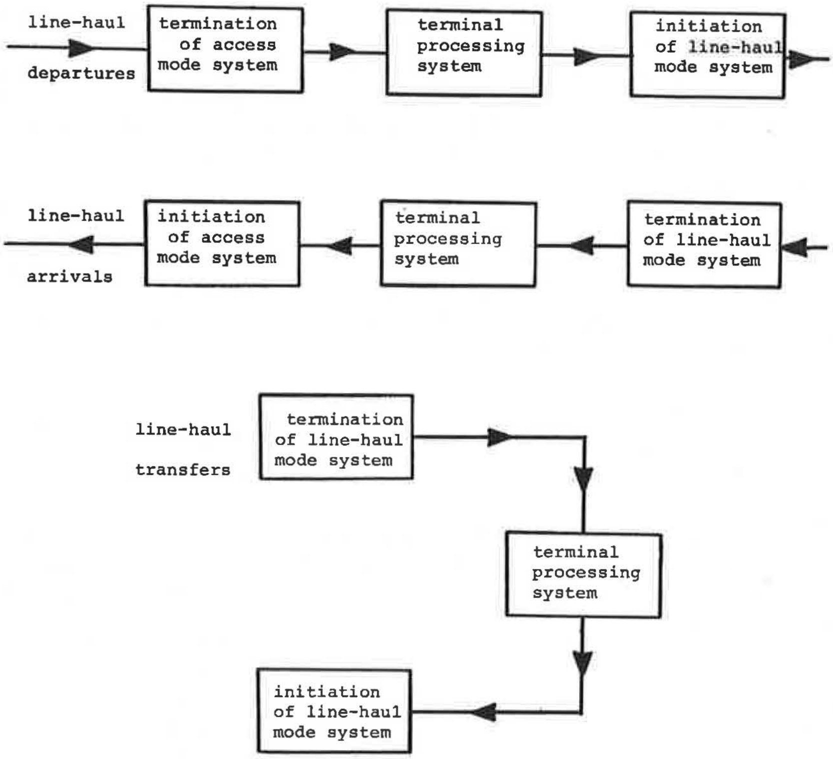

Figure 1. Terminal processing system.

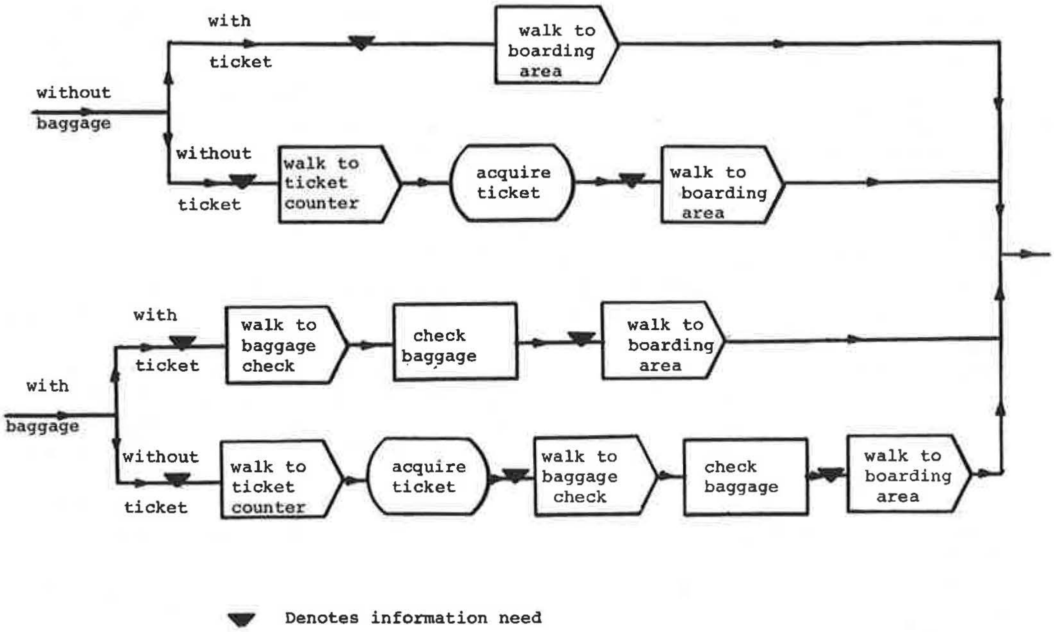

Figure 2. Terminal processing system of line-haul departures.

baggage might be made between those who carry their own baggage, those who use mechanical devices, and those who use porters. Such a distinction would make little difference in the functional flow through the various activities, but could involve different impedance values. Such considerations, however, can be ignored effectively for analytical purposes at the present time because mechanical devices are rarely used at corridor terminals and because porters do not necessarily alter the basic impedance parameter selected here; namely, processing time.

Also, rail and bus operators frequently encourage the passenger to carry his baggage onto the line-haul vehicle or to check it at the vehicle itself. In this case the baggage-check activity has been physically transferred to the initiation of the line-haul mode system, but may be analyzed with this structure of the terminal processing system. Obviously, the impedance associated with such a system will have considerably different values from those associated with equivalent activities in a more conventional system.

Most of the activities shown could occur in different sequences along any path. In addition, many of the activities can be broken down into subactivities. Some of the activities might be transferred to the initiation of the line-haul mode subsystem or to the termination of the access mode subsystem. An example of the former would be the use of express ticketing or boarding-area baggage checking for shuttle flights. An example of the latter would be curbside baggage checking. These activities can be analyzed as if they occurred in the processing subsystem; however, every terminal contains a number of these special activity linkages to a greater or lesser degree and must be analyzed separately.

In each case, the estimation of the final set(s) of impedance measures is based on a weighted combination of the outputs of a sequence of simple queueing models (representing the times spent within each required terminal function for the appropriate set of users) and the average walking times for all users between each function. The actual methods used to develop these values are described in the Results section. It should be noted that the estimates made do not consider explicitly the actual paths through the terminal, the perceived versus actual delays, or the congestion effects.

