

EVALUATING TRANSPORTATION FACILITY ARRANGEMENTS IN URBAN AREAS:

A BALANCED LEVEL OF SERVICE APPROACH

by

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Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Civil Engineering

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May, 1972

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ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Urban Mass Transit Administration for sponsoring the research performed for this study.

Special thanks are extended to his committee chairman, Dr. Jason C. Yu, who offered valuable assistance and advice throughout the duration of the project.

The author also wishes to express his gratitude to his typist,
 , for her patience, and to all friends and faculty
who made his stay at Virginia Polytechnic Institute and State
University an enjoyable one.

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I. INTRODUCTION

Background

Travel in urban centers, especially during peak periods, is characterized by a large magnitude of person trips concentrated in a relatively small area. Such a situation has been the result of historical urban development since growing population and urbanization have combined to make urban centers the major focal point of activity. Unfortunately, the urban transportation system has, in general, been unable to fully keep abreast of the rising demand for its facilities. The net result has been excessive delay and inconvenience to the users of those facilities comprising the transportation system.

Two classes of transportation system facilities exist: (i) highway system facilities including those modes which use the road network as a guideway, and (ii) transit systems which use other guideways. The major physical facilities comprising the roadway system include:

1. Roadways and intersections
2. Parking facilities
3. Toll facilities

For an existing urban transportation system a definite number of roadways and intersections with fixed capacities exist. These capacities collectively comprise the roadway network supply. As vehicle volumes approach the capacity of a roadway or intersection, the level of service provided by the facility decreases. Eventually a congested situation characterized by unstable vehicle flow arises.

To reduce congestion, several types of improvement tactics may be implemented. These include:

1. the addition of new street space
2. the update of traffic flow regulation
3. the introduction or expansion of mass transit facilities

The expansion of network capacity through the addition of more street space is most widely practiced where rights-of-way can be obtained with minimum disruption and economic feasibility. In many urban areas, however, such rights-of-way are at a premium. Even when they are obtained and developed, the better service provided by the added capacity tends to induce more tripmakers to switch from transit to their own vehicles. Thus, over the long run, congestion relief obtained in this manner diminishes. This phenomenon is also true to a lesser extent for operational improvement schemes. By their nature, these schemes attempt to increase service by introducing roadway markings and intersection signalization which can better handle the existing traffic flows. Although such tactics require relatively small expenditures when compared to the other improvement schemes, their overall effect on service can seldom be as pronounced. The final service improvement tactic, mass transit implementation, relieves congestion by reducing vehicle volumes on the network. This can provide effective long range reductions in congestion if the service provided by the transit mode is competitive with that of other modes. Such a stipulation must be met in order to insure a ridership which will cover the operating and initial capital expenses of the transit mode.

Before the actual implementation of new facilities is performed, it is desirable to test various arrangements blending existing and added facilities to determine the arrangement offering the best level of service. For an existing urban transportation system, this would require the evaluation of varying combinations and degrees of the aforementioned improvement schemes. On the other hand, in the case of new towns, this would require the testing of different configurations for both levels of service and roadway utilization. The latter term indicates the extent to which available street space is being used. In a planned area such as a new town, utilization can be controlled since the roadway network configuration and capacity have not already been defined.

Whether an existing area of new town is being considered, it would be most desirable to find the optimum arrangement of new facilities based on some evaluation criteria. Such a result would require the inspection of a great many alternative arrangements.

Speaking in a general systems sense, optimization requires the determination of steady state conditions which either minimize or maximize a function which relates them. For the specific case of arranging transportation facilities in urban centers with predicted travel demand, optimization requires that the distribution of facilities be such that individual facilities have constant demand while all facilities when combined offer the best level of service. The requirement for constant demand of transportation facilities is that the entire urban system be balanced. That is, no alternative facilities are more attractive to a user than the ones he presently uses. Therefore, to have a balanced system, it is necessary to balance level of service.

Balanced level of service is a two-dimensional concept. One dimension relates the service provided by the various modes used in the system. The other dimension relates the service among alternate routes. The two dimensions are themselves interrelated since the performance of one will affect the service of the other. For example, the travel times offered by a set of routes will influence the number of auto and transit trips whereas the modal split will affect the travel times due to the volumes they produce. Therefore, the balance point occurs when both dimensions provide balanced service individually and collectively.

If a balanced system is not provided, travel patterns will consistently fluctuate. This instability will occur because users will be attracted to those facilities which provide better service. Eventually, as the demand for these facilities continues to increase, service levels for other facilities will improve until they become more attractive. This will result in another shift until better service is provided elsewhere, and the process is repeated. Oscillations of this nature have negative effects. Primarily, they will cause an unnecessary over-utilization of some facilities causing overall system level of service to be less than might be achieved if the system was balanced. Over time, fluctuations may decrease as users adjust to conditions. However, the improper placement of new facilities can disturb the system and reinitiate the process.

Objectives

The goal of this study was to develop a process which would evaluate the service provided by balanced arrangements of facilities implemented into the systems. Through the application of this process, the scheme yielding the facility arrangement which offers the best service can be determined. The criteria chosen for evaluation was total community transportation costs. Such costs include user costs, and, in some cases, operating and utilization costs. The primary objectives of the study were:

1. to determine through research the variables required to characterize facility and demand and modal operating capabilities
2. to develop models for balancing service and computing community transportation costs for urban transportation systems
3. to develop a computer program which incorporates these models to determine balanced facility arrangements and to evaluate the resulting levels of service.

Scope

In order to perform conclusive research within the bounds of time and depth constraints, this study dealt only with peak hour conditions in urban areas. Since peak hours are the times during the day when

person trip movements are the greatest, it was felt that they would require the most immediate and stringent policies for reducing congestion.

Another restriction was that the study considered only roadway system oriented facilities. Of these facilities, bus service was taken as the most favorable form of congestion relief. Therefore, the major emphasis was placed on the effect different levels of bus service had on the overall level of service provided by the roadway system. Bus transit was selected because it either exists to some extent or can be easily implemented in all urban areas. In addition, installation of new or expanded bus facilities, when compared to that of other roadway facilities, is achieved with the greatest immediacy and least capital outlays making such a procedure the most favorable fast time solution to congestion problems. Finally, for further simplification, buses and autos were the only modes considered as competitors for person trip conveyance. Other forms of transit were assumed to be nonexistent.

II. LITERATURE REVIEW

Review

Literature was reviewed to investigate the use of cost factors as indicators of levels of service.

In a study of bus and car travel in central London (18), the community saving resulting from a transference of riders from auto to bus travel was investigated. Two major criteria were used to formulate a basis. First, the sum of the time costs for all travelers and operating costs of all vehicles on the roadway network should be minimized. Secondly, driver's preferences for using their own cars (mode-specific costs) should be considered to yield more accuracy to the results.

Initially, work was performed taking only the first criterion into consideration. For this case, different restraint levels of private car travel were established with the present situation and full restraint as the bounding conditions. Calculations for mean journey speeds for both bus and car travelers with modifications for parking, walking, and waiting times were made. The total journey cost for all travelers and total operating costs of all vehicles in the network were then combined and manipulated to yield the overall travel cost per mile of network per hour. In order to determine this value the following data were required: vehicular and passenger flows in the CBD, mean journey length, bus types, passenger car units (p.c.u.) for buses and commercial bus occupancy, value of time, bus crew costs, bus fares, and operating costs.

In relation to the second criteria it was assumed that auto users change their mode of travel when the road pricing charges plus their other travel costs exceed the travel cost by bus plus their mode-specific costs. Represented in quantitative terms, an elasticity of demand of unity was assumed for travel by auto. Therefore a one percent increase in overall travel costs for car travel, while costs for buses remain the same, meant a switch of one percent of the travelers to buses.

Another method for measuring mode changes by auto users was developed by F. Houston Wynn (22). Labeled the "Shortcut Modal Split Formula" for its easy applicability, it was devised for work trips in large and middle-sized cities. The computational aspect of the formula relied on two major data items: (i) the number of CBD workers who have their own cars, and (ii) the proportion of car-owning workers who presently arrive at work on transit.

The primary goal of this and other modal split techniques was to measure the number of auto users diverted to mass transit based on changes in relevant factors. In the case of the "Shortcut" formula these factors or variables were transit fares and door-to-door travel times.

The demand for transit in the CBD was expressed as a percentage of any particular trip movement according to the calculated cost difference between travel by transit and that by private automobile for an equivalent trip. It was assumed that when costs were equal (i.e. the cost difference was zero) half of the car-owning CBD workers

would be expected to use transit while the other half would continue to use their own vehicles. A logarithmic growth curve, Figure 1, has been calibrated to the following mathematical form to show the diversion conditions for the range of possible cost differences.

$$P = \frac{1}{1 + e^{(16x/c)}}$$

where, P = percent of car owners who use public transit to travel to work in the CBD

e = base of natural logarithms

x = net trip cost difference = transit trip cost - driver trip cost

c = cost of time in cents per mile

Martin and Wohl (21) considered trip costs as the price charged for using selected roadway facilities to complete the trip. It was felt that the total travel price is based on the supply characteristics of the facilities and the number of vehicles using them. Therefore, the actual level of service experienced was defined as the price of travel which is defined as the combined value of the money, time, and human resources required to make a trip. Price-volume functions like the one in Figure 2 were presented to show the relationship between travel price and the volume using a single facility. As can be seen, for rising volume levels, the unit price of travel increases at a growing rate. This function was considered to represent a "so-called" supply curve. Demand curves, which indicate the number of persons who will use the facility at various price levels, were used in

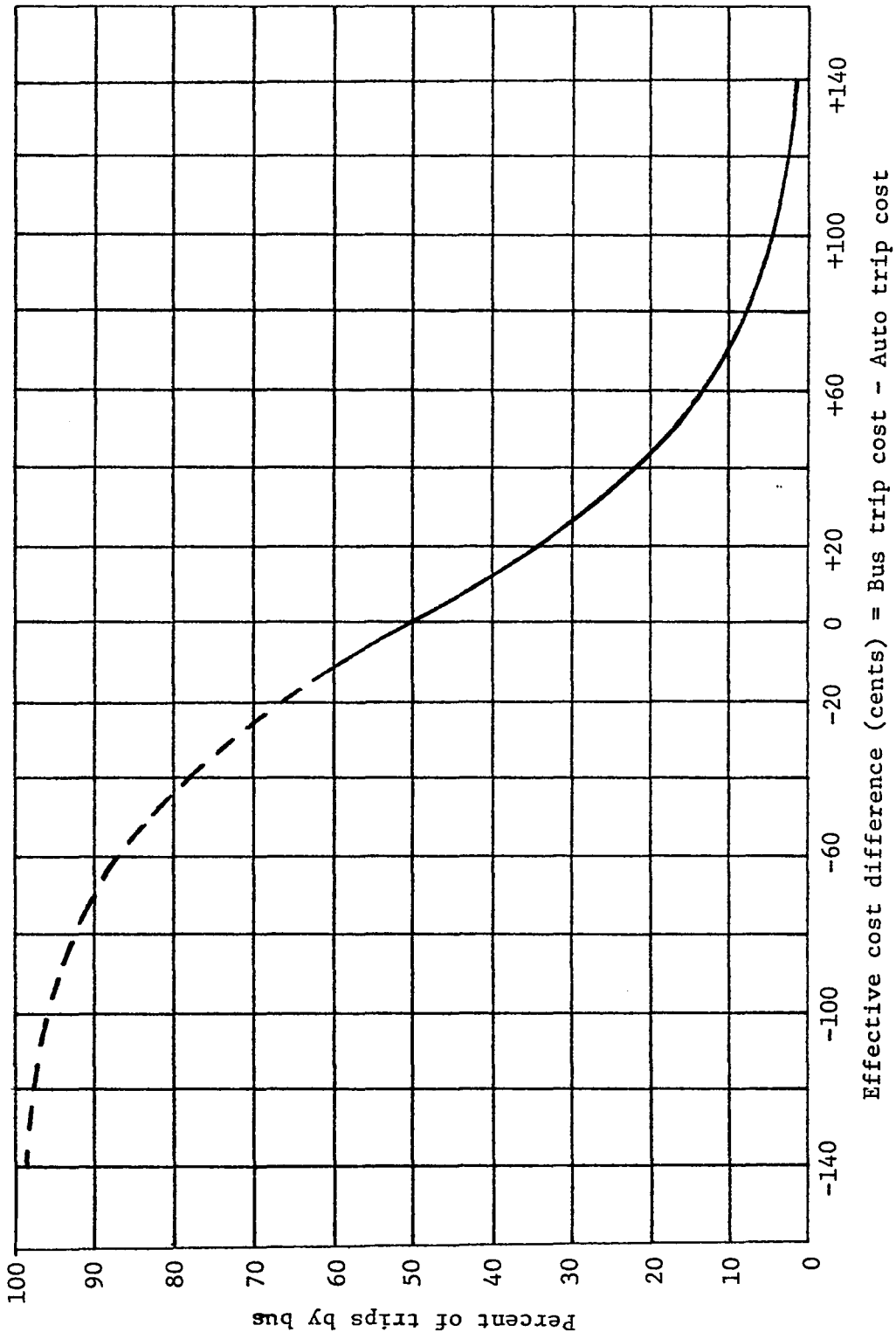


Figure 1. "Shortcut" modal split for a value of time = \$.05/min.

conjunction with supply curves to determine the volume of users for the facility (point 0, Figure 2). Shifts in the demand curve were expected to occur if a change in the price of competing facilities occurred.

When considering a system of roadway facilities it was pointed out that such a clear cut relationship is not as discernable. This is because interzonal routes are comprised of segments varying in design thus resulting in different price-volume curves for each. In addition, volumes on the segments usually contain travellers going between different sets of zones thus implying the need for more than one demand curve.

Discussion

In analysis of this review, it was felt that, although costs do not reveal the specific level of service in quantifiable terms, they do reflect differences in level of service components (travel time, driving comfort and convenience, and traffic interruptions) when transportation facilities or systems are compared. Such comparisons are, of course, only realistic for equivalent travel schemes. For example, when contrasting the service provided by auto and bus facilities to determine modal split, it is necessary that the prices of travel used to indicate this difference in service be computed from representative auto and bus trips using the same roadway facilities. In the case of evaluating the overall improvement in service for an entire transportation system based on the addition of new bus facilities, both the

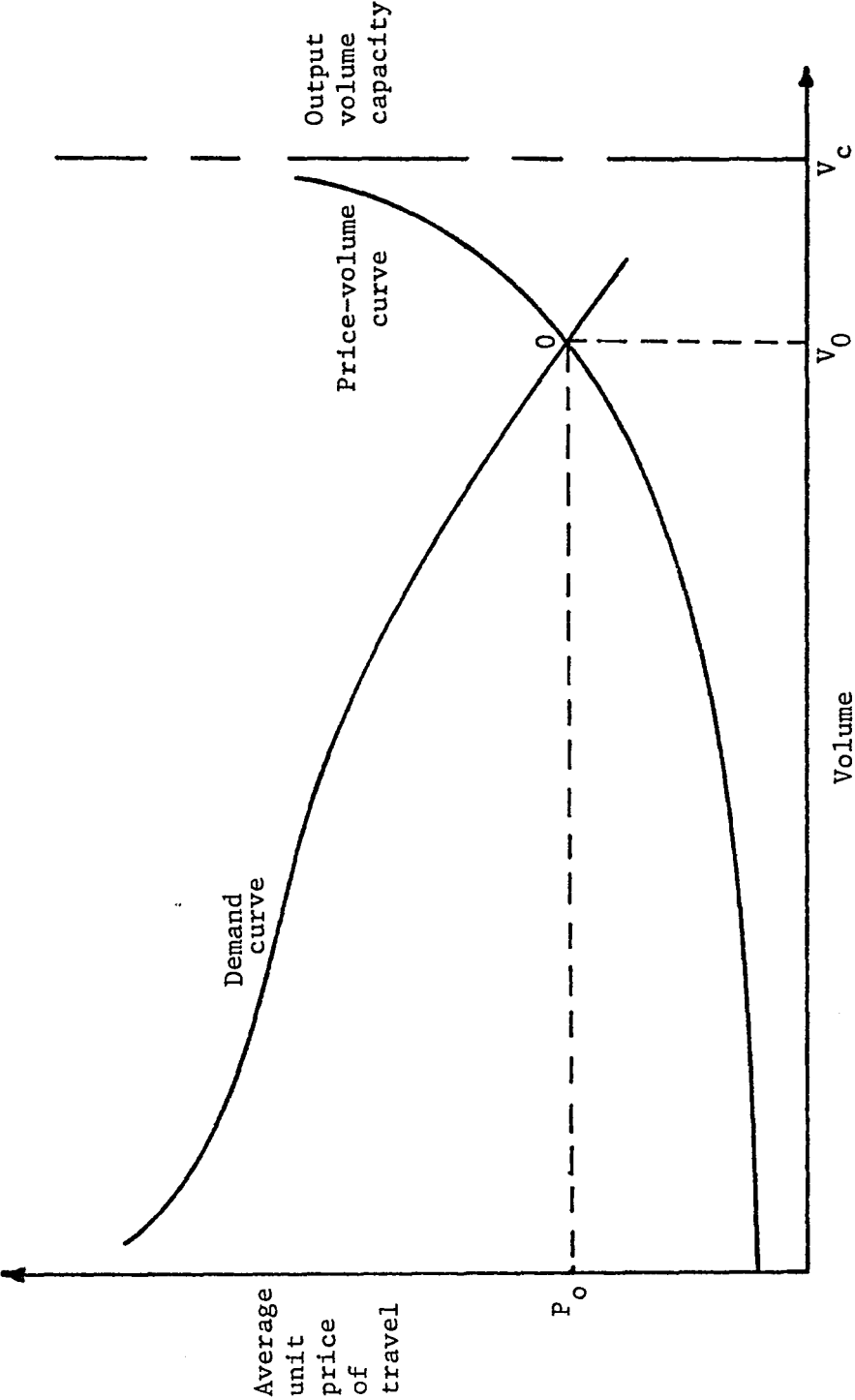


Figure 2. A typical price-volume function

original and improved system must have the same roadway network and handle equal numbers of person trips in order to be compared.

The effect of adding bus service on the supply and demand of roadway facilities was not considered by Wohl and Martin. Since references to such a relationship are made throughout, a discussion in regard to this concept is essential.

As can be seen in Figure 3, added bus service reduces the volume on a particular facility from V_0 to V_1 . If no alternative roadway facilities exist, the demand will shift downward and intersect the price-volume curve at point O_1 . The per unit travel price thus decreases to P_1 , indicating an increase in service. However, if this roadway facility is an alternative to users of other facilities, some of these users will switch over. Therefore, the demand curve will intersect the supply curve somewhere between V_1 and V_0 depending on where balance between the alternatives is achieved.

