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ANALYSIS OF EXPRESS BUS-FRINGE PARKING OPERATIONS

by

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Assistant Professor, University of Virginia,
and
Joint Appointee, Virginia Highway Research Council

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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PREFACE

This report is the first in a series by this agency dealing with the planning and evaluation of express bus-fringe parking operations. It was originally intended that this report include an application of the methodology in at least one case study in Virginia. Howevbr, due to implementation problems, projects in Richmond and Norfolk were delayed and evaluation is only in the initial stages at this time. However, as soon as these studies are completed, periodic reports will be made available. This report describes the methodological framework to be employed in the analysis of particular projects, and which will eventually be refined into practical procedures for general application.

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CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

There is currently much interest in alternative strategies for increasing the person-carrying capacity of existing highway facilities during peak periods.[1, 2] In most instances, congested corridor problems have been approached in an incremental fashion, i.e., by implementing and examining various marginal operational improvements which can be justified on their own merit. Research is in progress to develop tools which analyze special bus operations and obtain measures of effectiveness relative to improved service levels for passenger flows (total passenger travel time reductions, length of peak periods, volume-to-capacity ratios, trips per hour, etc.).[3,4,5] Typical elements of bus operations being examined include express service, exclusive bus lanes, preferential traffic controls, fringe parking facilities, transfer terminals, and exclusive bus usage of curb lanes in the central business district (CBD).

Although fringe parking requirements have been cited as a necessity for express bus mass transit,[1] parking has not been given due consideration as a variable in the planning process. The impact of the parking supply within the framework of contemporary transportation planning has been discussed[6] and its impact on modal split is shown in Figure 1. In practice, however, the parking element usually remains a secondary consideration (a result rather than a cause of travel decisions). A systematic appraisal of the total process indicates that the status of the parking supply within a major activity center (e.g., CBD, hospital, or university) may have a significant influence on the level of congestion. Accordingly, if parking is considered simultaneously with mass transit, constraints on CBD parking (or CBD entry) could force demand to shift to fringe lots and/or mass transit. Through this strategy, then, a balanced traffic stream of private automobiles and buses would result and provide a means to reduce congestion and increase the peak hour passenger carrying capacity of the the way facility.

Recently, an analytical model for the analysis of parking systems has been developed for the Federal Highway Administration which simultaneously considers the demand for parking and the availability of spaces in an activity center.[7] The model is, however, only appropriate when considering auto trips destined to the CBD. This study considers alternatives to the CBD auto trip and, accordingly, the FHWA Parking Model was not considered for the basic methodology given in this report, where average estimates of the impedances incurred by the parker in the CBD suffice. Future research, however, should examine the effects of incorporating the FHWA parking system model within the methodology given in this report.

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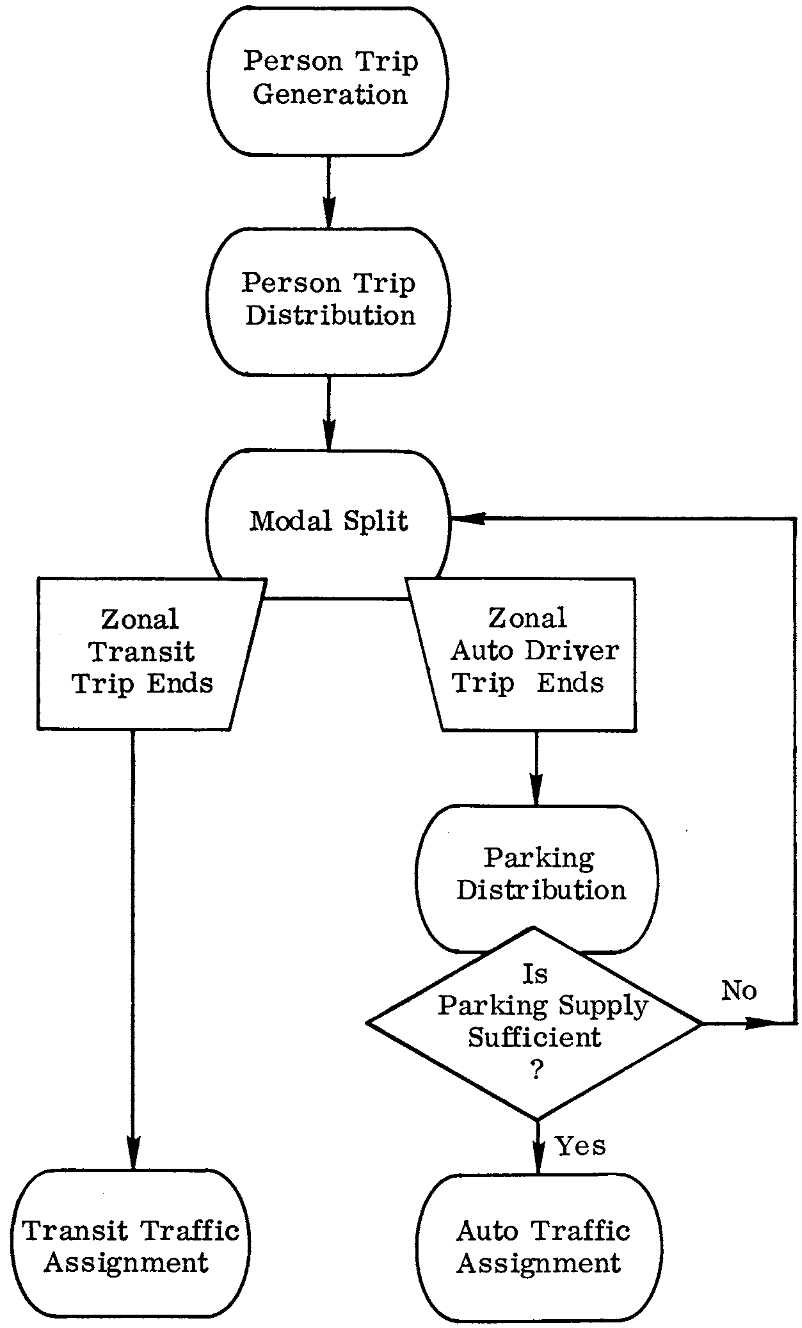

Figure 1. Parking considerations within the transportation planning process.

Objectives

In the research reported here existing transportation systems analysis and planning tools were evaluated to determine their adequacy for providing a comprehensive analysis of alternative strategies for expanding the passenger-carrying capacity of existing way facilities during peak travel periods. In particular, emphasis was placed on a methodological development for evaluating the transit patronage to be realized from the improvement of express transit service and/or the elimination of CBD parking. Accordingly, the findings of this study include recommendations for applying current tools for analyzing bus-highway-parking systems.

Scope of Research

The major effort in this Phase I research was to identify those factors which measure the effectiveness of express-bus fringe parking operations and the subsequent development of an analysis framework which in its rudimentary stage derives from applications of existing transportation planning models. Phase II research has been proposed for extensive application and refinement of these findings to provide an implementable package of techniques for the planning and evaluation of express-bus fringe parking operations.

The analytical development consists of the following stages for analysis.

1. Travel choice analysis.
2. System simulation.
3. The measurement and identification of the market for users of the service.

The corridor analysis modeling system is shown in Figure 2, where the market analysis is associated with the input data (travel volumes that can be obtained from recent O-D studies or census data) and the subsequent phases consider the modal split and level of service on freeways. The specific models cited for application were the Modal Split model developed for the Washington Council of Governments and the FHWA Priority Lane Simulation Model.

Initially the study group concentrated on the questions of travel choice behavior and system simulation, assuming a static CBD directed travel demand during the morning peak period. It became apparent, however, that realistic analysis must recognize the influence of the availability of transportation service on trip generation, particularly with trips other than the journey to work. Accordingly, the problem of market areas and the influence of the attractiveness of fringe parking on trip productions were formally considered subsequent to the choice and network analyses.

Having carefully considered each of the three dominant stages of the analysis, the final effort of this study synthesized the component models into an equilibrium simulation format.

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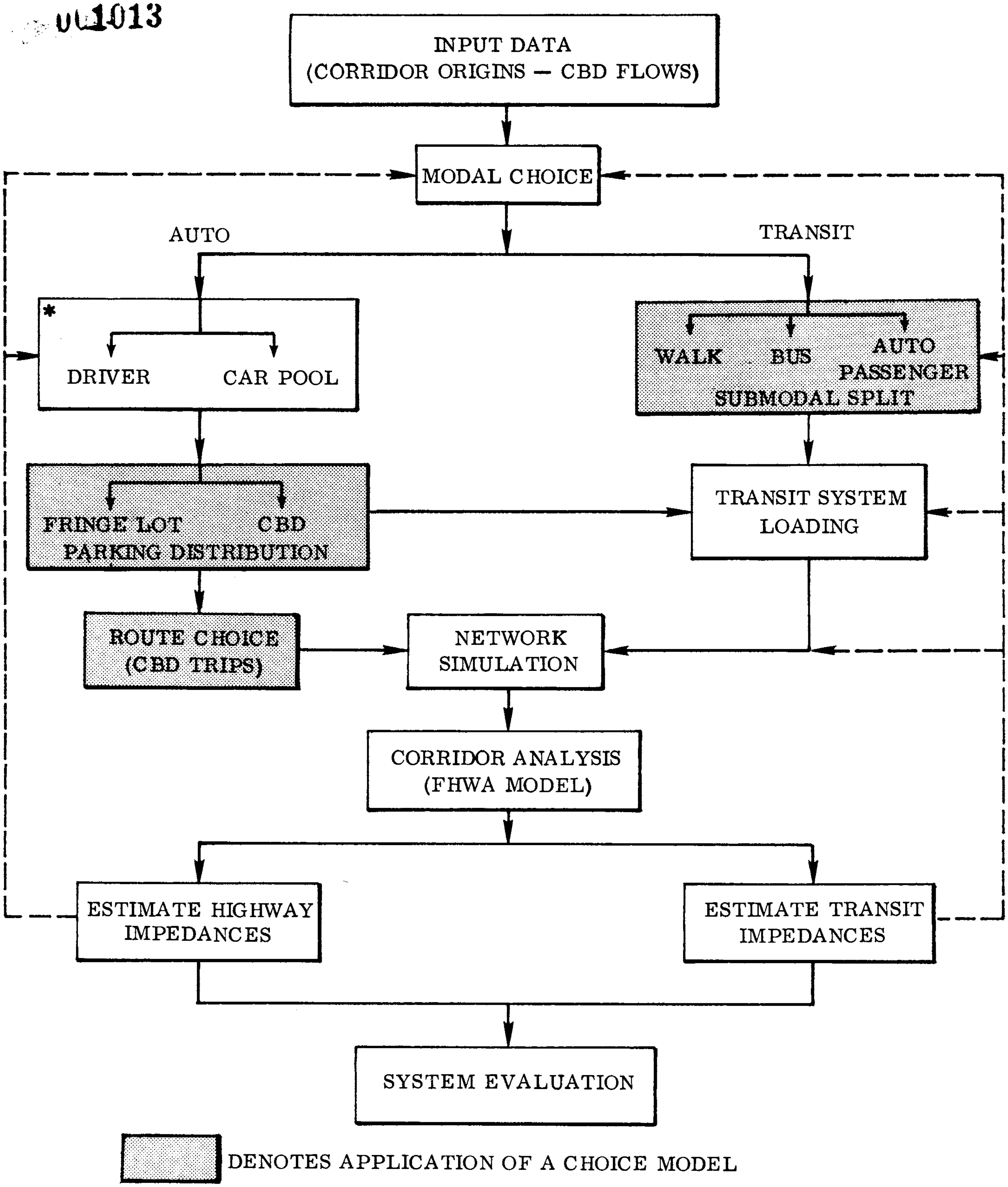

* IN THE PHASE I STUDY AN AVERAGE VEHICLE LOAD FACTOR WAS ASSUMED. THIS DECISION WILL BE THOROUGHLY INVESTIGATED IN THE PHASE II STUDY.

Figure 2. Corridor analysis modeling system.

CHAPTER 2

BACKGROUND

Remote or fringe parking-express bus operations have been seriously considered for implementation in U. S. metropolitan areas since 1948. Some of these projects have been successful while many have failed. In this section, park-and-ride experiments are examined and compared in order to establish the factors which must be reflected in a formal methodology for planning and evaluating the same.

There are several successful park-and-ride lots in operation in major metropolitan areas throughout the United States. Examples include Milwaukee's Freeway Flyer service, which consists of two rapid transit park-and-ride routes that mix with automobile traffic along urban freeways to the CBD. The buses operate from outlying parking lots made available by privately owned shopping centers. One route originates in the western suburbs of Milwaukee, approximately seven miles from the CBD. Parking is provided at no charge for 450 automobiles. The second lot is located on the north side of Milwaukee, five and one-half miles from the CBD. There are 200 free parking spaces provided. These services provide faster door-to-door service than private vehicles when walking time from the parking lot to CBD destination is combined with the in-vehicle travel time.

