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Contents

FOREWORD

The papers contained in this RECORD focus on methodologies for evaluating the implementation of urban mass transit systems, an overview of the development of personal rapid transit systems as well as a conceptual framework for the economic, environmental, and design aspects of such systems, and a research framework for the estimation of national (urban) markets for such systems as automated guideway and rail and bus rapid transit systems.

Reish and Surti discuss the feasibility of free bus service based on a survey and analysis of a selected area of Denver. It was found that total transportation expense was less under a free bus system than under the present fare system, but the margin of advantage was small. Additional benefits were cited by the authors in arriving at the conclusion that free bus service has the potential of being beneficial, but they emphasize that it should be tested and monitored to demonstrate its true worth.

Burco reports on a survey of activities in the personal rapid transit field that was done for the Organization for Economic Cooperation and Development. A primary concern of the paper, beyond simply reporting current research and development activities in the field, is the institutional factors that may cause the future application of such an advanced technology concept to be limited before it has even been adequately developed and demonstrated. The author states that most PRT studies have failed to effectively recognize and deal with a sizable clientele of users (city governments, environmental agencies, potential users) that could generate political support for implementing PRT systems if technologically and economically feasible. Without such support, the author feels that personal rapid transit is not likely to contribute much to urban transport improvement.

Dais and Kornhauser present a parametric study of systems variables of large-scale personal rapid transit networks. An idealized urban area having uniformly distributed population (trip) origins and destinations serves as the trip model, and a square mesh pattern serves as the PRT network model. Various independent and dependent variables are discussed as well as the identification of population (trip) densities and PRT system performances and costs for which PRT is either economically feasible or of benefit to society.

Golob, Canty, and Gustafson present a research framework for estimating the national markets and the social, economic, and environmental impacts of new systems of urban arterial transportation such as automated guideway and rail and bus rapid transit systems.

Keller reports on research results aimed at developing and demonstrating a model for evaluating mass transit systems. The model is intended to convert the criteria of public acceptance to those of technical design. The results should be useful to those responsible for writing specifications and evaluating proposals and to those responsible for design and optimization of mass transit systems.

FEASIBILITY STUDY OF FREE BUS SERVICE FOR A STREET CORRIDOR OF DENVER

Robert Reish and Vasant H. Surti, Center for Urban Transportation Studies, University of Colorado—Denver

An area of Denver was selected that contained most of the 3 bus routes that run in an east-west direction from suburban eastern Denver to downtown. A survey was conducted among automobile users in the area to obtain information on preferred mode of travel if free bus service were available. Estimates of increased bus ridership were developed by expanding the survey results. Transportation costs were analyzed for the present total operating and travel time cost and for the operating and travel time cost if free bus service were employed. It was found that total transportation expense was less under a free bus system than under the present fare system, but the margin of advantage was small. Additional economic and environmental benefits were cited in arriving at the conclusion that free bus service has the potential of being beneficial but that it should be tested in a closely monitored situation to demonstrate its true worth.

•A CITY works by taxing its resources, by manipulating its labor and wealth, and by arranging its systems in a logical way for the benefit of all. One of the most important of a city's systems is transportation. Yet today we view the urban transportation scene as chaotic and lacking. Because it is easy to believe that there is a method of reordering this situation, most of us try to pose simple solutions to the complex problem. One simple answer, yet one with merit, is free bus service.

Free transit is not a new idea. It was tried in Rome along with blocking off the city's central areas to auto traffic. In Denver, under the sponsorship of the Department of Housing and Urban Development, free bus service has been instituted on a trial basis in the Model City area (1). The purpose there is non-economic and is based on a desire to provide transportation to those without it.

The Rome scheme failed and the Model City program promises meager economic justification. But regardless of these problems, there is a real case for free bus service. The case is founded on the history of urban transportation as well as on a threatening future. The all-too-familiar pattern, followed in nearly every major U.S. city, is one in which there is a continuing decline in patronage of public transit in the face of increasing population and automobile use.

As a result of these trends, many Denver streets have reached their capacities during rush periods and carry very large amounts of traffic throughout the day. But the travel demand grows and traffic counts increase at a rate of 3 or 4 percent a year. The predictable conclusion is the inevitable lengthening of rush periods and increasing travel times.

Clearly, the versatility and independence of the automobile has altered transportation. But in view of congestion and increasing demand, the factors that have led to automobile supremacy may lead to its demise. The change from supremacy to demise is as unattractive as the history of public transit, simply because the demise of the automobile will be brought about by the strangulation of our cities.

Sponsored by Committee on New Transportation Systems and Technology.

Despite its history, proponents of public transit feel confident that it is a better alternative and that it will stave off the predictable urban transportation stagnation. But the important question is, "How does one change the transportation habits?" One possible way is to make public transit economically attractive to the auto drivers' limited perception. And one method of making public transit attractive is by making it free. Beyond the economic advantages, free transit would decrease noise and air pollution, and it would be much safer.

Free transit has been the subject of little technical investigation. Recently it was the subject of a study by Charles River Associates of Cambridge, Massachusetts (2). Charles River Associates approached the problem of predicting increased use from a user-service-cost model and only attempted to find the actual cost of free transit in Boston but did not try to establish the magnitude of benefits. Unfortunately, that study did not indicate that prediction of ridership for free transit is a unique situation and most likely is not possible on the basis of cost-service models.

With this in mind, the economic feasibility of free transit service was tested for an area in Denver. The study area and bus routes 14, 13, and 6 are shown in Figure 1. These 3 routes are the most profitable in Denver. The area is traversed in north-south and east-west directions by major streets that fulfill duties as major and minor arterial streets. Figure 2 shows the 1971 average daily traffic on major east-west streets.

Physically, the area's predominant land use is residential, with high-density developments in the Colorado Boulevard and western areas. The area is unique in that it functions as a hospitable place to live and yet furnishes a working street system that has served its needs without major reconstruction.

OBJECTIVE

In studying the economic feasibility of an unknown, a method of testing must be selected, and it is most easily done in the form of a hypothesis. In this study it is hypothesized that, based on operation 5 days a week from 6 a.m. to 9 p.m. and within the study area, free-fare transit will increase bus ridership and decrease auto transport to such a degree that total transportation costs will be less with free transit.

Other objectives might be to determine the actual cost of the free service, to find the projected number of new bus riders, and, if possible, to recommend new bus routes that might better serve persons working or living outside the area.

METHODOLOGY

The first step in achieving the objectives was to survey drivers in the area. Figure 3 shows a sample questionnaire. The questionnaire asks the driver and passengers if they would ride the bus if it were free and requests approximate origins and destinations.

The survey questionnaire was distributed to motorists and passengers at 3 key intersections in the study area at various times of the day. The intersections were 6th Ave. and Washington St., 8th Ave. and Logan St., and 13th Ave. and Clarkson St. Motorists stopped at red lights were asked to complete the questionnaire and return it by mail.

Table 1 summarizes the data from the survey. Group 1 consists of those persons answering the questionnaire who live in the study area and work either in the central business district or in the study area. Group 2 respondents live in the study area but do not work in the area and therefore cannot be adequately served by the studied routes. Respondents in group 3 do not live in the study area but work in the CBD or in the study area. Group 4 persons do not work or live in the study area.

In all, 1,195 questionnaires were handed out; 521 usable answers were received, for a return rate of 43.6 percent. The high return rate shows an obvious interest in transportation and bus service. It is also interesting to note the high percentage of persons who know the bus fare, especially among those of group 1. This leads one to believe that commuters are price-conscious.

The method of demonstrating the hypothesis is by showing that total transportation costs are less with bus transit than with auto transport. To do this, one must find the

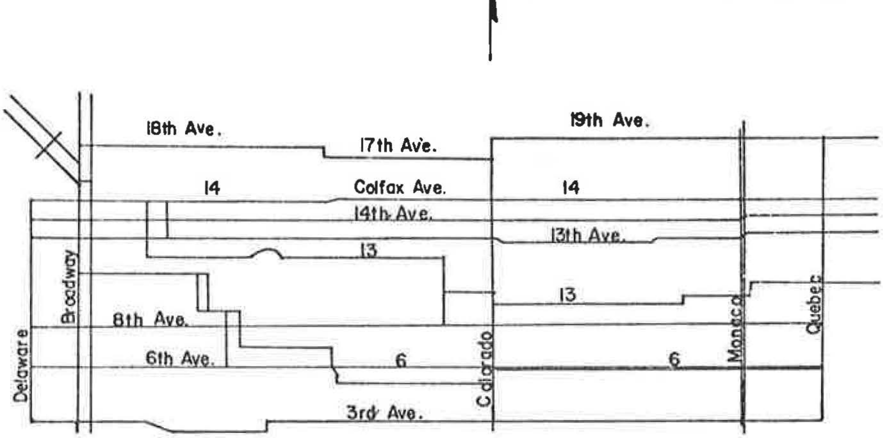

Figure 1. Denver study area, showing bus routes.

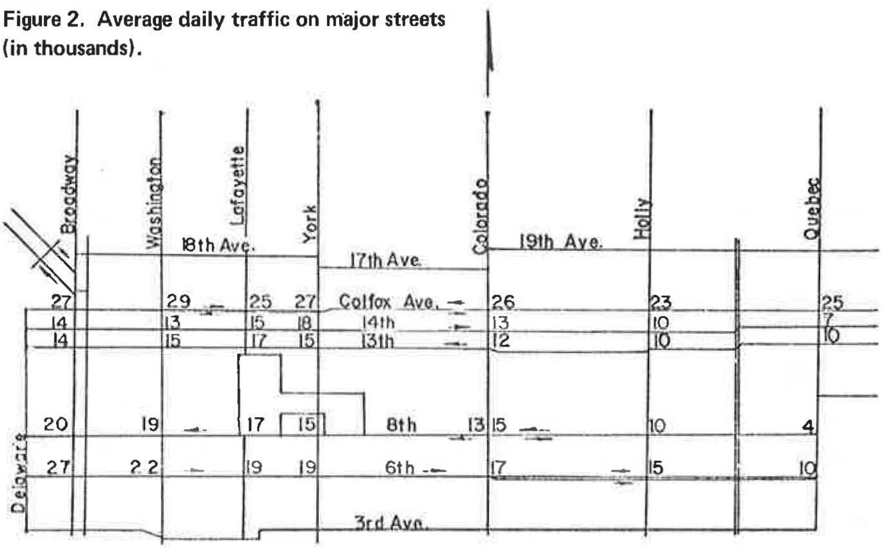

Figure 2. Average daily traffic on major streets (in thousands).

Table 1. Survey results.

Group No.	Persons Answering Correctly or Affirmatively						Total No. of Respondents
	Question 3		Question 4		Question 5		
	Percent	No.	Percent	No.	Percent	No.	
1	61	127	53	110	78.5	175	223
2	37.2	42	37.2	42	63	71	113
3	47	45	32.3	31	71.8	69	96
4	37	33	31.5	28	65.2	58	89
Mean	47.5	—	40.5	—	71	—	—
Total		247		211		373	521

Figure 3. Survey questionnaire.

UNIVERSITY OF COLORADO

Center for Urban Transportation Studies

This questionnaire is part of a feasibility study for free bus service. Please answer the questions and return the postcard by mail. Postage is paid. Thank you for your assistance.

1. What is your working address (nearest intersection)?

   ....

2. Home address (nearest intersection)?

   ....

3. What is the regular bus fare for an adult? ....¢

4. If bus service were free, would you ride if all other services were the same (routes, schedules and comfort)? ..... Yes, ... No.

5. If bus service were free, would you ride with improved service (more frequent service, routes closer to home, and sheltered bus stops)? ..... Yes, ... No.

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total costs of transport by private vehicles and buses in terms of operating costs and the cost of travel time by both modes. The total cost must be found for the present condition and, all other things being equal, for a situation in which there is increased bus ridership reflective of the survey results.

The cost of bus operations in the present situation was first calculated. The whole calculation was limited to operations Monday through Friday between 6 a.m. and 9 p.m.

Denver Metro Transit cites a figure for operation of about $0.90 per mile. However, this cost includes all routes throughout the city without regard to day. A more refined method of calculation of costs for the Denver system was derived by W. R. Gilman Company (3). The model established costs in 1970 dollars for operating expenses and appeared as

$$C = \$4.362\ VH + \$0.094\ VM + \$5{,}096.30\ PV + \$0.012\ RP$$

where

C = Total yearly operating cost,
VH = Vehicle-hours of operation,
VM = Vehicle-miles of operation,
PV = Number of peak vehicles, and
RP = Number of revenue passengers.

The last available data on the development of the model were from 1968, so costs were expanded to 1970 dollars as shown in Figures 4 and 5. In the same manner the model coefficients were expanded again to 1972 dollars.

It is important to note that revenue-passenger costs can be equally described in terms of vehicle-mile costs. A new model taking advantage of this relationship was developed that eliminates the revenue-passenger cost by developing it in terms of cost per mile, resulting in

$$C = \$4.75\ VH + \$0.1047\ VM + \$5{,}350\ PV$$

Therefore, to develop the cost estimate, one only needs to know the 3 variables of vehicle-hours, vehicle-miles, and number of peak vehicles, that is, the number of vehicles needed during rush periods minus the number used throughout the day.

In addition, to develop the total cost one must know the yearly cost of the vehicles. The cost amounts to $42,000 in purchase price at 6 percent interest over 15 years. Therefore, a fourth variable, the total number of vehicles used on the route, must be found as well.

Fortunately, Denver Metro Transit was very helpful in supplying accurate and detailed schedules and routes. From these schedules and routes and from other information, the 4 variables were found by a series of calculations. These are given in Table 2.

Application of the values to the model gives a present bus cost of $697,000 per year for the 3 routes. In addition, the cost of the buses is $203,000 per year.

In accounting for auto costs, one is concerned with the cost of operating all the vehicles. In addition, there is a possibility that some auto owners might decide to rid themselves of a second or third car because of free transit. Speculation about this possibility is indeed only speculation. Therefore, the actual purchase costs of automobiles are not included in the analysis.

Bus routes run from the east to the CBD. The institution of free service would predominantly aid the east-west corridor. Therefore, the automobile travel considered is that from east to west. There would be additional benefits for north-south streets, but measurement would be difficult.

The costs were determined for all traffic on the transportation corridors, 6th, 8th, 13th, 14th, and Colfax avenues. The additional traffic bound for the central business district from the east-west streets was considered for the length of travel from the corridor to 16th and Welton, which was picked as the center of the CBD.

Each of the studied streets was divided into segments with similar amounts of traffic. Then the traffic counts for the 15-hour period from 6 a.m. to 9 p.m. were simply multiplied by the segment length to find the total miles. The same method was used for that traffic bound for or coming from the CBD. After the final number of miles was calculated, it was multiplied by a factor of cost per 1,000 miles of travel at an average speed of 20 mph. Table 3 summarizes the data for the present condition.

The calculation of future operating costs is much the same as that done for present costs. But here the prediction rests on the survey. Both the prediction of future increased bus patronage and of decreased auto use rests on the interpretation and application of the results of the survey.

Approximately 34 percent of those answering the survey live in the study area, work in the CBD, and answered question 5 affirmatively and therefore would logically use the buses. These were considered to be the most likely to use the buses as the routes are constructed. Home addresses from the survey were spread over the whole area. Therefore, the survey is believed to be an independent event and not biased in any significant way.

The study area was divided into districts, with coordinates as shown in Figure 6. Results of the survey were tabulated and entered in the districts. The numerators in Figure 6 represent the number of affirmative answers out of the number of respondents in the area, which is the denominator in each district. The districts measure approximately 4,000 by 4,000 ft.

The number of affirmative responses was then divided by the total number of responses from all areas. In this way, a fraction of the total number of persons passing the survey point is obtained. Then simply multiplying the fractions by the total daily traffic would reasonably give the expected number of origins and destinations from each district whose mode of travel would be free bus. Table 4 summarizes this calculation for each district. The factor of 1.2 is an average occupancy ratio, and the factor of $\frac{1}{2}$ is used to obtain the number of round trips.

After the total number of round trips is found, the next step is to try to distribute the trips in some logical manner throughout the day. The manner chosen was to distribute them according to hourly traffic volumes. Figures 7 through 11 show the traffic distribution by hours on each arterial at locations in the western portion of the study area. Table 5 gives the stratification of demand on the basis of time periods.

From the period and district demands in Table 5, the number of buses necessary for service was established. Criteria for the number of buses are 60 passengers per bus during peak periods and 40 passengers per bus during off-peak periods and the respective total running times for each route. Table 6 summarizes the results of this analysis.

Using the Denver Transit Study bus cost model figures,

$$C = \$4.72\ VH + \$0.1047\ VM + \$5{,}350\ PV$$

where

$VH = 86.4 \times 10^3$ hours,
$VM = 474 \times 10^3$ miles, and
$PV = 4$,

gives the cost of the system as $482,000. Furthermore, the yearly cost of 25 buses at $42,000 each and 6 percent interest amounts to $108,000.

Because free bus service will be used by 34 percent of the survey respondents, the total number of miles traveled in the area will be reduced by about that amount. Hence, the cost of auto transport operation under a free transit system would be, conservatively, 30 percent less. It was assumed in this calculation that there would be no change in trip length. Therefore, because free bus service is to account for 30 percent of the automobile traffic, the cost of operation under a free transit situation is 70 percent of the present cost.

Both bus and auto system operating costs have been found. In a purely engineering sense this is enough analysis to either sustain the hypothesis or reject it. Yet there is

Figure 4. Revenue-passenger and vehicle-mile costs.

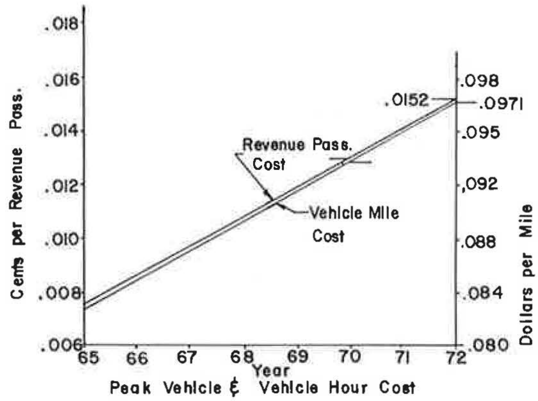


Figure 5. Peak-vehicle and vehicle-hour costs.

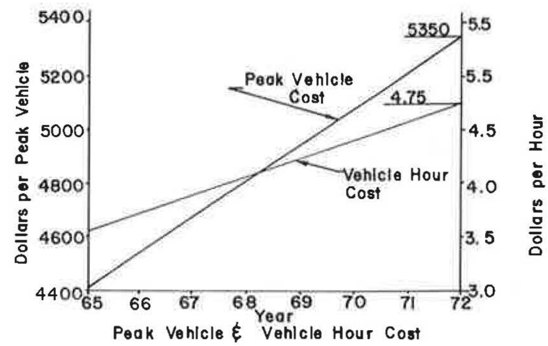


Table 2. Variables used in calculating costs.

Variable	Daily Rates Route 6[a]	Route 13[a]	Route 14	Yearly Rates
Weekday vehicle-miles	1,018	1,222	2,260	$1{,}170 \times 10^3$
Vehicle-hours	89	90	175	91.9×10^3
Number of peak vehicles	6	7	13	26
Total number of vehicles	16	20	23	

[a]Routes 6 and 13 extend far to the west beyond the study area; therefore the variables were found for only the portion of these routes within the study area.

Table 3. Miles per day traveled in the study area.

Street	Miles/Day	Miles/Day to CBD
Colfax	109,920	2,580
14th	57,880	14,380
13th	57,530	
8th	59,780	9,200
6th	73,570	
Total	358,680	26,160

Summary: 384,840 miles × 260 days per year × $37.10 per 1,000 miles = $3,710,000 per year.

Figure 6. Coordinates of districts, showing major streets and group 1 questionnaire respondents.

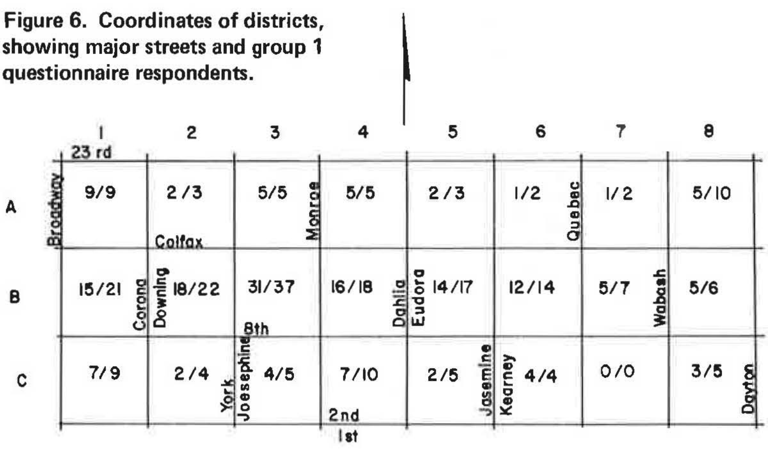


Table 4. Traffic volumes in study area.

Street	15 Hour ADT
Colfax	20,455
14th	14,456
13th	14,700
12th	17,700
6th	16,800

No. of round trips = 84,201 × 1.2 × ½ = 50,500

District Coordinate[a]	A	B	C
1	875	1,455	680
2	194	1,750	194
3	485	3,015	388
4	485	1,550	680
5	194	1,360	193
6	97	1,160	680
7	97	485	—
8	485	485	—
Total	2,911	11,060	2,815

[a]See coordinates in Figure 6.

Figure 7. Average weekday vehicles per hour on 6th Ave. (without York).

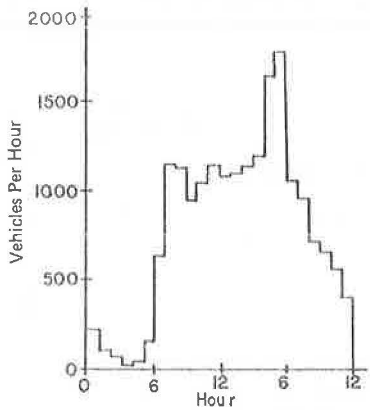


Figure 8. Average weekday vehicles per hour on 8th Ave. (without Grant).

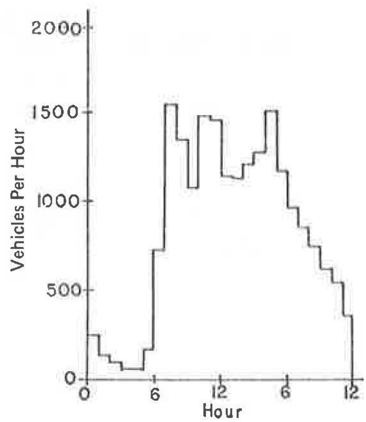


Figure 9. Average weekday vehicles per hour on 13th Ave. (without Colorado).

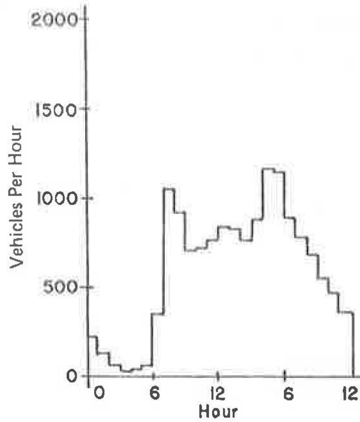


Figure 10. Average weekday vehicles per hour on 14th Ave. (without York).

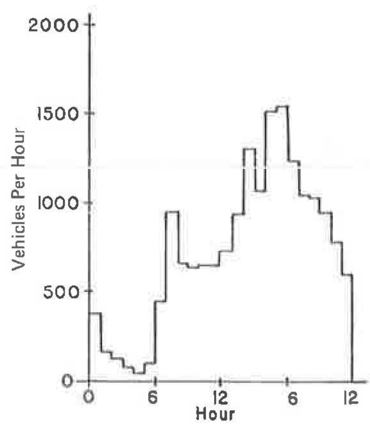
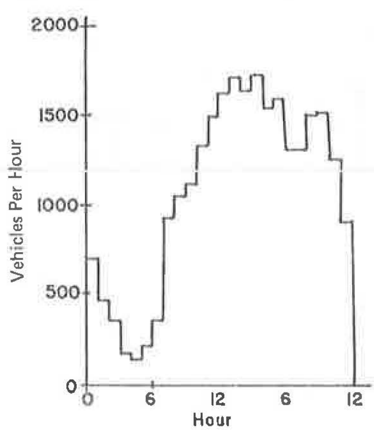


Figure 11. Average weekday vehicles per hour on Colfax Ave. (without Franklin).



undeniably a value to time, or rather there are many values to time to be accounted for. The value of time for a man hiking to the top of some pass in the Rockies may appear to be very small, yet after reaching that pass he may exclaim, "I wouldn't take a thousand bucks for this," and mean it! More realistically, the designers and builders of the SST believe that there is a significant portion of long-distance travelers who are willing to consistently pay $200 extra fare to save 2 hours of flying time on a flight from New York to London.

Denying the value of time is in essence denying the value of labor, because time makes labor available. The real problem in an economic analysis is finding an appropriate value of time that can be applied to all situations—that is, an expected value of time. In Winfrey's book (4) several values of time for commuters in the Chicago area are presented as results of studies. These values are in the vicinity of $2.50 per hour, which is the value used in this study.

Travel times were calculated for bus passengers and auto passengers, using conditions as they are now and conditions under free transit. The resulting cost is the biggest single item in the analysis, as it rightfully should be.

Denver Metro Transit does not have full information on the number of persons actually using the system on an hourly basis. What is known is an average figure of passenger fares per mile. This average, 2½ passengers per mile, is for all the routes in the city and does not relate much information on how far these passengers ride. In this analysis it was assumed that all passengers were picked up in the study area at the rate of 2½ per mile and were discharged in the central business district.

From the data supplied in schedules, an average bus speed was found, and, because the passengers were assumed to be picked up at a constant rate within the study area, an average number of passengers per bus trip traveling an average time was found for each route. Multiplying these two averages together with the number of trips resulted in the total daily travel time spent by passengers.

Although the assumptions in this process seem rather gross, they are of little importance. Passengers who ride under a fare system would be most happy to ride under a free system. Therefore, the travel times for these bus passengers will remain essentially the same in both a fare and a free bus system.

Because the calculation of passenger travel time costs under a free system is more important, a more involved analysis was done to find it. Of course this calculation is more relevant to the analysis.

New bus passengers were located geographically on the basis of their home addresses as described earlier. An average walking distance from each district to the nearest bus line was found. Walking time was based on an acceptable rate of 4.0 ft per second (5). Table 7 gives these calculations.

The second step in finding total times is to find an average waiting time for passengers at stops. It is reasonable to assume that waiting times are a function of headways. If headways are 20 minutes, then arrivals of potential passengers at the stop will be relatively infrequent for the moments after a bus has left and will increase as time passes, but then in the last few minutes before the bus arrives the frequency will again decline because of the penalty of being late. However, with headways of 4 minutes the average wait logically will be about 2 minutes because the penalty is small.

To find the average wait, new headways had to be calculated from the combination of the new buses and buses already in service. Table 8 gives the new average headways and the average wait.

An average walking distance of 1,000 ft was used for the distance from the bus stop in the central business district to the destination. With a walking speed of 4 ft per second, 4 minutes was used as the average walking time.

The most expensive single element of time in the trip by bus is the bus itself. From bus schedules, an average travel time for each district for peak and off-peak periods of the day was found and is given in Table 9. All the times involved in the separate steps were then added to obtain the total time a passenger would spend making the trip by bus. Then the expected number of passengers from each district and the expected time for each passenger were given in Table 10 in terms of passenger hours per day, per year, and cost at $2.50 per hour.

