Measuring Station Capacity for Seattle's Bus Tunnel

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ABSTRACT

A discussion of the passenger system capacity of the Downtown Seattle Transit Project is presented in this paper. The purpose of this paper is to analyze the design of the subway stations associated with the Downtown Seattle Transit Project with regard to the levels of service experienced under estimated passenger volumes using the facility. Level of service and capacity methodology for pedestrians are reviewed for individual components of the transit project. Primarily, this analysis is based on observed data and levels of service research conducted by Fruin (1) and Pushkarev and Zupan (2). Estimated station passenger volumes for the years 1990, 2000, and far into the 21st century are analyzed with respect to levels of service. System components examined are the station entrance, mezzanine levels, and station platforms. Presented are examples of Fruin's and Pushkarev's methodology applied to several specific design components of the subway stations.

The Downtown Seattle Transit Project is an innovative response to improving transit service hindered by heavy traffic congestion in downtown Seattle, Washington. Seattle is a city of approximately 0.5 million people and is the employment and population center of the Puget Sound region which has approximately 2.5 million people. During the past decade, significant population and employment growth has occurred in this area. Downtown Seattle has seen a dramatic growth in high-rise office buildings. Office space increased 39 percent between 1975 and 1982. Employment increased 25 percent from 1970 to 1980 and is expected to increase another 25 percent between 1980 and 1990 (3).

Increased transit service provided by Metro (Municipality of Metropolitan Seattle) has accommodated a significant percentage of trips to downtown Seattle. During 1980, 40 percent of peak-hour and 28 percent of daily trips to downtown Seattle were made by transit. The transit mode split to downtown Seattle is expected to grow to 55 percent during peak hour and 40 percent of daily trips by 1990 (3).

To alleviate the present and forecasted traffic congestion and enable buses to move faster (currently, buses average 4 to 5 mph downtown), a subway for buses has been proposed and is in the final design stage. A map of this project is shown in Figure 1.

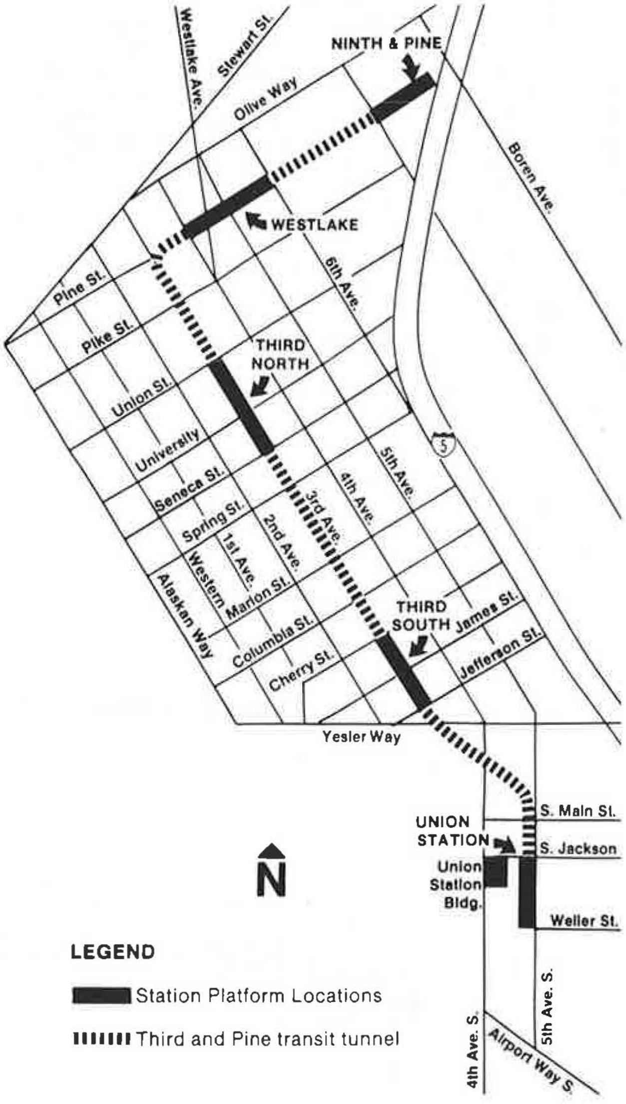

FIGURE 1 Map of project.