Seattle's Blue Streak is very similar to the Freeway Flyer. A 550 car free park-and-ride lot is located in the northern suburbs, eight and two-tenths miles from downtown. The buses operate nonstop on the freeway to downtown and use exclusive entrance-exit ramps and curb lanes in the CBD. This service has decreased average travel time from 40 to 16 minutes.

The Lincoln Tunnel Express Bus provides a somewhat unique service to New Jersey commuters. An exclusive bus lane on Interstate 495 between the New Jersey Turnpike and the Lincoln Tunnel takes commuters past congestion for a distance of two and one-half miles. A 1,600 car park-and-ride lot is located west of the tunnel at North Bergen, N. J. There commuters change mode to board buses which have preferential access through the Tunnel. The riders discharge on the east side of the tunnel for easy connection with the subway or a bus for the remainder of the trip. The service provides as much as 15 minutes time savings and from fifty cents to three dollars savings on parking costs per day.

The above are examples of typical express bus-fringe parking systems in operation. Comprehensive data from a sample of both successful and unsuccessful lots are compiled in Tables 1 and 2 and the Selected Bibliography provides a reference list on recent express bus service and/or fringe parking experiences.

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TABLE 1

SUCCESSFUL BUS PARK-AND-RIDE OPERATIONS

City	Lot	Lot Size	Cars Park.	Park Fee ($)	Trans. Fare ($)	Peak-Hr. Serv. (bus/hr.)	Off-Peak Serv. (bus/hr.)	Dist. To CBD (miles)	Travel Time (min.)	Aver. Speed (mph)	Comments
Milwaukee	**Mayfair** Shopping Center	450		.00	.40	2	0	7	20	21.0	Nonstop express shelter station time reduction.
Milwaukee	Bay Shore Shopping Center	200		.00	.35	4	0	5.5	11	30.0	Nonstop express shelter station time reduction.
Seattle	Special Lot	550	550	.00	.35	12	0	8.2	16	30.8	Exclusive on-off lot filled by 8:30.
New York	North Bergen Lot	1,600	1,650	1.00 Round Trip		15	4	2.5	12	12.5	Time reduction CBD parking $1.50-3.75. Tunnel cost $0.25 one way discharge of Port Authority.
Atlanta	Atlanta Stadium	900		.50–.75		6	6.7	1	10	6.0	Most riders travel 7 miles or more away. Used for shopping trips.
Atlanta	Civic Center	300		.50–.75		6	6.7	1	10	6.0	Used for shopping trips.
Cleveland	Lakeshore and 9th	2,552	2,200	.25	.10			.25	4	3.7	On-street parking not available. Many walked from lot.
Cleveland	East 22nd and Seaville	1,600	500	.25	.10			1	8		
Chicago	Soldier Field	1,200	1,000	.25	.15	10	10	2	12	7.5	Regular fare $0.25.

TABLE 2

UNSUCCESSFUL BUS PARK-AND-RIDE OPERATIONS

City	Lot	Lot Size	Cars Park.	Park. Fee ($)	Trans. Fare ($)	Peak-Hr. Serv. (bus/hr.)	Off-Peak Serv. (bus/hr.)	Dist. To CBD (miles)	Travel Time (min.)	Aver. Speed (mph)	Comments
San Diego	Balboa Park	900	10	.00	.17	4	0	2	8	15.0	Low downtown parking costs.
Louisville	Bowman Field	500	35	.00	.19	6	0	6	26-30	12.8	Low downtown parking costs.
Boston	Neponset Drive-In	1,500	25-30	1.00 Round Trip		12	0	5.5			Rail rapid transit. Fringe parking nearby.
Boston	Revere Drive-In	1,500	10	1.00 Round Trip		5	0	5			Rail rapid transit fringe parking nearby.
Richmond	30 Service Stations										Low downtown parking costs.
Cincinnati	Public Landing	1,400	1,400	.25	.10	10	0	.6	4	9.0	Buses discontinued.
Los Angeles	Hollywood Bowl		130	.15	.23	6	3	7	25	16.8	People unwilling to pay parking charge.
Washington, D. C.	Eastover Shopping Center	150	10-15	.00	.30	3	.5	5.5	25	13.2	On-street fringe parking available at lower cost.
Washington, D. C.	Penn Mar Shopping Center	150	5	.00	.50	2	1	8.5	35	14.5	On-street fringe parking available at lower cost.

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Analysis

Tables 1 and 2 show the price, service, and locational characteristics of both successful and unsuccessful park-and-ride operations. The data on successful operations were compared with those for unsuccessful operations to determine if any factors indicative of performance could be found. Of the successful operations, three were over five miles from the CBD and six were less than two and one-half miles away. In comparison, six unsuccessful lots were located over five miles from the CBD while two were closer than two miles. It appears that the chances of success are greater for peripheral lots and, accordingly, remote fringe lots require more careful planning.

The travel time involved appears to be an important variable as twenty minutes of bus riding appears to be the tolerable limit. Consequently, a lot can be successful at a distance of five or more miles from the CBD if the bus trip requires less than 15 minutes. The distance to downtown and the travel time in the transit vehicle are, of course, related by the average speed of the vehicle. The average speed is thus an important factor in the success of the outlying lots. The successful lots that were over five miles from the CBD had a total average speed of 22.8 mph. The unsuccessful operations at similar distances showed an average speed of only 14.3 mph. This implies that for an outlying lot to be successful it must be served by some form of express service. When a peripheral lot is located within two miles of the CBD, the average speed is not an important factor for success or failure.

Data for peak hour frequency of service were available for most operations, but this factor does not appear to be significantly related to ridership. Some successful operations had headways as high as 30 minutes while some unsuccessful park-and-ride lots provided 5-minute headways. The level of service during the off-peak hours, however, did seem to be important. None of the unsuccessful operations provided service during the off-peak hours, with the exception of the Hollywood Bowl Lot in Los Angeles, which attracted over 100 riders but failed due to parking costs. In comparison, the successful operations provided off-peak service in most cases.

The parking lot site appeared to be a very important consideration. Lots must be located along major corridors leading to the city, and if possible, they should be visible and easily accessible from the highway. All of the lots studied were along major routes. The data on their visibility and accessibility are not complete but almost all of the listed lots appeared to be located satisfactorily. The actual size of the lot and the number of spaces provided were not important factors in themselves since capacity must be tailored relative to demand.

The price of parking at the park-and-ride lot proved to be a very significant factor when it equalled or exceeded the costs of parking in the CBD area. In that case, tripmakers were discouraged from using the park-and ride facilities. On the other hand, if the parking charge was less than downtown costs or even free, this was not a sufficient incentive to attract riders. In either case, the deciding factor was the downtown parking costs and not the parking fee for the park-and-ride lot.

In retrospect, the successful park-and-ride operations revealed that some convenience or advantage was gained by using the facility. An important incentive was significant time savings in the range of 10 to 15 minutes. This savings was usually accomplished with the use of an express bus and/or preferential freeway lanes. Money savings attracted riders if the downtown parking costs were exorbitant. Easy and convenient pick-up and drop-off services attracted people. Nonstop service also contributed to success.

On the other hand, the unsuccessful operations reveal many improper financial considerations and oversights. A large number of the failures were due to the low parking costs of the downtown area and the ample availability of downtown parking. Some of the failures were due to improper location of the lots. In some cases lots were placed near existing rail park-and-ride operations which provided much better line haul service. Some lots were near a fare zone boundary where a short walk could reduce costs for commuters, and still other lots were placed too close to the CBD where most people walked from the lot rather than ride the bus. In several cities there was not even an urgent need for park-and-ride as access to downtown was relatively easy and congestion problems did not exist.

In terms of the objective factors that have been cited, downtown parking cost seems to be the most important factor influencing park-and-ride decisions. Other important factors for success were downtown parking availability, the time spent riding on the bus, total time savings, and lot location.

To this point no mention has been made of the value riders place on the relatively subjective factors affecting mode choice. Consideration of the reliability of the bus with regard to accidents, repairs, and overall vehicle condition influences commuters' decisions. Other things such as protection from the weather and fare payment procedures are important. People also enjoy privacy and diversions while traveling, such as a radio or conversation with friends, which a bus cannot always offer.

Convenience may be the subjective factor that needs the highest consideration. People would like to avoid walking, avoid waiting, and avoid transferring to another vehicle. It is difficult to determine just how much these subjective factors influence riders since data are scarce.

In summary, it appears that fringe parking-express bus service will succeed when it meets the needs of the tripmaker, real and perceived. Successful fringe parking-express bus service is then public transportation which is designed as a desirable service rather than one which is only a continuation of the failures of the past.

At the time of this writing the only major state agency that has made a serious effort toward developing planning procedures for park-and-ride service is the New York State Department of Transportation. Their reports (items 24, 57, and 66 of the Selected Bibliography) are highly recommended and complement this report.

The observations and conclusions derived from the data on park-and-ride operations provide a basis for investigating the feasibility of a planning methodology for the same. This objective is pursued in the subsequent sections of this report.

CHAPTER 3

MODELING EXPRESS BUS-FRINGE PARKING CHOICE

The projected usage of a new transit operation is typically based on transit-auto choices for existing transit services in the study area. This task is accomplished with some form of modal choice model which specifies an aggregated estimate (i.e., proportion of zonal trip productions using transit).(8, 9, 10) These models exhibit major shortcomings in that they do not derive from nor provide principles of choice behavior and are thus not really applicable to forecast decisions relative to a new service.

In an attempt to improve upon the limited predictive power and lack of theory indicative of the early models, a new generation of disaggregate behavioral models have been researched.(11, 12, 13, 14) These models are disaggregate in character as they take the individual as the primary unit of decision making; they are stochastic in nature since they predict the probability of using a particular mode.

The perception of the attributes of transportation modes varies from individual to individual. Therefore, the behavioral models are predicated on the assumption that, if the individual is taken as the basis for decision analysis, the large variance due to the use of aggregated characteristics will be reduced. The disaggregate models are, however, aggregated in practice by grouping individuals of similar characteristics in the same category. Here the aggregation process is assumed to result in less variation compared to the earlier models. Hence, the predictive power of the modal choice is expected to improve considerably if it is stratified over as many behavioral groups of tripmakers as possible.

At present, the exact prediction of the individual choice of mode is beyond the state of the art. However, the probability of individual mode choice can be predicted within reasonable accuracy.(11)

As a rule modal split models have been related to binary choice situations, i.e., automobile vs. mass transit. In many cities, however, competitive public transit modes such as rapid rail, local bus, and express bus exist. Ultimate splits among the transit modes are obtained with a submodal split model.(15) Such a strategy requires aggregation of transit characteristics to provide average system characteristics in the initial auto-transit split.

Realistically, however, all modes are simultaneously evaluated by the commuter and his choice mechanism does not follow a sequence of binary choices. Several theoretical studies have been concerned with expanding the alternative choices replicated by a simultaneous n-dimensional model.(16, 17, 18) The development of the n-dimensional model is not complete, however, and there has only been limited practical application.

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Selecting an Operational Choice Model

In view of the available applied models, the Washington Modal Split Model[19] was selected for this study. The major reason for this decision was that the model employed some characteristics of disaggregate and stochastic models. The Washington Model is essentially aggregate and the aggregation process is based on grouping tripmakers by three trip purposes, three income groups, and sixteen captivity rates. However, the primary unit of decision making is the individual and the model is based on the hypothesis that individual mode choice is utilitarian. Since utility theory is essentially universal, it is felt that the Washington Model should be applicable to the generalized corridor problem under study.

A utility measure (the utile) is the basic dependent variable of the model. The utile of a given mode corresponds to the dis-benefits that arise from the running time, excess time, and monetary cost of making a trip by that mode. The Washington Model represents a binary choice situation between mode A and B and states that a tripmaker will choose mode A over B if the utile of mode B is greater than that of A. But the perceived disutility of the tripmaker does not necessarily agree with that measured by the analyst. Therefore, there will be some misclassifications due to numerous chance errors.[10] These errors are accounted for by using a normal distribution curve which relates the probability of an individual choosing the mode that has been estimated to be inferior to the probability of misclassification. A theory based on a normal probability function will be correct if a tripmaker truly has a free choice between the two modes. In some cases, however, due to the socioeconomic characteristics of the traveler and the attributes of the transport system, the tripmakers are captive to one of the modes. Captivity to either mode modifies the shape of the free choice curve by introducing lower and upper bounds. This modification, however, is successfully accounted for by use of a formula in the Washington Model. A captivity rate is estimated as a function of income, trip purpose, and a measure of transit accessibility both by production and attraction zones.

