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CONTENTS

FOREWORD

The papers in this RECORD describe various aspects of passenger terminals. Passenger terminals are transportation interchanges whose scope includes anything from a transit platform to a multimodal regional transportation center. Despite the broad spectrum of facility types, passenger terminals have common design elements, which these papers address.

Vuchic and Kikuchi describe design principles and standards for different access modes of outlying rapid transit station areas. Examples of design elements for each mode are presented. The authors emphasize that station design should be such that the maximum concentration of automobile traffic is on the periphery of the station because close-in areas have pedestrian concentrations.

The bus or trolley stop is a form of miniterminal. The time required for passengers to board and alight from transit vehicles can account for a significant portion of their trip time and can be the largest portion of the total trip delay time. Kraft and Bergen report on studies they performed on boarding and alighting time requirements for various bus and trolley services. They present predictive equations that were developed to estimate passenger service time requirements under various conditions when the number of boarding and alighting passengers is known.

Gatens reviews rapid transit park-and-ride lots and their location. An analysis is presented to determine the characteristics of trip lengths, times, purpose, origin, and mode to bus. Some preliminary general planning guidelines relevant to the location and sizing of park-and-ride facilities are offered.

In recognition of the need for new tools to evaluate pedestrian movements and flows in terminal facilities, the Urban Mass Transportation Administration required that the development of such tools be an integral part of the new systems requirement analysis program. Fausch, Dillard, and Hoffmeister describe a procedure to evaluate transit station designs to determine whether a given layout achieves design objectives. Their model simulates the flow of pedestrians along the links that represent the station, and it accumulates appropriate data.

The Committee on Intermodal Transfer Facilities has developed a general outline and classification of the elements constituting the typical intermodal passenger transfer system. Included is a description of what the committee perceives as research needs. The statement will be revised periodically as research needs are filled and new problems emerge.

DESIGN OF OUTLYING RAPID TRANSIT STATION AREAS

Vukan R. Vuchic and Shinya Kikuchi, Department of Civil and Urban Engineering, University of Pennsylvania

Design of modern rapid transit stations in outlying areas is a complex process that has had only limited documentation. The paper attempts to help the designer in organizational and technical aspects of his or her work. Steps in the design procedure are outlined, and data needed for design are listed. The designer's work starts with an analysis of the requirements of the 3 interested parties: passengers, transit system operator, and community. Design principles and standards emphasize priority sequence for different access modes: pedestrians, feeder bus, kiss-and-ride, and park-and-ride. Maximum separation of modes is desirable: Bus stops should be close to the station entrance, preferably in a separate transit area; kiss-and-ride should be next in distance from the station; park-and-ride should be in the farthest areas. Design should be such that the maximum concentration of automobile traffic is on the periphery of the station, for close-in areas have pedestrian concentrations. Safe and convenient pedestrian movement must be provided for throughout the station area. Examples of design elements for each mode are presented. Finally, the paper contains several examples of total designs of different types of stations.

• RAPID transit lines serving low density suburban areas must rely on several access modes: walking, bicycle, bus, kiss-and-ride, and park-and-ride. Automobile access, the latter 2 modes, requires a larger land area and has a higher cost than do the other modes. And, if the design for automobile access is inadequate, it can result in major traffic problems, cause delays to passengers, discourage potential system users, and impose negative impact on the surroundings. Development of proper design for stations of extensive automobile access is therefore very important.

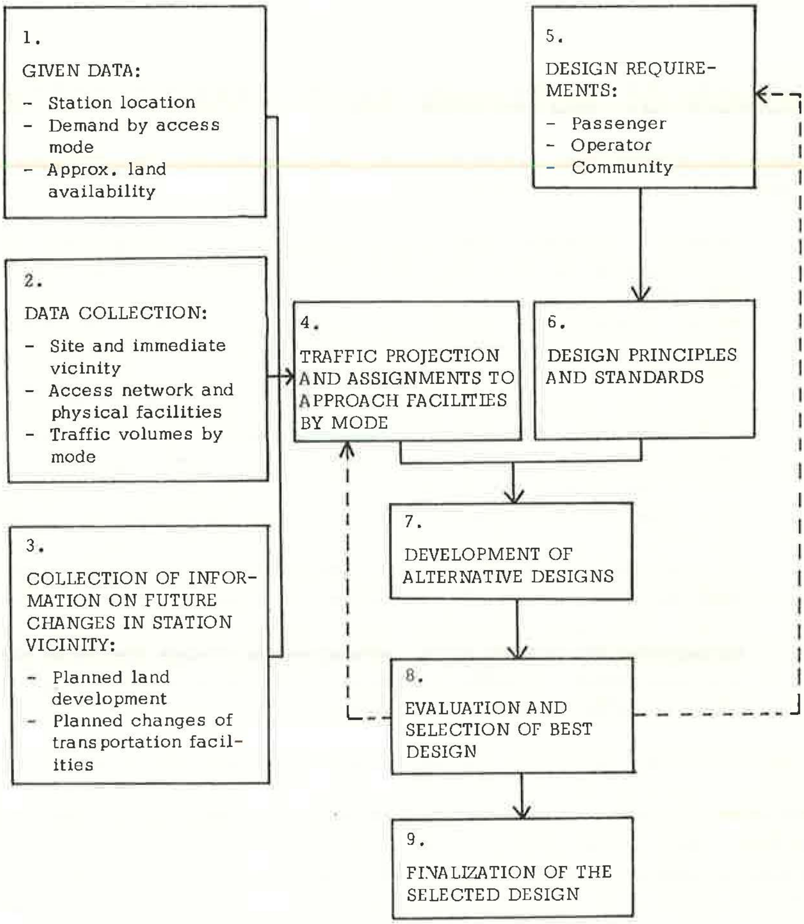
The organization of transit station design consists of the major steps shown in Figure 1. Transit line planners decide on right-of-way alignment and location of stations and determine projected volumes of passengers by access mode. Although planners have to take into account local conditions, highway network land use, and the like, they do not make detailed analyses of the immediate station surroundings. The designer must therefore supplement the basic data with data on existing and planned facilities relevant to station area design from other sources. Then, the designer develops composite projections of traffic on adjacent streets and highways for each mode. The designer must also have a systematic and detailed list of requirements as well as principles and standards for station area design.

After combining the data, principles, and standards, the designer makes several alternative station area designs and then evaluates them based on the degree to which they satisfy the design requirements and principles as well as how they can handle projected volumes. After the evaluation the selected design is finalized.

PURPOSE AND SCOPE

This study has 3 primary purposes: first, to define a methodology of design of outlying rapid transit station areas in a form that can be used in actual planning and design; second, to collect and systematically present basic principles and standards of design; and, third, to present designs of the individual components of stations.

Figure 1. Station design procedure.



DATA COLLECTION

Site and Immediate Vicinity

The designer should have at least some influence on the station area land acquisition and its future shape. Therefore, information on land costs for each lot that may be considered for acquisition must be collected. Data on topography and general condition of the area (such as other rights-of-way, land uses, and trends of expansion) must be obtained also. The designer must also know the total investment available for land and construction.

Access Network and Physical Facilities

All available data on adjacent or influencing transportation networks, land use in the area, and individual facilities should be collected, particularly on

1. Highway and street networks in the vicinity (their basic dimensions, capacities, and traffic regulation on individual streets);
2. Feeder transit services with routings, schedules, and types of vehicles;
3. Pedestrian facilities and volumes; and
4. Facilities for other access modes that may be used by bicycles, organized car pools, minibuses, and the like.

Traffic Volumes

For each access mode, average daily traffic and peak-hour traffic (30-, 15-, or 5-min peak volumes are best, if possible) must be estimated from present volumes, traffic growth in the area, and the projected traffic to be generated by the station. These composite volumes, assigned to individual facilities, must be analyzed for any hours that may be critical. Design hour volumes should then be determined. These are usually based on the highest 30-min volume in a week.

DESIGN REQUIREMENTS AND CONSIDERATIONS

Well-designed stations with coordinated services have been accepted favorably by passengers. Thus, passenger requirements should be given major attention in design. The 2 other concerned parties—operator and community—also have requirements that the designer must carefully provide for.

Passenger Requirements

Passengers approaching the station building have the following basic requirements for station design:

1. Minimum transfer time and distance—short walks between modes and good schedule coordination;
2. Convenience—good information service, adequate circulation patterns and capacity, easy boarding and alighting, and provisions for handicapped people;
3. Comfort—aesthetically pleasing design, weather protection, and small vertical climb; and
4. Safety and security—maximum protection from traffic accidents, safe surfaces, and good visibility and illumination to deter vandalism and prevent crime.

Operator Requirements

Operator's requirements that design must satisfy are

1. Minimum investment cost;
2. Minimum operating cost;
3. Adequate capacity;
4. Flexibility of operation; and
5. Passenger attraction.

Community Requirements

The community is interested in having an attractive and efficient transit system, so the station should be both attractive to passengers and efficient for the operator. This requirement coincides with the requirements listed for the operator and passengers. But the community also is interested in both the immediate and long-range effect of the station on its surroundings. The immediate effects include environmental impact, visual aspects, noise, and possible traffic congestion. Long-range effects include the type of developments in the vicinity that may be stimulated or discouraged by the design of the station. Design must therefore consider the relationship of the station to its immediate surroundings.

DESIGN PRINCIPLES AND STANDARDS

Every rapid transit station must be custom designed. Consequently, prototype designs cannot be produced. However, it is possible to define the basic principles and standards that are valid for overall design and for individual components.

General Principles

The most important principles that are valid for a general approach to design are as follows:

1. Give priority to individual station access modes in this sequence—pedestrians, bicycles, surface transit (feeder buses), taxis, kiss-and-ride modes, park-and-ride modes to pay areas, and park-and-ride modes to free areas.
2. Provide maximum possible separation of modes at all points. (Separation of pedestrians from motor vehicles is the most important one.)
3. Minimize distance between access modes and the station platform.
4. Provide easy orientation and smooth and safe circulation to and within the station area for all modes.
5. Provide adequate capacity for each access mode based on its design volume. Capacity should be uniform but, if there are space constraints, it should be provided to individual modes in the order of their priorities. If capacity for park-and-ride modes is insufficient, greater emphasis should be placed on other modes to divert passengers and reduce demand for parking.

Size of the station site depends mostly on the required capacity for kiss-and-ride and park-and-ride facilities. Parking area requirements depend on the necessary capacity and the design vehicle. A kiss-and-ride area, which requires easier circulation than a park-and-ride area, takes more space per stall, but its operation is less sensitive to capacity constraints.

The shape of the site is often influenced by the street network and land availability. Because the platform and station structure are typically 400 to 700 ft (120 to 210 m) long and 50 to 60 ft (15 to 18 m) wide, parking, circulation, and terminal facilities can be grouped around a long, narrow station island. If other factors are constant, site shape should be such that the weighted average walking distance of all passengers is minimal. This distance depends on the number and location of entrances to the station building, so it is desirable to have many strategically placed entrances.

Allocation of areas to different modes should be based on the priority sequence from principle 1.

Traffic Routing and Access Points

Traffic routing to and from the station must be analyzed for each mode. The basic objectives are

1. To provide direct access for each mode to its terminal area;
2. To minimize conflicts of station-destined traffic with other highway traffic;
3. To provide smooth, continuous flow and minimize traffic conflicts within the station area; and
4. To provide at least 2 choices for access so that drivers can recover from errors or avoid congestion.

The number of access points is determined separately for each mode based on design volume, fluctuations, and geometric and operational constraints of the network and the site. Ideally, buses should have 1 or 2 access points leading to the station terminal area; kiss-and-ride should have its own access points leading to the terminal area; sometimes buses and kiss-and-ride can share access points without major problems.

For park-and-ride, each peak volume must be analyzed separately. The morning peak is typically less pronounced than the afternoon peak; its importance may not be, though, for 2 reasons. First, people are in a greater hurry and more impatient in the morning than in the afternoon. Second, traffic backups that occur take place on adjacent streets in the morning, but are contained within the site in the afternoon. A minimum of 2 access points (4 lanes) is desirable for adequate traffic flow and reliability in emergencies. For larger lots when the capacity requirement governs, 1 pair of lanes per 300 spaces is adequate for stations with high peaks, but this ratio may be as high as 1 pair of lanes per 450 spaces if peaks are less pronounced.

Three major factors should be considered for location of access points. First, access points should not be located directly on major arterials. Access by way of minor streets allows some dispersal of traffic and better control at intersections with arterials. Second, access points should be evenly distributed to different sides of the station. Third, access points and major circulation routes should be located at the periphery of the parking area to minimize vehicle-pedestrian conflicts. Access points for kiss-and-ride and buses should, on the contrary, be closer to the station building.

Access points are usually designed as a T or a 4-legged intersection. Reversible lanes often can be employed because of directional peak flows. Special attention should be given to providing adequate space for both entering traffic in the morning peak period and exiting traffic during the afternoon peak period. Directional design for entrances and exite often reduces weaving on adjacent streets.

Pedestrians, Bicycles, and Provisions for the Handicapped

Walking should be favored over all other access modes. This is achieved by providing a continuous network of pedestrian walkways throughout the station area. The network must connect all adjacent streets, residential areas, stores, and other locations that generate pedestrian trips, as well as the park-and-ride and kiss-and-ride areas. The walkways must be separated from automobile and other mechanized traffic as much as possible. Pedestrian crossings should be carefully designed, well marked, and, if necessary, controlled by signs or signals.

Pedestrian paths should be as direct as possible from origin to destination. The coefficient of directness—the ratio between the actual length of the path and the aerial distance from origin to destination for each passenger—should never exceed 1.4, and, desirably, should be below 1.2. The walkways should have at least 2 lanes, with each lane being a minimum of 27 in. (68 cm) and preferably 30 in. (75 cm) wide. Pedestrian crossings of streets are usually 9 to 12 ft (2.7 to 3.6 m) wide, although very low or very high pedestrian volumes may justify narrower or wider crossings. Crossings that are more than 50 ft (15 m) long (across 4 or more lanes) should have a refuge area on the median for safety.

The main circulation road in the parking area, as shown in Figure 2, should be far from the station building to feed the lot from the outside as pedestrians gravitate toward the station building. This minimizes conflicts between pedestrians and automobiles. At some station entrances, particularly if the station serves a stadium or airport, the concentration of pedestrians can reach volumes that would justify a grade separation (overpass or underpass).

Use of bicycles for access should be encouraged. All stations should have bicycle racks with locks. If the use of bicycles is substantial, special paths, signalized crossings, and markings should be provided. Two-way bicycle paths should be at least 6 ft (1.80 m) wide.

Design must also provide for safe and convenient access for the handicapped. Lowered curbs, mild gradients, and adequate doors would allow access of wheelchairs into the stations, where special facilities such as those in the Bay Area Rapid Transit (BART) system should be provided.

Feeder Transit

Because feeder transit vehicles bring large numbers of people and require little space, their use should be strongly encouraged. Therefore, design should provide for their easy movement with efficient terminal operations and convenient passenger transfer.

Approach Routing—Feeder transit lines in the vicinity should have few turns and little interference with other flows.

Feeder-Line Stops—These should be as close to the station entrance as possible. A separate stop location for each route (except those with low frequencies) should be provided; they can often share common locations to reduce space requirements. Separating the arrival from the departure area at heavily used stations can provide increased capacity and more precise schedule maintenance. The number of stops depends on the number of feeder transit routes, the frequency of service on each route, boarding and alighting times, and the required reserved spaces for bus storage.

Figure 2. Separation of vehicular and pedestrian flows.