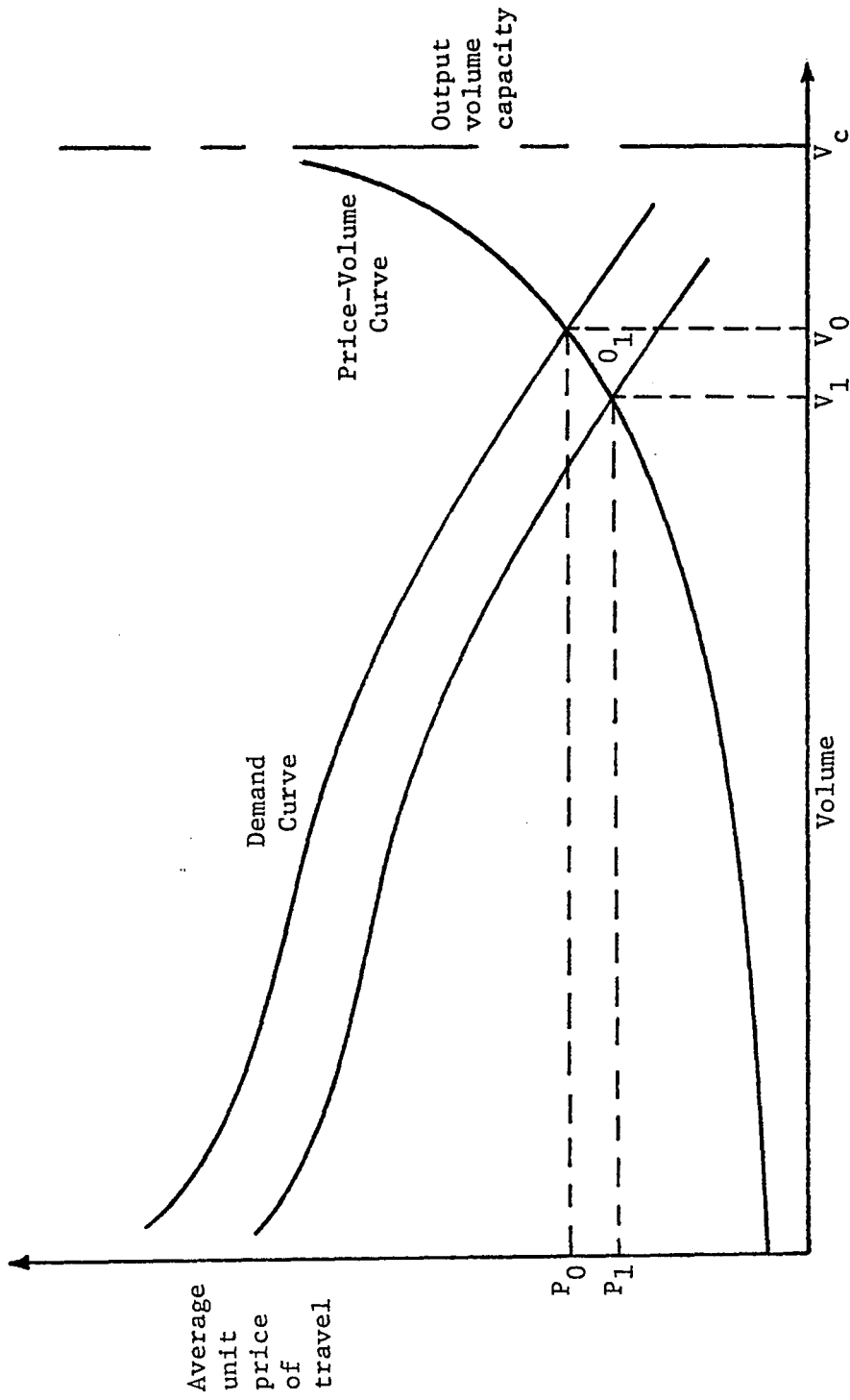


Figure 3. The effect of volume changes on roadway supply and demand

III. TRANSPORTATION FACILITY CHARACTERISTICS

Introduction

A strict auto-bus transportation system supplies several alternatives to tripmakers. It offers travellers a choice of conveyances (auto or bus) and a choice of routes between their origins and destinations. Users will base their selection on which alternative, in their estimation, offers the best price of travel. The travel price for each alternative will depend on both the supply characteristics of its composite facilities and the expected traffic conditions.

The collection of all user decisions indicates the total system traffic movement. The complete user costs incurred for each individual person trip can be combined to yield the total user costs for the system. The complete user costs for a trip and the price of travel for that same trip will be different. Whereas the full user costs include all costs for a trip, the price of travel embraces only those "perceived" costs that a user considers when making a decision on alternatives. "Perceived" costs consist of the more direct user costs such as out-of-pocket and time expenses (21).

In order to analyze user decisions and their effect on the demand requirements for facilities provided by the system, major variables describing these interrelationships were assembled. Such variables include those which describe the physical and operating characteristics of the three major types of facilities (roadways, buses, and autos) and the costs incurred through their usage.

Roadway Network

The pattern of roadways and intersections found in most urban areas is quite complex. This is due to the high instance of varying design and control incorporated throughout the urban area. Widths of streets and intersection approaches vary as do the types of signalization. To eliminate some of this complexity roadways were classified into groups which were characterized by their similarities in control and design. The three classifications are:

1. Expressways
2. Arterials
3. Collectors

Expressways and arterials are used for interzonal travel and are usually free of on-street parking. Expressways are distinguished from arterials by higher design speed and a lack of external delay. External delay, in the form of intersection signalization, occurs frequently on arterials. The last classification, collectors, are short stretches of roadway used to link arterials and expressways to origin or destination zones. These are usually heavily signalized with on-street parking found in many cases. A collector was assumed to be an average representation of a number of streets linking the same two areas.

The primary concern in regard to networks is the average time it takes to traverse sections of roadway based on volume conditions. This time includes the average delay experienced at each intersection along the way. Travel times can be estimated for different volume levels

if the capacity and length of the section and the volume-delay functions of intersections are given. Travel time changes were measured only for expressways and arterials. The high instance of external delay found at all volume levels due to on-street and concentrated parking as well as the relatively short distances traversed make travel times for collectors nearly constant.

Bus Operating Characteristics

Operating characteristics indicate the effect buses have on the system and their attractiveness to users.

- (1) Bus travel time--These times are composites of the time in transit and time for stops. Bus travel times will exceed auto travel times by larger margins as auto speeds increase.
- (2) Average bus occupancy--The value of bus occupancy varies with frequency of bus service and the demand for that service. Guidelines in this respect indicate an average occupancy of 125 percent of seating capacity for peak hours. Most buses in local service in the United States have from 45 to 53 seats (11).
- (3) Passenger car unit (p.c.u.) equivalencies--Equivalencies are computed in terms of their effect of saturation flow at intersections and are functions of the plan area of bus types (11). Although p.c.u. values vary with conditions, this variance is not felt to be so great that a constant approximation would be unrealistic.

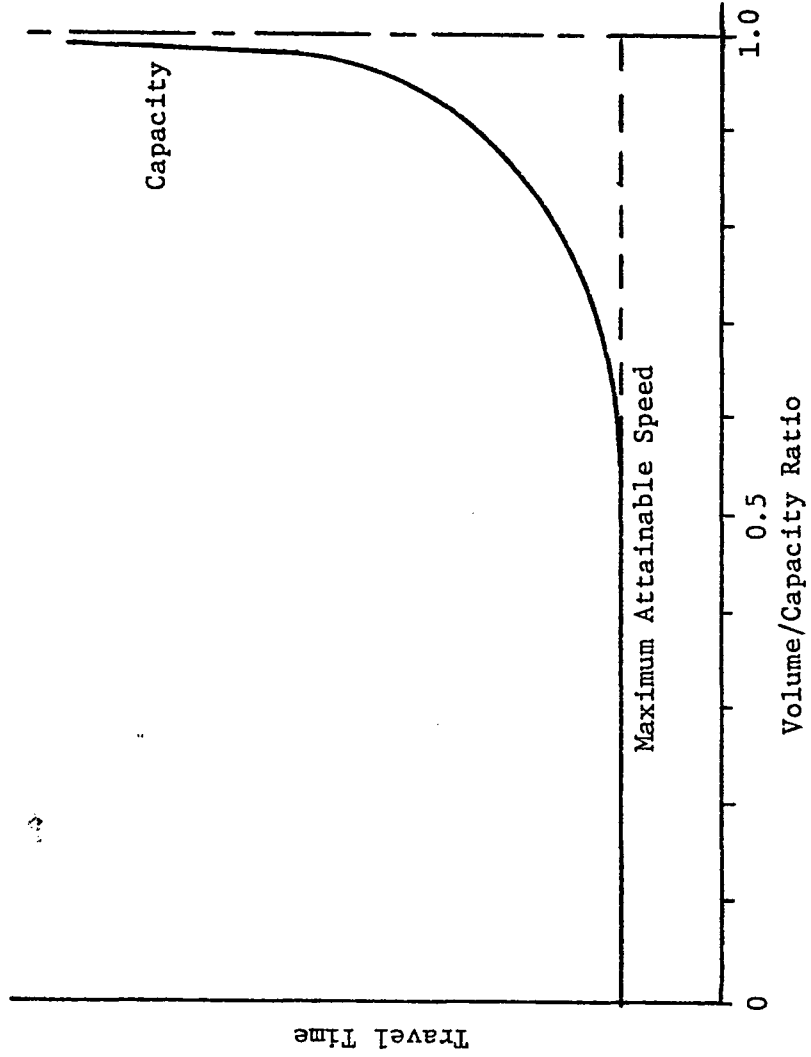


Figure 4. A typical auto travel time-volume relationship

Auto Operating Characteristics

It is necessary to study auto characteristics so that autos and buses can be compared on an equivalent level:

1. Auto travel time--Auto travel times are dictated by the roadway conditions. An auto user will drive as fast as the volume levels and speed limits allow. Figure 4 shows a typical travel time-volume relationship for a roadway facility.
2. Average auto occupancy--These rates are functions of sociological and economic factors, congestion, and the amount of parking available. An average value between 1.5-2.0 is considered to be representative in most cases (20).

User Costs

User costs are composed of all the costs users bear when using transportation facilities. As was mentioned previously, a subset of perceived user costs formulates the user's price of travel. Therefore, user costs are categorized as perceived and non-perceived costs.

Perceived User Costs

1. Average Parking Costs--Average parking rates for a one-way trip to or from the city center are one-half the average rate. Although only a certain percentage of drivers pay to park, an average per vehicle parking cost applicable to all auto users can be derived through factoring (22).

Parking costs vary with fluctuations in demand as shown in Figure 5. As more and more auto users switch to buses as their mode of travel, parking rates either decrease or remain stable. This is due to the competition for prospective parkers that owners of pay lots feel from both their constituents and bus modes. By reducing rates, individual owners hope to retard the loss of prospective customers to bus service and at the same time, hope to attract a bigger share of the remaining demand than do other pay parking facilities. Eventually, however, a point is reached where it is financially infeasible to maintain competitive rates due to the losses which would be incurred. As a result, the rates will increase as the demand continues to decrease causing factored costs per auto to rise.

2. Toll Costs--Toll costs may be represented as an average cost for all drivers or may be assigned in full value to only the direct users of the toll facilities. The latter scheme is used when only a few distinct toll facilities exist in the urban area. It is felt that an average value in this case, would not be representative since only a small percentage of trip makers are actually paying tolls. The value of toll costs varies much like that for paying rates as more bus trips and less auto trips are made.
3. Time Costs--Time costs are a function of travel times and the monetary value of user time. Therefore a decrease in

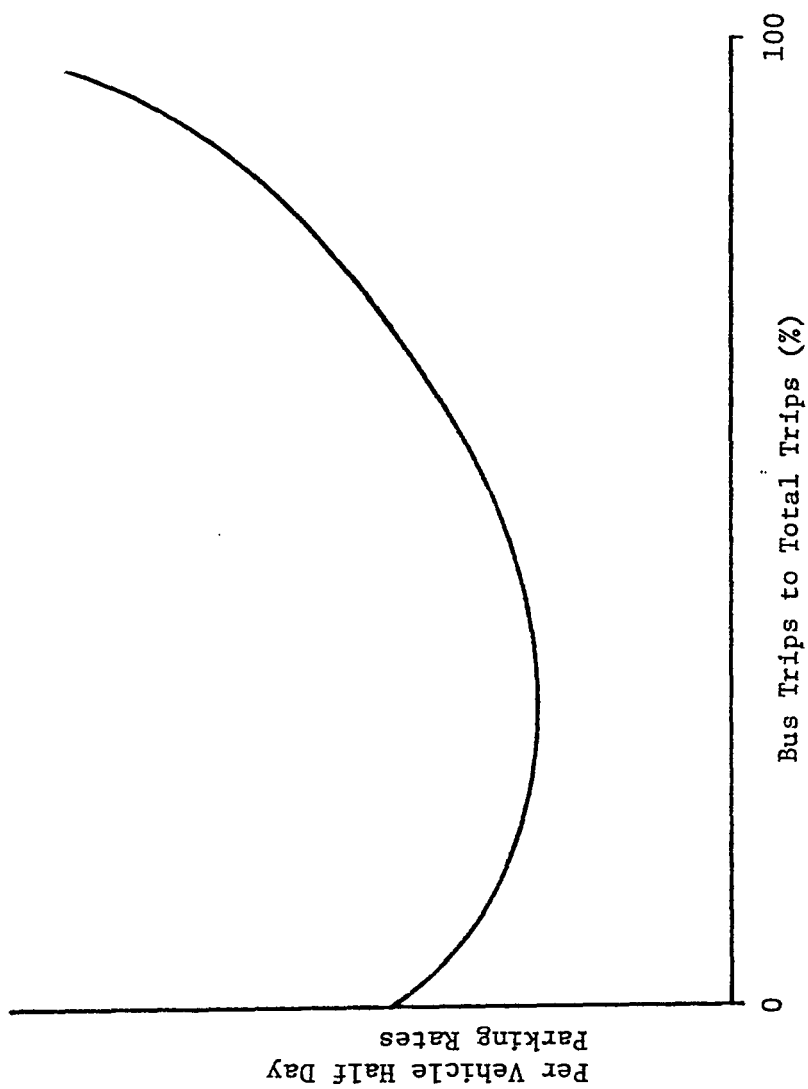


Figure 5. A representation of the relationship of per vehicle parking rates to changes in demand for pay parking facilities

the travel time required for a trip will reduce a trip maker's price of travel. Several studies concerning the value of time for peak period commuter work trips have been undertaken achieving varied results. The variance of these outcomes is primarily due to the fact that time value estimation depends largely on the characteristics of the locality under observation. Some of these characteristics include trip factors (distance, number of stops, etc.), traveler characteristics (age, sex, etc.), and environmental factors (highway design, land use, speed limits, etc.) (20). Probably the most in depth research of value of time during peak periods was performed by Thomas (15) and Lisco (10). The overall results of their work indicated an average value of time somewhere between \$2.50 and \$3.00 per hour. On the other hand, Wynn (22) in his Shortcut Modal Split analysis used values ranging from \$2.40 to \$4.20 per hour.

4. Bus Fares--The value of bus fares are normally set via the principle of total revenue exceeding total operating costs. Actual demand for bus service is, in this case, based on the fare charged. In this study, however, fares were used to adjust the price of bus travel. Their values depended on the price of bus travel required for a particular demand.
5. Out-of-pocket Auto Running Costs--It was assumed that of those components (depreciation, maintenance, gas and oil, insurance, etc.) which comprise total running costs, drivers

only perceive the price they pay for gas and oil. Therefore, a user will consider this expense in determining his choice of travel alternatives (20).

Non-perceived User Costs

1. Running costs excluding out-of-pocket cost--These costs include all those components of running costs which a user pays for but does not realize or consider when making a decision about alternatives. These include costs for depreciation, maintenance, insurance, and state and federal taxes which are not included in gas and oil prices.
2. Social benefits--These are negative costs which result from reduced congestion. Social benefits include savings from reduced accidents and pollution. Unfortunately, such items are hard to quantify as costs. For this reason, they were not incorporated into the calculation of total costs for this study.

IV. MODEL DEVELOPMENT

Overview

Based on the transportation facility characteristics, alternative facility arrangements, with varying degrees of new facilities added to the existing urban transportation system, can be determined. It is necessary to compare these alternatives to determine which one offers the best overall level of service in the form of minimum total community transportation costs. In order to perform a comparison of alternative facility arrangements effectively, a travel forecasting process which takes the predicted travel demand in person trips originated from or destined to a given area over a known time period determines the assignment of traffic is required. An example of a traditional travel forecasting model is given in Figure 6. Once the traffic assignment is known the total community transportation costs for a particular facility arrangement can be determined based on the summation of individual running, time, and fare costs to users. The combination of the travel forecasting process and the total community transportation function formulates the urban transportation facility arrangement evaluation process.

A variation of the traditional travel forecasting process (Figure 7) formed the basis for evaluating the effect of added bus service in an urban center. The travel demand (trip generation),

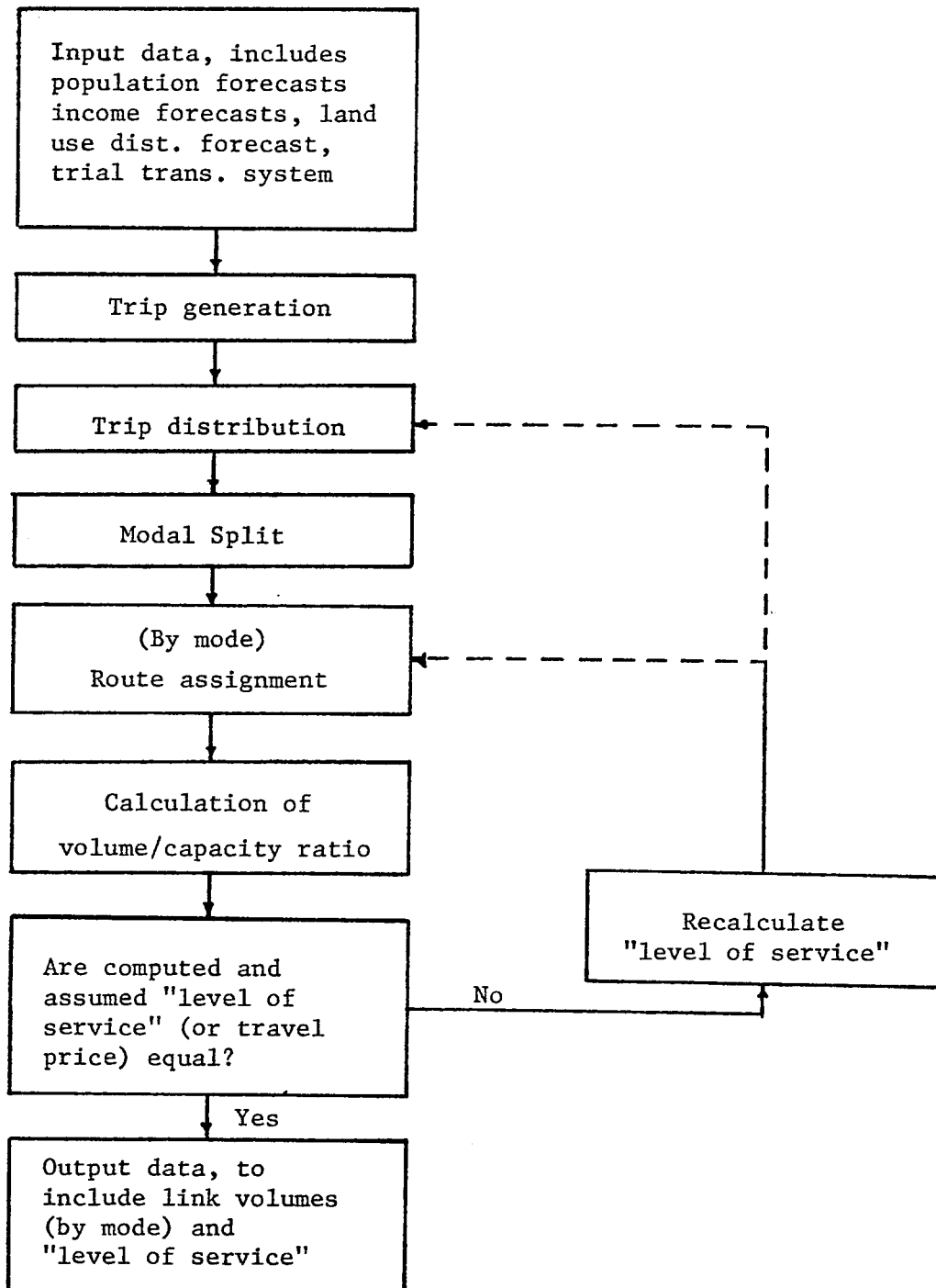


Figure 6. A standard travel forecasting process

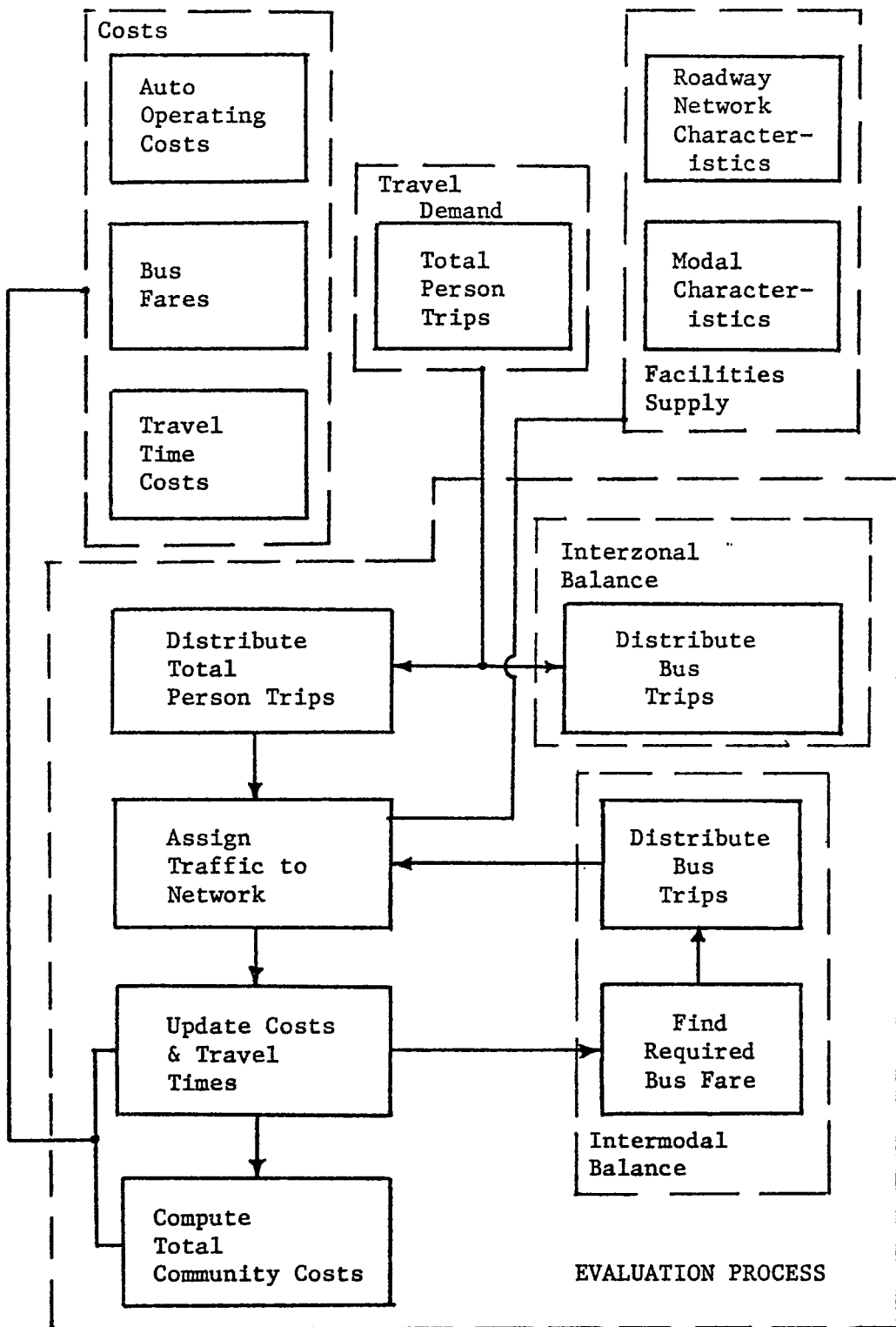


Figure 7. The revised travel forecasting process

in terms of person trips was considered constant for any arrangement of facilities. In addition, since peak hour travel is comprised mostly of work trips with set origins and destinations, trip distribution also was assumed not to be affected by additional bus service. The remaining segments of the traditional forecasting process were, however, changed considerably. This was particularly true for the modal split segment. The percent of total trips diverted to buses, in this case, was an input into the process rather than a result. Therefore, the modal split segment of the new process worked in reverse order to make the demand for buses equal to the supply.