A tripmaker within the corridor area is faced with more than a binary choice at the zone of his residence. A multinomial model which considers choices between all possible modes simultaneously seems to be more desirable in this case. However, as was previously stated, such models have not been fully developed and at the time of this study are not available. Development of a multinomial model which considers all available modes simultaneously will be pursued in the second phase of this research.

Choice Model Application

The choices available to the typical commuter within the corridor market under consideration include choices at the residence, the decision between fringe and CBD parking, and route choices.

Choices Available at the Residence

The travel decision at the zone of residence is important because it yields the number of persons who are willing to tie up their automobiles all day for the work trip.

Carpool passengers are included in the automobile trips in terms of the auto occupancy factor. The kiss-and-ride mode is not assigned to automobile trips because the automobile is not confined for the entire day. On the other hand, the commuter who decides to use transit for his trip to the CBD has two possible choices: a local bus or an express bus. The local bus is assumed to run from the zone of residence to the CBD. The express bus commuters, however, must first travel to the fringe lot (unless said lot is located within their residential zone). Thus, there is a further choice process involved with traveling to the fringe lot. Given that the commuter does not choose to tie up his automobile for his work trip, he can get to the express bus by bicycle, walking, kiss-and-ride, or a collector bus. These choices available to the commuter constitute the transit access choice.

Parking Choice

The tripmakers who choose to drive or participate in a carpool at the zone of residence have two subsequent choices. They can either park at the fringe lot and take the express bus or drive to the CBD and park. In either case, the automobile is not available to others during the entire day.

Route Choice

Those who drive to the CBD have a further choice, the route choice. Here they are assumed to take either the expressway or the shortest arterial route.

The mode choice situation at the corridor level is thus of a multinomial character. A flow chart of the choices available to the tripmaker is given in Figure 3. This conceptualization shows the tripmaker to be simultaneously considering all of the available choices at his zone of residence. However, for reasons previously cited, the development of this approach is not feasible at this time.

Two additional flow charts are introduced to represent the commuter choices in a fashion wherein a series of utilitarian choice models can be applied. The flow chart shown in Figure 4 assumes that the main decision of the tripmaker is that of choosing between auto and transit at the zone of residence. This decision directly yields the number of drivers who are willing to tie up their automobiles all day for the work trip. If the automobile is chosen at the zone of residence the tripmaker has another choice between parking at the fringe lot and driving directly to the CBD. Important results can be obtained in this secondary choice analysis such as the parking demand at the fringe lot and the number of cars driving along the congested routes of the corridor. A route choice is also required of auto trips to the CBD.

The transit trips obtained from the primary mode split are categorized as local bus trips, which originate at the zone of residence, and express bus trips. The share of the express bus in this split together with the number of auto trips to the fringe lot yield the express bus usage at the fringe lot. Since the express bus is available only at the fringe lot, a mode of arrival split is also included.

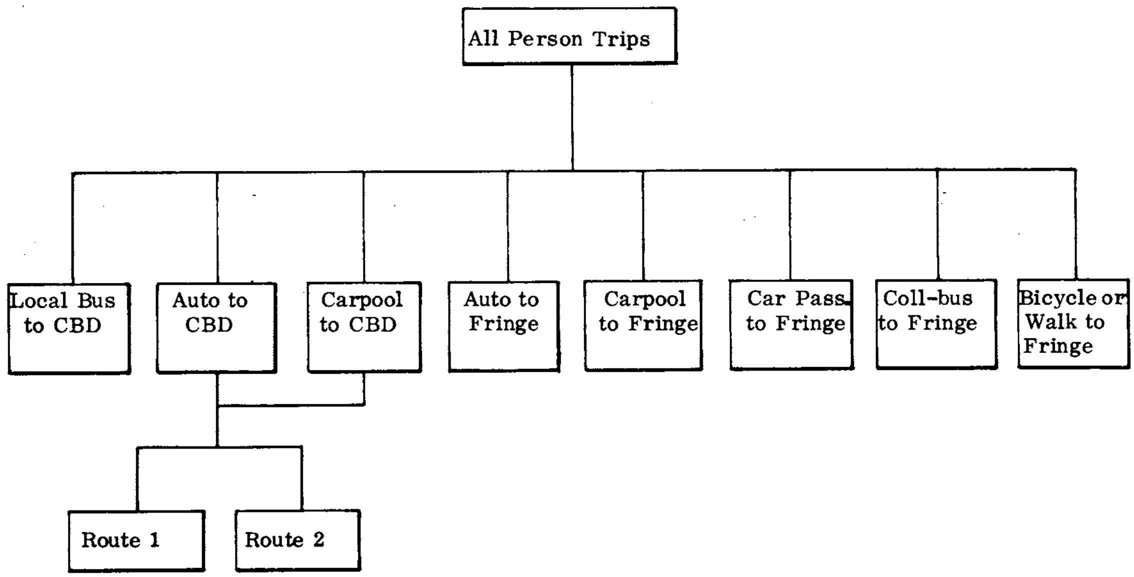

Figure 3. Flow chart for the multinomial mode choice model.

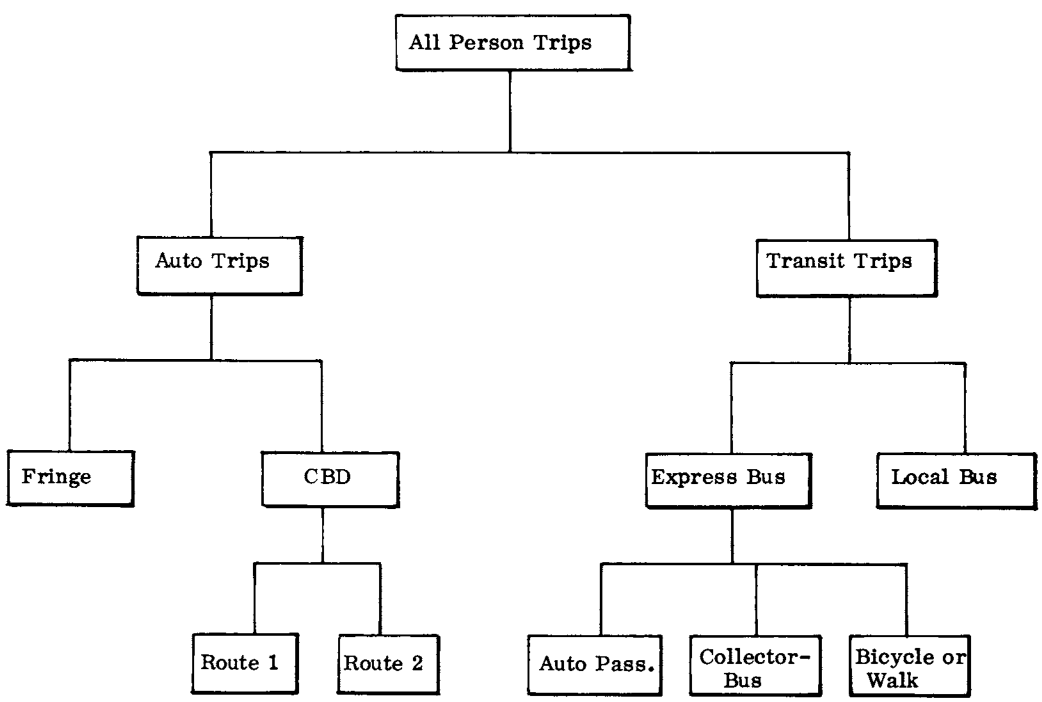

Figure 4. Flow chart for the binary mode choice model.

A further alternate flow chart is shown in Figure 5, where only those auto trips which end at the CBD are assigned as auto trips in the primary mode split. Fringe parking is included in the mode of arrival split, leading to a multinomial mode split situation.

The choice process shown in Figure 4 is employed to structure serial applications of The Washington Model in this initial phase of investigation. This strategy involves one primary mode split and four submode split analyses. The submodal split is used when the tripmaker has already been assigned to either the transit or auto modes. There is no captivity involved in the submodal choice mechanisms since all secondary decisions are free choices. Hence, at zero utile difference, there is a 50% probability of using either submode.

The second auto submodal split is a route choice. The utiles of each route are estimated and the difference corresponds to the percent usage on the free choice curve. The fringe parking utile, on the other hand, is obtained by summing the utile of driving to the fringe lot and the utile of riding the express bus. The utile difference yields the percent usage of each submode and, hence, the weights to be used in the estimation of the auto utile in the primary model split analysis.

The arrival mode split analysis for the express bus yields the percent usage of auto and bus or walk modes. Thus, the express bus utile can be estimated by summing the utile of riding the express bus and the utile of arrival mode weighted in accordance with the percent usage. The utile difference between the local bus and the express bus corresponds to the percent usage of each mode on the free choice curve. Hence, the transit utile can be estimated as the weighted average of the local bus and express bus utiles.

The primary mode choice split between automobile and transit is more complicated as captives to either mode should also be considered for a complete analysis. Obviously, the free choice curve does not apply to a tripmaker who has no alternate means of travel. A tripmaker is considered to be transit captive if he has no access to any kind of automobile transportation. Auto captives are those tripmakers who need an auto either at the destination or on one leg of the trip.

Captivity to either mode modifies the shape of the free choice curve by introducing upper and lower bounds. This modification is accounted for by using Pratt's formula.(11)

$$\text{Percent Free Choice} = \frac{100\left[(\text{overall \% transit}) - (\text{\% transit captives})\right]}{100 - \left[(\text{\% transit captives}) + (\text{\% auto captives})\right]}$$

The Washington zonal level computer program is the basic subroutine of the program developed for this project. The Washington program was modified in accordance with the assumptions given earlier. A program to read data and tabulate the results was added to the subroutine rather than using the U-mode program in the Urban Mass Transit Administration's modeling package as does the original Washington Model.

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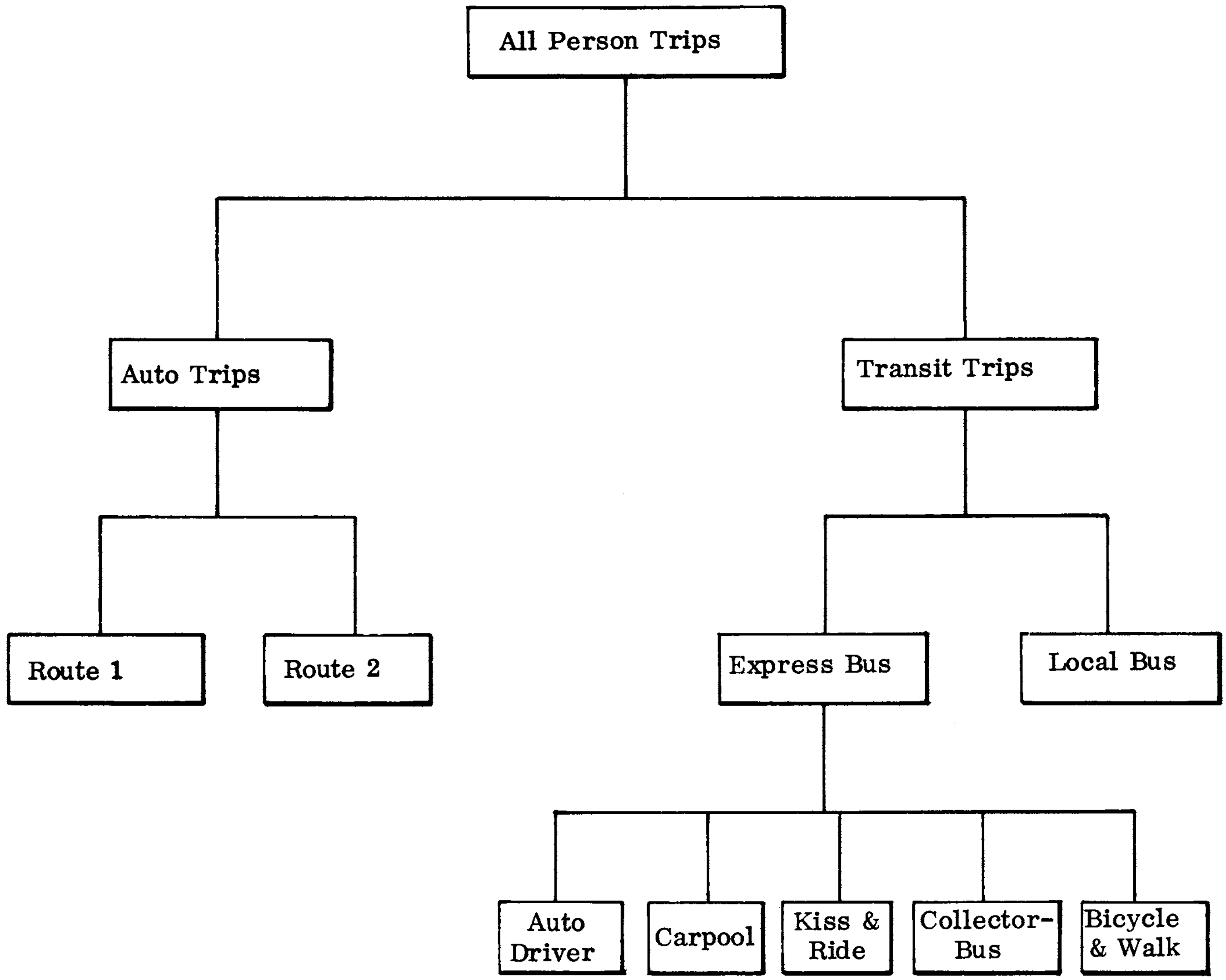

Figure 5. The alternate flow chart for the mode choice model.

