

DEMAND/SUPPLY EQUILIBRIUM
IN DESIGNING BUS ROUTE OF
SMALL URBAN AREA

by

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DEDICATION

To my parents, , who believe that embrace their children with knowledge is the true taste of love.

Also to my beloved , who gave me all the warmth and truthful love during my writing stage in the Architecture library.

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CHAPTER I

1.0 INTRODUCTION

Urban mass transportation - bus systems - have been plagued by the decline of their patronage since 1963. The present deficit involved in the bus system's operation is not only spatially ubiquitous over the United States but also is a heavy burden for the federal government to carry. While the excessive use of private auto results in the ecological deterioration of our environment, in terms of energy exhaustion, air pollution, noise, etc, the proposal for the comeback of mass transit is being advocated. The present study addresses some of the mass transit problems at the level of small urban areas which, hopefully, with further research could be extended to large metropolitan areas.

The problems of mass transit in small urban areas can be polarized to two main aspects, supply and demand. In the supply aspect, the development of bus route structure, the frequency of buses on each route, the estimation of the operating cost of the system, and the required subsidy are all bus functions that require improvement in the existing planning processes. The bus routes and frequencies are still developed by hand. The expected operating costs and

the required subsidies are treated independently of the developed bus route configurations and the equilibrium demand function. On the other hand, the demand is estimated without considering the attractiveness of the supply system, such as the bus system characteristics and performance. In short, there is no computerized methodology that will equilibrate the supply and demand functions in designing the bus routes in a small urban area.

The present study developed a computerized package that provides the optimal bus route structure of a small urban area providing certain attractiveness to the user, under certain subsidy levels. In addition, some indicators describing the system's performance such as travel time ratio between different travel modes, expected riderships, and in turn, expected revenues and subsidies are also included in the outputs of the package. The following paragraph briefly describes the remaining sections of this chapter.

Section 1.1 states the objectives of this study. These objectives are split into the supply side and the demand side of the transit market. Section 1.2 briefly states the problems to be handled. Section 1.3 discusses the benefits of this study. The benefits accrued to the transit and to the society are separately outlined. The strategy of the

approach is discussed in Section 1.4.

1.1 Objectives

The purpose of this study is to develop a computerized methodology which determines optimal or near-optimal routing structure of bus transit system in a small urban area.

In conjunction with the above prime objective, the methodology also maximizes the transit system's attractiveness. The term "attractiveness" is used in this study in two reference areas in the following context. One area is the attractiveness of the bus system to the individual and the other area is the attractiveness of the system to the whole community. In the former use the term is defined as the measure of the probability that a particular traveler will take a bus for his trip. In the latter use, the system's attractiveness to the whole community, the term is defined as the aggregated average of those foregoing individual probabilities. In other words, the attractiveness to the community is the mean of total individual probabilities within the local society. Over an extended period of time, the community's average probability of bus travel can also be viewed as the percentage of the total community's travel which require bus service.

Maximizing the system's attractiveness can now be viewed as to maximize the bus travel's percentage share in order to achieve the maximum usage of the bus system.

The two main objectives are complementary to each other. In fact, as the route structure design provides a more convenient bus travel, the more attractive the bus system becomes, which presumably will attract more riderships to the system. Furthermore, the result of more riderships is more revenue and, in turn, less subsidy to the system and so forth. It also should be noted here that these two objectives are concerned with the supply side as well as with the demand side of the transit market.

In addition to the above objectives, several subordinate objectives are developed for this study.

1. to review some of the existing methodologies in this field and list their advantages and disadvantages;
2. to develop an applied computer program to estimate the expected system's operational cost and travel time ratio;
3. to provide the bus manager with an easy tool in decision making, dependent upon tradeoffs between required subsidy and system's attractiveness.
4. to provide the involved community a clear picture of how the proposed system looks like and how much subsidy is required in running the system;

5. to initiate a stepping stone for the future accomplishment of metropolitan transit system routing design;

1.2 Problem Statement

The problem, as specified in Sections 1.0 and 1.1, is to develop a methodology for optimum route structure design which would in turn lead to the maximization of bus system's attractiveness. The methodology for route structure design develops a bus network with minimum total travel distance subject to the constraints of bus capacity and maximum travel distance by each bus. The network is an efficient supply system, because it best uses its resources of buses to provide a better service to the users. In other words, the less distance the buses need to travel in a certain period of time, the more they are available to serve other customers. Concerning the maximization of bus system's attractiveness the concept can be considered as maximizing the level of demand in the market which would utilize the service.

In short, the problem can be regarded as to provide better quality of supply (better route structure) and at the same time to achieve higher level of demand (greater

attractiveness) of the local transportation market. In literature, the supply problem is referred to as routing problem in the operations research field; on the other hand, the attractiveness problem or the demand behavior problem is a modal split problem in the transportation planning process. The conceptual mathematical formulation of the problems are included in Chapter II.

1.3 Benefits

The developed methodology is capable of contributing the following benefits to either the transit company or the whole society.