Table 5. Riders from each district by period in the day.

Period	District Horizontal Coordinate[a]	District Vertical Coordinate[a] A	B	C
6-7 a.m.	1	17	58	27
7-10 a.m.		140	262	136
10 a.m.-3 p.m.		332	437	238
3-7 p.m.		263	523	218
7-9 p.m.		122	174	61
6-7 a.m.	2	4	70	7
7-10 a.m.		31	315	39
10 a.m.-3 p.m.		73	524	67
3-7 p.m.		58	630	63
7-9 p.m.		27	210	18
6-7 a.m.	3	10	120	16
7-10 a.m.		78	543	77
10 a.m.-3 p.m.		184	902	136
3-7 p.m.		146	1,085	124
7-9 p.m.		68	362	35
6-7 a.m.	4	9	62	27
7-10 a.m.		77	280	136
10 a.m.-3 p.m.		184	465	238
3-7 p.m.		146	558	218
7-9 p.m.		68	168	61
6-7 a.m.	5	4	55	7
7-10 a.m.		31	245	39
10 a.m.-3 p.m.		73	207	67
3-7 p.m.		58	489	63
7-9 p.m.		27	163	18
6-7 a.m.	6	2	44	27
7-10 a.m.		16	209	136
10 a.m.-3 p.m.		37	348	238
3-7 p.m.		29	418	218
7-9 p.m.		14	139	61
6-7 a.m.	7	2	20	
7-10 a.m.		16	82	
10 a.m.-3 p.m.		37	146	
3-7 p.m.		29	174	
7-9 p.m.		14	58	
6-7 a.m.	8	9	20	12
7-10 a.m.		78	82	58
10 a.m.-3 p.m.		184	146	102
3-7 p.m.		146	174	93
7-9 p.m.		68	58	26
6-7 a.m.	Totals	58	442	124
7-10 a.m.		466	1,990	623
10 a.m.-3 p.m.		1,105	3,320	1,088
3-7 p.m.		822	2,980	995
7-9 p.m.		407	1,327	280

[a]See coordinates in Figure 6.

Table 6. Necessary vehicles.

Period	Route 6 No. Required	Route 6 Hours/Day	Route 13 No. Required	Route 13 Hours/Day	Route 14 No. Required	Route 14 Hours/Day
6-7 a.m.	3	3	8	8	6	6
7-10 a.m.	3	9	8	24	9	27
10 a.m.-3 p.m.	3	15	8	40	12	60
3-7 p.m.	4	16	11	44	10	40
7-9 p.m.	3	6	8	16	9	18
Total		49		132		151

Table 7. Walking distances and times from districts to bus routes.

District Horizontal Coordinate[a]	A Distance (ft)	A Time (min)	B Distance (ft)	B Time (min)	C Distance (ft)	C Time (min)
1	1,000	4.0	400	1.6	3,400	13.6
2	1,000	4.0	500	2.0	500	2.0
3	1,000	4.0	600	2.4	700	2.8
4	1,000	4.0	800	3.2	800	3.2
5	1,000	4.0	800	3.2	700	2.8
6	1,000	4.0	700	2.8	800	3.2
7	1,000	4.0	—	—	—	—
8	1,000	4.0	—	—	—	—

Column groups A, B, C are under the heading "District Vertical Coordinate[a]".

[a]See coordinates in Figure 6.

The cost of auto travel time is based on the same $2.50 per hour rate as bus time. Unlike the calculation of auto operating costs done earlier, the total time costs of every vehicle affected by free bus service are more complex. But again, only the most directly involved auto passengers are analyzed, which in this case includes all vehicles moving east and west on the studied streets and those autos traveling from the area to the central business district.

To establish travel times one must recall a well-known relationship among volume, capacity, and speed. The relationships shown in Figure 12 are adaptations of Figure 10.3 of the Highway Capacity Manual—1965 (6). The figure illustrates that as volume of vehicles increases, individual speed of the vehicles decreases. The ratio V/C is the actual volume divided by the capacity of the facility.

The two curves are of the same family but are different in values. This is a result of calibration of each of these models for the individual streets. Obviously, for streets of a different nature, a different relationship will develop. The numbered avenues represented in curve 1 are all one-way streets with a highly integrated signal system that allows for orderly progressive flow in platoons, and at low volumes the average observed speed for much of the street was the 30-mph speed limit. Curve 2 represents the relationship developed for Colfax Ave. Colfax Ave. is a two-way street with a "favored" signal system. That is, in the morning the traffic signals are arranged to favor smooth flow toward downtown, and in the evening the favored direction is reversed.

The models were calibrated by driving on the streets and recording the travel times over segments of the streets at different volumes.

There was variation in travel times on the same street with essentially the same volumes. Despite this variation, the relation between speed and volume holds as an average situation. As part of the calibration, observations were also made on the street system capacity. Each street was observed to have a different capacity, with streets having narrow and fewer lanes suffering the most constricted volumes.

Volumes on the streets were found through the records of the City of Denver Traffic Engineering Department as shown in Figures 7 through 11. The proportion of hourly traffic to the whole day's traffic was found and expressed in decimal form. The avenues were divided into five segments having similar capacity constraints and actual amounts of traffic. The hourly traffic factors were then multiplied by the daily traffic to find hourly volumes. When the capacity and the volume of each segment are known, the speed and hence the time over the link can be calculated from reference to the proper model for each hour of the workday.

After the individual expected speeds were found for each hour they were multiplied by the hourly traffic counts over that segment. The summation of the hourly counts by hour and by street gave the total time expended in the area oriented in an east-west direction.

Those vehicles originating in the area destined for the CBD were handled in a slightly different manner. Because the average speed over the streets from the study area to the CBD is slow, the sensitivity to a volume-capacity speed relationship is less noticeable. Therefore, the results of several runs over the streets were compiled into an average speed and an average time. This average time along with a terminal time of 6 minutes was added to the time necessary to traverse the study area. The total time was then calculated on a yearly basis and multiplied by $2.50 per hour and an occupancy factor of 1.2.

The calculation of future time costs for auto traffic is essentially a repeat of the present cost except that V/C ratios were reduced by 30 percent because of increased bus use, giving new speeds, times, and volumes. Hence, a whole new calculation is made based on the same relations. Figures 13 and 14 and Table 11 indicate that a 30 percent decrease in volume results in a greater decrease in overall time. Table 12 summarizes the results of the automobile travel time cost.

RESULTS

All the transportation costs have been accounted for on the basis of yearly costs. Proof of the hypothesis lies with the costs of the free bus system being less than those of the present system. Table 13 sums all the costs.

Table 8. New average headways and waiting times (in minutes) for bus routes.

Period	Route 6 Headway	Route 6 Wait	Route 13 Headway	Route 13 Wait	Route 14 Headway	Route 14 Wait
Peak						
Morning	6	3	4	2	4	2
Afternoon	6.3	3	4	2	4	2
Off-peak						
Midday	8	4	4	2	4.3	2
Evening	12	6	5	2.5	5	2.5

Table 9. Bus time (in minutes) from districts to CBD.

District Horizontal Coordinate[a]	A Peak	A Off-Peak	B Peak	B Off-Peak	C Peak	C Off-Peak
1	12	10	8	7	10	10
2	17	15	14	11	14	15
3	19	18	20	15	21	17
4	23	21	25	20	24	21
5	25	24	32	26	30	25
6	28	27	36	30	35	28
7	31	30	—	—	—	—
8	34	32	—	—	—	—

(District Vertical Coordinate[a]: A, B, C)

[a]See coordinates in Figure 6.

Table 10. Passenger-hours for new passengers.

District Vertical Coordinate[a]	1	2	3	4	5	6	7	8	Total Hours
A	643	170	478	534	229	124	135	728	3,041
B	728	1,026	2,624	1,622	1,730	1,670	952	809	10,841
C	672	148	361	717	235	948			3,081
									16,963

(District Horizontal Coordinate[a]: 1–8)

Summary: 16,963 hours per day × 260 days per year × $2.50 per hour = $11,026,000 per year.

[a]See coordinates in Figure 6.

Figure 12. Speed versus volume as a function of capacity.

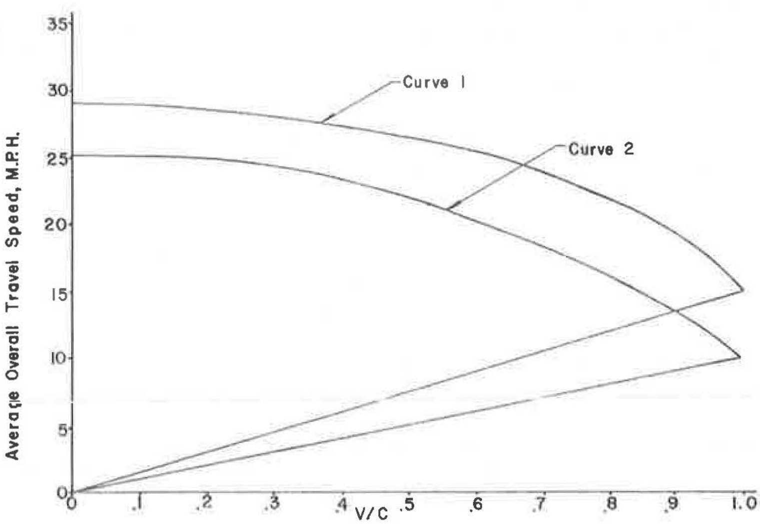


Figure 13. Comparison of hourly volumes.

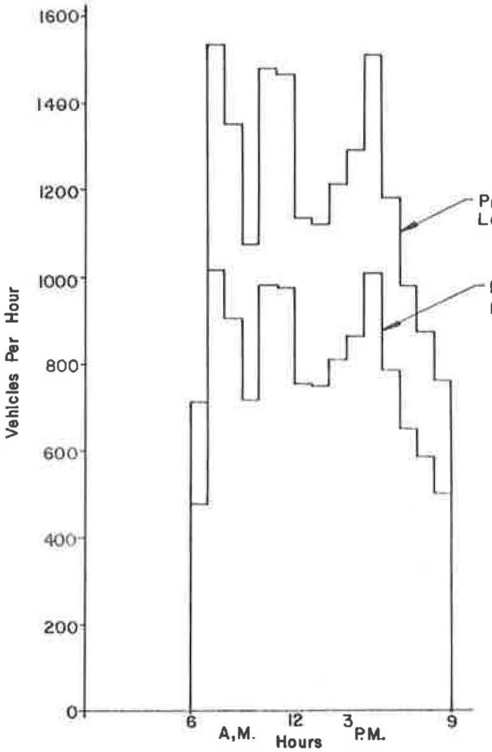


Figure 14. Comparison of travel times on 8th Ave. east of Broadway.

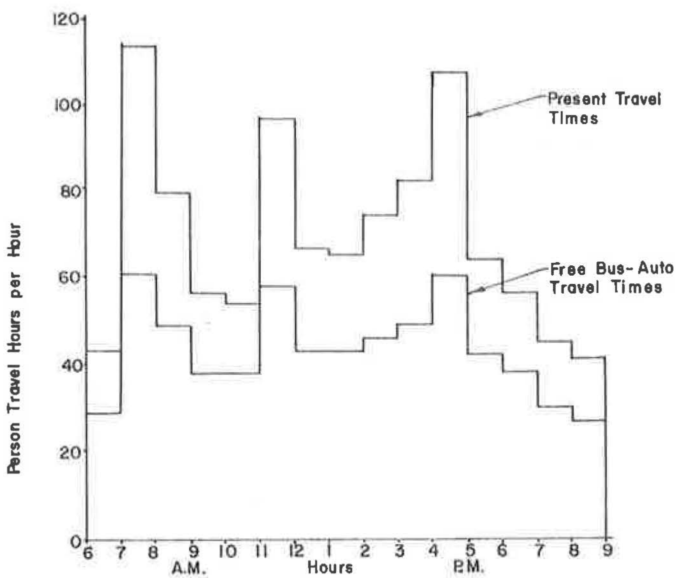


Table 11. Auto travel time (vehicle hours per hour) by segment.

Period	Broadway	York	Colorado	Quebec
Present Condition				
6-7 a.m.	43	19	38	5
7-8 a.m.	113	47	91	9
8-9 a.m.	79	40	78	10
9-10 a.m.	56	28	53	7
10-11 a.m.	54	45	88	11
11 a.m.-12 noon	96	44	86	10
12 noon-1 p.m.	67	32	62	8
1-2 p.m.	65	32	62	8
2-3 p.m.	74	35	68	8
3-4 p.m.	82	37	72	9
4-5 p.m.	107	39	76	11
5-6 p.m.	64	31	60	7
6-7 p.m.	56	28	55	7
7-8 p.m.	45	22	43	6
8-9 p.m.	41	20	39	5
Total	1,042	519	973	121
Grand total	2,655			
Free Bus Condition				
6-7 a.m.	29	13	25	3
7-8 a.m.	61	30	59	6
8-9 a.m.	49	26	51	6
9-10 a.m.	38	19	37	5
10-11 a.m.	38	29	55	7
11 a.m.-12 noon	58	27	53	7
12 noon-1 p.m.	43	21	41	5
1-2 p.m.	43	21	41	5
2-3 p.m.	46	23	45	6
3-4 p.m.	49	24	47	6
4-5 p.m.	60	30	59	7
5-6 p.m.	42	20	39	5
6-7 p.m.	38	19	37	5
7-8 p.m.	30	16	31	4
8-9 p.m.	27	14	27	4
Total	651	331	647	81
Grand total	1,710			

Summary: 2,655 hours per day at present bus service versus 1,710 hours per day with free bus service = a 35.5 percent reduction.

Table 12. Auto travel time cost.

Factor	Before	After
Driving hours in area per day	17,602	10,749
Driving hours to CBD from area	2,669	649
Total driving hours	20,271	11,443
Person-hours per day at occupancy ratio of 1.2	24,300	13,740
Person-hours per year	6,320,000	3,570,000
Person-trips per day to CBD	46,000	12,000
Terminal time at 0.10 hour per day	4,600	1,200
Person-hours of terminal time per year	1,195,000	312,000
Total person-hours per year	7,515,000	3,882,000
Cost at $2.50 per hour	$18,800,000	$9,700,000

Table 13. Total travel cost.

Item	Before	After
Vehicle operating cost	$ 3,710,000	$ 2,520,000
Bus operating cost	900,000	1,490,000
Total operating cost	4,610,000	4,010,000
Bus passenger travel time cost	2,750,000	13,790,000
Auto travel time cost	18,800,000	9,700,000
Total travel time cost	21,550,000	21,490,000
Total travel cost	$26,160,000	$25,500,000

CONCLUSIONS AND RECOMMENDATIONS

A study of this type is a practiced form of speculation; however, given the premises, the conclusion follows logically. Disputes arise early with the premises or with the methodology. In this particular paper, the final results show economic feasibility but by only a small margin, when millions are spent yearly.

The hypothesis is demonstrated, yet clearly there is reason for caution. To approach a conclusion with caution is to look at the whole problem from every vantage point. In this study, the margin of proof is well within the possible range of error.

The error, if any exists, could originate from two sources. The first might be the survey, its method, and the people it surveyed. The second follows from the first and is the application of the survey to prediction of bus use.

The survey was distributed to persons stopped at red lights. This system works well during rush periods when most trips are oriented to traveling to and from home. During off-peak periods, very few autos stopped at red lights because they progressed in platoons in signalized progression. As a result, the survey may be biased toward a larger percentage of trips heading for the high-employment center of Denver.

There are real economic compensations not dealt with in the paper. Parking cost, a significant expense to commuters, has not been included in the paper because the trips to the downtown area are of varying length and varying cost. But the cost, if included, would be significantly in favor of free bus transport. Likewise, there would be savings to Denver Metro Transit, because there is an expense in handling fares and no expense under a free system.

In addition to economics, there are environmental reasons that should influence a conclusion. Air pollution, noise pollution, and traffic are constantly increasing. Traffic in the area of the three routes increases at a rate of 3 or 4 percent a year. Free bus service would reduce traffic and therefore be a boon to the residents.

It is therefore the conclusion of this paper that free bus service is economically feasible and should be tested by one of two methods. The first would be to make a more sophisticated study of the city's total transportation system under free bus service. The second and more rewarding method would be to actually investigate free bus service by implementation.

This investigation could take the form of this paper in that free bus service could be implemented in a controlled situation. Detailed and accurate monitoring of the transportation system before and after the institution of the free service could be conducted. The results would concretely verify or dispute the conclusions of this paper.

With traffic increasing, pollution increasing, and the urban scene chaotic, there is a great need for quick and good answers. Yet, the complexities of the problems inspire complex and long-range plans for solutions that are often self-defeating. Free bus service is a simple answer to complex problems and one worthy of serious consideration and trial.

ACKNOWLEDGMENTS

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INTERNATIONAL ACTIVITY IN PERSONAL RAPID TRANSIT DEVELOPMENT AND ASSESSMENT

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This study reports on developments in the rapidly emerging field of personal rapid transit in western Europe, North America, and Japan. It deals with conflicting notions of the basic system concept as perceived in various nations and reports on the nature and the sources of financial and technical support for research programs in each country. Application studies in specific urban environments and technological research and development efforts are reported. Personal rapid transit is analyzed in the several evaluative contexts of transit services provided, social and environmental impacts, and institutional constraints to implementation. The study was carried out for the Organization for Economic Cooperation and Development as part of a larger study into a wide range of public transport service innovations in operations, planning, and technology.

•THE SURVEY of activities in the personal rapid transit field reported in this paper was carried out for the Organization for Economic Cooperation and Development during 1971-72. It represents but a portion of a larger study that sought to scan the status of a variety of innovations in urban public transport ranging from administrative reforms to new technologies (1). OECD is an international organization made up of member countries from western Europe, North America, and the Pacific and devotes its efforts to research, policy analysis, and mutual exchange on a variety of matters having to do with economic growth and common problems of urbanized, industrialized nations. It has been engaged in road research questions among other interests for a number of years, but the particular study reported here had its origins in more recent interests of the organization in environmental and urban matters.

On an ad hoc basis, a 2-year study of the "impact of the motor vehicle on the environment" was undertaken early in 1971 under the direction of an international committee drawn largely from the pollution-control agencies of the participating countries. My own study of innovations in the urban public transport field was viewed as exploring alternatives to the private automobile for urban mobility, in the context of policy discussions of urban environmental quality that might involve varying degrees of restraint on private motor vehicles in major world cities. Other studies that were carried out as part of the same inquiry have dealt with air and noise pollution caused by motor vehicles, traffic limitation techniques in urban areas, and natural resource demands of the automobile for fuels and metals.

A number of short-term improvements to the functioning of existing forms of transit were identified, particularly in the area of planning and administrative innovations. Although many of these might be carried out at relatively low cost and without long development or construction delays from conception to realization, the institutional resistances to implementation were found to be significant in many cases, Just getting the highway planning agencies and the transit planning agencies in a given metropolitan area to work together on common aims is an example of such difficulties, which vary widely from one city to another or from one country to another. What may be common practice in one country today will have to wait for political and institutional changes in another before it is feasible there.

Sponsored by Committee on New Transportation Systems and Technology.

In a more middle-term perspective there were also found to be a number of promising operating concepts, evolutionary technologies, and investment opportunities that had both a technological component and an organizational component necessary for successful implementation. Examples of this kind of public transport improvement were the construction of new highway facilities exclusively for bus operations, placement of central city tram lines underground, application of medium-sized automated vehicles in simple airport or downtown shuttle services, and computer-directed management of traffic priorities in complex street and highway networks. Applications of this nature already exist in selected cities, at least in the demonstration stage, but the realization of their potential will take some time to be communicated into policy on a widespread basis.

On a longer-term basis there are both significant opportunities and significant uncertainties in new transit concepts employing major technological advances. Personal rapid transit is perhaps the best example of these, but dual-mode systems and high-speed trains are others. But, despite the many and varied attempts at such technological innovations observed in the course of this survey, the prospects for realistically implementing much of their promise at present seem quite marginal. Too little governmental and public concern has thus far been expressed in defining the nature of the problems that these new technologies should help ameliorate and the processes by which they might be tested and selectively introduced to gain acceptance as a long-range alternative to existing transport modes. Thus the primary concern of this paper, beyond simply reporting current research and development activities in the field, is with the institutional factors that may limit the future applicability of such an advanced technology concept before it has ever been adequately developed and demonstrated.

CONFLICTING DEFINITIONS OF TRANSIT SYSTEM CONCEPT

Personal rapid transit here is intended to refer to small automated vehicle systems in area-wide service. Such a concept, and its technological realization in reliable and economical hardware, would offer a major advance in the service characteristics of urban public transport as experienced by the traveler. If it is possible to develop such a new technology system it would add a new personalized alternative to the present choice of transit modes, most of which are mass transportation devices, whether buses, trams, or trains. This is a potential quality of transit service of interest in relatively affluent cultures where the private automobile exercises much of its appeal in its highly flexible and personal use. It does not seem to be obtainable through any of the short- and medium-term innovations mentioned earlier, which can improve mass transportation over present standards but never attain the high level of service that may well be desired of public transportation in the future. Therefore it seems important to single out the potentials and the institutional pitfalls of this particular advanced technology concept for review.

Observing the national programs of several countries in this research and development area allows one a certain perspective on institutional problems that is not possible by observing efforts in the United States alone. As promising as the possibilities are for a new form of transit service through the development of a more personalized, yet public, mode of urban travel, the potentials in all countries for undue delay and embarrassing failures in application are significant, given the present array of organizational and political factors bearing on the whole structure of institutions involved in urban transit development. These dim prospects do not seem to lie so much in technological problems but in the gaps of communication and responsibility between those institutions with specific transportation missions and those with differing but intimately related tasks, such as enhancing the quality of the urban environment or promoting the application of science and technology to human affairs. The pattern may be different in Germany, France, Japan, Great Britain, or the United States, but certain common features of these communication failures and fragmented responsibilities are present in all existing national programs dealing with personal rapid transit.

Perhaps the most frustrating communications failure involves a definition of what personal rapid transit, or PRT, really is meant to be in transit service terms. There is frequent abuse of the term, which serves to confuse technology with service. The abuse is twofold and consists of describing as PRT (a) moderately large-vehicle, line-haul technologies because they are automated and can, incidentally, bypass stations; and (b) small-vehicle shuttles, loops, and networks in airports and other major activity centers because they are small and on guideways. Although both these types of systems are innovative in their own right and are immensely valuable as precursors to truly personal rapid transit systems, they do not embody the service characteristics that are central to the original concept of PRT.

Each of these alternatives has been discussed extensively in the report from which this paper is excerpted. As is also discussed there, the staging of research, development, and demonstration as we advance from these precursor systems to fully characteristic PRT networks and vehicles is critically important to the whole process of establishing technological and political feasibility for advanced transit systems.

Reportage in the popular press, and even in the technical literature, to the effect that PRT is already here must be treated with some skepticism. The pressures on industrial firms and government agencies to make such a claim are quite understandable in the short run, yet potentially very dangerous in the long run.

The need to demonstrate civil technological programs to the public in forms that they can readily understand, to overcome widespread doubts in the transit industry that anything technologically innovative in urban transport is possible or even desirable, to begin to spend real money in this field to keep industrial interest alive, to improve the image of a tired and dull public service in its political competition for scarce resources are all valid and important reasons for a bit of boosterism to spur interest, support, and future expectations. And for these reasons (as well as others less understandable), efforts are being made to simplify and to shortcut expensive research and development programs and to bring PRT systems—or their less exacting cousins—to limited performance demonstration soon.

But the importance of recognizing a thing for what it is—not for what it is called or wished to be—needs to be brought to current discussions. Therefore much of what is currently being said publicly about PRT in a variety of countries is in need of critical analysis to clear the air about a subject of immense importance to the future of urban transportation.

Without such critical review early in the process, the potential for disappointment and political backlash when costs rise, complexity increases, and failures occur becomes a very real and great danger, perhaps unrealized in many technical quarters today. A few such disappointments in the not-so-distant past have already occurred. It is with this perspective in mind that we offer the following optimistic yet critical interpretation of recent developments in the field of personal rapid transit.

Minus its current abuse, the term PRT originally referred to the concept of a public transport system featuring small automated vehicles that would operate on exclusive guideways, traversing extensive and complex area-wide networks in response to the origin and destination desires of individual passengers. The term seems to have been first used in the U.S. government report, "Tomorrow's Transportation" (2), to cover a range of such systems concepts, of which more than 20 had been proposed as early as 1967. (Other general terms then in use included "area-wide individual transit" or "network transit".) A longer and more precise definition appears in that report and is well worth reviewing by those seriously interested in the field (2, pp. 60-62). It serves to restore a focus on the importance of this systems concept, which has become so obscured in the past few years in the United States yet which has been adapted directly from American work as the central concept of both the Japanese and German research and development efforts in high-technology urban transit.

Perhaps the key point to be emphasized about PRT, as thus defined, comes in a paragraph from the 1968 federal report (2, pp. 61-62):

> The guideway network covering the metropolitan area is the essential ingredient of the personal rapid transit system. Without a network of guideways the system could hardly avoid conventional heavy dependence on work trips and a radial orientation to existing central business districts. Thus it could not provide adequate transportation alternatives in large metropolitan areas

> with a wide dispersion of trip origins and destinations. No matter how sophisticated the technology, transit which operates without some sort of network service pattern almost certainly will remain a marginal service in the movement of urban populations.

Thus the central issue and advantage of personal rapid transit as an innovative transit service with major, not minor, potential influences on urban transport is represented in the last sentence of the quotation above: "No matter how sophisticated the technology, transit which operates without some sort of network service pattern almost certainly will remain a marginal service in the movement of urban populations."

Although elements of the advanced technology that can lead in the direction of PRT are already under development in research laboratories around the world, it is less the technology and more the overall systems concept that is at issue now. It is a harmless enough expediency for an automated tram such as will operate at Morgantown, West Virginia, to be called a PRT, while development continues toward more sophisticated networks, vehicles, guideways, and operations. But if it becomes widely believed that such an installation truly represents personal rapid transit, and further research and development is thus curtailed at a relatively low level of service capability, then the mislabeling represents a major disservice to all of those who hold out some hope for major technological and service improvement in urban transport.

Instead, it should be possible to keep the concept of PRT intact while incrementally bringing the technology to higher and higher levels of sophistication. The Dulles Airport "Transpo" demonstrations could have some influence in that regard. But the crucial question there is, Which kinds of characteristics of the small-scale transit systems will be emphasized in the next demonstrations, if any, and possibly be slated for real cities, following technical tests and public trials at the exposition?

At some more distant, evolutionary point in system development, the sophistication of the needed control technology—perhaps the efficiency of the power-consumption requirements, the maintainability of the constituent system components, and other factors—will be central technological issues that must be resolved before really major commitments can be considered for PRT systems. But for the present and very near term, existing technologies are being utilized for as much of system hardware as possible by many of those companies promoting capabilities in this area. That is, rubber tired, automotive-type suspensions, conventional electric motors for on-board propulsion, small-scale computers for controls, and other such existing components are being lashed together in relatively crude but imaginatively adequate first-generation personal rapid transit systems. These will probably be adequate for small-scale, cheap public demonstrations soon that can be used—or misused—to powerfully convey an image of potential and progress in urban transit research and development.