SYSTEM DESCRIPTION

The Parsons Brinckerhoff Design Team was selected by Metro for preliminary engineering and final design of Seattle's proposed downtown transit tunnel. Work on the 1.3 mi system began in mid-1984, and preliminary engineering was completed in mid-1985. Construction is planned to start in 1986; the new system will open in 1990.

The proposed tunnel will help facilitate the growing transit demands of the downtown. Currently,

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in the peak hours, buses form a wall along Third Avenue, one of the major transit routes through the downtown. The tunnel is expected to remove approximately 300 buses entering the downtown surface street system during the year 2000 peak hours. Both system capacity and vehicle speed will be improved.

The tunnel is being designed for dual propulsion bus technology: a bus intended for electric operation in the tunnel and diesel operation when it leaves the tunnel. Such a bus will operate outside of downtown to suburban destinations. In addition, the tunnel design will permit conversion to light rail transit (LRT) in the future. The design can be expected to accommodate both the dual-propulsion bus and LRT service during a transition period that may involve shared operation for some years.

At this stage, a bored tunnel of twin 18-ft diameter line sections on a north-south alignment is proposed beneath Third Avenue. The tunnel will connect a surface station and south staging area to three underground stations spaced along Third Avenue and Pine Street in an L-shaped corridor. A cut-and-cover tunnel section extending east along Pine Street will connect the underground station under Pine Street at Westlake Avenue to a surface station at the north staging area. Both the north and south staging areas will receive and discharge buses to the freeway system that serves the downtown.

The three intermediate underground stations have been located to intercept existing and projected patronage and to avoid adverse impacts on key activity centers and historic structures in downtown Seattle. The stations are designed with a mezzanine located above low, side-loading platforms. Station entry will be accomplished by locating access within adjacent buildings where possible, avoiding the narrowing of sidewalks. Cut-and-cover construction of the stations will be used to reach levels as deep as 60 ft below Third Avenue in order to maintain tunnel alignment and to avoid major utility dislocation. Figure 2 shows an architect's sketch of the platform area of the Westlake station.

The centerpiece of the system will be the Westlake station, designed to connect, at the mezzanine level, the proposed Westlake Mall development, a relocated Seattle Monorail station, and three major department stores. Located near the Westlake station is Seattle's famous Pike Street Marketplace.

The south staging area will contain a surface station accommodating transferring passengers from surface circulation routes, Seattle Kingdome patrons, and the International and Pioneer Historic District visitors. The staging area will use the abandoned rail yard of historic Union Station, which lies below the grade of the surrounding streets east of the Kingdome.

The north staging area will contain a surface station serving functions similar to that at Union Station. The city of Seattle land use plan anticipates a major office center development in this area. The Seattle Convention Center, which is under construction, will be located nearby as well. The below-grade staging activity will accommodate dual-propulsion buses to be dispatched through the tunnel and will also relieve surface streets that are now used for bus deployment.

Each staging area serves three primary functions. Buses entering the staging area are to be formed into platoons of two to four buses. In addition, the coaches change to or from diesel operation to or from electric trolley bus operation. After the buses have been formed into platoons, they move into a platform station area for passenger loading.

Plans call for the two staging areas to be covered by lids. The intent is to mitigate adverse impacts resulting from the transit staging and conversion from diesel to electric operation. The lid design is expected to be capable of supporting substantial development of the air rights above the staging areas. These and other joint development options are being considered as the engineering proceeds.

PEDESTRIAN LEVELS OF SERVICE

This paper has been prepared to show the application of pedestrian level-of-service guidelines in defining the capability of major components of the Downtown