DATA COLLECTION AND ANALYTICAL PROCEDURES

Field data on air terminal operations were collected at Washington National Airport, Dulles International Airport, Union Station, and the Greyhound Bus Terminal during the month of April 1969. It is acknowledged that generalization of the results of these studies is a hazardous undertaking. It is believed, however, that the data collected at the Washington locations may legitimately be considered representative of similar operations at other existing terminals at the level of analysis pursued here.

Data collection was necessarily concentrated on estimates of delays within the terminal building. No attempt was made to collect data in the access/egress areas of the terminal. However, work in this area, which requires considerable time and manpower, is currently being undertaken by Peat, Marwick, Mitchell and Co.

Data collection in the terminal building itself focused on four major areas: ticketing and baggage-checking facilities, boarding areas, deboarding areas, and baggage-claim facilities.

Data collected at each type of ticketing and baggage-checking facility consisted of a simple record of the numbers of passengers arriving in the queue at each ticket station, broken down into 15-second intervals. Any passengers leaving the queue before being served were noted also. Simultaneously, an observer noted the arrival and departure times for each passenger at the counter, and also noted whether the passenger was buying a ticket, checking baggage, requesting information, etc. Service time distributions were obtained from these data as well as estimated percentages of passengers requesting various types of service.

The analytical tool chosen for studying the ticketing and baggage-checking process is the simplest, multiple-channel queueing model discussed in any standard queueing theory text (1, 2). The model, denoted in queueing theory terminology as M/M/c: (∞/FIFO), assumes Poisson arrivals at a rate of λ per minute, feeding a single queue

from which all stations or service channels are then fed. Although this model clearly does not apply exactly to the situation found in most airport ticket areas, the "jockeying" of passengers from one queue to another results in an effective queue discipline not unlike that assumed by the model. The assumption of exponentially distributed service times with mean value μ is similarly a reasonable approximation to the situation for most types of service.

Arrival times at the boarding gate were recorded by simply counting in successive 15-second intervals the number of passengers arriving over a period of 30 to 40 minutes before the scheduled departure of the aircraft. Data were collected only for those flights that had no posted departure delays. Additional time spent in the terminal because of in-flight delays is not to be considered within the purview of this study as terminal impedance. In the boarding area, similar observations were made of the processing times at the check-in desk and the rate at which passengers boarded the aircraft. Information concerning ticket purchase at the gate, gate baggage checking, and standby passenger handling was recorded along with the check-in times in a manner analogous to that used to record the supplementary data collected at the ticket counters in the main terminal.

Observations of arriving passenger flows included the rate at which the passengers passed out of the aircraft door. Separate studies were made of flow rates for different types of unloading devices. The type of device (see the Results section) proved to have a significant effect on the deplaning rates. It should be noted also that observations at Dulles International were made at the exit of the mobile lounge rather than at the aircraft door because the scheduled time for flights to and from that airport includes the necessary travel times via the mobile lounge from the terminal to the loading apron. Likewise, boarding-area arrival and boarding-gate studies at Dulles were all made at the mobile lounge entrance.

The fourth and final set of observations was made in the baggage-claim area. In this case a single observer recorded the arrival rates of baggage arriving from a given flight at the claim device. Simultaneously, one or more other observers recorded the rates at which this baggage was picked up by the passengers. These observations were coordinated with the passenger deplaning data to obtain the previously discussed estimates of the line-haul disengaging time for passengers with baggage.

The results of the analyses performed on these data were combined with estimated walking distances between terminal functions scaled from plans of airports. In accordance with the definitions given earlier, straight-line minimum paths were traced. The probability of significant passenger deviation from these paths, particularly because of a lack of adequate directional information, is acknowledged but is not treated explicitly in the analysis because the intent simply is to generate a simple, gross estimate of average terminal time. The walking distance to the boarding area is an average measure for all gates with no allowance for weighting by gate utilization. Several paths were traced for different airlines at Washington National Airport, where substantial asymmetry exists between various carriers.

These distances were converted to average walking times using an assumed average walking speed of 4 feet per second based on data derived from previous studies of walking speeds (3, 4). Further stratification of walking speeds, based for example on age/sex breakdown, was thought to be an unwarranted refinement at the current level of analysis. Congestion effects at specific points such as doorways and stairs likewise were ignored. The effect of these assumptions is not critical in the final impedance measure.

Similar data were collected at Union Station and at the Greyhound Bus Terminal and from plans of these facilities. Data for both regular train and Metroliner service were collected at Union Station because separate facilities are provided for these services and because passenger behavior was found to be somewhat different. No such breakdown was required at the bus station.

RESULTS

This section focuses on the results obtained from the field studies at Washington National Airport and uses these findings to develop a set of simple important measures

for this terminal. Equivalent findings for Dulles International Airport, Union Station, and the Greyhound Bus Terminal are summarized at the end of the section.

Ticketing and Baggage Check

Many different arrangements of ticket and baggage-checking facilities are in use by different airlines. One major distinction is the degree to which different service requests—e. g., ticketing and information—are separated and assigned to different counter stations. Different service combinations produce radically different service time distributions at a given counter station.

In most cases a primary, advanced-reservation ticket counter is provided, together with specialized express baggage, will-call, and information stations. Inevitably, however, some passengers approach the counter area at the wrong location, requesting a type of service not provided at that position. Airline policy, generally, is to serve these passengers whenever possible rather than to redirect them to a more appropriate counter. The relative inefficiencies introduced by this approach are, of course, more than balanced by its customer relations value.

The service time distributions observed at the primary ticket counters for four different airlines at National Airport are shown in Figure 3. Figure 3(a) shows the results of a highly specialized operation. Although express baggage and special information counters are provided to attract many of these brief service transactions, a substantial number of relatively short service times are still observed at the primary counter.

Figure 3(b) shows the distribution of service times for another airline that operates extensive express baggage and special service stations, again in addition to the primary ticketing station. This distribution differs substantially, however, from that shown in Figure 3(a). The airline in question operates a relatively simple set of routes from National Airport, involving fewer connections and less selection between alternatives than does that shown by Figure 3(a). As a result, the average service times are much shorter and the service time distribution is more compact.

Figure 3(c) shows an operation where provision is made for baggage checking at facilities away from the ticket counter. Again, a fairly complex routing structure leads to some quite lengthy service times.