1. It eliminates the personal biases associated with the development of bus route structure by hand.
2. It provides the participating public an explicit answer about the future performances of the proposed transit system.
3. It gives estimates of expected riderships, revenues, and required subsidy in running the system.
4. It exposes to the manager significant parameters dominating the system's performance by the aid of sensitivity analysis of the methodology.

1.4 Strategy of Approach

The economic principles of supply and demand are applied to the transit problem at hand. The route structure design is considered as the supply function to the market. The attractiveness (or mean probability of bus travel) is considered as the demand function of the market. The supply and demand functions are variables at any state of the market until they reach the equilibrium condition. Dynamic shifts happen whenever change appears in either supply or demand. Supply and demand stabilize to constants only when the equilibrium state is reached. The conceptual thinking behind this approach is provided in the following paragraphs. The detailed computational framework is discussed in Chapters III and IV.

Consider a small urban area of 20,000 to 100,000 people, either attempting to implement a new fixed route bus system or to improve the operation of an existing one. The first step in the planing stage of any transit system is the task of demand estimation. Using any of the available methodes to predict the travel demand, the total number of trips generated in the society can be estimated. After the total number of trips is obtained the next planning step is to estimate how many percent of these total trips would use

the bus system. The percentage of bus trip, pragmatically speaking, is obtained in two ways. If the system is in the implementation stage, the method of analogy is used. The analogy methodology is to select some other cities with similar socio-economic characteristics to the one under study. The percentage of trips that use the bus service in the other city is then adopted to the city under planning. If the system is in the improvement stage, the measure of this percentage can be obtained by dividing the number of annual revenue passengers by the total number of trips in the society. At this point, the bus system's share of the total trips is thus initialized.

After the total number of trips requiring bus service has been obtained, they are allocated in a uniform distribution with some adjustments to the chosen bus stops. The selection of locations of bus stops are done on an intuitive judgement basis, yet conforming to general practicing criteria, such as acceptable distances between stops, confinement to major and minor arterial streets, and service catchment area etc. However, it is a special topic that might require further study by itself, yet in this work it is considered as exogeneous input data. According to the locations of these bus stops, a heuristic algorithm called sweep algorithm is used to generate the optimal route

structure. The route structure is designed by utilizing the objective function of minimizing the total travel distance subject to physical and resource constraints. The algorithm gives heuristically optimal or near optimal route structure for the bus system. As a result, the quality of supply in the local transit market has been temporarily set up, because the particular route structure can be considered as some representation of the quality of supply.

According to the developed route structure, simulation technique is used to generate a number of travel demands. The simulation is based on mode choice models or behavioral models. This simulation generates the travel demand for each particular developed route structure. Two most important outputs amongst the statistics collected by the simulator are (1) the mean probability of the community's travel by bus (i.e. the attractiveness of the system); (2) the travel time ratio statistics. In addition, the simulation program also determines the values of significant parameters of the system's operation. These parameters include annual vehicle miles, annual vehicle hours, peak hour vehicles, revenue passengers, annual revenues based on some specified fare policy, annual operation costs, and, consequently, required subsidy.

The above gathered information can be considered as

responses of the demand to the bus service in the local transportation market. The calculated predicted attractiveness of the system is compared with the initial one obtained from the demand estimation. If significant difference exists between these two figures, modification of demand level at each bus stop then follows. The modification of demand level at each bus stop is carried out by the behavioral model. The predicted attractiveness substitutes the initial attractiveness. A feedback process proceeds to do the whole task over. As long as the system's attractiveness between two consecutive iterations are significantly different, the iteration process keeps working. It stops when the attractiveness measure remains unchanged, which means that the system is in the equilibrium state.

The final bus network structure obtained from the above procedure is the optimal design at the equilibrium state of the transit market. The structure of bus network configuration is in a most economical form as far as the total bus travel distance concerned. A descriptive flow chart of the strategy of approach is shown in Figure 1.1

