MACROPLANNING APPROACH TO THE ASSESSMENT OF REGIONAL BUS RAPID TRANSIT SYSTEMS

Robert C. Meier, Gregory E. Vederoff, and Dennis Porter,
University of Washington

Bus systems provide the major public transportation services in the Seattle area. System viability has become a matter of increasing concern in recent years, in many urban areas, as ridership has fallen and operating deficits have increased. There is considerable sentiment, however, that public transit should not be allowed to collapse, because this would leave many people with no economical means of transportation and place even greater reliance than at present on the private automobile and freeways. An approach to the problem is bus rapid transit, which would provide a different route structure and operating philosophy than present bus systems. A bus-based system has merit because it offers the possibility for relatively high-speed movement of people on existing arterials, highways, and freeways without the very high capital investment required for a rail system.

•A CONFIGURATION for a bus rapid transit system that is composed of line-haul routes between activity centers or nodes is discussed. Feeder systems and local systems that would be required around some nodes are not considered. Operations between nodes are assumed to be on a nonstop basis as much as possible and are assumed to use arterials, highways, and freeways.

SYSTEM STRUCTURE AND LOADS

Nodes and links included in the bus rapid transit system (Fig. 1) reflect opinions of a number of individuals familiar with the area or of those engaged in traffic planning in the area. An outer beltway on the periphery of the system is not shown in the network because present traffic volumes are too small to warrant their inclusion. These could be added as required to accommodate growth in the future. The network encompasses the area from Puget Sound on the west to North Bend at the foot of the Cascade Mountains on the east and from Tacoma in the south to Everett in the north. Essentially all activity centers in the Seattle area with significant traffic densities are covered.

Projected traffic volumes for the region for 1975 were obtained from the Puget Sound Governmental Conference (PSGC). All PSGC planning analysis zones west of Puget Sound were excluded from the analysis, and the remaining 571 zones were allocated to the 56 nodes in the network. Total forecast trips between nodes were broken down into home-based work, home-based shopping, home-based school and college, home-based recreational, home-based miscellaneous, non-home-based, and commercial. For this study, commercial trips were excluded as were internal trips within each zone. Total daily trips in the region after these exclusions are approximately 2.29 million. The 24 most significant destination nodes were determined so that the analysis could be simplified. Total trips involving these 24 nodes are 1.84 million per day or 80 percent of the regional total trips.

Figure 2 shows a representative distribution of total trips through the day, which is based on operating data from bus system operations and traffic volume data for the Seattle freeway. The distribution is shown for an assumed 18-hour operating day. The

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hourly trip distribution generally indicates the pattern of the ridership that might be expected, although the exact shape is not critical for the analysis. Data of major importance in Figure 2 are the percentages of trips in the morning and evening peak hours that determine the size of bus fleet required. Each of these peak hours is estimated to be 15 percent of the total daily trips.

For this study, it is assumed that 10 percent of all trips are made on the bus network. A 10 percent modal split is used because it is consistent with the present experience of Seattle Transit and agrees with estimates of patronage from previous technical studies of rapid transit in the Seattle area for a bus system. It is also assumed that the modal split is uniform throughout the area. Although this is not likely to be true, the assumption affects only the relative loads on individual links and does not greatly affect total system operating characteristics.

From PSGC data, a table was constructed that shows peak-hour bus trips from the 56 origin nodes to the 24 major destination nodes. Total peak-hour trips are about 27,600 or 1.5 percent of the 1,840,000 trips per day that involve the 24 major destinations. This total reflects a 10 percent modal split for the bus system and peak-hour patronage of 15 percent of the daily total.

Inasmuch as exact routes are not specified for the links in the network, road distances for each of the links in Figure 1 were estimated at 1.25 times the airline distance between nodes. Approximate travel speeds for each link were estimated on a judgment of road conditions that might be expected on each link. Round-trip time estimates in minutes for each link are given in Table 1.