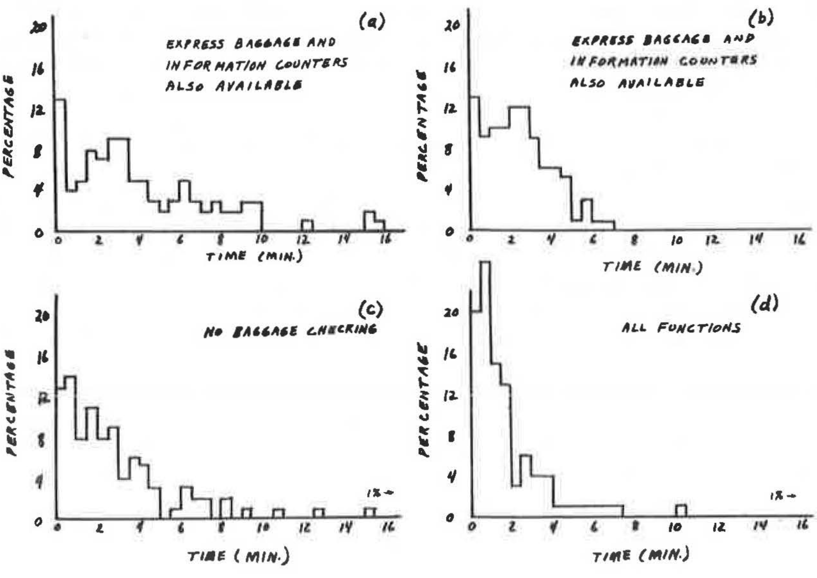

Figure 3. Washington National Airport ticket counter service times.

Finally, Figure 3(d) shows a situation where virtually all activities—ticket, baggage checking, information—are concentrated at a group of undifferentiated counters. The effect of brief information and baggage checking services is quite pronounced, whereas the airline's simple routing structure from National Airport serves also to eliminate the majority of complex and lengthy bookings.

The operation of an express baggage counter, shown in Figure 4(a) for one typical airline is essentially similar to that of the information counter 4(b) with the exception that extremely short times are somewhat less frequent. Again, there is a limited number of relatively long service times, reflecting transactions involving passengers with unusually large quantities of baggage.

The distribution of service times associated with a separate information counter is shown in Figure 4(b). Over half of the service times are of less than 30 seconds duration; i. e., they would fall within the first time intervals shown in Figure 3. A limited number of somewhat longer service times was also observed.

The service time distributions for the ticket counters and the baggage-checking counters at Dulles International Airport are shown in Figures 4(c) and 4(d) respectively. Very few extremely long service times were observed. The relatively large proportion of very short service times indicates that a considerable number of simple information requests were handled at the primary ticketing counters, despite the presence of the special information counter. The similarity between the two distributions illustrated in Figures 4(c) and 4(d) is partly explained by the occurrence of a considerable amount of "cross-servicing"; i. e., tickets were purchased at the baggage counter and bags were checked at the ticket counter. In fact, except during brief peak surges, the available differentiated counters were used effectively for undifferentiated service.

The major purpose of specialized service counters is to provide rapid service to those passengers with simple requests, to reduce overall passenger delays, and to reduce the load on those counter agents who must handle the more complex and lengthy transactions. An efficient alternative, or more properly an efficient supplement, to a system of specialized counters is the use of a "floating server" or agent in the lobby area ahead of the counter. These persons contact passengers as they approach a queue

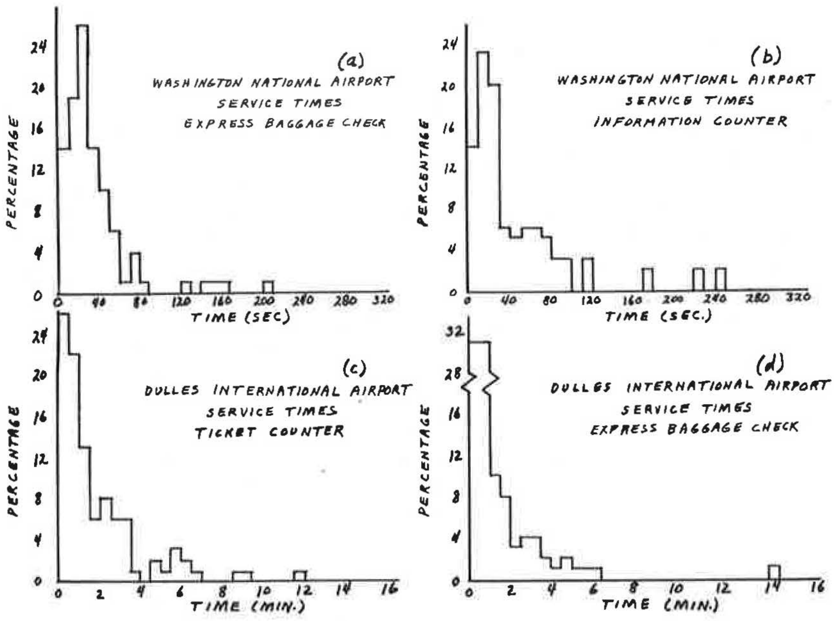

Figure 4. Typical service time distributions at Washington National and Dulles International Airports.

and provide service when possible or direct the passenger to the proper line when more specialized attention is required. This activity is called by various names by different airlines—front counter service, random servers, roving servers, etc. The latter term will be used here.

One of the most effective roving-server operations at Washington National Airport is carried on by Eastern Airlines. In this case, one or more roving servers are employed during all busy periods. They operate either by contacting the passenger and eliciting information on the service he requires or by simply responding to passenger queries, which are usually simple information requests and often are not connected with Eastern's operations at all. Under normal circumstances, the agent will answer information requests or confirm reservations while the passenger is waiting in line. In unusual cases, such as a last-minute passenger needing a ticket changed, he either will take the passenger to a vacant counter station and handle the request himself or else will lead him to the front of an existing queue and request that the agent deal with his request next. (This latter practice occurs very infrequently, and does not seriously affect the assumptions underlying the queueing models discussed here.)