Data Requirements

The proposed analysis considers only CBD destined trips. The system and tripmaker data required for the choice analysis include the following:

1. System Data
   (a) Highway travel distances
   (b) Highway travel times
   (c) Transit costs
   (d) Transit running times
   (e) Excess times (i.e., transit access, from parking lot to destination, etc.)
   (f) Parking costs at the CBD
2. Bus riders survey
3. Auto travelers survey.

The system data are obtainable from transit operators, the Highway Department, and via traffic engineering measurements. The bus rider survey developed for this study is shown in Figure 6. It is distributed at the beginning of the trip and collected as riders leave the bus or by requesting the respondents to return their questionnaire by mail. The license numbers of auto travelers entering the expressway in the vicinity of the fringe lot are recorded and questionnaires mailed. The typical auto survey is shown in Figure 7. The two questionnaires were implemented to survey the Parham Express Service in Richmond, Virginia. The analysis using this information will be documented in a subsequent report.

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This Survey is Sponsored by the Virginia Department of Highways

THE FOLLOWING QUESTIONS CONCERN THE BUS TRIP YOU ARE NOW MAKING

FOR OFFICIAL USE ONLY

If possible, please fill out this questionnaire during this trip and return it to our personnel who are on board this bus. If this is inconvenient, please fill out this questionnaire at your pleasure and return it in the postage-paid envelope.

1. Where did you initially begin your trip?
   ____
   (specify address - number and street name)

2. Was the place you came from: (check one)
   ___ home
   ___ work   ___ other (specify) ____________

3. Trip purpose. The reason for this trip was: (check one)
   ___ return home   ___ shopping
   ___ work   ___ recreation
   ___ school   ___ other (specify) ____________

4. Time you began your trip: _______ A.M.

5. How did you get to the Parham Road Lot to board this bus?
   ___ drove and parked   ___ another bus
   ___ car passenger-car parked   ___ walked, how many minutes ___
   ___ dropped off-car not parked   ___ other (specify) ________

6. What time did this bus leave the Parham Road Lot? _______ A.M.

7. Where will you get off this bus? (check one)
   ___ 8th & Clay   ___ Main & 11th
   ___ 9th & Broad   ___ Main & 10th
   ___ Broad & 10th   ___ Main & 8th
   ___ Broad & 12th   ___ 7th & Franklin
   ___ Broad & 14th   ___ 7th & Grace
   ___ 14th & Franklin   ___ 7th & Broad
   ___ 14th & Main   ___ 7th & Clay

8. How will you get to your destination after leaving this bus? (check one)
   ___ walk, how many minutes _____   ___ taxi
   ___ another bus   ___ other (specify) ________

9. What is your final destination?
   ____
   specify address (number and street name) or building

10. Time you expect to arrive at your destination: _______ A.M.

11. If this bus service were not available, how would you make this trip?
   ___ drive a car   ___ another bus
   ___ ride as a car passenger   ___ other (specify) ________
   ___ participate in a carpool

12. If you drove a car or rode as a car passenger for this trip in the past, why did you switch to this bus? ____________
   ____
   ____
   ____

13. Do you have any recommendations as to how this bus service could be improved? ____________
   ____
   ____
   ____

14. How many licensed drivers reside in your household? (count yourself) ________

15. How many cars are owned by members of your household? ________

16. Could you have used one of the cars to make this trip? ___yes ___no

17. Please indicate your: Sex: ___Male ___Female
   Age Group: ___ under 16 ___ 16-24 ___ 25-44 ___ 45-65 ___ over 65

18. What is the combined annual income of all members of your household?
   ___$0-$4000 ___$4000-$8000 ___$8000-$12000 ___over $12000

THANK YOU

Figure 6. Bus rider survey.

UU1027

This Survey is Sponsored by the Virginia Department of Highways

A vehicle registered in your name was observed entering I-64 eastbound at Parham Road between 7:00 a.m. and 2:00 p.m. on August 21, 1973 . It would be appreciated if you or the person who drove that vehicle on this trip would answer the following questions and return the questionnaire in the postage-paid envelope.

FOR OFFICIAL USE ONLY

Errors in recording license plates do occur. If this form was sent to you by error, please check here and return ___. Otherwise, please continue.

1. Where did you begin this trip?
____
specify address (number and street name)

2. Was the place you came from: (check one)
___ home
___ work ___ other (specify) ______________

3. Trip purpose. The reason for this trip was: (check one)
___ return home ___ shopping
___ work ___ recreation
___ school ___ other (specify) ______________

4. Time you began your trip: ________ A.M./P.M.

5. What was your final destination?
____
specify address (number and street name) or building

6. Time you reached the above address: ________A.M./P.M.

7. What was the vehicle parking cost? $_____ per ________

8. After you parked the automobile, how did you get to your final destination?
___ walk, how many minutes ___ taxi
___ bus ___ other(specify)__________

9. Do you use your car during the business day? ___ yes ___ no

10. Do you usually make this trip: (check one)
___ alone
___ carrying passengers, how many? ______
___ within a carpool, how many members (count yourself)? ______

11. Could you have used the express bus from the Parham Road Lot for this trip?
___ yes, but I chose not to because ______________
___ no, because ______________
___ not aware of this service

12. Are there any improvements possible regarding the Parham Express bus service which would make it acceptable enough to influence you to use it? ___ yes ___ no If yes, what might they be? ______

13. How many licensed drivers reside in your household (count yourself)? ________

14. How many autos are owned by members of your household? ______

15. Please indicate your: Sex: ___Male ___Female
Age Group: ___under 16 ___16-24 ___25-44 ___45-65 ___over 65

16. What is the combined annual income of all members of your household?
___$0-$4000 ___$4000-$8000 ___$8000-$12000 ___over $12000

THANK YOU

Figure 7. Auto survey.

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Summary

This section shows a framework for analyzing fringe parking decisions. An implementable model, the Washington Model, is cited for initial application. Further study that would incorporate multinomial choice modeling techniques is strongly recommended.

CHAPTER 4

SIMULATION OF FREEWAY SERVICE

The freeway simulation model, PRIFRE, evaluates bus and carpool priority schemes within a comprehensive transportation system and aids in proposing new alternatives to the auto-oriented system and/or rail-rapid transit options.[20] The model theoretically determines the proper number of lanes to reserve for high occupancy vehicles and simultaneously considers the question of what the number of occupants should be to qualify a vehicle for priority status (assuming known and static occupancy levels). The model can also be adapted to analyze the consequences of changes in the physical design of a freeway and to develop solutions to weaving problems.

Since changes in the capacity of a freeway cause shifts in the demand,[21] realistic analysis requires a synthesis of dynamic demand models with the freeway simulation model. The model should, therefore, be considered for use in conjunction with contemporary urban transportation planning models.

Present forecasting techniques generally use a trip generation procedure, a trip distribution technique, a modal split model, and, finally, a network assignment algorithm. In the last step, the volumes assigned to the transportation network are the same as the input required for PRIFRE. Hence, the PRIFRE model performs a microscopic link analysis and can be employed to interface with the traffic assignment algorithm to provide detailed information on the design elements and performance of the way facility.

In any priority operation, there will normally be some fringe parking supplied as an inducement for auto drivers to use transit. By interfacing the PRIFRE model with modal split and assignment models, it is theoretically possible to make demand predictions for the lot based upon the level of service provided by the freeway. For instance, if only one lane is presently reserved for high occupancy vehicles on a particular freeway, a certain demand for fringe parking would result. However, if the number of priority lanes were increased, there would be an expected increase in demand for fringe parking spaces. Thus, comprehensive planning must consider future land requirements for complementing facilities. Since future demand in person trips can be predicted reasonably well using present planning techniques, modal split techniques must specifically indicate the future fringe parking demand.

Input/Output Measures

Input

To use PRIFRE to test existing conditions on a freeway and to evaluate the impact of a priority lane, two basic types of data are required: freeway (supply) measures and demand. Initially, the freeway is divided into subsections of constant capacity. Lane width, number of lanes, lateral clearance, grade, and percent trucks on the freeways are the typical factors utilized to establish these sections of uniform capacity.[22] Since the model also requires demand to be constant throughout a subsection, entrance ramps may be located only at the beginning of a subsection and exit ramps may be located only at the end of a subsection.[20] Thus, subsections are specified by the entrance and exit conditions.

The travel-demand information needed includes an origin-distination (O-D) table for each time interval in the analysis period. The origins are represented as freeway entrance ramp volumes while destinations are indicated by exit ramp traffic. Extensive volume counts should be taken at all entrance and exit ramps throughout the study section with at least one mainline count. These counts should also include auto occupancy data over the entire time period. The volume counts are then converted to O-D tables by distributing each entrance ramp volume to the downstream exit ramps in proportion to the percent of total vehicle exits departing at each ramp. It is assumed that an entering vehicle will not exit at the next ramp on the freeway.

A set of speed-delay data from the freeway during the study hours provide a means for verifying the model's travel time outputs as well as providing the data necessary to generate speed vs. volume/capacity curves for the freeway. These generated curves are more realistic than the curves built into the model, which are average curves developed from observations on many freeways in varying locations.[22] In addition to the O-D data for automobiles, an O-D table for buses is required for priority lane analysis.

Output

In order to compare alternative situations, the output of the model supplies measures of traffic flow conditions and the passenger-carrying ability of the freeway system. Traffic flow conditions are given by the matrices of single vehicle trip times showing travel time from each entrance ramp to all downstream exit ramps for each time interval in the study period. Thus, the effect of changing demand on travel time is shown by comparing travel times from different time intervals. While this measure in itself may not be of great importance, it is the basis for all other measures included in the model's output. It is, therefore, important that the times generated concur with real travel times on the freeway. Under priority operations, a separate travel time matrix is developed for vehicles operating in the reserved lane and for vehicles operating in the unreserved lane, thus offering a means of comparing the time savings of one individual trip where a reserved lane has been established. Since travel times are calculated for three situations (normal, priority lane, and non-priority lanes) it is also possible to evaluate the increase in travel time for non-priority vehicles resulting from the implementation of a priority operation.

The final output of the model is perhaps the most significant measure of effectiveness. Here the total passenger-hours traveled and total vehicle-hours of operation are compared for priority and non-priority operations. Any aggregate savings or losses in time are noted, and any reduction in vehicle-hours through a priority lane reflects a potential for decreasing pollution and fuel consumption as well as travel time.

Model Application and Evaluation

The FHWA model, PRIFRE, was made operational and tested in two case study applications in Virginia. The first consisted of calibrating the model to represent the Norfolk-Virginia Beach Expressway in Norfolk and evaluating hypothetical express bus schemes. This analysis was initiated in response to a tentative demonstration project in the vicinity of which certain events have delayed implementation. However, this application provided information on the working characteristics of the model and its uses in practical planning situations.

In a second investigative study, the model was employed to examine the Shirley Highway exclusive bus lane in Northern Virginia. Ultimate comparisons were then made between these two studies and applications of the model by other agencies to suggest relationships between preferential bus operations and particular corridor characteristics. The findings in these initial investigations into uses of the model were takpn to guide subsequent application in the evaluation of a new express bus operation in Richmond, Virginia.

Preliminary Case Study 1: The Virginia Beach Expressway

The site for this agency's first application of PRIFRE was the Norfolk-Virginia Beach Expressway in Norfolk, Virginia, as shown in Figure 8. The actual study section of the expressway lies between the Independence Boulevard entrance ramp inbound to the City Hall Avenue exit ramp. The express bus operations which was implemented subsequent to this study uses the parking facilities at Pembroke Mall and, hence, increased the length of the run along the Virginia Beach Expressway. Entries along the first three miles of the study section, from Independence Boulevard to the I-64 Interchange, pay a toll of $0.25, while the remaining five miles are toll-free. In addition to the change from toll road to toll-free road the freeway widens from two lanes to three lanes for the last three and a half miles from the Military Highway entrance ramp to City Hall Avenue exit ramp.