Keeping a perspective on the differences between where PRT is today and where it must develop in the future to become more than an exposition or test track novelty will be crucially important in the next few years for industry, governments, and the public. It will be, that is, if initial visibility is to be turned into adequate political and financial support to carry out the necessary research, development, and demonstration work to make real urban PRT installations possible in the long run.

COMPARATIVE NATIONAL PROGRAMS OF RESEARCH AND DEVELOPMENT

The research and development activities that must precede the actual delivery of an extensive, complex, safe, reliable, and unobtrusive system of personal rapid transit in an important urban environment have recently begun to get under way in several advanced industrial countries.

United States

In the United States, where it is generally acknowledged that serious interest in personal rapid transit began, a variety of relatively small industrial firms began doing their own systems design and prototype development, following the systems analysis performed for the "Tomorrow's Transportation" report in 1968 and refined elsewhere since. Most visible among these are Alden, Transportation Technology, Dashaveyor, Monocab, Carveyor, and Uniflo. But operating at relatively low levels of financial investment and in a climate of skepticism at both urban and federal levels of government, these firms generally failed to establish sufficient credibility to move their designs beyond their own test tracks into serious consideration for urban applications. And without the prospects of either production contracts for their relatively rudimentary initial systems efforts or substantial infusions of public or private investment to increase the complexity of the designs, the whole field seemed stymied. There was no way that a small, private firm could, by itself, break through into a field that must, by its very nature as a public service, be supported by public funds.

Only with the agreement of the Urban Mass Transportation Administration to sponsor demonstrations of 4 such systems at a special public exposition did these individual firms obtain the opportunity to establish the needed public credibility to move privately initiated, small-vehicle transit systems forward in the United States. Even at that, the relatively cheap investment of $6 million to $8 million was divided equally among the 4 systems that were selected from some 13 applicants. Much of the cost that then went into design of the systems for demonstration at Transpo was private investment, leveraged by the federal involvement and "seed" investment.

A significant change in the industrial composition of the private firms now active in the PRT field in the United States has followed. Almost immediately following the sorting-out process involved in the Transpo competition, Dashaveyor was purchased by the Bendix Corporation, the Monocab division of Varo was purchased by Rohr Corporation, and the Ford Motor Company became a serious entry in the field. The other final participant, Transportation Technology, had already been affiliated with the Otis Elevator Company for some time. Thus, with this qualitative shift in the financial makeup of the private sector and the federal credibility afforded to the overall enterprise, it can be expected that the pace of development of new transit technologies will increase in the United States.

Another recent variation on the processes involved in developing a new small-vehicle transit technology—one that recruited and employed high-technology laboratories of government and the aerospace industry—is also being carried out in the United States as part of the Morgantown demonstration project. In this instance the systems analysis was first carried out, not by a producer company or a government systems laboratory, but by a university and local government that together had a specialized transit problem in need of solution.

Once given the national importance now afforded the Morgantown system, the Jet Propulsion Laboratory (one of the quasi-governmental systems facilities with a good record in managing space programs) was brought in by UMTA to do the systems design and to direct the overall implementation of the project. Awards for actual development of the vehicles and controls were subsequently awarded to the Boeing Company, a major aircraft manufacturer, and the Bendix Corporation, another aerospace and electronics enterprise (3).

None of the 3 proprietary systems that had been studied by the joint university-city team in their own initial systems analysis and systems design studies was selected for development as had been originally envisioned, although the Alden Self-Transit Systems Corporation, which had been the preferred choice of the university-community team, was included as a subcontractor to Boeing on vehicle development. After the systems design phase had been completed, the Jet Propulsion Laboratory withdrew from further managerial responsibilities. Project management, in addition to the continuing vehicle development work, was awarded to Boeing.

It is still too early to tell the ultimate value of the project. Costs have risen, the system has been cut back in extent, and the date for ultimate public use of the system is still somewhat unresolved. The system has begun to operate in a test track configuration, however, as of October 1972.

The Transpo and Morgantown demonstrations are recognized as measures to at least start the whole field of new technology moving, without necessarily delivering a workable PRT technology (as it has been defined for this paper). An additional program that it is hoped will lead to more advanced PRT systems is under discussion by presidential advisors and the Department of Transportation. The outlines of this program are still unclear, but it was given prominent mention in a background briefing held in conjunction with the 1972 State of the Union message and in a special presidential message on research and development.

The program is likely to involve a considerable contribution of skills from the National Aeronautics and Space Administration (NASA), the Aerospace Corporation, and other high-technology laboratories. Some of these groups have already been hard at work for several years now on systems aspects of the concept (4). Analyses, simulations, and model configurations of networks have been variously sponsored in ad hoc circumstances.

Germany

In Germany the PRT situation is less ambiguous, organizationally more advanced, and technically progressing at a somewhat steadier pace than in the United States. There, a consortium of firms has been funded by the central government to carry out an entire research, development, and prototype demonstration program leading to an initial version of a PRT technology, all at a relatively low cost and within a tight time schedule. The two industrial firms participating in this program are of considerable technical diversity and financial strength. Demag is a producer of heavy machinery and steel products located at Duisburg in the Ruhr, and Messerschmitt-Bölkow-Blohm is an aerospace and aviation-based firm headquartered near Munich.

These firms had separately been surveying previous work in the field of transit technology as a potential market opportunity in 1970-71 and had been carrying out preliminary systems analysis of PRT-type concepts when they discovered their overlapping activities. They subsequently decided to join forces in exploring the potentials of small, automated-vehicle technology for urban transit applications.

Demag's interest can be broadly identified with the energy and steelwork aspects of such systems, whereas those of MBB run to the controls and vehicles. Together, they are identified with a substantial systems study performed in 1971 with the city of Freiburg, Germany, as the example application used for data and detailed analysis (5). Since that initial study they have continued their systems analysis and design work with travel data and urban environmental constraints from a variety of real settings, including portions of Munich and the town of Hagen in the Ruhr.

The project—called Cabin Taxi or Cat for short—is sponsored by the German Ministry of Education and Science in conjunction with in-house funds of MBB and Demag. A letter of intent to this effect was transmitted to the firms early in 1972 indicating that some DM 15 million would be available for an initial 2 years, with 80 percent government funding and 20 percent from the individual firms themselves. A development schedule announced in 1972 (6) has the following targets:

1. Testing of all essential components of this personal rapid transit system on test stands in 1972;
2. A test track for the prototypes to commence operation in 1973;
3. Completion of a first larger experimental network to study user acceptance in 1974; and
4. The first public network to start operation in 1976.

A decision on whether or not to go ahead with installation of a public network, as opposed to merely an experimental one, will have to be made after the results of the first 2 years of the project are evaluated. The 1976 date for opening operations of an installation in a real urban setting is thus contingent on successful performance in the next 2 years and on additional funding becoming available beyond that now committed.

France

In France, the single firm of Engins Matra—an aerospace, automotive, and communications conglomerate of sizable proportions, headquartered in the Paris suburbs at Velizy—has been selected by the national government to examine the prospects of

PRT-type technology from systems analysis on to prototype demonstration. The origin of French interest in such technology stems both from domestic innovations, such as the novel coupling/decoupling concepts in an earlier proposal called AT 2000, and from the general level of activity in the field elsewhere in the world.

A 28-month contract that commenced in March 1971 was negotiated between Engins Matra and the French government. As a research and development grant, it carries Frs 7.3 million of government commitment and calls for another Frs 2 million of investment by Matra itself.

Systems studies of a range of technologies having somewhat different performance characteristics but all having small-vehicle systems that are generically called ARAMIS are being carried out. The emphasis is on quick delivery of a system using off-the-shelf technologies for its components. Data for analysis and designs have been obtained from a variety of French urban settings, such as medium-sized communities like Nice and Strasbourg and the suburban communities ringing Paris to its south. A test track was initially scheduled for operation by the summer of 1973.

Public reporting of the status of this work has been minimal, and unfortunately no references seem publicly available at this time. It is thus impossible to say accurately whether or not schedules will be met or what the performance characteristics of the system will be.

United Kingdom

British efforts in developing PRT technology were well along on a system called Cabtrack by the spring of 1971 but were slowed by the Department of the Environment, which oversees transport in the United Kingdom. The decision came just short of a contract award to the industrial firm of Hawker-Siddeley to carry the systems studies closer to hardware production (7). The effect of this position is to take Cabtrack back to the drawing boards for comparative study with minitrams and more conventional technologies, with an admonition to watch carefully the costs and environmental impacts of each alternative.

Japan

In Japan, serious efforts to develop a PRT system under the name CVS (computer-controlled vehicle system) are well advanced under the sponsorship of the Japan Society for the Promotion of Machine Industry (JSPMI) and the technical guidance and instructions of some faculty members of the University of Tokyo and the Ministry of International Trade and Industry (MITI).

A New Machines and Systems Development Center was set up in April 1972 within JSPMI. Through this center the project team, consisting of university scholars and technical representatives of a variety of participating industrial firms, is now designing and testing the first full-scale vehicles, tracks, and control systems for an automatically controlled small-vehicle system.

Previous to this effort, feasibility analyses, systems studies, and construction and operation of a 1-to-20 scale model of a CVS network were carried out in 1970-71 to ascertain whether the project warranted significant support. The model, with some 60 vehicles operating over a simulated portion of the central Ginza area of Tokyo, was prominently displayed at the fall Tokyo Motor Show in 1971.

With financial support assured for the next stage of research and development in 1972-74, plans have been made to construct a test course for the CVS at the automotive test course of MITI at Higashimurayama, Tokyo. An initial 200 m of this track was opened in September 1972, and test runs of the first CVS cars were performed from October to December 1972. A full test course of 4,700 m is due for completion in 1973, and full computer operation of a 100-vehicle test system will be carried out from February to October 1974 (8).

No plan nor schedule has yet been announced for an urban demonstration. That will probably have to await successful completion of test under the present 2-year research and development phase of effort.

Summary of Programs

In the European countries and Japan the PRT research and development has been sponsored by science and technology ministries or special agencies, not by transport ones. This appears to be related to a difference in aims regarding the short and long term. Transport ministries and departments in every country mentioned are skeptical about uncertain, high-technology transit systems. This has to do not only with the technical risks and development costs involved but also with the desires of the constituencies that transport agencies rely on for political support. These constituencies often have short-term goals relating to current problems or the maintenance of existing industries or institutions such as rail transit suppliers and operators, highway builders, urban mayors, transit employee unions, automobile manufacturers, and trucking companies. Few of such groups could be expected to take a long-term view, particularly if it appears threatening to their interests later on or drains resources away from current programs of financial interest to them. Science, education, or technology ministries, on the other hand, typically have constituencies with high-level research interests, such as universities and advanced-technology laboratories and firms. Such groups, in seeking research opportunities and new markets, could naturally be expected to support innovative ventures with less regard to whether or not they solved a valid transportation need of cities.

Any one, or all, of the research and development programs discussed in this paper could be curtailed by 1974, when they run out of financial support for the relatively low-cost phase of initial prototype development. Most programs are now budgeted at a few tens of millions of dollars until then and can be carried out with only minor threats to existing urban transportation programs. But hard decisions will have to be made in each country soon on whether or not to spend sums at least an order of magnitude greater on development and demonstration of more complex systems with low headways and network configurations. By at least 1976 these choices will lead to severe political and budgetary conflicts with priorities for existing urban transport modes. My own feeling is that unless PRT systems can be demonstrated to be clearly technologically feasible and politically sensible as a major portion of the transportation investment priorities for cities in the 1980's they will not be continued past the next few years.

To find out whether or not such systems make political sense as other than technological novelties it would seem imperative now that application studies be carried out to find out how such systems would be applied in real urban environments, what effect they would have on the quality of urban mobility, and how they would specifically relate to the several ecological and economic stresses now approaching urban transportation in terms of air quality and increased fuel costs for private automobiles. This job has been poorly done in the past and often ignored. It can hardly wait much longer if PRT applications are to begin to make major claims for transportation funds in any of the countries now involved in such research.

APPLICATION STUDIES AND SYSTEM EVALUATION

The technological aspects of the research and development, at least as far as getting a single prototype into simplified operation, probably appear quite simple and straightforward to industries comfortable with meeting the high-technology challenges of aerospace and electronics systems. Indeed, individual firms and government laboratories with strengths in these areas are quite noticeable in the present flurry of technological activity surrounding PRT concepts in every country now taking an active interest in the field.

But to existing urban transit operators and to the lower technology, mass-market-oriented automotive industry, as well as to other skeptics of whatever stripe, the issues of mass production, reliability, maintenance and operating costs, and consumer acceptance are among the major concerns. And these issues cannot be grasped well at the early stage of prototype demonstration.

In addition to the technological aspects of research and development, there are a host of political, social, and environmental issues that will appear only at the stage of actually attempting to demonstrate a system in an urban setting. Then other values also will be at stake, and failure could be costly to the community as well as to the transport system proponents themselves. Dealing with such issues requires a different type of research, and a different view of development and demonstration, than that used to deal with technological, or even economic and production, concerns.

Most of the research and development now under way is of the technological prototype sort, or its analytic precursor, systems analysis. But a limited effort is also being devoted to application studies that seek some indication of the general functioning and acceptability of such PRT systems in real urban situations. In addition, simpler types of systems that have some of the PRT features and can be readied now or in the very near future are serving as partial tests of the technological components, operating requirements, production costs, urban design requirements, and consumer acceptance of the more complex and extensive systems that should gradually follow.

In some ways it is certainly too early to attempt to predict or assess the consequences of a major commitment to an innovative urban transport mode such as this one, but it is exactly because of the unexpected social and physical consequences related to the implementation of another urban transport technology—the private automobile—that interest was initially aroused in PRT as an alternative. High-quality application studies of the potential effects of personal rapid transit systems in widespread use are thus a desirable and important part of any nation's research and development activities in this field.

Urban studies have been made by virtually all industrial firms and technological laboratories with programs in new transit system development, but the types of studies carried out are almost always of the nature of a travel demand forecast, for later use in designing the location and capacity of hypothetical system vehicles, guideways, and stations. Although such studies are valuable inputs to the design process, they fall far short of the types of social, architectural, and planning studies that would be beneficial to cities, citizens, and national governments in appraising the merits and demerits of these technological research activities.

Three recently suggested actions placed before the U.S. government by a special committee of the National Academy of Engineering (9) are extremely pertinent to this point:

1. Federal urban transportation programs should focus increasingly on providing better quality of urban life, not just better transportation.

2. The increasing focus on the quality of urban life clearly calls for a better understanding of the interactions and relationships between urban transportation systems and the functions of metropolitan areas. This, in turn, requires an enhanced program of analysis and real-world experimentation.

3. The proper design of urban transportation experiments and the implementation of more effective investment programs also call for an increase in supporting social science thinking and analysis.

The thrust of these suggestions would appear to be (a) that a good deal more attention needs to be paid in the future to the roles of transport service in urban life, not just to its engineering and economic features; (b) that conscious thought about how, when, and where technologies are applied in demonstration and initial application deserves additional emphasis; and (c) that broader areas of professional competence ought to be drawn upon early in the systems analysis and design process and on throughout the demonstration and implementation phases of transport system development. Although these points were meant to apply to an entire spectrum of urban transport-related programs, they are especially important in the case of a service concept as significant as personal rapid transit could become.

Three recent application studies are worth mentioning, because they have gone somewhat outside the limited engineering perspective of industrial laboratories. As such, they are indicative of additional sources of evaluation for new industrial products like PRT and of application studies of slightly broader scope.

In Gothenburg, Sweden, a study of possible application of personal rapid transit to the future needs of that city of approximately 500,000 has been under way for several years now. It began as a separate study of one alternative to the proposed rail rapid transit program for the city, but it has become an integral part of a comprehensive town planning study of several transport alternatives and their potential influence on city development.

Here, the city government is itself carrying out the study. And because there are no potential PRT system suppliers active among Swedish industries today, the inquiry has been able to look worldwide for comparisons of potential technologies. Final results are not due for several years yet, but interim progress has been reported (10).

A somewhat similar study—this one carried out by a university research group—has been undertaken in Minneapolis-St. Paul with the partial support of the Minnesota legislature. Although not part of a comprehensive study of alternative modes of transport for the Twin Cities, it has played a part in transit decision-making there along with studies of rail rapid transit and bus improvements (11).

And in the United Kingdom, an architectural study performed for application of Cabtrack has been the most detailed environmental assessment of PRT yet attempted (12). The results of the study showed such a system to bring mixed blessings in a complex urban environment such as central London. But it has provided a valuable contribution to the assessment of transit system impacts in certain architectural surroundings and has raised some warnings as to the manner in which such interdisciplinary collaborations will have to be conducted in the future.

But most of these study efforts aimed at broader evaluation of the costs and benefits of PRT investment in real urban environments have failed to effectively recognize and deal with a sizable clientele of users—city governments, environmental agencies, potential travelers, and so on that could generate the political support for implementing PRT systems if they were indeed found to be technologically and economically feasible. Without such support, and a fairly clear notion of how one proceeds politically from where we are today to the transport investments of the 1980's, personal rapid transit is not likely to contribute much to urban transport improvement but will be buried by prior commitments to rail transit systems and further highways.

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ECONOMIC, ENVIRONMENTAL, AND DESIGN ASPECTS OF LARGE-SCALE PRT NETWORKS

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A parametric study of system variables of large-scale personal rapid transit (PRT) networks is presented. An idealized urban area having uniformly distributed population (trip) origins and destinations serves as the trip model, and a square mesh pattern serves as the PRT network model. Independent variables in the analysis are population (trip) density, PRT operating and fixed costs, mesh spacing, automobile speed, perceived automobile cost per mile, and PRT speed and fare. Dependent variables are modal split (patronage), reduced automobile emissions, cost and subsidy per mile, benefit-cost ratio, electrical power requirements, fleet size, and needed guideway and station capacity. The analysis identifies ranges of population (trip) densities and PRT system performances and costs for which PRT is either economically feasible or a benefit to society. Quantified societal benefits include reduced automobile costs, reduced travel time and pollution, and increased safety. The results provide useful guidelines for system designers, urban planners, and decision-makers.

•EVERY urban area is faced with a transportation problem. The problem lies not so much in how people might be transported but in how people wish to be transported. The desire for comfort, convenience, flexibility, and speed has led to the overwhelming success of the automobile. Most American cities are characterized by low-density residential areas and a dissolving central core, and thus trip origins and destinations are widely dispersed. Because conventional transit serves only few origins and destinations at high speeds (subways) or many origins and destinations at low speeds (buses), ridership consists primarily of the transit captive (those who do not have access to an automobile) and those whose origins and destinations are in the areas that can be served well by transit. The extensive reliance on the automobile has in turn influenced the development of the city. The auto's ability to serve widely dispersed origins and destinations has spurred development in the urban area's outer ring, which in turn has demanded more dependence on the auto. The result is a transportation problem in terms of pollution, congestion, land use, and reduced mobility for the transit captives.

In an attempt to provide a viable public transit system for the typical auto-oriented city, a substantial effort has been generated in both the United States and abroad for the development of a new-technology system known as personal rapid transit (PRT). PRT is a class of fixed-guideway transit systems for which the stations are off the main line. The PRT vehicles are small (2 to 6 passengers) and operate individually under automatic control. Trips are nonstop from origin to destination—high capacity is achieved by operating at close headways. Its auto-like characteristics (privacy, comfort, speed) make it a potentially viable competitor with the auto. In its completed

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form, PRT would serve as an area-wide carrier of people and goods. This would be accomplished by the construction of a network of lines with closely spaced stations, thus providing easy access to the captive vehicles. PRT networks have been studied for London (1), Los Angeles and Phoenix (2), Frieberg (3), Vancouver (4), and Gothenburg (5). These studies have provided valuable insight about network design, PRT economics and ridership, and certain system requirements such as guideway capacity and the effect of fare on ridership. An excellent study of the visual intrusion of the London network has also been reported (7).

This paper presents a parametric study of PRT design and cost variables. An urban area is idealized by assuming a uniformly distributed population, i.e., a uniformly distributed transportation demand model. Two population (trip) densities are assumed, one representing residential areas, the other representing major activity centers (MAC)—e.g., employment, shopping, and educational centers. The PRT network of lines serving the idealized city is one having a square grid. Residential areas have a larger mesh spacing than the major activity centers. The analysis uses aggregate information on auto travel time, trip distance, and income that happens to characterize the Twin Cities of Minneapolis-St. Paul, Minnesota, but also represents many of America's larger urban areas. The study was performed concurrently with our study of real-city networks for the Twin Cities and Duluth. The motivation for the idealized network study is that it permits the easy variation of parameters such as mesh spacing and population density.

The core of the analysis consists of a modal split assumption whereby trip-makers are assigned to PRT or the auto on the basis of a comparison of travel time and costs via each mode. A Monte Carlo procedure (2) is used whereby the modal split is determined by sampling a large number of trips. Once the modal split is determined, other system parameters such as reduction in air pollution, guideway capacity requirements, station requirements, electrical power, fleet size, cost per passenger mile, revenues, subsidies, and benefits can be calculated. Previous economic analyses (2, 3, 6) quantitatively have focused on costs, revenue, and subsidies. The present study broadens the outlook and applies the benefit-cost ratio method of economic analysis. Benefits quantified are reduced auto costs, travel time, air pollution, and auto accidents.

SYSTEM MODELS

Trip and Trip-Maker Characteristics

The idealization of a real urban area by simply modeling only two population densities—i.e., residential areas and major activity centers—provides a sensible level of abstraction for parametric analysis and a convenient point of departure for a transportation study. A substantial amount of compiled statistics describing trips and trip-makers is available on which to build. Major activity centers include schools, shopping centers, employment centers, and, more generally, all trip destinations except residences. Figures 1b, trip length distribution, and 1f, trip purpose distribution, show some trip characteristics of the Twin Cities. Both figures are based on information from the TCAT study (8). Figure 1b illustrates the predominance of shorter trips. Figure 1f indicates that about 80 percent of the total trips have one end at a residence and the other at an MAC. Residence-to-residence and MAC-to-MAC trips each comprise about 10 percent of the total. As indicated in Table 1, residents average about 3 trips daily and 0.3 trips during each of the 4 peak hours. Figure 1c, family income distributions, is based on 1970 income data supplied by the Metropolitan Council.

PRT Network Design Parameters

The Twin Cities street layout is largely rectangular, as is typical of many American cities. The simplest geometric PRT network consists of equally spaced one-way lines, as shown in Figure 2. Vehicle ramps connect all intersecting lines, enabling passengers to travel without transfer between any two stations in the network. This paper considers a square network, which is thought to be appropriate when modeling essentially square cities with no predominant direction of travel. Table 1 summarizes nominal values for residential and MAC mesh spacings.

Stations located at the midpoints of grid lines minimize both the longest walk distances (L/2) and the average (L/3). Stations serve an area within the dashed line shown in Figure 2. If a uniform trip generation density over the station attraction area is assumed, the walk distance distribution is as shown in Figure 1a. For this network design it follows that

$$N_s = 1/L; \; N_i = 1/L; \; M = 2/L \tag{1}$$

where M is the route miles of guideway per square mile of area, N_i is the number of single interchange ramps per mile of guideway, and N_s is the number of stations per mile of guideway. Equation 1 will facilitate the determination of system cost in a later section of this paper.

Three vehicle design parameters have a substantive effect on network design; they are nominal line speed, jerk, and acceleration. Switch and acceleration (deceleration) lane lengths are estimated respectevely from

$$\begin{aligned} L_s &= 47.04V\,(h/J)^{1/3} \\ L_a &= 1.08V^2/a + 1.47\,(Va/J) \end{aligned} \tag{2}$$

These equations are derived elsewhere (9). V is the nominal speed in miles per hour, h is the distance in feet between ramps and guideways, a is acceleration in ft/sec^2, and J is jerk in ft/sec^3. A station ramp consists of 2 switches, an acceleration lane, a deceleration lane, and additional lane length for queuing, loading, and unloading. An interchange ramp consists of the same components. A positive distance must be maintained between station ramps and interchange switches. This places a lower limit on the mesh spacing. For the nominal values of acceleration (8 ft/sec^2) and jerk (8 ft/sec^3), both acceptable for seated passengers, and velocity (35 mph), the minimum mesh spacing is 0.3 mile.

PATRONAGE ESTIMATION

A thorough patronage estimate would include induced travel as well as that diverted from existing modes. This effort is, however, beyond the scope of the present study. This study considers two modes—the auto and PRT—and solves for the patronage diverted from the auto. The prediction is based on auto trip and PRT trip cost functions that involve travel time and out-of-pocket expenses. A trip is assigned to auto or PRT according to which mode offers the lower cost. A large number (1,000) of trips are sampled in a Monte Carlo fashion. The procedure is to sample from a digitized version of the curves shown in Figure 1. That is, trips and trip-makers are drawn randomly from these distributions.

It is recognized that a mode assignment based on travel times and out-of-pocket costs is at best imperfect. User preference studies (3, 10) indicate that several other attributes—e.g., privacy, comfort, safety, and reliability (arriving when planned)—are also important in mode choice. However, it is expected that a well-engineered and maintained PRT system would provide levels of these attributes similar to if not better than the automobile.

PRT Trip Description

A PRT trip involves time for several components of the trip—walk, station process, and station-to-station travel. The station-to-station travel time can be computed from

$$t_{ss} = X/V + V/a + 2L/V \tag{3}$$

where X is the trip distance, V is the PRT line speed, a is acceleration, and L is mesh space. The second term on the right side accounts for time accelerating and decelerating; the third represents an average detour penalty because of the one-way grid.

The cost function for a PRT trip is taken as

$$C_{PRT} = FX/1.3 + fW\ (t_{as} + 2t_{proc} + 2X_W/V_X) \qquad (4)$$

where F is the fare in dollars per vehicle-mile, W is the hourly wage rate, f is the fraction of the hourly wage rate that the trip-maker places on his time, t_{proc} is the station process time at each trip end, X_W is the combined walk distance at the 2 trip ends, and V_X is the walk speed. Nominal values chosen for these quantities are given in Table 1. The formula assumes an occupied vehicle occupancy of 1.3 passengers/vehicle. Attitudinal studies indicate that walk times and station process times are considered as "nuisance" times, and consequently they are weighted twice as seriously as in-vehicle travel time.

Auto Trip Description

An auto trip is modeled to include time riding and walking at the ends. The ride time can be estimated from Figure 3, which represents the authors' rough estimation of trip speeds in the Twin Cities. The auto cost function is then

$$C_A = C_m X/1.3 + C_p/1.3 + fW\ (t_{ar} + 2X_w/v_w) \qquad (5)$$

where C_m is the perceived cost per mile, t_{ar} is the ride time, and C_p is the parking cost; C_m and C_p are sampled from distributions given respectively in Figures 1d and 1e. Both figures represent the authors' best guess. The 10-cent mean of Figure 1d is intermediate between operating and total costs. Parking cost, C_p, is automatically taken as zero at residential ends. A zero walk distance was assumed at all residential ends and a $^1/_{10}$-mile walk was assumed at all MAC ends. Equation 5 assumes an auto occupancy of 1.3 passengers per vehicle.

Modal Split Estimate

A trip is assigned to PRT or the auto depending on whether the ratio C_{PRT}/C_A is respectively lesser or greater than 1. The trip modal split (TMS) is then determined by sampling 1,000 trips. The passenger-mile modal split is given by the ratio $X_{PRT}/(X_{PRT} + X_A)$, where X_{PRT} and X_A are respectively the passenger-miles traveled by PRT and by auto for the 1,000 trips. The trip modal splits are shown in Figure 4. Also plotted is the percentage reduction of auto emissions, which is equivalent to the passenger-mile modal split.