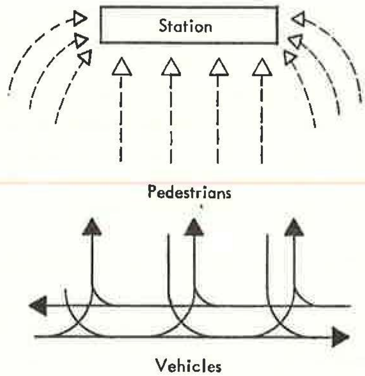
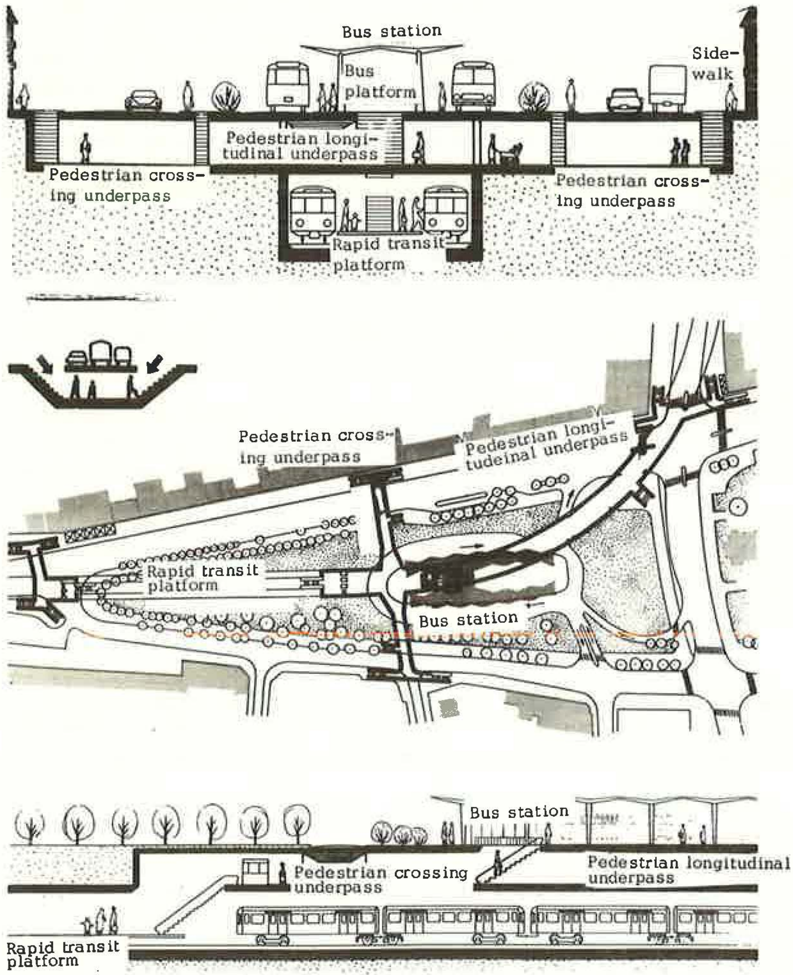


Figure 3. Oval bus island, Hamburg.



Routing in the Station Area—When the station is alongside an arterial and feeder routes pass the station rather than terminate at it, their stopping zone can be either on a wide median or on 1 side of the street, with the 2 directions crisscrossing. This allows pickup and discharge of all passengers from the same area that leads to the escalators toward station platforms. When feeder routes terminate at the station, a loop arrangement is necessary. The entering vehicles cross the path of the existing ones and circle around the island in a clockwise direction. At stations where more than 1 route arrives, this design permits arrivals from more than 1 direction to travel in the same direction as departures in a continuous 1-way flow. The loop roadway can be rectangular or oval, as shown in Figure 3 (3), with at least 2 lanes to allow passing. (An additional lane is often needed for storage of buses.) This design allows alighting on 1 side; buses could then be driven to boarding or to storage areas. The benefits of this are that there is a 1-way flow of passengers on the island and a better use of curb loading capacity. When there are many buses, more than 1 island may be necessary. Bus boarding and alighting areas are doubled, but pedestrians must cross the middle roadway, or special stairways (escalators) must be provided for them from each island. When straight or slightly curved curbs are used, the geometric problem of bus arrival exactly to the curb always exists and much space between standing buses cannot be used. A design, shown in Figure 4, that permits better use of space is the sawtooth pattern. This design also gives the passengers standing in the vicinity a good view of all stop locations.

Kiss-and-Ride and Taxis

Kiss-and-ride has 2 distinctly different functions. In the morning, passengers are dropped off. Because this procedure is very short, all that is needed is sufficiently long curb space close to the station entrance. The pickup function in the afternoon hours is different, though, because the driver usually arrives before the passenger. The average waiting is longer in short headway lines than in long headway lines because approximate times are agreed on for meeting. Kiss-and-ride pickup therefore requires not only a curb zone but also a special short-term parking area that should be easy to drive into and out of because of the high turnover of cars. Ideally, the kiss-and-ride area should be designed as angled parking with through stalls. Some elements of kiss-and-ride area design are shown in Figure 5 (11).

Based on these drop-off and pickup characteristics, the following principles should be observed:

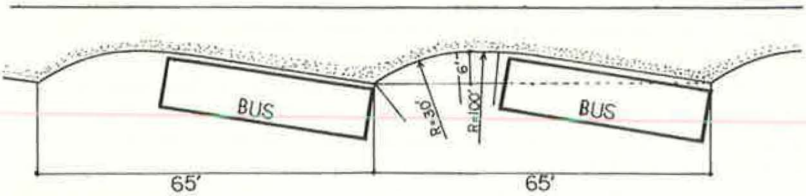
1. There should be 1 kiss-and-ride area easily accessible for automobiles from all directions and by walking from the station building.
2. A drop-off and pickup zone, preferably with loading on the right side, should be sheltered.
3. The kiss-and-ride area should be laid out for 1-way traffic and permit convenient return to the direction of arrival.
4. The kiss-and-ride waiting area should be located close to the pickup zone, have good visibility of the station exit, and permit recirculation.
6. Kiss-and-ride parking stalls should be a minimum of 9 by 18 ft (2.75 by 5.50 m).

Park-and-Ride

Capacity for a park-and-ride facility is difficult to plan with precision. Because of the cost involved in land acquisition and construction of a park-and-ride facility, overdesign should be avoided. Inadequate capacity, though, has often proved to be a bottleneck in the use of transit lines, thus limiting their effectiveness.

Aisles should be perpendicular to the station to facilitate pedestrian walking. If this is not possible, pedestrian walkways can be created across the aisles by well-marked 5-ft (1.5-m) wide paths. Right-angled parking should be used in all park-and-ride areas because it allows simpler circulation and more orderly parking and has lower area requirement per space.

Figure 4. Sawtooth bus loading area.



Note: 1 ft = 0.3048 m.

Figure 5. Kiss-and-ride and short-term parking.

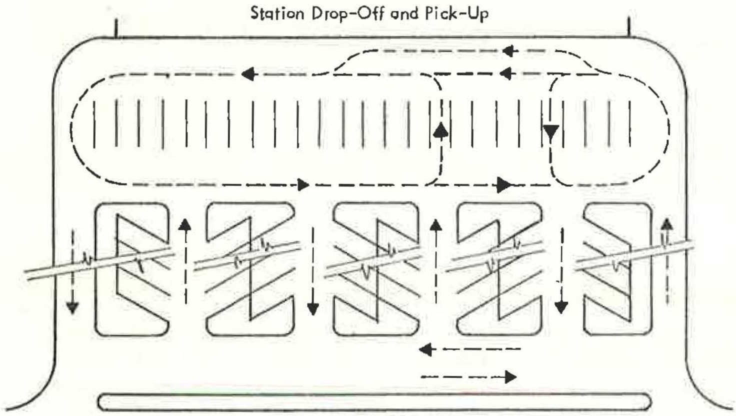


Table 1. Recommended parking dimensions.

Access Mode	Stall Width (ft) Generous	Stall Width (ft) Acceptable	Aisle Width (ft) Generous	Aisle Width (ft) Acceptable
Kiss-and-ride		10		66
Park-and-ride				
Standard car	8.67	8.33	64	62
Compact car[a]	7.5	8	52	48

Note: 1 ft = 0.3048 m.

[a]Cars not more than 16.5 ft (5.14 m) long.

Dimensions of parking aisles and stalls can be smaller than those for shopping centers and other areas because cars arrive in sequence and have low turnover. Table 1 gives the dimensions considered advisable for park-and-ride areas at rapid transit stations.

The average area needed per parking space varies with the shape and size of the facility. To provide adequate circulation 320 to 350 ft^2 (29.8 to 32.5 m^2) per space for standard cars and 200 to 220 ft^2 (18.6 to 20.4 m^2) for compact cars would be required. If there were awkward site geometry or extensive landscaping, a 30 to 50 percent greater area might be required. When 7 stations of the Lindenwold Line in Philadelphia were redesigned to accommodate compact rather than standard cars, parking capacities increased 40 to 60 percent. And, when parking demand is high, as is typical for outer terminal stations, construction of parking garages should be considered.

EXAMPLES OF STATION DESIGNS

The first 2 examples of well-designed stations (Hamburg and Munich) provide for pedestrian and surface transit access only; the following 2 (Toronto and Oakland) have pedestrian, bus, kiss-and-ride, and park-and-ride access; the last example represents an ideal design developed in the course of this research.

Wandsbek Station, Hamburg

Wandsbek Station (Fig. 3), which was opened in 1962, is a major transfer point for rapid transit and 15 suburban bus lines. The transfer area is an island directly above the station platform. Pedestrian access from the surrounding streets is through entrances on opposite sides of the streets. All bus passengers are discharged on or picked up from the island. Escalators connect the island with the rapid transit station below it.

Ostbahnhof, Munich

During extension and modernization of the regional rail system in Munich, completed in 1972, 1 major station at the fringe of the central city was rebuilt to improve transfers from light-rail and bus feeders to the regional rail station. The design, shown in Figure 6 (6), has a major island for light rail stops, several islands for bus stops, and loop arrangements for both modes. A pedestrian underpass connects all islands with the station to provide safety and convenience for passengers.

Finch Station, Toronto

This facility, shown in Figure 7 (7), was opened in 1974. It provides for circular flow of kiss-and-ride vehicles with drive-through parking stalls for waiting vehicles so that the driver who does not find his or her passenger can either park or make another circle.

Fruitvale Station, Oakland

Interesting features of this BART station, shown in Figure 8 (11), include the proper allocation of areas: Buses are separated from other traffic and come directly to the south station entrances; kiss-and-ride areas are also adjacent to the station; outer portions of the site are for park-and-ride. Most of the traffic approaches the station on East 12th Street, from east and west. These traffic flows are directed into the site in 2 nonintersecting back-to-back loops. The 2 kiss-and-ride frontages on the north side use the curb along the station frontage, as well as both sides of the pedestrian island. This island permits direct connection for pedestrians from the station to East 12th Street. This traffic flow pattern provides for a minimum number of conflicting movements at the adjacent intersections.

An Ideal Station

An ideal station design is shown in Figure 9. It was assumed that the station coincided with a 700-ft (214-m) long city block and that the site consisted of an area

Figure 6. Ostbahnhof, Munich.

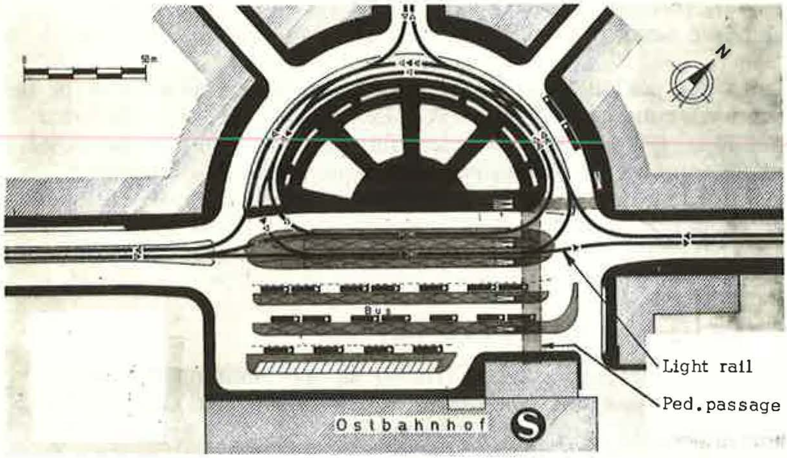


Figure 7. Kiss-and-ride facility at Finch Station, Toronto.

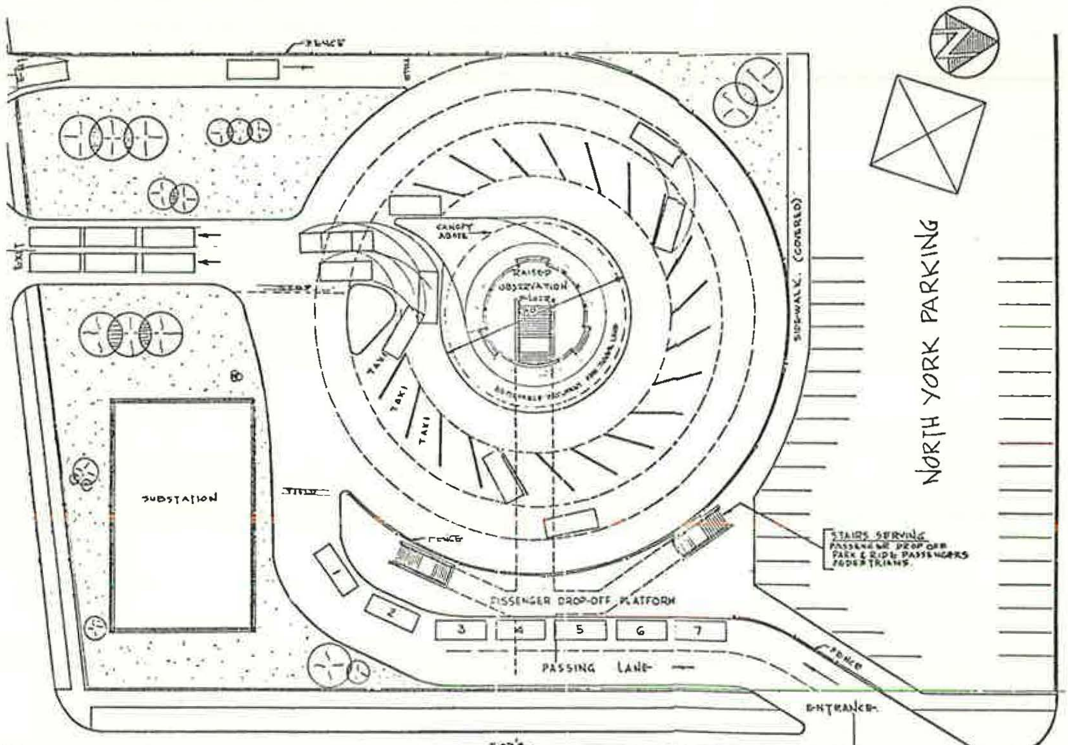


Figure 8. Fruitvale Station, Oakland.

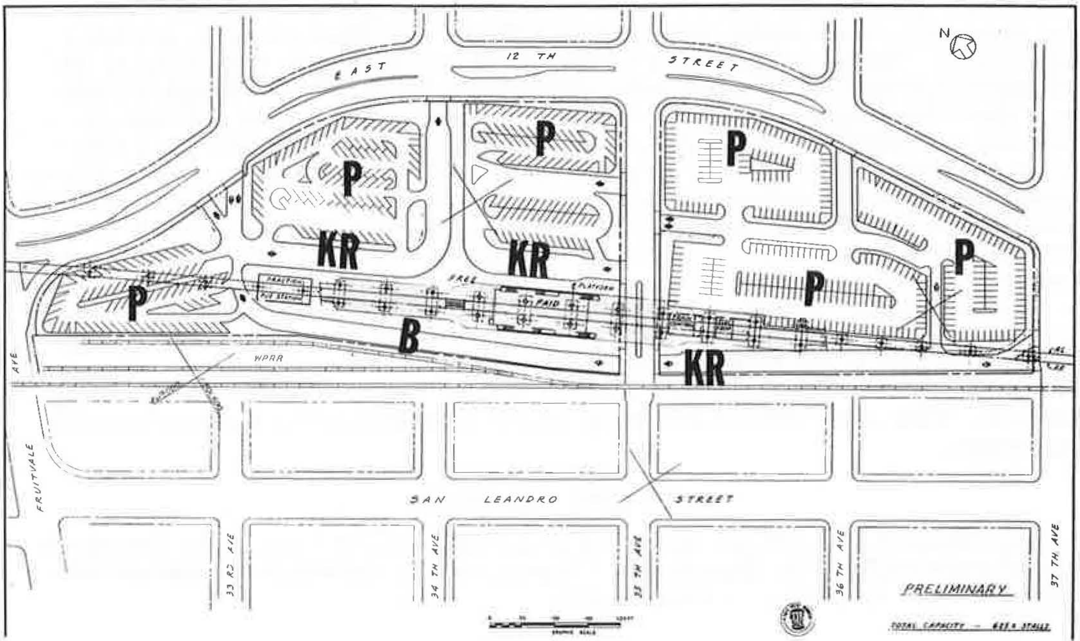
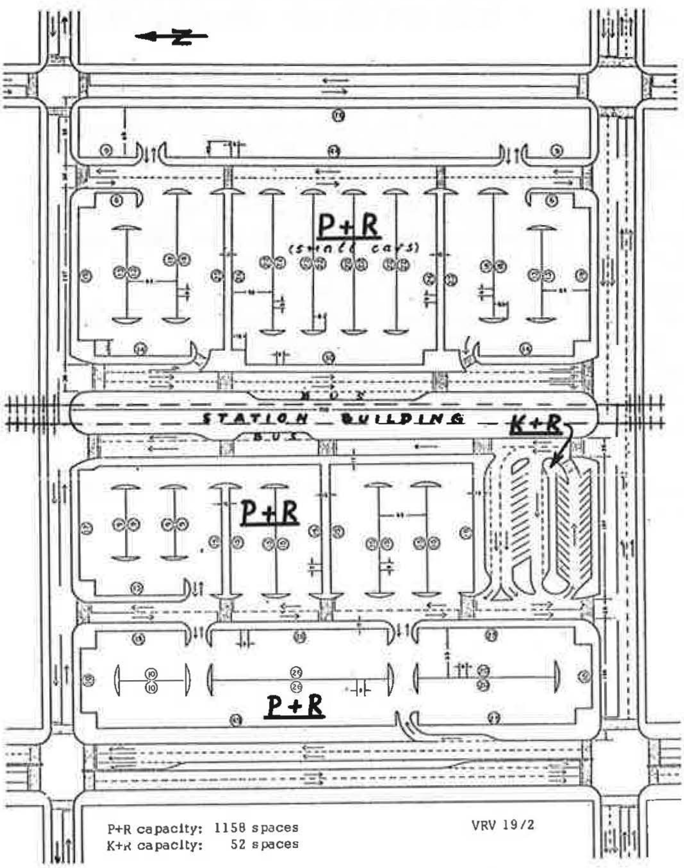


Figure 9. Ideal station.



between the station and a major arterial on its west side with a minor street on its east side. All access points, with the exception of 1 right-turn entrance, are from side streets. Buses have roadways directly along the station with stops close to the entrances; kiss-and-ride vehicles enter together with buses, but then branch off into their specially designed area. The eastern bus roadway is shared on both ends by park-and-ride vehicles. The park-and-ride facility consists of several areas with aisles perpendicular to the station axis for easier pedestrian movement. Several aisle dividers separate the parking area into sections at the inner sides of the parking areas. These dividers prevent cruising of automobiles in search of parking spaces in those areas where pedestrian concentration is high and serve as continuous pedestrian ways through the station area.