At the time of the study, traffic on the freeway was free-flowing at all times. Some minor delay was noted at several entrance ramps, but no mainline queueing occurred. Existing transit operations on the freeway were insignificant, with only one bus operating during the morning peak period.

The data collection for the analysis was performed on November 29, 1972. No conditions were apparent on this day that might alter the validity of the data as being representative. In order to prepare O-D tables for the model input, 15-minute counts were taken at all entrance and exit ramps and one mainline counting station was established for a period of 24 hours. At the mainline counting station, indicated on Figure 8, auto occupancy counts were made for the peak period.

In order to generate O-D tables for the model input, a procedure had to be established to convert the raw data into the appropriate form. The sample calculations shown in Table 3 for Merrimac Drive (see Figure 8 for location) show the basic procedure utilized to express the flows (persons/hour from entry ramp to exit ramp) as required for the program. Table 4 is a typical O-D table compiled from the raw data.

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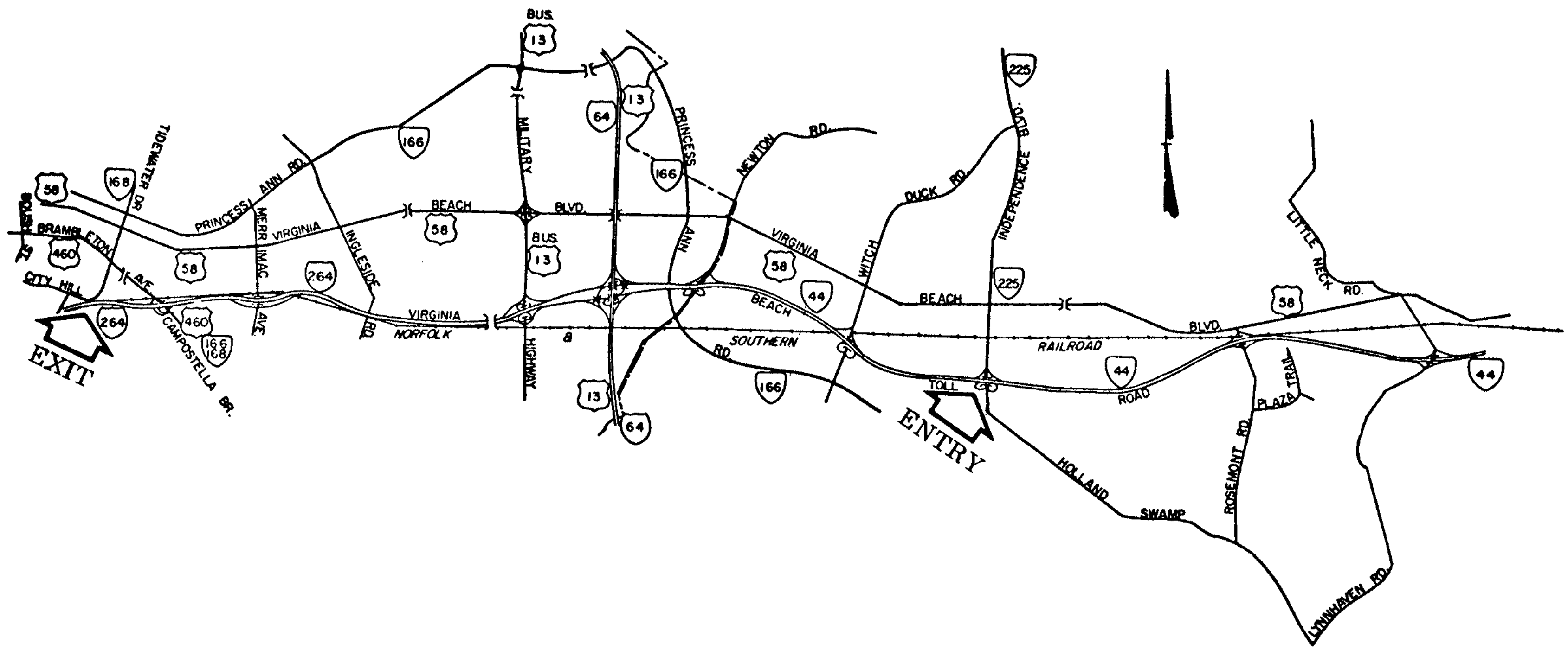


Figure 8. Norfolk-Virginia Beach corridor.

TABLE 3

ORIGIN-DESTINATION FLOWS

Entrance Ramp	Volume (Vehicles/15 min.)
Merrimac Drive	66

Downstream Exit Ramps	Vehicles	%	Vehicles Exiting*	Occupancy Rate	Persons/hr.
Route 168 S	98	9.87	7	1.29	36
City Hall Ave.	894	90.13	59	1.29	304
Total	992	100.00	66	----	340

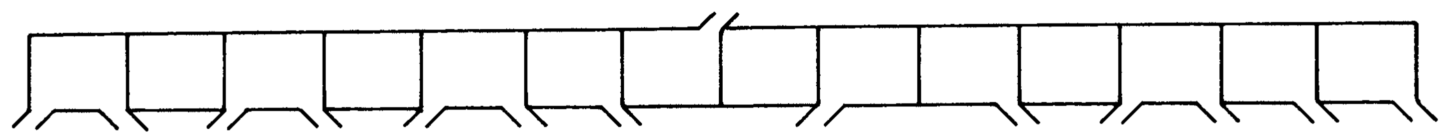
*Vehicles Exiting — This represents only the vehicles which entered at Merrimac Drive and exited at the ramp shown.

TABLE 4

O-D TABLE FOR 6:30-6:45 A.M.; ALL VALUES IN VEHICLES

	Witch Duck Rd.	Newton Rd.	I-64 North	Military Highway	I-64 South	Merrimac Dr.	Brambleton Ave.	Rt. 1685	City Hall Ave.
Independence Blvd.	3	7	373	41	62	7	2	10	138
Witch Duck Rd.	0	0	37	4	6	1	0	1	4
Newton Rd.	0	0	0	0	0	40	9	52	296
Military Highway	0	0	0	0	0	0	4	26	146
Merrimac Drive	0	0	0	0	0	0	0	4	27

Road geometrics, taken from a graphic log supplied by the Virginia Department of Highways, aided in dividing the freeway into 14 subsections of constant capacity demand, shown in Figure 9.



Section No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. Lanes	2	2	2	2	3	3	2	2	3	3	3	3	3	3
Capacity	3,960	3,960	3,960	3,960	5,940	5,940	3,960	3,960	5,940	5,940	5,940	5,940	5,940	5,940
Length (Ft.)	5,386	2,006	5,386	1,742	1,584	634	211	6,864	4,171	6,442	1,478	3,115	1,214	2,270
	Normal								Priority Operations					Nor.

Figure 9. Schematic subsection map.

In order to properly initiate the model, the capacity of the initial ramp and the freeway are assigned a joint capacity. For example, a value of 5,000 veh./hr. was input for the first entrance ramp capacity. This value was chosen to allow a compromise between the ramp capacity of 1,500 veh./hr. and the mainline capacity of 3,940 veh./hr. to give an accurate simulation of conditions at the start of the study section. A similar situation was detected at the end of the study section. Again, by assigning a joint capacity of 5,000 veh./hr., a realistic simulation was possible.

In order to check the accuracy of the simulation process, the single trip travel times generated by using Highway Capacity Manual curves were plotted (Figure 10) and compared with the travel times obtained from the speed delay runs. The results indicated that when the Highway Capacity Manual curves were used, the model computed excessive travel times. Therefore, additional curves were developed from the data collected at the study site. Figure 11 shows the comparison between actual and simulated travel times on the freeway, which indicated that the curves developed for the facility provide for an accurate simulation of the existing freeway conditions.

Previous studies have determined that priority lanes are only feasible when two or more lanes remain open to mixed traffic.[20, 22] Therefore a hypothetical priority lane proposed for this freeway began at the Military Highway Interchange where the freeway widened from two to three lanes and extended to the City Hall Avenue exit ramp at the end of the study section.

The simulation was carried out for travel conditions between 6:30 and 9:00 A.M., during which the total number of passenger-hours traveled was 3,306. This value was selected as a standard for comparisons with proposed changes in the system.

The first priority situation was tested using the existing travel demands. The minimum occupancy required to enter the priority lane in this example was established at three persons per vehicle. This included only one bus during the entire peak period, thus the priority lane was used primarily by carpools. At present occupancy rates, the institution of a priority lane under these constraints results in less than 5% of the vehicles utilizing 33% of the available capacity. The net result was an increase of 114.6 in total passenger-hours traveled over the existing situation.

The analysis showed that present demands do not warrant a priority lane since the change had only a small effect on travel time for those in the priority lane (average trip time went from 8.29 minutes to 8.20 minutes). A more significant consequence of the establishment of a priority lane was the increase in travel time of users in the non-priority lanes (9.51 minutes vs. 8.29 minutes). Even though this is a relatively small amount, it must be heavily weighed since 95% of the vehicles, or 88% of the travelers, would incur the increase.

The second phase of this analysis was to simulate the priority scheme under the proposed express bus service from a fringe parking lot. These plans call for buses to operate every half-hour from Independence Boulevard to City Hall Avenue. This analysis was performed with the same occupancy factors and demands as in the prior case. The simulation of the fringe parking proposal showed that a priority lane would not be warranted as an increase of 112.9 passenger-hours of travel over normal operation would result.

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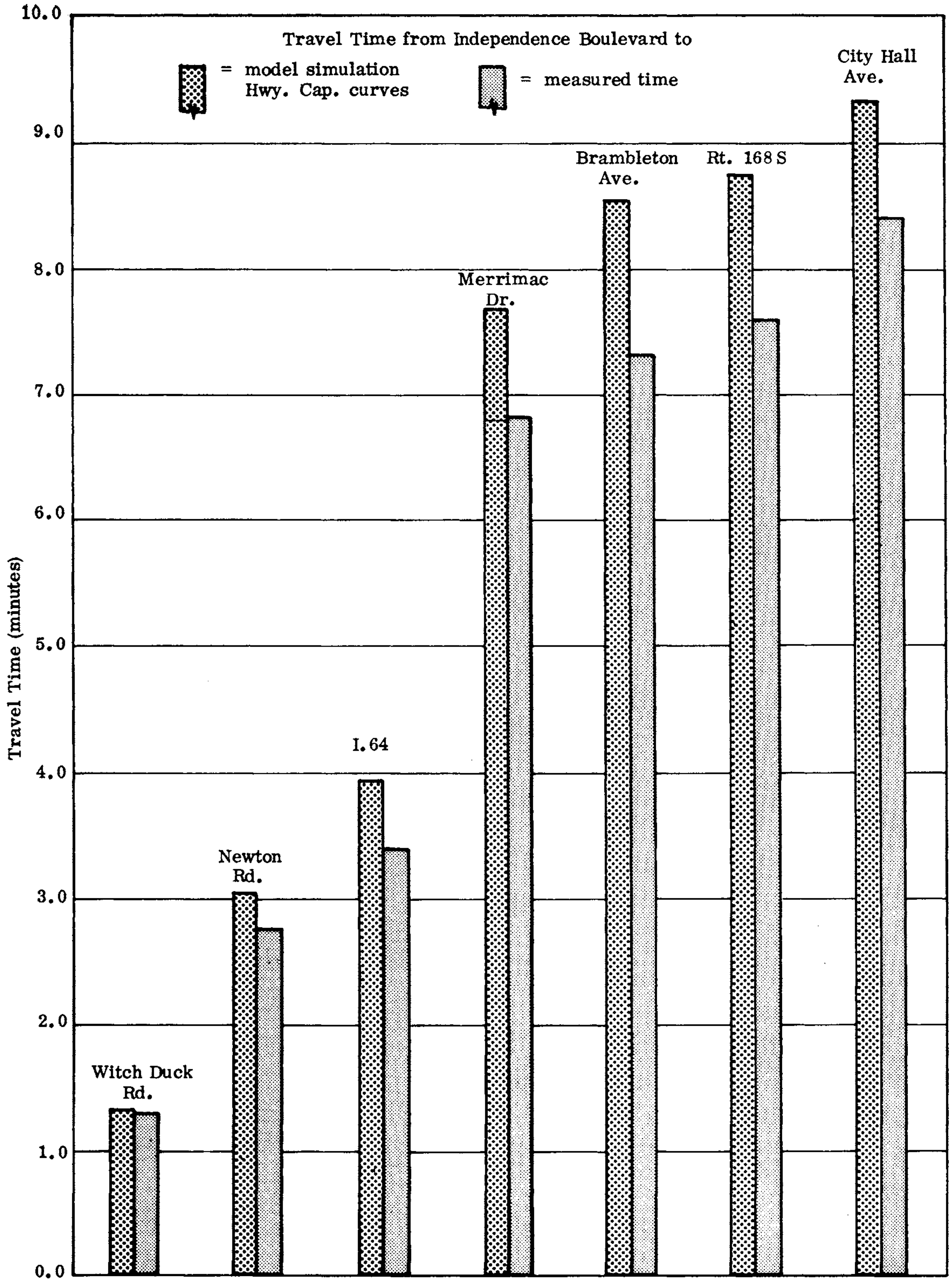

Figure 10. Comparative travel times from Independence Boulevard to selected points using The Highway Capacity Manual Curves.