Determination of the modal split permits the easy computation of other system parameters, as shown in Figure 4. The formulas are presented in this section, but their derivations are given in the Appendix. The peak-hour station demand in passengers per hour is directly proportional to TMS and is obtainable from

$$D_s = 150\ \text{TMS}\ L^2 \qquad (6)$$

where D_s is the station demand per 1,000 people per square mile. Several more quantities are directly proportional to the passenger-mile modal split. The important ones are N_v, the fleet size per million people; P_e, the number of gigawatt plants required per million people; and C_v, the peak-hour guideway capacity requirement, which is plotted on a per hour per 1,000 people per square mile basis. These respective quantities are obtained from the formulas

$$C_v = 0.2\ LX_{PRT} \qquad (7)$$

$$P_e = \begin{cases} 0.000054\ X_{PRT} & \text{(without regenerative braking)} \\ 0.000041\ X_{PRT} & \text{(with regenerative braking)} \end{cases} \qquad (8)$$

Figure 1. Trip models.

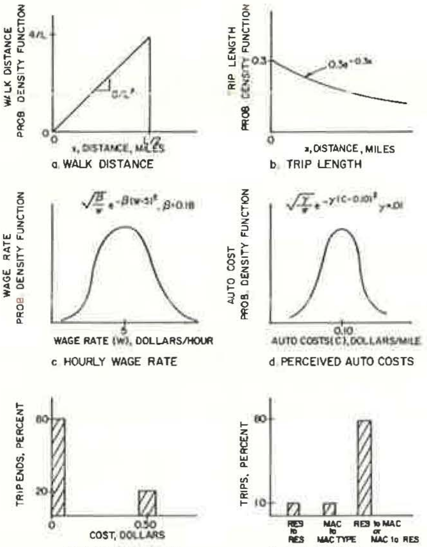


Figure 2. Idealized square mesh PRT network of one-way interchangeable lines.

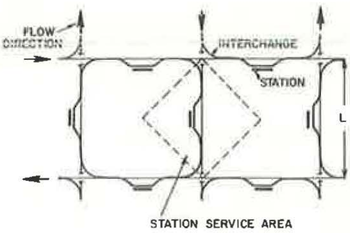


Figure 3. Auto trip time.

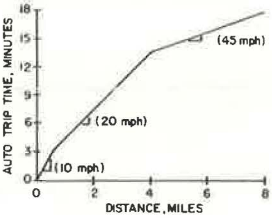
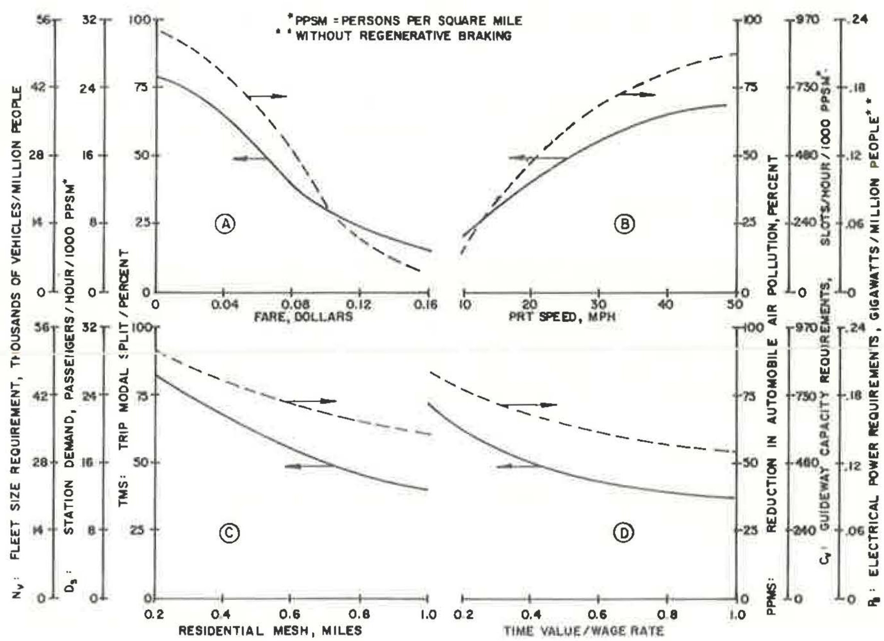


Table 1. Nominal values and range of variation of parameters.

Symbol	Name	Nominal Value	Range of Variation
V_x	Walk speed	3 mph	–
L	Residential mesh spacing	0.5 mile	0.2 to 1.0 mile
	MAC mesh spacing	0.2 mile	–
V	PRT speed	35 mph	10 to 50 mph
F	PRT fare	$0.05/occupied-vehicle-mile	$0 to $0.20
f	Time value/wage rate	0.25	0.2 to 1.0
	Interest rate	6 percent	–
	Amortization time for fixed facilities	30 years	–
	Amortization time for vehicle	5 years	–
t_{proc}	Station process time	1 minute	–
	Daily trip generation rate	3 trips/person	–
	Peak-hour trip generation rate	0.3 trips/person	–
a	Vehicle acceleration	8 ft/sec²	–
J	Vehicle jerk (maximum)	8 ft/sec³	–

Figure 4. Modal split and PRT system requirements.



$$N_v = (2{,}000/L/V)\ C_v \quad (9)$$

and are plotted in Figure 4.

ECONOMIC ANALYSIS

This section develops quantities of interest to decision-makers. The quantities are cost per passenger-mile, subsidy per passenger-mile, and benefit-cost ratio (BCR). Detailed considerations for financing the subsidy are beyond the scope of this paper; however, possible sources, some controversial, include federal capital grants, property taxes, general funds, and highway user taxes. Furthermore, studies by Lea (4) and Smith (11) indicate that goods movement should be investigated as a potential source of significant revenue and better system utilization.

Systems Costs

Cost estimates for this paper are given in Table 2. The estimates are in line with those used elsewhere (2, 3, 12). The most substantial departure from these works is to assume a higher price for vehicle storage, namely $3,000 per vehicle. This estimate is based on the assumption that guideway ramps costing $1.5 million per mile would be used for the storage; $3,000 would then buy about 10 ft of ramp. Interest rates are assumed to be 6 percent (Table 1). Fixed facilities are assumed to be amortized over 30 years. Vehicles are amortized over a lifetime of 5 years. The 3 cents-per-mile operating cost includes the computer facility and personnel costs, electricity, maintenance, and cleaning. All ramp lengths were computed from Eq. 2 with $a = 8\ \text{ft/sec}^2$ and $J = 8\ \text{ft/sec}^3$. Equation 1 provides an estimate for the number of stations and interchange ramps.

Cost and Subsidy per Passenger-Mile

The fixed cost per passenger-mile, C_f, is computed by converting fixed costs to an annualized basis and dividing by the number of annual passenger-miles, obtained from the modal-split analysis. The variable cost per passenger-mile, C_v, is found by converting the variable costs to a per-vehicle-mile basis. With an assumed 1.3 passengers per vehicle and with total vehicle mileage equal to an assumed 1.3 times occupied-vehicle mileage (due to shuttling of empties), the total cost per passenger-mile is given by

$$C_m = C_v + C_f \quad (10)$$

The subsidy per passenger-mile is then given by

$$C_s = C_m - F/1.3 \quad (11)$$

where F is the fare per occupied-vehicle-mile. The cost and subsidy per passenger-mile are shown in Figure 5 for a wide range of system parameters.

Benefit-Cost Ratio

The benefit-cost method of economic analysis obtains a parameter BCR, termed the benefit-cost ratio, defined by the equation

$$BCR = \text{benefits/costs} \quad (12)$$

The present analysis identifies three benefits that are quantifiable in dollar terms. They are auto-cost savings, travel-time savings, and auto pollution-safety savings. The total benefit is assumed to consist of the sum of these. Auto-cost savings include parking fares not encountered plus a mileage cost, taken to be 10 cents per mile (intermediate between total cost and variable cost). Pollution and safety benefits can be estimated from the RECATS report (13), where it is estimated that by 1976 automobiles will incur an added retail price of about $870 and require about one-third more fuel to satisfy presently planned auto-emission standards. The added fuel requirement is about 1 cent per mile; 2 cents per auto mile not driven is an approximate figure for the pollution and safety benefit of PRT.

As suggested by Winfrey (14), time savings are valued at the assumed average wage rate. Time is saved by travelers for two reasons: First, most of the trips taken by PRT are faster than by auto, and second, PRT will take trips from the roads, thereby alleviating congestion. Methods for estimating the latter effect on an urban-wide basis are not known, so a crude approach is presented here. First, consider congestion to be a problem only during the 4 peak hours, therefore affecting only about 35 percent of the daily trips. It seems reasonable to assume a form

$$T/T_{peak} = \frac{2}{3} + \frac{1}{3}\left(\frac{D}{D_{peak}}\right)^2 \tag{13}$$

where T is the auto trip time at demand level D and T_{peak} is the trip time at the present level of demand D_{peak}. This representation projects that if there is no traffic a trip takes two-thirds as long as at peak times. If demand is double the present level, then a trip would take twice as long. The resulting curve is shown in Figure 6. The benefit-cost ratio is plotted in Figure 7 for a range of parameters.

DISCUSSION OF NUMERICAL RESULTS

Output of the patronage and economic model of large-scale PRT systems is shown in Figures 4, 5, and 7. The data are presented in the form of network performance indices (patronage, Fig. 4; cost/mile, Fig. 5; and benefit-cost ratio, Fig. 7) versus system design and cost parameters (residential population density, fare, vehicle speed, residential network mesh size, capital costs, and operating costs). Nominal values of the system parameters used in this study are given in Table 1. They are initial values for a base-line Twin Cities PRT system. The mesh spacing (0.5 mile) provides reasonable access by walking and the speed (35 mph) and fare (5 cents per vehicle-mile) are competitive with the automobile. Our model predicts that this nominal PRT system would attract about 60 percent of the trips, which represents 75 percent of the passenger-miles. This 75 percent diversion of automobile trip miles to transit implies among numerous things a 75 percent reduction in auto air pollution and a reduced dependence on scarce petroleum reserves. For a city of 1 million people a 0.15-gigawatt power plant would be needed to power a PRT system requiring a fleet of 35,000 vehicles at the peak hour (assuming no regenerative braking). Regenerative braking could reduce the power requirements by approximately 25 percent. The 24-hour average power requirement is about 40 percent of the peak-hour requirement. In an area having a density of 10,000 people per square mile (ppsm), peak-hour station demand would be 200 passengers per hour and guideway capacity at 35 mph would require 0.5-sec headways.

It is of interest to compare the energy requirement of PRT travel with that of the automobile. If a reasonable power plant efficiency of 40 percent is assumed, it follows from Eq. 8 that PRT without regenerative braking requires 1,500 Btu per vehicle-mile (equal to assumed average passenger-miles). For auto travel 9,000 Btu per passenger-mile are required, assuming 12 miles per gallon and 1.3 passengers per auto. It follows that a PRT system that attracts 75 percent of the passenger-miles from the auto could effect an urban transportation energy reduction of roughly 60 percent.

Figure 5 shows the effect of variations in the system parameters on patronage and system requirements. The ordinates are normalized with respect to population density to permit easy application to specific urban areas. Principal results are as follows:

1. Modal split (patronage) is very sensitive to fare in the neighborhood of fare = average auto cost. At lower fares, PRT attracts many (and longer) trips, whereas at high fares only few (and shorter) trips are by PRT.
2. Patronage is very sensitive to PRT speed at its lower values. At speeds of 35 to 40 mph, PRT has captured most of the market, and a point of diminishing return is reached.

Figure 5. Cost and subsidy per passenger-mile.

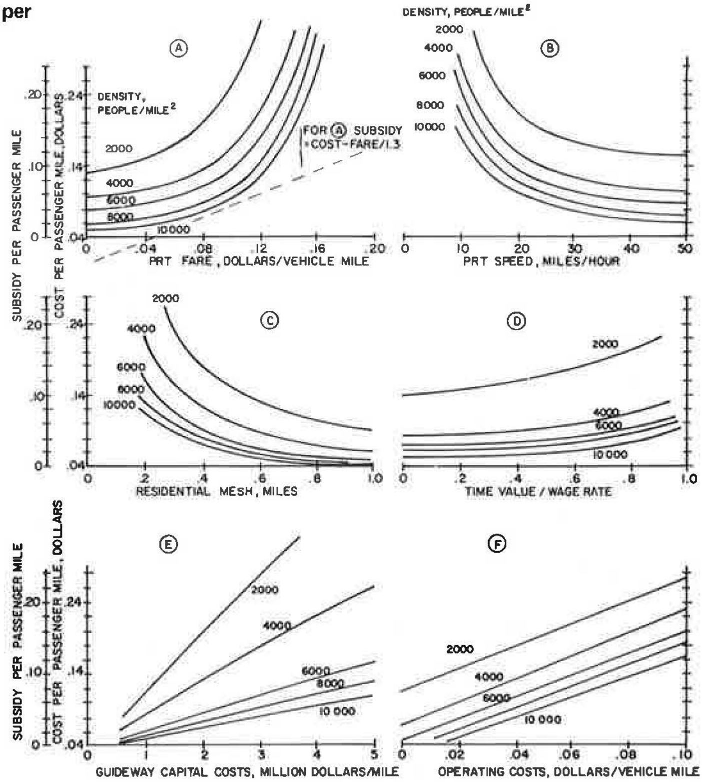


Table 2. Cost estimates.

Item	Fixed Costs: Capital	Fixed Costs: Other	Variable Costs: Capital	Variable Costs: Other
Guideway, right-of-way support, electrification	\$1.5 million per mile	Maintenance, 1 percent[a]	–	–
Stations				
Ramps	\$1.5 million per mile	Maintenance, 1 percent	–	–
Buildings and controls	\$200,000	Maintenance, 1 percent	–	–
Interchange				
Ramps	\$1.5 million per mile	Maintenance, 1 percent	–	–
Queue area and controls	\$100,000	Maintenance, 1 percent	–	–
Maintenance garage	–	–	\$100/vehicle	Maintenance, 1 percent
Carbarn	–	–	\$3,000/vehicle	Maintenance, 1 percent
Vehicle	–	–	\$4,000/vehicle	Operating, 3 cents/mile

[a]Maintenance cost refers to annual cost equal to 1 percent of capital cost.

Figure 6. Travel time versus congestion.

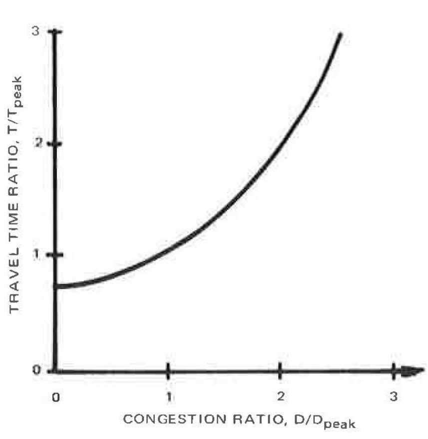
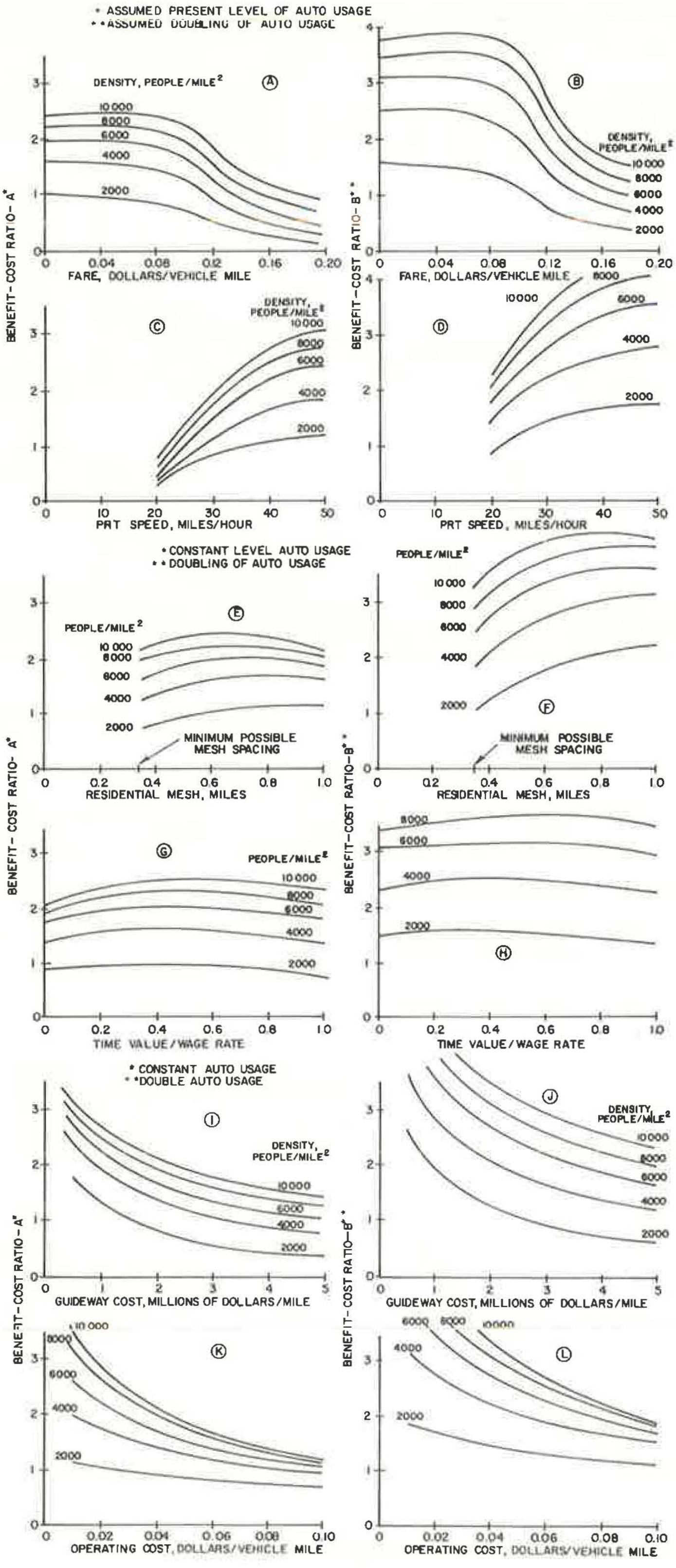


Figure 7. Benefit-cost ratio.



3. A steady decrease in patronage results from increased residential mesh size.

Perhaps the most significant result of Figure 5 is that the total cost (including full capital costs) per PRT passenger-mile is less than 10 cents for cities of 9,000 ppsm or more. This means that PRT travel costs are competitive with travel costs by auto, buses, and dial-a-ride. Figure 5 also provides some insights concerning economic uncertainties of PRT. The guideway capital cost variation curves show that in the higher density areas, the cost per passenger-mile is not highly sensitive to guideway cost (and other fixed-cost) estimation errors. For example, if density equals 10,000 ppsm, then a doubling of the assumed guideway cost to $3 million per mile would change the per-passenger-mile cost from 7 cents to 9 cents. At lower population densities, per-mile costs become very sensitive to fixed costs.

Another uncertainty is the degree of validity of the modal split assumption. Figure 5 shows that the cost per ride is largely insensitive to variations in the time value per wage rate ratio, particularly in high-density areas. In another computer run it was assumed that the actual ridership was only half of that predicted. For 10,000 ppsm, the cost per mile then jumped from 7 cents to only 8 cents; for 2,000 ppsm, the cost per mile jumped from 17 cents to 27 cents. At high densities a large percentage of the cost is variable. This makes the cost per passenger-mile rather insensitive to ridership and fixed-cost estimation errors.

Figure 7 shows that the benefit-cost ratios are generally favorable for a wide variation of system parameters at densities above 4,000 ppsm. At lower densities BCR is marginal or unfavorable. Two forms are presented. BCR-A is based on present travel demands. Most metropolitan master plans for the future are based on predicted large increases in transport demands resulting from population growth and increased per capita trip-making. Consequently the second benefit-cost ratio, BCR-B, assumes a doubling of the total demand. The BCR curves indicate that the fare should be less than 10 cents per vehicle-mile, and an optimum is actually attained between 4 and 6 cents per vehicle-mile. Coupling these data with those of Figure 5 indicates that a fare of 8 cents per vehicle-mile would minimize the subsidy requirement and provide an excellent BCR for a wide range of population densities. In areas having 7,000 ppsm or more, this fare would cover operating costs of 4 cents per occupied-vehicle-mile plus enough for the capital cost to permit completion of the financing of a one-third local share of a capital grant program. The benefit-cost curves also yield optimum values of residential mesh size (0.6 to 0.8 mile) and PRT speed (~50 mph).

CONCLUSIONS

The analyses presented indicate that large-scale PRT networks have the potential to divert a significant portion of urban travel from the automobile. At population densities above approximately 4,000 ppsm, PRT offers attractive benefit-cost ratios and costs per passenger-mile. At somewhat higher densities, the financing of a PRT system is possible with farebox revenues and two-thirds federal capital grants. Furthermore, at these higher densities, moderate estimation errors in fixed costs and ridership do not significantly distort the favorable system economics. On the environmental side, about 0.15 gigawatt of electrical power would be required to serve 1 million people if the PRT system does not have regenerative braking; somewhat less would be needed if regenerative braking is used. The trade-offs would be large reductions in auto emissions and petroleum requirements as well as a significant overall reduction in the total urban transportation energy requirement.

ACKNOWLEDGMENT

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APPENDIX

DERIVATION OF FORMULAS

Station Demand

The demand at stations is directly proportional to population density. Equation 6 is based on a population density of 1,000 people per square mile. The demands at other densities are higher by a proportional amount. Assuming a trip generation of 0.3 trip per person in the peak hour, it follows that there are 300 TMS peak-hour trips per square mile by PRT. Since there are $2/L^2$ stations per square mile, Eq. 6 follows immediately.

Electrical Power Requirements

A frequently used formula for automobile motion resistance R is

$$R = (7.6 + 0.09V + C_s)W + C_c V^2$$

where C_s = 0 for roadbeds in good condition, V is speed in mph, C_D is drag coefficient, and W is the vehicle weight in thousands of pounds. The formula contains terms accounting for rolling resistance and air drag. The formula will not be directly applicable to air or magnetically suspended systems. It is assumed that the weight and drag coefficient is about the same as for a Volkswagen, which weighs about 2,000 lb. Furthermore, VW's used to have about 30 horsepower and reach speeds of about 75 mph on flat terrain. It follows that the motion resistance formula would be

$$R = (15.2 + 18V) + 0.022V^2$$

It follows further that the energy required to travel 5,280 ft at 35 mph is 256,000 ft-lb. If an average of 3 accelerations in a 4-mile trip at 0.25 g for 190 ft is assumed, it follows that an additional 71,000 ft-lb per mile are required for accelerations. Statistics on the amount of grade changes encountered in urban travel are not available, so it will be assumed that vehicles will climb 25 ft per mile, requiring an additional 50,000 ft-lb. The total energy requirement per vehicle-mile is 386,000 ft-lb. If it is assumed that regenerative braking can recover 80 percent of the energy used in accelerating and climbing, then the requirement would be 289,000 ft-lb per mile. If it is assumed that there are 1.3 people per occupied vehicle and that the total number of vehicle-miles is 1.3 times the number of occupied-vehicle-miles (due to the shuttling of empties), it follows that the power requirements per passenger-mile are also 386,000 and 289,000 ft-lb respectively. In units of kW-h per passenger-mile, the respective figures are 0.145 and 0.108. Assuming a 10 percent transmission line loss and 90 percent motor efficiency, the requirements are respectively 0.18 and 0.135. For 1 million people and 0.3 peak-hour trip per person, the number of peak-hour trips is 300,000. The number of peak-hour passenger-miles by PRT is 300 X_{PRT}. It follows that the peak-hour power requirements in kilowatts are respectively 54 X_{PRT} and 41 X_{PRT}. This is Eq. 8 of the text.

Guideway Capacity

Studies (1, 15) indicate that merging can be handled with a relatively low abort rate, even if more than 80 percent of the guideway slots are occupied. Our capacity calculations are made on the assumption that 70 percent of the guideway slots are filled. Guideway capacity is proportional to population density, so expressions are derived for a population density on the basis of 1,000 people per square mile.

The number of passenger-miles of travel generated by 1,000 ppsm is 0.3 X_{PRT}. The number of guideway miles on that square mile is 2/L, and so the passenger flow requirement is 0.15 X_{PRT} L/0.7, which approximates Eq. 7. The time headway T can then be computed from the formula $T = 3,600/C_v$.

Fleet Size

The vehicle fleet includes the vehicles on the guideway plus those being processed in stations, stored in carbarns, maintained, and repaired. The fleet requirement for the guideway would be 70 percent of the slots. It is assumed that the remaining fleet would fill up the remaining slots. Thus, the fleet requirement per square mile (assuming 1,000 ppsm) is 2/L/ (V T/3,600 = $2C_v$/ (L/V), which if multiplied by 1,000 gives Eq. 9.

NATIONAL STUDIES OF URBAN ARTERIAL TRANSPORTATION: A RESEARCH FRAMEWORK

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A research framework is presented for the estimation of the national markets and the social, economic, and environmental impacts of new systems of urban arterial transportation, such as automated guideway and rail and bus rapid transit systems. A statistical step-wise procedure, based on the extrapolation of results from a limited number of analytical case studies to the set of all candidate metropolitan areas, is specified. Results are provided for the application of all steps in the procedure before the conducting of actual case studies: 80 candidate metropolitan areas are classified into 9 relatively homogeneous groups with respect to their arterial transportation needs; the most representative areas within each group are identified as preferred case study locales; and guidelines are developed for the extrapolation of system costs, benefits, and market estimates from the case studies to the remaining areas within the groups through sensitivity analyses. In addition, intermediate multivariate statistical results are interpreted as inputs to the development of hypotheses describing relationships between transportation and urban structure.

•THE INTENT of this research is to improve the processes of planning and implementing new transportation systems designed to meet the arterial transportation needs of metropolitan areas through the development and application of a statistical procedure to estimate the national markets and the total social, economic, and environmental impacts of such proposed new systems. Such estimations of the potential range and consequences of implementation are important to considerations of product markets and returns on capital investments when private funds are employed in research and development and are also important to considerations of the distributions of costs and benefits when public funds are so employed.

The diverse needs and requirements of the hundreds of metropolitan areas in the United States create substantial difficulties in generating such estimates. In light of the infeasibility of conducting analytical case studies of a new system in each area, the procedure developed involves the extrapolation of the results from a minimum number of selected case studies to the total set of candidate metropolitan areas. The viability of this approach was recognized by the Urban Mass Transportation Administration of the U. S. Department of Transportation in the definition of requirements analysis (61):

> New Systems Requirements Analysis comprises three essential objectives. The first is the design and development of a set of public transportation demand analysis techniques and associated computer programs that will facilitate the evaluation of proposed public transportation implementations. The second is the application of the techniques to a sample set of urban areas to determine the requirements of new systems of public transportation in these areas. The third is an estimation of national requirements for new systems by extrapolating needs detected in the sample urban areas to other areas having similar socio-economic and other characteristics.

Sponsored by Committee on New Transportation Systems and Technology.

Specifically, the procedure structures the relationships between characteristics of the social and physical spaces of metropolitan areas and characteristics of transportation systems perceived of being imbedded in the metropolitan area environments through a series of sequential steps. These steps are methodologically described in Canty and Golob (18) and involve the classification of metropolitan areas into relatively homogeneous groups with respect to their arterial transportation needs, the selection of preferred case study locales from the areas within each group, and the extrapolation of the results of case studies conducted within the selected locales to the remaining areas within each group by means of sensitivity analyses and statistical relationships.