The system evaluation sector shown in Figure 7 comprises the major adjustments incorporated into the normal travel forecasting process. In this sector, bus trips are distributed throughout the network to obtain interzonal balance. Such distributions are used in conjunction with the total trip distributions to determine, via the assignment segment, the effect that reduced volume brought about by the additional bus service, has on parking and toll costs and interzonal travel times. Based on this information, the prices of travel for bus trips between each zonal pair for which service is provided, is adjusted by the fare to meet the demand requirements for the new facility arrangements. Traffic assignment is then reapplied

to determine the final travel times. Using this output, the total community costs are calculated via a designated function.

Many techniques for the generation, distribution, and assignment of trips have already been developed. Most of these would be integrable into the evaluation process. The other major components of the evaluation process, however, a level of service balancing technique and a user cost function, had to be developed.

Balancing Process

Input to the balance process was expected to consist of a set distribution pattern for the number of total trips between zones, and a prescribed proportion of bus trips. The process was designed so that balance was achieved for each dimension (roadway system and modes) as well as for their interaction.

The strategic allocation of bus trips via a bus trip distribution formula was used to reduce volumes on slower, more congested interzonal routes. The criterion used for allocating these improvements was average interzonal speed. The largest percentages of bus trips to total trips were assigned to those routes having the lowest average speed. A "gravity" type relationship was used to distribute the bus trips on this basis.

$$t_{bij} = (S_i) (P_d) \frac{(T_j) \left(\frac{a_{tij}}{d_{ij}} \right)^y}{\sum_{j=1}^n (T_j) \left(\frac{a_{tij}}{d_{ij}} \right)^y} \quad (4.1)$$

where: t_{bij} = bus trips between zone i and j

S_i = total trips produced by zone i

T_j = total trips attracted by zone j

P_d = prescribed percentage of total bus trips
(diversion percentage)

a_{tij} = travel time from zone i to zone j

d_{ij} = distance between zones i and j

n = total number of zones

y = a parameter based on existing traffic conditions

If the demand in terms of the number of bus trips connecting two zones i and j is not sufficient enough to merit the implementation of bus service over that route, the following holds,

$$t_{bij} = 0$$

The "Shortcut" Modal Split Formula (22) was used to develop the intermodal segment of the balancing technique. Based on the percentage of bus trips to total trips obtained for a zonal pair, the modal split formula computes the desired difference in the price of travel for equivalent auto and bus trips. The actual trip cost difference for travel between a zonal pair based on the conditions resulting from

the assignment of the distributed bus trips is computed as follows:

$$D_{ij} = v_t (b_{t_{ij}} - a_{t_{ij}}) - (c_{r_p})(d_{ij}) + f'_{ij} - c_p - c_{t_{ij}} \quad (4.2)$$

where: D_{ij} = cost difference for route i-j

v_t = value of time in dollars

$b_{t_{ij}}$ = average bus travel time from zones i to j

c_p = average parking cost per auto

c_{r_p} = "perceived" average per mile running costs

$c_{t_{ij}}$ = toll costs per auto on route i-j

f'_{ij} = bus fare for travel between zones i and j

Other variables as defined previously (see glossary in Appendix A)

To equalize this cost difference with the one computed by the modal split formula, a new fare is computed. The equation for this fare has the following form:

$$f_{ij} = \ln \left[\frac{1 - \frac{t_{b_{ij}}}{t_{b_{ij}}}}{\frac{t_{b_{ij}}}{t_{t_{ij}}}} \right] \left(\frac{v_t}{0.16} \right) - D'_{ij} \quad (4.3)$$

where: $t_{t_{ij}}$ = total person trips going from i to j

$D'_{ij} = D_{ij} - f'_{ij}$

Others as defined previously (Appendix A)

It was felt, however, that individual fares for each pair of zones was unrealistic. Instead, a standard fare for all bus trips was proposed. This fare would be a function of the difference between the average variance of all "actual" interzonal trip cost differentials and the cost variance computed by the modal split model using the total urbanwide percentage of trips diverted to buses.

The equation used for calculating the average "actual" trip cost difference weights each individual interzonal cost difference by the ratio of the bus trips to total trips going between the zones. It has the following form:

$$D'_A = \frac{\sum_{i=1}^n \sum_{j=1}^m \frac{t_{b_{ij}}}{t_{t_{ij}}} (D'_{ij})}{\sum_{i=1}^n \sum_{j=1}^m \frac{t_{b_{ij}}}{t_{t_{ij}}}} \quad (4.4)$$

where: D'_A = the overall average cost difference excluding fares

Others as previously defined (Appendix A)

The actual percentage of total trips diverted to buses may be less than originally prescribed due to corrections made in the bus distribution process. Therefore the corrected value must be computed. The equation is as follows:

$$P_d = \frac{\sum_{i=1}^n \sum_{j=1}^m t_{b_{ij}}}{\sum_{i=1}^n \sum_{j=1}^m t_{t_{ij}}} \quad (4.5)$$

where: P_d = corrected diversion percentage

Finally, the amount by which the required trip cost difference, based on the diversion percentage, exceeds the calculated average "actual" cost difference reveals the standard fare.

$$F = \left[\ln \left(\frac{1 - P_d}{P_d} \right) \right] \left[\left(\frac{v_t}{0.16} \right) - D'_A \right] \quad (4.6)$$

where: F = the standard fare

In order to determine the new interzonal bus distribution based on this standard fare, the updated interzonal trip cost variations are computed for each zonal pair.

$$D_{ij} = v_t (b_{t_{ij}} - a_{t_{ij}}) - (c_{r_p}) (d_{ij}) + F - c_p - c_{t_{ij}} \quad (4.7)$$

Variables as described previously (Appendix A)

The bus-auto trip cost differences, D_{ij} , for each zonal pair are substituted independently into the modal split formula to determine the percentage of total person trips between them which are diverted to buses.

$$P_{d_{ij}} = \frac{1}{1 + e^{\left(\frac{16 D_{ij}}{v_t} \right)}} \quad (4.8)$$

Finally, the actual number of bus person trips for each zonal interchange which provide both interzonal and intermodal balance are calculated.

$$t_{b_{ij}} = (P_{d_{ij}}) (t_{t_{ij}}) \quad (4.9)$$

Total Community Transportation Cost Function

The total community cost function was designed to include all major costs incurred by all users of a urban transportation system during the peak period. Input for this function can be assembled through the application of traffic assignment processes. This will be discussed in more depth in Chapter V. The general form of this function is as follows:

$$C = \{ (c_r) (A_m) + (c_p + c_t) \frac{A_r}{o_a} + v_t [(o_a) (A_h) + (o_b) (B_h)] + U \} \quad (4.10)$$

where: C = total community transportation costs for the system

c_r = average per mile total running costs

c_p = average toll costs per auto

c_t = average toll costs per auto

A_r = total auto riders

o_a = average auto occupancy

o_b = average bus occupancy

v_t = the value of user's time in dollars per minute

b_o = bus per mile operating costs

A_m = total auto vehicle-miles

B_m = total bus vehicle-miles

A_t = total auto vehicle-minutes

B_t = total bus vehicle-minutes

U = roadway utility factor

Roadway utility considerations are made when a roadway network does not already exist, such as for new towns. In this case, since the design and configuration of the roadway network is controllable, it would be desirable to study interrelationships between bus service and roadway implementation for two major reasons: (i) to insure good peak hour level of service and (ii) to make certain that the provided roadway facilities will be adequately utilized. For the latter case, disutilization will occur whenever the available roadway space within an urban area is not fully used during the peak hour. This disutilization can be considered a community cost which is measured by the opportunity lost by not allowing the unused space to be available for other use. Total opportunity costs are thus products of the land value prorated for the peak hour and the total unused roadway area for this period. Therefore, the major concern in the case of new towns, is to find a facility arrangement which minimizes the sum of total user costs and total opportunity costs.

Opportunity costs can be determined for an individual roadway facility by first determining the area required per person trip on the facility. This should be a function of the desired characteristics of the facility. For the auto-bus urban transportation system, the required area per passenger for a roadway facility with a specified level of service can be computed by the following equation (12):

$$A_{p_i} = \frac{w_i [(1 - P_d) (h_{d_a}) + (P_d) (h_{d_b})]}{(o_a) (1 - P_d) + (o_b) (P_d)} \quad (4.11)$$

where: A_{p_i} = the required area per passenger on facility i

w_i = the specified width of facility i

P_d = the percentage of bus trips

h_{d_a} = the auto headway

h_{d_b} = the bus headway

o_a = average auto occupancy

o_b = average bus occupancy

The headway required by a vehicle is a function of the speed associated with the specified level of service. It is equivalent to the total stopping sight distance and is computed for any mode k as follows:

$$h_{d_k} = L_k + 1.47 RV_i \quad (4.12)$$

where: h_{d_k} = the headway required for mode k

L_k = the length of mode k

R = perception-reaction time

V_i = desired speed

Based on the value for the required area per passenger and the actual volume level on the facility, the actual width required for this volume can be calculated:

$$w'_i = \frac{A_{p_i} v_i}{(1.47) (3600) v_i} \quad (4.13)$$

where: w'_i = the actual width required for facility i

v_i = the actual volume level

Given the length of the facility, the unused space can be determined:

$$q_i = l_i (w_i - w'_i) \quad (4.14)$$

The product of the unused space and a value for the opportunity cost per square foot during the peak hour yields the lost utility for the facility under the given conditions:

$$u_i = (O_i) (q_i) \quad (4.15)$$

The summation of these individual disutilities comprises the total utility loss, U , which is added to the community cost function.

$$U = \sum_i u_i$$

Summary

The models developed here will be useful only if they are included in the total evaluation process as shown previously in Figure 7. In turn, the total evaluation process is only of value if the results can be computed in an accurate and quick fashion. For this purpose, computational techniques in the form of a computer program are introduced in the next chapter.

V. COMPUTATIONAL EVALUATION PROCEDURE (TRANSFARE)

Introduction

TRANSFARE (Transportation Facility Arrangement Evaluation) is the computer program which was designed to perform the functions of the evaluation process shown in Figure 7, Chapter IV. Staying within the lines of this study, the program was directed toward finding the best facility arrangement when bus service is added. However, slight modifications would allow it to be used for the implementation of other facility types as well.

The computer techniques employed by TRANSFARE are advantageous for two reasons: (i) the extensive manipulation required in the evaluation process, and (ii) the numerous evaluations of distinct facility arrangements required to determine the best arrangement. TRANSFARE is designed to test any number of alternatives implementing different levels of bus service. It also has capabilities for performing a search for the optimum facility arrangement if certain requirements are met. This will be discussed in detail later in this chapter.

Certain segments of TRANSFARE were taken from a traffic assignment program originally developed by Wolfgang S. Homburger (7). The remaining portions were developed through the research effort of this study. The total program is listed in Appendix C. A general discussion of it is given in the remainder of this chapter.

Background Information

Before the computational procedure can be discussed, it is necessary to outline the format used by TRANSFARE to describe the roadway system. References to the terms introduced here will be used in all further discussion.

For the purpose of characterizing the urban roadway system, a network (Figure 8) showing all expressways, arterials, and local streets is utilized. Like any other network, its two major components are nodes and links.

Nodes can have any one of the following forms:

1. centroid
2. gateway
3. intersection

Centroids are points which are centrally located within the zones into which the study area has been divided. They handle the trip origins and destinations for the zones they represent. Associated with each centroid will be a terminal time which indicates the average walking time for that zone. It is necessary that centroids are not located directly on the arterial network so that through traffic is not penalized by these terminal times.

Gateways are located on the exterior cordon of the urban area where trips enter and leave the system. These can be located on the arterial network because, theoretically, all trips start or end at gateways. Terminal times, in this case, measure the average time for travel from exterior points to the gateways.

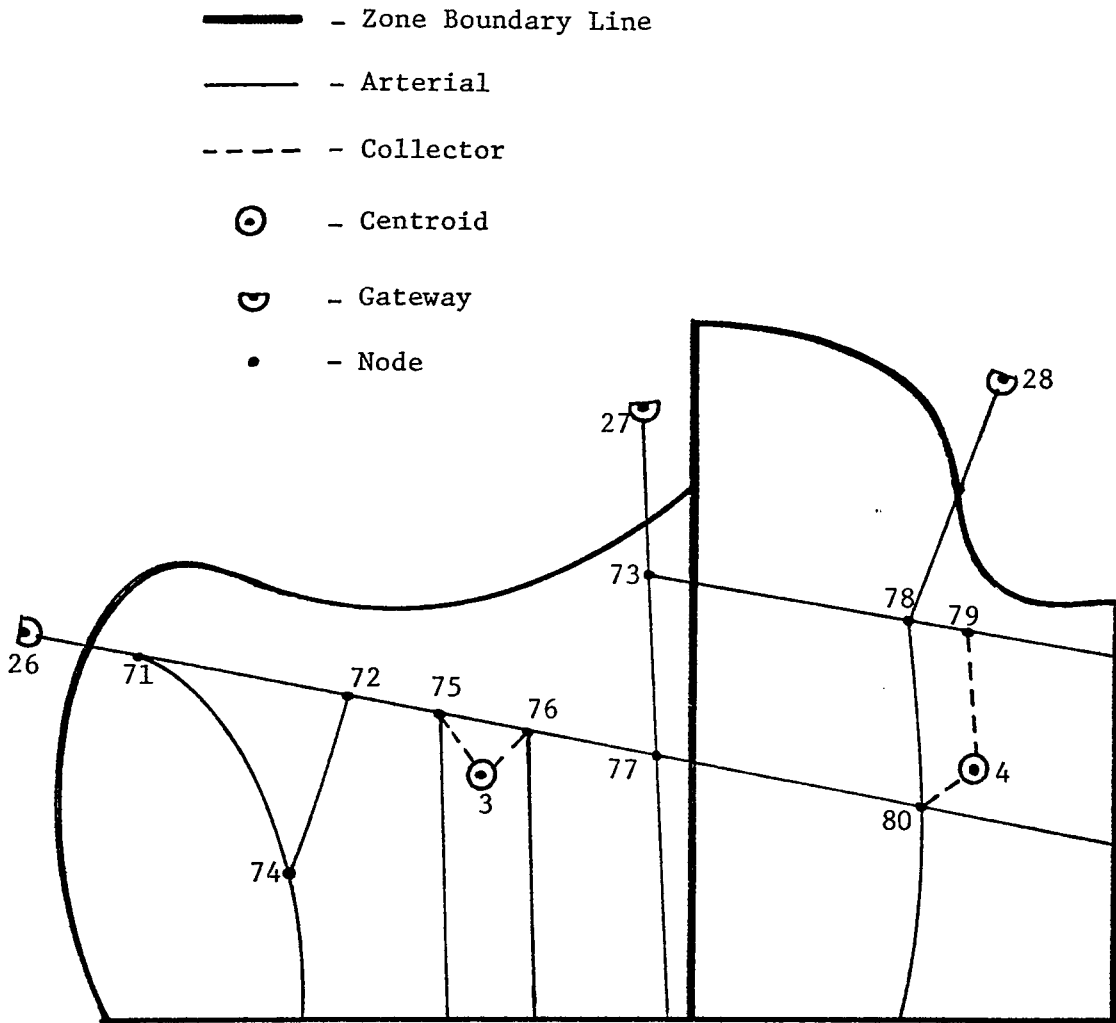


Figure 8. A segment of a representative TRANSFARE network.

When calibrating the network, certain labelling criteria are introduced to aid in node identification. The zonal centroids are numbered from 1 to c , where c represents the total number of centroids. The gateways are then listed from $c+1$ to $c+g$ where g is the total number of gateways. Finally, the intersection nodes are numbered from $c+g+1$ to n , the total number of nodes in the network.

The major interest when considering facility arrangements is in the characteristics of travel between zonal pairs. Such travel may be distributed over several routes as determined by shortest path techniques. These routes are identified by the links that compose them. The links, in turn, are defined by the nodes they connect.

Links are one directional, therefore, a two way street must be described by two links. There are four types of links to be utilized in this study.

1. Local links (link type 1) are collectors which connect the centroids to the arterial network. These provide a schematic representation of the local street system and are used only at the start and end of trips thus assuring that traffic does not pass through one centroid enroute to another destination.
2. Intersection-delay links (link type 2) are arterial links which end at stop signs and signal-controlled intersections. For these, additional travel time is a function of the traffic flow at the exit node (intersection delay) and not the total link length.

3. Link-delay links (link type 3) include freeways and some arterial links on which delay is a function of the link length only.
4. Dummy links (link type 4) are artificial links which connect centroids to the arterial network in cases where centroids are located directly on an arterial. In addition, they are used to represent turning movements at major intersections. These links have zero length.

For computational purposes, each link will be given another means of identification. All the links should be arranged so that the link or links with the lowest origin node, usually 1, are listed in ascending order of their destination nodes. These are followed by the next lowest set of origin nodes once again arranged in ascending order of their destination nodes. This process is continued until the highest origin node and destination node are reached. The links are then numbered consecutively from 1 to the total number of links.

Information regarding the characteristics of individual nodes and links is essential to the development of the optimization procedure. Each important characteristic, thus, must be determined and labeled according to the node or link it represents.

For each link, i , the following characteristics need to be known:

1. type of facility
2. number of lanes
3. capacity
4. length

5. average travel time

6. average speed

The type of facility indicates whether it is a local, intersection-delay, link-delay, or dummy link. Link capacity is measured for the entire link regardless of the number of lanes, and link length measurement extends from the exit of the origin node up to and through the destination node. Average travel time and speed will be updated as trips are added to the network but initially they should be determined by free flow or existing conditions applicable to each link.

Description of the Process

The total computational process of TRANSFARE is shown in flow chart form in Figure 9. To initialize the process, input data describing the system characteristics is required. The person trip attractions and productions for each zone should be specified, and the link travel times should be estimated. Network characteristics, cost variables, and equation parameters should be entered as indicated by the input specifications in Appendix B.