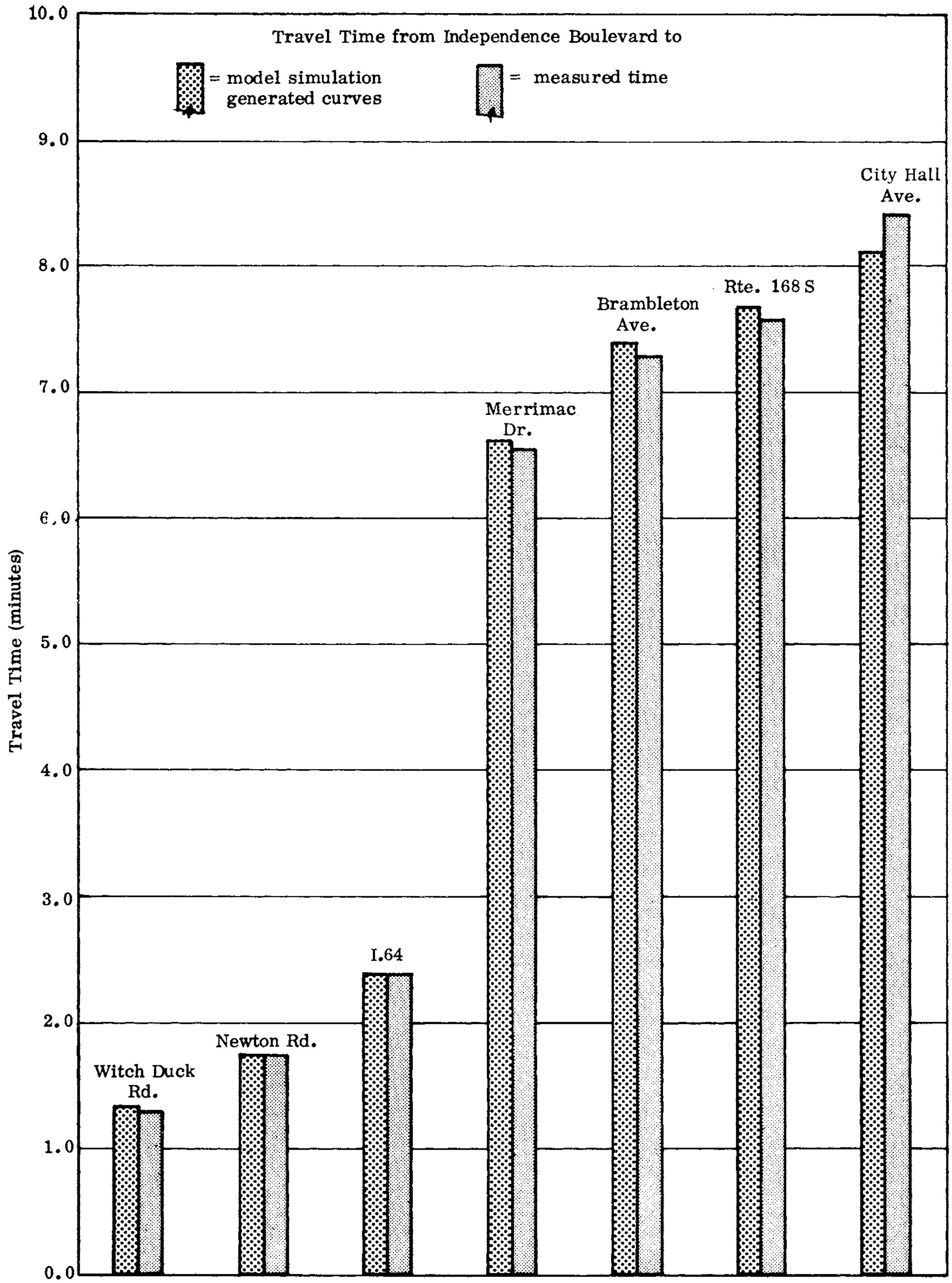

Figure 11. Comparative travel times from Independence Boulevard to selected points using curves from travel data.

The failure of a priority lane in the two test situations is attributed to the low travel demand relative to the capacity of the freeway. The low vehicle count (v/c) in the priority lane causes a small increase in travel speed over normal operations, but not a significant difference. Actually, throughout a large range of v/c values, speed is relatively unchanging, but from v/c = .8 to 1.0, speed drops off drastically with small changes in the v/c. With the institution of the priority lane, the v/c in the unreserved lanes rises to within this range. It may be seen that while only small travel speeds are gained for the priority vehicles, a significant decrease in speed occurs for non-priority vehicles. From these observations it is concluded that a freeway must be close to congestion and operating in a high v/c range and transit demand must be significant in order for savings to occur from the institution of a priority operation.

The next phase in this analysis was to determine the level of transit demand and the overall growth in traffic demand that would be required to justify a priority lane along this corridor. In conjunction with growth in transit demand, hypothetical auto occupancy shifts were considered. It is assumed that if a priority operation were implemented, some shifting would occur into higher occupancy vehicles to qualify for the priority lane.

In this phase of analysis, the first situation considered was a hypothetical shift from auto to transit with no growth in overall demand. A shift of 20% to transit was assumed with a 5% shift into carpools. The increased transit demand, however, was still not sufficient to warrant the institution of a priority operation, but passenger hours of travel increased by only 58.7. This is approximately 50% less than the increase incurred under present demand conditions.

The second growth situation reflected a uniform demand increase of 5%. This condition was applied to the operation consisting of the fringe parking lot with one bus departure every half-hour. This demand increase brought the unreserved lanes' volumes up to capacity in several subsections and caused large reductions in travel time over them. The difference in travel time for a single trip between the reserved and unreserved lanes increased from that for the previous fringe parking scheme (1.71 minutes) to 2.43 minutes. While this was a significant difference in travel time between lanes, other factors must also be considered. A primary concern is the increase in travel time incurred by the non-priority vehicles. A 5% growth rate brings demand in the three-lane portion of the expressway to a level that may be efficiently processed with three open lanes. However, the reserving of one lane for higher occupancy vehicles leaves only two lanes to supply a demand which exceeds two-lane capacity and results in negating any savings accrued by vehicles in the priority lane. Here an additional 167.4 passenger hours are caused over normal operations.

Next, a growth rate of 10.25% over the base (fringe parking) conditions was considered. This resulted in severe congestion along the entire length of the study section, with queues forming in the unreserved lanes and extending throughout the entire two-lane portion of the study section. An increase of 215.4 passenger hours resulted from the institution of a priority lane under these circumstances. Under normal operations, queueing occurs only during one of the seven 15-minute time slices considered, while under priority operations queueing occurs in four of the 15-minute periods considered. The queueing extends up the freeway from the priority lane, thus affecting all vehicles before they reach the priority lane. The net result is that under priority operations a single priority trip takes almost 2 minutes longer than a trip would take if normal operations were in use and a non-priority trip takes almost 4 minutes longer.

The next situation tested was a combination of the two prior cases where both growth and shifting occur simultaneously. A 20% shift into buses and a 5% shift into carpools were assumed with a uniform growth in demand of 50%. With the institution of priority operations here, traffic flow breaks down completely. Extensive queueing occurs during six of the seven 15-minute analysis periods. As in the previous case, one priority trip due to queueing would take longer than a trip of equal length under normal operations. The resulting total passenger hours traveled under priority operations were up more than 100% over normal operations.

In order to show that under some circumstances priority lanes do in fact result in time savings, hypothetical demand for the freeway was directly imposed in view of the capacity of the facility. The first step in this phase was to assume that the entire freeway consisted of three lanes, giving a capacity of 5,940 vehicles per hour. The freeway was now assumed to operate at a v/c ratio of .93 (5,500 vehicles/hour) and all vehicles were assumed to traverse the entire length of the freeway. The stated demand gave 7,150 person trips per hour using for an average auto occupancy of 1.3 persons per vehicle. For a period of one and a half hours this demand produced 1,738 passenger hours of travel and the speed along the freeway was consistently in the 50 mph range.

To test the savings offered by a priority lane scheme, the hypothetical demand of v/c = .93 was used as a base condition. Assuming that 27% of the passengers traveled by bus, this gives a bus flow rate of 44 buses per hour. The minimum occupancy required to qualify for priority status was set at 3 persons per car. This simulation resulted in a slight increase in the v/c ratio in the unreversed lanes, a rise from .93 to .96. This was reflected by a decrease in speed by 5 mph (as compared to the base simulation) for vehicles in the unreserved lanes. In the priority lane, however, the simulation produced speeds in the mid-60's, an increase of 15 mph over base conditions. As a result of this speed increase, a priority trip takes 3.17 minutes less than a non-priority trip. When total passenger-hours traveled under priority operations are compared with normal or base conditions, an overall savings of 23 passenger-hours occurs by the institution of a priority scheme. Thus, these tests show that a priority lane is justified only when the facility is operating close to capacity and that significant shifts to bus transit would occur if a priority lane were implemented.

Preliminary Case Study 2: Shirley Highway

PRIFRE was applied to a section of the Shirley Highway (I-95) in Northern Virginia to analyze the operation of this highway with and without a priority lane for buses. The segment studied runs from the intersection of I-95 and Virginia Route 236 (Duke Street) to a point approximately one mile beyond the Glebe Road interchange, where the permanent inner roadway ended at the time of data collection. The study considered the time period between 6:30 and 9:00 A.M. with the major traffic flow in the direction of Washington, D.C.,

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taking into account conditions before and after the priority lanes were opened and compared the freeway operating conditions resulting from several policies of priority lane usage.

Because of the uniqueness of the Shirley Highway's priority setup, including physical separations of inner and outer roadways and multiple entry points to the priority lanes, it was treated as two separate freeways, each operating under normal, non-priority conditions. The establishment of priority was accomplished by controlling the number and type of vehicles which enter the inner roadway. Thus, for this evaluation, the Shirley Highway was considered to be made up of an outer roadway ranging from two to four lanes and having several entrances and exits and a two-lane inner roadway. The inner roadway has limited entrance points, three as compared to seven for the outer roadway, and only one exit. In other words, once a vehicle has entered the inner roadway, it must remain there and travel all the way through the study section.

The situations simulated in this case consisted of a "before" condition, where only the outer roadway was considered to exist with all traffic using it, and several priority situations whereupon buses and automobiles of a specified occupancy could use the inner roadway. These priority situations were as follows:

(1) buses only,

(2) buses and 4-person carpools,

(3) buses and 3-person carpools,

(4) buses and 2-person carpools,

(5) no restrictions on inner roadway use.

In case 1, all buses entered the inner roadway at the three entrance points (Duke Street, Seminary Road and Shirlington Circle) and proceeded to the end of the study section while all other vehicles were confined to the outer roadway. For cases 2 through 4 those vehicles with the required occupancy that enter the freeway at these three points and which are destined for the end of the section, as determined from the O-D tables, are automatically assigned to the inner lanes. All others, either because they do not have the required occupancy, enter at some other point (i.e., King Street), or are destined for an intermediate exit (i.e., Shirlington Circle) are restricted to the outer lanes.

Case 5, that of no priority restrictions, presented a bit of a problem as to how to distribute the eligible vehicles between the two roadways, since they are physically separate. It was finally decided to proportion them based on capacity considerations. As there are two inner and, on the average, three outer lanes, for a total of five, 40% of the eligible vehicles, determined by origin-destination, were assigned to the inner lanes and the remainder to the outside, along with those vehicles which could not use the express lanes for the same reasons as in cases 2-4. Problems like this arise due to the model's inability to simulate, by itself, a driver's demands or his behavioral patterns when confronted with this type of choice.

Due to the fact that both roadways are treated as distinct freeways operating under "normal", that is, unreserved, conditions, there is no direct way to evaluate the effects of several priority options. For the purposes of this analysis, the basis of comparison was the travel time and the delay through the study section. Initially, there is a significant drop in travel time due to the removal of buses from the outer lanes. Since each bus carries 51 passengers and the time units are passenger-hours, each bus given priority takes 51 times more passenger time from the outer lanes than does a single auto carrying one passenger. However, removal of buses from the outer roadway does not reduce the delay encountered by those motorists who are in non-priority status. In order for this delay to be reduced significantly, all vehicles should be allowed to use the priority lanes.