This paper documents the application of the procedure through all phases prior to the initiation of individual case studies of a particular new arterial transportation system under investigation. This system, called the Metro Guideway, is described in Canty (17) and is an integrated urban facility for dual-mode private automobiles and buses, personal rapid transit vehicles, and freight movement vehicles. The system is designed to serve commuter and cross-town arterial transportation needs now being provided by limited-access facilities such as freeways and rapid transit lines.

Because metropolitan area aggregations of people, institutions, and activities are appropriate for many proposed types of rail rapid transit, bus rapid transit, automated highway, or area-wide personal rapid transit systems as well as the Metro Guideway concept, the results of the application reported here are expected to be directly or indirectly of interest in a number of research studies. However, studies of other forms of urban transportation systems may require a different level of aggregation, such as major activity centers [see Canty (16) for discussions of system forms and urban scale]. Caution must thus be observed in the extension of the results reported here to the study of other than arterial systems.

DATA SELECTION

The determination of a data base on which the classification of metropolitan areas, identification of case study locales, and establishment of guidelines for case study sensitivity analyses were to be based was accomplished by first selecting a set of metropolitan areas and then selecting a set of variables measured on these areas. The metropolitan areas considered as candidate locations for the new system of urban arterial transportation under study are a subset of all standard metropolitan statistical areas and associated urbanized areas and standard consolidated areas in the United States defined by the Bureau of the Census. Such a pre-selection of a subset of areas is desirable (whenever possible) because inclusions of metropolitan areas for which the probabilities of implementation of a new system are extremely small would dilute the estimations for the more probable areas while adding no significant statistical information.

A subset of 80 metropolitan areas was selected as meeting criteria of minimum population and minimum geographical size (both projected for 1985) to warrant consideration as locations for limited-access arterial transportation systems. The minimum populations and area values were established by means of a simplified cost-benefit analysis based on intra-area as opposed to inter-area transportation needs. This analysis, which was biased toward the inclusion of all marginal cases, is reported in Golob et al. (27). The list of 80 candidate metropolitan areas is shown in Figure 1.

The set of 53 variables, on which the analyses of the similarities and differences between the 80 candidate metropolitan areas were based, was selected from the set of all compatibly defined measurements on social and physical spaces of the metropolitan areas. Each of the variables was judged by a multidisciplinary team of research economists, engineers, and urban planners to be related especially to arterial transportation needs or requirements. The list of the 53 variables is shown in Figure 2.

A CLASSIFICATION OF METROPOLITAN AREAS

The 80 candidate metropolitan areas were classified into relatively homogeneous groups on the basis of their observed values on the 53 variables selected as being related to arterial transportation needs and requirements. The objective of this classi-

Figure 1. Metropolitan areas selected.

STANDARD METROPOLITAN STATISTICAL AREA	ABBREVIATED TITLE
AKRON, OHIO	AKRON
ALBANY-SCHENECTADY-TROY, N.Y.	ALBANY
ALBUQUERQUE, N. MEX.	ALBUQUERQUE
ATLANTA, GA.	ATLANTA
BALTIMORE, MD.	BALTIMORE
BEAUMONT-PORT ARTHUR-ORANGE, TEX.	BEAUMONT
BIRMINGHAM, ALA.	BIRMINGHAM
BOSTON, MASS.	BOSTON
BRIDGEPORT, CONN.	BRIDGEPORT
BUFFALO, N.Y.	BUFFALO
CHARLOTTE, N.C.	CHARLOTTE
CHICAGO, ILL.-NORTHWESTERN INDIANA**	CHICAGO
CINCINNATI, OHIO-KY.-IND.	CINCINNATI
CLEVELAND, OHIO	CLEVELAND
COLUMBUS, OHIO	COLUMBUS
DALLAS, TEX.	DALLAS
DAVENPORT-ROCK ISLAND-MOLINE, IOWA-ILL.	DAVENPORT
DAYTON, OHIO	DAYTON
DENVER, COLO.	DENVER
DETROIT, MICHIGAN	DETROIT
DULUTH-SUPERIOR, MINN.-WIS.	DULUTH
EL PASO, TEX.	EL PASO
FLINT, MICHIGAN	FLINT
FT. LAUDERDALE-HOLLYWOOD, FLA.	FT. LAUDERDALE
FORT WORTH, TEX.	FORT WORTH
GRAND RAPIDS, MICH.	GRAND RAPIDS
HARTFORD, CONN.	HARTFORD
HONOLULU, HAWAII	HONOLULU
HOUSTON, TEX.	HOUSTON
INDIANAPOLIS, IND.	INDIANAPOLIS
JACKSONVILLE, FLA.	JACKSONVILLE
KANSAS CITY, MO.-KANS.	KANSAS CITY
KNOXVILLE, TENN.	KNOXVILLE
LANSING, MICHIGAN	LANSING
LOS ANGELES-LONG BEACH-ANAHEIM-SANTA ANA-GARDEN GROVE, CALIF.*	LOS ANGELES
LOUISVILLE, KY.-IND.	LOUISVILLE
MADISON, WIS.	MADISON
MEMPHIS, TENN.-ARK.	MEMPHIS
MIAMI, FLA.	MIAMI
MINNEAPOLIS-ST. PAUL MINN.	MINNEAPOLIS
MOBILE, ALA.	MOBILE
NASHVILLE, TENN.	NASHVILLE
NEW ORLEANS, LA.	NEW ORLEANS
NEW YORK, N.Y.-NORTHEASTERN N.J.***	NEW YORK
NEWPORT NEWS-HAMPTON, VA.	NEWPORT NEWS
NORFOLK-PORTSMOUTH, VA.	NORFOLK
OKLAHOMA CITY, OKLA.	OKLAHOMA CITY
OMAHA, NEBR.-IOWA	OMAHA
ORLANDO, FLA.	ORLANDO
PHILADELPHIA, PA.-N.J.	PHILADELPHIA
PHOENIX, ARIZ	PHOENIX
PITTSBURGH, PA.	PITTSBURGH
PORTLAND, OREG.-WASH.	PORTLAND
PROVIDENCE-PAWTUCKET-WARWICK, R.I.-MASS.	PROVIDENCE
RICHMOND, VA.	RICHMOND
ROCHESTER, N.Y.	ROCHESTER
SACRAMENTO, CALIF.	SACRAMENTO
ST. LOUIS, MO.-ILL.	ST. LOUIS
SALT LAKE CITY, UTAH	SALT LAKE CITY
SAN ANTONIO, TEX.	SAN ANTONIO
SAN BERNARDINO-RIVERSIDE-ONTARIO CALIF.	SAN BERNARDINO
SAN DIEGO, CALIF.	SAN DIEGO
SAN FRANCISCO-OAKLAND, CALIF.	SAN FRANCISCO
SAN JOSE, CALIF.	SAN JOSE
SEATTLE-EVERETT, WASH.	SEATTLE
SPRINGFIELD-CHICOPEE-HOLYOKE, MASS.-CONN.	SPRINGFIELD
SYRACUSE, N.Y.	SYRACUSE
TACOMA, WASH.	TACOMA
TAMPA-ST. PETERSBURG, FLA.	TAMPA
TOLEDO, OHIO	TOLEDO
TUCSON, ARIZ.	TUCSON
TULSA, OKLA.	TULSA
UTICA-ROME, N.Y.	UTICA
WASHINGTON, D.C.-MD.-VA.	WASHINGTON
W. PALM BEACH, FLA.	W. PALM BEACH
WICHITA, KANS.	WICHITA
WILMINGTON, DEL.-N.J.-MD.	WILMINGTON
WORCESTER, MASS.	WORCESTER
YOUNGSTOWN-WARREN, OHIO	YOUNGSTOWN

*	INCORPORATES SMSA'S OF LOS ANGELES-LONG BEACH AND ANAHEIM-SANTA ANA-GARDEN GROVE, CALIFORNIA
**	STANDARD CONSOLIDATED AREA CONSISTS OF CHICAGO, ILL., AND GARY-HAMMOND-EAST CHICAGO, IND. STANDARD METROPOLITAN STATISTICAL AREAS
***	STANDARD CONSOLIDATED AREA CONSISTS OF THE FOLLOWING STANDARD METROPOLITAN STATISTICAL AREAS: NEW YORK,N.Y.; NEWARK, N.J.; JERSEY CITY, N.J.; PATERSON-CLIFTON-PASSAIC, N.J.; AND OF MIDDLESEX AND SOMERSET COUNTIES, N.J.

Figure 2. Variables selected.

VARIABLE TITLE	ABBREVIATED TITLE
1. LAND AREA OF URBANIZED AREA, 1970	AREA
2. APPROXIMATE NUMBER OF 45° SECTORS OF URBAN DEVELOPMENT AROUND CBD	RADIUS OF DEVELOPMENT
3. NUMBER OF INCORPORATED CITIES WITHIN URBANIZED AREA, 1960	No. INC. CITIES
4. NUMBER OF CENTRAL CITIES DEFINED FOR SMSA, 1970	No. CENTRAL CITIES
5. TOTAL POPULATION OF URBANIZED AREA, 1970	POPULATION
6. APPROXIMATE YEAR IN WHICH CENTRAL CITY EXCEEDED 50,000 POPULATION	AGE OF CENTRAL CITY
7. POPULATION GROWTH FACTOR FOR SMSA, 1965-1985	POP. GROWTH FACTOR
8. PERCENT OF URBANIZED AREA POPULATION LOCATED IN CENTRAL CITY, 1970	% POP. IN CENTRAL CITY
9. POPULATION PER SQUARE MILE IN CENTRAL CITY, 1960	POP. DENSITY IN CENTRAL CITY
10. POPULATION PER SQUARE MILE IN URBAN FRINGE, 1960	POP. DENSITY IN FRINGE
11. PERCENT OF SMSA POPULATION NON-WHITE, 1970	% NON-WHITE
12. PERCENT OF SMSA POPULATION LESS THAN 18 YEARS OLD, 1970	% POP. < 18 YRS.
13. PERCENT OF SMSA POPULATION GREATER THAN 64 YEARS OLD, 1970	% POP. >64 YRS.
14. MEAN NUMBER OF PERSONS IN HOUSEHOLD IN SMSA, 1960	PERSONS/HOUSEHOLD
15. PERCENT OF SMSA HOUSING WHICH IS SOUND WITH ALL FACILITIES, 1960	% HOUSING SOUND
16. PERCENT OF SMSA HOUSEHOLDS IN ONE-UNIT STRUCTURES, 1960	% SINGLE-UNIT HOUSING
17. PERCENT OF SMSA POPULATION IN GROUP QUARTERS, 1960	% GROUP QUARTER HOUSING
18. MEDIAN VALUE OF ALL OWNER-OCCUPIED HOUSING IN SMSA, 1960	MEDIAN HOUSING VALUE
19. PER CAPITA INCOME, 1970	PER CAPITA INCOME
20. PROJECTED PER CAPITA INCOME GROWTH, 1970-1990	PER CAPITA INCOME GROWTH
21. PROJECTED MEAN HOUSEHOLD INCOME IN SMSA, 1985	PROJ. MEAN HOUSEHOLD INCOME
22. PROJECTED PERCENT OF SMSA HOUSEHOLDS WITH LESS THAN $ 4,000 INCOME, 1985	PROJ. % POOR HOUSEHOLDS
23. PROJECTED PERCENT OF SMSA HOUSEHOLDS WITH GREATER THAN $ 15,000 INCOME, 1985	PROJ. % AFFLUENT HOUSEHOLDS

VARIABLE TITLE	ABBREVIATED TITLE
24. RATIO OF NUMBER OF FAMILIES WITH LESS THAN $ 3,000 INCOME IN CENTRAL CITY TO THOSE IN URBANIZED AREA, 1960	CONCENTRATION OF POOR IN CENTRAL CITY
25. RATIO OF NONWORKER TO WORKER POPULATIONS IN URBANIZED AREA, 1960	NONWORKER-WORKER RATIO
26. PERCENT MARRIED WOMEN WITH HUSBAND PRESENT IN LABOR FORCE IN URBANIZED AREA, 1960	% MARRIED WOMEN WORKING
27. PERCENT WHITE COLLAR EMPLOYMENT IN SMSA, 1960	% WHITE COLLAR
28. MEAN NUMBER OF AUTOMOBILES AVAILABLE PER FAMILY IN SMSA, 1960	AUTOS/FAMILY
29. PROPORTION OF HOUSEHOLDS IN CENTRAL CITY WITH NO AUTOMOBILE AVAILABLE, 1960	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO
30. PROPORTION OF HOUSEHOLDS IN URBAN FRINGE WITH NO AUTOMOBILE AVAILABLE, 1960	% FRINGE HOUSEHOLDS WITH NO AUTO
31. PERCENT OF WORKERS COMMUTING CENTRAL CITY TO URBAN FRINGE, 1960	% REVERSE COMMUTING
32. PERCENT OF WORKERS COMMUTING SMSA FRINGE TO CENTRAL CITY, 1960	% COMMUTING TO CENTRAL CITY
33. PERCENT OF WORKERS COMMUTING TOTALLY WITHIN SMSA FRINGE, 1960	% FRINGE COMMUTING
34. PERCENT CENTRAL CITY WORKERS USING PUBLIC TRANSIT, 1960	% CENTRAL CITY WORKERS USING TRANSIT
35. PERCENT URBAN FRINGE WORKERS USING PUBLIC TRANSIT, 1960	% FRINGE WORKERS USING TRANSIT
36. PROPORTION OF WORKERS WALKING TO WORK IN SMSA, 1960	% WORKERS WALKING
37. PROPORTION OF WORKERS USING RAIL TRANSIT IN SMSA, 1960	% WORKERS USING RAIL
38. TOTAL OF ALL PUBLIC TRANSIT VEHICLES IN SMSA, 1966	TOTAL TRANSIT VEHICLES
39. PERCENT OF SMSA RETAIL SALES IN CENTRAL BUSINESS DISTRICT, 1967	% SALES IN CBD
40. PERCENT CHANGE IN CBD RETAIL SALES, 1963-1967	% CHANGE IN CBD SALES
41. NUMBER OF SMSA RETAIL ESTABLISHMENTS PER 1000 POPULATION, 1967	RETAIL STORES/CAPITA
42. AVERAGE NUMBER OF EMPLOYEES PER MANUFACTURING ESTABLISHMENT IN SMSA, 1967	EMPLOYEES/MFG. ESTABL.
43. RECEIPTS OF SMSA SELECTED SERVICE ESTABLISHMENTS PER CAPITA, 1967	SERVICE RECEIPTS/CAPITA
44. MEAN JANUARY TEMPERATURE IN DEGREES FAHRENHEIT	MEAN JAN. TEMP.
45. TOTAL DAILY VEHICLE MILES OF TRAVEL ON PRINCIPAL ARTERIAL ROADWAYS IN URBAN AREA, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT

VARIABLE TITLE	ABBREVIATED TITLE
46. PERCENT CHANGE IN PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL, 1968-1990	% CHANGE-PRINCIPAL ARTERIAL DVMT
47. PERCENT OF TOTAL ALL ROADWAY DAILY VEHICLE MILES OF TRAVEL ON PRINCIPAL ARTERIALS, PROJECTED 1990	PROJ. % DVMT ON PRINCIPAL ARTERIALS
48. PERCENT OF TOTAL ALL ROADWAY DAILY VEHICLE MILES OF TRAVEL ON FREEWAYS, PROJECTED 1990	PROJ. % DVMT ON FWYS.
49. PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL PER CAPITA, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA
50. TOTAL ROUTE MILES OF FREEWAYS PROPOSED FOR 1990	PROJ. RT. MI.-FWYS.
51. TOTAL INCREASE IN PRINCIPAL ARTERIAL ROUTE MILES PROPOSED FOR 1968-1990	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI.
52. RATIO OF PROJECTED 1990 PRINCIPAL ARTERIAL DVMT PER ROUTE MILE TO 1968 PRINCIPAL ARTERIAL DVMT PER ROUTE MILE	GROWTH FACTOR: PRINC. ART DVMT/RT. MI.
53. PRINCIPAL ARTERIAL DAILY VEHICLE MILES OF TRAVEL PER ROUTE MILE, PROJECTED 1990	PROJ. PRINCIPAL ARTERIAL DVMT/ROUTE MILE

fication is to permit more valid extrapolation of case study results by restricting that process to the range of variation between a chosen representative area and the other areas within the same relatively homogeneous group. Berry (13) defines this objective as "improved modes of prediction" in his comprehensive list of purposes of city classification. In addition, the analytical attributes of the classification technique allowed the explicit isolation of important latent dimensions of differentiation between the metropolitan areas, an input to further research concerning the formulation and testing of hypotheses linking transportation and urban form.

The classification was accomplished through the sequential application of two multivariate statistical methods: factor analysis and cluster analysis. Factor analysis was used to simplify the multivariate data structure by identifying the predominant interrelationships between the variables and removing redundancy due to intercorrelations that might attribute an implicit weighting to strongly correlated variables in the grouping process [see Green et al. (29) for a discussion of redundancy in classification]. This simplification is accomplished by formulating a smaller set (<53) of new latent factors that are linear combinations of the original 53 variables and are the best set of factors in the sense of describing as much of the original variance as possible within the limits of the decreased dimensionality. Factor analysis is described in general in texts on multivariate statistical methods [e.g., Anderson (3), Kendall (43), and Morrison (50)] and in considerable detail in specific expositions [Harman (32), Horst (36), and Mulaik (53)].

The factor analytic model can be written in matrix form as

$$X = A \cdot F + E \tag{1}$$

where X is the original (m by n) data matrix of the (m = 53) variables measured on the (n = 80) candidate metropolitan areas, A is the (m by p) matrix of factor coefficients or loadings relating the (m = 53) variables to the (p < 53) new latent factors, F is the (p by n) matrix of scores or evaluations of the (n = 80) metropolitan areas on the new (p) factors, and E is the (m by n) data matrix of observations on the composite of the (m) unique and error components for each variable. Following the establishment of certain plausible assumptions regarding the mutual independent of common, unique, and error components of each original variable (see previously cited references), the factor analytic model can be specified in statistical variance terms as

$$\Sigma = A\,\Phi A' + \psi \tag{2}$$

where Σ is the (m by m) matrix representing either the correlations, covariances, or cross-products of the original (m = 53) variables, A is the (m by p) matrix defined in Eq. 1, Φ is the (p by p) matrix of either correlations, covariances, or cross-products of the new latent factors, and ψ is the (m by m) composite matrix of the unique and error variances associated with the (m = 53) variables.

In the factor analytic model employed in this research, the new latent factors are specified as orthogonal or mutually independent, and Φ becomes a diagonal matrix. Moreover, because of the diverse nature of the measurement scales of the 53 variables (e.g., absolute numbers of persons and percentages of the populations using public transit), the correlation matrix was chosen to portray the variable variance interrelationships. Thus Φ is the identity matrix (each diagonal element being the correlation of a factor with itself), and

$$\Sigma = AA' + \psi \tag{3}$$

Equation 3 was solved for the loadings matrix A through a determination of the latent roots (eigenvalues) and latent vectors (eigenvectors) of the correlation matrix Σ. The scores matrix F in Eq. 1 is then found through a least-squares estimation

$$\hat{F} = (A'A)^{-1} A'X \tag{4}$$

such that the contribution of the unique and error composite matrix E (the information to be discarded in favor of the simplified data structure) is minimized [see Johnston (40) and texts on regression analysis for a discussion of this estimation technique].

The eigenvalues defining the new latent factors are extracted sequentially, in order of the proportion of the original variance in Σ accounted for by each factor. Through subjective judgment, in which reduction in dimensionality was compared to sufficiency of explanation, this extraction process was terminated at $p = 15$; the new 15 latent factors together accounted for over 86 percent of the original variance of the 53 manifest variables. The resulting (53 by 15) loadings matrix A was then rotated through application of the varimax procedure developed by Kaiser (41) and discussed in the previously cited references on factor analytic methods. This was done in order to simplify the interpretation of the latent factors in terms of the original variables by creating as many coefficients of very large and very small absolute value as possible (i.e., approaching 1.0, -1.0, or 0.0 in magnitude, or expressing very strong positive, very strong negative, or very weak correlation between a variable and a factor) while preserving the important properties of the solution. The rotated A matrix is shown in Figure 3.

Interpretation of the 15 latent factors in terms of the original 53 manifest variables is useful in improving understanding of the complex interrelationships between aggregate urban structure and needs and requirements for arterial transportation systems. As stated by Janson (37) and Palm and Caruso (56) in discussions of the applications of factor analytic models to ecological data, these types of interpretations are necessary if latent factors are to have anything more than a purely mathematical meaning. In the research described here, such interpretations are only a first step in the determination of such interrelationships; further steps are explicitly incorporated within the procedure to estimate national markets and total social, economic, and environmental impacts of new systems of arterial transportation.

A brief interpretation of the 15 latent factors is shown in Figure 4; the most significant factor-variable correlations are identified, as well as the metropolitan areas that have extremely high or low scores on each factor (i.e., outstanding elements in the F matrix). Such an interpretation of latent dimensions of differentiation between metropolitan areas is consistent with studies known as factorial ecology conducted by urban geographers and sociologists. These studies, in which the spatial units of analysis range from urban neighborhoods to nation states, have their genesis in a study of cities by Price (57) and the social area analysis of metropolitan census tracts by Shevky and his colleagues (65, 66).

Social area analysis, in which latent factors of differentiation are linked to broad postulates concerning dynamics of industrialization and urbanization, has been verified and extended through studies in numerous metropolitan areas [e.g., see Tryon (72, 73), Van Arsdol et al. (76), Bell (5, 6), McElrath (46), Sweetzer (70), Uldry (75), and Salins (64)], but the sociological hypotheses have been the subject of much debate [see Hawley and Duncan (34) and Bell and Greer (7)]. Other applications of factor analytic and related multivariate methods to spatial data are found, for example, in Berry (8, 9, 10, 11), Stone (69), and Ray and Berry (58). Integration of the basic concepts of social space and urban ecological space to be found in the foregoing works is pursued in Greer (30), Orleans (55), Clarkson (21), and Johnson (39), and a typology of factorial ecology methods and application is given in Berry (12) and Rees (59).

Cluster analysis, the second multivariate statistical method employed in the classification process, was used to determine optimal groupings of the 80 candidate metropolitan areas on the basis of their values on the 15 latent factors. A variety of cluster analysis techniques is available for the purpose of classifying objects into relatively homogeneous groups, and the choice among these techniques depends on the selection of a criterion for optimality, characteristics of the solution algorithm, and summary statistic options. Sokal and Sneath (68) and Frank and Green (24) describe a number of taxonomic techniques, and Taylor (71) provides a typology [reprinted in Rees (60)] of techniques applied to spatial data. Specific techniques of note are given in Rohlf and Sokal (62), Ward (77), McQuitty (47), Cattell and Coulter (19), Tryon and Bailey (74), Friedman and Rubin (25), and Johnson (38).

Figure 3. Rotated factor loadings matrix (only loadings with absolute value > 0.40 shown).

VARIABLE	FACTOR														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. AREA	.87														
2. RADIUS OF DEVELOPMENT							-.89								
3. No. INC. CITIES	.65														
4. No. CENTRAL CITIES	.74														
5. POPULATION	.95														
6. AGE OF CENTRAL CITY														.75	
7. POP. GROWTH FACTOR											-.80				
8. % POP. IN CENTRAL CITY		.47				-.52									
9. POP. DENSITY IN CENTRAL CITY	.55													.64	
10. POP. DENSITY IN FRINGE						.40								.51	
11. % NON-WHITE									-.64						
12. % POP. < 18 YRS.				.87											
13. % POP. > 64 YRS.				-.83											
14. PERSONS/HOUSEHOLD				.85											
15. % HOUSING SOUND		-.81													
16. % SINGLE-UNIT HOUSING	-.41								-.40					-.55	
17. % GROUP QUARTER HOUSING										-.84					
18. MEDIAN HOUSING VALUE		-.63													
19. PER CAPITA INCOME		-.82													
20. PER CAPITA INCOME GROWTH		.83													
21. PROJ. MEAN HOUSEHOLD INCOME		-.68		.45											
22. PROJ. % POOR HOUSEHOLDS		.80		-.41											
23. PROJ. % AFFLUENT HOUSEHOLDS		-.71		.45											
24. CONCENTRATION OF POOR IN CENTRAL CITY														.74	
25. NONWORKER-WORKER RATIO					.72										
26. % MARRIED WOMEN WORKING					-.84										
27. % WHITE COLLAR			-.81												
28. AUTOS/FAMILY						.43								-.67	
29. % CENTRAL CITY HOUSEHOLDS WITH NO AUTO														.84	
30. % FRINGE HOUSEHOLDS WITH NO AUTO		.61					.42								
31. % REVERSE COMMUTING															.62
32. % COMMUTING TO CENTRAL CITY						.40									
33. % FRINGE COMMUTING						.90									
34. % CENTRAL CITY WORKERS USING TRANSIT	.53													.78	
35. % FRINGE WORKERS USING TRANSIT	.48													.71	
36. % WORKERS WALKING									.88						
37. % WORKERS USING RAIL	.89														
38. TOTAL TRANSIT VEHICLES	.94														
39. % SALES IN CBD						-.47									
40. % CHANGE IN CBD SALES															-.60
41. RETAIL STORES/CAPITA				-.61											
42. EMPLOYEES/MFG. ESTABL.			.68												
43. SERVICE RECEIPTS/CAPITA	.54		-.52												
44. MEAN JAN. TEMP.									-.61						
45. PROJ. PRINC. ART. DVMT	.84														
46. % CHANGE-PRINCIPAL ARTERIAL DVMT								.80							
47. PROJ. % DVMT-PRINCIPAL ARTERIAL												.84			
48. PROJ. % DVMT-FWYS.												.69			
49. PROJ. PRINCIPAL ARTERIALS DVMT/CAPITA								.56	-.41						
50. PROJ. ROUTE MILES-FWYS.															
51. PROJ. INCREASE-PRINC. ART. RT. MI.	.91														
52. GROWTH FACTOR; PRINC. ART. DVMT/RT. MI.	.83												-.81		
53. PROJ. PRINC. ART. DVMT/RT. MI.												.48			
PERCENT VARIANCE ACCOUNTED FOR:	16.9	11.4	4.1	7.0	4.2	4.6	3.2	3.2	5.3	2.7	2.7	4.1	2.7	11.3	2.8
RANK	1	2	8	4	7	6	10	11	5	13	14	9	15	3	12

Figure 4. Factor interpretation.