This ideal design has very generous parking dimensions, which would apply primarily to areas with low land cost. For locations with higher land cost or high demand for parking, dimensions given in Table 1 are recommended.

Although it is not likely that this design would ever apply in its entirety to a real situation, many of its sections and design details could be used for portions of nearly any station.

ACKNOWLEDGMENTS

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EVALUATION OF PASSENGER SERVICE TIMES FOR STREET TRANSIT SYSTEMS

Walter H. Kraft and Terrence F. Bergen, Edwards and Kelcey, Inc., Newark, New Jersey

The time required for passengers to board and alight from transit vehicles can play a significant role in the determination of realistic transit schedules and berth requirements for intermodal transfer facilities. This paper investigates the effects on passenger service time of various vehicles, different methods of fare collection, combinations of boarding and alighting through the front and rear doors, and time. The method of least squares is used to analyze and develop equations to predict passenger service time when the number of passengers boarding and alighting is known. Peak-period service time requirements were similar for a.m. and p.m. The exact-fare method of fare collection provided for faster passenger service times than did the conventional cash-and-change method. Trolleybuses with double doors had faster service times than did those with single doors. In addition, intercity passenger service times were found to be greater than those for local transit service.

•DESIGN of bus terminals and other intermodal transfer facilities is influenced by passenger loading and unloading times. For example, the amount of platform space, the number of bus berths, and transit vehicle schedules are contingent on the time required to service patrons. These design considerations often govern the acceptability of a particular site, the layout of a proposed terminal, and the cost of such facilities. In the downtown areas of many cities (prime locations for terminals), space for transit facilities is severely limited. Miscalculating the number of loading berths or required platform space can result in using too much valuable land and cause inefficiencies in facility operations. Too often, a transit vehicle arriving after its scheduled time promotes critical and dangerous density levels of patrons on the platform. Overestimating demand causes underuse of platform space. Therefore, to aid in determining requirements for berths, platform space, and scheduling, investigations have been undertaken to determine the effects of type of vehicle, fare collection, boarding and alighting patterns, and time of day on passenger loading and unloading times.

BACKGROUND

During 1968 and 1969, the authors participated in the preparation of NCHRP Report 113 (3). A phase of the project involving the evaluation of transit system operations indicated that the time required to serve bus passengers at a stop could be predicted if adequate knowledge of the number of passengers boarding and alighting was available. The method of least squares was used to predict passenger service time for 3 distinct situations, as follows:

1. When passengers were boarding,
2. When passengers were alighting, and
3. When passengers were simultaneously boarding and alighting.

Equations were developed from data collected in Louisville, Kentucky, for 2 methods of fare collection—the cash-and-change system in which the driver collects the fare and gives change when necessary and the exact-fare system in which the driver does not handle the fare. In the exact-fare system, the passengers deposited the exact fare in a sealed box as they entered the vehicle. The driver gave redeemable script for any overpayment.

Although the Louisville data indicated the predictability of the passenger service time, there still remained questions about the effects of other factors. Therefore, it was decided to obtain additional information to consider the following effects:

1. Type of vehicle (bus, trolleybus, trolley car),
2. Time of day (a.m. peak, midday, p.m. peak),
3. Type of service (local transit, intercity transit),
4. Method of fare collection (no fare, cash and change, exact fare), and
5. Various combinations of boarding and alighting through front and rear doors.

STUDY AREA AND PROCEDURES

Data on bus passenger service time used in the study were collected in San Francisco and Los Angeles, California; Newark, Morristown, New Brunswick, and Clifton, New Jersey; New York City; Chicago, Illinois; Louisville, Kentucky; and Wilmington, North Carolina.

All data were collected in 1973 except in Newark and Louisville, where data were collected between 1968 and 1970. Data on trolley cars and trolleybuses were collected in San Francisco; information on the double-deck bus was obtained in Chicago.

Passenger service times were recorded from the moment the doors opened until the last passenger alighted from or boarded the vehicle. The number of passengers boarding and alighting by each door was recorded during the same time interval. Stragglers boarding the vehicle after the initial queue were not counted in the passenger service time and passenger volume measurements. Likewise, stalling time was not included in the recorded service times.

ANALYSIS

Categories of boarding and alighting times are shown in Figure 1. Three categories of boarding are possible, but only category B1 was analyzed in this study. Sufficient information was not gathered for analysis of rear door boarding on the trolleys. Sufficient data were obtained, however, for 2 methods of local transit fare collection to analyze all 3 alighting categories. Intercity bus service was analyzed for category A1 only, because buses used for this type of service had only 1 passenger door. Only categories S1, S4, and S5 were analyzed for the category of simultaneously boarding and alighting because of the lack of information on rear door boarding.

Two types of analyses were performed by the method of least squares. The first developed a series of analysis equations that were used to investigate effects of fare collection methods, time of day, and use of front and rear doors. Although nearly 1,500 observations were analyzed in this study, sufficient data were obtained to investigate only those effects for local bus service with exact-fare and cash-and-change methods of fare collection. The results of these analyses are given in Table 1. In some cases the number of observations or the coefficient of determination or both are not adequate for reliable results, but they have been listed for purposes of interest. Conclusions that can be drawn from Table 1 are as follows:

1. Passenger service time requirements for a.m. and p.m. are similar;
2. Midday time requirements are usually greater than those for a.m. and p.m.;
3. Boarding time requirements exceed those for alighting; and
4. Rear door and front door alighting time requirements are the same.

Predictive equations were developed to estimate passenger service time requirements when the number of boarding and alighting passengers is known. These equations are given in Table 2. Conclusions drawn from this table are as follows:

1. Peak-period service time requirements for a.m. and p.m. are similar;
2. Midday service time requirements exceed peak-period requirements;
3. Boarding time requirements are greater than those for alighting;
4. Local service time requirements are less than intercity requirements, irrespective of the method of fare collection;

Figure 1. Passenger service time categories.

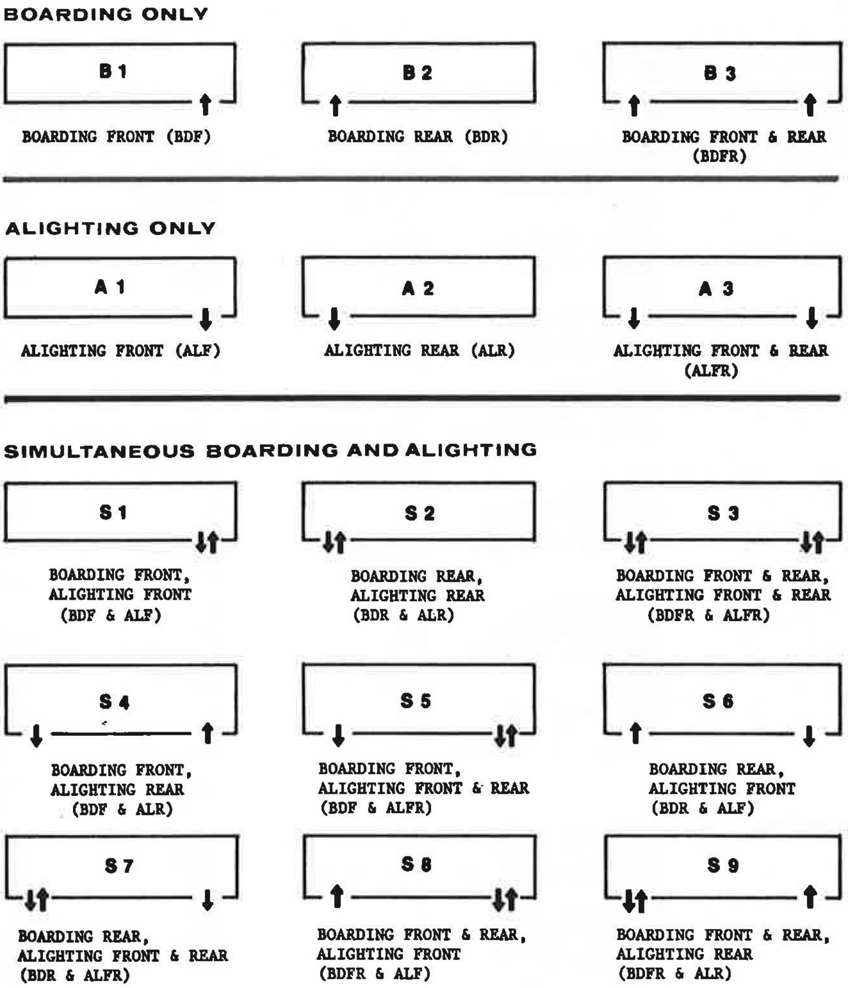


Figure 2. Time differences for boarding only, a.m. peak.

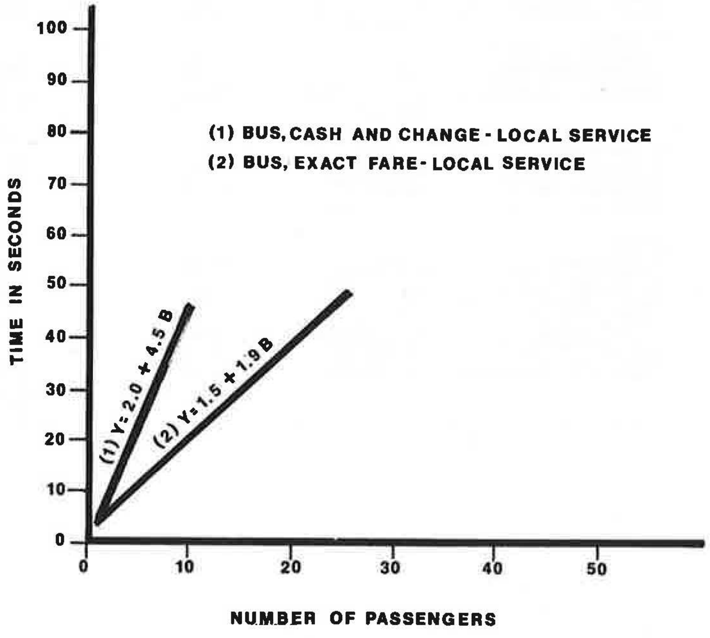


Table 1. Analysis equations.

System	Category	A.M. Peak	Midday	P.M. Peak
Exact fare, local bus	B1: BDF			
	Number of observations	50	94	257
	Coefficient of determination	0.94	0.89	0.90
	Standard error of estimate	0.34	0.41	0.40
	Equation, passenger service time	Y = 1.5 + 1.9 BDF 1 ≤ BDF ≤ 25	Y = 0.7 + 2.7 BDF 1 ≤ BDF ≤ 20	Y = 2.4 + 2.2 BDF 1 ≤ BDF ≤ 56
	A1: ALF			
	Number of observations	38	47	22
	Coefficient of determination	0.80	0.83	0.31
	Standard error of estimate	0.27	0.27	0.42
	Equation, passenger service time	Y = 0.6 + 1.7 ALF 1 ≤ ALF ≤ 9	Y = 0.9 + 2.1 ALF 1 ≤ ALF ≤ 8	Y = 2.1 + 1.3 ALF 1 ≤ ALF ≤ 4
	A2: ALR			
	Number of observations	7	13	9
	Coefficient of determination	0.67	0.47	0.29
	Standard error of estimate	0.42	0.77	0.56
	Equation, passenger service time	Y = 0.5 + 1.5 ALR 1 ≤ ALR ≤ 3	Y = 2.1 + 1.9 ALR 1 ≤ ALR ≤ 5	Y = 2.8 + 1.0 ALR 1 ≤ ALR ≤ 4
	A3: ALF and ALR			
	Number of observations	125	58	35
	Coefficient of determination	0.64	0.61	0.89
	Standard error of estimate	0.21	0.51	0.51
	Equation, passenger service time	Y = 2.4 + 0.7 ALF + 1.1 ALF 1 ≤ ALR ≤ 11 1 ≤ ALF ≤ 10 2 ≤ ALFR ≤ 19	Y = 2.3 + 0.8 ALR + 1.7 ALF 1 ≤ ALR ≤ 9 1 ≤ ALF ≤ 11 1 ≤ ALFR ≤ 20	Y = 1.9 + 2.2 ALF 1 ≤ ALR ≤ 21 1 ≤ ALF ≤ 19 2 ≤ ALFR ≤ 37
	S1: BDF and ALF			
	Number of observations	21	42	40
	Coefficient of determination	0.86	0.91	0.96
	Standard error of estimate	0.73	0.76	0.44
	Equation, passenger service time	Y = 3.1 + 2.0 BDF 1 ≤ ALF ≤ 4 1 ≤ BDF ≤ 15	Y = 1.0 + 1.0 ALF + 2.8 BDF 1 ≤ ALF ≤ 9 1 ≤ BDF ≤ 25	Y = 4.0 + 0.7 ALF + 1.3 BDF + 0.5 (ALF·BDF) 1 ≤ ALF ≤ 8 1 ≤ BDF ≤ 53
	S4: BDF and ALR			
	Number of observations	12	17	38
	Coefficient of determination	0.88	0.80	0.75
	Standard error of estimate	0.88	1.05	0.72
	Equation, passenger service time	Y = 0.4 + 2.0 BDF 1 ≤ ALR ≤ 5 1 ≤ BDF ≤ 13	Y = 3.2 + 2.2 BDF 1 ≤ ALR ≤ 4 1 ≤ BDF ≤ 16	Y = 3.0 + 1.9 BDF 1 ≤ ALR ≤ 8 1 ≤ BDF ≤ 15
	S5: BDF, ALF, and ALR			
	Number of observations	36	32	80
	Coefficient of determination	0.84	0.72	0.93
	Standard error of estimate	0.37	0.81	0.75
	Equation, passenger service time	Y = 0.1 + 1.0 ALR + 1.4 ALF + 2.4 BDF 1 ≤ ALR ≤ 8 1 ≤ ALF ≤ 12 1 ≤ BDF ≤ 8	Y = 4.6 - 0.5 ALR + 2.1 ALF + 2.2 BDF 1 ≤ ALR ≤ 17 1 ≤ ALF ≤ 11 1 ≤ BDF ≤ 10	Y = 1.8 + 2.2 ALF + 2.1 BDF 1 ≤ ALR ≤ 21 1 ≤ ALF ≤ 17 1 ≤ BDF ≤ 87
Cash and change, local bus	B1: BDF			
	Number of observations	26	No data	97
	Coefficient of determination	0.90	No data	0.85
	Standard error of estimate	0.72	No data	0.62
	Equation, passenger service time	Y = -2.0 + 4.5 BDF 1 ≤ BDF ≤ 10	No data	Y = 1.7 + 3.6 BDF 1 ≤ BDF ≤ 20
	A1: ALF			
	Number of observations	29	No data	18
	Coefficient of determination	0.83	No data	0.60
	Standard error of estimate	0.24	No data	0.35
	Equation, passenger service time	Y = 2.6 + 1.5 ALF 1 ≤ ALF ≤ 7	No data	Y = 3.0 + 1.4 ALF 1 ≤ ALF ≤ 6
	A2: ALR			
	Number of observations	8	No data	No data
	Coefficient of determination	0.89	No data	No data
	Standard error of estimate	0.84	No data	No data
	Equation, passenger service time	Y = 0.5 + 2.2 ALR 1 ≤ ALR ≤ 4	No data	No data
	A3: ALF and ALR			
	Number of observations	37	No data	5
	Coefficient of determination	0.66	No data	0.91
	Standard error of estimate	0.26	No data	0.73
	Equation, passenger service time	Y = 3.5 + 1.0 ALFR 1 ≤ ALR ≤ 7 1 ≤ ALF ≤ 7 2 ≤ ALFR ≤ 11	No data	Y = 4.5 + 0.8 ALFR 1 ≤ ALR ≤ 8 1 ≤ ALF ≤ 5 2 ≤ ALFR ≤ 13
	S1: BDF and ALF			
	Number of observations	Insufficient data	No data	23
	Coefficient of determination	Insufficient data	No data	0.95
	Standard error of estimate	Insufficient data	No data	0.55
	Equation, passenger service time	Insufficient data	No data	Y = 4.0 + 4.3 BDF 1 ≤ ALF ≤ 2 1 ≤ BDF ≤ 13
	S4: BDF and ALR			
	Number of observations	Insufficient data	No data	Insufficient data
	Coefficient of determination	Insufficient data	No data	Insufficient data
	Standard error of estimate	Insufficient data	No data	Insufficient data
	Equation, passenger service time	Insufficient data	No data	Insufficient data
	S5: BDF, ALF, and ALR			
	Number of observations	Insufficient data	No data	6
	Coefficient of determination	Insufficient data	No data	0.81
	Standard error of estimate	Insufficient data	No data	1.90
	Equation, passenger service time	Insufficient data	No data	Y = 4.5 + 3.5 ALR + 2.7 BDF 1 ≤ ALR ≤ 5 1 ≤ ALF ≤ 4 1 ≤ BDF ≤ 6

Table 2. Predictive equations.