The roving server provides an extremely valuable service to certain travelers by considerably reducing their waiting times and, of course, generates considerable "good will" for the airline. His main function is to reduce the level of input to the queue, to prevent the occurrence of major unnecessary delays, and to reduce congestion and confusion in front of the counter area.

Eastern Airline's roving servers at Washington National Airport concentrate on passengers queueing at the primary ticket counter. A limited study showed that roughly 32 percent of all passengers arriving at these counters were both contacted and served in this fashion. In addition, about 1 percent of the passengers in the express baggage line were similarly served. These figures represent a conservative evaluation of the efficiency of the system in that they do not include passengers served before they joined a specific queue.

The times for roving service are naturally very short. Roughly two-thirds of all service times were of less than 30 seconds duration, although an occasional lengthy contact was made. These latter were typically rush services of the type mentioned before. A simple breakdown of the service provided by the agent is given in Table 1.

The presence of the roving server was just one of several complications in the ticketing area that served to confuse the queueing analysis. Another was the use of additional servers behind the ticket counter during peak periods. Some airlines seemed to prefer this technique to that of the roving server. The result to the airline is similar of course—the reduction of the workload on the agents manning primary counter stations. The result is clearly not so desirable for the passenger, however, because he must wait in the queue at least until the person immediately in front of him reaches the counter. This situation also has the additional disadvantage of defying simple analytical treatment: Neither can the two servers be considered to be handling independent queues, nor can the net inputs to the queues be simply reduced by filtering as occurs with the roving server.

A further complication lay in determining the actual passengers because air travelers frequently travel in groups. The counting technique discussed previously was not adequate, and a "synthetic" approach derived from the actual counter services was used. Although the theoretical inadequacies are acknowledged, the technique was adequate for the purposes of this study.

The calculation of the necessary queueing service times is also complex. As previously mentioned, arrival and departure times were noted for each passenger as well as the service provided that individual at the counter stations. The difference between these values gives an estimate of the service. A simple average of

TABLE 1

SERVICES PROVIDED BY EASTERN AIRLINES ROVING SERVER AT NATIONAL AIRPORT

Service and Result	Passengers Contacted (percent)
Agent checked ticket and passenger remained in line	39
Agent checked ticket and passenger left line	33
Agent directed passenger to another line	22
Other	6

these latter times, however, does not provide the necessary input to the queueing model because a few seconds of agent bookkeeping time typically occur between the end of one service and the beginning of the next. This extra time must be included in the model to give a true service-start to service-start block time.

Once the average input rates and the average service rates are available, the average time spent waiting in the queue may be determined directly from standard, published charts for the appropriate queueing model. See, for example, Molina (5) and Lee (1). To this waiting time must then be added the average service time obtained from the raw data to yield an estimate of the average total delay to a typical passenger. The results obtained from such an analysis for three typical airlines at National Airport are given in Table 2.

TABLE 2

QUEUEING TIMES AT WASHINGTON NATIONAL AIRPORT

Airline	Activity	Waiting Time (min)	Service Time (min)	Total Time (min)
A	Ticketing	2.94	4.05	6.99
A	Express baggage	5.59	0.54	6.13
B	Ticketing	4.57	2.74	7.31
B	Express baggage	1.78	0.57	2.35
C	Ticketing	1.56	2.96	4.52
C	Baggage	4.18	0.80	4.98

Boarding Area

A basic input to the impedance calculations is an estimate of the time before scheduled departure that the passenger commits himself to the line-haul system by entering the boarding area. Distributions of passenger arrivals were obtained from the field data for a representative sample of departing flights, and the time for the average (50th percentile) passenger was computed. These average times and the distributions themselves were found to vary considerably both among flights and among airlines.

At least five different factors influence the shape of these distributions.

1. The time of day—passengers tend to arrive closer to the scheduled departure time for flights leaving early in the morning or at the close of the business day than for midday flights.

2. Destination of the flight—all other things being equal, a flight to a location associated with pleasure or vacation travel, such as Miami, attracts passengers earlier than a heavily business-oriented flight; e.g., Washington to New York.

3. Frequency of service—closely allied to the destination factor is the passenger's perception of the penalty associated with missing a flight. Service for some flights is much more frequent, and the consequent penalty for missing a flight is much less severe than for others.

4. Number of connecting passengers—the impact of connections on the distribution of arrivals at the boarding area depends, of course, on the meshing of the connecting flight schedules. The most noticeable effect of passengers arriving from a connecting flight is a sudden surge in the arrival rate. This can have significant impact on the average value, particularly from one day to another, if the on-time performance of the connecting flights varies.

5. Availability of an attractive holding area—again other things being equal, this is probably one of the most significant variables for seasoned travelers; if the passenger knows that the boarding area is particularly uncomfortable to wait in, he is much more likely to spend any excess time at some other place in the terminal than if an attractive, comfortable waiting area is available.

Figure 5(a) shows the arrival pattern for three different flights on the same airline at Washington National Airport. As might be expected, the arrival patterns suggest that the New York flight, with its associated high proportion of business travelers, has the "tightest" distribution (i.e., the largest proportion of late arrivals) whereas the passengers tend to be more "strung out" for the Memphis-Dallas flight. Although it cannot be proved directly from the data, one might suspect that the early arrivals for the Chicago flight are pleasure or vacation travelers headed for connecting flights at O'Hare Airport, whereas the last-minute stragglers, following the New York pattern, are businessmen.

Also shown in Figure 5(a) is a curve developed by Paullin (6) for San Francisco International Airport. Other flights, not shown here, were also plotted against Paullin's curve. Some, particularly long-distance flights, showed much better agreement than those shown by Figure 5. Others, however, were steeper than the New York flight and thus deviated further from Paullin's curve.

Data on passenger arrival distributions at the Dulles mobile lounge boarding area were taken for a variety of flights. A typical flight is shown in Figure 5(b). The most remarkable thing about this distribution, as compared to those observed at National Airport, is the absence of the traditional S-shaped arrival patterns. The curve for Dulles is, in fact, concave downward throughout its length. This phenomenon may be explained by the reactions of passengers to boarding announcements. Virtually no passengers were found to queue at the lounge until the first boarding announcement was made. Then a very rapid surge of passengers was observed, followed by a gradual tapering off, much as had been observed for conventional boarding areas. A behavior pattern of this type is believed to apply to any terminal where a departure hold room has not been specifically assigned to a flight.