RANK ORDER	EIGENVECTOR NUMBER	% OF ORIGINAL VARIANCE ACCOUNTED FOR	FACTOR INTERPRETATION	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
1	1	16.9	SIZE OF POPULATION AND AREA; CENTRAL CITY DENSITY; PUBLIC TRANSIT USAGE; SERVICE SECTOR ACTIVITY.	NEW YORK CHICAGO LOS ANGELES PHILADELPHIA	WILMINGTON ROCHESTER BRIDGEPORT SALT LAKE CITY
2	2	11.4	INCOME LEVEL; VALUE AND SOUNDNESS OF HOUSING; CONCENTRATION OF POPULATION IN SUBURBS; AUTO AVAILABILITY IN SUBURBS.	SAN JOSE BRIDGEPORT	MOBILE BIRMINGHAM KNOXVILLE MEMPHIS
3	14	11.3	POPULATION DENSITY; PUBLIC TRANSIT USAGE; UNAVAILABILITY OF AUTOS; AGE OF CITY; CONCENTRATION OF AREA POOR IN CENTRAL CITY.	WASHINGTON BOSTON NEW ORLEANS BUFFALO	SAN BERNARDINO LOS ANGELES PHOENIX
4	4	7.0	INCOME LEVEL; YOUTHFULNESS OF POPULATION; FAMILY SIZE; LOW LEVEL OF RETAIL SALES ACTIVITY.	WASHINGTON EL PASO HONOLULU	TAMPA W. PALM BEACH FT. LAUDERDALE PORTLAND
5	9	5.3	WHITE POPULATION IN MULTIPLE-UNIT HOUSING; HIGH PROPORTION OF WORK TRIPS ON FOOT; FEW PRINCIPLE ARTERIAL ROADS; COLDER CLIMATE.	DULUTH EL PASO MADISON WORCESTER UTICA	HONOLULU FT. LAUDERDALE
6	6	4.6	POPULATION CONCENTRATION AND DENSITY IN SUBURBS; WORKERS COMMUTING WITHIN SUBURBS AND TO CENTRAL CITY; AUTO AVAILABILITY; LOW CBD RETAIL ACTIVITY.	PITTSBURGH LOS ANGELES SAN BERNARDINO ORLANDO W.PALM BEACH	TOLEDO INDIANAPOLIS NEWPORT NEWS NEW YORK CHARLOTTE
7	5	4.2	LABOR FORCE PARTICIPATION RATE.	HONOLULU DALLAS CHARLOTTE HARTFORD	DETROIT PITTSBURGH TAMPA TUCSON
8	3	4.1	CONCENTRATION OF EMPLOYMENT IN BLUE COLLAR JOBS AND IN LARGE MANUFACTURING PLANTS; LOW SERVICE SECTOR ACTIVITY.	FLINT YOUNGSTOWN BEAUMONT NEWPORT NEWS DAVENPORT	ALBUQUERQUE WASHINGTON SALT LAKE CITY
9	12	4.1	CONCENTRATION OF PROJECTED ROADWAY USAGE ON FREEWAYS AND OTHER PRINCIPAL ARTERIALS.	LOS ANGELES EL PASO DALLAS SAN ANTONIO SAN FRANCISCO	YOUNGSTOWN ORLANDO DAYTON
10	7	3.2	HIGH PROPORTION OF HOUSEHOLDS IN SUBURBS WITH NO AUTO; LAND DEVELOPMENT RESTRICTED BY PHYSICAL FEATURES.	SAN FRANCISCO	LANSING FLINT RICHMOND NASHVILLE
11	8	3.2	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL ROADWAY USAGE; LEVEL OF ARTERIAL USAGE PER CAPITA.	W.PALM BEACH SAN BERNARDINO ORLANDO WORCESTER	LOS ANGELES
12	15	2.8	PROPORTION OF WORKERS REVERSE COMMUTING; PROPORTIONAL DECREASE IN CBD RETAIL SALES ACTIVITY.	HONOLULU WICHITA ALBANY TUCSON	DALLAS MINNEAPOLIS
13	10	2.7	PROPORTION OF POPULATION LIVING IN GROUP QUARTERS.	NORFOLK TACOMA SAN DIEGO	TULSA DALLAS
14	11	2.7	RATE OF POPULATION GROWTH	TAMPA MIAMI	OKLAHOMA CITY MOBILE AKRON KANSAS CITY
15	13	2.7	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL USAGE PER MILE OF ROADWAY	ALBUQUERQUE	BEAUMONT JACKSONVILLE WASHINGTON

The cluster analysis technique chosen was a version of a method developed by Friedman and Rubin (25) in which an approximation of the Wilks' λ-statistic is optimized through use of a hill-climbing partitioning algorithm due to Rubin (63). The algorithm features heuristic object reassignments and restarts in order to dislodge from local optima, and the relatively homogeneous groups found are mutually exclusive and exhaustive of the set of metropolitan areas. The criterion function is derived from the basic matrix identity relating variance or scatter in grouped data (79):

$$T = W + B \tag{5}$$

where T is the total data scatter matrix, W is the pooled within-group scatter matrix, and B is the between-group scatter matrix. Since the clustering of the 80 metropolitan areas was based on the distribution of the areas in the space of the 15 latent factors, given by the (15 by 80) factor scores matrix F,

$$T = FF' \tag{6}$$

which remains constant throughout the clustering process. A clear objective is then to minimize W (i.e., make the individual groups, taken together, as compact as possible) or, equivalently, maximize B (i.e., make the groups as far removed from each other as possible).

The scalar function chosen to represent this objective is the ratio of the determinants of T and W:

$$\frac{|T|}{|W|} = |I + W^{-1}B| \tag{7}$$

where I is the identity matrix. This function, due to Wilks (78), exhibits the important property of being invariant under non-singular linear transformations of the factor scores matrix, thus addressing the problem of circular indeterminancy between metric and group formulation discussed in Friedman and Rubin (25). In the degenerate case of one-dimensional data (p = number of latent factors = 1), maximization of the Wilks' λ-statistic is equivalent to maximization of a quantity (B/W) proportional to the familiar F-statistic.

Eight applications of the clustering program, each application complete with a series of restarts from random group partitions to help avoid termination on local maxima (which is never completely assured), were used to classify the 80 metropolitan areas into 5, 6, 7, 8, 9, 10, 11, and 12 groups. From these clusterings the 9-group level was selected through subjective judgment in which increases in homogeneity were weighted against numbers of potential case studies as the classification scheme for empirical elaboration of the further steps in the procedure to estimate national markets and total social, economic, and environmental impacts of new systems of arterial transportation. This classification is shown in Figure 5. The pronounced geographical distributions of the groups are shown in Figure 6. The salient features of the 9 groups, as reflected in their outstanding mean values on the 15 latent factors, are summarized in Figure 7. Two-dimensional plots of the metropolitan areas by group in the spaces formed by pairs of the most important latent factors (i.e., factors associated with eigenvectors 1, 2, 4, and 14) are given in the expanded version of Golob et al. (27).

Two additional multivariate statistical methods were applied to the data in order to provide information about the classification scheme complementary to that obtained in the cluster analysis: A hierarchical grouping analysis based on the diameter method evaluations of Euclidean distances [due to Johnson (38)] supplied information concerning outlying (i.e., difficult to classify) metropolitan areas, and a step-wise multiple linear discriminant analysis [see previously cited references on multivariate methods and Morrison (51)] supplied information concerning the replication of groups through the use of hyperplanes in the spaces of particular subsets of the original manifest variables. Results from these applications are detailed in Golob et al. (27).

Figure 5. Nine-group level clustering (Wilks' λ criterion value = 8.23).

9-GROUP LEVEL CLUSTERING (WILKS'-LAMBDA CRITERION VALUE = 8.23)				
GROUP 1 NEW YORK GROUP 2 LOS ANGELES CHICAGO GROUP 3 BALTIMORE BOSTON DETROIT PHILADELPHIA PITTSBURGH ST. LOUIS WASHINGTON	GROUP 4 ATLANTA BIRMINGHAM CHARLOTTE HONOLULU JACKSONVILLE KNOXVILLE LOUISVILLE MEMPHIS MOBILE NASHVILLE NEW ORLEANS NORFOLK GROUP 5 DENVER INDIANAPOLIS KANSAS CITY OKLAHOMA CITY PORTLAND PROVIDENCE SEATTLE SPRINGFIELD TACOMA TULSA	GROUP 6 AKRON ALBANY BRIDGEPORT BUFFALO CINCINNATI CLEVELAND COLUMBUS GRAND RAPIDS HARTFORD MILWAUKEE RICHMOND ROCHESTER SACRAMENTO SALT LAKE CITY SYRACUSE TOLEDO WILMINGTON WORCESTER	GROUP 7 BEAUMONT DALLAS EL PASO FORT WORTH HOUSTON PHOENIX SAN ANTONIO SAN BERNARDINO SAN DIEGO SAN FRANCISCO SAN JOSE GROUP 8 FORT LAUDERDALE MIAMI ORLANDO TAMPA WEST PALM BEACH	GROUP 9 ALBUQUERQUE DAVENPORT DAYTON DULUTH FLINT LANSING MADISON MINNEAPOLIS NEWPORT NEWS OMAHA TUCSON UTICA WICHITA YOUNGSTOWN

Figure 6. Geographical distribution of the groups.

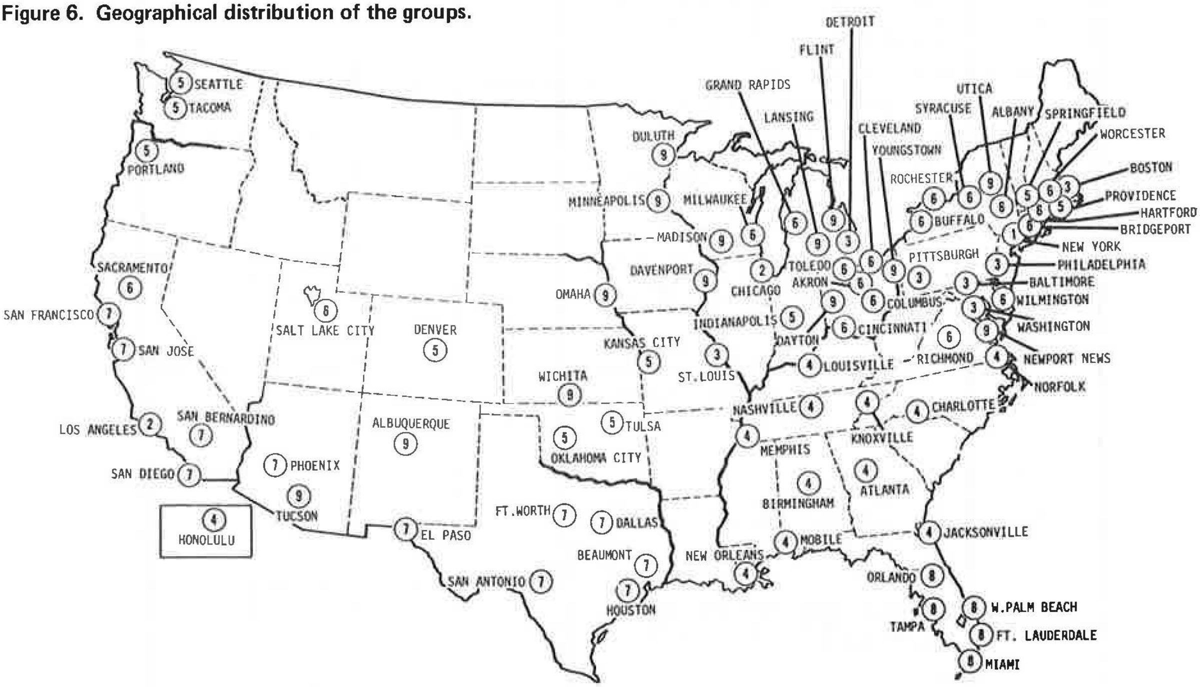

Figure 7. Factor interpretation for 9 groups.

EIGENVECTOR NUMBER	FACTOR INTERPRETATION	GROUPS WITH OUTSTANDING MEANS		GROUPS WITH OUTSTANDING STD. DEV.	
		HIGH	LOW	HIGH	LOW
1	SIZE OF POPULATION AND AREA; CENTRAL CITY DENSITY; PUBLIC TRANSIT USAGE; SERVICE SECTOR ACTIVITY.	--	6	3	--
2	INCOME LEVEL; VALUE AND SOUNDNESS OF HOUSING; CONCENTRATION OF POPULATION IN SUBURBS; AUTO AVAILABILITY IN SUBURBS.	6	4	7	--
14	POPULATION DENSITY; PUBLIC TRANSIT USAGE; UNAVAILABILITY OF AUTOS; AGE OF CITY; CONCENTRATION OF AREA POOR IN CENTRAL CITY.	3	7	--	--
4	INCOME LEVEL; YOUTHFULNESS OF POPULATION; FAMILY SIZE; LOW LEVEL OF RETAIL SALES ACTIVITY.	--	8	3,8	--
9	WHITE POPULATION IN MULTIPLE-UNIT HOUSING; HIGH PROPORTION OF WORK TRIPS ON FOOT; FEW PRINCIPLE ARTERIAL ROADS; COLDER CLIMATE.	9	8	9	4
6	POPULATION CONCENTRATION AND DENSITY IN SUBURBS; WORKERS COMMUTING WITHIN SUBURBS AND TO CENTRAL CITY; AUTO AVAILABILITY; LOW CBD RETAIL ACTIVITY.	3	6	--	--
5	LABOR FORCE PARTICIPATION RATE.	3	--	--	5
3	CONCENTRATION OF EMPLOYMENT IN BLUE COLLAR JOBS AND IN LARGE MANUFACTURING PLANTS; LOW SERVICE SECTOR ACTIVITY.	--	5,8	9	--
12	CONCENTRATION OF PROJECTED ROADWAY USAGE ON FREEWAYS AND OTHER PRINCIPAL ARTERIALS.	7	9	--	--
7	HIGH PROPORTION OF HOUSEHOLDS IN SUBURBS WITH NO AUTO; LAND DEVELOPMENT RESTRICTED BY PHYSICAL FEATURES.	8	--	--	3
8	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL ROADWAY USAGE; LEVEL OF ARTERIAL USAGE PER CAPITA.	8	--	8	4,5
15	PROPORTION OF WORKERS REVERSE COMMUTING; PROPORTIONAL DECREASE IN CBD RETAIL SALES ACTIVITY.	8	--	9	--
10	PROPORTION OF POPULATION LIVING IN GROUP QUARTERS.	8	5	5,7	--
11	RATE OF POPULATION GROWTH	5	8	--	5,7
13	PROJECTED RATE OF INCREASE IN PRINCIPAL ARTERIAL USAGE PER MILE OF ROADWAY	5	--	--	5,8

Results of the 6, 7, 8, 10, and 11-group clusterings are also found in the expanded version of Golob et al. (27). The maximum value of the Wilks' λ-statistic was found to be approximately linear across this range, providing evidence that there exists no "natural" number of groups in the range and contributing assurance that no clustering was determined by local maxima significantly different from the global maxima.

While the factor and cluster analytic classification process described here is, to the knowledge of the authors, a unique approach in terms of its integration as one step in an estimation procedure and in terms of its methodologies and its data base, it is related in concept to functional city classification studies conducted by geographers and other social scientists. The first city classification related in terms of being based on empirically derived multivariate classification criteria was that of Ogburn (54). This non-factorial work was advanced by Harris (33) and Kneedler (45), among others, and has been expanded in a number of studies [particularly Forstall (22)].

Classifications based on latent structure derived through factor analytic or related methods began with Moser and Scott (52) in their study of British towns. Ahmad (1), Hadden and Borgatta (31), and King (44) have all contributed revealing analyses (of Indian cities, U. S. cities over 25,000 population, and Canadian cities respectively), and comprehensive classifications of all U. S. urban places have been recently reported by Forstall (23), Berry (14), and Meyer (49). Discussions of the methods, purposes, and limitations of such city classification schemes can be found in Smith (67), Berry (13, 14), Alford (2), Arnold (4), and Clark (20). Noteworthy transportation-related classifications (which have not, in general, reflected the state of the art as demonstrated in the above studies) are those of Bottiny and Goley (15), Ganz (26), Henderson et al. (35), Mendelson et al. (48), Graves and Rechel (28), and Kassoff and Gendell (42).

A SELECTION OF CASE STUDY LOCALES

The number of groups chosen to represent the similarities and differences between the 80 candidate metropolitan areas (in this application, 9) determines the necessary number of case studies of the proposed new transportation system. However, the intensity of the individual case studies might vary significantly, and, in the extreme, entire groups might be dismissed from consideration of the national markets and impacts on the basis of criteria external to the estimation procedure. For example, the group consisting of the New York Standard Consolidated Area, or even the group consisting of the Chicago and Los Angeles areas, might be a priori dismissed from considerations of certain classes of arterial systems.

The order of preference within each group for case study locales is identical to the order of representativeness of the metropolitan areas within that group. This is a basic postulate in the development of the statistical procedure to estimate national markets and total social, economic, and environmental impacts of new systems of urban transportation; it is conceptually discussed in the section of this paper on research objectives and is methodologically specified in Canty and Golob (18).

The representativeness rankings for groups 3 through 9 (the concept is not defined for groups made up of less than 3 metropolitan areas) were generated by subjectively combining for each group 3 distinct statistical criteria of representativeness for each of the metropolitan areas within that group. The first criterion was the generalized Mahalanobis distance from the metropolitan area to the center of its group in the space of the 15 orthogonal factors, which is simply the Euclidean distance between the points weighted in terms of the metric of the pooled within-group scatter matrix W [see Friedman and Rubin (25)]. The second criterion was the measurement of the decrease in the maximum value of the Wilks' λ-statistic resulting from movement of the area from its assigned group to the "next best" group. And the third criterion was the number of significant Q-type product-moment correlations between the area and the other areas within its group. This latter criterion, measuring the number of pair-wise significant associations, was employed in isolation by Zenk and Frost (80) to similarly identify case study locales.

The resultant representativeness rankings for the 9 groups are given in Figure 8. The representativeness rankings for the 6, 7, 8, 10, and 11-group clusterings, which

Figure 8. Areas ranked by representativeness in each group (9-group level).

GROUP 1	GROUP 4	GROUP 6	GROUP 7	GROUP 9
(1) NEW YORK	1. NASHVILLE	1. MILWAUKEE	1. SAN JOSE	1. OMAHA
	2. MEMPHIS	2. GRAND RAPIDS	2. FORT WORTH	2. DAVENPORT
GROUP 2	3. BIRMINGHAM	3. CINCINNATI	3. HOUSTON	3. UTICA
	4. JACKSONVILLE	4. SYRACUSE	4. PHOENIX	4. DULUTH
(1) CHICAGO	5. ATLANTA	5. COLUMBUS	5. SAN ANTONIO	5. LANSING
(1) LOS ANGELES	6. CHARLOTTE	6. AKRON	6. SAN BERNARDINO	6. DAYTON
	7. MOBILE	7. TOLEDO	7. SAN DIEGO	7. YOUNGSTOWN
GROUP 3	8. NEW ORLEANS	8. ROCHESTER	8. BEAUMONT	8. MINNEAPOLIS
	9. KNOXVILLE	9. CLEVELAND	9. DALLAS	9. TUCSON
1. ST. LOUIS	10. LOUISVILLE	10. HARTFORD	10. EL PASO	10. WICHITA
2. BOSTON	11. NORFOLK	11. ALBANY	11. SAN FRANCISCO	11. MADISON
3. DETROIT	12. HONOLULU	12. BRIDGEPORT		12. FLINT
4. PHILADELPHIA		13. SALT LAKE CITY	GROUP 8	13. ALBUQUERQUE
5. PITTSBURGH	GROUP 5	14. WILMINGTON		14. NEWPORT NEWS
6. BALTIMORE		15. SACRAMENTO	1. FORT LAUDERDALE	
7. WASHINGTON	1. KANSAS CITY	16. BUFFALO	2. WEST PALM BEACH	
	2. OKLAHOMA CITY	17. WORCESTER	3. MIAMI	
	3. DENVER	18. RICHMOND	4. TAMPA	
	4. PORTLAND		5. ORLANDO	
	5. SEATTLE			
	6. SPRINGFIELD			
	7. INDIANAPOLIS			
	8. PROVIDENCE			
	9. TULSA			
	10. TACOMA			

are different from the 9-group rankings because of the distinct shifts of group centers and area assignments encountered in clustering into varying numbers of groups, are provided in the expanded version of Golob et al. (27). Also given in this reference are summary tables of the 3 representativeness criteria measurements for the 8- and 9-group clusterings of the 80 metropolitan areas.

While the selection of case study locales should be highly influenced by the degree of representativeness of metropolitan areas relative to their groups, additional factors enter into the decision. These include the quality and quantity of available and relevant data on the metropolitan area and its projected needs for arterial transportation facilities. Inasmuch as local planning agencies should be involved in the conduct of the case studies and sensitivity analyses, either in a leading or technically supportive role, the qualifications and staffing of local land use and transportation planning agencies are also important, as is their evidenced interest in cooperative efforts with planning groups conducting parallel studies in other case study areas. Case study areas should also be selected where the community as a whole and its political leaders would likely be receptive to the implementation of the subject system, if and when the system could be shown to be cost-effective and socially and environmentally beneficial. Such reception enhances the likelihood of acquiring a more empirical data base on which system size, costs, and impacts can be estimated for other metropolitan areas. Clearly, the selection among metropolitan areas as case study locales must be based on such subjective judgments of sociopolitical factors as well as rank order of representativeness as determined by statistical analyses.

EXTENSION OF CASE STUDY RESULTS

The objective here is to estimate the overall market for, or the overall costs and benefits that would be incident to the implementation of, some specified urban system (e.g., the Metro Guideway arterial transportation system providing personal rapid transit and dual-mode functions). In this context, "overall" is for some totality of metropolitan areas to which the new system might initially be considered applicable.

Let it be assumed that case studies of the contemplated new system have been conducted in some limited number of metropolitan locales such that the remaining tasks are to estimate the appropriate system size (market), its cost, social and environmental impacts, etc., in the remaining metropolitan areas, and to aggregate the results. If the case study locales were selected by some disciplined process (such as described in the preceding sections) so that each is representative of a fairly homogeneous group of metropolitan areas (the groups being mutually exclusive and exhaustive of the total set of metropolitan areas considered), the most appropriate procedure is extrapolating case study results from each case study area to the other metropolitan areas in its group and then aggregating results over all groups. The process of extrapolation presents conceptual difficulties whereas the process of aggregation is comparatively trivial, and only the first warrants detailed discussion.

The present state of the art of market research, requirements analysis, and national benefit-cost analysis for urban systems is relatively primitive. The most common procedure appears to be based on stratifying the total set of metropolitan areas by one or two variables (typically metropolitan area population, or population plus a second variable such as density) and then to extrapolate the results (e.g., the required number of transit vehicles) in direct proportion to the population of the case study area and the other areas in its stratified group [for examples, see Kassoff and Gendell (42) or Graves and Rechel (28)]. It will be recognized that a decision to extrapolate case study results in direct proportion to population or any other single metropolitan area characteristic carries with it the assumption that no other variables need be or should be considered as influencing system utilization, costs, environmental impacts, etc.

An alternative approach, part of the research framework described in this paper, is to estimate the influence of several metropolitan area characteristics (variables), rather than population size alone, in the extrapolation of case study results. Differentials in the size, costs, and impacts of the new system between a case study area and other metropolitan areas in its group are estimated on the basis of knowledge of the differences in their metropolitan area characteristics and the sensitivity of system size, cost, and impacts to those metropolitan area characteristics. Differences in the characteristics between the case study locale and other metropolitan areas (intra-group variance) are described via a factor analytic process similar to that outlined earlier. Sensitivity analyses are made with respect to several metropolitan area characteristics as a part of the case study process.

This approach is tantamount to assuming that, within a relatively homogeneous group of urban areas, the system size, cost, or impact (each of which is considered as a vector, i.e., composed of an array of numbers) can be expressed as a continuous and differentiable function over a space defined from the metropolitan area characteristics, with the partial derivatives of the function developed via the sensitivity analyses. In comparison, the currently employed procedure of scaling system size, cost, and impacts in direct proportion to metropolitan area population represents a special and restrictive case of the alternative approach suggested here, with all but one of the partial derivatives (sensitivities) being considered to be null.

For the case of 80 metropolitan areas classified into 9 groups, factor analyses were performed on data sets composed of the original variables and the metropolitan areas in groups 3 through 9. (All 53 variables were included in the factor analysis for group 3; however, one variable—the percentage of work trips by rail transit—was excluded from the analyses for groups 4 through 9 due to zero variance. Honolulu, a statistical outlyer, was excluded from analysis of group 4.) The methodology of the factor analyses is similar to that discussed and referenced previously except that in each factor analysis here, the set of observations is restricted to those metropolitan areas comprising each group, and the process is repeated for each group. Group 1, the New York Consolidated Area, and Group 2, composed of the Chicago and Los Angeles areas, were not subject to these analyses.

Summary results of these intra-group factor analyses are given in Figure 9. As before, factors are listed in rank order by the amount of variance for which they account and are identified in terms of the most significant factor-variable correlations. Those metropolitan areas are noted that have particularly high positive or high negative (i.e., low) scores on the factors.