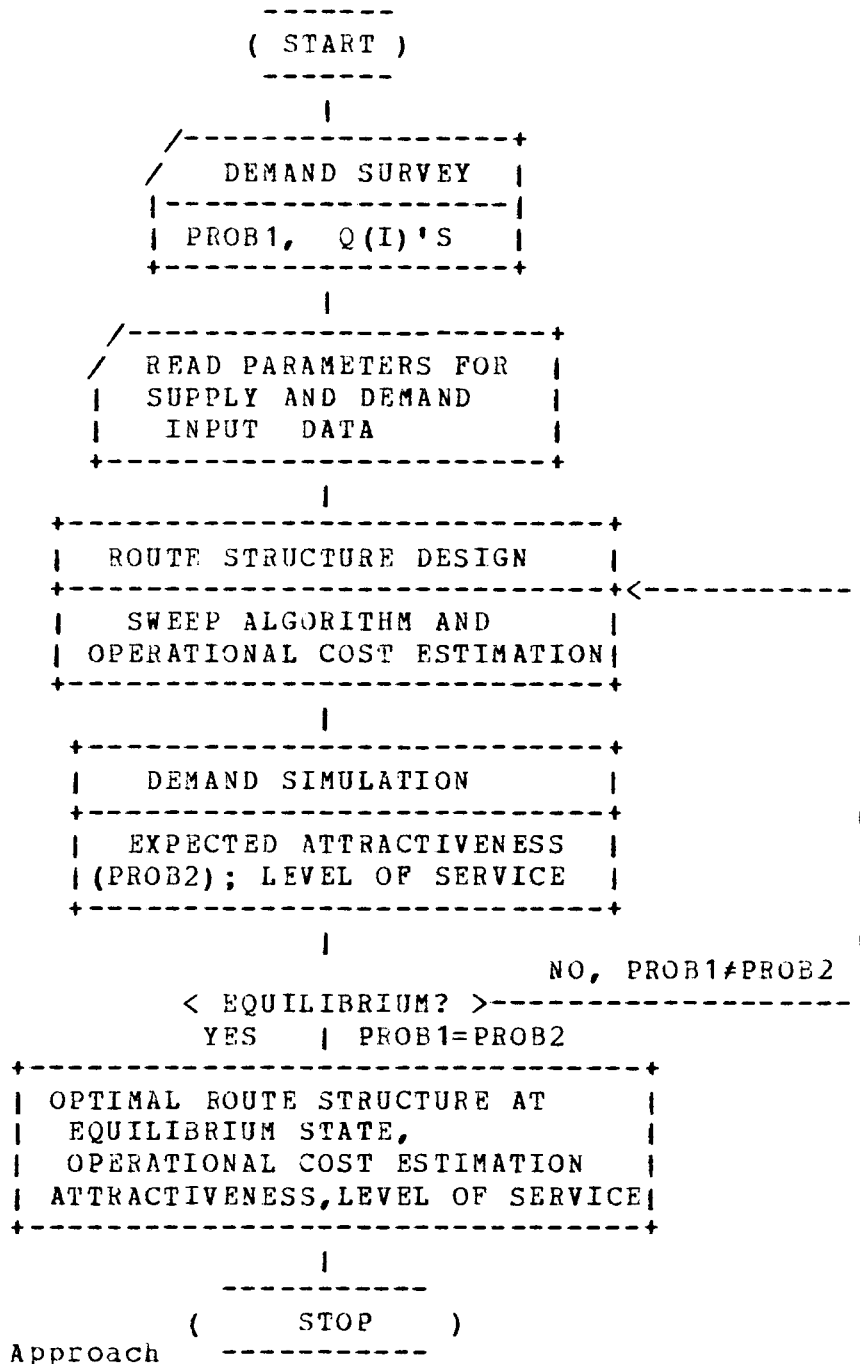


Figure 1.1
Strategy of Approach

CHAPTER II

2.0 PROBLEM FORMULATION AND RELATED WORKS

This chapter concentrates on the mathematical formulation used under this study and briefly reviews previous approaches to solving the problem. The problem on the supply side of the transit market is an optimization problem in the area of interger programming. The objective function is to minimize the total travel distance subject to a number of constraints. The demand side of the problem is usually estimated by utilizing behavioral models. Probabilistic approach to estimating the individual probability of taking a bus for a journey is discussed. Problem formulations are the contents of Section 2.1. Section 2.2 reviews other works related to this problem. On the supply side, it discusses methodologies concerning optimal route structure design. On the demand side, this section reviews behavioral approach to demand forecasting, and estimation to travel time value.

2.1 Problem Formulation

The transit problem as stated earlier may be split into two aspects, supply and demand. The former is primarily based on the transit management views and the latter is based on the community views. Consequently, supply can be primarily considered as an efficiency problem and demand as a behavioral one.

ROUTE STRUCTURE DESIGN (SUPPLY)

The transit manager is businessman. He is interested in the overall efficiency of his transit industry. The design of route structure is an important element of this overall efficiency. The better the route structure is designed, the smaller amount of money he has to spend in operating the service. Also, better route structure provides more convenient and faster bus service and in turn attracts more customers to use the bus system. As a result, more revenue can be obtained or less subsidy is required. Therefore, the problem on the supply side is to develop an algorithm capable of giving optimum routing structure which links all bus stops through a minimum travel distance.

Investigating the concept in the science of Operations Research, the problem can be viewed as an applied problem in

graph theory or as an integer programming problem. In fact, numerous routing problems have been formulated and solved by these two approaches. The description of the routing problem, the definition of the systems variables and the mathematical representation are discussed below.

Consider a set of bus stops distributed over the bus company's service area. The bus trip is assigned to start from the terminal point and to terminate at the terminal point. All bus stops except the terminal point must be visited once and only once by one bus. The total travel distance by all buses should be minimized. The above statement is a concise description of the routing problem. The pertinent variables involved in this problem are as follows.

D_{ij} = distance from stop i to stop j ; stop 1 is assumed to be the origin, or terminal point.

D_{ii} = extra distance per stop; an input variable in program.

P_k = the operating cost or travel time per mile incurred by bus k (if the objective function is to minimize total travel distance, $P_k = 1$).

$Y_{ijk} = 1$, if bus k goes from i to j
 0, otherwise.