System	Category	A.M. Peak	Midday	P.M. Peak
Exact fare, local bus	Alighting only			
	Number of observations	170	119	66
	Coefficient of determination	0.68	0.62	0.65
	Standard error of estimate	0.18	0.31	0.34
	Equation, passenger service time	$Y = 2.3 + 1.0 A$ $1 \le A \le 19$	$Y = 2.5 + 1.4 A$ $1 \le A \le 20$	$Y = 2.5 + 1.1 A$ $1 \le A \le 37$
	Boarding only			
	Number of observations	50	94	257
	Coefficient of determination	0.94	0.89	0.90
	Standard error of estimate	0.34	0.41	0.40
	Equation, passenger service time	$Y = 1.5 + 1.9 B$ $1 \le B \le 25$	$Y = 0.7 + 2.7 B$ $1 \le B \le 20$	$Y = 2.4 + 2.2 B$ $1 \le B \le 56$
	Simultaneous boarding and alighting			
	Number of observations	69	91	158
	Coefficient of determination	0.83	0.83	0.92
	Standard error of estimate	0.36	0.54	0.46
	Equation, passenger service time	$Y = 0.5 + 1.3 A + 2.2 B$ $-0.1 (A \cdot B)$ $1 \le A \le 14$ $1 \le B \le 15$	$Y = 0.8 + 1.4 A$ $+ 2.9 B$ $- 0.1 (A \cdot B)$ $1 \le A \le 25$ $1 \le B \le 25$	$Y = 2.4 + 1.1 A + 2.1 B$ $1 \le A \le 38$ $1 \le B \le 87$
Exact fare, trolleybus	Alighting only			
	Number of observations	No data	No data	No data
	Coefficient of determination	No data	No data	No data
	Standard error of estimate	No data	No data	No data
	Equation, passenger service time	No data	No data	No data
	Boarding only			
	Number of observations	No data	Insufficient data	13
	Coefficient of determination	No data	Insufficient data	0.97
	Standard error of estimate	No data	Insufficient data	0.49
	Equation, passenger service time	No data	Insufficient data	$Y = -1.8 + 1.7 B$ $1 \le B \le 20$
	Simultaneous boarding and alighting			
	Number of observations	No data	13	15
	Coefficient of determination	No data	0.89	0.85
	Standard error of estimate	No data	0.70	0.65
	Equation, passenger service time	No data	$Y = 2.8 + 1.6 B$ $1 \le B \le 15$ $1 \le A \le 8$	$Y = 1.3 + 0.7 A + 1.7 B$ $1 \le A \le 8$ $1 \le B \le 12$
Exact fare, trolley car	Alighting only			
	Number of observations	No data	No data	No data
	Coefficient of determination	No data	No data	No data
	Standard error of estimate	No data	No data	No data
	Equation, passenger service time	No data	No data	No data
	Boarding only			
	Number of observations	No data	Insufficient data	7
	Coefficient of determination	No data	Insufficient data	0.64
	Standard error of estimate	No data	Insufficient data	0.90
	Equation, passenger service time	No data	Insufficient data	$Y = 3.4 + 0.9 B$ $1 \le B \le 13$
	Simultaneous boarding and alighting			
	Number of observations	No data	11	5
	Coefficient of determination	No data	0.80	0.94
	Standard error of estimate	No data	1.67	1.50
	Equation, passenger service time	No data	$Y = -4.2 + 4.1 A$ $+ 2.0 B$ $- 0.3 (A \cdot B)$ $1 \le A \le 13$ $2 \le B \le 20$	$Y = -4.0 + 2.0 B$ $1 \le A \le 8$ $6 \le B \le 21$
Cash and change, local bus	Alighting only			
	Number of observations	75	No data	27
	Coefficient of determination	0.76	No data	0.82
	Standard error of estimate	0.18	No data	0.29
	Equation, passenger service time	$Y = 3.2 + 1.1 A$ $1 \le A \le 11$	No data	$Y = 3.8 + 0.9 A$ $1 \le A \le 13$
	Boarding only			
	Number of observations	26	Insufficient data	96
	Coefficient of determination	0.90	Insufficient data	0.85
	Standard error of estimate	0.72	Insufficient data	0.62
	Equation, passenger service time	$Y = -2.0 + 4.5 B$ $1 \le B \le 10$	Insufficient data	$Y = 1.7 + 3.6 B$ $1 \le B \le 20$
	Simultaneous boarding and alighting			
	Number of observations	14	No data	36
	Coefficient of determination	0.80	No data	0.91
	Standard error of estimate	0.74	No data	0.55
	Equation, passenger service time	$Y = 5.3 + 1.5 (A \cdot B)$ $1 \le A \le 7$ $1 \le B \le 3$	No data	$Y = -0.1 + 2.2 A + 4.9 B$ $-0.5 (A \cdot B)$ $1 \le A \le 8$ $1 \le B \le 13$
No fare, double-deck bus	Alighting only			
	Number of observations	No data	10	No data
	Coefficient of determination	No data	0.92	No data
	Standard error of estimate	No data	0.75	No data
	Equation, passenger service time	No data	$Y = -1.8 + 2.3 A$ $2 \le A \le 12$	No data
	Boarding only			
	Number of observations	No data	15	No data
	Coefficient of determination	No data	0.87	No data
	Standard error of estimate	No data	0.30	No data
	Equation, passenger service	No data	$Y = 1.0 + 2.0 B$ $1 \le B \le 7$	No data
	Simultaneous boarding and alighting			
	Number of observations	No data	12	No data
	Coefficient of determination	No data	0.82	No data
	Standard error of estimate	No data	3.48	No data
	Equation, passenger service	No data	$Y = -8.9 + 3.5 A$ $+ 3.8 B$ $1 \le A \le 10$ $1 \le B \le 14$	No data
No fare, local bus	Alighting only			
	Number of observations			11
	Coefficient of determination			0.97
	Standard error of estimate			0.65
	Equation, passenger service			$Y = 3.1 + 1.4 A$ $1 \le A \le 25$
Various fares, intercity bus	Alighting only			
	Number of observations	30	53	
	Coefficient of determination	0.90	0.63	
	Standard error of estimate	1.4	0.91	
	Equation, passenger service	$Y = 4.5 + 1.7 A$ $4 \le A \le 57$	$Y = 5.7 + 2.1A$ $4 \le A \le 69$	
Cash and change, intercity bus	Boarding only			
	Number of observations		10	27
	Coefficient of determination		0.81	0.99
	Standard error of estimate		19.05	2.55
	Equation, passenger service		$Y = -19.5 + 6.1 B$ $8 \le B \le 63$	$Y = -13.4 + 6.6 B$ $1 \le B \le 52$
Pay leave, intercity bus	Boarding only			
	Number of observations			18
	Coefficient of determination			0.90
	Standard error of estimate			2.29
	Equation, passenger service			$Y = 3.2 + 3.9 B$ $33 \le B \le 64$

Figure 3. Time differences for boarding only, p.m. peak.

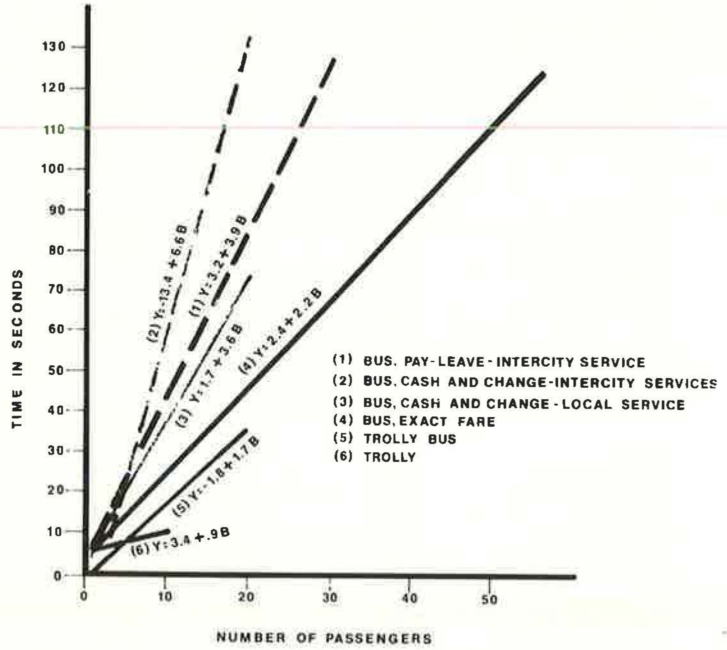
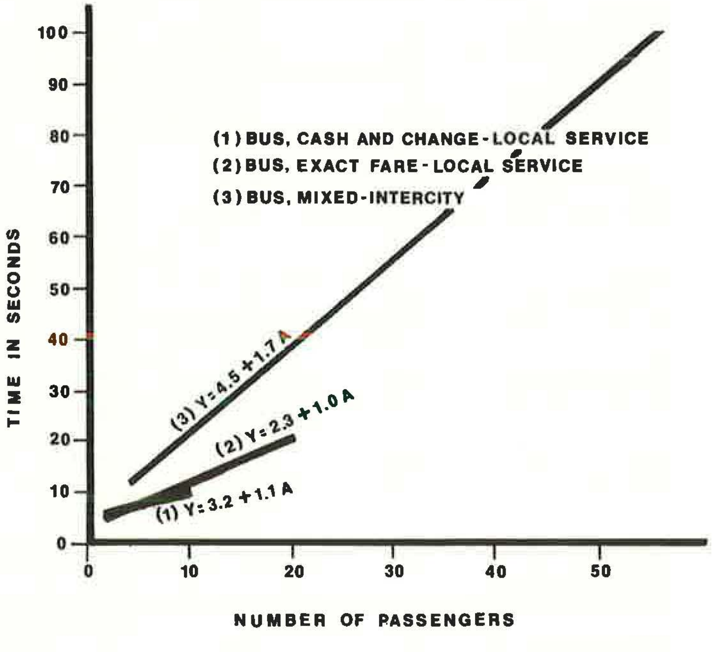


Figure 4. Time differences for alighting only, a.m. peak.



5. Time requirements for trolley cars and trolleybuses having double doors are less than those for buses with single doors; and

6. The exact-fare method of fare collection provides faster passenger service time than does the cash-and-change method.

Figure 2 shows the difference between the exact-fare system and the cash-and-change system for boarding during the a.m. peak period. It shows a time savings of 2.6 seconds per passenger for the exact-fare system. This difference is reduced to 1.4 seconds per passenger during the p.m. peak period as shown in Figure 3. A time savings of 0.6 second per passenger for all time periods was indicated in NCHRP Report 113. Because sufficient data were not collected for the midday time period, further analysis and interpretation could not be made. Figure 3 also shows sizable differences in time requirements for local service and intercity service. In all cases intercity service required considerably more time. This may have resulted from the following:

1. Intercity passengers ask more questions;

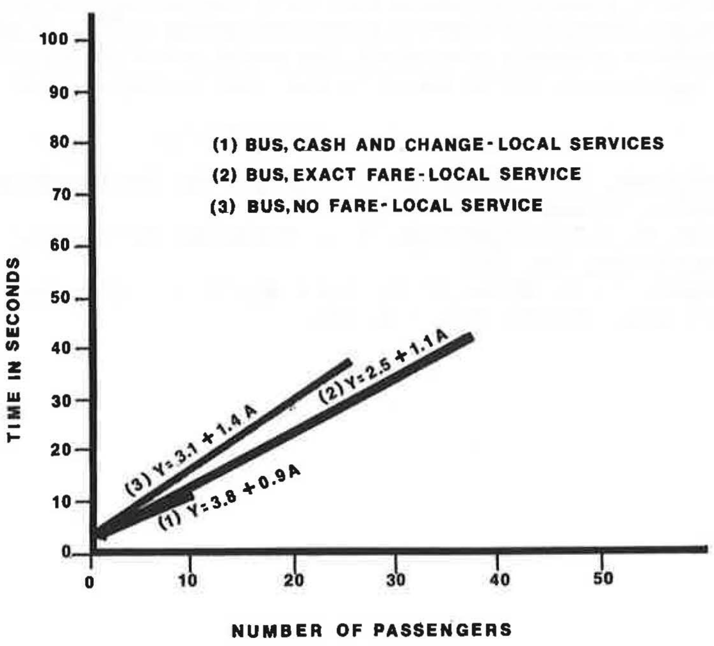
2. Passengers inside the bus store their coats and luggage on overhead racks and delay boarding operations; and

3. Intercity passengers exit from the bus to wait for another when all seats are occupied.

Internal congestion or platform queuing frequently had an effect on the operation of all vehicles. This condition was noticeable for trolley car and trolleybus passengers as observed on Market Street in San Francisco. The loading platform was approximately 5 ft wide and located between the trolley car and trolleybus lanes. Frequently the crowding on the platform delayed passengers alighting from the trolley cars. Furthermore, congestion inside the trolley cars and trolleybuses frequently delayed boarding passengers. These conditions probably accounted for some of the higher than expected service times for the vehicles with double doors.

Figure 4 shows alighting only during the a.m. peak period for buses. As expected, there was almost no difference between the methods of fare collection for local service. Results do indicate, however, that intercity service requires more time than local ser-

Figure 5. Time differences for alighting only, p.m. peak.



vice. The internal congestion and higher floor height of intercity vehicles may account for this.

Figure 5 shows alighting only during the p.m. peak period for buses. Again, there is little difference between the cash-and-change and the exact-fare systems. The no-fare system seems to require slightly greater service time, but this is probably not significant. The no-fare data were collected at Rutgers—The State University in New Brunswick, New Jersey; the characteristics of the university passenger may differ from those of the downtown transit commuter and thereby have affected the results.

CONCLUSIONS

Many factors influence passenger service time of street transit systems. Those found to be most significant in this study include

1. Time of day—a.m. and p.m. peak periods are similar, but midday passenger service time requirements are greater than those for peak periods;
2. Type of service—local transit service requires less loading and unloading time than does intercity service;
3. Type of vehicle—double-door vehicles consume less passenger service time than single-door vehicles (vehicles with greater distance between the floor of the vehicle and the ground and those with narrower doors and aisles and tight seating configurations require more boarding and alighting time);
4. Method of fare collection—for local service, the exact-fare system saves between 1.4 and 2.6 seconds per passenger; and
5. Type of passenger—elderly people, handicapped people, and commuters exhibit distinctly different characteristics.