Minimum time paths from each of the 56 origin nodes to the 24 major destination nodes were constructed by using the link travel times and a minimum path algorithm in the interactive graphic simulation package available at the Urban Data Center, University of Washington. Peak-hour link loads given in Table 1 are the sum of the loads obtained from the 24 minimum time path analyses.

An analysis is given in Table 1 of peak-hour fleet requirements that are based on estimated 1975 travel times and peak-hour link loads and an assumed 10 percent modal split. In Table 2, all links have been analyzed separately as if each bus operates only between one pair of nodes in the network. The number of buses required for each link is rounded upward to determine an integral number of buses required to service a link. This results in a fleet size of 300 buses that is larger than the theoretical minimum but that allows for turn-around time and losses when actual schedules are developed. Neither of these is taken into account explicitly.

The fleet size in Table 1 is also based on trips to the 24 most important destinations in the network that account for 80 percent of total trips. No allowance in fleet size has been made for the missing 20 percent because it is felt that this additional load could be accomodated by capacity for standees and because minimum frequencies have been specified on a number of links where loads are small.

SYSTEM REVENUES AND COSTS

Estimates of system loads in Table 1 are based on an estimated 2,290,000 internodal, noncommercial trips per day in the Puget Sound region. With an assumed modal split of 10 percent, the bus system would carry approximately 230,000 riders per day. By using 300 equivalent full-time operating days per year as the basis for calculation, the system would carry approximately 69 million riders per year. In 1970, Seattle Transit received average fare box revenues of \$0.27 per passenger. A minimum fare of \$0.30 per ride, consequently, is consistent with fares on the present system. Annual revenues from a fare of \$0.30 paid by 69 million riders would be \$20.7 million.

Operating costs for the system are difficult to estimate because of lack of operating data for a comparable system. Current operating costs both in Seattle and nationally are about \$1.00 per mile. On an hourly basis, operating costs are about \$12.00 per hour and this reflects average speeds of 12 mph. For the network under study, operating speeds would be considerably higher than at present because service is essentially nonstop between nodes.

About 85 percent of current operating expenses in Seattle are wage-related; therefore, it is more reasonable to base an estimate of operating costs on hourly costs rather

Figure 1. Node-oriented bus rapid transit system.