The first time through the process, the total person trips are distributed and assigned to yield the link travel times and total costs associated with a system offering no bus service. Only trips having at least one end in the CBD are considered. A gravity type relationship based on the distance between zones is utilized whereby:

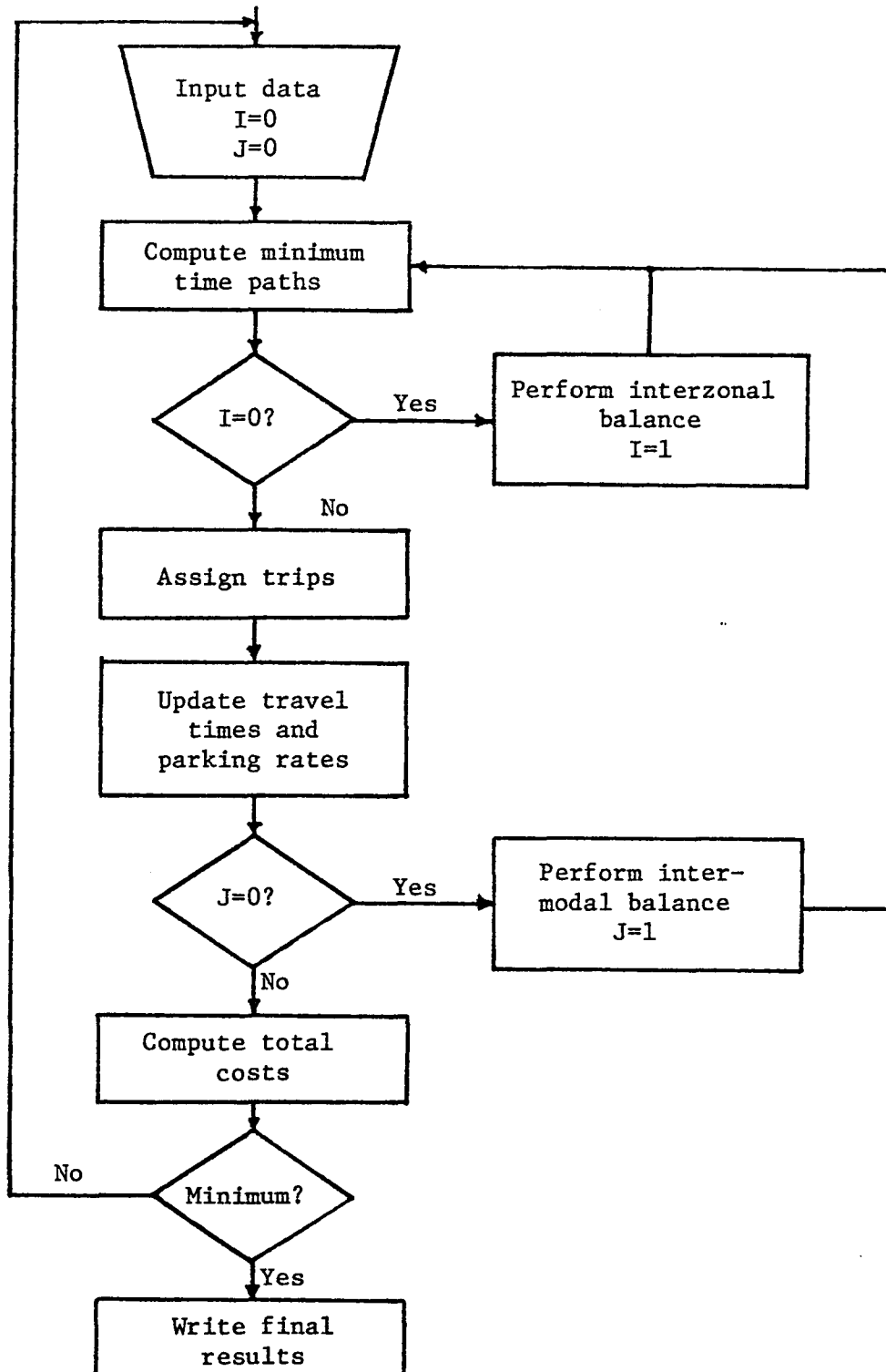


Figure 9. The computational evaluation process as performed by TRANSFARE.

$$t_{t_{ij}} = S_i \left[\frac{\frac{T_j}{d_{ij}^x}}{\sum_{j=1}^n \frac{T_j}{d_{ij}^x}} \right] \quad (5.1)$$

for which: $t_{t_{ij}}$ = the number of person trips from zone i to zone j.

S_i = the total trip origins at zone i.

T_j = the total trip destination at zone j.

n = the total number of destination zones.

d_{ij} = distance between zones i and j.

x = an exponent based on social and economic factors

The distribution results are tested for errors of closure. If the error is greater than a level specified in the program, distribution is recalculated until the acceptable level is reached or a specified number of recalculations have been performed.

After the first iteration, the process evaluates the transportation system under consideration for different levels of bus service. The level for each iteration is based on the increment for diversion percentage (computer parameter DIP), which is specified. An increment of 0.10 would evaluate the system at ten levels of diversion ranging from 10 to 100 percent.

As was indicated in Figure 9, the total computational process performs several major functions. These are:

1. minimum time path computation
2. vehicle-trip assignment
3. travel time and average parking cost updates
4. interzonal balance
5. intermodal balance
6. total cost and computation
7. minimum cost search

Interzonal and intermodal balance have been discussed previously, (Equations 4.1 and 4.9). The other functions will be explained herein.

Minimum Time Paths

The minimum time path trees are built from every centroid or gateway to all other centroids and gateways in the network. The time, distance, and link sequence of the minimum paths are determined for each zonal pair. The procedure employed in TRANSFARE was originally developed by the Road Research Laboratory and programmed by B. V. Martin (7).

Traffic Assignment

The assignment process, as shown in Figure 10, is an iterative procedure which employs capacity restraint. Therefore, based on the limiting volume-capacity (v/c) ratio, which is specified, a certain proportion of total auto and bus vehicle trips can be loaded onto the network for a particular iteration. Continued iterations are

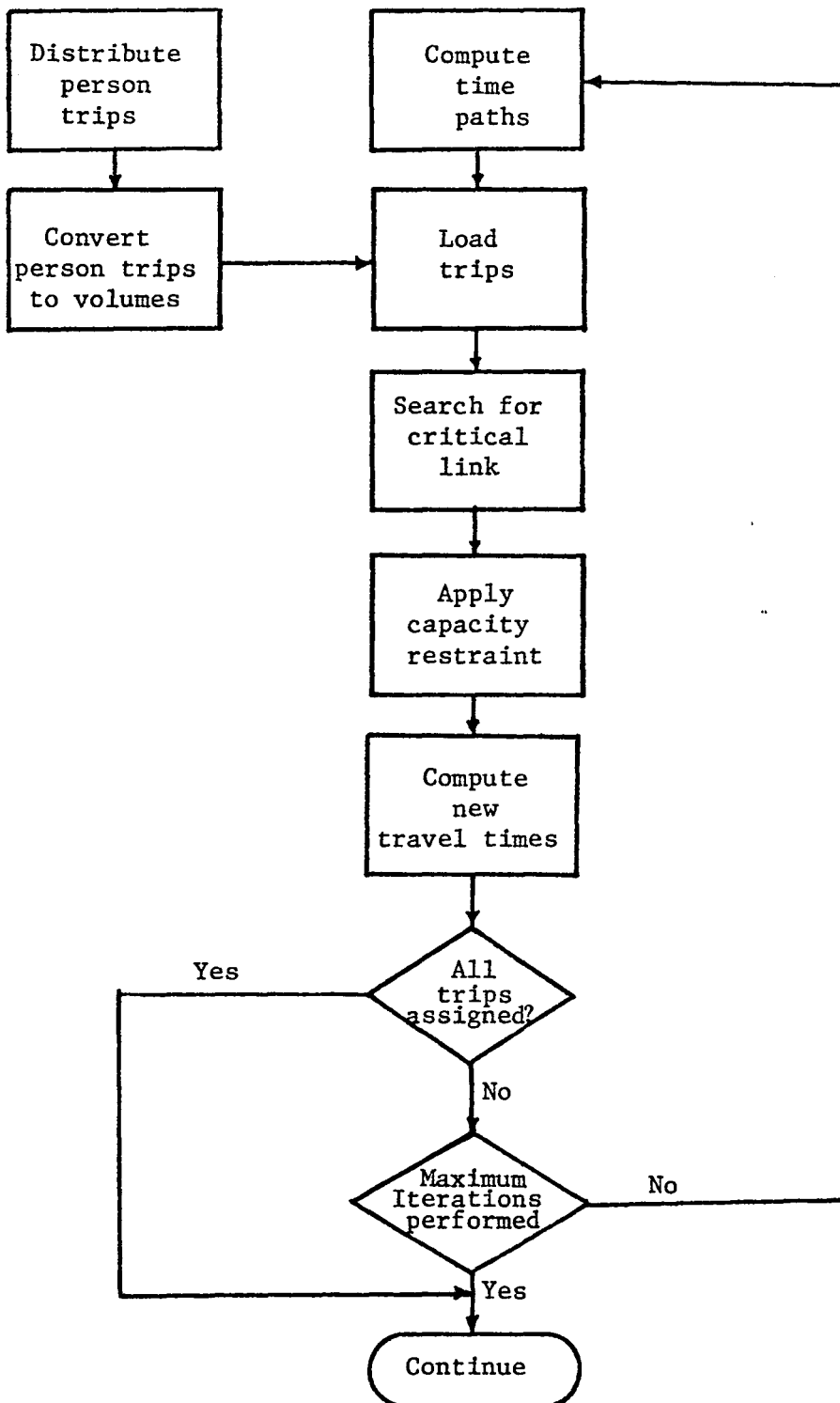


Figure 10. The assignment process as applied in TRANSFARE.

performed until all volumes are assigned or a specified maximum number of iterations is reached.

The number of bus and auto vehicle trips which require assignment on an interzonal route are based on the person-trip information provided by both the bus and total trip distributions. Auto volumes are computed by

$$v_{a_{ij}} = \frac{t_{t_{ij}} - t_{b_{ij}}}{o_a} \quad (5.2)$$

where: $v_{a_{ij}}$ = auto volumes going from zone i to zone j

$t_{b_{ij}}$ = bus person trips from zone i to zone j

$t_{t_{ij}}$ = total person trips from i to j

o_a = average auto occupancy

The number of buses required for the amount of interzonal bus trip demanded must be computed before the value of bus volume is determined. Integer division is utilized to truncate the computed value. If the left over bus trips exceed one half the average bus occupancy another bus will be added. The equations are as follows:

$$n_{b_{ij}} = \frac{t_{b_{ij}}}{o_b} \quad (5.3)$$

if $t_{b_{ij}} > o_b (n_{b_{ij}} + .5)$

$$n_{b_{ij}} = n_{b_{ij}} + 1 \quad (5.4)$$

for which: $n_{b_{ij}}$ = the number of buses going
from i to j

o_b = average bus occupancy

The value of bus volume for route i-j can now be computed as follows:

$$v_{b_{ij}} = (n_{b_{ij}}) (e_b) \quad (5.5)$$

where: $v_{b_{ij}}$ = bus volumes going from zone i to j

e_b = bus equivalency factor in p.c.u.'s

The proportion of volumes loaded throughout the network for one iteration is dictated by the proportion which can be loaded on the critical link. A critical link is one whose volume is in excess of 98% of the maximum volume allocated by the specified v/c ratio.

If all trips are not assigned after an iteration, new travel times based on the present volume levels are computed. Times for the critical link or links are increased by 500 minutes. The new travel times are used to build revised minimum time paths for the next iteration. The large times assigned to critical links will insure that new time paths excluding these links will be found. This, thus, insures a further loading of trips for the new iteration.

Travel Time Update

Updated travel times and speeds are required for all link types except those designated as dummy and local links. For this purpose,

volume-travel time functions were developed for each of the other link types; intersection-delay and link-delay links. Based on the values of specified parameters, the travel time of an individual link can be determined from the appropriate link type function.

The volume-travel time functions are derived from speed-volume relationships which can be measured by moving observing methods. From these relationships, points of free, critical, and maximum flow are determined as shown in Figure 11. Based on the speeds and volumes associated with each point and the slopes of the straight line approximations of the curve, linear equations describing a volume-travel time (minutes per mile) relationship can be determined (8).

The equations for link travel times along with those describing average intersection delay, where applicable, are used to determine total link travel times. Typical total travel time functions for each link type are developed in the following manner:

1. Intersection-delay link function. Intersection-delay links are arterials with intersections at their exit nodes, which add delay to the link. The average intersection delay as a function of volume can be represented by observed characteristics or by one of several equations developed for this purpose. The total intersection-delay link travel time is, thus, computed as follows:

$$\text{for } 0 \leq V_i \leq V_{c_i} : t_i = \{t_{c_i} + m_{o_i} [V_i - (l_i) (V_{c_i})]\} d_i + D(V) \quad (5.6)$$

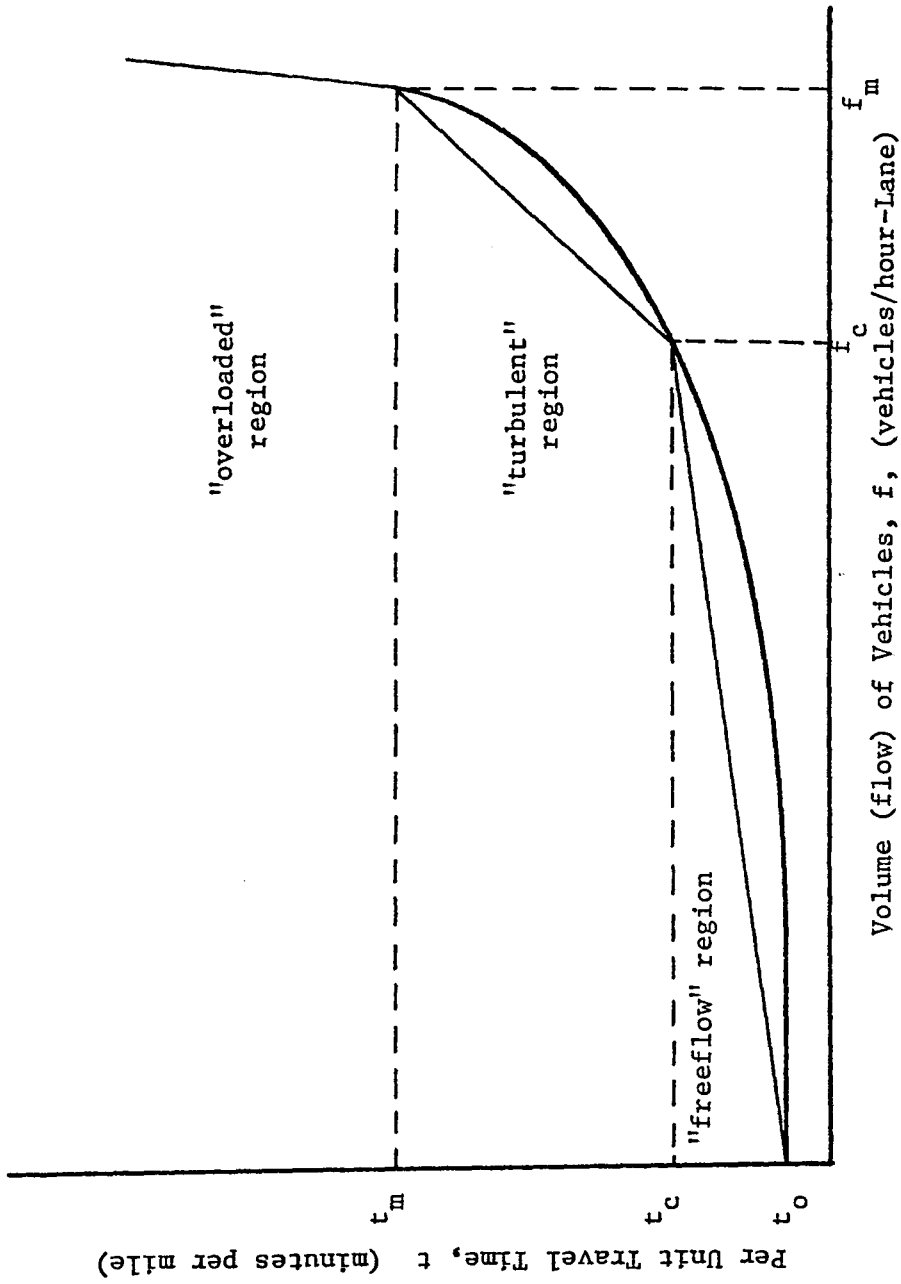


Figure 11. A typical volume-travel time function

$$V_{c_i} < V_i \leq V_{m_i} : t_i = \{t_{c_i} + m_{c_i} [V_i - (\ell_i) (V_{c_i})]\} d_i + D(V)$$

$$V_{m_i} < V_i : t_i = \{t_{m_i} + m_{m_i} [V_i - (\ell_i) (V_{m_i})]\} d_i + D(V)$$

where: V_{c_i} = critical volume for link i

V_{m_i} = maximum volume for link i

t_{c_i} = travel time per mile at critical volume

t_{m_i} = travel time per mile at maximum volume

m_{o_i} = slope for "free flow" region

m_{c_i} = slope for the "turbulent" region

m_{m_i} = slope for the "overloaded" region

d_i = length of link i

ℓ_i = number of lanes on link i

$D(V)$ = delay value for intersections based on the volume level.

2. Link-delay link functions. Link-delay links are arterials and expressways which do not experience delay at intersection nodes. Therefore, the total travel time equations for link-delay links are the same as for intersection-delay links except that the intersection delay factor is excluded.

Average Parking Cost Update

As was discussed in Chapter III, average parking costs are expected to vary with different levels of bus diversion. A function describing the situation for a particular area should be developed. It can be implemented into TRANSFARE at a point specified by the program. Values computed by the function must be labelled by program variable, PCA.

Total Community Transportation Cost Function

The total cost function was developed previously (equation 4.10). To determine values for some of its components, such as total vehicle-miles and vehicle-hours, a large amount of computations are required. Through procedures provided by TRANSFARE, these computations can be performed rapidly.

For the computation of the total vehicle-miles traveled by each mode, the following formulas were utilized.

For total auto vehicle-miles:

$$A_m = \sum_{i=1}^n (d_i) (v_{a_i}) \quad (5.7)$$

where: A_m = total auto vehicle-miles

v_{a_i} = auto volume on link i for a specified period

d_i = length of link i

n = total number of links

For total bus vehicle-miles:

$$B_m = \sum_{i=1}^n (d_i) (v_{b_i}) \quad (5.8)$$

where: B_m = total bus vehicle-miles

v_{b_i} = bus volume on link i for a specified period

The total travel time for each mode is determined by the total vehicle-minutes of travel.

For autos:

$$A_t = \sum_{i=1}^n (a_{t_i}) (v_{a_i}) \quad (5.9)$$

where: A_t = total auto vehicle-minutes of operation

a_{t_i} = present travel time on link i

For buses:

$$B_t = \sum_{i=1}^n (b_{t_i}) (v_{b_i}) \quad (5.10)$$

where: B_t = total bus vehicle-minutes of operation

b_{t_i} = present bus travel time on link i

Optimization Search Procedure

When all possible facility arrangements are presented, forming a concave cost function, an optimum can be determined. In the case of

TRANSFARE, an heuristic search procedure was developed to determine the optimum level of bus service to be implemented into the system.

To accomplish the search, the total community transportation costs associated with each level of bus service is tested and compared with the previous test to determine which is the smaller value. As long as the total costs decrease, the procedure will search at designated increments. This will continue until the new cost becomes greater than the one immediately previous to it. The search increment will then be reduced to half its initial size and the search direction is reversed. Searching continues in this direction until an increase in total community costs is again noted whereupon the process of halving the increment and reversing the direction is once again applied. The search procedure will continue until the increment is less than or equal to 1%. At this point it is assumed that the optimum has been found.

To institute this procedure, all that is necessary is to make the computer parameter, KSRCH = 1. The necessary instructions for this are given in the input section of Appendix B.

Output

The major output provided by TRANSFARE is the fare and total community costs for each balanced facility arrangement which is evaluated. In addition, the final bus trip distribution is given. This provides an indication of the bus fleet size and scheduling

requirements. Finally, the anticipated volumes and speeds are listed for every link in the network. A list of the output formats for the aforementioned information as well as additional intermediate outputs are given in Appendix B.

VI. APPLICATION OF TRANSFARE

Description

In order to demonstrate the capabilities of TRANSFARE, the program was applied to a sample urban area with an assumed existing roadway network as shown in Figure 12. The area was assumed to be one of approximately 20,000 population, having 10 major zones (6 centroids and 4 gateways) of activity. The trip productions and attractions (Appendix D, Table I) were based on typical morning peak hour flow. In all it was assumed that 8800 person trips would be made during this time.