The intra-group factor analyses provide an analytic framework for the extension of the case study results. As before, one may give an interpretation to the factors in terms of which variables are principally involved, but here one is interested in using such interpretations as guidelines for sensitivity analysis. Thus, for group 7, factor 1 is highly correlated with size variables such as population and factor 2 with variables

Figure 9. Results of intra-group factor analyses.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS: COEFFICIENT	OUTSTANDING FACTOR LOADINGS: VARIABLE	OUTSTANDING FACTOR SCORES: AREAS WITH HIGHEST SCORES	OUTSTANDING FACTOR SCORES: AREAS WITH LOWEST SCORES
GROUP 3					
1	32.3	+0.98	PROJ. MEAN HOUSEHOLD INCOME	WASHINGTON	
		+0.98	CONCENTRATION OF POOR IN CENTRAL CITY		
		+0.95	MEDIAN HOUSING VALUE		
		+0.93	% WHITE COLLAR		
		+0.92	PROJ. % AFFLUENT HOUSEHOLDS		
		+0.91	SERVICE RECEIPTS / CAPITA		
		+0.89	% WORKERS COMMUTING TO CENTRAL CITY		
		+0.89	PROJ. PRINCIPAL ARTERIALS DVMT / CAPITA		
		-------	-------		
		+0.83	PERSONS / HOUSEHOLD		
		+0.82	PROJ. % POP. < 18 YRS.		
		-0.82	PROJ. % POOR HOUSEHOLDS		
		-0.77	NONWORKER-WORKER RATIO		
		-0.76	RETAIL ESTABLISHMENTS / CAPITA		
		-0.76	AVG. EMPLOYEES / MFG. ESTABL.		
		-------	-------		
		(0.72)	(NEXT HIGHEST LOADING)		
2	22.8	+0.95	PER CAPITA INCOME GROWTH	PHILADELPHIA	DETROIT
		+0.92	% CENTRAL CITY WORKERS USING TRANSIT	BOSTON	
		+0.91	POP. DENSITY IN CENTRAL CITY		
		-------	-------		
		-0.86	PROJ. % DVMT ON PRINCIPAL ARTERIALS		
		+0.85	TOTAL TRANSIT VEHICLES		
		+0.83	No. OF CENTRAL CITIES		
		+0.81	% WORKERS USING RAIL		
		+0.79	FRINGE WORKERS USING TRANSIT		
		-------	-------		
		(0.72)	(NEXT HIGHEST LOADING)		
3	20.0	+0.94	% FRINGE COMMUTING	PITTSBURGH	BALTIMORE
		-0.90	% NON-WHITE	BOSTON	
		-------	-------		
		-0.82	% POP. IN CENTRAL CITY		
		-0.80	PER CAPITA INCOME		
		-0.80	% CHANGE-PRINCIPAL ARTERIAL DVMT		
		+0.78	% FRINGE HOUSEHOLDS WITH NO AUTO		
		+0.74	% WORKERS WALKING		
		-0.70	POP. GROWTH FACTOR		
		-------	-------		
		(0.63)	(NEXT HIGHEST LOADING)		
4	15.3	+0.92	AREA	DETROIT	BALTIMORE
		+0.92	POPULATION		
		+0.91	PROJ. PRINCIPAL ARTERIAL DVMT		
		+0.86	PROJ. PRINCIPAL ARTERIAL DVMT / ROUTE MILE		
		-------	-------		
		-0.75	RADIUS OF DEVELOPMENT		
		-------	-------		
GROUP 4					
1	18.7	+0.96	TOTAL TRANSIT VEHICLES	NEW ORLEANS	
		+0.90	POPULATION	ATLANTA	
		-0.87	% SINGLE-UNIT HOUSING		
		-------	-------		
		+0.82	MEDIAN HOUSING VALUE		
		+0.79	% CENTRAL CITY WORKERS USING TRANSIT		
		+0.78	AREA		
		+0.76	% WHITE COLLAR		
		+0.74	PROJ. PRINCIPAL ARTERIAL DVMT		
		-------	-------		
		(0.61)	(NEXT HIGHEST LOADING)		
2	13.6	+0.93	PERSONS / HOUSEHOLD	NORFOLK	
		+0.80	PROJ. MEAN HOUSEHOLD INCOME		
		-0.76	% POP. >64 YRS.		
		-------	-------		
		+0.69	% GROUP QUARTER HOUSING		
		+0.68	PROJ. % AFFLUENT HOUSEHOLDS		
		-0.68	% SALES IN CBD		
		+0.66	% POP. <18 YRS.		
		-------	-------		
		(0.61)	(NEXT HIGHEST LOADING)		
3	13.5	+0.91	% MARRIED WOMEN WORKING	CHARLOTTE	
		-0.90	NONWORKER-WORKER RATIO		
		-0.82	POP. DENSITY IN FRINGE		
		-------	-------		
		-0.74	% FRINGE WORKERS USING TRANSIT		
		+0.71	PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA		
		+0.66	SERVICE RECEIPTS / CAPITA		
		-------	-------		
		(0.53)	(NEXT HIGHEST LOADING)		

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS: COEFFICIENT	OUTSTANDING FACTOR LOADINGS: VARIABLE	OUTSTANDING FACTOR SCORES: AREAS WITH HIGHEST SCORES	OUTSTANDING FACTOR SCORES: AREAS WITH LOWEST SCORES
GROUP 4 (contd.)					
4	12.5	+0.86 +0.84 +0.82 +0.76 ------- (0.67)	% COMMUTING TO CENTRAL CITY % FRINGE COMMUTING CONCENTRATION OF POOR IN CENTRAL CITY % CHANGE IN CBD SALES ------- (NEXT HIGHEST LOADING)	KNOXVILLE	CHARLOTTE MOBILE
5	12.3	+0.90 ------- -0.76 +0.71 +0.69 ------- (0.64)	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI. ------- PER CAPITA INCOME GROWTH % CHANGE-PRINCIPAL ARTERIAL DVMT POP. GROWTH FACTOR ------- (NEXT HIGHEST LOADING)	JACKSONVILLE LOUISVILLE	KNOXVILLE
6	11.4	-0.84 +0.82 ------- +0.74 +0.67 -0.65 ------- (0.50)	PROJ. % POOR HOUSEHOLDS PROJ. % DVMT ON FREEWAYS ------- PROJ. RT. MI. - FWYS. AUTOS / FAMILY % CENTRAL CITY HOUSEHOLDS WITH NO AUTO ------- (NEXT HIGHEST LOADING)	ATLANTA	NEW ORLEANS
7	6.9	+0.83 ------- (0.54)	MEAN JAN. TEMP. ------- (NEXT HIGHEST LOADING)	JACKSONVILLE	NORFOLK LOUISVILLE
GROUP 5					
1	17.8	+0.91 +0.90 +0.85 -0.83 ------- -0.74 +0.69 -0.67 +0.66 -0.66 +0.65 ------- (0.60)	PROJ. % POOR HOUSEHOLDS MEAN JAN. TEMP. % SINGLE-UNIT HOUSING % WORKERS WALKING ------- PERSONS / HOUSEHOLD PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA AGE OF CENTRAL CITY AUTOS / FAMILY PER CAPITA INCOME % WHITE COLLAR ------- (NEXT HIGHEST LOADING)		SPRINGFIELD PROVIDENCE
2	14.7	+0.93 -0.88 +0.84 ------- +0.76 ------- (0.67)	% GROUP QUARTER HOUSING % CHANGE IN CBD SALES NONWORKER-WORKER RATIO ------- % COMMUTING TO CENTRAL CITY ------- (NEXT HIGHEST LOADING)	TACOMA	TULSA SEATTLE
3	14.4	-0.88 +0.83 ------- +0.73 +0.71 +0.67 ------- (0.58)	% SALES IN CBD No. INC. CITIES ------- PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI. AREA CONCENTRATION OF POOR IN CENTRAL CITY ------- (NEXT HIGHEST LOADING)	KANSAS CITY OKLAHOMA CITY	TULSA
4	13.5	+0.85 ------- +0.75 -0.73 -0.70 -0.69 ------- (0.63)	% CHANGE - PRINCIPAL ARTERIAL DVMT ------- RETAIL STORES / CAPITA TOTAL TRANSIT VEHICLES EMPLOYEES / MFG. ESTABL. % CENTRAL CITY WORKERS USING TRANSIT ------- (NEXT HIGHEST LOADING)	OKLAHOMA CITY TULSA PROVIDENCE	SEATTLE
5	12.6	+0.92 ------- +0.70 +0.68 ------- (0.64)	PROJ. % DVMT ON PRINCIPAL ARTERIALS ------- PROJ. PRINCIPAL ARTERIAL DVMT % HOUSING SOUND ------- (NEXT HIGHEST LOADING)	DENVER	TULSA
6	12.5	+0.90 +0.85 ------- -0.73 -0.70 ------- (0.65)	% FRINGE COMMUTING % POP. > 64 YRS. ------- % NON-WHITE % POP. in CENTRAL CITY ------- (NEXT HIGHEST LOADING)	PROVIDENCE PORTLAND	INDIANAPOLIS

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS: COEFFICIENT	OUTSTANDING FACTOR LOADINGS: VARIABLE	OUTSTANDING FACTOR SCORES: AREAS WITH HIGHEST SCORES	OUTSTANDING FACTOR SCORES: AREAS WITH LOWEST SCORES
GROUP 6					
1	17.0	+0.95 +0.95 +0.93 +0.91 +0.90 +0.87 ------- (0.65)	POPULATION TOTAL TRANSIT VEHICLES No. INC. CITIES AREA PROJ. PRINCIPAL ARTERIAL DVMT PROJ. RT. MI. - FWYS. ------- (NEXT HIGHEST LOADING)	CLEVELAND	
2	13.1	-0.91 -0.84 +0.82 -0.77 ------- +0.69 -0.67 +0.66 ------- (0.57)	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA MEAN JAN. TEMP. % WORKERS WALKING % SINGLE - UNIT HOUSING ------- % POP. > 54 YRS. % NON-WHITE RETAIL STORES / CAPITA ------- (NEXT HIGHEST LOADING)	ALBANY	RICHMOND SACRAMENTO
3	11.4	-0.88 +0.80 +0.80 -0.80 ------- +0.71 ------- (0.61)	PROJ. % POOR HOUSEHOLDS PROJ. % AFFLUENT HOUSEHOLDS PROJ. MEAN HOUSEHOLD INCOME PER CAPITA INCOME GROWTH ------- PER CAPITA INCOME ------- (NEXT HIGHEST LOADING)	BRIDGEPORT HARTFORD ROCHESTER AKRON	
4	8.9	+0.91 +0.88 ------- (0.63)	CONCENTRATION OF POOR IN CENTRAL CITY % CENTRAL CITY HOUSEHOLDS WITH NO AUTO ------- (NEXT HIGHEST LOADING)	WILMINGTON	
5	8.5	+0.88 ------- +0.77 +0.73 ------- (0.53)	% GROUP QUARTER HOUSING ------- POP. GROWTH FACTOR % SALES IN CBD ------- (NEXT HIGHEST LOADING)	WORCESTER	
6	8.3	+0.85 ------- (0.53)	AUTOS / FAMILY ------- (NEXT HIGHEST LOADING)	SALT LAKE CITY	
7	7.5	+0.90 +0.81 ------- (0.47)	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT. MI. POP. DENSITY IN FRINGE ------- (NEXT HIGHEST LOADING)	BUFFALO	
8	6.1	+0.86 ------- +0.67 ------- (0.61)	SERVICE RECEIPTS / CAPITA ------- % WHITE COLLAR ------- (NEXT HIGHEST LOADING)	ALBANY	WILMINGTON WORCESTER
9	5.4	-0.75 ------- (0.56)	PROJ. % DVMT ON FWYS. ------- (NEXT HIGHEST LOADING)	BUFFALO	
GROUP 7					
1	23.1	+0.97 +0.94 +0.92 +0.92 -0.90 +0.88 ------- +0.78 -0.77 +0.75 +0.74 +0.69 ------- (0.59)	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO TOTAL TRANSIT VEHICLES POP. DENSITY IN CENTRAL CITY % CENTRAL CITY WORKERS USING TRANSIT % SINGLE - UNIT HOUSING AGE OF CENTRAL CITY ------- POPULATION RADIUS OF DEVELOPMENT No. INC. CITIES % FRINGE WORKERS USING TRANSIT PROJ. PRINCIPAL ARTERIAL DVMT ------- (NEXT HIGHEST LOADING)	SAN FRANCISCO	
2	22.2	+0.94 +0.92 -0.91 ------- +0.86 -0.86 +0.83 +0.81 +0.80 ------- (0.71)	PROJ. % AFFLUENT HOUSEHOLDS % HOUSING SOUND PROJ. % POOR HOUSEHOLDS ------- PROJ. MEAN HOUSEHOLD INCOME PER CAPITA INCOME GROWTH MEDIAN HOUSING VALUE AUTOS / FAMILY PER CAPITA INCOME ------- (NEXT HIGHEST LOADING)	SAN JOSE	SAN ANTONIO

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 7 (contd.)					
3	15.5	+0.81 -0.80 ------- +0.76 +0.74 +0.72 ------- (0.65)	PROJ. RT. MI. - FWYS. % REVERSE COMMUTING ------- PROJ. PRINCIPAL ARTERIAL DVMT / CAPITA AREA % MARRIED WOMEN WORKING ------- (NEXT HIGHEST LOADING)	DALLAS	BEAUMONT
4	9.7	-0.91 ------- -0.77 ------- (0.67)	No. CENTRAL CITIES ------- % POP. > 64 YRS. ------- (NEXT HIGHEST LOADING)	EL PASO SAN JOSE	SAN BERNARDINO
5	9.4	+0.93 ------- -0.75 ------- (0.65)	% GROUP QUARTER HOUSING ------- RETAIL STORES / CAPITA ------- (NEXT HIGHEST LOADING)	SAN DIEGO	BEAUMONT FT. WORTH
6	7.8	-0.81 +0.78 +0.77 ------- (0.66)	% FRINGE HOUSEHOLDS WITH NO AUTO MEAN JAN. TEMP. PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI. ------- (NEXT HIGHEST LOADING)	SAN DIEGO SAN ANTONIO	EL PASO
GROUP 8					
1	35.4	+1.00 +0.98 +0.97 -0.96 +0.94 +0.92 ------- +0.89 +0.86 ------- (0.79)	POPULATION PROJ. PRINCIPAL ARTERIAL DVMT PROJ. % DVMT ON PRINCIPAL ARTERIALS % CHANGE-PRINCIPAL ARTERIAL DVMT PROJ. RT. MI. - FWYS. AREA ------- TOTAL TRANSIT VEHICLES POP. DENSITY IN FRINGE ------- (NEXT HIGHEST LOADING)	MIAMI	
2	30.0	+0.96 -0.95 -0.95 -0.90 +0.89 ------- +0.84 +0.82 -0.81 ------- (0.76)	% MARRIED WOMEN WORKING % SALES IN CBD % POP. IN CENTRAL CITY NONWORKER - WORKER RATIO % NON - WHITE ------- MEDIAN HOUSING VALUE PER CAPITA INCOME No. CENTRAL CITIES ------- (NEXT HIGHEST LOADING)		TAMPA
3	18.8	-0.95 +0.91 ------- -0.83 +0.82 +0.81 ------- (0.77)	No. INC. CITIES PERSONS / HOUSEHOLD ------- PROJ. % DVMT ON FWYS. % POP. < 18 YRS. % COMMUTING TO CENTRAL CITY ------- (NEXT HIGHEST LOADING)	ORLANDO	

Figure 9. Continued.

FACTOR	PERCENT VARIANCE ACCOUNTED FOR	OUTSTANDING FACTOR LOADINGS		OUTSTANDING FACTOR SCORES	
		COEFFICIENT	VARIABLE	AREAS WITH HIGHEST SCORES	AREAS WITH LOWEST SCORES
GROUP 9					
1	19.4	+0.98	TOTAL TRANSIT VEHICLES	MINNEAPOLIS	
		+0.97	POPULATION		
		+0.97	PROJ. INCREASE IN PRINCIPAL ARTERIAL RT.MI.		
		+0.95	AREA		
		+0.95	PROJ. RT. MI. - FWYS.		
		+0.94	No. INC. CITIES		
		+0.91	PROJ. PRINCIPAL ARTERIAL DVMT		
		-------	------------------------------		
		(0.68)	(NEXT HIGHEST LOADING)		
2	19.2	-0.88	% FRINGE COMMUTING	ALBUQUERQUE	DULUTH
		+0.83	PROJ. PRINCIPAL ARTERIAL DVMT/CAPITA	NEWPORT NEWS	UTICA
				TUCSON	
		-------	------------------------------		
		-0.78	% POP. > 64 YRS.		
		-0.77	AGE OF CENTRAL CITY		
		+0.75	MEAN JAN. TEMP.		
		-0.73	% CENTRAL CITY HOUSEHOLDS WITH NO AUTO		
		+0.72	PROJ. PRINCIPAL ARTERIAL DVMT/ ROUTE MILE		
		+0.70	% HOUSING SOUND		
		-0.69	% WORKERS WALKING		
		+0.68	% POP. < 18 YRS.		
		+0.67	% SINGLE - UNIT HOUSING		
		-0.64	% FRINGE WORKERS USING TRANSIT		
		-------	------------------------------		
		(0.55)	(NEXT HIGHEST LOADING)		
3	12.1	+0.81	POP. DENSITY IN FRINGE	LANSING	DULUTH
		+0.81	% COMMUTING TO CENTRAL CITY	FLINT	TUCSON
				YOUNGSTOWN	WICHITA
		-------	------------------------------		
		-0.76	% POP. IN CENTRAL CITY		
		-0.76	PROJ. % POOR HOUSEHOLDS		
		+0.73	PROJ. % AFFLUENT HOUSEHOLDS		
		-------	------------------------------		
		(0.65)	(NEXT HIGHEST LOADING)		
4	11.6	-0.90	PER CAPITA INCOME GROWTH	WICHITA	NEWPORT NEWS
		-------	------------------------------		
		-0.72	PERSONS / HOUSEHOLD		
		-------	------------------------------		
		(0.66)	(NEXT HIGHEST LOADING)		
5	10.6	-0.81	AUTOS / FAMILY	NEWPORT NEWS	ALBUQUERQUE
		+0.81	AVG. EMPL. / MFG. EST.	FLINT	TUCSON
		-------	------------------------------		
		-0.74	% WHITE COLLAR		
		-0.74	SERVICE RECEIPTS / CAPITA		
		+0.70	% NON - WHITE		
		-------	------------------------------		
		(0.59)	(NEXT HIGHEST LOADING)		
6	8.2	-0.86	NONWORKER - WORKER RATIO	MADISON	YOUNGSTOWN
		+0.82	% MARRIED WOMEN WORKING		DULUTH
					TUCSON
		-------	------------------------------		
		(0.55)	(NEXT HIGHEST LOADING)		

relevant to the affluence of the community. Because the metropolitan areas comprising group 7 are thus differentiated in terms of variables related to affluence, such variables should be employed in extending system size, cost, and impacts from the case study results to the remaining metropolitan areas in group 7.

Those variables, or consistent sets of variables, that may appropriately be considered for inclusion in the case study sensitivity analyses (and thus in the process of extrapolating case study results) are identified in Figure 10 relevant to the various groups and factors. One criterion for inclusion is that the variable should be heavily loaded onto the indicated factors; a second criterion is that assumed changes in a variable should be meaningful in the context of the transportation planning process. Thus, while an assumed variation in nonworker-to-worker ratio might be interpreted in terms of revised distributions of travel by peak hours and trip types, the effects of an assumed change in mean January temperature would be more difficult to handle in the planning process, and the latter variable is not included in the list of Figure 10.

The information in Figure 10 is one possible set of guidelines for the structuring of case studies and sensitivity analyses. Thus, in the example for group 7, appropriate and consistent assumptions would be made concerning changes in the affluence-related variables (percent housing sound, median housing value, per capita income, projected mean household income, and projected percentages of both poor and affluent households). The assumed new variables would be loaded onto the 6 factors identified through the factor analysis process for group 7 such that the true case study area and the assumed more affluent version of the case study area are 2 distinct points in the 6-dimensional space defined by the factors (and with the imposed deviation within that space primarily along the direction of factor 2). Consistent adjustments would then be estimated in trip generation rates, modal split effects, right-of-way acquisition costs, perceived value of time, etc., in the transportation planning and evaluation process so as to yield modified estimates of system size, cost, and impacts. This process would be repeated for additional sets of variables (so as to produce deviations along other directions in the factor space and to result in additional estimates of size, cost, and impacts), as planning resources may permit and with priority directed toward factors of higher rank.

The desired sensitivity measurements would then be estimated as partial derivatives of the functions (system size, cost, impacts) at the point defined by the case study area

Figure 10. Variables for inclusion in case study sensitivity analyses.

VARIABLE	RANK ORDER OF FACTOR							ASSOCIATED VARIABLE TYPE*
	GROUP 3	GROUP 4	GROUP 5	GROUP 6	GROUP 7	GROUP 8	GROUP 9	
POPULATION	4	1	-	1	1	1	1	SIZE (VAR. NO. 1,2,3,5,45)
PROJ. MEAN HOUSEHOLD INCOME	1	2	-	3	2	-	-	AFFLUENCE (15,18,19,21,22,23)
PROJ. % POOR HOUSEHOLDS	1	-	1	3	2	-	3	AFFLUENCE (15,18,19,21,22,23)
% NON-WHITE	3	-	6	2	-	2	5	-
% CENTRAL CITY HOUSEHOLDS WITH NO AUTO	3	6	-	4	1	-	2	-
% POP. > 64 YEARS	-	2	6	2	4	-	2	LIFE CYCLE (12,13,14)
PERSONS/HOUSEHOLD	1	2	-	-	-	3	4	LIFE CYCLE (12,13,14)
POP. DENSITY IN CENTRAL CITY	2	-	-	-	1	-	-	DENSITY-TRANSIT USE (9,16,34,35,38)
% CENTRAL CITY WORKERS USING TRANSIT	2	1	4	-	1	-	-	DENSITY-TRANSIT USE (9,16,34,35,38)
NONWORKER-WORKER RATIO	-	3	2	-	-	2	6	LABOR FORCE PARTICIPATION (25,26)
% MARRIED WOMEN WORKING	1	3	-	-	3	2	6	LABOR FORCE PARTICIPATION (25,26)
% GROUP QUARTER HOUSING	-	2	2	5	5	-	-	-
POP. GROWTH FACTOR	3	5	-	5	-	-	3	GROWTH RATE (7,46)
% CHANGE IN PRINCIPAL ARTERIAL DVMT	3	5	4	-	-	1	-	GROWTH RATE (7,46)
% COMMUTING TO CENTRAL CITY	1	4	2	-	-	3	3	
% FRINGE COMMUTING	3	4	6	-	-	-	2	

* - VARIABLES, IN GENERAL, WITH SIMILAR LOADING VALUES. SEE FIGURE 9 FOR SPECIFIC RELATIONSHIPS ON FACTORS. SEE FIGURE 2 FOR INDEX TO VARIABLES

in the directions defined by the orthogonal factors. The estimation of system size, costs, and impacts in the additional metropolitan areas in group 7 would then follow through the knowledge of the location of those metropolitan areas relative to the case study area in the factor space (based on known values of the variables and the factor loadings) and the estimated value of the partial derivatives of system size, cost, and impacts.

The foregoing process of case studies, sensitivity analyses, and extrapolation of results would be accomplished for each of the groups 3 through 9. For the three metropolitan areas comprising groups 1 and 2 (i.e., New York, Chicago, and Los Angeles), it is suggested that individual case studies be performed if the system under study is considered applicable to those locales. Overall costs and impacts, and the likely market for the new system, are then estimated by summation over all groups; Canty and Golob (18) discuss the methodology of such aggregation processes.

DIRECTIONS FOR FURTHER RESEARCH

The research framework discussed in this paper contains features that are new to the urban transportation systems requirements analysis, planning, and evaluation process, including

1. A procedure, and selected results, for the classification of metropolitan areas into groups, each of which is relatively homogeneous in regard to a multiplicity of metropolitan area characteristics relevant to a perceived transportation need (rather than with respect to just 1 or 2 such characteristics), plus a companion procedure for the identification of the most representative metropolitan areas within each group as preferred locales for case studies; and
2. A procedure, in outline form with statistical guidelines, for the extension (extrapolation) of case study results to other metropolitan areas, taking into account the influence of a number of metropolitan area characteristics.

Although the classification and extrapolation procedures are compatible and complementary, each is of value independent of the other. Thus, metropolitan areas could be stratified on the basis of size alone, with case study results being extrapolated on the basis of several characteristics as in procedure 2 above. Also, metropolitan areas could be classified into homogeneous groups as in procedure 1 above and results extrapolated on the basis of a single variable (e.g., population size). The latter approach has much appeal in terms of minimizing level of effort, inasmuch as the classification procedure needs to be performed only once for each type of application (e.g., urban arterial transportation) while the extrapolation process must be repeated for each and every case study (i.e., each combination of metropolitan area group, system requirement, and system design).

The approach most often used currently, where metropolitan areas are stratified by a single variable—population size—and where case study results are simply scaled to other metropolitan areas on the basis of population, is much less likely to yield valid results. The fact that each group is made as homogeneous as possible with regard to population size and not with regard to other factors minimizes the usefulness of population size as an extrapolating factor. When metropolitan areas are classified, as in procedure 1 above, into groups that are relatively homogeneous with regard to a host of variables, extrapolation of case study results on the basis of size should become more valid.

These considerations lead to the following directions for further research:

1. The procedure for classification of metropolitan areas into homogeneous groups could be repeated for additional urban transportation applications (including transportation for the young, old, poor, handicapped, and other mobility-deprived members of urban society, and medical, education, and housing system studies) and with appropriately different data bases (different variables and possibly levels of urban structure other than the metropolitan scale).
2. A consensus could be reached among governmental, university, and industrial research groups on a consistent classification of metropolitan areas in order to maxi-

mize the usefulness of data bases and to integrate the results of numerous ongoing system requirements analysis, design, and evaluation studies in transportation and other urban systems.

3. Planning groups concerned with the task of estimating overall markets or costs-benefits-impacts of new system development and implementation based on analyses and demonstrations in case study areas should consider the processes outlined in this paper as a basis for case study selection and extrapolation of results.

4. The procedure outlined in this paper for the conduct of sensitivity analyses and the extrapolation of case study results could be performed, at various levels of complexity (i.e., for 1, 2, 3, or more sets of variables) in order to analyze and evaluate the cost-effectiveness of the procedure, that is, the necessary level of effort versus the degree of difference in the results (estimated system size, cost, and impacts).

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METHOD FOR DEVELOPMENT OF A MASS TRANSIT EVALUATION MODEL BASED ON SOCIAL SYSTEM VALUES

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This paper describes a method in transportation systems engineering that provides a means of identifying the customers, or decision-makers, and their wants. The method was developed and applied to the hypothetical example of a peoplemover for downtown Los Angeles. The approach couples the methodology of systems engineering with utility theory and survey techniques. It includes steps to identify needs, characterize systems, establish performance criteria, identify decision-makers and their criteria, identify the implementation process, and generate the evaluation model. In the example, 4 basic groups of decision-makers were identified: government technicians, government managers and public officials, local businessmen, and potential riders. Questionnaires, tailored for each group, provided weightings of the decision-maker's influence, delegation of responsibility, criteria from the general down to the component level, and utility data points for all significant component criteria. Results were formulated into a composite value model that was used to generate both a tabular and a computerized evaluation model based on corresponding performance criteria and measures. The method provides identification of the social system decision-makers, their needs and influence, and a meaningful correlation and translation into technical criteria. The research shows the effectiveness of utility curves both as a quantitative measure of performance for a given criteria and as a means of combining worths of multidimensional criteria.

•THE DISTINGUISHING characteristic of a social system, such as mass transit, is by definition its intimate involvement with people, or, more specifically, the existence of a complex, multiple customer. This paper summarizes a method, developed during research for a dissertation in the field of transportation systems engineering, that provides a means of identifying these customers (or decision-makers) and their wants during the implementation process and provides results that can be meaningfully translated into technical terms.

The objective of the research was to develop and demonstrate a model for evaluating mass transit systems that bridges the communication gap between social systems decision-makers and technical systems designers. In other words, the model was intended to convert the criterion of public acceptance to that of technical design. The results are intended to be useful both to those responsible for writing specifications and evaluating subsequent proposals and to those responsible for design and optimization of mass transit systems. Complete results are described elsewhere (1).

Two references provide basic inspiration and a point of departure. The first, by Lifson (2), applies utility and decision theory to system evaluation and establishes the validity of incorporating weighted sets of a single decision-maker's technical utility curves for pertinent design criteria into a value model.

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Utility theory has been the subject of study by economists for more than 200 years and is beyond the scope of this paper for detailed discussion. In brief, economists have established that there exists for individuals a variable quantity, i.e., utility, associated with a quantity of money or other commodities that can be quantitatively measured and formulated on an interval scale; further, that an informed, rational individual will select the alternative that maximizes expected utility in accordance with his expressed preferences.

This concept of incorporating utility curves into a value model has been adopted here; it represents a powerful tool, in that it provides both a quantitative measure of the worth of varying degrees of performance on a given criteria as well as a means of combining on a common reference base the worths of multiple criteria possessing diverse measures of performance. In other words, it is a way of measuring both the desirability of a given apple as well as its worth in comparison with a given orange. Justification of application of utility theory to social systems is provided by Engel (3), who states that consumers do make decisions in a structured way that can be at least partially predicted and that the behavioral motive of maximization of utility is a reasonable approximation. Further, Thiel (4) indicates that, if this is so, the social system utility function will be a linear combination of individual functions.

The second reference basic to this method, by Pardee (5), provides a study of the measurement and evaluation of total transport system effectiveness. This study introduces the ideas of trying to understand the major objectives of all groups affected by transport change, the hierarchical ordering of criteria, and the concept of evaluating potential utility.

A key aspect of the method is the reliance on survey information, based on the belief that the complex of social system decision-makers are able and willing to express their criteria for a system. Thus, direct inputs from the social system are required—not the analyst's estimates or guesses, but the real thing. To provide these inputs a hypothetical example, a people-mover for the downtown Los Angeles area, was postulated, and the informal cooperation of city government officials, employees (from the executive level down to file clerks), and businessmen was solicited and received. Results of research with this example will be summarized. Because of its informal nature, this must be looked on as a pilot study; however, it performs the useful functions of providing initial data for the value model and trying the procedures required by the evaluation method in the real world.

