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

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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

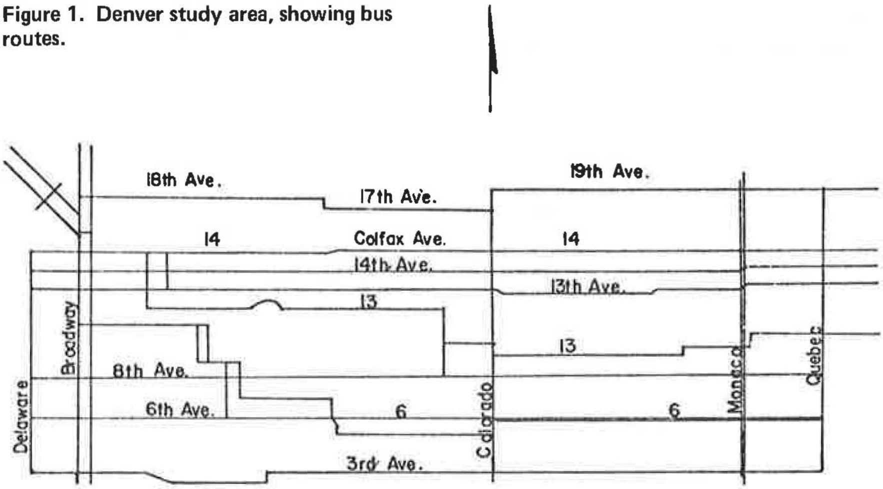

Figure 1. Denver study area, showing bus routes.

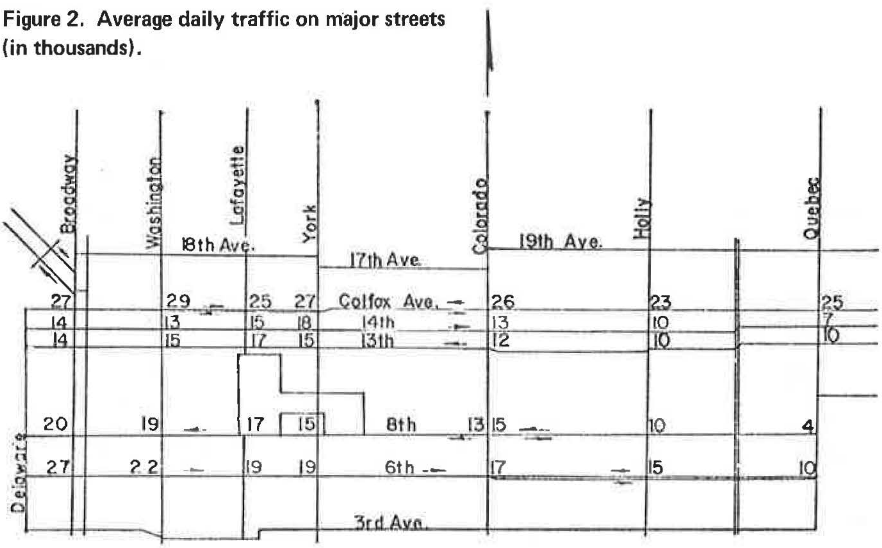

Figure 2. Average daily traffic on major streets (in thousands).

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.

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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.

No Postage Stamp Necessary If Mailed in the United States

Postage Will be Paid by Addressee

BUSINESS REPLY CARD

FIRST CLASS PERMIT No. 4679, Denver, Colo.

University of Colorado, Denver Center
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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.

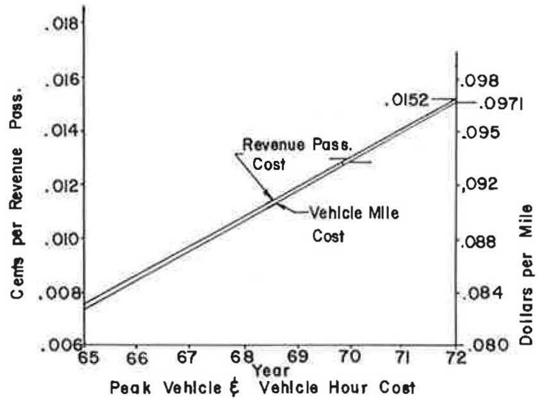


Figure 5. Peak-vehicle and vehicle-hour costs.