CPk = passenger capacity of bus k

Xijk = percent of bus k's capacity left at bus stop j after coming from stop i.

Qj = demand at stop j.

n = total number of bus stops, including the origin.

m = number of buses.

According to the foregoing description and variable definitions the problem is formulated as

$$\begin{aligned}
 \text{MIN.} \quad & \sum_i \sum_j \sum_k D_{ij} P_k Y_{ijk} & (2.1) \\
 \text{S.T.} \quad & \sum_i \sum_k C P_k X_{ijk} = Q_j & j=2, \dots, n \\
 & \sum_i \sum_j X_{ijk} \geq 1 & k=1, \dots, m \\
 & \sum_j Y_{rjk} - \sum_i Y_{irk} = 0 & r=1, \dots, n \\
 & Y_{ijk} - X_{ijk} \leq 0 & \text{all } i, j, k \\
 & X_{ijk} \leq 0 & \text{all } i, j, k \\
 & Y_{ijk} = 0 \text{ or } 1 & \text{all } i, j, k
 \end{aligned}$$

The indices on tops of sigma signs represent

i=1, ..., n, j=1, ..., n, k=1, ..., m.

This problem is in fact identical to the well-known traveling salesman problem. Given n cities; the salesman has to visit each city once and terminate the trip at origin through a minimum total travel cost, travel time, or travel distance.

Attractiveness Estimation (Demand)

The mass transit today can alleviate a number of existing transportation as well as environmental problems in most urban area. Mass transit systems provide alternative solution to environmental perservation, energy conservation, and traffic jam alleviation. The more the usage of mass transit system, the less air pollution, energy consumption and traffic congestion will have in our cities. Therefore, the problem on the demand side is how to maximize the user's desire to use the bus or, in other words, how to maximize the bus system's attractiveness to the users. A prerequisite to maximize the system's attractiveness is what are the factors affecting the system's attractiveness and how the attractiveness can be measured. However, as discussed in Section 1.1, the measure of system's attractiveness can be considered as the aggregated statistics of individual probabilities of taking a bus for a particular trip. Therefore, the attractiveness measure can

be considered as to how to calculate the individual probability of taking a bus for his or her trip and how to maximize the mean of these probabilities.

In order to formulate the individual's probability of taking a bus we can utilize the economic concept in which the probability is defined as a function of disutilities with respect to all travel modes in the market. The terminology disutility will be explained later in this section. The function can be expressed in the following equation;

$$P_{ib} = \exp(-B_i) / \sum_j [\exp(-J_i)], \quad j=1,2,\dots,n \quad (2.2)$$

The above equation describes that the probability for a passenger i to take the travel mode b is the exponential of this particular modal utility $(-B_i)$ divided by the sum of total exponentials of all modal utilities, $\sum_j [\exp(-J_i)]$, in the market where n is the number of total available modes. When there are only two modes available the equation is in the form of

$$P_{ib} = \exp(-B_i) / [\exp(-A_i) + \exp(-B_i)] \quad (2.3)$$

where A_i and B_i are disutilities of mode auto and mode bus for individual traveler i . Furthermore, the equation can easily be derived into the following form.

$$B_i = A_i - \ln [P_{ib} / (1 - P_{ib})] \quad (2.4)$$

The plot of the above equation shown in Figure 2.1 is a

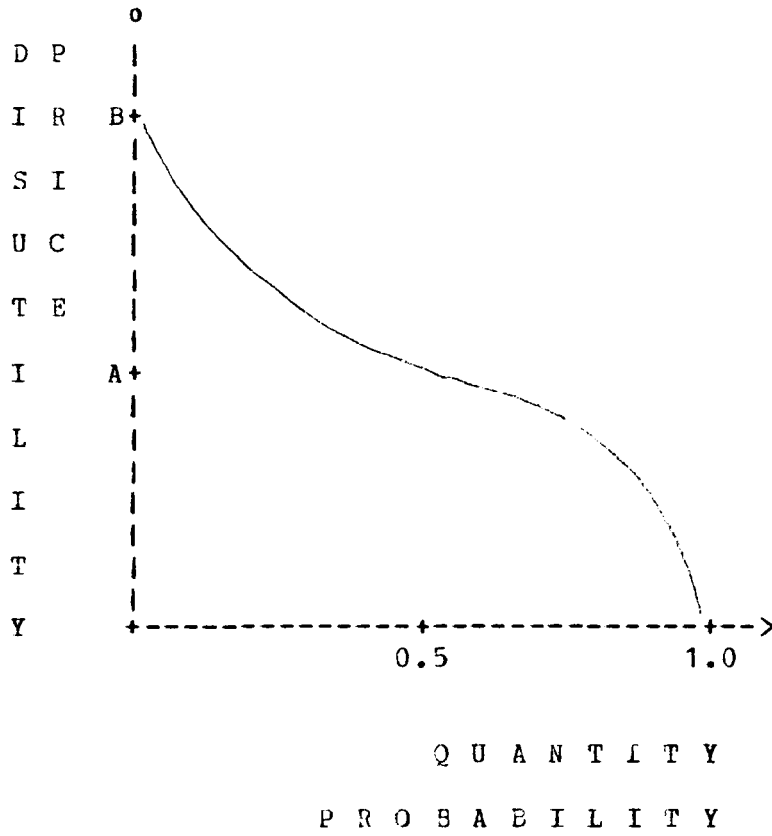


Figure 2.1 Behavioral Model as a Shape of Demand Function

wellknown form of demand curve in economy theory.