METHOD

As shown in Figure 1, the method requires a series of steps or tasks to be conducted. The first step, identify needs, provides input data for both step 2 and step 4. The second step, characterize systems, establishes the kinds of transport systems that can satisfy the needs and characterizes them by their functional elements. With this information, step 3, establish performance criteria, is accomplished by determining which technical and economic criteria and measures are appropriate estimators of performance. Step 4, identify decision-makers, is placed at the same level as step 1 to indicate that it may be started concurrently. When the types of decision-makers and the kinds of systems involved are established, step 5, establish decision-makers' criteria, may be conducted. Iterating with this information will permit accomplishment of step 6, establish decision-makers' value models. In step 7, generate a composite decision-makers' value model, the individual group value models are combined, and one composite value model is established. In step 8, relate decision-makers' criteria to technical criteria, the transfer from decision-maker language to technical language is accomplished. With this complete, the decision-makers' composite value model may be interpreted in technical terms and step 9, generate evaluation model, accomplished. A discussion of these steps is given in the sections that follow.

Identify Needs

The general tasks in step 1 are to establish the needs, identify the governmental bodies and funding options involved, and establish the external constraints or environment. Specific tasks include formulation of a listing of requirements—essentially a "shopping list" or preliminary specification; establishment of routes and ridership demand projections; development of an initial list of appropriate government agencies, departments, and points of contact; and establishment of system interfaces.

These tasks were greatly simplified for the hypothetical example of a people-mover in downtown Los Angeles by the availability of a document prepared for the guidance of public and private agencies by the Transportation Committee of the General Plan Advisory Board (6).

For this example, present system interfaces are with the freeways and with sidewalks and building access. A system of peripheral parking structures and people-mover stations located at the freeway off-ramps would appear to provide excellent systems integration. Planning for the future would include interfacing with a proposed second-level pedestrian-way system and with a line-haul rapid transit system.

Characterize Systems

The object in step 2 is to characterize systems by constituents, so as to remain independent of specific designs or concepts. This has been done for people-movers in Figure 2. The terminology of "system," "subsystem," and "component" has been adapted to aid in a hierarchical ordering by increasing level of detail. This provides a consistent methodology that may be paralleled in developing decision-maker criteria; it will also serve later as a vertical framework on which to add horizontally technical and economic criteria and then an integration with the decision-maker value model. It may be seen that the first level serves to characterize the major elements that constitute the people-mover system. Although service and management/operation are not elements of hardware, they need to be treated at the same level as hardware-type elements. The subsystem level provides the next breakdown of elements, serving both to identify available choices and to categorize at greater level of detail. The component level brings us to the final and greatest level of detail.

Establish Performance Criteria

Technical and economic performance criteria, influenced by environmental, physiological, and socioeconomic criteria, would normally form the basis for development of a rational, technical decision-maker's value model. Here they are but one step along the way. The criteria and their measures are listed in a form that parallels the hierarchical ordering of Figure 2 and are primarily assigned at the component level; this seems proper because it is only at this level of detail that a technical specification can be written. A partial sample for the vehicle system is given in Table 1. In contrast to a technical decision-maker's value model, ranges of acceptable values are not assigned here; they will be determined by the social system decision-makers' value model. When technical criteria and/or measures are not readily apparent, assignments are deferred to the decision-makers.

Identify Decision-Makers

Step 4 includes determination of the identity of the social bodies involved plus their influence, or weight, and requires synthesizing or charting the implementation process. Both steps 4 and 5 embody an iterative, gradually expanding process of establishing personal contacts with members of the decision-making agencies, where both direct information and referrals are obtained. The process as it evolved in the hypothetical example should be typical of that for any major city.

Although the task appears formidable at the start, organization relationships are usually available that significantly reduce the problem. In the example, one such organization was the Transportation Committee of the General Plan Advisory Board, an active group meeting weekly that consists of technical staff members of all city agencies concerned with transit planning. Another, the General Plan Advisory Board, a chartered group required to pass upon all major city planning, consists of the managers (or their assistants) from all major departments. It includes all the agencies represented on the Transportation Committee plus several others. These two organizational

Figure 1. Evaluation model for mass transit.

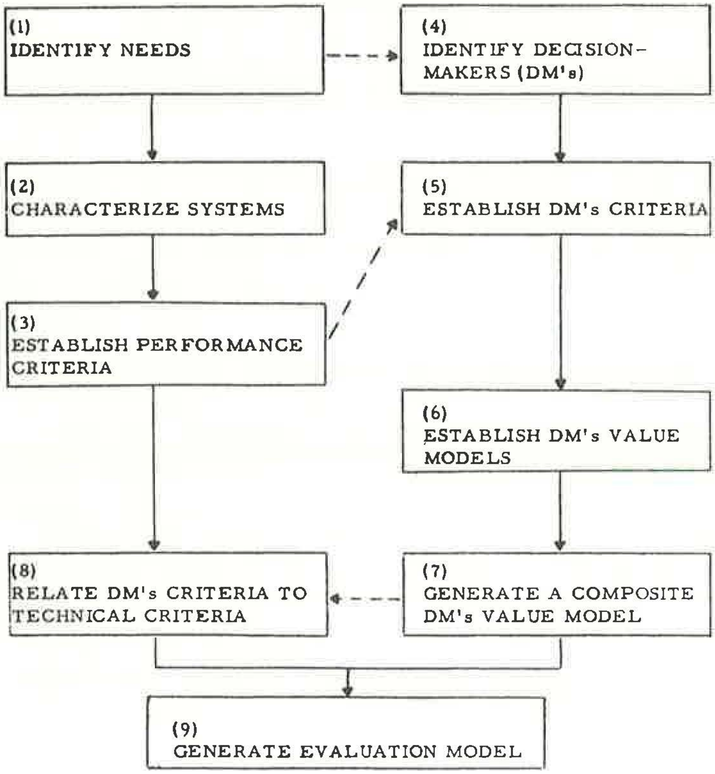
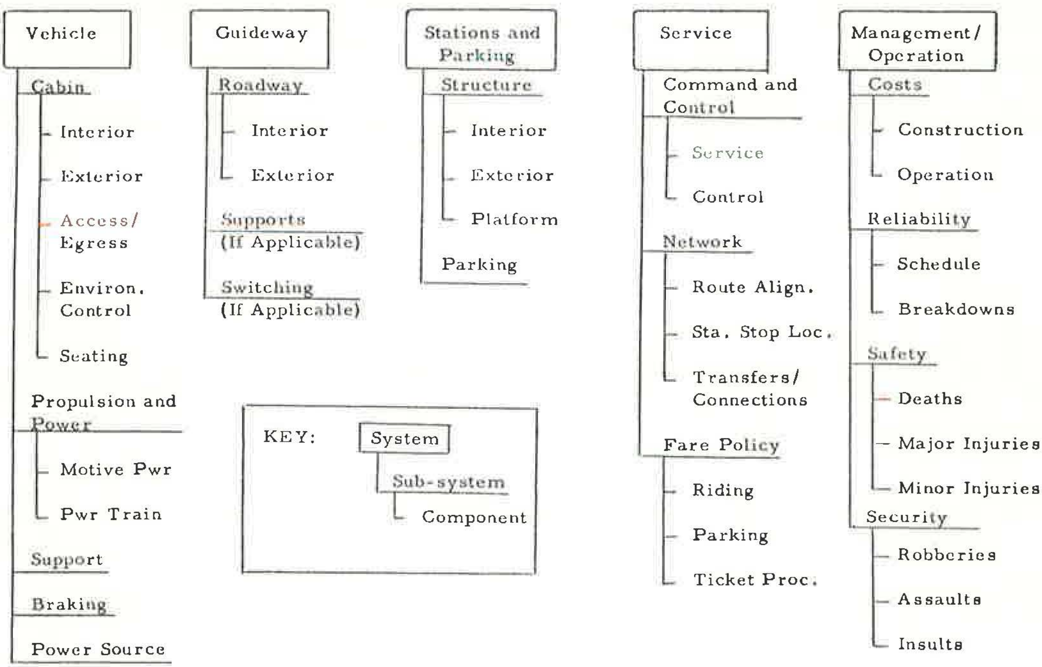


Figure 2. Systems characterization.



relationships significantly helped to make this task tractable, the first as a gathering point of the technicians involved in transit planning and the second as a gathering point of executive approval of transit planning. The Transportation Committee is thus a working, technical arm of the General Plan Advisory Board and a perfect entry point into the implementation process. From the committee it was possible to branch out into contacts with all pertinent agencies on the board and to related city council and public committees. Cooperation at all points of contact in this study was received without official endorsement, and the amount of thought and time freely given attests to the worth of the results. This voluntary cooperation also attests to the acceptability of the procedure to the social system decision-makers.

It became apparent that 4 basic groups of social system decision-makers existed: the technicians (i.e., Transportation Committee and other agency staff members), the government officials (councilmen, board chairmen, department managers, etc.), local businessmen and property owners (this being a downtown business district, residents were not significant), and riders (primarily employees and shoppers). Just as a thread of relationships was found to exist between various city agencies, a similar arrangement was found in the business community. Identification of these 4 basic groups of decision-makers pointed the way to establishment of a survey methodology consisting of 3 distinct approaches and associated questionnaires (the approach to the officials also served in slightly modified form for the local businessmen). A straightforward approach is used in determining decision-maker influence weights by simply asking them. Therefore, the technicians and government officials were asked to weight on a scale of 0 to 10 the importance in the process of implementing the project of various groups and organizations (including their own). There was no problem of reluctance by the participants to answer (anonymity was promised, however). Results were remarkably consistent, both within the 2 groups and between them.

The final product included both a flow chart of the implementation process (unfortunately, too detailed for clear reproduction here) and identification and weighting of the decision-makers, Table 2. Some 23 discrete bodies were identified. The weights given in the table, normalized to a base of 10, were aggregated and applied to the criteria in the next step.

Establish Decision-Makers' Criteria

An initial hierarchical chart of criteria is prepared for incorporation into questionnaires. The object is to be inclusive and to decompose criteria from the general level into the specific to a level where they may be converted to measurable technical performance and to obtain weightings at each level. In parallel with the designations for the system elements of system, subsystem, and component, these criteria levels are designated general criteria, subcriteria, and component criteria. Using the hierarchical ordering of Pardee (5) as a starting point, modifications were made to account for a difference in philosophy regarding multiple use of the same criteria and to clarify terminology for the social system's decision-makers. The resulting criteria and ordering were to be verified by direct questioning of the decision-makers. The final result provides the basis for derivation of value models in the next steps.

As an example of ordering to increasing level of detail until a measurable level is attained, Figure 3 shows the breakdown for convenience. It may be seen that neither the general criterion, convenience, nor the first of its subcriteria, schedule (convenience), possesses measurable quantities to which degrees of value, or worth, may be assigned; the component of schedule, rush-hour frequency, can, however, be readily evaluated in terms of waiting time, ranging from zero (or on demand) upward. At this level, the decision-maker is asked to weight, on a 0 to 10 scale, the value to him of given lengths of waiting time and a utility curve obtained. Criteria presented in the questionnaires in this form are self-explanatory because lower levels serve to explain the higher levels. It is important to make every effort to include all appropriate criteria at all levels. Superfluous criteria will drop out automatically by receiving low weights from the decision-makers. Similarly, criteria placed at a lower level than they should be will automatically receive higher weightings equivalent to their proper level.

Validity of survey results was ensured by using the scaling rules set down by Torgerson (7) in the questionnaires: First, stable estimates of the scale values can be obtained via repeated judgments (over multiple judges); second, the origin and the unit of measure are specified. Responses of subjects within the groups were combined using the mean of ratings assigned. Questionnaires are developed and tailored to the type of decision-maker with respect to method of application, size, content, and terminology. In the study, all groups were questioned on weightings of general criteria, government and business officials were permitted to indicate delegation of lower level criteria (a proper and useful reduction of effort), and both technician and rider questionnaires (300 copies distributed to city employees as representative riders) carried the questioning process down to the lowest levels of detail. The resulting master chart of decision-maker criteria is shown in Figure 4. Weightings of relative importance on a 0 to 10 scale were obtained at all levels—general criteria against each other, subcriteria relative to each other for given general criteria, etc. Although these criteria were established for the specific transit mode of people-movers, they should generally apply to most forms of mass transit.

Establish Decision-Makers' Value Models

Before proceeding, a few definitions are in order. A value model is defined by Lifson (2) as a representation of the value system that motivates the design effort. Lifson defines utility as the scalar measure of relative contribution to success. The objective function in an evaluation model may be considered simply as an aggregation of weighted utility functions.

The equation for the objective function is essentially a methodical aggregation of weights from each criterion level. These criteria levels are subscripted and weights indicated as follows:

Level	Subscript	Weight
Decision-maker	j	w_j
General criteria	ji	w_{ji}
Subcriteria	jik	w_{jik}
Component criteria	jikl	w_{jikl}

These weights are relative weightings, summing to 1. If $f(y)_{jikl}$ represents a single decision-maker's utility function for the measureable performance of component criterion, the objective function for the composite set of general criteria is given by

$$U = \sum_{j=1}^{m} w_j \left(\sum_{i=1}^{n} \left(w_{ji} \sum_{k=1}^{o} \left(w_{jik} \sum_{l=1}^{p} w_{jikl} \cdot f(y)_{jikl} \right) \right) \right)$$

Results of this step consist of tables of weights and utility points or curves for all key decision-makers and all levels of criteria. Based on the survey of delegation of responsibility, 9 complete sets of such data were assembled for the example. These data are used in the next step.

General Composite Decision-Makers' Value Model

In step 7 the tables of criteria weightings and utility points representing the key decision-makers are integrated into one composite value model representing the social system. Integration is conducted in accordance with the delegations and weightings of decision-makers determined in step 4, the criteria obtained in step 5, and the criteria weightings and utility points determined in step 6.

The composite decision-makers' weights for general criteria are given in Table 3. Results, when arranged on an ordinal scale, agree quite well with those of rider surveys summarized by ABT Associates (8). Composite weights at the subcriteria and component level plus component-level utility curves are given in the original reference.

Table 1. Sample tabulation of technical and economic performance criteria.

Constituent	Technical Criteria	Measures
System: Vehicle		
Subsystem: Cabin		
Component		
Interior		
Windows	Size	Percentage of sides
Material	*	*
Capacity	Capacity	Passengers
Parcel space	Storage volume	Cubic feet per passenger
Exterior	*	*
Access/egress	Doorway dimensions	*
Environment control	Comfort	Temperature, relative humidity
Air	Odor	*
Lighting	Intensity	Average footcandles
Noise	Intensity	Average decibels
Seating	Type	Bucket, bench
	Hip room per passenger	Inches
	Leg room per passenger	Inches
	Direction	Forward, aft, in, out
	Vibration of passenger	g's

*To be provided by decision-makers.

Table 2. The decision-makers and their weights.

Decision-Makers	Weights
Southern California Rapid Transit District Board/Manager	0.589
Southern California Rapid Transit District Technical Staff	0.510
Technical Review Committee	0.467
General Plan Advisory Board	0.485
Transportation Committee of GPAB	0.424
Chamber of Commerce/Central City Association	0.478
Southern California Automobile Club	0.282
City Planning Commission	0.488
Board of Public Works	0.528
Board of Public Utilities	0.374
Municipal Art Commission	0.235
Council Industry and Transportation Committee	0.462
Council Planning Committee	0.548
Council State, County, and Federal Affairs Committee	0.497
Council Finance Committee	0.492
City Administrative Office	0.184
City Council	0.588
Mayor	0.553
State Office of Intergovernmental Relations	0.202
Los Angeles County	0.356
Southern California Association of Governments	0.307
U.S. Department of Transportation	0.580
Public riders	0.371

Figure 3. Hierarchical ordering of convenience.

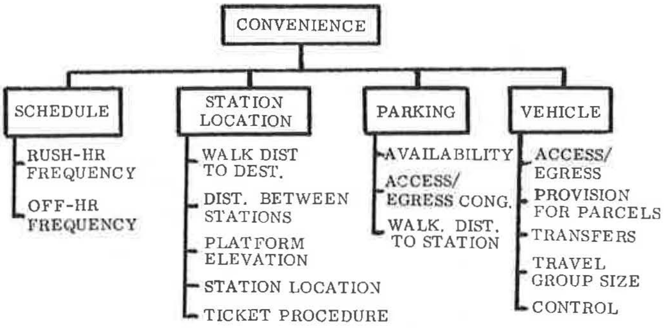


Table 3. Composite weightings of general criteria.

Criteria	Composite Weight
Travel time	0.945
Travel cost	0.808
Convenience	1.033
Comfort	0.827
Safety and security	0.900
Reliability	0.927
Human physiology	0.727
Right-of-way	0.574
Economic	0.808
Metropolitan form and design	0.831
Sociopolitical	0.584
Psychological	0.719
Flexibility	0.273

Figure 4. Master chart of decision-maker criteria.

TRAVEL TIME*
- WALKING
- WAITING
- RIDING

TRAVEL COST*
- PARKING
- RIDING

CONVENIENCE
- SCHEDULE
  - RUSH-HOUR FREQUENCY
  - OFF-HOUR FREQUENCY
- STATION
  - DISTANCE TO DESTINATION
  - DISTANCE BETWEEN STATIONS
  - PLATFORM ELEVATION
  - STATION LOCATION
  - TICKET PROCEDURE
- VEHICLE
  - ACCESS/EGRESS
  - PROVISION FOR PARCELS
  - TRANSFERS
  - TRAVEL GROUP SIZE
  - CONTROL
- PARKING
  - AVAILABILITY
  - ACCESS/EGRESS CONGESTION
  - DISTANCE TO STATION

COMFORT
- RIDE QUALITY
  - ACCELERATION/DECELERATION
  - JERK
  - VIBRATION
  - LINEAR MOTION
- VEHICLE SEATING
  - SEAT TYPE
  - SEAT DIRECTION
  - CRAMPEDNESS
- VEHICLE ENVIRONMENT
  - NOISE
  - AIR CONDITIONING
  - LIGHTING
- PRIVACY
  - SEAT DIRECTION
  - CAR CAPACITY
- AESTHETICS
  - AGE OF CAR
  - CLEANLINESS
  - VIEW
- STATION COMFORT
  - WAITING TIME
  - AESTHETICS
  - CROWDING

SAFETY AND SECURITY
- PERSONAL SAFETY
  - DEATHS
  - MAJOR INJURIES
  - MINOR INJURIES
- PERSONAL SECURIT
  - ROBBERIES
  - ASSAULTS
  - INSULTS
- ANXIETY
  - WHEREABOUTS
  - CONNECTIONS

RELIABILITY
- SCHEDULE
  - % ON-TIME OPERATION
- DELAYS ENROUTE
  - MAJOR
  - MINOR

HUMAN PHYSIOLOGY**
- AIR POLLUTION
- NOISE POLLUTION
- VIBRATION OF BUILDINGS
- ACCIDENTS TO NONUSERS

RIGHT-OF-WAY ASSOCIATED
- PARTITIONING COMMUNITY
- DISPLACEMENTS
- CONSTRUCTION INCONVENIENCE
- PROPERTY VALUES

ECONOMIC
- COST
  - CONSTRUCTION
  - OPERATION
  - TRAVEL COST REDUCTION
- BUSINESS INCOME
- PERSONAL INCOME
- TOTAL JOBS IN AREA
- JOBS ON SYSTEM

METROPOLITAN FORM AND DESIGN
- LAND USE DISTRIBUTION
  - PARKING TO OFFICES
  - PARKING TO PARKS
  - PARKING TO CULTURAL
  - STREETS TO MALLS
- INTEGRATION/FIT
  - STATION LOCATION
  - STATION/GUIDEWAY ELEV.
  - STATION/GUIDEWAY APPEAR.
- POPULATION DISTRIBUTION
  - CHANGE IN RESIDENCY
- TRAFFIC CONGESTION RELIEF
- DESIGN FLEXIBILITY
  - REMOVABLE/PERMANENT
- AESTHETICS
  - STYLE
  - DESIGN

SOCIOLOGICAL – POLITICAL
- INDIVIDUAL LIFE STYLE
  - INCREASED USE PUBLIC FACIL.
  - INCREASED USE CULTURAL FACIL.
- COMMUNITY INVOLVEMENT
  - INCREASED PUBLIC INTEREST
  - INCREASED PUBLIC VISITS
- POLITICAL FEASIBILITY
- INCREASED TAX BASE
- INTEGRATION EFFECTS

PSYCHOLOGICAL
- SOCIAL ACCEPTANCE
  - ACCEPTANCE BY INC. GROUP
  - APPEARANCE
- PLEASANTNESS
- SAFETY AND SECURITY
  - GUIDEWAY ELEVATION
  - VEHICLE APPEARANCE
  - WINDOW SIZE

GROWTH FLEXIBILITY
- LINE EXPANSION
- SPEED INCREASE
- CAPACITY INCREASE

*WITH REGARD TO THE VALUE OF TIME AND MONEY
**EXTERNAL EFFECTS OF SYSTEM

A typical set of utility curves, for travel time, is shown in Figure 5. These curves show the value of utility curves in indicating worth of varying quantities of a given criterion measure. While the weightings indicated only a small difference in worth of the 3 subcriteria, the figure shows that this worth depends on how much time is being considered. ABT Associates discussed research that found that 2 minutes of waiting or walking time is equal to the disutility of 5 minutes of riding time; this is very close to what the curves of Figure 5 show.

Relate Decision-Makers' Criteria to Technical Criteria

The way has been prepared for step 8 by step 2, which characterized the systems hierarchically and provided a vertical framework; by step 3, which established technical performance criteria and added horizontally to the framework; and by steps 5 through 7, which identified decision-maker criteria in a corresponding hierarchy (including conversion of subjective measures to technical measures during preparation of utility curves in the previous step). The construction is completed in this step with the addition and correlation of decision-maker criteria.

As may be seen in Table 4, the correlation is usually obvious. Some decision-maker component criteria are associated with more than one system component; for example, linear motion (a component criterion of ride quality) relates to both vehicle motive power and to support. Matching of a few of these criteria is judgmental. In both instances, placement is not critical; however, inclusiveness of all appropriate criteria somewhere in the matrix is important. (Although double-counting is not a consideration here, it is guarded against in the final step, generation of evaluation model.)

Generate Evaluation Model

The evaluation model is presented in the original reference in 2 forms, tabular and computerized. The tables provide points of worth for corresponding measures of performance, requiring only the addition by an evaluator of columns to rate alternatives under consideration. The points are derived from the weighted utility curves that were related to component criteria in the previous step. Maximum points (i.e., highest points for each criterion) were summed and normalized to a base of 100. Thus, a "perfect" design would receive 100 points of worth. Points of worth for each subsystem and system are obtained by summing maximum points for appropriate components and subsystems respectively. Values for the people-mover systems were as follows: vehicle, 20; guideway, 13; stations and parking, 8; service, 36; and management/operation, 23. The order of importance seems logically consistent.

A small sample portion of the tabular model is given in Table 5. As an example of the table's use, the interior component would be evaluated on the aspects of windows, material, capacity, and parcel space. Window size of a particular design would be compared against the range of sizes given and points assigned accordingly; in a specification, a size resulting in the maximum points would be specified. Some points, such as those for capacity, represent the combination of 2 decision-maker utility curves (in this example, privacy aspects of capacity with convenience aspects of travel group size). Points of worth for the style and design aspects of exterior represent half of the total allocated; the remaining half has been assigned to similar aspects for the guideway. It will be noted that, although some criteria still require judgmental opinion by the evaluator, measures have been provided that serve to confine the judgment within fairly narrow limits.

CONCLUSIONS

The following conclusions appear valid:

1. It has been verified in the application studied that the method provides (a) identification of the social system decision-makers, along with their needs and influence in the process of implementation, and (b) correlation of their criteria with technical performance criteria.

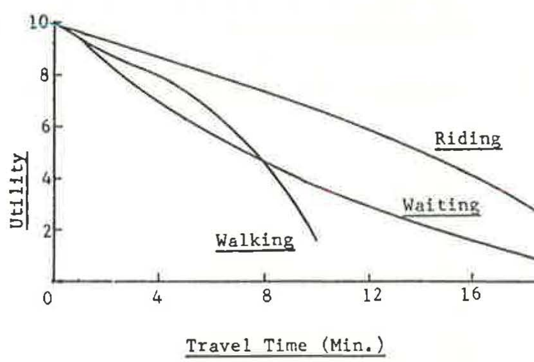
Table 4. Sample of final performance criteria.

			Decision-Maker Criteria							
				Comfort					Metropolitan Form and Design	Psychological
			Convenience							
Constituent	Performance Criteria	Measure	Vehicle	Ride Quality	Vehicle Seating	Vehicle Environment	Privacy	Aesthetics	Aesthetics	Safety and Security
System: Vehicle Subsystem: Cabin Interior										
Windows	Size	Percentage of sides								Window size
Material	Ability to hold appearance	Clean–dirty						Cleanliness		
Capacity	Capacity	Passengers	Travel group size				Capacity			
Parcel space	Storage volume	Cubic feet per passenger	Parcel provision							
Exterior	Style	Old fashioned→modern							Style	
	Design	Simple→complex							Design	
	Appearance of age	Perceived age						Age of car		
	Appearance of weight	Perceived mass								Vehicle appearance
Access/egress	Ease of access/egress	Method of entry	Access/egress							
Environment control										
Air	Comfort	Temperature, relative humidity				Air-comfort				
	Odor	CFM air per passenger				Air-odor				
Lighting	Intensity	Average foot-candles				Lighting				
Noise	Intensity	Average decibels				Noise				
Seating	Type	Bucket→bench			Seat type					
	Hip room per passenger	Inches			Cramped-hip					
	Leg room per passenger	Inches			Cramped-legs					
	Direction	Forward, aft, in, out			Seat direction					
	Vibration of passenger	g's		Vibration						

Table 5. Evaluation model part 1, vehicle cabin.

Constituent	Performance Criteria	Measure	Points of Worth
System: Vehicle			20.079
Subsystem: Cabin Interior			11.080
Windows	Size	<30 percent of side area	0.104
		30 percent of side area	0.428
		40 percent of side area	0.874
		>50 percent of side area	0.394
Material	Ability to hold appearance	Spotless	0.672
		Clean but discolored	0.463
		Discolored and dirty	0.088
Capacity	Number of passengers	1 passenger	0.350
		2 passenger	0.405
		4 passenger	0.685
		8 passenger	0.583
Parcel space	Storage volume per passenger	0 cubic feet	0.231
		2 cubic feet	0.473
		4 cubic feet	0.234
Exterior	Style	Old fashioned	0.030
		Modern	0.674
		Futuristic	0.244
	Design	Simple	0.674
		Average complex (auto)	0.380
		Complex	0.068
	Appearance of age	New	0.379
		<2 years	0.334
		<4 years	0.279
		>4 years	0.208
	Appearance of weight	Massive	0.601
		Like auto	0.670
		Light weight	0.838
		Flimsy	0.231
Access/egress	Ease of access/egress	Duck	0.457
		Duck and slide over	0.330
		Enter erect	0.880

Figure 5. Utility of travel time.



2. The effectiveness of utility curves as both a quantitative measure of performance value for a given criterion and as a means of combining worths of multidimensional criteria has been shown.

3. Although initiation of a mass transit system may in many, if not all, instances be a political decision, the method of evaluation described here can help to guide this decision. Further, the method should enhance potential for implementation—i.e., the potential for completion of the system from planning to financing to public approval and use—by ensuring that the final system design meets the weighted needs of the social system decision-makers.

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