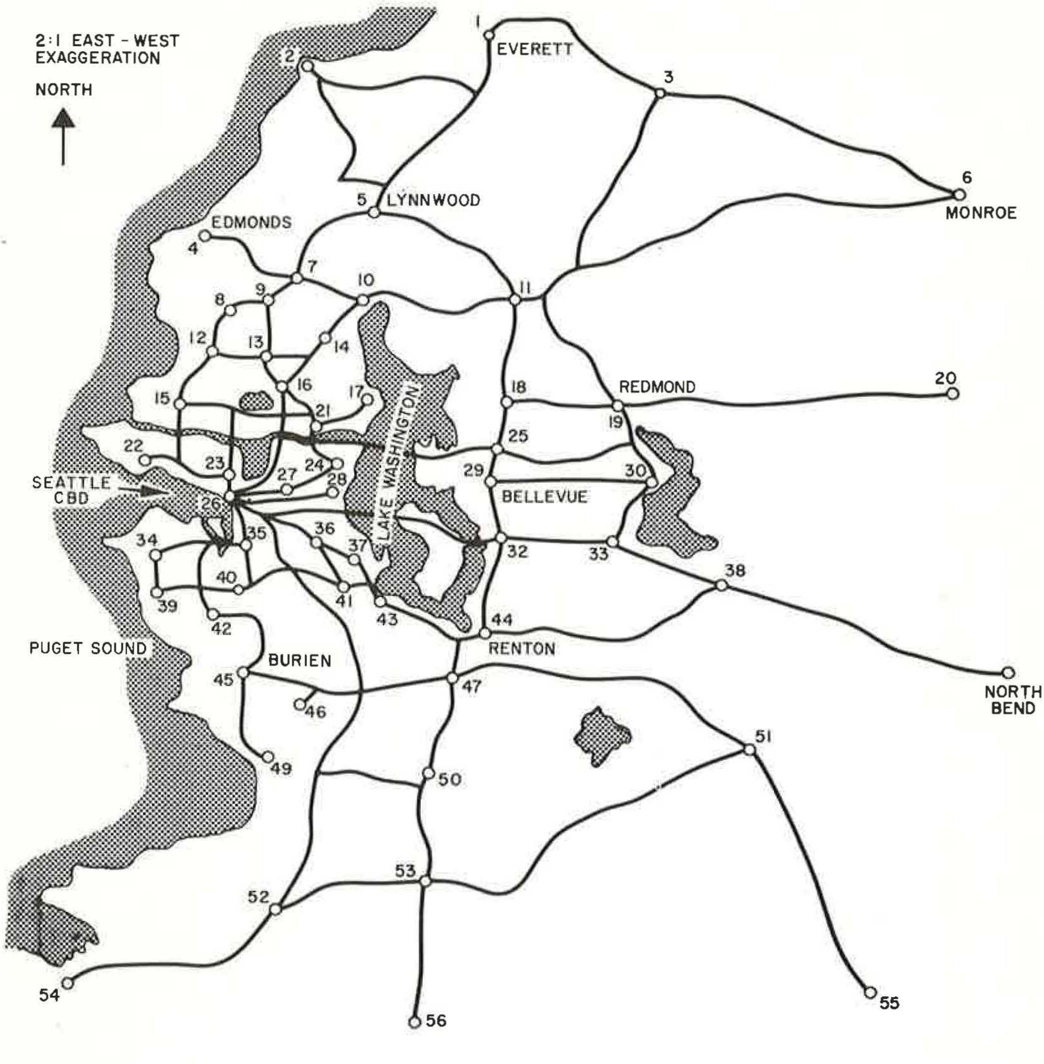

Figure 2. Daily trip distribution.

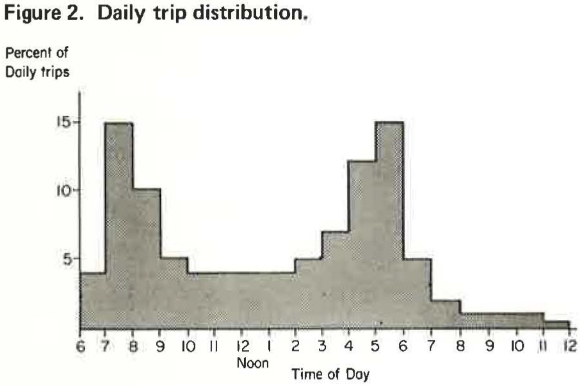

Table 1. Fleet size requirements for peak-hour service.