Note that in economy theory the horizontal axis, the probability, usually represents the demand quantity in the market whereas the vertical axis, disutility, is the commodity price in the market. Up to this stage, the problem on the demand side is quite clear. As long as the disutility function is formulated the demand function or the expected individual's probability can easily be formulated from equations 2.2 or 2.3. Therefore, the following paragraphs discuss the formulation of disutility function.

The terminology disutility means some measurement characterizing a particular commodity in the market. Whenever a customer comes upon a situation in which to choose, what commodity in the market he should purchase, he compares all respective prices associated with each provided service. The most preferable choice of the customer is the one with least expense. The commodity with the least expense and yet satisfies his travel needs is the one with the highest probability to be purchased. Because the expense is used to compensate the supply, the expense must be spent in spite of the customer's reluctance. Therefore, in economic theory the disutility can be viewed as the market sale price of the goods.

In the area of transportation market, the composition of disutility is much more complicated. It includes not merely the money term of price as in the economics but also considers other factors referring to the quality of the transportation service. Travel time, convenience, reliability, and socio-economic characteristics are other considerations involved in the term of disutility. However, because convenience, reliability, and socio-economic characteristics are either very difficult or very expensive to measure, the disutility function here includes only one more factor, the total travel time by each mode. Again, applying the analogy of economics theory, where distility is represented by price, money term, the disutility in the transportation market is also expressed by a generalized money term in unit of dollar value. Therefore, the value of disutility is a combination of total travel cost as well as total travel time in terms of dollars. The disutility in the transportation market thus can be formulated as the following formula

$$D_{ij} = C_j + V_i * T_j \quad (2.5)$$

which means that the disutility for the traveler i on a particular mode j is the total travel cost for mode j plus the individual's time value V_i times the total travel time spent on mode j .

Substituting equation 2.5 into equation 2.2, the probability of taking a particular mode for a specific trip thereby can be predicted.

$$P_{ib} = \exp(-C_b - V_i \cdot T_b) / \sum_j [\exp(-C_j - V_i \cdot T_j)] \quad (2.6)$$

At this stage, the remaining problem left is how to calculate the modal travel cost, total travel time, and individual's time value. These works are straight forward and have been discussed extensively in literature. The detailed conceptual approach to estimating these values will be discussed in Chapter IV. Finally, the first problem on the demand side, the formulation of the individual's probability for traveling by bus, has been solved. The formulation of the bus system's attractiveness to the whole community is then merely calculated by taking the average of the aggregated set of the individual probabilities data.

The other problem on the demand side is how to maximize the bus system's attractiveness to the community. The approach to this problem solution requires a feedback process. The explanation to this approach is as follows.

Under a set of real world's constraints, there is a maximum value that the attractiveness can achieve. Generally speaking, to find this maximum value, search technique methodologies can be used. The use of search technique is very expensive and unapplicable to the

transportation market since transportation market is characterized by an interactive behavior. However, the search for the maximum attractiveness can be easily achieved by a feedback process. The objective of the feedback process is usually to achieve the equilibrium state of the transportation system. The equilibrium state is arrived when the values of demand and supply stay stable and can not be improved any more. At this stage, it can be considered that the attractiveness measure reaches its maximum limit under a set of specific societal policies. As long as societal policy changes, the attractiveness will have different maximum value through the feedback process. Because the policy affects the attractiveness of the bus system, the global maximum attractiveness is obtained through the sensitivity analysis from a number of computer runs. Therefore, in each computer run, the local maximum attractiveness is obtained at the equilibrium state. When different policies are evaluated, the one that generates the global maximum attractiveness is the most preferable set of policies.

In summary, the supply side of the problem is an integer programming problem in the area of operations research. It can be formulated as a traveling salesman problem. The first problem on the demand side is the

formulation of disutility functions for different travel modes. The disutility function can be represented by total travel cost, total travel time, and individual's time value. Proper transformation of the disutility function will give the measure of bus system's attractiveness to the community. The second problem on the demand side is the search for the equilibrium state. Feedback process is used to approach this state. When the system is in equilibrium the local maximum attractiveness is reached. The global maximum attractiveness is determined by the sensitivity analysis.

2.2 State of the Arts

In this section a review of related works is discussed. Although transportation literature is quite rich in the area of transit planning, on the supply side, very few can be found dealing with the route structure design. Some literatures may be found dealing with routing problems in general; however, they do not focus particularly on the route development of transit systems in transportation area. On the demand side, the research works are plenty and resourceful. The works fall in the area of modal split models or behavioral models. The other related work is the determination of the value of travel time. The following

paragraphs will review first the selected works toward route structure design. The modal split and evaluation of time value will be subsequently discussed.