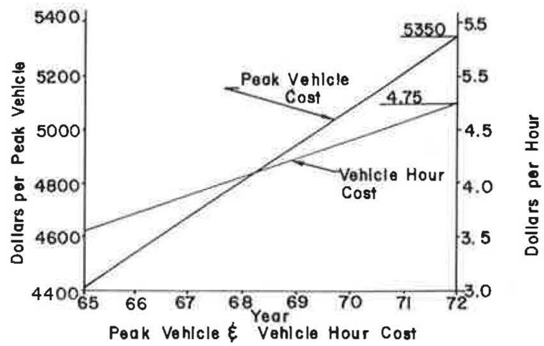


Table 2. Variables used in calculating costs.

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.

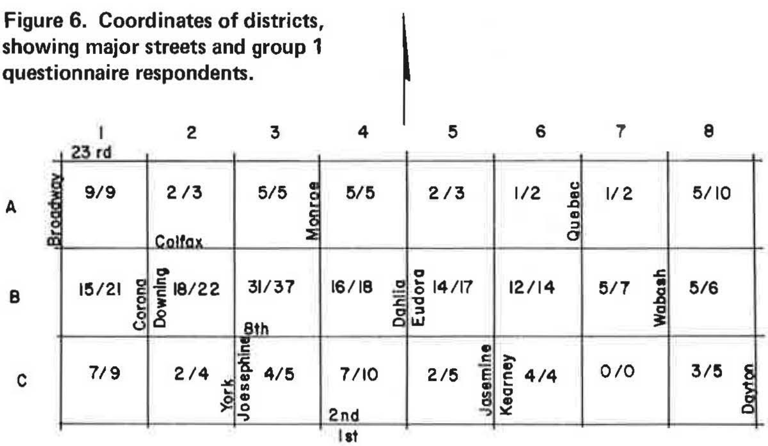


Table 4. Traffic volumes in study area.

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).

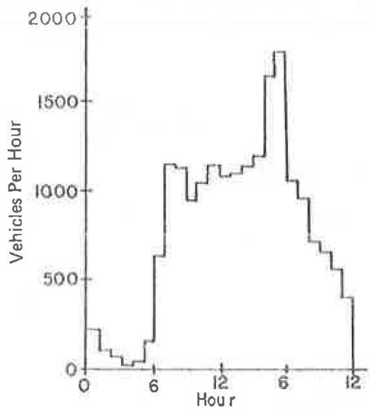


Figure 8. Average weekday vehicles per hour on 8th Ave. (without Grant).

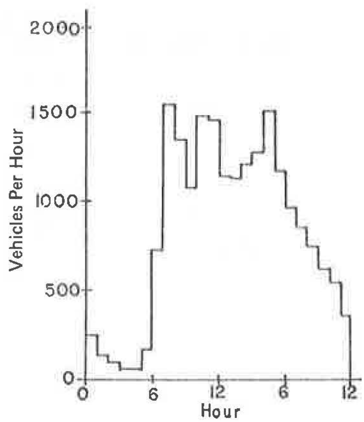


Figure 9. Average weekday vehicles per hour on 13th Ave. (without Colorado).

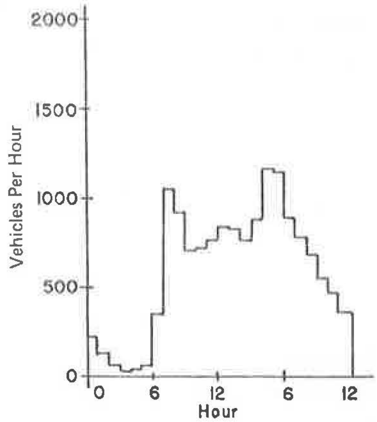


Figure 10. Average weekday vehicles per hour on 14th Ave. (without York).

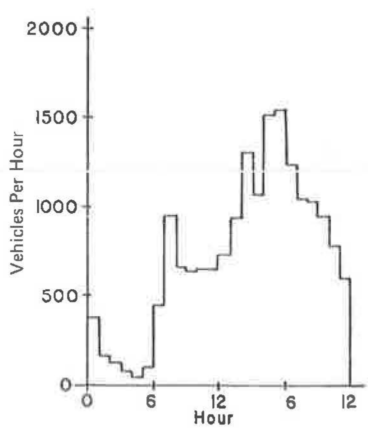
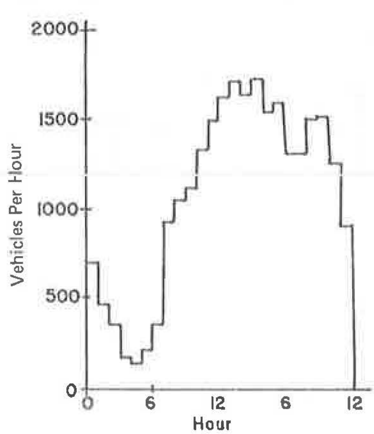


Figure 11. Average weekday vehicles per hour on Colfax Ave. (without Franklin).