Allowing all traffic to use the bus lanes results in travel time increases, especially during the peak hour of 7:00-8:00 A.M., that are in the range of 20%. Such a policy creates adverse effects on the efficiency of these lanes and, while not causing actual delays, does reduce the average travel speed by 7-10 mph. It must be remembered that this simulation assumed that only 40% of the total auto traffic now confined to the three outer lanes would be using the inner lanes if allowed. Since PRIFRE assumes a static demand and is insensitive to driver strategies, it is definitely possible that more drivers could switch to the inner lanes and, in fact, change their route so as to enter Shirley at a point where they could enter the inner lanes. With this in mind, it seems that the best solution is to keep the inner lanes as they are now, exclusively for buses, and encourage increased bus ridership through more comprehensive routing and fringe parking facilities.

Conclusions

An analysis of proposed priority operations on Route I-90 in Cleveland was conducted in 1970.[23] I-90 is an 8-lane expressway which experiences heavy congestion during the peak periods, and simulation analysis indicated that a priority operation would result in significant time savings if a minor degree of shifting into higher occupancy vehicles occurred.

Perhaps the most noteworthy difference between the Cleveland and Norfolk situations concerns the current vehicle speeds. In Norfolk the average vehicle speed was 65 mph (free flow) and, in turn, there was a reduction of travel speed in the unreserved lanes when compared with non-priority operations. On I-90, however, the increase in speed of priority vehicles was twice the decrease of non-priority vehicles. Conditions on I-90 fall on the lower portion of the v/c curve, connecting 0 mph with 28 mph (level of service F).[21] The slope of this curve is small, so a large change in v/c brings only a small change in speed. However, the priority lane operates along the upper portion of the curve and the shift from the lower curve results in a large increase in speed. Under all conditions the Norfolk-Virginia Beach Expressway operates along the upper portion of the curve and, therefore, no large gain in speed is accomplished by reducing the volume in a given lane (the unreserved lane).

An additional factor in the success of priority operations appears to be a high initial transit demand. In Cleveland a total of 43 inbound bus trips in the morning peak hours transports between 6% and 9% of the passengers traveling along the corridor[23], while in Norfolk the situation is quite different, with less than 0.5% of the existing tripmakers traveling by transit. On I-90, a 5% shift into buses and a 5% shift into

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carpools resulted in a time savings of approximately 200 passenger-hours per day, yet a shift of 20% into buses resulted in a loss of passenger-hours in Norfolk. The smaller percentage of transit passengers required to justify a priority lane on I-90 is a result of two factors: (1) the large gains in speed, and (2) the face that only one-fourth of the freeway capacity is reserved for high occupancy vehicles on I-90, while one-third of the capacity is reserved in Norfolk.

From the comparisons between I-90 in Cleveland and the Norfolk-Virginia Beach Expressway it can be concluded that two conditions are necessary for a successful priority lane operation: (1) traffic demand on the freeway must be close to capacity in order to produce a speed differential of 20-30 mph between the reserved and unreserved lanes, and, (2) the demand for transit must be of a relatively significant level. Because a substantial transit demand existed along I-90, only a small amount of shifting was required for a successful priority operation, while in Norfolk, even if 20% of the passengers shifted to transit, overall travel time for the freeway would be reduced. At present auto occupancy rates, 15% of the autos would be removed. Assuming that one bus is equivalent in traffic to two autos, but carries the passengers normally occupying 30 cars, the net result is a 14% reduction in vehicle demand. Conversely, in Norfolk, such shifting results in even less justification for a priority lane than in the case of no shifting.

This study indicates that several changes would make PRIFRE a more valuable tool. In the current version of the model no entrance is allowed to the priority lane except at the beginning of the priority operations. This severely limits the length over which a priority operation may be tested and causes problems as shown in the Shirley Highway example. In that case, several bus-only ramps provided entrance to and exit from the reserved lanes. In order to evaluate this freeway with the model, several runs were required and the output needed to be synthesized exogenously. Since the model treats the priority lane as a separate freeway from the unreserved lanes, it would not be difficult to provide a capability to incorporate exclusive ramps. Also, if priority operations are to be accepted on a large-scale, some provisions for entrance and exit at more than one point along the freeway must be provided.

One feature of the model is the capability to test more than one auto occupancy rate in a single run. An extension of this feature to allow shifting from autos to buses would make the model a more valuable tool. To specify shifts from autos to transit the user is now required to punch new data cards for each case, a procedure which is both costly and time-consuming. A procedure similar to that which now varies the growth factor should be developed to account for auto-bus shifts.

Finally, in order that the model be an efficient and useful planning tool, it must be used in conjunction with a complete forecasting package. Reserving a lane for higher occupancy vehicles will affect transport supply and modal split as well as the travel times along a given freeway. With the reduced single vehicle capacity, some shifting to alternate routes will occur and affect the flow in parallel routes as well as that in the unreserved lanes. In addition, a significant difference in travel times should influence some travelers to shift from private auto to transit, with the result that transit service can be economically expanded. Further increases in the level of service should accordingly cause further shifts to transit. Realistic equilibrium states can be determined only through the use of modal split and assignment models in conjunction with the PRIFRE model.

CHAPTER 5

THE URBAN CORRIDOR TRAVEL MARKET

This section supplements the primary effort of this study, which examines the feasibility of using existing transportation planning models to study corridor express bus mass transportation operations (i.e., the travel choice process and network simulation). The corridor is viewed with respect to historical development, population densities, socioeconomic dimensions, and accessibility considerations. This additional insight into the problem is valuable since the primary research effort concerns the latter stages of the urban transportation planning process and neglects the earlier phases. Accordingly, measures which explain the differences in the generation of CBD-oriented trips among various corridors are investigated.

The success or failure of an express bus-fringe parking operation is highly related to the characteristics of the market area and the population which it serves. Such a conclusion arises from a history of experience with numerous urban transit routes and experiments which have exhibited a spectrum of results from overwhelming success to complete failure. At this point, areal differences are stated in general terms in order to introduce the various measures of urban development and population settlement that can likely be employed to establish a list of factors explanatory of variations in the patronage of express bus systems or, alternatively, to determine potential usage on corridor transit facilities. The primary hypothesis proposed for guiding this analysis is stated as follows: "Given that two similar transit services are developed in two significantly different urban areas, the variation in patronage can be attributed to differences between the areas in which they are set".

Two study objectives are now stated: (1) To define the corridor boundaries (area of impact of the transit service) and, (2) to recognize the significant areal attributes which are explanatory of the relative transit patronage along a given corridor to the CBD. Also, since transportation facilities along high volume corridors are likely to become congested during peak hours, this section of the report is also concerned with the journey to work during the morning peak period.

The Background for Urban Transportation Corridor Analysis

At present, no objective methodology exists for a standard classification of corridors. Thus, the initial task is to provide a basis for inter-corridor comparisons. A primary factor which must be considered when defining an urban corridor is its historical development. As transportation routes either create or serve urban development (cause or effect), transportation supply is highly integrated with urban growth trends.

Different urban areas show growth patterns which can be focused on a core area, but variations in density of development and patterns of travel corridors are evident.

The level of service provided by an urban transportation network promotes activity which is visualized in terms of flows. These flows, or trip patterns, reflect accessibility, urban opportunity, and activity concentration. The concept of accessibility (ease of communication) indicates the relative effectiveness of various transport systems in providing mobility. This measure also accounts for the potential interactions among spatially separated activity units. The typical accessibility index is quantified in the following way:

$$A_i = \sum_j O_j F_{ij}$$

where:

A_i = Accessibility Index of source area i

O_j = opportunity measure at tributory area j

F_{ij} = travel impedance factor between locations i and j.

The common interpretation of the travel impedance is $1/t_{ij}^n$, where n is a function of trip purpose and local travel behavior and t_{ij} is travel time between zones i and j.

It is also suggested that observed travel volumes along corridor facilities can be directly related to accessibility measures as a result of their role in a number of the steps in the urban transportation planning model system; specifically in small area land use allocation, trip distribution, and modal split. A significant omission of accessibility sensitivity is noted by the neglect of such considerations in trip generation. In other words, here the decision to travel does not directly reflect proximity or ease of access to opportunities. This point is considered indirectly in the decision to locate (small area land use allocations) and in the trip generation stage in terms of auto availability. However, the rate of trip production of transit captives is insensitive to transit service levels and provides no basis to show the impacts of new systems or services.

To fully describe a corridor's development it is also necessary to identify the constituent entities and their relative intensities. Such factors include demographic data, employment statistics, commercial developments, industrial concentration, etc., and must be related in absolute terms and also relative to the attractions of the CBD and other corridors.

Many factors, therefore, must be investigated in order to classify and identify corridors. Other considerations include the location of the corridor within the metropolitan region, distances served with respect to the CBD, and the supply of transportation facilities. The effectiveness of the transport system within the corridor can also be examined to include, in addition to transport-cost effectiveness, a variety of typical community objectives such as economic development, employment opportunity, and the social and physical environment.

The majority of the factors mentioned above must be reflected in case studies and ultimately compared. Subsequent development in this section seeks to provide the

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means to accomplish the following: (1) measure the relationship between transit accessibility and trip productions, and (2) define the tributory area of flows (trips) that are are attracted to the major transit facilities which splinter a corridor. It is intended that these procedures will complement the modeling methodology investigated in this report in order to provide a generalized approach for planning upgraded bus mass transportation services.

Analysis of CBD Directed Flows Relative to Accessibility

The concept of the general share model as presented by Manheim[24] is employed to represent the role of accessibility in analyzing the corridor travel problem. Particular elements of this methodology are taken to derive expressions which define CBD directed corridor travel.

Total trip generation is given by:

$$V_c = \left[\sum_k Z_k \left(Z_d \cdot R_{kd.}^{\delta_{12}} \right)^{\delta_{21}} \right]^{\delta_{30}} \qquad (1)$$

where:

V_c = volume of CBD trips from corridor region

Z_k = combined effect of all activity system characteristics in zone k

$R_{kd.}$ = combined effect of all levels of service characteristics of all modes as they influence trips from zone k to the CBD (zone d)

The zonal trip generation is then

$$V_{kd} = V_c \left[\frac{Z_k \left(Z_d R_{kd.}^{\delta_{11}} \right)^{\delta_{20}}}{\sum_k Z_k \left(Z_d R_{kd.}^{\delta_{11}} \right)^{\delta_{20}}} \right] \qquad (2)$$

Equation (2) also satisfies trip distribution requirements since only CBD directed trip productions are considered.

Modal split becomes

$$V_{kdm} = V_{kd} \left(\frac{R_{kdm}}{R_{kd.}} \right) \qquad (3)$$

For more than one path, say an expressway and an arterial, route assignment is represented by

$$V_{kdmp} = \left(\frac{R_{kdmp}}{R_{kdm.}}\right) V_{kdm} \tag{4}$$

Within this development, a variable termed "potential" of zone k is defined as

$$P_{k1} = \frac{E_1}{t_{k1}^{\theta}} \tag{5}$$

and when related only to CBD trips equation (5) is the accessibility of the CBD to zone k:

$$P_{kd} = \frac{E_d}{t_{kd}^{\theta}} \tag{6}$$

Similarly, a generalized accessibility is given by

$$P_{kd} = Z_d \quad R_{kd}^{\delta 1} \tag{7}$$

where a number of variables are allowed to enter the Z and R terms in addition to employment (E_d) and travel time (t_{kd}).

Substituting the accessibility term (equation (7)) into equations (1) and (2), we get

$$V_c = \left(\sum_k Z_k \cdot P_{kd}^{\delta_2}\right)^{\delta_3} \tag{8}$$

$$V_{kd} = V_c \left(\frac{Z_k \quad P_{kd.}^{\delta_2}}{\sum_k Z_k \; P_{kd.}^{\delta_2}}\right) \tag{9}$$

If a trip generating potential is further defined as

$$G_k = Z_k \cdot P_{kd.}^{\delta_2} \tag{10}$$

then

$$V_c = G.^{\delta 3} \tag{11}$$

$$V_{kd} = V_c \frac{G_k}{G.} \tag{12}$$

Then V_c gives the travel potential for the corridor and V_k shows the contribution of an individual zone. Transit accessibility can be directly related to trip productions within this framework. Finally, the CBD trips along the corridor forecasted to use a fringe parking-express bus service is

$$V_{kdb} = G.^{\delta 3} \left(\frac{G_k}{G.}\right)\left(\frac{R_{kdb}}{R_{kd.}}\right) \tag{13}$$

Equation (13) is then an aggregate estimate of the zonal CBD trips using the express bus. This expression is particularly useful for preliminary investigation into corridor selection and parking provision. The generalized impedance term (R) is particularly appropriate in viewing the elasticity of the various service characteristics related to fringe parking such as time to the lot and time to the CBD, parking cost at the lot and CBD, alternative total costs and relative parking supply. These concepts are similar to those used by Nakkash and Grecco to derive an activity — accessibility model of trip generation.[25]

A study by Thibeault, et al. shows that individuals are least satisfied with the accessibility of their workplace relative to other destinations.[26] This information is reproduced in Table 5.