These results form the framework from which quantitative analyses can be performed, that is, the translation of loading and unloading time into terminal space and design criteria. Analyses of this type will become more and more critical in the future, particularly in view of increasing land costs in urban areas and reduced fuel allocations, which cause greater dependence on public transportation.

ACKNOWLEDGMENTS

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LOCATING AND OPERATING BUS RAPID TRANSIT PARK-AND-RIDE LOTS

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This paper reviews and synthesizes previous experiences with locating and operating park-and-ride lots throughout the country. The data included represent the experience of 7 municipalities and account for approximately 4,500 park-and-ride spaces in 13 lots serving as change-of-mode facilities for bus transit. The characteristics of the lot users were investigated. Data were analyzed to determine the characteristics of trip length, trip times, trip purpose, type of employment, trip origin, and mode to bus. Further considerations included mode of travel to work before the establishment of park-and-ride lots and environmental-impact factors. From the analysis of data gathered, some preliminary and general planning guidelines relevant to the location and sizing of a park-and-ride facility in an urban transportation corridor were developed.

•IT APPEARS that growth of regional centers will continue to be vigorous in the 1970s. A major consequence of this will be the inability of transport systems within such centers to meet the population's increasing mobility requirements. The growing demand for a transit mode to collect riders in low density suburbs, funnel them rapidly along existing transportation corridors, and distribute them within high density employment locations has been made evident by the proliferation of unregulated commuter parking at freeway interchanges that have good bus transit accessibility.

The myriad problems connected with unregulated commuter parking and the market potential for financially troubled bus transit companies have prompted several attempts to develop or expand the park-and-ride mode. This has required the establishment of more formalized change-of-mode facilities. These facilities have ranged from existing but unused parking areas at gasoline stations, drive-in theaters, and shopping centers to specially constructed parking lots with varying degrees of amenities.

The park-and-ride mode is unique in that it uses the private automobile to collect riders in the low density residential areas and then funnels them by public transit along existing transportation corridors. This increases the efficiency of the highway for moving people and decreases pollutants. The effect of the automobile is to increase the service area of the transit station. Increased service areas would allow greater station spacing, which, in turn, would allow greater efficiency within the transit system. The efficiencies fostered by the park-and-ride mode are not limited to the transportation network alone. Land use efficiencies may be realized because of a decentralization of parking demand. Park-and-ride facilities in fringe areas reduce the demand for parking in the higher density core areas. A benefit is realized because of the diversion of parking to areas of lower land use density and hence lower land values. This latter consideration is not only the most important factor influencing park-and-ride users today, but also the greatest potential for increasing park-and-ride patronage in the future.

Of the many variables affecting the success of bus change-of-mode facilities, downtown parking rates have been found to be the most significant. In the future, as metropolitan areas continue to grow and travel in established transportation corridors increases, central business district (CBD) land values may be expected to rise. This will necessitate even higher downtown parking costs. Also, the future pressures brought about by higher density land development, irregular street patterns, increasing congestion, imposition of tolls in certain areas, and increased accident exposure underscore the potential of the park-and-ride mode. The prime factors for motivating people to choose the park-and-ride mode would be lower cost parking, arrival within an acceptable walking distance to place of employment, and no time penalty for using the mode.

A major concern for the future will be the ability to reasonably predict the demand for park-and-ride facilities. To develop a strategy for estimating this demand, it may be helpful to understand the behavior and attitudes of the park-and-ride user today. The purpose of this paper is to review past experience with bus transit change-of-mode facilities, to add to the growing body of information on the location of these facilities, and to provide a foundation for further research.

CHARACTERISTICS OF PARK-AND-RIDE USERS

Choosing the park-and-ride mode for the work trip is determined by the inconveniences the commuter associates with it. The commuter weighs the inconvenience of the bus and the time lost in the change of mode against the higher downtown parking costs and driving strain. The individual's choice is subjective, so predicting behavior may be difficult. But, when groups of individuals are studied, patterns emerge and successfully predicting behavior of the group is easier. The planner can use this fact to predict the demand for park-and-ride spaces in a particular location along an established transportation corridor.

Trip Purpose

Table 1 (7, 8, 11) gives the trip purpose for park-and-ride users in 3 metropolitan areas. Work is the primary trip purpose of the majority of park-and-ride users. An average of 89 percent of those in the 3 metropolitan areas used park-and-ride for work trips.

Type of Employment

The primary types of employment for park-and-ride users are given in Table 2 (8). White-collar workers employed in retail and office work far outnumber the blue-collar workers. This is not surprising when one considers the density of retail and office employment trip terminations within the core of the central city. It also underscores the present downtown orientation of park-and-ride routes.

Trip Origin

The origins of change-of-mode trips may come from a wide service area. Figure 1 shows a scattergram of trip origins of commuters bound for the Seattle Blue Streak park-and-ride lot in January 1973. The significant number of trip origins south of the park-and-ride facility (closer to downtown) indicates that employees of retail establishments near the lot may have been using park-and-ride spaces for all-day employee parking. The spatial distribution shown in Figure 1 indicates the distance people are willing to drive, especially laterally, to use a park-and-ride facility that has good service.

Trip Length

An important consideration in determining the size of the park-and-ride lot and its distance from downtown is the distance the typical park-and-ride user is willing to travel from home to the lot, and from the lot to the downtown destination. A survey in the northeastern United States conducted among interchange parkers revealed that more than 50 percent of those who used public transit drove less than 5 miles from their point of origin to the change-of-mode facility. More than 80 percent drove less than 10 miles. Figure 2 (8) shows the distribution of parkers who drove less than a given distance to a transit interchange parking area in New Jersey. The illustration shows that, in this case, about 70 percent drove less than 5 miles and 90 percent drove less than 10 miles to the change-of-mode facility. Table 3 (8) gives the distance traveled between home and shopping center (change-of-mode location) for 2 park-and-ride routes in Milwaukee. An average of 89 percent of the commuters drove less than 5 miles from their home to the park-and-ride facility.

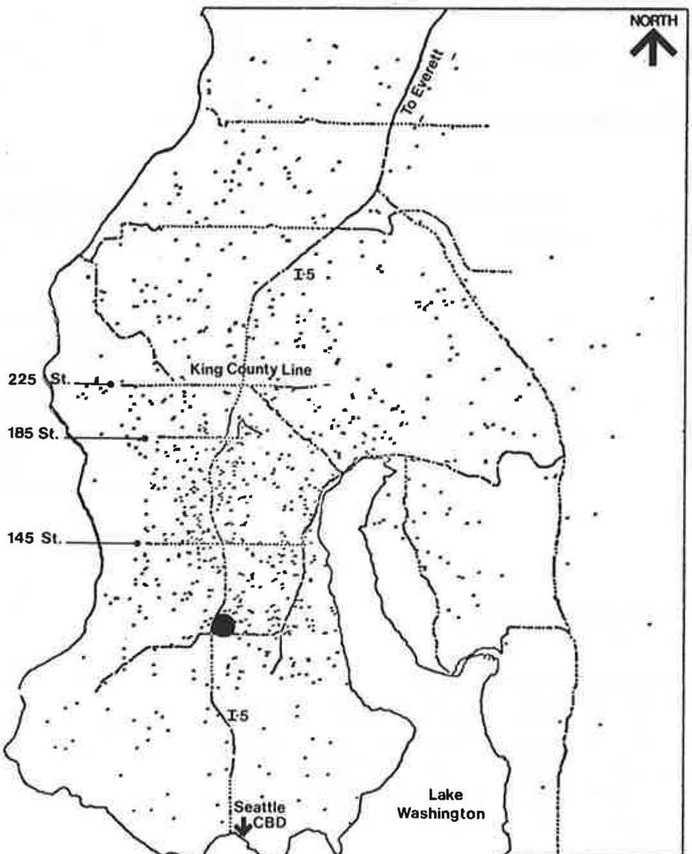
Table 1. Trip purpose of park-and-ride users in 3 metropolitan areas.

Purpose	Northeast Corridor (percent)	Washington, D.C. (percent)	Seattle, Washington (percent)
Work	91	92	85
Business	4		9
School	2		
Shopping	3	4	1
Other			5
Not reported	0	4	0

Table 2. Employment and mode of travel for interchange parkers.

Employment	New Brunswick, N.J., Bus (percent)	All Transit (percent)
Manufacturing	8	4
Retail	10	11
Office	69	77
Construction	5	3
Student	3	1
Unemployed	5	4

Figure 1. Southbound trip origins to Seattle Blue Streak park-and-ride lot.



● Park-ride Lot Location

Figure 2. Distance from home to interchange parking area in New Jersey.

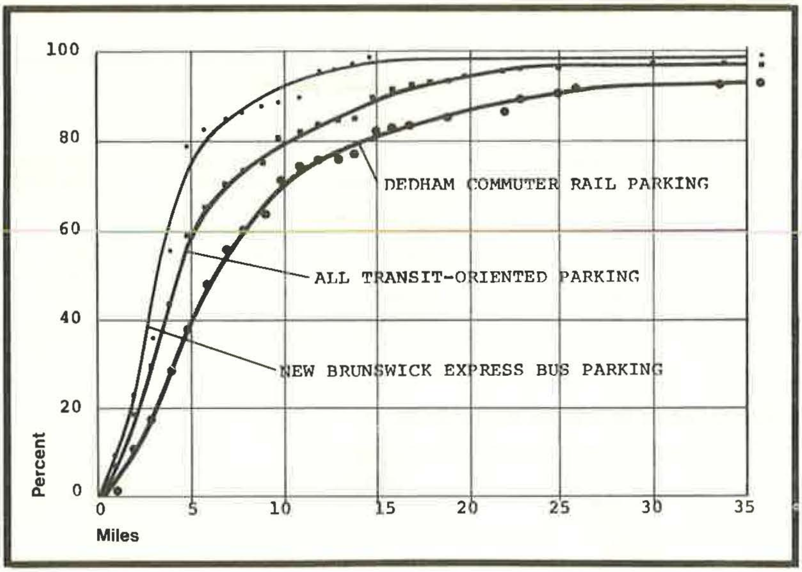


Table 3. Distance between home and commuter parking for transit riders on Mayfair and Bayshore lines, Milwaukee.

Miles	Mayfair (percent)	Bayshore (percent)
0 to 1.0	16	26
1.1 to 2.0	34	33
2.1 to 3.0	24	10
3.1 to 4.0	10	14
4.1 to 5.0	7	4
5.1 to 6.0	1	3
Over 6.0	8	10

Table 4. Average trip length and time for transit and car-pool parkers.

	Transit		Car Pool	
Trip Section	Minutes	Miles	Minutes	Miles
Home to interchange	14.1	7.9	13.7	8.7
Interchange to destination	45.9	28.6	46.1	33.8
Total	60.0	36.5	59.8	42.5

Table 5. Transit parking related to travel time and distance.

Transit Travel Time to CBD During Peak Hour (minutes)	Number of Spaces by Distance From CBD (miles) 0 to 1	2 to 3	4 to 5	6 to 10	Over 10	Total	Percent
0 to 10	4,410	620	0	150	0	5,180	34
11 to 30	0	1,870	1,760	1,130	150	4,910	32
31 to 60	0	290	0	2,000	2,990	5,280	34
Total	4,410	2,780	1,760	3,280	3,140	15,370	100
Percent	29	18	12	21	20		

Table 6. Mode of arrival of park-and-ride users at 3 Washington, D.C., fringe lots: Fairfax, Soldiers' Home, and Carter Barron.

Mode	Percent
Drove	76
Was driven and car parked	9
Was driven and car not parked	9
Walked	3
Other	3

Table 7. Mode to work before park-and-ride was used.

Mode	Washington, D.C. (percent)	Seattle, Washington (percent)
Automobile driver	25	65
Automobile passenger	9	12
Other transit	29	23
Other	37	—

When time is considered, the data for the northeastern corridor study follow the same pattern as that of distance. Fifty percent of the parkers drove less than 10 min from their home to the interchange parking facility and 75 percent drove less than 15 min. Table 4 (8) gives average trip lengths for transit and car-pool riders by trip section. The home-to-interchange trip section is approximately 20 percent of the total trip length and about 23 percent of the total trip time. Table 5 (6) gives bus transit parking as related to travel time and distance. The data indicate that 80 percent of the spaces surveyed were within 10 miles of the CBD. Sixty-six percent of the spaces were within 30 min transit travel time to the downtown during the peak hour.

The less than 5-mile link from home to change-of-mode facility for 70 percent of the commuters in the northeast corridor and 89 percent in Milwaukee is about 20 percent of their total journey-to-work time.

Mode to Bus

Mode of arrival at the park-and-ride facility has been used to determine the number of transit trips generated per car for a given park-and-ride facility. In addition to driving to the lot, a person can be driven as a passenger, walk in, or be dropped off by a driver who does not use the parking lot (kiss-and-ride). Table 6 (7) gives the mode of arrival at 3 Washington, D.C., fringe lots.

The Washington, D.C., study found that approximately 1.2 transit trips were generated by each car occupying a park-and-ride space. The Seattle Blue Streak study similarly found that 1.3 trips were generated by each car. In general, the Washington, D.C., study found that about 10 percent of the total transit patrons started their journeys by automobile. For suburban riders this jumped to approximately 40 percent.

Mode Prior to Park-and-Ride

In addition to the present habits of park-and-ride users, data were gathered on the mode to work before the park-and-ride user began using the fringe lot. These data are given in Table 7 (7, 11) for Washington, D.C., and Seattle. The Seattle data show a significant diversion from driving the automobile. The Washington, D.C., data show a lesser trend toward diversion from the automobile. In both cases, though, a substantial number of patrons were diverted from other transit service.

The great majority of the people who choose the park-and-ride mode use it for the work trip. They are generally employed in a high density CBD and typically work in office or retail establishments. Their trip origins come from a widely scattered area. Movement toward the facility is along radials to downtown and laterally across radials. The majority of bus transit change-of-mode patrons travel less than 5 miles from their residences to the park-and-ride lot. This link accounts for approximately 20 percent of the total work trip distance. Generally, the maximum total trip time spent for the park-and-ride mode is about 40 min. This would normally include a 5-mile trip from origin to change-of-mode facility, waiting for a bus with 5-min headways, and 25 min in transit. Although the 4 to 1 ratio of distance from the lot to downtown to distance from the lot to origin seemed consistent in the data, a more important guideline might be trip time instead of distance.

Surveys of habits and attitudes of park-and-ride users revealed that the majority chose the mode to avoid high downtown parking fees and congestion on the freeways. The weights that users placed on avoiding these elements in their trip were underscored by the fact that in Washington, D.C., 53 percent indicated that they would still prefer to drive all the way downtown if parking were plentiful and cheap.

Most park-and-ride users arrived by car. As a general rule 1.2 to 1.3 transit trips per automobile parked were generated. (If one assumes that these inbound trips are matched by an outbound transit trip in the evening, 2.4 to 2.6 daily transit trips per automobile parked were generated.) There was a strong indication that the park-and-ride operation diverted as many as 65 percent of the users from the driving mode. In Washington, D.C., park-and-ride apparently offered improved service to 29 percent of the former transit patrons who switched from their previous transit route to the park-and-ride service.

LOCATING PARK-AND-RIDE FACILITIES

To optimally site a change-of-mode facility, one must consider a wide range of locational aspects including those at both the community and local levels. The following is a discussion of the objectives, requirements, limitations, and environmental aspects of locating a fringe parking facility in an urban transportation corridor.

Objectives

A basic objective of transportation systems is to provide adequate mobility to all at the least possible cost to the public. A basic goal might well be the reduction of capital expenditures for more high-cost facilities like freeways and downtown parking garages. Therefore, the location of park-and-ride facilities should be such that they may be served by existing transportation facilities. Further, they should be located to provide the best service to the most users in an economical manner. Additional objectives of the community include the improvement of the convenience of transportation (more frequent headways); the promotion of desirable land use; the minimizing of adverse impacts on neighborhoods; and the reinforcement of existing travel corridors.

Distance From Downtown

A change-of-mode facility must be located at a distance greater than 1 mile from the core area. When fringe parking facilities are located up to 1 mile from a high concentration of employment destinations, the commuter will park in the park-and-ride lot and walk to the final destination. Just how far from downtown is optimal? A location as close as possible to downtown is preferred because there would be an increased draw area; the commuter could minimize overall trip time by completing most of the trip in an automobile; and there would be more frequent and less expensive transit service. But location farther from the downtown is advisable in view of the lower land values and the desirability of reducing total trips on the heavily loaded freeway links approaching downtown.