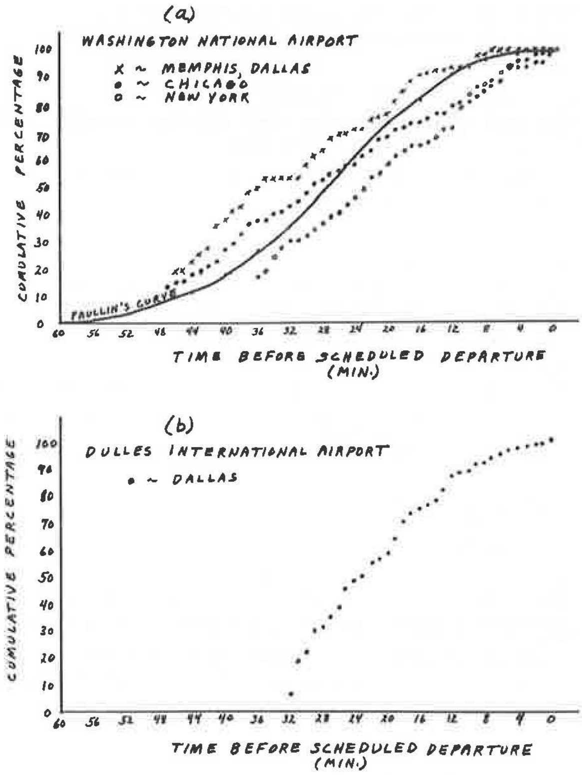

Figure 5. Airline passenger arrival patterns.

Data were not collected on boarding rates into the lounge because an extensive study of this and other features of mobile lounge operations had recently been completed by the Bureau of National Capital Airports (BNCA). Also, this event occurs after the time a passenger is assumed to be committed to the line-haul system, and thus the event is excluded from the impedance calculation.

The service time distributions at the check-in point or entry point to the boarding area were developed at National Airport. As might be expected, this is a very compact distribution because the range of activities to be carried out by the boarding-area agent is very limited. The distribution times for check-in services varied slightly between airlines. One important source of variation was the use of seat assignment at the check-in desk. As might be expected, flights with seat assignment resulted in longer average check-in times. A few airlines, however, had sufficient flights of each type so that meaningful comparisons could be drawn. Where entries in both columns appear in Table 3, the seat-selection data are usually the result of observations of a single flight, whereas the others are averages computed for several flights.

Boarding-area processing times were observed also at Dulles Airport. The processing time over several carriers and flights was found to be 0.24 minute. This did not include

TABLE 3

BOARDING AREA PROCESSING TIMES AT WASHINGTON NATIONAL AIRPORT

Airline	Seat Selection (min)	No Seat Selection (min)
A	—	0.37
B	0.67	0.52
C	0.44	0.36
D	0.25	0.23

processing for flights for which check-in and seat selection had been done at the ticket counter. For such flights, the boarding process time was trivial; the passengers simply flashed their boarding passes at the gate attendant as they boarded the mobile lounge.

Observations of comparative boarding rates were also made for each of the major types of boarding device currently in use. Because the act of boarding occurs after the passenger has committed himself to the line-haul system, its evaluation is not required for the terminal impedance analysis; these data will not be analyzed in detail here. The data were collected mainly for use in an evaluation of the efficiency of alternative boarding schemes proposed for future research.

TABLE 4

DEBOARDING RATES

Device	Rate (pass./min)
Jetway	32.0
Jetway with stairs	31.7
Weighted average	31.9
On-aircraft stairs	22.1
Mobile stairs	28.9
Weighted average	25.3

Deboarding and Baggage Claim

Data on arriving line-haul passengers were collected at both the deboarding gate and in the baggage-claim area. Passenger deboarding rates were recorded for a range of aircraft types and passenger unloading devices. Average values are given in Table 4 and should be compared with airline industry standards of 25 passengers per minute. The superiority of the jetway is clearly seen from these data; the passengers deboard much faster through this device than if they are required to descend a flight of stairs. The use of a jetway with adjustable stairs within it, such as that used by Eastern at National Airport, does not noticeably impede the passengers. Deboarding rates for this device are virtually the same as for the second-level jetways used by American, for example.

A second interesting point is the significantly slower deboarding rates for aircraft using attached stairways, such as the DC-9 and the 737, as compared to a set of mobile stairs, either self-propelled or mounted on a truck. The ladder-like stairs of these aircraft do not seem easily traveled by passengers and result in a significantly longer and more cumbersome deboarding process.

Only relatively smooth deboarding processes were used to generate these values. Frequently, a considerable delay was generated by one particular individual such as an elderly person or a woman carrying an infant. These delays were much more frequent when stairs were used rather than jetways; thus, the potential difference in the efficiency of the two devices is underestimated rather than overestimated by the data.

Data collected in the baggage-claim area at National Airport proved to be, again, somewhat awkward when using simple manual techniques. Recording the arrival of baggage onto the claim device and coordinating this with aircraft arrival is straightforward. Observing the collection of individual pieces of baggage as they are claimed is less easy, however, in part because several of the claim devices are shared by more than one airline, each of which may have one or more scheduled flights arriving in a short time interval. Thus, baggage from more than one flight often was observed on a single claim device at one time, making proper determination of the claiming activity extremely awkward.

Average claim times for those airline serving Washington National Airport are as follows:

Airline	Baggage Claim Time (min)
A	8.93
B	9.75
C	9.53

These values represent the time after the aircraft door opened when the average (50th percentile) bag was claimed, assuming that the passenger claimed it as soon as

possible; bags left in the claim area 30 minutes after flight arrival were not included in the average.

Deboarding data for Dulles used the results of the BNCA study referred to earlier. The average deboarding time found in this study was 1.90 minutes, and this value was employed subsequently in the analysis.