The network itself was composed of 108 links and 39 nodes. The characteristics of each individual link are given in Appendix D, Table II. It was assumed, for simplification, that all link-delay links and intersection-delay links had the same physical dimensions with a maximum attainable speed of 30 miles per hour. This assumption thus meant that all of these link types in the network had the same per lane capacity. For trip assignment purposes, a maximum allowable v/c ratio of 1.0 was utilized.

All other input data was researched so that the values used would be realistic. The values for constant data and explanations of variable functions are given in Appendix D.

Four data sets were examined. They were selected to show the sensitivity of the model to changes in the value of time and bus size.

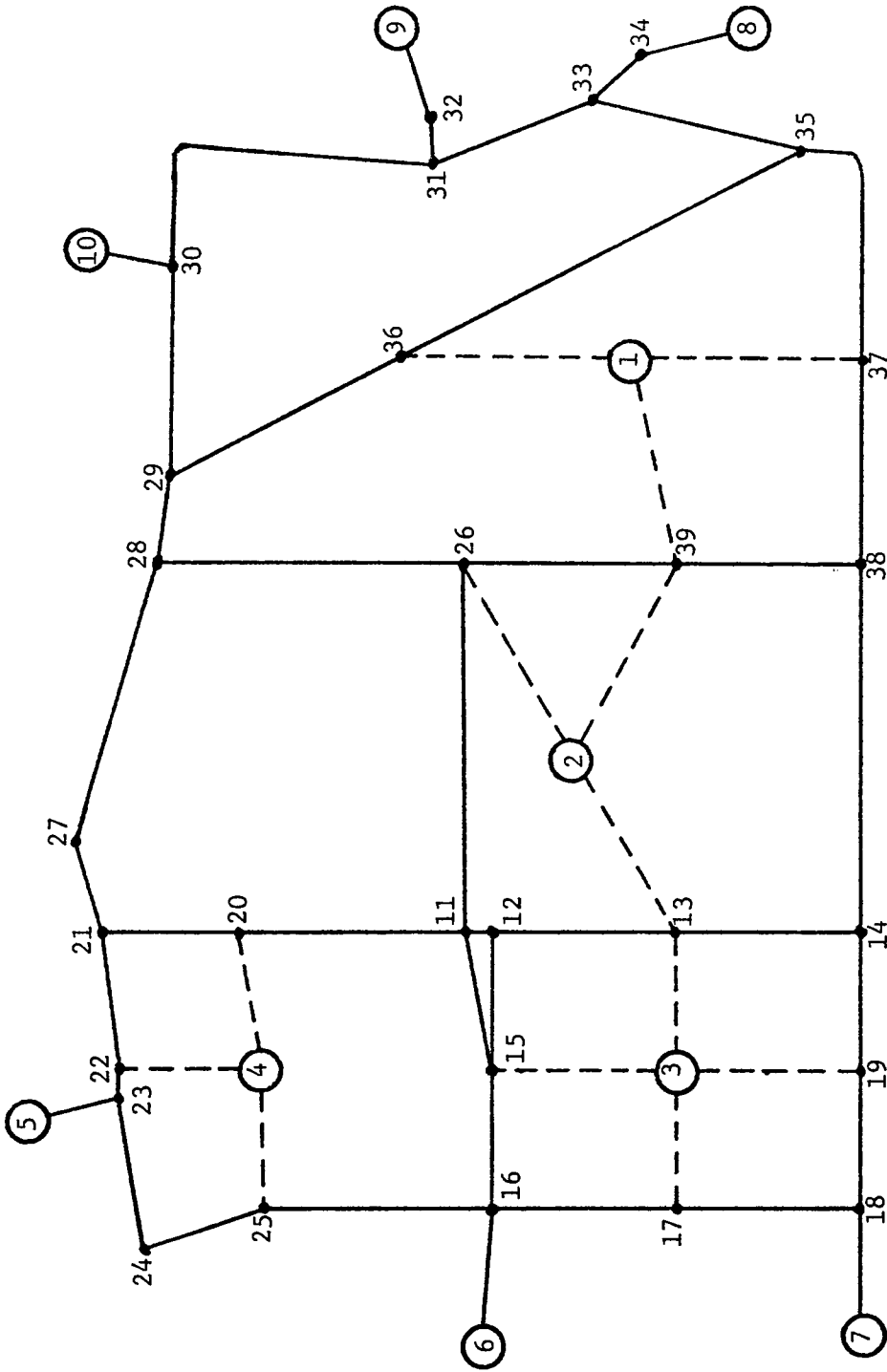


Figure 12. Network representation of the sample urban area

All other data remained the same. The four runs that were performed consisted of the following:

1. Value of time = \$.05/min
Bus capacity = 40 passengers
2. Value of time = \$.05/min
Bus capacity = 50 passengers
3. Value of time = \$.03/min
Bus capacity = 50 passengers
4. Value of time = \$.07/min
Bus capacity = 50 passengers

Initially, the evaluation of bus service implementation at 10% intervals was performed for each data set. The search procedure provided by TRANSFARE was then applied to determine the optimum percentage of diversion of bus trips to total trips and the standard bus fare that should be charged at this level. The results of the evaluation for the data sets are plotted in Figures 13 through 16.

Analysis of Results

Overall, the functions derived for the data sets were basically concave. Where no bus service existed the effects of congestion and large travel times were indicated by high total community transportation costs. As more bus service was implemented, travel times improved and bus fares decreased at rates which outweighed the effect of increased per auto parking and toll costs. Eventually, as average speeds neared the specified 30 m.p.h. limit, the rate of improvement in travel times

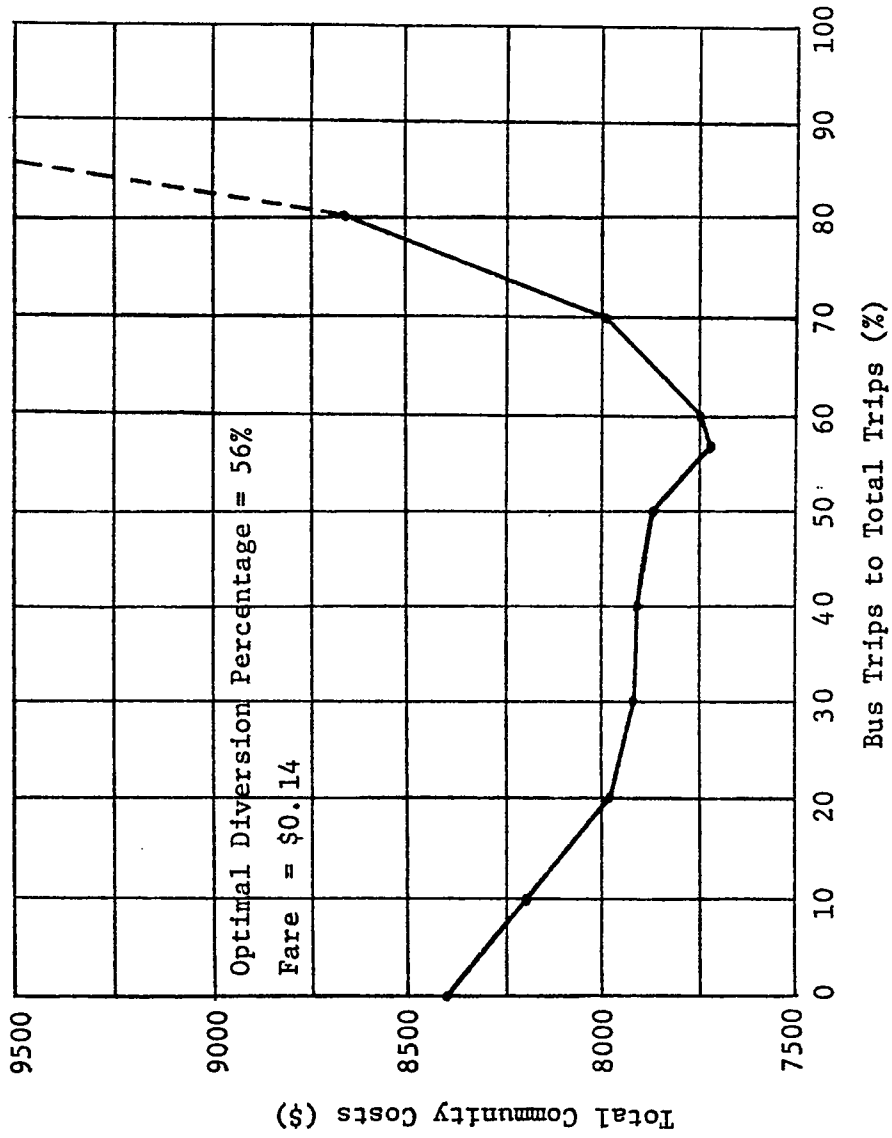


Figure 13. Total community costs vs. diversion percentage for value of time = \$.05 and bus capacity = 40

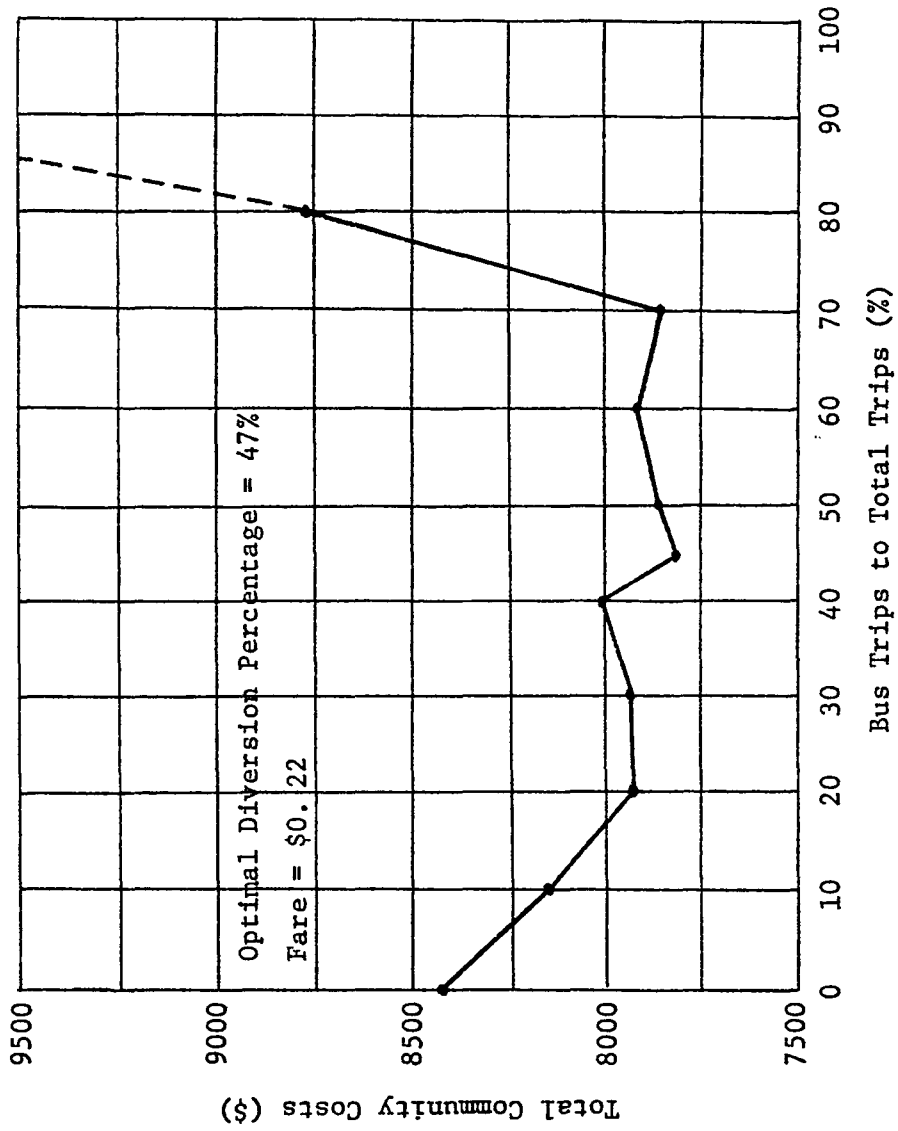


Figure 14. Total community costs vs. diversion percentage for value of time = \$.05 and bus capacity = 50

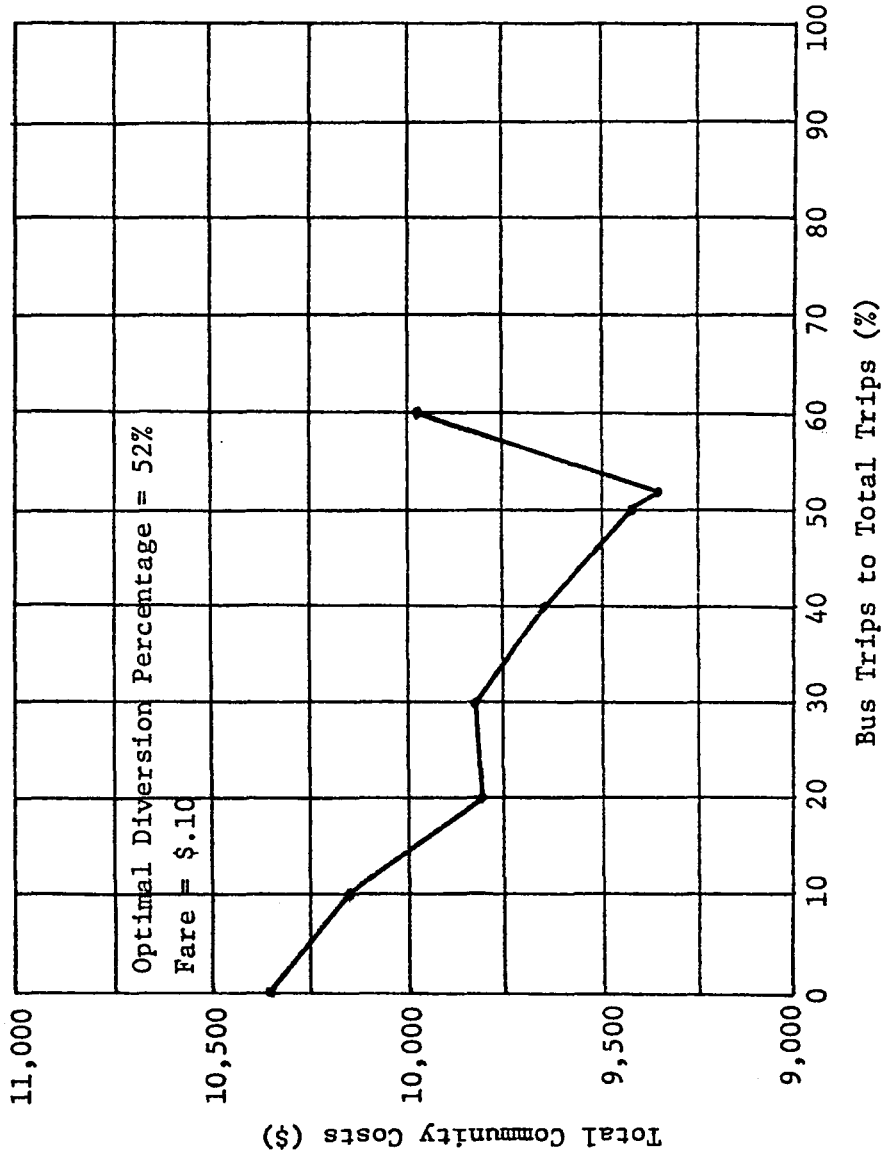


Figure 15. Total community costs vs. diversion percentage for value of time = \$.07 and bus capacity = 50

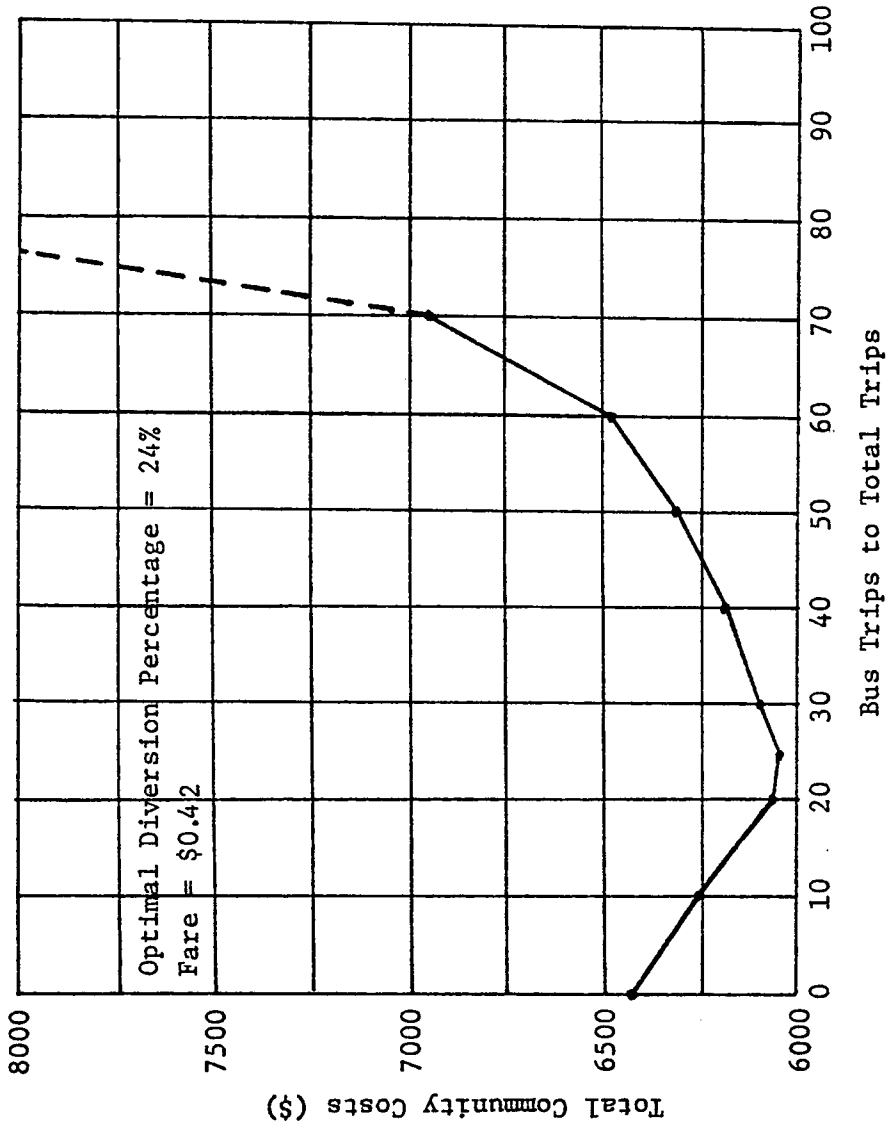


Figure 16. Total community costs vs. diversion percentage for value of time = \$.03 and bus capacity = 50

was not as pronounced and the rising parking and toll costs caused increases in auto trip costs. By the design of the intermodal balancing model, the larger auto trip costs caused bus fares to increase in order that the required cost difference could be achieved. The combined effect of increasing auto and bus trip costs brought about a growth in total community transportation costs at higher levels of diversion.

The percentage of bus service specified as optimal for the sample area appeared to be exceptionally high for the four data sets. This can be attributed to several causes. One is the fact that the initial assignment of traffic volumes was poor. That is, traffic was not assigned as uniformly as one might expect in existing urban areas. The major causes for this undoubtedly stemmed from the network which was utilized and the travel demand patterns which were assumed. The network had too few zones and a lack of equivalent alternative routes. This caused traffic to be concentrated on one route which, although operating at a poor level of service, still provided the minimum time path between a pair of zones. This initially brought about an imbalance of roadway usage where some links were heavily loaded while others were barely used. Since an objective of TRANSFARE is to balance level of service, buses were added to the heavily traveled routes. However, more bus service was implemented than was necessary because some of the lesser used arterials were capable of carrying much more volume, while still offering speeds of 30 m.p.h. For an actual situation, the assignment process will undoubtedly perform more accurately due to a better distribution of trips and a more complete network.

Another possible reason for high optimal values was due to the input data used. This data was selected either through research or by assumption. At best, this information could only be truly indicative of an average situation. Much more accurate results can be obtained if data values representative of the study area are collected.

A look at the effect of varying time values and bus capacities revealed that TRANSFARE is indeed sensitive to such changes. In the case of varying bus capacities (Figures 13 and 14), it was shown that the greater the capacity the less the optimal diversion percentage. Since both bus sizes were assumed to have an equivalency of 3.0 p.c.u.'s, the larger bus reduced volumes at a faster rate as diversion increased. For changes in the value of time (Figure 14, 51, and 16), TRANSFARE proved to be exceptionally sensitive. It indicated that the greater the time value, the greater the optimal division percentage. This is primarily due to the fact that larger time values cause time costs to form a greater percentage of the total transportation community costs. This means that initial total community costs are higher and, as more bus service is introduced, the total time costs are more significant. Therefore, minimum total transportation community costs are realized at a higher diversion percentage.