Link Pair	Peak-Hour Link Load	Round-Trip Time (min)	Buses Required[a]	Link Pair	Peak-Hour Link Load	Round-Trip Time (min)	Buses Required[a]
1-2	223	32	3	26-35	628	10	2
1-3	496	25	5	26-36	720	14	4
1-5	618	40	9	26-37	0	40	2[b]
3-6	50	35	2[c]	26-46	0	50	2[b]
3-11	34	45	2[c]	26-47	1,324	40	18
4-7	1,202	25	10	27-28	86	9	1
5-7	849	8	3	28-37	0	24	1[c]
5-11	186	25	2	29-30	204	14	1
6-11	0	25	1[b]	29-32	564	12	3
6-20	0	40	2[b]	30-33	0	17	1[b]
7-9	1,166	7	3	31-32	290	7	1
7-10	210	15	1	32-33	243	9	1
8-9	570	15	3	32-44	191	24	2
8-12	307	15	2	33-38	143	15	1
9-10	494	10	2	34-35	866	12	4
9-13	1,568	12	7	34-39	475	10	2
10-11	304	15	2	35-36	123	12	1
10-14	0	14	1[b]	36-37	403	7	1
11-18	312	20	2	36-41	287	14	2
11-19	0	36	2[b]	37-43	127	15	7
12-13	782	10	3	38-44	58	30	1
12-15	234	17	2	38-48	103	26	1
13-14	202	8	1	39-40	247	24	2
13-16	1,958	9	6	40-42	225	12	1
14-16	0	20	1[b]	40-43	240	22	2
15-16	122	24	1	41-43	551	15	3
15-21	150	26	2	42-45	897	20	6
15-22	158	20	1	43-44	277	14	2
15-23	330	26	3	44-47	868	8	3
16-21	2,461	10	9	44-50	261	17	2
17-21	691	12	3	44-51	177	42	3
18-19	0	14	1[b]	45-46	449	16	3
18-25	847	8	3	45-47	1,392	16	8
19-20	71	42	2[c]	45-49	843	22	7
19-30	0	20	1[b]	46-47	520	7	2
19-25	332	18	2	46-50	183	22	2
20-40	32	35	2[c]	47-50	263	17	2
21-24	180	15	1	50-53	746	26	7
21-25	501	26	5	51-53	72	51	2[c]
21-26	2,019	21	14	51-55	12	51	2[c]
22-23	237	18	2	52-47	398	42	6
23-26	1,492	12	6	52-53	477	18	3
24-27	325	15	2	52-54	840	24	7
25-26	495	34	6	53-55	190	51	4
25-29	545	8	2	53-56	263	26	3
26-27	575	9	2	54-56	801	22	6
26-28	490	12	2	55-56	0	51	2[b]
26-31	538	18	4				

[a]Buses required are rounded up to an integer number of buses. Total buses = 300.
[b]Number of buses on zero load links are set by policy of 30-min headway maximum on all links.
[c]Number of buses are increased to reduce headway to less than 30 min.

Table 2. Comparison of study scope.

Study Element	Macroplanning Study	Metro Study
Approximate total cost, $	<25,000	450,000
Time span	3 months maximum	1 year
Personnel requirement	1 to 2 persons full time	Approximately 8 people full time

than costs per mile. If one considers inflation and the effect of higher operating speeds, a cost of $15.00 per hour is a reasonable expectation. Current use of equipment by Seattle Transit is about 2,700 hours per year for each unit. Based on 300 equivalent days of operation per year, daily use is about 9 hours. Inasmuch as a conservative cost estimate is desired and improved off-peak service may be required to attract riders, 10 hours per day is used as the basis for cost estimation. Yearly operating hours for each bus in the node-oriented system are estimated at 3,000.

Table 1 gives a minimum required fleet of 300 buses for peak-hour needs. To this must be added some additional buses to provide for scheduling flexibility, maintenance, repairs, and so on. With a reserve of 50 buses for such contingencies, the total required fleet size is 350 buses. At 3,000 hours per bus, total operating hours per year are 1,050,000 and operating costs are $15.75 million per year, based on a cost of $15 per hour.

Although the $15-per-hour operating cost estimate includes some capital costs, it does not include full charges for expenditures for the bus fleet and other facilities. Assuming a 350 bus fleet and a life of 5 years, 70 buses must be purchased annually. Costs are about $50,000 for a 50-passenger bus, or an annual outlay of $3.5 million. Other capital improvements and facility costs have not been estimated in detail, but these might amount to $1.5 million per year, and this gives a total capital outlay for the system of $5 million per year. When these capital costs are included, annual costs for the system are $15.75 million in operating costs plus $5 million in capital costs for a total of $20.75 million. A comparison of this cost with the revenue estimate based on a $0.30 fare indicates that the system would just about break even.

It should be emphasized that the revenue estimate is based on an assumption that 10 percent of the noncommercial, internodal trips would be attracted to the system. If the modal split were less than 10 percent, revenues would be reduced accordingly. If a 10 percent modal split were not obtained, however, an offsetting factor would be a reduction in operating costs caused by a smaller fleet size and reduced number of operating hours.