Data in the baggage-claim areas were again collected for a variety of flights and carriers. The average time interval between the arrival of the mobile lounge at the terminal and collection of the average (50th percentile) piece of baggage was 5.12 minutes. It must be noted, however, that all data collection took place during moderately busy rather than during peak times when the existing baggage delivery process becomes seriously overloaded.

Eastern Airlines Shuttle Service

The Eastern Airlines shuttle service between Washington and New York differs markedly from conventional service. Departing passengers using the shuttle may bypass the main terminal area completely and proceed directly to the boarding area where they pick up a boarding pass from an automated ticket machine. Tickets are purchased on board the plane after it is airborne. Passengers may also purchase shuttle tickets at the special shuttle desk on the lower concourse. The numbers of passengers choosing this option, however, was small during the course of the field study.

Assuming that a passenger simply walks to the boarding area and picks up a boarding pass, the only values required as input to the average transfer time are the walking distance and the time before scheduled departure that the passenger arrives in the boarding area. This latter value, however, is somewhat difficult to determine for all but the early morning flights because the guaranteed-seat service with hourly departures and almost inevitable second sections during busy periods results in a relatively continuous stream of arrivals over the greater part of the day. On the basis of limited observations at Washington National Airport, a value of 22 minutes was estimated as the mean "before departure" arrival time.

For the minimum essential processing time estimates, a nominal value of 30 seconds may be allocated to allow for acquiring the simple boarding pass. Likewise, a value of 10 seconds was assigned for baggage handling at the boarding gate—no checking is required, bags are merely deposited on a device near the boarding gate.

Shuttle passengers arriving at National follow a pattern much similar to that used by passengers on regular system flights. The only significant difference is the use of a separate baggage-claim area and a slightly different average walking distance. Limited data on baggage claiming yielded a value of 11.06 minutes as an average for the 30 percent of passengers estimated to carry baggage on shuttle flights.

Impedance Calculations

The framework for the impedance calculations for a typical airline at National Airport is shown schematically in Figure 6 illustrating the calculation of average terminal time for departures. Other paths would be drawn for other airlines that would reflect the different arrangements of ticketing and baggage-checking options used by each. Schematic drawings likewise could be used to summarize the minimum essential processing time for departure and the average terminal time for arrivals.

Very few passengers purchased tickets or checked baggage at the gate, although the option was available from all of the airlines. The "penalties" associated with each of these activities thus were determined from a very small number of observations. A value of 1.25 minutes was estimated for the ticket purchase penalty, 0.10 minute for baggage checking, and 1.30 minutes for both. Although only crudely estimated, the accuracy of these measures is considered adequate because of the small number of passengers involved and the relatively short times.

The individual processing elements used in the calculations have been discussed earlier. To arrive at a weighted average, however, the "path split" or the percentage of passengers utilizing each of the separate process sequences must be estimated.

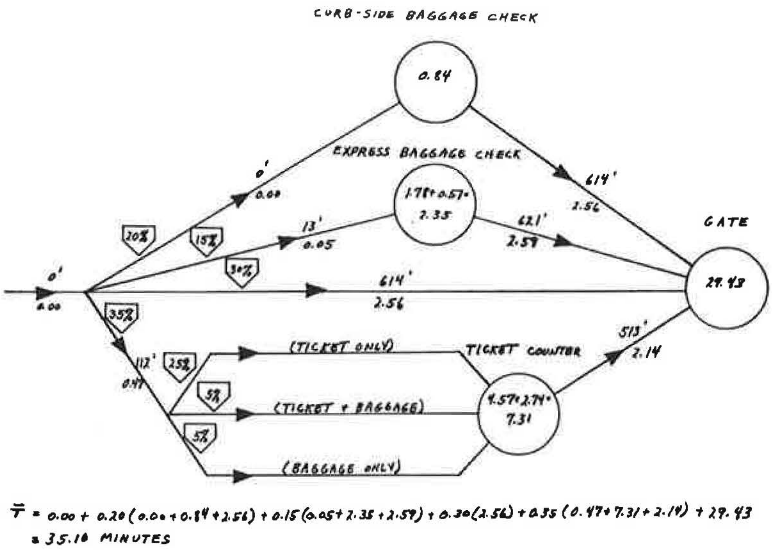

Figure 6. Calculation of average terminal time departures.

Because of data collection limitations, it was not possible to determine exactly what every passenger was doing as he passed through the terminal. Reliable percentage figures thus could not be determined from field observations alone. An approximate method was therefore used to estimate these splits based on airline passenger flow data. The dangers inherent in this approach are acknowledged, and it is proposed that the validation of these percentages by more rigorous data collection techniques should be a major goal for future research. The final estimated terminal impedance values for Washington National Airport are given in Table 5.

The equivalent calculations of impedances for Dulles International Airport also are given in Table 5. The path splits, or percentages of passengers using each option, are the same as those developed for National Airport. (This assumption is admittedly somewhat tenuous.) No data were collected on carriers using the apron loading facilities at Dulles. It is thought, however, that reliable impedances could be estimated for these carriers by combining the appropriate process times and the walking distances from the terminal plans.

TABLE 5

SUMMARY OF IMPEDANCE VALUES

Process	Average Terminal Time (min)	Min. Essential Processing Time (min)
National Airport:		
Line-haul departures	25.55-35.10	3.15
Line-haul arrivals	7.12	7.12
Shuttle departures	24.59	2.95
Shuttle arrivals	5.39	5.39
Dulles Airport:		
Line-haul departures	24.54	4.17
Line-haul arrivals	1.01	4.17

Summary of Results at Union Station and Greyhound Bus Terminal

Figure 7(a) shows the service time distribution for coach ticketing for all trains at the main ticket counter. This distribution follows a quite typical pattern: A few extremely short times (0 to 10 seconds) appear; the majority lie in the 10- to 80-second range; and a few remaining times are scattered over the 80- to 300-second range. These service times include a number of information requests, which predictably fall primarily in the 0- to 20-second range.