VII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The development of procedures for determining the best roadway-oriented facility arrangements in urban areas yielded the following general observations:

1. Given certain information about the roadway network, the expected travel pattern, and modal operating characteristics and expenses, the best facility arrangement can be determined from a set of alternatives. The validity of such a selection depends, of course, on the accuracy and depth to which such information is accumulated.
2. Computer-oriented applications such as that performed by TRANSFARE allow the inspection of facility arrangements for an entire urban transportation system. The most significant advantage of such a capability is that interrelationships between all facilities can be measured so that system wide balanced level of service can be attained.
3. The ability of the evaluation process to determine the best transportation facility arrangement offers a strong planning tool. The process can be inserted into the travel prediction sector of the transportation system planning

process. Unlike other travel prediction models, this evaluation process yields arrangements for an urban area which provide both balanced and acceptable levels of service for any point in time based on predicted travel demand.

4. The application of the evaluation process indicates not only the fare structure and diversion percentage for the best facility arrangement, but also gives an indication of the capital costs required to achieve such a configuration. With this information, facility addition scheduling for obtaining the facility arrangement which is prescribed as best can be developed. In some cases the best facility arrangement may be economically infeasible from an investment standpoint. In such cases, the results of the evaluation process can offer some direction for the allocation of available funds.

Recommendations

The methodology introduced in this study forms the basis for the evaluation of arrangements of any and all types of facilities in the urban transportation system. In order to provide these capabilities as well as improving the overall effectiveness of the procedures developed herein, extensions to this study must be considered. Possible directions for further research would be:

1. The expansion of facility arrangement procedures to include modes other than buses and autos. This would require adjustments to the modal split techniques employed herein and the incorporation of those characteristics associated with the new modes.
2. The development of level of service balancing procedures for the implementation of all types of facilities other than just buses.
3. The expansion of the community transportation cost function to include changes in subjective costs. For instance, reduced volumes would bring about sizeable benefits to the community in the form of reduced accidents, decreased noise and air pollution, etc. which are not presently measured.
4. The development of functions for items assumed constant in this study. Such items would include occupancy rates, running costs, etc. which can vary with volume changes. Their variance may have a significant effect on community transportation cost calculation.
5. The development of standard computer subprograms for determining parking costs, utilization costs, etc. These subprograms could be instituted into TRANSFARE to make its application even more simplified.
6. The application of TRANSFARE to a large existing urban area to see what type of results occur. Such an

application would provide a measurement of the validity of the results obtained by applying the techniques developed in this study. This would serve to show where added refinements to TRANSFARE may be needed.

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APPENDIX A

GLOSSARY OF WIDELY USED VARIABLES

A_m = total auto vehicle-miles

A_r = total auto riders

A_t = total auto vehicle-minutes

B_m = total bus vehicle-miles

B_t = total bus vehicle-minutes

D'_A = average auto-bus trip cost difference for all zones

D'_{ij} = average auto-bus trip cost difference for travel between
zones i and j

$D'_{ij} = D_{ij} - f'_{ij}$

F = standard urbanwide bus fare

P_d = prescribed percentage of total bus trips (diversion percentage)

S_i = total trips produced by zone i

T_j = total trips attracted to zone j

$a_{t_{ij}}$ = travel time from zone i to zone j

$b_{t_{ij}}$ = average bus travel time from zone i to zone j

c_p = average parking cost per auto

c_r = average per mile running costs

c_{r_p} = "perceived" average per mile running costs

c_t = average toll costs per auto

$c_{t_{ij}}$ = toll costs per auto on route i - j

d_{ij} = distance between zones i and j

f_{ij} = calculated fare for travel between zones i and j

f'_{ij} = bus fare for travel between zones i and j

h = total number of zones

o_a = average auto occupancy

o_b = average bus occupancy

t_{bij} = bus trips between zones i and j

t_{tij} = total trips between zones i and j

$v_{a_{ij}}$ = auto volumes going from zone i to zone j

$v_{b_{ij}}$ = bus volumes going from zone i to zone j

v_t = value of time in dollars per minute

x = a parameter based on social and economic factors

y = a parameter based on existing traffic conditions

APPENDIX B

INPUT-OUTPUT FORMATS FOR TRANSFARE

Input

1. The first parameter card containing:
 - a. The number of centroids and gateways in c.c. 2-5.
 - b. The number of links in c.c. 7-10.
 - c. The highest node number in c.c. 12-15.
 - d. The maximum number of iterations to be run in c.c. 20.
 - e. The percent of capacity to which the critical link is to be loaded, to one decimal place, in c.c. 22-25.
This is 100 times the highest v/c ratio desired.
 - f. The percent of the highest v/c ratio (specified in d above) which defines "almost critical" links which are also to be removed from the network. Suggested value = 98.0 or higher. Expressed to one decimal place in c.c. 27-30.
2. A data card for each link
 - a. Node from in c.c. 6-10.
 - b. Node to in c.c. 11-15.
 - c. Initial travel time in c.c. 16-21.
 - d. Link length in c.c. 22-27.
 - e. Link speed in c.c. 28-31.
 - f. Link capacity in c.c. 32-39.
 - g. Capacity class in c.c. 40-42.
 - h. Number of lanes in c.c. 43-44.

3. A data information card containing:
 - a. Average per mile running costs in c.c. 5-10.
 - b. Average per mile "perceived" running cost in c.c. 15-20.
 - c. Initial per unit toll costs in c.c. 25-30.
 - d. Value of time per minute in c.c. 35-40.
 - e. Average per mile bus operating costs in c.c. 45-50.
4. Another information card containing:
 - a. Average peak hour bus occupancy in c.c. 5-10.
 - b. Average peak hour auto occupancy in c.c. 15-20.
 - c. Bus equivalency factor (p.c.u.) in c.c. 25-30.
5. Another information card containing:
 - a. Initial diversion percentage in c.c. 5-12.
 - b. Initial diversion percentage increment in c.c. 20-25.
 - c. The number "1" in c.c. 35 if an optimization procedure is desired; leave blank if successive levels of bus service are to be tested.
6. One or more volume-travel time function parameter cards containing:
 - a. The critical volume in c.c. 1-10.
 - b. The maximum volume in c.c. 11-20.
 - c. The critical travel time in c.c. 21-30.
 - d. The travel time at maximum volume in c.c. 31-40.
 - e. The slope for the free flow region in c.c. 41-50.
 - f. The slope for the turbulent region in c.c. 51-60.
 - g. The slope for the overloaded region in c.c. 61-70.

7. The second parameter card containing:
 - a. The lowest gateway number in c.c. 4-5.
8. The terminal times, to two decimal places (minutes). That for zone 1 is placed in c.c. 1-5, that for zone 2 in c.c. 6-10, etc. The first sixteen zones appear on one card, zones 17 and up on the second card (if needed).
9. A third parameter card containing:
 - a. The value for "x" to be used in the distribution formula, to three decimal places, in c.c. 7-11.
 - b. An acceptance level for the error of closure, to one decimal place, in c.c. 13-15. Suggested value = 1.0.
 - c. The maximum number of iterations to be run, in case the desired acceptance level for the error closure is not achieved, in c.c. 20. (Suggested value = 6).
 - d. The value for "y" to be used in the bus trip distribution formula, to three decimal places in c.c. 22-26.
10. The trip productions or origins, punched in groups of eight, each using a field of eight card columns. C.c. 1-8 of the first card contain trip origins for zone 1, c.c. 9-16 those for zone 2, etc. C.c. 1-8 of the second card contains trip origins for zone 9, etc. For gateways, origins of only "external-internal" trips are listed.

Output

For the base travel scheme:

1. A series of minimum-path trees, listing the travel time from origin to each destination and then the nodes passed through from the origin in reverse order; the last node number reported is the home node of the tree. In the first iteration the output should be checked against the network map for realism. If some minimum paths appear to be unduly circuitous or otherwise unrealistic, the original link data and its coding should be checked.
2. A table of trip productions and attractions listed by zones.
3. A report on the error of closure for every iteration of the total trip distribution.
4. The final trip matrix indicating the total person trips to be used in loading the network. Each line contains eight values, plus an identification of the form "FTM 3, 9-16." "FTM" identifies the final trip matrix, "3" is the origin node, and the eight person trip values apply. Zeros appear both for intrazonal and intergateway trip interchanges and beyond the last gateway to the end of the line.
5. A cumulative distribution of trips, grouped according to trip length in minutes.

For every travel scheme

6. The matrix of minimum travel times as computed from the minimum-paths trees. Each line contains eight values,

plus an identification of the form "TTM 3, 9-16." "TTM" identifies this as a travel time matrix.

7. The travel-time matrix with terminal times (input item 8) added in the same form as output item 6 above.
8. The final bus trip matrix to be used in loading the network. Each line contains eight values, plus an identification of the form "BTM 3, 9-16." "BTM" identifies the bus trip matrix.
9. Other pertinent output information:
 - a. Specified percentage of total person trips diverted to buses.
 - b. Actual total number of auto person trips.
 - c. Actual total number of bus person trips.
 - d. Actual per bus ridership.
 - e. Standard bus fare.
 - f. Total revenue from bus fares.
 - g. Total bus operating costs.
 - h. Total community costs.

For each trip loading iteration:

10. a. A report of the iteration number, the identity of the critical link, the percent of the complete trip matrix loaded in this iteration, and the total loaded in all iterations so far.
- b. A new link listing, reporting the current loadings on each link, the newly-computed travel times for arterial links,

and the newly-computed speeds. The original trip times and speeds are also reported for comparison purposes. Each link is identified as being a local or dummy link, or-if an arterial link--how it was handled:

- (1) "V/C UNDER 0.5" indicates that the v/c ratio 0.5, and that the original travel time was retained.
- (2) "INTERS. DELAY" indicates a link whose trip time was adjusted by means of the intersection delay formula.
- (3) "LINK DELAY" indicates a link whose trip time was adjusted by means of the link delay formula.
- (4) "*SATURATED*" indicates a link which has been "removed" from the network because it is the critical link or an "almost critical" link.
(KAPCL changed to 5).

APPENDIX C


```

C TC2 = CRITICAL TIME
C TM2 = MAXIMUM TIME
C D02 = SLOPE FOR FREE FLOW REGION
C DC2 = SLOPE FOR CRITICAL FLOW REGION
C DM2 = SLOPE FOR TURBULENT FLOW REGION
C PD = PERCENTAGE OF BUS TRIPS TO TOTAL TRIPS
C DIP = INCREMENT FOR THE DIVERSION PERCENTAGE
COMMON/BLOK1/ NO(600),ND(600),TLINK(600),TCUM(150),NCUM(150),
IN(150),NN(150),TSUM(300),K1(300),DCUM(150),DSUM(300)
COMMON/BLOK2/ ULINK(600),VOL(600),USPD(600),CAP(600),KKPCL(600)
1 ,AVOL(600),BVOL(600),AVCUM(600),BVCUM(600),NL(600),KAPCL(600),
2 VCUM(600),DIST(600),SPD(600)
COMMON/BLOK3/BTR(40,40),TR(40,40),D(40,40),RD(40,40),TP(40,40)
COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,D8,OA,EB,BOC,IDIST,CPR,ICNT,DIP,
1 ITER,NCENT,NLINK,NNODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
COMMON/BLOK5/ VC2,VM2,TC2,IM2,D02,DC2,DM2
COMMON/BLOK6/ S(40),T(40),TG(40),F(40),TGW(40),T1(32),P(32),C(40),
1 BTGW(40),TTRMNL(40)
READ (5,100) NCENT,NLINK,NNODE,MAXIT,Q,QQ
100 FORMAT (4I5,2F5.1)
C READ IN LINK DECK
READ (5,101)(VOL(I),NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
1 KKPCL(I),NL(I),VCUM(I),ULINK(I),USPD(I),I=1,NLINK)
101 FORMAT (1I,4X,2I5,2F6.2,F4.0,F8.0,I3,1X,I1,1X,F9.0,F7.2,F4.0)
C INITIALIZE DATA
READ (5,931) CRA,PCA,CTA,VT,CPR,BOC
931 FORMAT (6(5X,F5.2))
READ (5,932) OB,OA,EB
932 FORMAT (3(5X,F5.2))
READ (5,934) VC2,VM2,TC2,IM2,D02,DC2,DM2
934 FORMAT (4F10.3,3F10.6)
READ (5,933) PD,DIP,KSRCH

```

```

933 FORMAT (5X,F7.4,8X,F5.2,4X,I1)
      IDIST = 0
      NB = 0
      J2 = 1
      I3 = -1
      I2 = 1
      PTUC = 9999999.
      HOB = OB/2.
      DO 76 I = 1,40
      DO 76 J = 1,40
76   TP(I,J) = 0
83   ICNT = 0
194  ITER = 0
      NBT = 0
      L1 = 1
      K1(L1) = 1
      DO 49 I=1,NLINK
      KAPCL(I) = KKPCL(I)
      VCUM(I) = 0
      BVOL(I) = 0
      AVOL(I) = 0
      VOL(I) = 0
      AVCUM(I) = 0
      BVCUM(I) = 0
      IF (ICNT.EQ.1) GO TO 49
      ULINK(I) = TLINK(I)
49  CONTINUE
      DO 2 I = 2,NLINK
      IF (NO(I)-NO(I-1)) 2,2,43
43  L1 = L1 + 1
      K1(L1) = I
      2  CONTINUE

```

```

DO 92 I=1,40
DO 92 J=1,40
D(I,J) = 0
92 RD(I,J) = 0.
IF (IDIST.EQ.1) GO TO 93
893 DO 892 I=1,40
DO 892 J=1,40
892 TR(I,J) = TP(I,J)
93 CONTINUE
C FIND MINIMUM TIME PATHS BETWEEN ZONES
CALL TREE
IF (ITER.GT.0) GO TO 31
C DISTRIBUTE BUS AND TOTAL TRIPS
CALL TRIPS
ITER = 1
IF (IDIST.EQ.0) GO TO 893
GO TO 93
31 CONTINUE
C ASSIGN TRAFFIC TO THE ROADWAY NETWORK
CALL LOAD
C ITERATION OR EXIT
IF (100.-A) 79,79,91
91 ITER = ITER + 1
IF (ITER-MAXIT) 94,94,79
94 NHOME = 1
DO 97 L=1,NLINK
AVOL(L) = 0
BVOL(L) = 0
97 VOL(L) = 0.
GO TO 93
79 ICNT = ICNT + 1
C SUBSTITUTE PARKING FUNCTION (PCA)

```

```

561 DO 831 I=1,NLINK
    IF (ULINK(I).GT.500.) GO TO 832
    GO TO 831
832 ULINK(I) = ULINK(I) - 500.
831 CONTINUE
    IF (ICNT.EQ.1) GO TO 194
    COMPUTE TCTAL COMMUNITY COSTS
    CALL COSTS
    IDIST = 1
    C SEARCH PROCEDURE IS EMPLOYED IF KSRCH = 1
    IF (KSRCH.EQ.1) GO TO 201
    C ARRANGEMENTS TO BE TESTED AT SELECTED INTERVALS
    PD = PD + DIP
    IF (PD.GT.1.) GO TO 84
    GO TO 83
201 IF (TUC-PTUC) 42,42,44
44 IF (DIP.LE.0.01) GO TO 84
    I2 = I2 + 1
    I3 = (-1)*I2
    JJ = 2*J2
    J2 = JJ
    DIVINC = DIP/J2
    DIP = DIVINC
42 PD = PD - DIP*I3
    PTUC = TUC
    GO TO 83
84 WRITE (6,122) PD,TUC
122 FORMAT ('1', ' FINAL DIVERSION PERCENTAGE = ',F6.4, ' TOTAL USER
    1 COST = ',F12.2)
99 STOP
    END

```

```

C
C
C
C
SUBROUTINE TRIPS
  DISTRIBUTE BUS AND TOTAL TRIPS
  TRIP ASSIGNMENT ANALYSIS
  LGATE = LOWEST GATEWAY NUMBER
  D(I,J) = DISTANCE BETWEEN ZONES I AND J IN MINUTES
  COMMON/BLOK2/ ULINK(600),VOL(600),USPD(600),CAP(600),KKPCL(600)
  1 ,AVOL(600),BVOL(600),AVCUM(600),BVCUM(600),NL(600),KAPCL(600),
  2 VCUM(600),DIST(600),SPD(600)
  COMMON/BLOK3/BTRCOM(40,40),TR(40,40),D(40,40),RD(40,40),
  1 TRCOM(40,40)
  COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,CB,QA,EB,BOC,IDIST,CPR,ICNT,DIP,
  1 ITER,NCENT,NLINK,NNODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
  COMMON/BLOK6/ S(40),T(40),TG(40),F(40),TGW(40),T1(32),P(32),C(40),
  1 BTGW(40),TTRMNL(40)
  COMMON/BLOK7/ BTR(40,40)
  IF (ICNT.EQ.1) GO TO 500
  IF (IDIST.EQ.1) GO TO 500
  READ (5,300) LGATE
  300 FORMAT (I5)
  C
  C
  C
  PREPARE TRAVEL TIME MATRIX
  TRIP TIME BETWEEN TWO GATEWAYS IS ZERO, SO THAT NO THROUGH TRIPS
  WILL BE ASSIGNED
  500 DO 207 I=LGATE,NCENT
  DO 207 J=LGATE,NCENT
  207 D(I,J) = 0
  IF (ICNT.EQ.0) GO TO 285
  WRITE (6,401)
  401 FORMAT (1H1/36H COMPUTED MINIMUM TRAVEL TIME MATRIX//)
  DO 403 I=1,NCENT
  DO 403 J=1,NCENT,8
  J1 = J + 7
  403 WRITE (6,303) (D(I,K),K=J,J1),I,J,J1

```

```

303 FORMAT (8F8.2,2X,3HTTM,I2,1H,I2,1H-,I2)
285 CONTINUE
      IF (IDIST.EQ.1) GO TO 501
      IF (ICNT.EQ.1) GO TO 501
C    READ IN TERMINAL TIMES TO BE ADDED AT EACH CENTROID
      READ (5,305) (TTRMNL(I),I=1,NCENT)
305 FORMAT (16F5.2)
501 CONTINUE
      DO 203 I=1,NCENT
      DO 203 J=1,NCENT
      IF (D(I,J)) 208,203,208
208 D(I,J)=D(I,J)+TTRMNL(I)+TTRMNL(J)
203 CONTINUE
      IF (ICNT.EQ.0) GO TO 185
      WRITE (6,407)
407 FORMAT (1H1/45H TRAVEL TIME MATRIX WITH TERMINAL TIMES ADDED//)
      DO 220 I=1,NCENT
      DO 220 J=1,NCENT,8
      J1 = J + 7
220 WRITE (6,303) (D(I,K),K=J,J1),I,J,J1
185 CONTINUE
      IF (ICNT.EQ.1) GO TO 84
C    TRIP ASSIGNMENT BY GRAVITY MODEL OR EXPONENTIAL DISTRIBUTION
C    X = EXPONENT IN TOTAL TRIP DISTRIBUTION EQUATION
C    Y = EXPONENT IN BUS TRIP DISTRIBUTION
C    A = ACCEPTANCE LEVEL FOR CLOSURE
C    MAXIC = MAX. NO. OF ITERATIONS TO BE RUN IN CASE ERROR DOES NOT CLOSE
C    S(J) = TRIP PRODUCTIONS FROM ZONE J
C    T(J) = TRIP ATTRACTIONS TO ZONE J
C    TG = ITERATED VALUE OF T
C    TR(I,J) = TRIPS FROM ZONE I TO ZONE J
      DO 10 I=1,40

```

```

DO 10 J=1,40
  BTRCOM(I,J) = 0
  10 BTR(I,J) = 0
  IF (IDIST.EQ.1) GO TO 502
  READ (5,100) X,A,MAXIC,Y
  100 FORMAT (5X,F6.3,F4.1,I5,F6.3)
  502 ITNO = 0
  IF (IDIST.EQ.1) GO TO 6
  READ IN TRIP PRODUCTIONS, AND TRIP ATTRACTIONS IF DIFFERENT.
  READ (5,101) (S(J),J= 1,NCENT)
  101 FORMAT (8F8.0)
  READ (5,101) (T(J),J=1,NCENT)
  6 DO 7 J=1,NCENT
    7 TG(J) = T(J)
    IF (IDIST.EQ.1) GO TO 1
    WRITE (6,110)
  110 FORMAT (1H1/33H ZONE PRODUCTIONS ATTRACTIONS/)
    WRITE (6,111) (J,S(J),T(J),J=1,NCENT)
  111 FORMAT (14,6X,F8.0,6X,F8.0)
    4 WRITE (6,109)
  109 FORMAT (1H1/18H TOTAL TRIP MATRIX//)
    1 DO 20 J=1,NCENT
      20 F(J) = 0
  C DISTRIBUTE TRIPS
    ITNO = ITNO + 1
    SSF = 0
    SS = 0
    DO 21 I=1,NCENT
      IF (S(I)-1.) 52,52,5
    52 DO 55 J=1,NCENT
      55 TR(I,J) = 0
      F(I) = 1.