Route Structure Design (Supply)

In 1967 Lampkin and Saalmans¹⁵ have indicated, in fixed-route systems analysis, that very few attention, comparing with other topics in this area, has been given to two important tasks, those relating to route and schedule design. Part of these problems, however, have been attacked in various studies. For example, a method of sequencing routes which share a common segment has been provided, and other studies have examined the spacing of stops along a route¹⁰. Work of this sort is valuable when the route and schedule plans are essentially complete.

Relatively little attention has been given to the full routing and scheduling problem. Lampkin and Saalmans' approach was the most direct one to this area. Their model computes expected wait and travel time for passengers traveling between each point pair and attempts to minimize total travel time by careful assignment of schedule frequencies to each of the routes in the system.

Jewell¹³ has formulated a network model which uses uncapacitated route and assumes perfectly regular service

along the routes. The representation of routes in the model is restrictive, and the model is best suited for radial systems with little interference between routes.

Formulations have also been prepared for Tokyo, Japan¹² and Bombay, India²⁵. These models are designed for areas with very limited data and are restricted in their ability to tackle the full routing scheduling.

Routing and scheduling models have also been developed for use in air transportation²⁶. However, this problem is somewhat different from that of public mass transportation because the latter places great emphasis on the exact number of vehicles available, and solutions must be much more specific in their use of vehicles than is necessary for bus operations. The treatment of wait time is quite different in air schedule formulations, since passengers generally arrive on the basis of known time table. Most bus passengers do not arrive at stops to meet a particular scheduled vehicle unless the headway is large. It is generally assumed that bus passengers arrive independently of the schedule.

Routing models have been developed for utility vehicles*, such as school buses, mail trucks, delivery vehicles, and garbage trucks². In most of these applications, no attention is given to many service

characteristics which are important to bus users, i.e. travel time, wait time, and crowding conditions. The emphasis is on minimizing costs subject to making all deliveries. The service characteristics central to bus operations are not represented in these models.

Kulash^{1*} developed two simulation models for analyzing fixed route bus systems. These models evaluate the quality of service which results from various operator policies. They may be used to predict the impacts of operator decisions and to improve route and schedule designs. One model examines in detail the operations of a single route, the other focuses on an entire network of routes. These models can be used to allocate schedule frequencies for a bus system. Kulash has put more emphasis on the supply side of the system; yet the route structure in his models is still developed manually.

Rapp and Gehner^{2*} developed an interactive graphic computer system known as Urban Transit Analysis System (UITRANS). The system is used to evaluate different route and schedule policies based upon criteria of quality of service. The frequency and route structure, again, are used as input data of the computer system.

There has never been any attempt to successfully formulate the bus route structure in the area of

transportation research. However, in topics of graph theory and operations research, the routing problem has been extensively studied although, as discussed before, it did not adequately consider the important transit system's characteristics such as travel time, waiting time, and crowding condition etc. In that area, the traveling salesman problem attempting to find the travel route with a minimum total travel distance happens to have the identical objective function of our transit problem on the supply side. The approaches to solving the traveling salesman problem are prolific. The Lin's 3-optimum algorithm¹⁸ is considered, up to date, the most efficient and successful heuristic method to find a looping route structure.

In summary, relatively little work has been done which examines routing and scheduling in public transportation at the network level. The models in other applications such as airline and utility vehicles are of a very different character and are not applicable to urban mass transportation. Kulash's simulation models¹⁴ and UTRANS²⁴ have significant contribution to transit planning but they do not provide a solution for most economical route structure. Traveling salesman problem can be applied to this area, but considerations for particular characteristics of bus system should be included.

Attractiveness Estimation (Demand)

Some researchers have developed models to explain and predict individual modal choice behavior, taking account of individual travel and household characteristics. At the level of individual choice of mode, the work of Warner³⁴, Beesley, Sharp, and Quarmby²³, is probably the most comprehensive.

Warner³⁴ used multiple regression and discriminate analysis techniques to arrive at probability function which predict the probability that a traveler with given travel time, cost and other characteristics will choose a particular mode for both work and non-work trips. This model avoids the problems associated with zonal aggregation of data. Warner's method is also appealing because it relates travel behavior to explanatory variables such as parking availability and transit speeds which are appropriate for testing different policy alternatives for public transportation.

Beesley, using a conceptual framework similar to Warner's, predicted modal choice by assessing the trade-off between time and cost. Lave¹⁶ used probit analysis to handle the yes-no decisions of modal selection and incorporated travel cost as a ratio and as a difference between modes. Sharp ascertained the effect on speeds and

times by different vehicles of a shift of commuters from one mode to another.

Quarmby²³, By combining the work of Warner and Beesley, used a multivariate approach to attack the modal choice problem. He developed a model for representing how people make their decisions about using private or public transport to travel to work, and found relative door-to-door travel times, time spent on walking and waiting, and costs to be important factors affecting choice of mode. The model was used to predict the probability that a car owner will choose to use his car to travel to work, given information about conditions of travel by the alternative means available to him. Perhaps, the most important aspect of his work is that the method of predicting individual choice of means of travel now enables us to forecast, given the assumptions of the model, how many car commuters would be diverted onto any proposed public transport system, and this permits a more rigorous evaluation of proposed public transport improvements than has previously been possible.