Additional calculations with the basic data can provide other estimates of possible operating profits or losses. For example, with an average fare of $0.35 and an average modal split of 5 percent, revenues would be $12,075,000. A revised computation of the fleet size indicates that operating costs for a fleet of 240 buses would be $10.5 million, not including capital costs. Including capital costs of $3.9 million, annual costs would be about $14.4 million with a yearly loss of $2,325,000. Figure 3 shows estimated annual profits or losses for modal splits of 5 percent and 10 percent and various fare levels.

INTERPRETATION OF RESULTS

The analysis suggests that a node-oriented bus transit system is potentially an economically feasible method for providing regional public transportation in an area such as Puget Sound. Average fares necessary to attain a break-even level of financial operations assuming either a constant 10 percent or 5 percent modal split are well within the range of fares that could reasonably be obtained. Cost estimates are conservative because they include full internal funding of capital outlays. With federal or state assistance for capital expenditures, annual costs would be considerably lower.

Methodologically, this study has shown that initial feasibility assessments of node-oriented regional bus systems can be accomplished at low cost. Figure 4 shows the basic steps. With the exception of steps 2 and 4, all steps are accomplished by using easily obtainable parameters, informed judgment, and simple analytical procedures that can be carried out manually. Step 2, which requires the creation of an internodal trip table, may be a major task. In regions that have available trip data between principal origins and destinations, as in the Puget Sound region, only a summary of existing data is required. Because the resulting trip table may have over a thousand entries, a computer is useful, although not essential, for compiling the table and for determining peak-hour network link loads in step 4. Because a shortest path determination must be made for each entry in the trip table, automatic computation sub-

Figure 3. Estimated annual profits or losses.

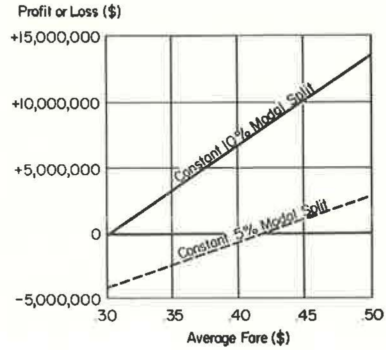

Figure 4. Major steps in node-oriented bus system study.

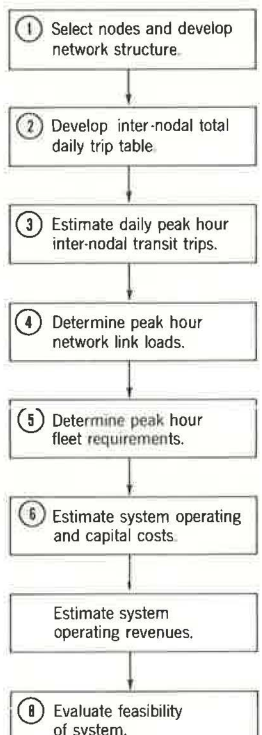

Table 3. Comparison of 1975 estimates of system costs.

System Element	Macroplanning Study	Metro Study[a]
Number of buses	350	325
Total bus operating hours	1,050,000	840,000
Bus miles	—[b]	10,937,000
Operating costs, $	15,750,000	11,816,000
Capital cost, $	5,000,000	6,000,000 to 7,000,000

[a]Calculated from Table 2-4-12 (10) by using an express bus-total system ratio of 0.5.
[b]Not required for macroplanning purposes but can be readily calculated.

stantially reduces the work involved. If no massive data collection is required to generate the trip table in step 2, a feasibility analysis similar in scope to the present study can be conducted for less than $25,000.

COMPARISON WITH FULL-SCALE PLANNING STUDY

The procedure used in defining the gross operating characteristics of a bus rapid transit system in the Seattle area is basically similar in concept to that used in a full-scale bus transit planning study for the same region. The full-scale study, which we will call the Metro study, was performed by a consultant firm in conjunction with the PSGC. Table 2 gives, in perspective, the differences in time and cost between the macroplanning study and the Metro study.