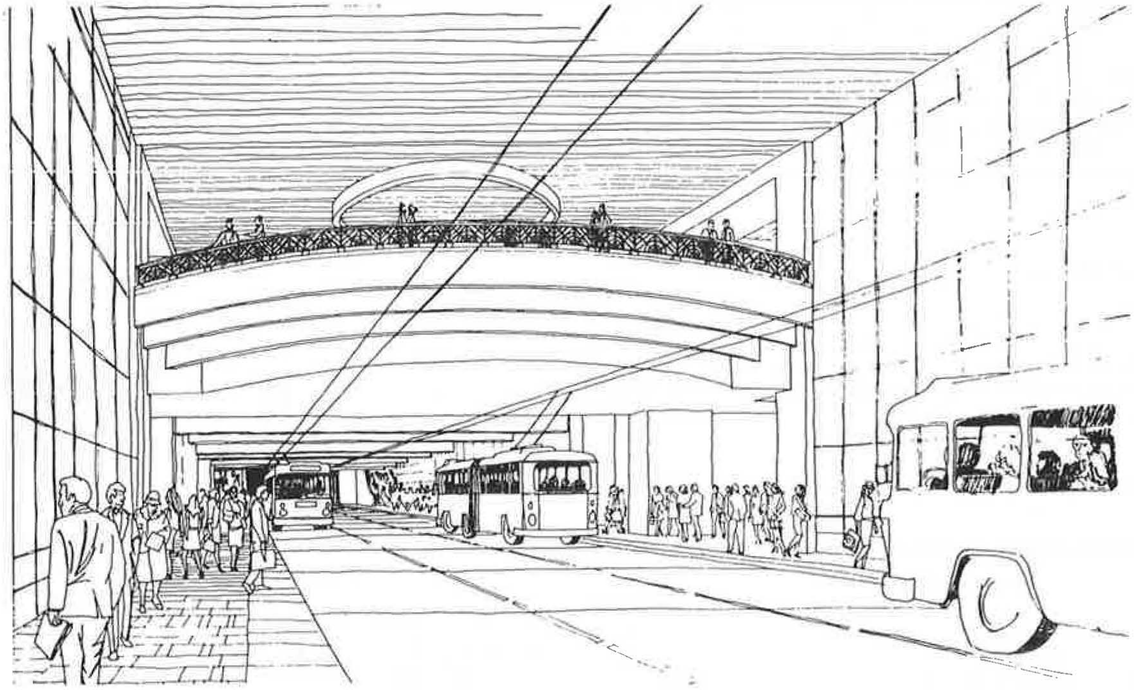

FIGURE 2 Platform view—Westlake station.

Seattle Transit Project to meet the projected levels of patronage for bus operations in 1990, 2000, and at future LRT operations at central business district (CBD) buildout. Major components of the system analyzed include the following:

- Station entrances and exits;
- Station mezzanines (ticketing equipment, areas for queuing and circulation); and
- Station platforms.

The objective of a transportation facility is to accommodate a quantity of demand (pedestrian or vehicular) with an acceptable quality of service. The capacity of various components of the Downtown Seattle Transit Project are measured by either a volume-to-capacity ratio (V/C) or a level of service. Levels of service are a way of assessing the performance of various components of a transportation system under varying conditions of patronage or usage. In general, the six levels of service range in descending order from A to F. Level of service A is associated with a complete lack of congestion and free-flowing operations. Level of service E is the ultimate capacity of a component and is associated with extreme congestion. Level of service F represents forced flow conditions where demand exceeds capacity. Level of service C, typically the level of service designed for, is between A and F and is associated with moderate congestion and is regarded as acceptable to peak periods of service demand.

Volume-to-Capacity Ratio

A volume-to-capacity ratio is the volume of passengers or vehicles experienced at a certain demand level divided by the maximum volume a system component can accommodate. A volume-to-capacity ratio greater than 1.0 means the facility is over capacity; less than 1.0 means either excess design or excess ultimate capacity exists on the facility. This level can vary depending on the denominator; that is, either design capacity or ultimate capacity. In general, here reference to a V/C ratio is meant in terms of design capacity.

The capacities required of a component to meet projected demands were identified for two selected demand levels for bus operations and a future level of rail operations. These are defined as follows:

- Bus tunnel in 1990: 80 buses per hour or 4,800 riders in each direction during the peak hour.
- Bus tunnel in year 2000: 145 buses per hour or 9,000 riders in each direction during the peak hour.
- LRT at buildout: 4-car trains at a 90 sec headway or 25,800 riders in each direction in the peak hour.