The remaining related work to be discussed is the value of time spent in traveling. This problem is related to modal choice models since the choice between two modes of travel frequently involves a trade-off of time against money, i.e. one mode is cheaper but takes longer than the

other. Here the most important work is that of Moses and Williamson, who developed an economic model to predict people's choice of mode based on indifference curves and rates of substitution between working time, traveling time and leisure time. Using the marginal wage rate to represent time spent in traveling to work, they predict the fares that would be needed on public transport to attract different proportions of commuters to use it. Pratt²² suggested that the probability of choosing a mode is related to the resulting savings in the disutility of travel time and cost of a mode.

With few exceptions, the value of travel time have been a secondary output of stochastic disaggregate models. The time-cost trade-off concept for commuters was developed by Beesley, in a unimodal context, to drive an implied value of travel time by comparing travelers who choose a time savings at extra cost with travelers who choose a cost savings at extra travel time. Stopher²⁹ suggested a methodology to estimate the value of travel time. For each of a range of values of time V , a linear regression of probability of choosing the car, on the individual values of $(C1-C2)+V*(T1-T2)$, was conducted. The value V giving the largest correlation coefficient was chosen. The main criticism of his study are the implicit assumption of

homogeneous disutility of travel time, which in effect biased upward the value of in-vehicle travel time, and the initial use of a linear estimation procedure for an S-shaped behavioral relationship. Stopher subsequently reanalyzed his data by using the logit transformation²⁹ and theoretically developed the value of travel time from disaggregated travel demand model²⁷.

However, several studies have suggested what the value of travel time is related to the individual's income level²⁸. Recent work also has suggested both empirically and theoretically that a number of values of travel time may exist. Specifically, it appears that value of travel time is likely to vary with traveler income, trip purpose, and amount of time saved²⁸. Currently, several different studies have suggested that the time spent on the journey to work is valued at about one-quarter to one-half of the wage rate. On the other hand, vacation travel appears to be valued at between one-half and one and half times the wage rate

CHAPTER III

3.0 ROUTE STRUCTURE DESIGN

The purpose of the route structure design in this study is to minimize the total traveling distance of the bus system. The problem of finding the route structure which minimizes the travel distance can be solved by the traveling salesman algorithm as stated in Chapter II. There can be two algorithmic types of designs for this particular route configuration. One is in a linear form, i.e. an open edge sequence form. It takes the farthest pair of stops as the initial and terminal stops; then link all bus stops between them as intermediate stops through a minimized travel distance. The other route configuration design is in a loop form. The initial and the terminal stops coincide at only one point which is the terminal station of the bus network. The linear form of network can be designed by Hamiltonian path algorithm. The loop form of network can be designed by using the traveling salesman algorithm.

The contents of this chapter are organized as follows. Section 3.1 discusses the necessary assumptions prior to the model development. Section 3.2 discusses how and why

finally a heuristic approach is selected to solve this problem. Sections 3.3 and 3.4 list the input data and the output data of the network development model. Section 3.5 describes the conceptual work of the model.

3.1 Assumptions

In attempting to develop models with ambitious goals but limited resources, one must make some simplifying assumptions to achieve anything. The degree of realism with which various aspects of the systems in question are modeled is a critical issue in the design of models. Frequently, critical problems and tradeoffs revolve around the assumptions made. The purpose of this section is to list the key assumptions of these models. The discussion will be limited here to major assumptions of general significance to the basic methodological approach.

1. First of all, it is assumed that there always exists a link connecting any two bus stops. That means it is always accessible from one stop to another. This assumption enables the computer program to construct an n by n distance matrix for the travel distance calculation, where the total number of bus stops in the bus network is n .

2. It is also assumed that the real travel distance

between two bus stops can be obtained by multiplying the direct distance with some adjustment factor. This assumption has been proven to be acceptable by Wilson³⁵, who stated that the real distance between two nodes is 1.3 to 1.4 times the direct distance.

3. All links within the bus network are assumed two way path. This assumption enables the bus system utilizes two way loop structure in its operation. However, in real world situation, this assumption can be considered reasonable because, in urban area, one way streets of opposite directions are usually very close to each other.

3.2 Algorithms

The traveling salesman problem has been studied for many years with limited success. Approaches to solving this problem generally can be categorized into two types, exact and heuristic. Exact approach gives exact optimal solution and has some theoretical support to its algorithm. Heuristic approach does not guarantee an optimal solution. Its algorithm is developed reasonably rather than theoretically, and does not secure the optimality for its solution. The judgement on an acceptable heuristic algorithm is to compare the results from both heuristic and

exact ones. If no significant difference between these results exists, the heuristic can be considered acceptable. The heuristic approaches are used only if problems that exact approaches can not handle or too expensive to handle. The following paragraphs will discuss what is the most adequate approach to solve the traveling salesman and why should it be this way.