The macroplanning approach represents a simplification of the much more comprehensive Metro analysis. In both, trip assignment results from a step-by-step process of zonal identification, trip generation, trip distribution, and modal split. The major simplifying assumption that the macroplanning approach makes is of a system-wide, constant value of modal split that is judgmentally decided on. Thus the need for a modal-split model with its parameters is bypassed. A second simplification relates to the network and estimation of the number of buses required in the system. Buses are considered to run only back and forth between two adjacent nodes, and no consideration is given to actual routing of buses through the network.

Cost estimates obtained from the macroplanning approach are generally consistent with those obtained from the Metro study. The main difficulty in making straightforward numerical comparisons is that the Metro plan covers a combined express and local bus service, whereas the macroplanning study included only an express bus service. Table 3 gives a rough comparison of macroplanning and Metro estimates of system operating costs. The Metro estimates given in Table 3 are one-half of the values stated in the Metro report because the Metro express systems and local systems are approximately equal in size.

On the revenue side, the Metro study estimated total system patronage of 35.7 million passengers in 1975. Of these, about half—some 13 million—would be express bus riders. This figure is only one-quarter of the 69 million riders obtained from the 10 percent across-the-board modal split used in the macroplanning approach. The large difference is because the off-peak bus patronage is proportionately much less than during peak hours. Peak-hour loads must be used in sizing the bus fleet, and the 10 percent modal split used in the macroplanning study is a reasonable upper bound on peak-hour patronage, but it is too high for off-peak hours. Adjustment of the 10 percent modal split during off-peak hours to a more typical level would bring the ridership estimate in the macroplanning study much closer to the Metro study results. No such adjustment was made in the macroplanning study because the 10 percent modal split was viewed at the time of the study as a goal of the system rather than a forecast.

Aside from the discrepancy in revenue estimates discussed, results of the macroplanning study and the full-scale Metro study are quite comparable. This similarity suggests that the macroplanning approach may be a useful tool in assessing the gross operating characteristics of proposed transit systems.

REFERENCES

1. Duncan, Kandor, Michelson, Orlob, and Vederoff. A Regional Bus System for the Seattle/King County Area. Urban Transportation Program, Depts. of Urban Planning and Civil Engineering, Univ. of Washington, Seattle, Workshop 4 Rept., Aug. 1971.
2. DeLeuw, Cather and Company. The Rapid Transit Plan for the Metropolitan Seattle Area, Technical Appendix. Municipality of Metropolitan Seattle, March 19, 1970.
3. Homburger, W. S., ed. Urban Mass Transit Planning. Institute of Transportation and Traffic Engineering, Univ. of California, Berkeley, 1967.
4. Management and Operational Review of the Seattle Transit System. Price, Waterhouse, and Company, Seattle, Washington, July 6, 1970.
5. Study Area Planning Analysis Zones Map. Puget Sound Governmental Conference, Seattle, Washington.

6. Preliminary PSGC 1975 IRDP Person P-A Trips, U-W District. Puget Sound Governmental Conference, compressed table repts., Seattle, Washington, Oct. 26, 1971.
7. Rapp, M. H., Goldman, M., and Smallwood, R. The Interactive Graphic Transit Simulator, A Tool for Planning Node-Oriented Transit Systems. Urban Transportation Program, Depts. of Urban Planning and Civil Engineering, Univ. of Washington, Seattle, Res. Rept. 7, 1971.
8. Annual Report, Year Ending December 31, 1970, Seattle Transit System. Seattle Transit Commission, Washington, 1971.
9. Wilbur Smith and Associates. The Potential for Bus Rapid Transit. Automobile Manufacturers Association, Inc., Detroit, Michigan, Feb. 1970.
10. A Transit Plan for the Metropolitan Area: Seattle and King County, Technical Appendix. Puget Sound Governmental Conference, Seattle, Washington, May 1972.