Figure 7(b) shows service times at the Metroliner ticket counter in the main terminal. This distribution is quite widely

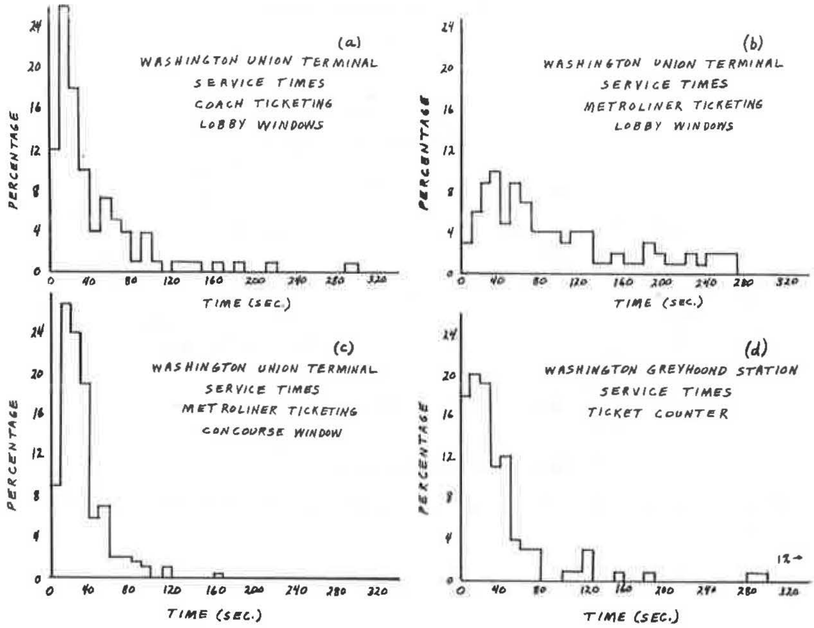

Figure 7. Typical train and bus service time distributions.

spread with a number of service times somewhat in excess of 3 minutes. This result should be interpreted with considerable caution. The ticketing system in use at the time of the study was an interim one, designed to operate only until the planned computerized ticketing and reservation system is installed. Once such a system is in operation, the average processing time should drop radically. It should also be noted that although certain windows are marked expressly for Metroliner service, tickets on other trains may be purchased there. Several complicated bookings for non-Metroliner trains were recorded at these windows, increasing considerably the dispersion of the data and resulting in an effective overestimate of the true Metroliner service time.

Finally, the service times at the special concourse Metroliner window are plotted in Figure 7(c). These times follow a pattern similar to that for the regular coach sales, but with a shorter range. This is readily explained by the fact that any ticket sales at this point represent a definitely available seat, and thus no complex telephoning ahead is required.

The service time distribution at the Greyhound ticket windows in shown in Figure 7(d). The plot shows, as might be expected, a decline in service time frequencies up to 80 seconds followed by a long "tail," representing the occasional lengthy, complex, ticket purchase. Slightly more than 50 percent of the services recorded in Figure 7(d) were for ticket purchase. The majority of the remainder were requests for some type of information, and transactions such as making change also were observed. Most of these nonticketing services were relatively brief, less than 30 seconds duration in most cases.

The results of applying the simple M/M/C: (∞/FIFO) queueing model to rail and bus ticketing are given in Table 6.

TABLE 6

BUS AND TRAIN TERMINAL TIMES

Location	Waiting Time	Service Time	Total Time
Coach tickets, all trains	4.43	0.83	5.25
Metroliner, terminal	1.19	1.84	3.03
Metroliner, concourse	1.71	0.50	2.21
Greyhound station	2.13	0.70	2.83

Note: All times in minutes.

Departing Metroliner passengers tended to arrive at the boarding gate a considerable time before the scheduled departure of the train. A typical arrival pattern for a Metroliner departure is shown in Figure 8(a). The average arrival time for all Metroliner departures studied was 18.61 minutes before departure. This figure was consistent for all trains.

Departing passengers for regular train service, however, showed a markedly different pattern, which is also shown in Figure 8(a). Passengers tended to arrive later for these trains, with an average time of 13.37 minutes, over 5 minutes less than for the Metroliner. This result is somewhat surprising and may be explained by the relative novelty of the Metroliner service. The value will probably decrease as passengers become more familiar with the operation of the service.

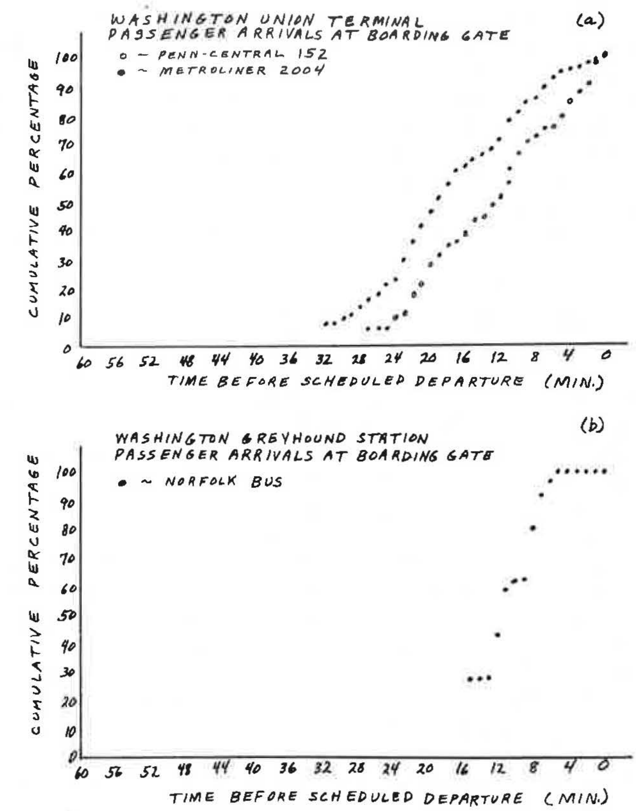

Figure 8. Bus and train passenger arrival patterns.

Departing bus passengers also arrive at the departure gate some time before the bus is scheduled to depart. Their arrival pattern prior to a typical bus departure is shown in Figure 8(b). The first entry on this graph represents the beginning of the data collection period; the earliest arrivals are often found waiting 30 to 40 minutes before the scheduled departure time. The average observed arrival time prior to all departures was 13.50 minutes; variations from the average were related to the size of the busload and the time at which the boarding announcement was made over the public address system.