STATION ENTRANCES AND EXITS

Different components of the system were investigated for their capacity to accommodate projected pedestrian demand. The first component examined was the entrance and exit capacity of the various stations. Station entrances and exits consist of stairways, or stairways and escalators, for passenger ingress/egress between the street level and the mezzanine level. The capacity of an entrance and exit varies based on the width of stairways (or the total width of stairways and escalators) available for entering and exiting passenger flows and the quality of passenger flow. In analyzing the entrance and exit capacity of the bus tunnel stations, several commonly cited stairway and escalator capacity values were reviewed. These are discussed in the paragraphs that follow.

Stairway Capacity

Stairway capacity was based on studies by Fruin (1) and Pushkarev and Zupan (2). Fruin originally performed a speed-flow analysis of stairways and derived flow-space and speed-space curves based on measurements at the Staten Island Ferry terminal in Manhattan and Shea Stadium in Queens. These yielded a theoretical maximum flow of 18.9 pedestrians/min/ft of width ascending and 20.0 pedestrians/min/ft descending, strictly one-directional flow. Actual observations by Fruin did not exceed 16 or 17 pedestrians/min/ft of stairway width. These observations revealed that movement on stairways begins to approach free flow at 8.7 pedestrians/min/ft of stairway width up and 7.6 pedestrians/min/ft down. Flows as high as 20 pedestrians/min/ft were observed at the PATH World Trade Center station, and this was a surge over a previously empty stairway. Free flow in one direction is usually attained at a flow rate of 5 to 7 persons/min/ft of stairway width (1).

Pushkarev and Zupan (2) made counts at eight subway stairways between the mezzanine and the street in Manhattan. These counts revealed that the maximum upward flow rate was 16.2 persons/min/ft of stairway width. Heavy queuing at the bottom of the stairway was associated with that flow rate. No queuing was observed at flow rates of less than 12 persons/min/ft, if the flow was exclusively in the upward direction and nobody was coming down the stairs in the opposite direction. When an occasional downward movement did occur, that figure dropped to 11 persons/min/ft.

On the basis of their own work and the work of Fruin and others, Pushkarev and Zupan (2) suggest the stairway capacities for three service levels as shown in the following table:

Service Level (quality of flow)	Maximum Flow (persons/min/ft) in Platoons
Impeded	Under 6
Constrained	6-12
Congested	12-17

These flow rates are pedestrians in platoons. The corresponding average flow rate can be much less, depending on passenger arrival and exiting patterns at the station. Stairway flows of less than 6 people/min/ft offer the pedestrian an adequate level of comfort, with some choice of speed, the ability to bypass slower-moving persons, and little conflict with reverse flow. Flows in the 6- to 12-people/min/ft range are constrained. The pedestrian is without the ability to bypass and experiences turbulence and delay due to reverse flow. Under these conditions, walking is shoulder to shoulder, and queuing is possible. A queue is present and congestion exists with flows in excess of 12 people/ft/min.

It is evident that stairways in subway stations or other transit terminals can accommodate up to 20 persons/min/ft of width under congested conditions and with the presence of a long queue. Although flow rates in the congested state have been used in design at several locations, it cannot be considered a standard practice. For the purpose of capacity calculations, a flow rate of 12 persons/min/ft was chosen as a service standard for the Downtown Seattle Transit Project system. At this flow rate, the passenger flow is at the upper end of the constrained level according to Pushkarev and Zupan, which would correspond to the low end of level of service C, defined in this exercise as design capacity (2).

Escalator Capacity

An escalator capacity of 80 persons/min (per 40 in. tread width) at a 90 ft/min speed is cited in the National Fire Protection Association Code 130 standards (4). For 1 ft of tread width, the capacity of a 90 ft/min escalator is about 1.36 times that of a stairway. However, the entire escalator installation is much wider than its moving treads. An escalator with a 40 in. tread width and a nominal dimension of 48 in. at the hip level is about 6 ft wide in terms of total width of escalator and railings. At the no-queuing flow rate of 18 people/ft of tread width, it is really moving people at a rate of 10 people/ft of total width occupied. At a maximum flow rate of 27 people/ft of tread width, it is moving people at a rate of 15 people/ft of total width occupied. Thus, on the basis of total width occupied, the capacity of an escalator is similar to that of a stairway. The capacity of a given band of space to move people is not increased by replacing a stairway with an escalator. An escalator only saves the effort of climbing a grade and does not generally increase capacity without increasing the speed of ascent. For the purpose of this analysis, escalator capacity is defined as 12 persons/min/ft of total width occupied, the same as for a stair at an escalator speed of 90 ft/min (2).