A predominant factor discouraging the location of park-and-ride facilities close to downtown is the cost of providing parking close-in. The economics of providing fringe parking dictate a location at a distance from the downtown at which land costs become reasonable. An analysis of 12 change-of-mode parking facilities providing approximately 4,500 parking spaces for transfer to bus transit revealed that the lots were located an average of 4.5 miles from the downtown. The median distance was 3.2 miles. As bus-miles increase to maintain 5-min headways to origins increasingly farther from downtown, operating costs increase in the face of dwindling patronage from the reduced service areas. As has been mentioned earlier, a decrease in service or increase in fare to offset these factors will increase the inconveniences associated with the park-and-ride mode and patronage will decline.

> Guideline–A park-and-ride lot should be located as close to the major activity center as land value distribution will permit but no closer to the high density employment center than 1 mile.

Reducing total trips on the approaches to downtown is an objective of park-and-ride. So, it is desirable to locate the park-and-ride lot, which will intercept incoming trips, farther from downtown than the point where substantial congestion develops. This will relieve pressure on existing transportation facilities as much as possible.

As long as the freeway leading to the CBD remains relatively uncongested, the commuter will opt to continue using an automobile, thus minimizing total trip time. When the freeway becomes congested, the inconveniences associated with the automobile mode approach the inconveniences associated with the transit mode. Here, the driver is a potential park-and-ride user and, if other conditions are favorable (such as the nearby location of a change-of-mode facility with good access), the driver may elect to change modes.

> Guideline–A park-and-ride lot should be located in a dense travel corridor approaching a high density employment center and adjacent to a radial freeway beyond serious congestion.

Access

A major locational consideration is access to the lot for both public transit and automobiles. Instead of constructing special bus connections to the freeway (which would be contrary to the objective of minimizing capital costs), it would be desirable to locate the park-and-ride facility near the intersection of a major arterial and the freeway. For buses, good freeway access is important to minimize the amount of travel on slower moving arterials and to maximize the amount of travel on the faster moving freeway. This obviously cuts down on trip time for the public transit portion of the journey, and thus lowers the inconveniences associated with the park-and-ride mode. For the automobile, good freeway access is equally important. The Seattle Blue Streak study revealed that over 18 percent of the lot users came from Snohomish County and 13 percent came from north of the Seattle city limits and west of the freeway. It may be assumed that this large portion of the lot users used the freeway to access the park-and-ride lot. If special bus access were constructed, it would not benefit those users who employed the freeway to access the park-and-ride lot.

Ideally, the lot should be located not so far from freeway access as to cause the commuter loss of travel time from passing through signalized intersections. Many major arterial intersections function near or at capacity during the peak hours. Thus, in addition to the delay caused by the normal cycle of the signal, queuing at the signal causes additional delays. These losses in travel time are weighed by the commuter and tend to raise the total inconvenience associated with the park-and-ride mode. The park-and-ride lot should not directly access the major arterial. Because the park-and-ride lot is a low turnover traffic generator with definite peaking characteristics, the demand for access conflicts with the movement of through traffic on the arterial. Because of the short duration of the access demand, it is doubtful that a park-and-ride lot would qualify, under accepted warrants, for a separate traffic signal. Thus, access onto a major arterial would be disfunctional for both the through traffic and the lot users. Access onto the local street system also would be undesirable. Commuter automobiles should not be made to travel on purely local residential streets because the streets were not designed to handle large volumes of traffic, the residents of the community do not want the traffic, and the traffic is a hazard to the children.

Guideline–A park-and-ride lot should be located where access to the lot is convenient for both bus and automobile and where it intercepts trips bound for the freeway.

Development Opportunities

The cost of alternative developments is a prime locational consideration. The desirable location for a park-and-ride facility—next to a major arterial intersecting a freeway—is also a desirable location for other facilities like gasoline stations. Thus, the market value of land this close to an interchange may be quite high even though it is far from the CBD. When analyzing the benefits derived from a park-and-ride location, one must consider the effects of various locations on patronage. Evaluation techniques like cost-benefit analysis must be applied with consideration for the fragility of the demand factors. A higher expenditure for a site may benefit the public far more than a lesser expenditure for a less desirable site.

Guideline–A park-and-ride lot should be located to minimize the cost of development to the public and to use existing available parking facilities if possible.

Competing Facilities

Overlapping service areas may decrease the fill ratio of certain lots. This may be expected with park-and-ride lots that are located farther from downtown than another facility within the same service area. Commuters will bypass facilities that are located farther from their ultimate destinations to find parking spaces in park-and-ride lots that are closer. This fails to remove work trips from freeways going toward the CBD. In some instances, the potential park-and-ride user may not find a space at a closer facility because of its larger draw area. Then, the commuter may continue the trip by automobile and not use the park-and-ride mode at all.

Inappropriate lot location also generates additional trips between lots, especially when the lots are sized close to demand capacity and are located close together. Often these trips will be on arterial streets that are already operating at or near capacity during the morning peak hour.

Guideline–A park-and-ride lot should be located so that it does not compete with other service areas.

Site

The site should be flat and well-drained. The parker, if forced to walk up steps because of uneven topography, will attach a stronger inconvenience to that link. Uneven topography also imposes restraints on the parking and circulation plan, which could be expensive in terms of efficient use of costly land. In large park-and-ride facilities (1,000 automobiles), the parking area may be large enough to justify more than 1 pickup point.

Civil and architectural criteria should include considerations of traffic and circulation, geometrics, design standards, drainage, landscaping, fencing and barriers, illumination, signing, shelters, aesthetics, and environment.

Guideline–A park-and-ride lot should be large enough to permit proper traffic circulation and pedestrian safety and convenience.

Expansion Potential

The demand for park-and-ride spaces is not static. The demand should increase as population increases. More people choose public transit as rising costs drive downtown parking fees higher. An expansion potential is, therefore, a necessary locational consideration.

Effect on Adjacent Areas

A change-of-mode facility is essentially a large parking area. It is desirable that it be located in an industrial, commercial, or high-density residential area. In residential areas, buffer zones or adequate topography would be required to provide the necessary transition between the 2 adjacent land uses. In commercial areas, the park-and-ride lot should be located on the periphery because conflicts may arise between park-and-ride users and employees of retail establishments in the vicinity of the park-and-ride lot.

The environmental considerations surrounding a proposed park-and-ride lot should be comprehensive in nature. There should be full cooperation and coordination with federal, state, and local officials and officially sanctioned advisory groups, quasi-official advisory groups, and the citizenry at large to identify the social, economic, and environmental effects of the proposed project.

Guideline–A park-and-ride lot should be located to minimize adverse effects on adjacent areas. Particular attention should be given to the effect on local traffic circulation.

Visibility

The park-and-ride facility should be visible from the freeway to strengthen the diversion factor as commuters observe others using the lot.

Demand

An indicator of a potential park-and-ride lot location would be considerable use by commuters of on-street parking near transit stops. A survey of this type of activity may indicate demand for such facilities.

Service

Transit service headways increase as the distance from the central destination decreases. This indicates that, if park-and-ride lots are to succeed and remain economically feasible, they should be located as close as possible to downtown. However, a park-and-ride lot of sufficient size can generate enough trips by itself to justify fast headways during the peak periods. Although increased distance from the central destination means more buses (and higher costs) for a given level of service, the demand generated by a park-and-ride lot can make fast headways economically feasible.

Guideline—Service to park-and-ride lots should be maintained at 5-min headways during the peak hour. Off-peak headways should be maintained at no less than 1 bus per hour. Alternate routing of nearby local bus service with minimum headways of 1 bus per hour may be considered.

Fee for Park-and-Ride Lot Use

Charging a fee for parking in a park-and-ride lot deserves much study. It might be argued that a small fee (say, 10 cents) would be insignificant to the parker and would greatly aid the economic feasibility of establishing park-and-ride facilities. However, paying additional out-of-pocket fares to use the park-and-ride mode might be a significant enough inconvenience to cause the park-and-ride user either to continue entirely by automobile or to park on the public street and switch to other convenient transit. Although the latter choice still generates a transit trip (and revenue), parking on the city street is not desirable. Of 36 cities surveyed, only 3 cases of successful bus change-of-mode parking were found where a parking fee was levied.

Even if no fee is charged, the lot must offer something more than on-street parking does. A single, large park-and-ride lot cannot be as convenient for as wide a range of potential riders as on-street parking. Thus, it must offer additional benefits. This may be better bus service, more security for the vehicle and patron, an assured place to park, or improved shelter and amenities while waiting for the bus. Charging even a small fee may upset the delicate balance of factors influencing people to park in the park-and-ride lot. Charging a fee would most likely be successful only in special cases.

Guideline—There should be no charge for using a park-and-ride lot. Parking fees significantly discourage park-and-ride mode usage. It costs less to park on the street in the vicinity of a transit stop. Past park-and-ride experience has shown that success of lots that have a parking fee is unusual and exists only under special circumstances.

Fare Zone Boundaries

Past park-and-ride lot experience indicates that, if a lot is located within a few blocks of a fare zone boundary, and there is adequate service in that area, the commuter will bypass the park-and-ride lot and drive a few blocks farther across the fare boundary, park on the street, and thus lower his or her transit costs.

Service at Destination

To be attractive to the commuter, transit service should terminate within an acceptable walking distance to a high percentage of employment destinations.

CONCLUSIONS

This paper has underscored the importance of the change-of-mode parking terminal in the urban transport system. The park-and-ride mode diverts automobiles from the radial freeways approaching the central city. It has several sensitive links that can be easily influenced by such things as downtown parking cost, congestion, and fees for park-and-ride lot use. A park-and-ride facility should be located on land that has optimal urban land values, is already used for parking, and is near freeway interchanges where the public transit portion of the trip can be competitive in terms of travel time. It should not compete with similar facilities having better service and lower fares. Parking should be free.

The park-and-ride mode holds significant potential for the future because it promotes greater efficiency for existing transportation facilities and generates renewed interest in public transit as a transportation alternative.

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EVALUATION TOOL FOR DESIGNING PEDESTRIAN FACILITIES IN TRANSIT STATIONS

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This paper describes the Urban Mass Transportation Administration station simulation package—a model for evaluating transit station designs to determine whether a given layout achieves the design objectives of providing enough space for pedestrian movement, providing enough service facilities, and connecting these areas and facilities in the most efficient manner. To determine this, the package provides pedestrian occupancy data in all movement and queue areas; walk times, time in queue, and total times for specific areas, partitions, or the entire length of the station; and distribution of the previous variables for comparison with level-of-service standards. The model user converts a station building layout into nodes, links, and areas that represent queue devices or decision points, pedestrian paths between these devices or points, and the area associated with these devices and paths. The model simulates the flow of pedestrians along the links that represent the station and accumulates appropriate data.

•TRANSPORTATION system analysts have developed and applied sophisticated computer-based system techniques to design transportation systems, but similar techniques have generally not been available for the planning associated with pedestrian flow through station facilities. Station designers have had to rely on individual judgments or basic pedestrian flow-space relationships gathered from stations where problems already have been identified. At present, there are a few analytical design tools for analyzing pedestrian needs at stations on a systematic basis.

USS is a model that was developed for the Urban Mass Transportation Administration (UMTA) to simulate pedestrian flow through the various areas of a transit station. The general purpose of USS is to allow transit planners to study the station system before it is constructed to predict how it will function. When the final testing, documentation, and operation demonstration is completed, USS will become an integral part of the UMTA Transportation Planning Systems (UTPS). UTPS is a set of 13 computer programs with documentation to aid transportation planners in planning for urban multimodal transportation.

USS was developed in 4 phases—a general system model, detailed technical specifications for the simulation technique, an actual computer code, and acceptance testing. This paper is based on the results of the first 3 phases of the project (19, 20).

ROLE OF USS IN STATION DESIGN

Design Process

The physical design problem is a question of how much space or how many facilities are needed to meet satisfactorily pedestrian design objectives. The problem is solved in a repetitive fashion where a design is proposed and then evaluated against a set of objectives to select the optimum design as follows:

1. Define site constraints; basic architectural standards; and station origin-destination (O-D) statistics including mode, line, headway, and loadings;
2. Develop design objectives for the station (e.g., level-of-service standards for pedestrian occupancy in sq ft per person and waiting time);

3. Develop a station layout that appears to meet basic site constraints and design objectives;
4. Evaluate the layout by design objectives;
5. Refine the layout;
6. Reevaluate the layout;
7. Evaluate further and refine as required; and
8. Select the optimum design.

USS is an evaluation model that creates a machine-designer interaction—the designer makes the basic proposal and the machine provides the evaluation. Future activities may be directed toward developing a true design model that would fully automate station design.

Design Objectives

An early phase in developing USS was to define the station design problem by specific design objectives. A review of the literature revealed that, although there were many standards and design procedures, there were no universally accepted objectives for transit station design. Representatives of the professional planning community observed at a station simulation symposium that walking time, waiting time, total time in station, space standards per person, and delay times were important variables that should be considered to determine design objectives. Fruin further suggested that the overall objectives in planning for pedestrians were safety, security, convenience, continuity, comfort, system coherence, and attractiveness (8).

Based on the results of the symposium and on available literature, the station design problem was converted into the following 3 principal objectives for a safe, convenient, and comfortable pedestrian environment:

1. Provide enough space in basic queuing and movement areas;
2. Provide enough service facilities (e.g., doors, gates, and stairs); and
3. Connect these areas and facilities.

Achieving Design Objectives

The role of USS in the design process is to generate design data by measuring the extent to which design objectives are achieved. USS produces 3 basic types of design data for a layout submitted for evaluation.

1. Walking times, time in queue, total in-system times for individuals and an individual's paths in specific movement areas or the entire station;
2. Pedestrian occupancy (sq ft per person) in specific areas of the station; and
3. Distribution of these variables to compare them against design standards or level of service standards.

CHARACTERISTICS OF THE USS MODEL

System Concept

The station system was envisioned as the activities and facilities within the station building plus adjacent transit vehicle loading facilities (Fig. 1). USS can be used to evaluate any pedestrian-oriented station facility. The facility could be a small portion of a station, such as the fare collection area, or the entire station. USS is not restricted to any form of vehicular arrival or departure mode associated with the station.

System Modeling

A station system is subdivided into a series of subsystems. In general, each of the subsystems is modeled by using links, nodes, and areas that represent the basic functional areas of a station as shown in Figure 2. Pedestrian flow areas generally are represented by a link that connects the ends of the area. The ends of the area are represented by nodes that can represent queue devices, decision points, and points where arrivals or departures are created or destroyed.

Figure 1. Transit station concept.

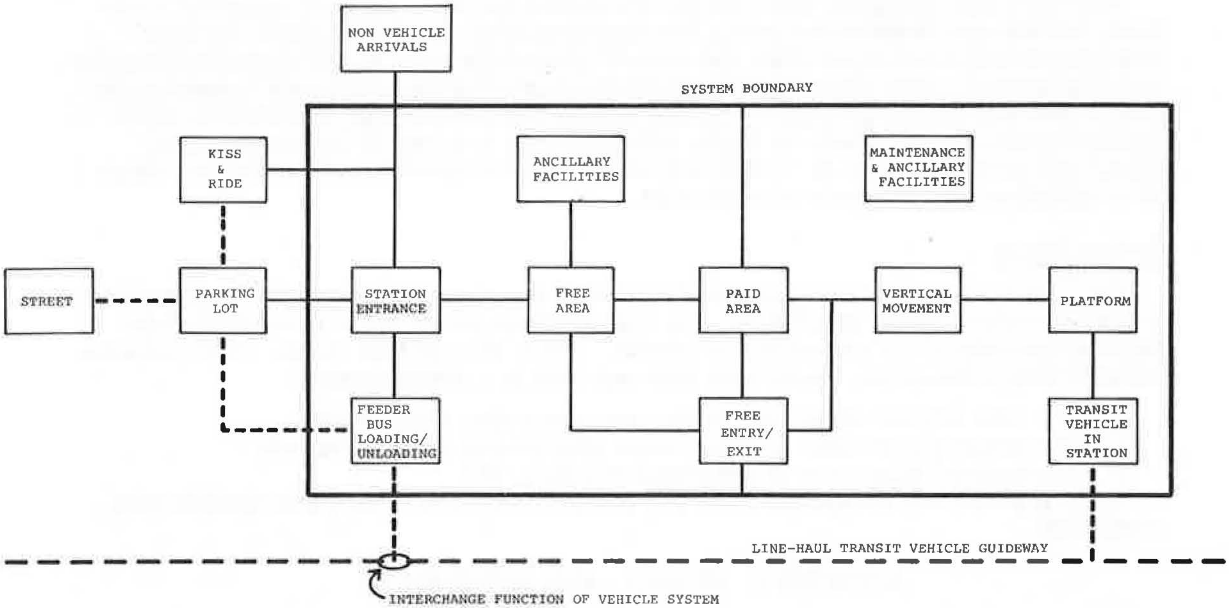


Figure 2. Link, node, and area modeling convention.