TABLE 5

PERCENT OF RESPONDENTS SATISFIED WITH ACCESSIBILITY TO DESTINATIONS IN 1966

Destination	Income	
	Less than $5,250	$5,250 or More
Elementary School	92	90
Head's Work	70	81
Shopping Center	86	93
Grocery Store	85	91
Church	84	91
Hospital-Clinic	85	91
Doctor's Office	82	90
Home of Best Friend	87	92
Downtown	88	89
Park or Playground	90	91

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Table 5 therefore shows a potential market for express bus-fringe parking operations where they improve the tripmaker's perceived accessibility to his place of work.

The development of this section has been specifically designed to provide a means to establish the potential ridership in zones along a high volume corridor for express bus service. The application of this methodology for locating and sizing a fringe parking facility is considered in the next section.

Accessibility Analysis of Fringe Parking

In order to estimate the feasibility of a fringe parking-express bus operation a number of considerations must be addressed. In this section the fringe parking lot is examined solely in terms of its location and parking capacity. The hypothesis is made that the potential market area of a given fringe lot is a function of the following:

1. The accessibility of the lot to the respective residential zones via local roads.

2. The accessibility of the lot to the CBD via the express transit service.

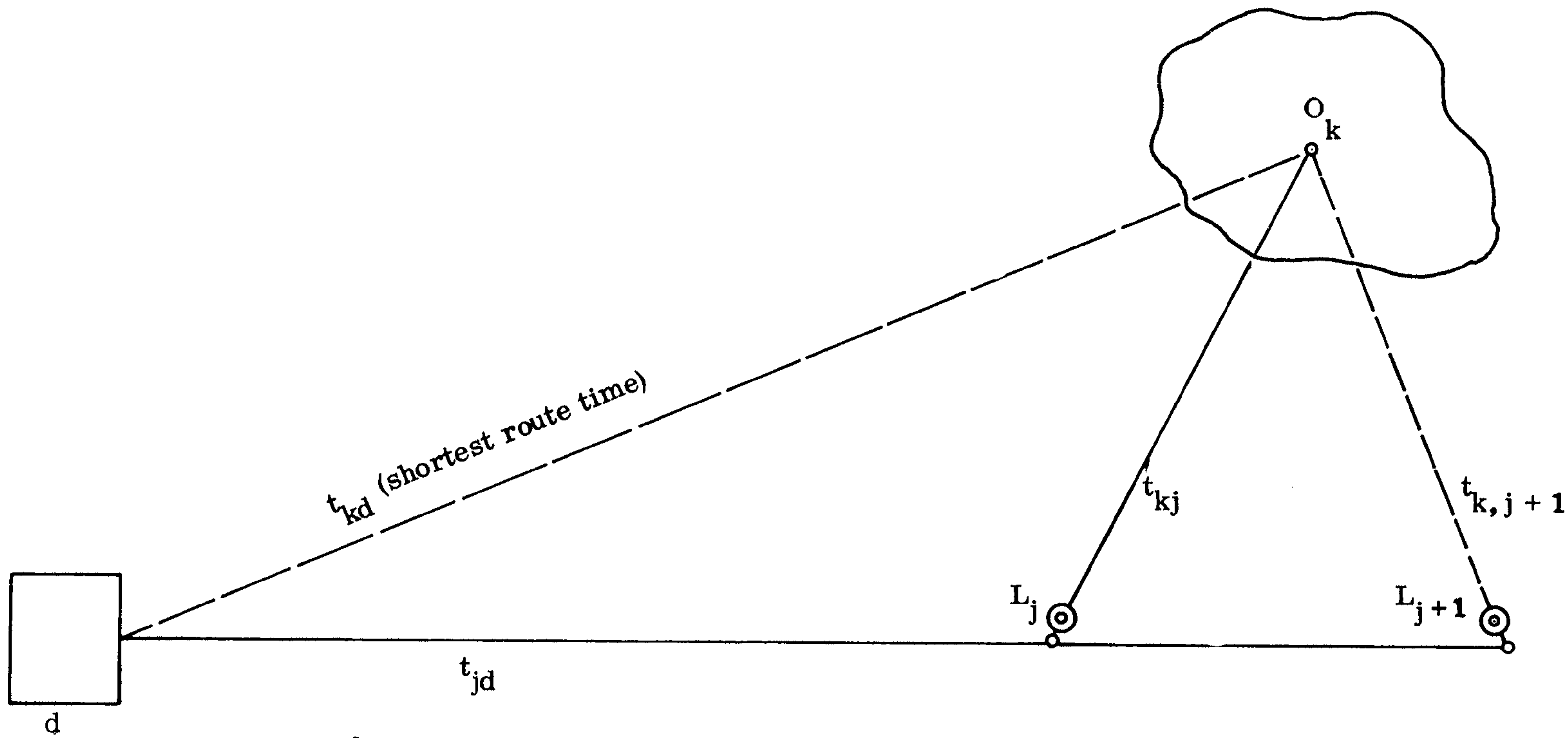
3. The accessibility of the residential zone to the CBD via direct auto transportation.

Figure 12 shows this conceptualization applied through the terminology previously derived. It is thus proposed that the location and size of a fringe parking facility can be estimated in terms of an accessibility measure which basically derives from time and capacity factors.

This approach differs somewhat from that used to analyze station-market areas along the Lindenwald Line between South Jersey and Philadelphia.[27] In that study the station selection decision was formulated by a cost model which equates the costs of alternative choices (i.e., among various stations for transit and the auto driver mode) to obtain a locus of indifference (or choice boundaries). Then the tripmaker is assumed to choose his travel mode in an optimal fashion, i.e., the lowest cost alternative relative to his residential location, whether it be auto or a certain station along the Line.

The problem is addressed in a more fundamental fashion here; that is, the market area is first established via macro analysis and then behavioral models are applied in the demand analysis. Sensitivities to service parameters such as cost are measured by the choice models.

The fundamental accessibility measures that have been introduced are not developed further in this phase of the research. They are taken to formulate elementary data analyses of the performance of existing facilities in hope of providing the information necessary for calibrations in subsequent research.



$$P_{kj} = Z_j R_{kj}^{\delta_1}, \quad P_{jD} = Z_d R_{jd}^{\delta_1} \quad \text{Accessibility to CBD via Fringe Lot-Express Bus}$$

$$P_{kD} = Z_d R_{Ld}^{\delta_1} \quad \text{Direct Accessibility to CBD}$$

O_k = k^{th} zone

L_j = J^{th} lot

d = CBD

Figure 12. Definition of fringe lot location in terms of accessibility.

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Station Demand Surfaces

Using express transit user data, auto trip information, and travel time measures the following descriptive models can be developed.

1. Access trip length distribution for fringe lots.

2. A market contour around a fringe lot.

3. An auto trip contour around the fringe lots.

It is envisioned that the above models will assist in locating future lots to provide maximum user potential.

Summary and Conclusions

The application of the accessibility models will require careful design. Even if it is assumed that travel time is sufficient as the friction factor, the definition of an appropriate measure of attractiveness in the numerator will require considerable study. For example, capacity may be a sufficient index of attractiveness of a lot. In this case, from equation (7)

$$P_k = Z_1 R_{k1}^{\delta 1}$$

$$= V_1 / t_{k1}^{\delta 1}$$

where:

V_l = capacity of lot

t_{kl} = travel time from zone k to lot 1

Questions which must be resolved before such a formulation is acceptable include:

(1) Is there any relationship between parking capacity in the CBD and in a fringe lot?

(2) Should t_{k1} be measured for each mode of access such as kiss-and-ride, walking, and park-and-ride?

In order to most efficiently pursue the objectives outlined earlier regarding the macro analysis, it is thus concluded that an initial diagnostic analysis of recently established fringe lots in Virginia will be implemented to the fullest extent in deriving further methodological development.

The feasibility study of employing existing choice and network simulation models to evaluate CBD directed corridor express bus mass transportation revealed that broader dimensions of the corridor should be established in order to provide an understanding of dominant variations in travel behavior. The analysis indicates that areal characteristics can possibly be employed to estimate the overall feasibility of an express bus operation. Relationships are proposed for study which may provide a meaningful basis for inter-corridor comparisons and complement the choice and network models. Particularly, the relevance of accessibility considerations needs investigation.

CHAPTER 6

EQUILIBRIUM CONSIDERATIONS AND EVALUATION CRITERIA

The exclusive phases in the proposed framework for simulating fringe parking-express bus operations are now interrelated with one another to specify equilibrium conditions. The theory of equilibrium in transportation systems is documented elsewhere[28, 29] and is not introduced here. The primary objective is to provide an interactive solution for a system of models and to ultimately account for shifts among trip production, modal choice, and system performance to produce short-run equilibrium between supply and demand.

Theoretically, this model system interacts as shown in Figure 13. Initially, levels of service are assumed for a specific operations policy, the demand is estimated, and the level of service is measured. If the level of service given as a result of network simulation differs from that initially assumed, then the first round estimates for the system performance patterns are used to present revised trip productions and travel choices. This cycle is thus repeated until the levels of service experienced on the network are the same as those used in the prior estimates. By using this strategy, the system simulation model becomes sensitive to changing demand patterns.

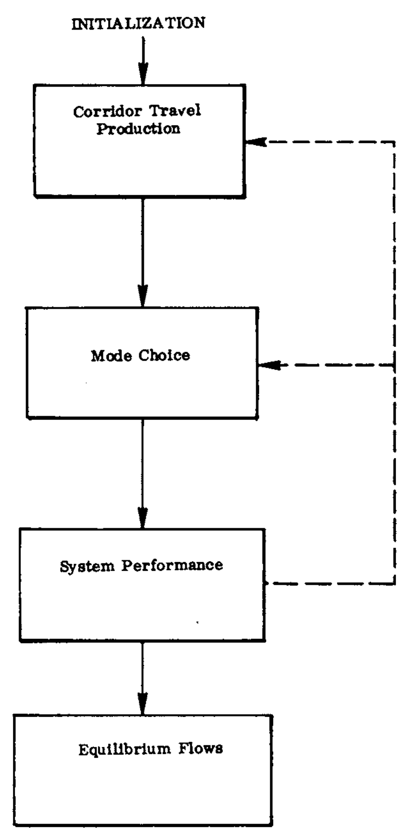

Figure 13. The model system in equilibrium.

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Evaluation Criteria

The foregoing modeling system provides the capability for evaluating alternative fringe parking-express bus operations. In this context, alternatives may relate to selecting among different corridors for implementing such a service or comparing alternative designs for systems along a given corridor. Whatever the particular decision of interest may be, the following measures for comparison are obtainable from the analysis models either directly or in conjunction with additional non-traffic related facts.

a. Number of autos entering the CBD.

b. Fringe lot usage and reduced parking needs at the CBD.

c. Congestion.

d. Air pollution.

e. Number of persons using the express bus.

f. Fare box revenue.

g. Aggregate travel time.

h. Changes in auto ownership, i.e., decrease in need for second cars.

i. New trips induced by the system change.

The above listing summarizes the various measures which this analysis process provides to the decision maker. It is envisioned that in the next phase of this research car pooling decisions and effects on system performance will be an integral part of the methodology. The considerations cited in this section will be shown by application in a future report on a case study analysis of the Parham Express Project.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study shows that existing transportation planning techniques can be adopted to formulate a methodology for evaluating express bus-fringe parking systems. In particular, corridor originated-CBD directed trips are simulated in view of trip volumes, travel route choices, and network performance. Explicit models have been selected to model choice behavior and freeway performance. A means has been presented for estimating trip productions in a manner that is sensitive to the provision of transportation services. Finally, the complex dimensions of urban corridors are acknowledged and utilized to indicate procedures for establishing the market for rapid bus line haul service.

The ideas and stages presented are synthesized in a supply-demand equilibrium structure. This result is significant in the theoretical sense as well as giving substance for standardized methods for planning, studying, and reporting on park-and-ride activities.

Thus, the results of this feasibility study in methodological development are encouraging and clearly indicate a direction for continued work in developing, testing, and refining the models with case study data.

Recommendations

As a result of the findings cited in this report, the following research is recommended:

1. Evaluation and refinement of the methodology in case study applications,

2. Development of a realistic multi-choice model,

3. Incorporation of car pooling as a variable (or mode),

4. Development of a manual for planning and testing fringe parking-express bus alternatives.

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