Determining Peak Pedestrian Flow

The peak passenger flow rate was determined by two different methods. In the first method passenger flow rates exiting stations in the a.m. peak hour are examined, because that is anticipated to be the heaviest a.m. peak hour directional flow. The second method involved examining entering passengers during the p.m. peak hour, because that is expected to be the prime direction and heaviest volume during that time period. The higher peak passenger flow rates, either exiting passengers in the a.m. peak hour or entering passengers during the p.m. peak hour are then used to calculate the entrance and exit capacity requirements.

In the first method the passenger flow during the a.m. peak hour was examined when exiting passengers are dominant. Maximum flow occurs in exiting passengers when two bus platoons (one in each direction) arrive at a station at the same time. For year 1990 bus tunnel operations, the maximum exiting passenger volume was based on two 3-bus platoons at 85 passengers per bus. For year 2000 bus tunnel operations, the maximum exiting volume was based on two 4-bus platoons at 85 passengers per bus. For LRT at CBD buildout operations, the maximum exiting volume was based on two 4-car trains at 200 passengers per car. In all cases, all exiting passengers were expected to clear the stairways or escalators within 1 min. At this rate, passengers would be in platoons and no further adjustments are necessary. This method yields the peak flow rates for all CBD riders during the a.m. peak period given in the following table:

	Exiting Flow (passenger/min)	Entering Flow (passenger/min)	Total Peak Flow (passenger/min)
1990 Bus tunnel	510	32	542
2000 Bus tunnel	680	51	731
LRT at CBD buildout	1,600	351	1,951

Entering passenger flows during the p.m. peak hour are examined in the second method. This method involved first converting the estimated p.m. peak hour total station passenger volumes into peak 1-min flows using a 1.3 surge factor for arriving passengers. The peak 1-min flow was further increased by a factor of 1.5 for a platooning effect in passenger flow. The conversion yields the following total peak flow rates for all CBD station users as given in the following table:

	P.M. Peak Hour Total Station Users	Peak Passenger Flow in Platoon (passenger/min)
1990 Bus tunnel	9,622	313
2000 Bus tunnel	17,844	580
LRT at CBD buildout	15,528	1,675

The higher peak passenger flow rates from the two estimates, those from the a.m. peak, were used in calculating the entrance and exit capacity discussed in the example below.

An example of applying this methodology for an actual entrance designed for the Seattle system is presented in Table 1. The performance of the currently designed southwest entrance to the Westlake station is examined under estimated 1990, 2000, and LRT at buildout patronage volumes.

The width in inches required to accommodate the pedestrian volumes at 12 people/min/ft (1 person/min/in.) equals the estimated pedestrian volumes. The width required is then divided by the total width provided by the design (in this case, one escalator occupying 72 in. and one stair occupying 72 in., for a total of 144 in.) to obtain a volume-to-capacity ratio.

For this particular entrance, the volume-to-capacity ratio using 12 pedestrians/min/ft of width as design capacity (low end of level of service C, constrained but with no queuing present) rises from 0.21 in 1990 to 0.29 in the year 2000. Even under LRT at buildout volumes, the volume-to-capacity ratio at 0.72 is still below 1.0.

STATION MEZZANINES

Station mezzanines provide areas for passenger activities between the street level and the platform

TABLE 1 Performance of Southwest Entrance, Westlake Station

	Estimated Peak a.m. Volume (passenger/min)	Width Required (at 12 passenger/min/ft) (in.)	Width Provided by Design (in.)	V/C
1990 Bus tunnel	31	31	144	0.21
2000 Bus tunnel	42	42	144	0.29
LRT at buildout	103	103	144	0.72

level. These activities include ticketing, queuing, and circulation. Often, certain passenger amenities are also provided at the mezzanine level, which would require additional spaces. The capacity of a station mezzanine is determined by the area available for each of these activities to accommodate the peak station passenger volume. Metro's current bus operation does not require fare collection in the CBD, and that activity is not anticipated for bus tunnel operations.