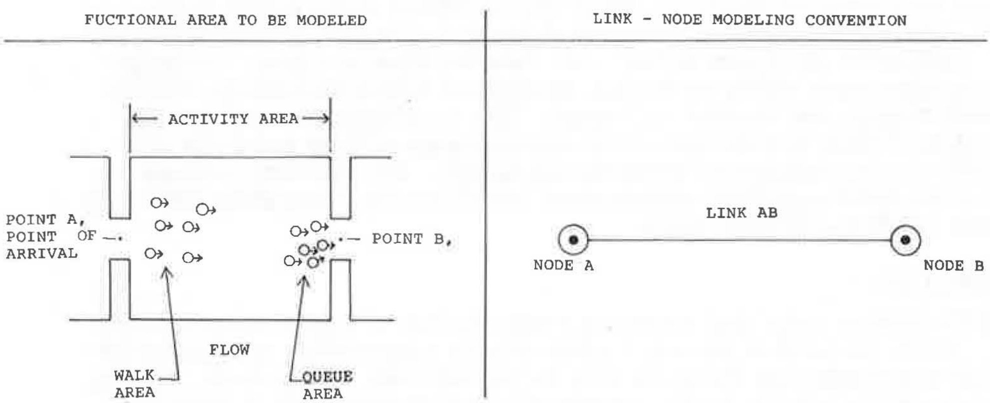
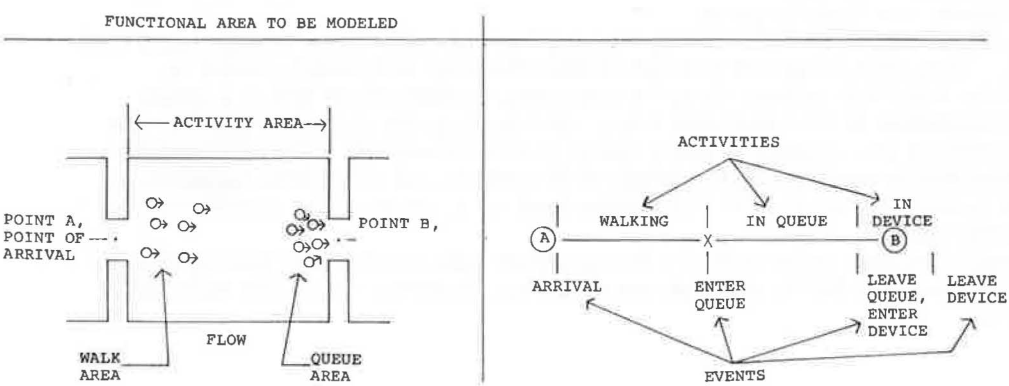


Figure 3. Relation of events, activities, and system model.



The link-node convention provides the framework for describing all important activities, events, and interactions within any station system. It also provides the user flexibility to add or combine links and thereby control the level of detail used to describe a station system. The link-node convention also provides the framework to develop efficient data processing techniques because it uses methods already developed in other transportation models. And, by laying out the station in terms of functional areas, links, and nodes, the user is forced to think through the operation of the station, which is an effective and rigorous evaluation tool.

System Image

The link-node convention provides the physical description of the station system from which the system image is created. The system image is the set of numbers that describes the state of the system at any instant. There is a system image, which includes the following information, associated with each link in a station system:

1. The total number of persons in the area associated with the link;
2. The number of persons in queue at the downstream node of the link;
3. The number of persons in movement on a link; and
4. The pedestrian occupancy (area per person) associated with the movement area of the link.

ACTIVITIES, EVENTS, AND ATTRIBUTES

The mathematical operations of the simulation model the activities of people and vehicles within the station. The simulation is event oriented; that is, the beginning of an event may stop or start an activity (Fig. 3). An event usually triggers a change in the system image or a modification of the changeable attributes of the people in the system or both. There are 2 types of attributes of people in the station—changeable and unchangeable. Changeable attributes include walk time and time on a link. Unchangeable attributes include origin within the station, destination within the station, whether the person is handicapped, and desired walk speed. The accumulation of information on the changes of individuals and changes in the system image of links and nodes provides the required data to evaluate any given station design. The following sections describe some of the more important mathematical operations and processing steps that generate data and create the system image.

Determining Walk Time

Determining the time an individual spends on a specific link of a system has 2 major complications. First, the node at the end of a link usually represents a queuing device so there is a high probability that the speed near the end of a link breaks down. Second, there is a high probability that the person's speed will be modified by other individuals moving in the same direction, people moving in the opposing direction, or people crossing the flow. Thus, the actual time on a link is a function of link length, desired walk speed, concentration of people in the area of movement, amount of conflicting flows, length of the queue, and time in queue.

Walk time is calculated by determining the length of the queue when an individual first enters a link. Then, this length is subtracted from the total link length, and it is assumed that the individual moves along the remaining portion of the link at a speed based on the congestion in the movement area. On reaching the end of the queues, the individual is inserted into a queued events list to wait to be served. The length of the queue is determined by multiplying the length of the designated queue area (supplied by the user) by a queue link factor—the ratio of the number in queue to the capacity of the designated queue area.

The difference between an individual's desired walk speed in the free flowing area of a link and actual speed is due to other persons sharing the same area. The walk time in a corridor is

$$(t_{AB})_i = \frac{60\ x}{(u_i)\text{actual}}$$

where

$(t_{AB})_i$ = actual walk time over AB for individual, i, in sec, and
(u_i) actual = walk speed of individual, i, in congestion, in ft/min (m/min).

The actual walk time of an individual in a specific area of a station is a function of the desired walk speed and the ability to maintain this speed. The determination of actual travel time for an individual is thus related to the macroflow characteristics of the area being analyzed. The effect of competing flows on the travel times on a specific link is based on the absolute number of people in the area associated with the link and the desired walk speeds of individuals on the link.

Service Time

The most critical operation in the station system, for effect on the system image, is determining service times at a queue device. The congestion created by doors, fare collection gates, escalators, corridor constructions, and vehicle doors is of prime importance to the station designer. In USS, the service time is described by a service time distribution that defines the times between passengers served (interservice times). Variation between the interservice times of the service channel and the interarrival times creates the queuing environment.

In the simulation model, specifying service time distribution is a user option. The negative exponential distribution defines the time relationship between individuals if none is supplied by the user. And, in most cases, this assumption will be the best estimate of service time distributions.

Deriving Numerical Values From Distribution Functions

Numerical values are determined in USS by obtaining a sample from a distribution specified by the user or a list of default values in the program. The distributions are used by a table lookup procedure or by the inverse form of the theoretical distribution. The theoretical distributions to be included initially as user options are the negative exponent, Erlang, where K = 1, and the normal distribution. The derivation of these functions can be found in several texts. In addition, the algorithm to derive random deviates from these distributions is described by Alan et al. (16).

Generation of Arrivals

Associated with every station system to be simulated is a series of loading bays, sidewalks, doorways, or similar devices where people come into and leave the system. At the arrival and departure point, a node representing a zone of origin or destination will indicate the location of the arrival and departure device. Each of these nodes (also called zones) will be connected to a link that will tie the arrival point to the remaining portions of the system (Fig. 4). The type of arrival mode will determine the types of statistics to be generated. Two major types of nodes are possible—vehicle loading bays and walkways-doorways.

Path Choice

One of the critical and sophisticated simulation algorithms in USS is the procedure for simulating individual path choices. The following items are considered in the path choice algorithms:

1. Station arrival-departure mode and line;
2. Passenger attributes such as handicaps;
3. Activities that can be reached on alternate paths; and
4. Length of queues where equal alternate paths are available.

The actual procedure can be thought of as a modified, continuous-parameter, dynamic Markov chain (3) where the transition probabilities from node to node within the station are updated dynamically as a function of congestion within the station. The sequential computational steps in the path choice model are as follows before simulation begins:

1. Determine preliminary t(i, j) values for the network where t(i, j) is the anticipated hindrance time link;
2. Calculate shortest time path from a destination in the network to all other nodes in the network;
3. Calculate preliminary link likelihoods (e.g., link resistances as opposed to path resistances); and
4. Calculate preliminary link weights.

The sequential computational steps are as follows during simulation:

1. When a passenger reaches a node in the station, determine the reasonable links emanating from this node by applying a closer-to-destination criterion;
2. Check for user-specified input percentages applying to either reasonable or unreasonable links;
3. Screen the efficient and inefficient links by relevant passenger attributes;
4. Determine t(i, j) for the next link based on walking times over the next link and relative queue lengths;
5. Calculate link likelihoods over the reasonable links;
6. Calculate dynamic link weights;
7. Calculate transition probabilities by using link weights and, if applicable, user-specified input percentages; and
8. Repeat steps 2 through 8 for each node traversed by each passenger in the network.

The path-choice algorithm just given models the nonoptimal behavior of passengers within the station. (For example, all passengers do not choose the shortest path from their origins to their destinations within the station.) It also models the probability of their selecting alternate paths at a decision point within the station. It minimizes the user-specified input needed and allows the user the flexibility to specify input percentages at nodes in the station network to divert passengers on efficient or inefficient paths to auxiliary facilities such as phone booths, concessions, rest areas, restaurants, and newsstands.

The path-choice model satisfies 3 functional specifications. First, the model gives a nonzero probability of use to all reasonable paths between a given origin and destination, whereas all unreasonable paths have a zero probability use. Second, all reasonable paths of equal time have an equal probability of use. Third, when there are 2 or more reasonable paths of unequal time, the shorter path has the higher probability of use.

OUTPUT

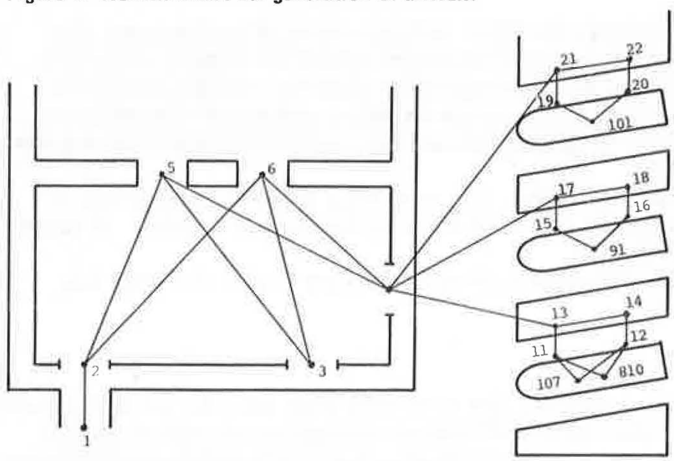
The development of output reports is the end product of the transit station simulation model. Output reports can be put into 2 general groups—stationwide statistics and link-node statistics.

Station Statistics

Four types of output reports present overall station statistics for various types of information.

1. The output for overall station statistics is a presentation in numerical order of basic system operating characteristics by link and node. For a link, the basic output is the maximum number of persons that were in the area associated with the specific link at any instant, the lowest pedestrian occupancy in the movement area (in sq ft per person) at any instant, and the total number of persons that were assigned to the link (e.g., the hourly volume) during the simulation period. For a node, the basic output is the maximum number of persons in queue at the node at any instant during the simulation period, the maximum density of people in the queue area expressed as a percentage of the capacity of the queue area, and the total volume through the node. The data for the node are presented for both the inbound and the outbound sides of the node.

Figure 4. Nomenclature for generation of arrivals.



NODES 1 AND 3 ARE NODES OF PEDESTRIAN ARRIVAL GENERATION AND DEPARTURE, NODES 107, 810, 91 AND 101 ARE NODES OF VEHICLE ARRIVAL GENERATION AND DEPARTURE WITH NUMBERS CORRESPONDING TO LINES WHICH LOAD AND UNLOAD AT THIS BAY, LINES 107 AND 810 USE THE SAME BAY.

Figure 5. Station time summary.

```
PAGE XXX     10JUL73    SAMPLE TRANSIT STUDY - STATION XX   RUN XX
  0    4    8   12   16   20   24   28   32   36   40
  +----+----+----+----+----+----+----+----+----+----+   P.C.   CUM  COUNT
 0.                                                      0.0    0.0     0
 5.........................                            21.0   21.0    21
10...........................................           35.0   56.0    35
15................................                      26.0   82.0    26
20.................                                     13.0   95.0    13
25.......                                                5.0  100.0     5

REMAINING VALUES ARE ALL ZERO
XXXXXX OBSERVATIONS      XXXXXX OBSERVATIONS TRUNCATED TO ELIMINATE BIAS
XXXXXXX. = SUM    XXX.XXX = MEAN    XX.XXX = VAR    XX.XXX = SD
XXX.XXX TO XXX.XXX = CONFIDENCE INTERVAL FOR MEAN
```

Figure 6. Overall station statistics.

PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

ORIG NODE	DEST NODE	-----ARRIVALS----- MODE/LINE		PEOPLE	----DEPARTURES---- MODE/LINE		PEOPLE
1001	1316	BUS	11	475	WALK		469
1005	1211	TRANS	42	1021	BUS	17	1001
1010	1316	BUS	13	242	TRANS	12	242
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1201	1412	WALK		47	TRANS	7	46

PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

ORIG NODE	DEST NODE	----WALK TIME----- MEAN	MIN	MAX	--TIME IN QUEUE--- MEAN	MIN	MAX	--TIME IN SYSTEM-- MEAN	MIN	MAX
1001	1316	12.3	7.1	17.3	7.1	3.1	14.1	20.2	11.1	30.2
1005	1211	15.6	7.9	23.1	9.7	4.9	19.1	25.9	11.7	43.1
1010	1316	10.1	6.6	14.2	11.2	6.2	16.3	22.3	13.9	35.7
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1201	1412	8.1	3.1	12.8	2.1	0.8	4.1	10.6	2.1	18.2

2. To allow the user to easily identify the most critical areas of system use, the output reports could be reformatted to print in descending order the density of people for both links and nodes. To minimize core storage and computer running time, the user will need to limit the number of links and nodes on which statistics will be saved. This output report will allow the user to identify those links and nodes where saving detailed statistics will have some value.

3. To evaluate the overall station operation, the user may request summaries of overall station walk time, time in queue, and total time in the station system. A sample of this type of output is shown in Figure 5.

4. To evaluate station hindrance times by arrival-departure mode, the user can specify output as shown in Figure 6.

Link and Node Statistics

For selected links and nodes in the system, the user will want specific occupancy and hindrance time characteristics. Based on a preliminary evaluation of critical station areas, or experience on previous runs, the user will select specific link and node output reports for these purposes. The following are types of link and node output reports.

1. Figure 7 shows an occupancy report for a link in a station. This report summarizes the system image at each simulation interval. Activity in the link is frozen every 10 seconds to show area requirements and the number of persons arriving, departing, in movement, competing with the movement, and in queue. The user may find the number of persons in queue exceeds that designated for the queue area. Then, the station planner may increase the queue area. Average values of the statistics during the simulation period are also shown.

2. For each of the output statistics in the occupancy report, the user may request a more detailed summary of the characteristics similar to that in Figure 5.

3. Hindrance time statistics are also available for selected links or nodes. There are 3 types of link and node hindrance summaries. First, the user may request a summary for a walk time between 2 nodes. Second, the user may request time-in-queue statistics at a particular node. Finally, the user may request statistics for total in-system time from 1 node through another node. The user could specify statistics for 1 link or a number of links. The format of these reports also would be similar to Figure 5.

Application of Statistical Analyses

Most of the output reports summarize output values by mean, variance, and confidence intervals. Because the values used to calculate the output statistics are generated by a stochastic, time-dependent process, the values in the time series will be correlated with each other. So, a finite autoregressive technique to represent the autocorrelated behavior in the time series must be used. The station simulation model uses the autoregressive statistical package to generate the following statistics for any series of user-specified output values:

1. The sample mean;
2. The sample population variance;
3. The lower confidence point of the confidence interval for the mean;
4. The sample size used to calculate the mean and variance; and
5. The upper confidence point of the confidence interval for the mean.

The output statistics generated by the model when the station first starts do not represent stable operating characteristics. Because they depend on the initial condition, observations near the beginning of the simulation period do not represent the true process, and including them in calculating the mean biases the true mean value. But, as the number of observations used to calculate the mean becomes large, the bias goes to zero because the early observations have less influence on the average. Thus, the statistical package used in the model identifies the number of observations, x, that must be discarded from the total observations to ensure that the output statistics are not biased by the initial conditions.