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 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		Route 13		Route 14	
	Headway	Wait	Headway	Wait	Headway	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]	District Vertical Coordinate[a] A		B		C	
	Peak	Off-Peak	Peak	Off-Peak	Peak	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	—	—	—	—

[a]See coordinates in Figure 6.

Table 10. Passenger-hours for new passengers.

District Vertical Coordinate[a]	District Horizontal 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

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.

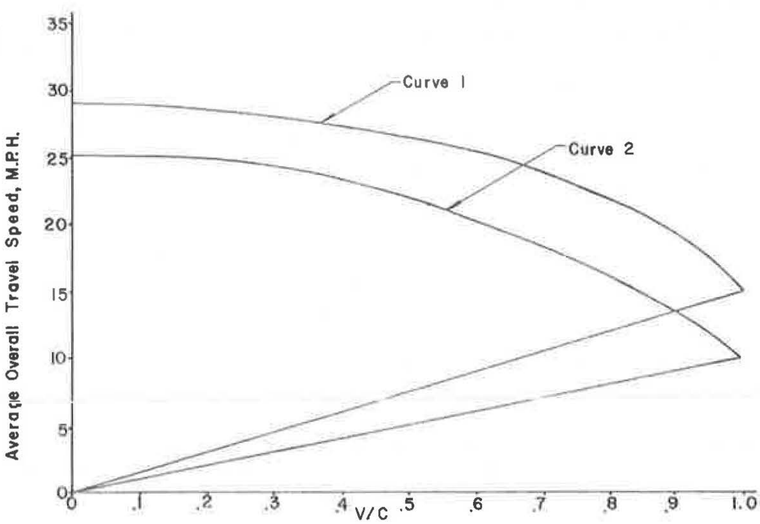


Figure 13. Comparison of hourly volumes.

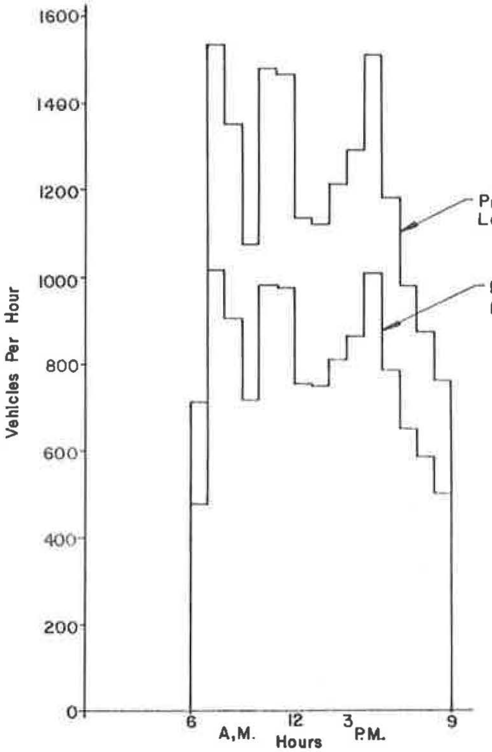


Figure 14. Comparison of travel times on 8th Ave. east of Broadway.

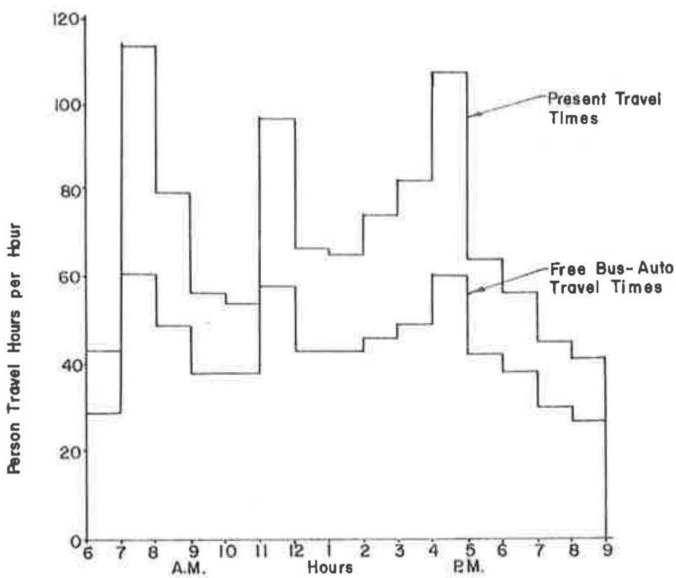


Table 11. Auto travel time (vehicle hours per hour) by segment.

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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