Under normal conditions, the time a passenger takes to complete the various activities at the mezzanine level was estimated to take about 75 sec. This includes 30 sec at ticket vendors and 45 sec for walking between activities and queuing at stairway or escalator approaches. This, of course, assumes that adequate capacity is available at each activity location such that no long queues would occur. Thus, the maximum number of passengers the mezzanine must serve is the projected peak passenger flow rate times 75 sec.

The space required for each activity at the mezzanine level is determined from the estimated number of persons engaged in that activity and the space required by a person to complete the activity at an acceptable level of service. For calculating the volume-to-capacity ratios of station mezzanines under 1990 and 2000 patronage estimates, the area per person required for various mezzanine activities (ticketing, queuing at escalator and stair approaches, walking, etc.) was multipled by the number of persons engaging in that particular activity. This resulted in a total area required for mezzanine activities that was then divided by the mezzanine area provided by the design. In this manner, the maximum volume-to-capacity ratio obtained for any station mezzanine under year 2000 patronage volume was 0.31 for the Third Avenue North station mezzanine, below design capacity. For LRT at buildout volumes, this increased to a V/C ratio of 0.64.

STATION PLATFORMS

Platform space required for passenger queuing was calculated using estimates of p.m. peak-passenger accumulation. A level of service standard of 7 ft^2/person was used in the calculation. This standard corresponds to a design level of service on the low end of C, based on the levels of service that Fruin reports in the book Pedestrian Planning and Design and reported in the following table:

Level of Service	Ft^2/Person
A	13 or more
B	10-13
C	7-10
D	3-7
E	2-3
F	2 or less

The example from the proposed Seattle system that shows how this methodology was used is the southbound platform of the Third Avenue North station (Table 2). As designed, this platform is 380 ft long and 16.5 ft wide. However, when a 3.5-ft walkway and a 1.5-ft buffer from the edge of the platform is subtracted from the width, the total width available for queuing is 11.5 ft. Multiplying 380 by 11.5 produces 4,370 ft^2 available for queuing. Peak passenger accumulation estimates for 1990, 2000, and LRT at capacity are then divided by the area available to determine square feet per passenger and level of service.

Although passenger volume for the system as a whole is estimated to be much greater during LRT operations, the peak accumulation on the platforms is estimated to be less than that experienced under year 2000 bus operations. This is because one LRT train should clear the platform of all waiting passengers, while a platoon of buses will not, because of the different route designations (based on a single corridor operation). Therefore, more passengers accumulate under the year 2000 bus tunnel operations.

For this particular platform, this analysis shows that the level of service will be A under 1990 and future LRT passenger accumulations. Even under year 2000 volumes, while at level of service C, the area per passenger is still 2 ft^2 greater than the minimum design standard providing a comfortable level of service.

SUMMARY

The reason for applying previous research in the pedestrian design field to the design of this particular project was to provide feedback from the preliminary engineering phase into the final design phase. The methodologies presented in this paper for the analysis of platforms, mezzanines, and entrances were applied to all five stations in the system. Ten platforms, five mezzanines, and 12 entrances were analyzed. Examples of each have been presented in this paper. Issues raised by reviewing this analysis of the system as it was defined in preliminary engineering were used as input for change in the final design process.

There is potential for a more refined approach to the analysis for platform capacity. Levels of service for queuing were based on observations at rail platforms. Under bus operations, there exists a potential for a greater amount of movement among the waiting passengers at the platform than observed at rail platforms, on which the level of service used in this analysis is based. Although this is hoped to be minimized by consistent placement of individual bus routes in the bus platoon, it could have the effect of raising the area required per passenger on the platform. Further analysis of this, using the time-space concept, may yield a more refined result to platform capacity (5).

REFERENCES

1. J.J. Fruin. Pedestrian Planning and Design. Metropolitan Association of Urban Planners, New York, 1971.

TABLE 2 Level of Service Third Avenue North Station Southbound Platform

	P.M. Peak Accumulation	Area Available for Queuing, ft^2	Square Feet per Person	Level of Service
1990	249	4,370	17.5	A
2000	481	4,370	9.1	C
LRT at buildout	289	4,370	15.1	A

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