Checkpointing

The simulation will terminate when 1 of the following conditions is met:

1. The simulation period ends;
2. The number of persons outside any queue area exceeds the user's specified limit (in percent); and
3. The occupancy in any movement area is less than the user's specified limit.

Termination is always considered a checkpoint and the user receives the output statistics specified plus the checkpoint file for preloading the network on a future run. The checkpoint file includes card images of user input plus the attribute records of all persons in the station at the time the checkpoint occurred. At restart after checkpoint, the user has the option of adding, deleting, or changing the input values used on the previous run and modifying station loadings for the next run. Checkpoint termination should be triggered by situations where simulation of output values exceeds a specified limit that reflects an out-of-control situtation rather than by an undesirable level of operation that should be allowed to occur to experience a full range of values. For example, the user might specify that the program be checkpointed if the number of persons in queue exceeds 200 percent of the queue space or if the occupancy values in the movement area exceed the level of service F.

Input

The bulk of the input data will be coded on 1 of 9 different types of input cards. In many cases, however, the user may use only 5 or 6 of these cards. The 9 types of input cards are as follows.

Distribution Input Card—When it is necessary or desirable to specify a distribution for use in generating numerical values in the program, the user will specify either the parameters of a theoretical distribution or the x and y points of an empirical distribution.

Device Input Card—The user may wish to specify input data for 1 form of device, such as an escalator, and use the same input data each time that device is specified. This card would be particularly valuable for minimizing the amount of input required where nodes representing queuing devices have the same characteristics.

Node Data Card—For each node in the station, the user must specify node characteristics including identification number, type of device, and queue characteristics.

Link Data Card—For each link in the station, the user will specify link identification, link length, movement area, capability to accept handicapped persons, and other pertinent data.

Shared Area Card—Where links and nodes share the same area (overlapping movement or queue areas), the user must specify these interrelationships. This would be used primarily in the platform area, and, because of the impact on computer running times, the user would limit the number of shared areas to an absolute minimum.

Arrival-Departure Node Data Card—For each node that represents a point where passengers are generated and removed from the systems, data describing the arrival process must be specified and include O-D zone number, type of distribution of arrivals, and characteristics of the door where the arrivals occur.

Elevator Input Card—Specific data is required for a link that describes an elevator. The user must specify headways, link lengths, and door opening times.

O-D Input Card—An O-D table by O-D zone is required.

Output Report Generator Card—For the user to generate data on selected links or nodes, the links or nodes on which reports are desired must be specified.

How USS Is Used

To start, the user would review the Program Write-Up and User's Guide supplied with the USS package, which will provide all the information that the user requires to use the program. After reviewing the guide, the user would run the sample problem that is part of the computer code. Although the sample problem includes only a small

Figure 7. Link occupancy report.

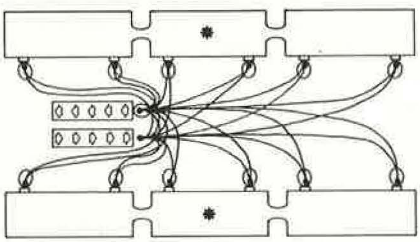
PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

TIME	PERSON ARRIVALS	PERSON DEPARTS	NUMBER ON LINK	NO. THAT COMPETE	TOTAL IN MOVEMENT	AREA/ PERSON
0010	53	15	47	3	50	10.1
0020	77	17	75	0	75	10.6
0030	62	43	87	6	93	9.2
.	.	.	.	.	.	.
3600	14	51	99	18	117	5.3
TOTAL	6143	6002	5800	407	6207	
MEAN	21	20	22	2	21	8.2
MIN	0	0	0	0	0	4.2
MAX	123	151	150	20	151	12.7
BIAS	12	14	14	50	12	15

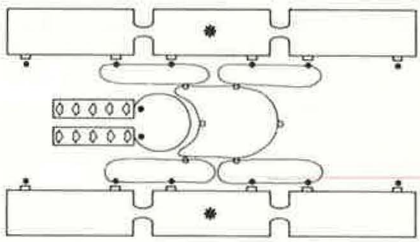
PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

	----'A' NODE QUEUE-----			----'B' NODE QUEUE-----		
TIME	NO. IN QUEUE	REQ'D AREA	OUTSIDE QUEUE	NO. IN QUEUE	REQ'D AREA	OUTSIDE QUEUE
0010	7	35	0	0	0	0
0020	12	60	2	1	5	0
0030	11	55	1	5	25	1
.	.	.	.	.	.	.
3600	14	70	3	7	35	11
TOTAL	8732		120	2670		175
MEAN	15	75	0	7	35	0
MIN	0	0	0	0	0	0
MAX	60	300	4	10	50	12
BIAS	15	15	50	32	20	70

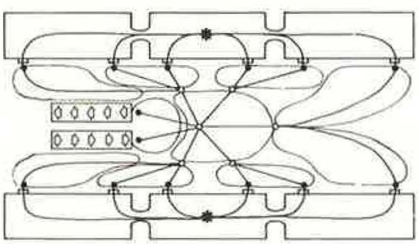
Figure 8. Station layout process.



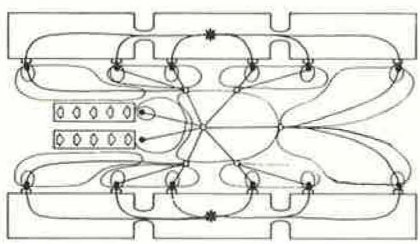
1. LAYOUT ACTUAL PATHS AND QUEUE AREAS



2. LAYOUT SHARED AREAS AND NODES TO CONSOLIDATE PATHS



3. CONNECT NODES WITH LINKS (ADJUST TO EQUALIZED AREAS)



4. DESIGNATE QUEUE AREAS

● QUEUE DEVICE NODE

○ DECISION POINT NODE (NO QUEUING ASSUMED)

✱ ORIGIN-DESTINATION NODE (ZONES)

network, it would familarize the user with the basic capabilities and options of the program. The user then would be ready to select an actual station layout for evaluation. Initially he or she probably would select a simple layout or a portion of a layout for testing to become more familiar with the package.

The first step in evaluating the layout would be to convert the layout into links, nodes, and areas. This begins when the user lays out paths that people follow and queuing areas that they use in the station. The user would consolidate areas of conflicting movement into shared areas, locate nodes where paths intersect or areas come together, connect the nodes with links, determine movement areas and other link and node statistics, and designate queue areas. This process is shown in Figure 8.

The user then would prepare the input cards for the program. At first, the user would want to code only a minimum of data to keep running time short and the problem simple. The program includes default values for all but the basic network description. The minimum input includes the following:

1. A parameter card listing the number of links and nodes in the station network and the number of O-D zones;
2. An O-D table (number of persons from inbound node x to outbound node y);
3. A node card for each of the nodes in the network with the mean service time, (e.g., 2.5 seconds per person for a doorway) and the designated queue area (sq ft per person);
4. A link card for each of the links in the network with the link length and the movement area; and
5. An O-D node card for each O-D zone in the network with the node identification number, the O-D zone number that corresponds to this node in the O-D table, the minimum door-open and door-open-extension time, and, if the node represents a vehicle loading bay, the vehicle arrival pattern expressed as a mean headway (e.g., 15 min between vehicles) or a distribution of headways.

With this minimum input the user would run the program. At the termination of a typical run, a checkpoint file would be created for preloading the network on the next run. The user then would add, delete, or change input values to modify the network or its characteristics. As the user became more familiar with the package he or she could change distributions supplied by the program, use device input cards, create more shared areas, and select more detailed output.

SUMMARY

USS can be used in evaluating proposed transit station layouts. Although it will require additional testing and calibration to integrate USS into the transit station design process, it is clear that it will significantly increase the identifying of potential operational problems on the drawing board.

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INTERMODAL TRANSFER FACILITIES RESEARCH NEEDS

Committee on Intermodal Transfer Facilities,
Transportation Research Board

The Committee on Intermodal Transfer Facilities was recently formed as part of Group 1, Transportation Systems Planning and Administration. As one of its initial activities, the committee developed this general outline and classification of the elements in the typical intermodal passenger transfer system and a brief description of each element and its perceived research needs. The statement will require periodic revision as these needs are filled or new problems emerge. Comments on the statement are welcomed by the committee.

•INTERMODAL transfer facilities are interchanges between transportation subsystems. They range from relatively simple bus or rail platforms to multimodal regional transportation centers or large airport terminals. Because intermodal transfer facilities are expensive to construct and operate, it is important to optimize their function.

INTERMODAL TRANSFER SYSTEM

Figure 1 shows a schematic of the intermodal transfer facility system. The intermodal transfer system is complex; it involves many planning factors to determine not only location, size, and configuration but also effects on the transportation network, the region, and the community.

The classification of elements shown in Figure 1 is useful because it forms the basis for a systematic approach to passenger-transportation system interface problems, and illustrates factors that are common to other modal interfaces. For example, improvements in building technology, maintenance, or information systems could apply to rail, bus, or air terminals. Although the research needs discussed in this paper follow this outline, enough interrelationships between system elements exist that several could be combined into 1 research project.

SYSTEM ELEMENTS AND RESEARCH NEEDS

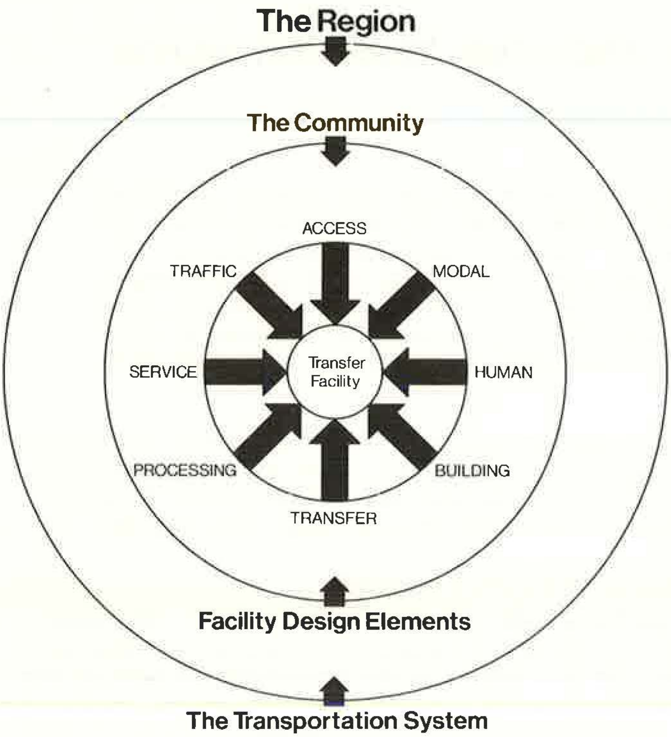
Regional

Intermodal transfer facilities are important because they connect the small feeder service systems with the large line-haul system; they promote passenger accessibility and enhance the utility of the total system. The efficiency of passenger interchange between transportation subsystems determines patron usage. Their regional influences involve land use, socioeconomic, and environmental effects. For example, airport terminals occupy large amounts of land space and central business district transportation centers occupy strategic, expensive core space. Transportation systems have significant socioeconomic effects as employers, generators of commercial development, and enhancers of regional mobility. Therefore, factors that determine optimal sizing and location of intermodal transfer facilities, including quantitative data requirements and analytical procedures, should be established.

Community

The intermodal transfer facility promotes community accessibility to the regional transportation network. The transfer facility can provide a nucleus for community development; it can be the focal point of the local supporting transportation network and the center for governmental, cultural, commercial, or other development. Commercial

Figure 1. Intermodal transfer facility system.



development within the facility can provide useful user services and help to defray facility costs. The relationship of the facility to community development should be determined. This includes considerations of land use strategy and control near terminals, facility expansion and change, zoning techniques, joint development programs, institutional and financial arrangements, jurisdictions, and commercial development within and surrounding the facility.

Transportation System

The intermodal transfer facility determines total transportation network effectiveness. As a connecting node, the facility integrates the various transportation modes to maximize the number of users. A poor connector would discourage potential users or cause them to be diverted to other modes. Poor transportation system operating practices sometimes introduce crowding and delay, which can be attributed wrongly to inadequacy of the transfer facility. There is a need to establish factors that optimize total transportation network effectiveness. More information is required on the effect of system operating practices on modal transfer efficiency and space use, and procedures should be developed to improve efficiency and reduce space requirements, passenger inconvenience, and delay.

Access

Access adequacy determines the operating capacity of a modal transfer facility. Inadequate access can result in underuse of the facility and wasted investment. To maximize productivity and minimize passenger crowding and delay, equipment supply must match passenger demand. The relationship of the access system to facility productivity must be determined. This includes not only equipment arriving off the line, but also equipment held in reserve for increased demand. Passenger and equipment arrival characteristics, including expected variances in arrival times and demand, must be studied. Planning, design, and development criteria for feeder systems such as para-transit, pedestrian ways, bikeways, and kiss-and-ride must be determined along with regulatory or design strategies for proper use of station parking facilities.

Modes

The physical dimensions, configuration, and operating characteristics of the modes serving the transfer facility determine its form. For example, conventional rail transit configurations dictate linear platform designs, which result in long pedestrian walking distances. The number, size, and location of transit vehicle doors determine the size and positioning of many design features such as stairs, escalators, columns, and signs. The positions of trains at platforms can affect platform clearance times, which are a measure of convenience and efficiency. After the relationships of vehicle configurations and operating characteristics have been established, it can be determined whether changes in equipment design or operation will improve the efficiency and convenience of passenger movements from one mode to another.

Passengers

Passenger perceptions of service efficiency, convenience, comfort, and security greatly influence their choices of transportation modes. There are no existing analytical techniques to quantify the values that passengers place on waiting time or walking distances or other activities at transfer facilities. The relationship of human behavioral factors to facility design should be established to evaluate alternative designs and their relationship to increased facility investment and improvements in service. One aspect of this would be to determine the factors affecting human delay tolerance and its relationship to situations such as transit platform clearance times and delays in long headway versus short headway systems.

Building

The building houses the intermodal transfer function and includes the electrical and mechanical systems. The basic configuration of the building is determined by human and modal requirements, but construction methods, materials, architecture, and finishes can affect its cost and useful life. Maintenance costs over the life of a terminal facility can far outweigh the first construction cost. Therefore, the building types, finishes, maintenance procedures, and systems that will best minimize total facility-life costs should be determined, and the relative building costs per processed passenger for different facilities should be established. The variability of transportation demand and evolutionary changes in transportation systems emphasizes the need for flexible building design that is capable of alteration as use characteristics change.

Transfer

Transfer elements are mechanical subsystems requiring substantial investment and continuing maintenance for movement and storage of people and goods. When these systems are not adequate, or are out of service because of mechanical failure, the passenger may be subjected to delay and inconvenience. Typical problems faced by designers are the height at which escalators should be used to supplement stairs and the proportion of the user population that should be accommodated by the mechanical system. The human factors, traffic capacity, and costs that govern the use of mechanical vertical movement systems (elevators, escalators, and walks) also need to be determined. In addition, the need for balance in standby systems; the need for higher speed escalators and moving walks, such as those in operation in Europe; actual traffic flow capacities of mechanical movement systems, rather than manufacturers' claims; and preventive maintenance procedures or redesign of mechanical service systems must be determined.

Processing

Processing elements are turnstiles, ticket dispensing devices, and other passenger control systems. Processing system efficiency can affect passenger demand. An example of processing system effect may be seen in the long-distance bus industry. There is no ticket reservation system in this industry, so passenger arrivals are uncontrolled; this causes serious passenger congestion and delay during seasonal peak periods. The functions, capacities, and costs of passenger processing systems should be established; criteria should be developed to optimize efficiency.

Service

Service elements are auxiliary subsystems such as rest rooms, waiting rooms, and concessions. Concessions can be an important determinant of the economic feasibility of some facilities. But, concession revenues are extremely variable; they are related to factors such as terminal location, the type of passenger and his or her needs, and the type of concession and its marketing. There is a need to determine planning criteria for concessions to provide guidelines on the amount of revenue for different types of concessions so that revenue can be optimized.

Traffic

Traffic is related to hourly, daily, seasonal, and other factors that determine the size, efficiency, and service of the facility. There are few industry criteria to aid in designing facilities to accommodate traffic. Regulated passenger traffic, controlled by ticket reservation systems such as those in the air industry, limit terminal demands and provide more balanced facility use. Unregulated passenger arrival traffic, such as that in the long-distance bus industry, causes unbalanced passenger demands, severe crowding, and lengthy service delays. Staggered work-hour programs reduce facility traffic and improve passenger service levels. Traffic characteristics that change over time affect passenger service levels. Design guidelines should be established for various types of facilities based on traffic characteristics and operational techniques. Procedures should be developed to modify traffic patterns and provide optimal use of facilities.

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