Arriving train passengers reach the end of the platform at an average time of 3.17 minutes after the train has stopped for the Metroliner and 4.11 minutes for regular trains. Passengers deboarding below the main concourse, of course, must ascend to the concourse level before leaving the terminal. The additional delay thus incurred has been estimated by increasing the necessary walking distance to the concourse gates. No attempt has been made to weight the average walking distance based on tract utilization; a simple arithmetic average has been used. The error involved here is believed to be slight.

No significant difference was observed between the arrival rates of passengers with and without baggage. This indicates that passengers with baggage do not take longer to reach the gate than passengers not so encumbered.

Separate deboarding distributions were recorded for bus passengers with carry-on baggage and those with no baggage. It was found that passengers with baggage required a somewhat longer time to deboard. The median deboarding time after bus arrival for a passenger with baggage was 2.11 minutes, compared to only 1.56 minutes for a passenger without baggage. Whether this difference in fact represents a delay inherent in having to manipulate baggage or simply reflects an element of courtesy in allowing unhindered passengers to leave first is debatable.

The results of the study suggest that approximately 35 percent of deboarding bus passengers carry their own baggage. Slightly less than half of the remaining passengers were observed reclaiming checked baggage at the bus side. The following breakdown was used in the impedance calculations: baggage checked at bus side, 30 percent; baggage carried onto bus, 35 percent; no baggage, 30 percent. These percentages predictably varied from one bus to another, though in no way that could be related systematically to differences in trip length.

Finally, the time required to recover baggage checked at the bus side was recorded. The average time was found to be 4.80 minutes. Again, a substantial variation was observed. The major reason for this appeared to be the delay in opening the baggage compartment of the bus. Because this was done for all buses, by a single terminal employee, the time that any particular bus was serviced was obviously a function of the number of other buses in the terminal.

The final set of estimated impedances for Union Station were calculated in a manner analogous to that shown in Figure 6. The percentages of passengers following the various paths for the Metroliner services were based on the observation that approximately 12 percent of all Metroliner passengers acquired tickets at the concourse window prior to train departure and that about 3 percent picked up boarding passes there. About 12 percent of the passengers acquired their tickets at the lobby window, and an assumed (though unverified) 3 percent figure for boarding-pass pick-up seems reasonable.

For regular trains, it was estimated that 50 percent of the passengers acquire their tickets immediately prior to departure. This figure seems reasonable, since many passengers purchase round-trip tickets and thus need to use a ticket counter only on one leg of their trip. Those passengers purchasing one-way tickets would be offset by those having weekly or monthly passes.

Final bus terminal impedances were generated in a similar fashion. The percentages of passengers following the various paths were determined jointly from the field observations outlined before and from simple visual estimates. Probably the most questionable assumption is the 50 percent split between ticketed and nonticketed passengers. This split was estimated by a logic similar to that given for rail passengers. These values for the Greyhound Bus Terminal given in Table 7 include within-terminal times only. They do not include any time spent in access/egress activities.

EXTENSIONS AND APPLICATIONS

The impedance analysis could be extended in at least three important areas. First, in-depth investigation of passengers reaction to perceived versus actual terminal times could be performed. These investigations would show whether the various impedance components are simply linearly additive or if some elements should be weighted to reflect significant perceived impedances.

Second, the simple queueing model used in this study could be examined and possibly refined. At the same time, other analytical refinements could be investigated such as the development of explicit functions to account for increased delays caused by congestion within the movement areas of the terminal.

Finally, the impedance analysis could be extended into the access/egress areas of the terminal complex. Peat, Marwick, Mitchell and Co. is currently pursuing this topic in its attempt to estimate the delays associated with parking lot operations at major airports. Delays involving other access/egress modes can be estimated in a fairly straightforward manner.

TABLE 7

TERMINAL TIMES

Process	Average Terminal Time (min)	Minimum Essential Processing Time (min)	
		With Ticket	Without Ticket[a]
Union Station:			
System departures	18.31	3.17	9.43
System arrivals	5.83	—	—
Metroliner departures	20.90	2.81	5.07
Metroliner arrivals	4.52	—	—
Greyhound Bus Terminal:			
Intercity departures	15.37	0.64	3.62
Intercity arrivals	3.25	—	—

[a]Rail passengers without tickets are assumed to purchase them in the terminal. If tickets are purchased on the train, the impedance becomes the value given for passengers with tickets.

In addition to its use in estimating impedances associated with the nodes in a transportation network analysis, the methodology discussed in this paper may be applied to the evaluation of alternative functional arrangements within the terminal system. Such alternatives as the provision of purpose-specific ticketing and baggage-checking facilities may be evaluated by the simple queueing models. Other more substantial changes in passenger-processing philosophy, such as the widespread use of computer-printed tickets acquired at remote locations, could be analyzed within this framework; however, individual process time estimates would have to be developed for any novel elements. The evaluation of alternative arrangements thus would become a simple "pen and paper" simulation. This approach is more appropriate for many applications than the development of large-scale, general-purpose computer simulation models.

SUMMARY

A simple methodology for estimating the impedances associated with passenger terminals has been developed and applied to terminals in the Washington metropolitan area. The techniques may be extended readily to other terminals. This would require a minimum amount of input data on the other facilities in order to provide reasonable estimates of impedance levels at these facilities. The impedances may be used in large network simulation models, and the methodology itself may be extended to the evaluation of alternative functional arrangements within the terminal complex.

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REFERENCES

1. Lee, A. M. Applied Queueing Theory. The MacMillan Company, New York, 1966.
2. Saaty, T. L. Elements of Queueing Theory, with Applications. McGraw-Hill Book Company, New York, 1961.
3. Traffic Engineering Handbook. Institute of Traffic Engineers, 1965.
4. MacDorman, L. C. An Investigation of Pedestrian Travel Speeds in the Business District of Washington, D. C. Catholic University, Washington, D. C., May 1967.
5. Molina, E. C. Application of the Theory of Probability to Telephone Trunking Problems. Bell System Tech. Jour., July 1927.
6. Paullin, R. L. Passenger Flow at the Departure Lounges. Institute of Transportation and Traffic Engineering, University of California, July 29, 1968.