```

```

GO TO 21
5 SUM = 0
BSUM = 0.
DO 51 J=1,NCENT
IF (D(I,J)) 44,44,45
45 IF (RD(I,J)) 44,44,54
44 TGW(J) = 0
BTGW(J) = 0.
GO TO 137
54 BTGW(J) = TG(J)/(((RD(I,J))/D(I,J))*60.):**Y)
TGW(J) = TG(J)/(RD(I,J)**X)
137 BSUM = BSUM + BTGW(J)
51 SUM = SUM + TGW(J)
DO 61 J=1,NCENT
DISTRIBUTE TOTAL TRIPS
TR(I,J) = (S(I)*TGW(J))/SUM
DISTRIBUTE BUS TRIPS
BTR(I,J) = ((S(I)*BTGW(J))/BSUM)*PD
IF (BTR(I,J).GT.TR(I,J)) BTR(I,J) = TR(I,J)
61 F(J) = F(J) + TR(I,J)
21 CONTINUE
DO 91 J=1,NCENT
SLF = T(J) - F(J)
SLF = ABS(SLF)
SSF = SSF + SLF
91 SS = SS + T(J)
ERR = SSF*100./SS
IF (IDIST.EQ.1) GO TO 75
WRITE (6,105) ITNC,ERR,X
105 FORMAT (14H ITERATION NO.,I3,5X,7H ERRCR=,F6.2,12H EXPONENT=,F7.3
1 )
75 IF (ERR-A) 84,84,40

```

```

40 IF (MAXIC-ITNO) 84,84,41
41 DO 42 J=1,NCENT
42 TG(J) = TG(J)*T(J)/F(J)
   GO TO 1
84 CONTINUE
   IF (ICNT.EQ.0) GO TO 86
   CALL BALNCE
   C      OBTAIN INTERMODAL BALANCE
   C      WRITE OUT TOTAL TRIP MATRIX, AND DISTRIBUTION OF TRIPS BY LENGTH
   C      GO TO 837
86 DO 737 II=1,NCENT
   DO 737 IJ=1,NCENT
737 BTRCOM{II,IJ} = BTR{II,IJ}
   IF (IDIST.EQ.1) GO TO 837
76 TOTAL = 0
   DO 33 I=1,32
33 T1(I) = 0
   DO 50 I=1,NCENT
   DO 30 J=1,NCENT
   IF (TR(I,J)) 37,30,37
37 IF (D(I,J)) 34,32,34
34 IF (D(I,J)-31.) 36,36,38
38 M = 32
   GO TO 31
36 M = IFIX(D(I,J))
31 T1(M) = T1(M) + TR(I,J)
32 TR(I,J) = TR(I,J) + 0.5
   TRCOM(I,J) = TR(I,J)
30 CONTINUE
   DO 59 J=1,NCENT,8
   J1 = J + 7
   IF (J1-NCENT) 59,59,49

```

```

49 N = NCENT + 1
   DO 48 L = N,J1
48  TR(I,L) = 0
59  WRITE (6,108) (TR(I,K),K=J,J1),I,J,J1
108 FORMAT (8F8.0,2X,3HTTM,I2,1H,I2,1H-,I2)
50 CONTINUE
   DO 24 L=1,32
24  TOTAL = TOTAL + T1(L)
   DO 23 L = 1,32
23  P(L) = T1(L)*100./TOTAL + 0.005
   WRITE (6,103)
103 FORMAT (1H1/13H TRIP LENGTH,6X,6HNO. OF,6X,7HPCT. OF,3X,
110HCUMULATIVE,/3X,9H(MINUTES),7X,5HTRIPS,8X,5HTOTAL,5X,7HPERCENT//)
   C(1) = P(1)
   DO 22 L=2,32
   K = L - 1
22  C(L) = P(L) + C(K) - 0.005
   DO 25 L=1,31
   K = L + 1
25  WRITE (6,102) L,K,T1(L),P(L),C(L)
   WRITE (6,106) T1(32),P(32),C(32)
   WRITE (6,104) TOTAL,C(32)
102 FORMAT (I6,1H-,I2,6X,F9.0,5X,F8.2,5X,F8.2)
106 FORMAT (13H 32 AND OVER, 2X,F9.0,5X,F8.2,5X,F8.2)
104 FORMAT (/5X,5HTOTAL,6X,F9.0,4X,F8.2,7X,6H-----)
837 CONTINUE
    RETURN
    END

```

```

SUBROUTINE BALNCE
COMMON/BLOK3/BTRCOM(40,40),TR(40,40),D(40,40),RD(40,40),
1 TRCOM(40,40)
COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,OB,OA,EB,BOC,IDIST,CPR,ICNT,DIP,
1 ITER,NCENT,NLINK,NNODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
COMMON/BLOK7/ BTR(40,40)
PCSM = 0.
PCSUM = 0.
DO 204 II=1,NCENT
DO 204 IJ=1,NCENT
IF (IDIST.EQ.1) GO TO 599
BTR(II,IJ) = 0
GO TO 204
599 IF (D(II,IJ).EQ.0.) GO TO 204
C DETERMINE AVERAGE BUS-AUTO TRIP COST DIFFERENCE
PCSUM = PCSUM + BTR(II,IJ)/TR(II,IJ)
C SUPPLY A FUNCTION FOR BUS-AUTO TRAVEL TIME COSTS (DTT)
PCSM = PCSM + (BTR(II,IJ)/TR(II,IJ))*DTT*VT*RD(II,IJ) - PCA - CTA
1 - CPR*RD(II,IJ)
204 CONTINUE
PC = (ALOG(1.-1.*PD) - ALOG(PD))*(VT/.16)
WRITE (6,590) PCSM,PCSUM,PC
590 FORMAT ('0',F12.2,6X,F12.2,6X,F12.2,6X,F12.2)
IF (PCSM.EQ.0) GO TO 633
C DETERMINE STANDARD FARE
FA = PC - PCSM/PCSUM
GO TO 634
633 FA = PC
C DISTRIBUTE BUS TRIPS
634 DO 205 II=1,NCENT
DO 205 IJ=1,NCENT
IF (BTR(II,IJ).EQ.0) GO TO 205

```

```

C      IF (D(I1,IJ).EQ.0.) GO TO 205
      SUPPLY A FUNCTION FOR BUS-AUTO TRAVEL TIME COSTS (DTT)
      CD = RC(I1,IJ)*VT* DTT + FA - PCA - CIA - CPR*RD(I1,IJ)
      Z = (.16*CD)/VT
      BTRCOM(I1,IJ) = (1.0/(1.0 + EXP(Z)))*TR(I1,IJ)
205  CONTINUE
C      WRITE OUT BUS DISTRIBUTION MATRIX
      WRITE (6,112)
112  FORMAT (1H1/16H BUS TRIP MATRIX//)
      DO 13 I=1,NCENT
      DO 13 J2=1,NCENT,8
      J1 = J2 + 7
13  WRITE (6,113)(BTRCOM(I,J),J=J2,J1),I,J2,J1
113  FORMAT (8F8.0,2X,3HB1M,I2,1H,I2,1H-,I2)
      RETURN
      END

```

```

C
SUBROUTINE TREE
  FIND MINIMUM TIME PATHS BETWEEN ZONES
  COMMON/BLOK1/ NO(600),ND(600),TLINK(600),TCUM(150),NCUM(150),
  IN(150),NN(150),TSUM(300),K1(300),DCUM(150),DSUM(300)
  COMMON/BLOK2/ ULINK(600),VOL(600),USPD(600),CAP(600),KKPCL(600)
  1 ,AVOL(600),BVOL(600),AVCUM(600),BVCUM(600),NL(600),KAPCL(600),
  2 VCUM(600),DIST(600),SPD(600)
  COMMON/BLOK3/BTR(40,40),TR(40,40),D(40,40),RD(40,40),TP(40,40)
  COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,OB,OA,EB,BOC,IDIST,CPR,ICNT,DIP,
  1 ITER,NCENT,NLINK,NNODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
C
TREE BUILDING ROUTINE
DO 90 I =1,150
  TCUM(I) = 0.
  DCUM(I) = 0.
  NCUM(I) = 0.
90 NCUM(I) = 0.
DO 5 NHOME=1,NCENT
  DO 1 I=1,NNODE
    1 TSUM(I)=9999.
    NTREE = 1
    NN(NHOME) = 0
    TSUM(NHOME) = 0
    DSUM(NHOME) = 0.
    NCM = 0
    NM = NHOME
    6 L1 = NM
    L2 = K1(L1)
    DO 7 I=L2,NLINK
      IF (NO(I) - NM) 7,3,8
    3 K = ND(I)
      IF(TSUM(K) - 9999.) 7,18,7
    18 NCM = NCM + 1
      IF (150 - NCM) 28,29,29

```

```

28 WRITE (6,107) NHOME
107 FORMAT (' TREE FROM',I4,' OMITTED, TCUM OVERFLOW')
GO TO 5
29 TCUM(NCM) = TSUM(NM) + ULINK(I)
DCUM(NCM) = DSUM(NM) + DIST(I)
NCUM(NCM) = I
7 CONTINUE
C FIND MINIMUM PATH TABLE
8 TMIN = 999.9
DO 9 K=1,NCM
IF (TMIN-TCUM(K)) 9,9,10
10 TMIN = TCUM(K)
DMIN = DCUM(K)
L = NCUM(K)
M = K
9 CONTINUE
K = ND(L)
IF (TSUM(K)-TMIN) 11,11,13
13 TSUM(K) = TMIN
DSUM(K) = DMIN
NN(K) = L
I = 0
NTREE = NTREE + 1
IF (NTREE-NNODE) 12,19,12
11 I = 1
12 NCM = NCM - 1
IF (NCM) 21,52,27
21 DO 22 I=1,NNODE
IF (TSUM(I)-9999.) 22,23,22
23 WRITE (6,106) I
106 FORMAT (' NODE',I4,' MISSING')
22 CONTINUE

```

```

      STOP
27  DO 14 NM=M,NCM
      TCUM(NM) = TCUM(NM + 1)
      DCUM(NM) = DCUM(NM+1)
14  NCUM(NM) = NCUM(NM + 1)
52  CONTINUE
      IF (I) 8,17,8
17  NM = K
      IF (NM-NCENT) 8,8,6
      SKIMMING ROUTINE AND OUTPUT
19  DO 16 J1=1,NNODE
      K=NN(J1)
      IF (J1-NHOME) 4,16,4
4   NN(J1) = NO(K)
16  CONTINUE
      DO 58 I=1,NCENT
      N1 = 1
      IF (NN(I)) 40,58,40
40  J1 = NN(I)
55  NCUM(N1) = NN(J1)
      IF (NN(J1)-NHOME) 56,57,56
56  N1 = N1 + 1
      J1 = NN(J1)
      GO TO 55
57  N2 = N1 + 2
      N(1) = 1
      N(2) = NN(I)
      DO 59 M=3,N2
      K = M - 2
59  N(M) = NCUM(K)
      D(NHOME,I) = TSUM(I)
      RD(NHOME,I) = DSUM(I)

```

```

C      IF (ITER.EQ.0) GO TO 58
      DETERMINE VOLUMES TC BE LOADED ON EACH LINK
      IF (TR(NHCME,I)) 58,58,85
85     NB = BTR(NHCME,I)/GB + 1
      NBR = NB*GB - BTR(NHCOME,I)
      IF (NBR.GT.HOB) NB = NB-1
      IF (BTR(NHCME,I).GT.HOB) GO TO 951
      NB = 0
951     NBT = NBT + NB
      DO 82 M=1,67
      L1 = N(M + 1)
      L2 = K1(L1)
      DO 48 L=L2,NLINK
      IF (N(M+1) - NO(L)) 48,81,48
81     IF (N(M)-AD(L)) 48,47,48
48     CONTINUE
47     AVOL(L) = ((TR(NHCOME,I) - BTR(NHCOME,I))/1.6) + AVOL(L)
      BVOL(L) = BVOL(L) + EB*NB
      VOL(L) = AVOL(L) + BVOL(L)
      IF (N(M+1)-NHCOME) 82,58,82
82     CONTINUE
58     CONTINUE
5     CONTINUE
      RETURN
      END

```

```

C
SUBROUTINE LOAD
  ASSIGN TRAFFIC TO THE ROADWAY NETWORK
  COMMON/BLCK1/ NO(600),ND(600),TLINK(600),TCUM(150),NCUM(150),
  IN(150),NN(150),TSUM(300),K1(300),DCUM(150),DSUM(300)
  COMMON/BLCK2/ ULINK(600),VOL(600),USPD(600),CAP(600),KKPCL(600)
  1 ,AVOL(600),BVOL(600),AVCUM(600),BVCUM(600),NL(600),KAPCL(600),
  2 VCUM(600),DIST(600),SPD(600)
  COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,OB,OA,EB,BOC,IDIST,CPR,ICNT,DIP,
  1 ITER,NCENT,NLINK,NMODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
  COMMON/BLCK5/ VC2,VM2,TC2,TM2,D02,DC2,DM2
  DIMENSION DI(150)
  LOAD TRIPS
  CRITICAL LINK SEARCH
  XMAX = MAX. PROPORTION OF CTM WHICH CAN BE LOADED IN THIS ITERATION
  A = PERCENT OF TRIPS LOADED IN PREVIOUS ITERATIONS
  31 XMAX = 100.
    IF (ITER.LE.1) A=0
    DO 35 L=1,NLINK
      IF (VOL(L)) 32,35,32
    32 KAP = KAPCL(L)
    GO TO (35,15,15,35,15), KAP
  15 X = (Q*CAP(L)-100.*VCUM(L))/VOL(L)
    IF (XMAX - X) 35,35,33
  33 XMAX = X
    LCRIT = L
  35 CONTINUE
    IF (100.-A-XMAX) 88,88,89
  88 XMAX = 100. - A
    LCRIT = 0
  89 A = A + XMAX + 0.005
    XMAX = XMAX + 0.005
    WRITE (6,119) ITER,LCRIT,XMAX,A

```

```

119 FORMAT (1H1/30X,13HITERATION NO.,I3//
1 12H CRIT.LINK =,I4,18H PERCENT LOADED =,F7.2,9H TOTAL =,F7.2//)
WRITE (6,118)
118 FORMAT (6X,4HFROM,3X,2HTO,3X,13H1ST MILES 1ST,2X,
1 22HCAPA- CAP. CUMUL. ,3X,7HNEW NEW,5X,7HREMARKS/
2 17X,4HTIME,7X,16HMPH CITY CLASS,3X,6HVOLUME,4X,8HTIME MPH/)
LINES = 0
XMAX = XMAX - 0.005
CAPACITY RESTRAINT PROCEDURE
DO 71 I=1,NLINK
VCUM(I) = VCUM(I) + XMAX*VOL(I)/100.
AVCUM(I) = AVCUM(I) + XMAX*(AVOL(I)/100.)
BVCUM(I) = BVCUM(I) + XMAX*(BVOL(I)/100.)
KAP = KAPCL(I)
GO TO (30,36,36,25,72), KAP
25 WRITE (6,111) I,NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
1 KAPCL(I),VCUM(I),ULINK(I),USPD(I)
111 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,11H DUMMY LINK)
GO TO 20
30 WRITE (6,112) I,NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
1 KAPCL(I),VCUM(I),ULINK(I),USPD(I)
112 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,13H LOCAL STREET)
GO TO 20
C COMPUTE NEW TRAVEL TIMES FOR ARTERIALS
36 GO TO (30,61,62,25,72), KAP
61 IF (VCUM(I) - NL(I)*VC2) 135,135,136
136 IF (VCUM(I) - NL(I)*VM2)137,137,138
135 ULINK(I) = (TC2 + D02*(VCUM(I) -NL(I)*VC2))*DIST(I) +
1 VCUM(I)/CAP(I) + DI(I)
GO TO 63
137 ULINK(I) = (TC2 + DC2*(VCUM(I) -NL(I)*VC2))*DIST(I) +
1 VCUM(I)/CAP(I) + DI(I)

```

```

GO TO 63
138 ULINK(I) = (TM2 + DM2*(VCUM(I) - NL(I)*VM2))*DIST(I) +
1 VCUM(I)/CAP(I) + DI(I)
GO TO 63
62 IF (VCUM(I) - NL(I)*VC2) 140,140,141
141 IF (VCUM(I) - NL(I)*VM2) 142,142,143
140 ULINK(I) = (TC2 + D02*(VCUM(I) - NL(I)*VC2))*DIST(I)
GO TO 63
142 ULINK(I) = (TC2 + DC2*(VCUM(I) - NL(I)*VC2))*DIST(I)
GO TO 63
143 ULINK(I) = (TM2 + DM2*(VCUM(I) - NL(I)*VM2))*DIST(I)
63 IF (VCUM(I)/CAP(I) - QQ*Q/10000.) 64,70,70
64 USPD(I) = 60.*DIST(I)/ULINK(I)
GO TO (20,401,402,20,72), KAP
C APPLY SPEED LIMIT FOR INTERSECTION-DELAY LINKS
401 IF(USPD(I).LT.25.) GO TO 403
ULINK(I) = 2.40*DIST(I)
USPD(I) = 25.
GO TO 403
C APPLY SPEED LIMIT FOR LINK-DELAY LINKS
402 IF(USPD(I).LT.35.) GO TO 403
ULINK(I) = 1.71*DIST(I)
USPD(I) = 35.
403 GO TO (30,65,66,25,72), KAP
65 WRITE (6,114) I,NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
1 KAPCL(I),VCUM(I),ULINK(I),USPD(I)
114 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,14H INTERS. DELAY)
GO TO 20
66 WRITE (6,115) I,NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
1 KAPCL(I),VCUM(I),ULINK(I),USPD(I)
115 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,11H LINK DELAY)
GO TO 20

```

```

70 ULINK(I) = ULINK(I) + 500.
   KAPCL(I) = 5
   USPD(I) = 0.
72 WRITE (6,116) I,NO(I),ND(I),TLINK(I),DIST(I),SPD(I),CAP(I),
   1 KAPCL(I),VCUM(I),ULINK(I),USPD(I)
116 FORMAT(3I5,2F6.2,F4.0,F8.0,I3,3X,F9.0,F7.2,F4.0,12H *SATURATED*/)
   LINES = LINES + 2
20 LINES = LINES + 1
   IF(LINES.LT.50) GO TO 71
   WRITE (6,117)
117 FORMAT (1H1)
   WRITE (6,118)
   LINES = 0
71 CONTINUE
   RETURN
   END

```

```

C
SUBROUTINE COSTS
  COMPUTE TOTAL COMMUNITY COSTS
  COMMON/BLOK1/ NO(600),ND(600),TLINK(600),TCUM(150),NCUM(150),
  IN(150),NN(150),TSUM(300),K1(300),DCUM(150),DSUM(300)
  COMMON/BLOK2/ ULINK(600),VOL(600),USPD(600),CAP(600),KKPCL(600)
  1 ,AVOL(600),BVOL(600),AVCUM(600),BVCUM(600),NL(600),KAPCL(600),
  2 VCUM(600),DIST(600),SPD(600)
  COMMON/BLOK3/BTR(40,40),TR(40,40),D(40,40),RD(40,40),TP(40,40)
  COMMON/BLOK4/ PD,CRA,PCA,CTA,VT,OB,OA,EB,BOC,IDIST,CPR,ICNT,DIP,
  1 ITER,NCENT,NLINK,NNODE,MAXIT,Q,QQ,FA,A,NBT,NB,TUC,HOB
  AVMLS1 = 0.
  BVMLS1 = 0.
  AVHRS1 = 0.
  BVHRS1 = 0.
  COMPUTE TOTAL AUTO AND BUS TRIPS
  TATR = 0
  TBTR = 0.
  DO 46 I=1,NCENT
    DO 46 J=1,NCENT
      TATR = TATR + TR(I,J) - BTR(I,J)
      TBTR = TBTR + BTR(I,J)
    APD = PD*100.
    WRITE (6,570) APD
  570 FORMAT ('1',9X,'DESIRED PERCENTAGE OF TOTAL PERSON TRIPS DIVERTED
  1TO TRANSIT =',F7.2,' PERCENT')
    WRITE (6,571) TATR
  571 FORMAT ('///',10X,'ACTUAL TOTAL NUMBER OF AUTO PERSON TRIPS =',F6.0
  1,' PERSON TRIPS')
    WRITE (6,572) TBTR
  572 FORMAT ('0',9X,'ACTUAL TOTAL NUMBER OF BUS PERSON TRIPS =',F6.0,'
  1PERSON TRIPS')
    IF (NBT.EQ.0) GO TO 877

```

```

AB = TBTR/NBT
GO TO 878
877 AB = 0
878 CONTINUE
WRITE (6,573) AB
573 FORMAT (///,10X,'ACTUAL PER BUS RIDERSHIP =',F5.0,' RIDERS')
DO 74 I=1,NLINK
  KAP = KAPCL(I)
  GO TO (75,75,75,74,75), KAP
  SUM TOTAL VEHICLE-MILES AND TOTAL VEHICLE-MINUTES
75 AVMLS1 = AVMLS1 + DIST(I)*AVCUM(I)
  BVMLS1 = BVMLS1 + DIST(I)*(BVVCUM(I)/3.0)
  AVHRS1 = AVHRS1 + ULINK(I)*AVCUM(I)
  SUPPLY A FUNCTION FOR BUS-AUTO TRAVEL TIME COSTS (DTT)
  BVHRS1 = BVHRS1 + (DTT + ULINK(I))*BVVCUM(I)/3.0
  IF (IDIST.EQ.1) GO TO 749
  TLINK(I) = ULINK(I)
  SPD(I) = USPD(I)
749 CONTINUE
74 CONTINUE
C COMPUTE TOTAL BUS FARES
  TBF = FA*TBTR
C COMPUTE TOTAL BUS OPERATING COSTS
  BVMC = BVMLS1*BVC
  WRITE (6,574) FA
574 FORMAT (///,10X,'STANDARD BUS FARE =',F5.2,' DOLLARS')
  WRITE (6,575) TBF
575 FORMAT (///,10X,'TOTAL REVENUE FROM BUS FARES =',F8.2,' DOLLARS')
  WRITE (6,576) BVMC
576 FORMAT ('0',9X,'TOTAL BUS OPERATING COSTS =',F8.2,' DOLLARS')
  IF (TBF-BVMC) 87,86,86
86 TUBC = TBF

```

```

GO TO 45
87 TUBC = BVMC
C  COMPUTE TOTAL COMMUNITY COSTS
45 TUC = CRA*AVMLS1 + (PCA + CTA)*(TATR/OA )+TUBC+VT*(OA*AVHRS1+OB*
1 BVHRS1)
WRITE (6,578)
578 FORMAT (//////,44X,'*****')
WRITE (6,577) TUC
577 FORMAT (' ',19X,'TOTAL COMMUNITY COSTS = **',F9.2,' DOLLARS **')
WRITE (6,579)
579 FORMAT (' ',43X,'*****')
RETURN
END

```

APPENDIX D

Constant Input

Average per mile auto running costs (1)

$$CRA = \$.12$$

Average per mile "perceived" auto running costs (1)

$$CPR = \$.04$$

Average auto occupancy in persons/car (9)

$$OA = 1.6$$

Bus equivalency factor in p.c.u.'s (6)

$$EB = 3.0$$

Bus per mile operating costs in dollars/mile (13)

$$BOC = \$1.00$$

Travel time equation parameters (6) critical volume

$$VC2 = 480$$

Maximum volume

$$VM2 = 640$$

Travel time per mile at critical volume

$$TC2 = 2.4$$

Travel time per mile at maximum volume

$$TM2 = 3.0$$

Slope for "free flow" region

$$DO2 = 0$$

Slope for "turbulent" region

$$DC2 = .00083$$

Slope for "overloaded" region

$$DM2 = .0037$$

Variable Input

Parking costs function - The function shown in Figure 17 was used to describe the per auto cost for parking as the diversion percentage increased. To relate this function in the program the following statements were placed in the parking cost segment of TRANSFARE

```

      IF (DO.GT. 20.) GO TO 560
      PCA = .20
      GO TO 561
560 PCA = .16/(1 - PD)

```

Difference between bus and auto travel times (14) - The relationship shown in Figure 18 was used to develop a function for the difference in travel times. It was assumed that for speeds of 5 mph the travel times for both modes were the same but for the maximum speeds of 30 mph the travel time for a bus was twice that for an auto. The following statement was implemented in TRANSFARE to compute the travel time difference.

$$DTT(I,J) = 2.40*RD(I,J) - 0.20*D(I,J)$$

Intersection delay - This was computed as the sum of the average red waiting time (assumed to be 15 sec) and the delay time. The delay was assumed to be directly proportional to the volume/capacity ratio of the link entering the intersection. Therefore, the following statement was implemented into TRANSFARE for the calculation of intersection delay.

$$DI(I) = .25 + VCUM(I)/CAP(I)$$

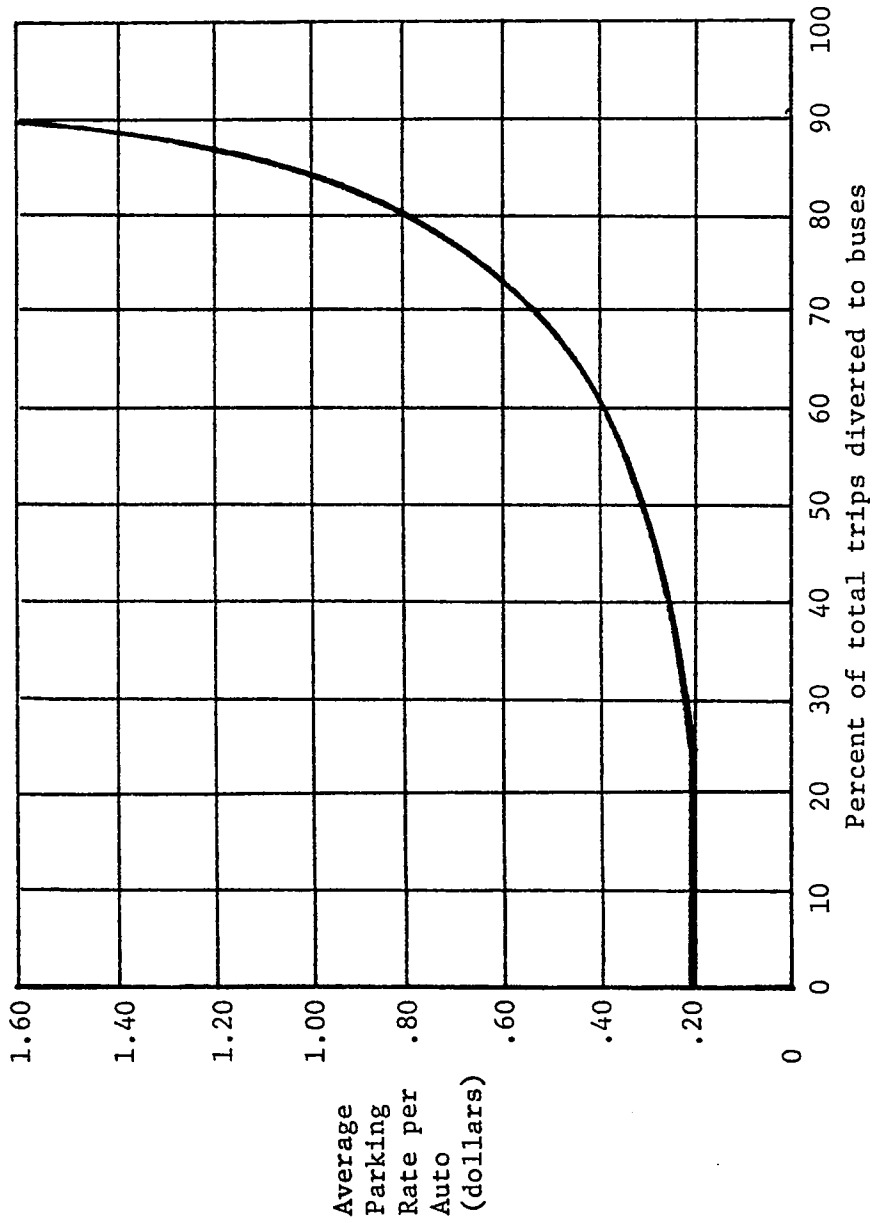


Figure 17. Parking cost function for sample urban area

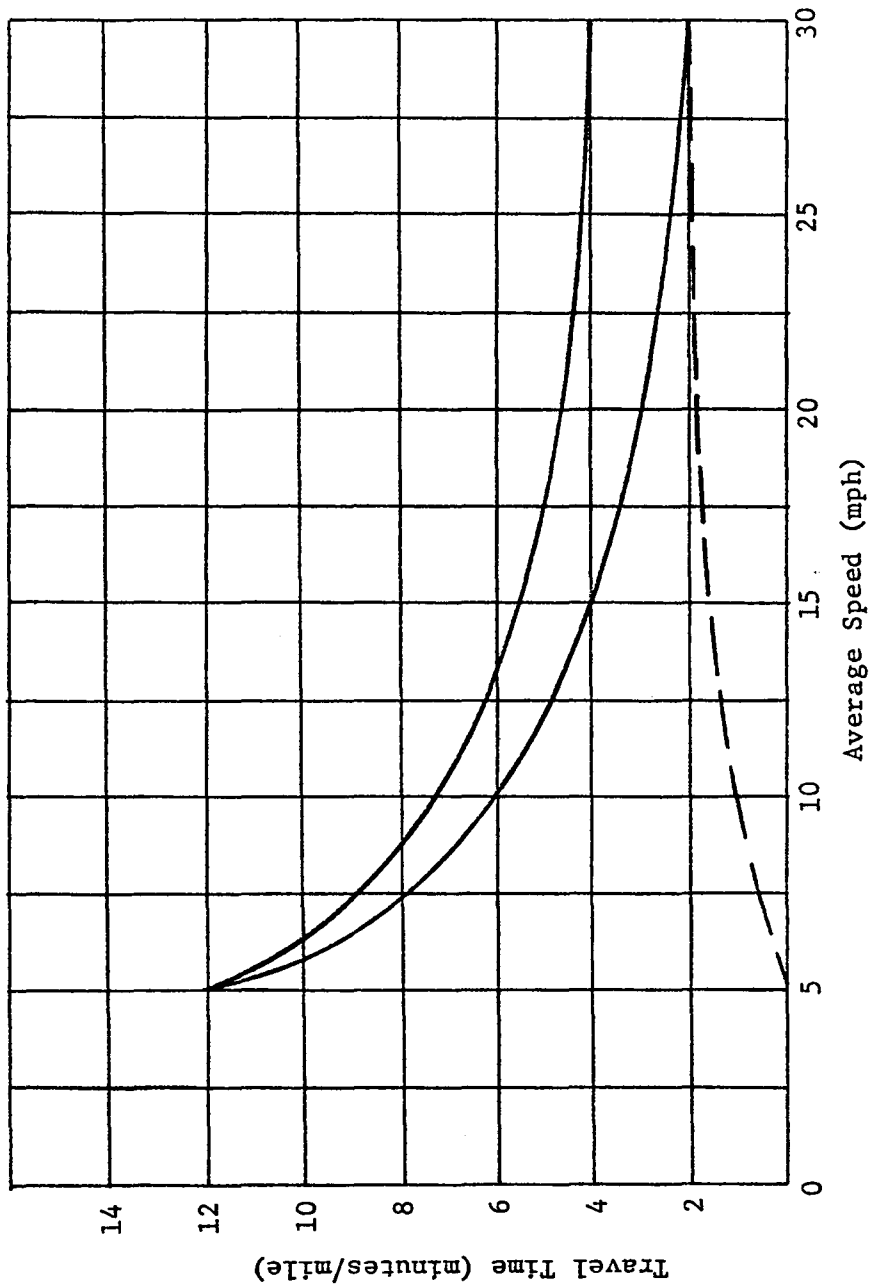


Figure 18. The difference between auto and bus travel times for varying average speeds

TABLE I. Person Trip Attractions and Productions for Each Zone in the Sample Urban Area

ZONE	PRODUCTIONS	ATTRACTIONS
1	100.	2400.
2	200.	2400.
3	300.	1200.
4	200.	1700.
5	1200.	300.
6	2400.	100.
7	2400.	100.
8	500.	100.
9	500.	200.
10	100.	300.

TABLE II. Characteristics of the Roadway Network Links for the Sample Urban Area

Link	From	To	First Time	Distance	Capacity	Cap. Class	Remarks
1	1	36	1.15	0.42		1	Local Street
2	1	37	1.31	0.48		1	Local Street
3	1	39	1.37	0.50		1	Local Street
4	2	13	0.57	0.30		1	Local Street
5	2	26	1.04	0.52		1	Local Street
6	2	39	0.87	0.46		1	Local Street
7	3	13	0.71	0.26		1	Local Street
8	3	15	1.26	0.46		1	Local Street
9	3	17	0.69	0.25		1	Local Street
10	3	19	1.48	0.54		1	Local Street
11	4	20	0.58	0.21		1	Local Street
12	4	22	1.14	0.38		1	Local Street
13	4	25	0.66	0.22		1	Local Street
14	5	23	11.56	2.00	800.	3	Link Delay
15	6	16	17.05	2.00	1600.	3	Link Delay
16	7	18	17.05	2.00	1600.	3	Link Delay
17	8	34	2.26	1.00	800.	3	Link Delay
18	9	32	2.26	1.00	800.	3	Link Delay
19	10	30	2.94	1.00	800.	3	Link Delay
20	11	12	0.43	0.18	800.	2	Inters. Delay
21	11	15	0.72	0.35	800.	3	Link Delay
22	11	20	0.93	0.43	800.	3	Link Delay
23	11	26	1.59	0.76	800.	3	Link Delay
24	12	11	0.53	0.18	800.	2	Inters. Delay
25	12	13	1.17	0.47	800.	3	Link Delay

TABLE II. Characteristics of the Roadway Network Links for the Sample Urban Area - continued

Link	From	To	First Time	Distance	Capacity	Cap. Class	Remarks
26	12	15	0.50	0.25	800.	3	Link Delay
27	13	2	0.57	0.30		1	Local Street
28	13	3	0.71	0.26		1	Local Street
29	13	12	0.99	0.47	800.	3	Link Delay
30	13	14	1.09	0.53	800.	3	Link Delay
31	14	13	1.27	0.53	800.	3	Link Delay
32	14	19	0.44	0.25	1600.	3	Link Delay
33	14	38	1.77	0.75	1600.	3	Link Delay
34	15	3	1.26	0.46		1	Local Street
35	15	11	0.72	0.35	800	3	Link Delay
36	15	12	0.60	0.25	800.	3	Link Delay
37	15	16	0.69	0.34	800.	3	Link Delay
38	16	6	3.42	2.00	1600.	3	Link Delay
39	16	15	0.92	0.34	800.	3	Link Delay
40	16	17	2.25	0.46	800.	3	Link Delay
41	16	25	2.22	0.62	800.	3	Link Delay
42	17	3	0.69	0.25		1	Local Street
43	17	16	1.05	0.46	800.	3	Link Delay
44	17	18	1.27	0.54	800.	3	Link Delay
45	18	7	3.42	2.00	1600.	3	Link Delay
46	18	17	1.47	0.54	800.	3	Link Delay
47	18	19	1.09	0.25	1600.	3	Link Delay
48	19	3	1.48	0.54		1	Local Street
49	19	14	1.09	0.25	1600.	3	Link Delay
50	19	18	0.43	0.25	1600.	3	Link Delay

TABLE II. Characteristics of the Roadway Network Links for the Sample Urban Area - continued

Link	From	To	First Time	Distance	Capacity	Cap. Class	Remarks
51	20	4	0.63	0.21		1	Local Street
52	20	11	0.89	0.43	800.	3	Link Delay
53	20	21	0.81	0.38	800.	3	Link Delay
54	21	20	0.79	0.38	800.	3	Link Delay
55	21	22	0.46	0.21	800.	3	Link Delay
56	21	27	0.89	0.36	800.	3	Link Delay
57	22	4	1.14	0.38		1	Local Street
58	22	21	0.50	0.21	800.	3	Link Delay
59	22	23	0.18	0.01	800.	2	Inters. Delay
60	23	5	4.22	2.00	800.	3	Link Delay
61	23	22	0.65	0.01	800.	2	Inters. Delay
62	23	24	0.62	0.14	800.	2	Inters. Delay
63	24	23	0.34	0.14	800.	2	Inters. Delay
64	24	25	0.86	0.39	800.	3	Link Delay
65	25	4	0.66	0.22		1	Local Street
66	25	16	3.42	0.62	800.	3	Link Delay
67	25	24	0.78	0.39	800.	3	Link Delay
68	26	2	1.04	0.52		1	Local Street
69	26	11	1.62	0.76	800.	3	Link Delay
70	26	28	0.80	0.38	800	3	Link Delay
71	26	39	1.52	0.74	800.	3	Link Delay
72	27	21	0.77	0.36	800.	3	Link Delay
73	27	28	1.60	0.65	800.	3	Link Delay
74	28	26	0.90	0.38	800.	3	Link Delay
75	28	27	1.39	0.65	800.	3	Link Delay

TABLE II. Characteristics of the Roadway Network Links for the Sample Urban Area - continued

Link	From	To	First Time	Distance	Capacity	Cap. Class	Remarks
76	28	29	0.81	0.13	800.	2	Inters. Delay
77	29	28	0.81	0.13	800.	2	Inters. Delay
78	29	30	1.18	0.55	800.	3	Link Delay
79	29	36	1.73	0.77	800.	3	Link Delay
80	30	10	2.11	1.00	800.	3	Link Delay
81	30	29	1.31	0.55	800.	3	Link Delay
82	30	31	1.58	0.70	800.	3	Link Delay
83	31	30	1.45	0.70	800.	3	Link Delay
84	31	32	0.32	0.10	800.	2	Inters. Delay
85	31	33	1.75	0.68	800.	3	Link Delay
86	32	9	2.07	1.00	800.	3	Link Delay
87	32	31	0.62	0.10	800.	2	Inters. Delay
88	33	31	1.41	0.68	800.	3	Link Delay
89	33	34	0.36	0.15	800.	2	Inters. Delay
90	33	35	1.75	0.25	800.	3	Link Delay
91	34	8	2.04	1.00	800.	3	Link Delay
92	34	33	0.73	0.15	800.	2	Inters. Delay
93	35	33	0.52	0.25	800.	3	Link Delay
94	35	36	1.53	0.67	800.	3	Link Delay
95	35	37	1.98	1.00	1600.	3	Link Delay
96	36	1	1.15	0.42		1	Local Street
97	36	29	1.55	0.77	800.	3	Link Delay
98	36	35	1.36	0.67	800.	3	Link Delay
99	37	1	1.31	0.48		1	Local Street
100	37	35	1.71	1.00	1600	3	Link Delay

TABLE II. Characteristics of the Roadway Network Links for the Sample Urban Area - continued

Link	From	To	First Time	Distance	Capacity	Cap. Class	Remarks
101	37	38	0.99	0.50	1600.	3	Link Delay
102	38	14	1.31	0.75	1600.	3	Link Delay
103	38	37	1.16	0.50	1600.	3	Link Delay
104	38	39	1.08	0.47	800.	3	Link Delay
105	39	1	1.37	0.50		1	Local Street
106	39	2	0.87	0.46		1	Local Street
107	39	26	1.57	0.74	800.	3	Link Delay
108	39	38	0.95	0.47	800.	3	Link Delay

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EVALUATING TRANSPORTATION FACILITY ARRANGEMENTS IN URBAN AREAS:

A BALANCED LEVEL OF SERVICE APPROACH

by

Ronald Kenneth Giguere

(ABSTRACT)

A theoretical study is performed to provide methods for evaluating balanced transportation facility arrangements. The study examines, in depth, arrangements of bus, auto, and roadway facilities for urban areas. Models for balancing intermodal and interzonal travel are developed for such transportation systems. A total community cost function incorporating auto operating costs, bus fares, travel time costs, and, in some cases, utilization costs is developed to indicate the level of service provided by specific arrangements. The best arrangement for a set of alternatives being evaluated is assumed to be the one offering the lowest total community costs.

A computerized process, TRANSFARE (Transportation Facility Arrangement Evaluation), is developed to allow for easy application of the evaluation process. It is presented in package form so as to be available for further application.

A sample urban network is evaluated for different levels of bus diversion under varying values of time and bus capacity conditions. Output of the example yields functions for evaluating arrangements at various diversion levels. These functions indicate the best arrange-

ment for each set of data as well as the sensitivity of the models incorporated within TRANSFARE.

The evaluation methods which are developed here apply only to a specialized auto-bus urban transportation system. However, it is concluded, based on the results, that the study forms a basis for the examination of existing and more complex urban areas.

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