It can be easily deducted from the previous paragraph that exact solution should be considered first because it gives the exact optimal solution. Therefore, the exact approaches to solving traveling salesman problem will be discussed prior to the heuristic approaches. Generally speaking, traveling salesman problem can be solved by exact approaches of integer programming, dynamic programming, and branch and bound.

First, to investigate the feasibility of integer programming, the dimensionality of its formulation becomes drastically unreasonable, even for relatively small problems. For example, refer to the problem formulated in equation 2.1, a 100-stop 6-vehicle problem requires $6 \times 100 \times 100 = 60,000$ zero-one variables (Y_{ijk}), $6 \times 100 \times 100 = 60,000$ continuous non-negative variables (X_{ijk}), and $100 + 6 + 6 \times 100 + 60,000 = 60,706$ constraints excluding the non-negativity requirements. Therefore, realistic problems can

not be solved by interger programming.

Second, dynamic programming techniques solves the traveling salesman problem through recursive and backward process. Simplified guidelines are discussed by Hillier and Lieberman⁸ and the solution was proposed by Lawler and Wood¹⁷. The non-applicability of dynamic programming also can readily be shown by reviewing previous work in this area. Gonzalez⁷ and Held and Karp⁹ have developed and tested algorithms of this problem. Gonzalez solved problems of up to 10 stops, the largest taking about 8 minutes on an IBM 1620. Held and Karp solves up to 13 stop problems requiring up to 13 seconds on an IBM 7090. However, computation time grows even faster than exponentially with the number of cities, and Little et.al¹⁹ noted that under this growth rate, a 20 stop program would take about 10 hours on the 7090. Storage requirements would be exceeded before this stage is reached. Thus, realistic problems can not be solved by dynamic programming either.

Third, branch and bound, also known as combinatorial programming or reliable heuristic programming, was first proposed by Little et.al¹⁹ and has been successfully applied to a production sequencing problem with job deadline constraints by Pierce and Hatfield²¹. Pierce defined branch and bound:

"The branch notion stems from the fact that in terms of a tree of alternative potential solutions to the problem the procedure is continually concerned with choosing a next branch of the tree to elaborate and evaluate. The bound term denotes their emphasis on, and effective use of, means of bounding the value of the objective function at each node in the tree, both for eliminating dominated paths and for selecting a next branch for elaboration and evaluation."

Pierce's method is the best in terms of computation time and storage space. However, this method is limited to small problems. Examples of problems that can be solved this way are refuse collection in rural areas utilizing large roadside containers, bus routing in industrial or university complexes, and refuse routing in subdivisions. Once the augmented distance matrix exceeds 30-49 stops, this class becomes unreasonable.

As a result, none of the previously discussed exact approaches can be applied to the realistic transportation problem either because of their tremendous computer storage requirement or their excessive computational time when a large number of bus stops involve. In fact, it has been found that the computational time usually increases exponentially with the number of bus stops for anyone of the aforementioned algorithms. For this reason, most large scale problems have been solved heuristically

The chronological record of heuristic approaches to

traveling salesman problem has been discussed by Ghare⁵. In this thesis only the most up-to-date, and the most efficient, algorithm is discussed.

In 1965 Lin proposed a "tour r -optimum" theorem: "based on the principle if no improvement can be found by removing any r -links and replacing them with any other r -links, the route structure is optimum". The algorithm is named according to the choice of r -value, say "tour 2-optimum" if $r=2$, or "tour 3-optimum" if $r=3$. In 1973 Lin and Kerigham¹⁸ proposed a modified phase of the r -optimum algorithm which has been proven to be the most successful to date. This method can be used only for symmetrical problems and computational time is approximately a ratio of the square of the number of nodes in the problem. The algorithm starts with a pseudo-random solution and continues to improve the solution until no further improvement can be found. Its difference from the original algorithm is that the number r is flexible in its searching process. The algorithm not only is efficient in computer running time and economical in storage requirement, but also possesses very high probability of obtaining optimum solution. Comparison of results has been made between those from Lin's algorithm and from abovementioned integer programming. When the number of nodes involved in the traveling salesman problem is less

than 42 the probability of obtaining optimality is very close to one. While the number of nodes is larger than 42, which integer programming can not handle, different r values have been tried and the answers appear almost identical. Presumably optimum solution is within the solution set. Due to the particular advantages the r -optimum algorithm possesses, the computer models of this study utilizes this algorithm as a part of its optimal network design.

In summary, realistic network design problems can not be solved by exact approaches because of their tremendous storage requirements or large computational time. Various heuristic solutions are applicable to the traveling salesman problem. Lin's r -optimum algorithm is the most efficient among them.

3.3 Models Input

The following data should be specified and defined before the operation of optimum network search, the Sweep Algorithm, is proceeded.

N	number of bus stops in the service area.
CP	capacity of each bus-vehicle.
XD	the distance constraint each vehicle can travel

XLD the added distance per stop
 X(I),Y(I) rectangular coordinates for each bus stop.
 Q(I) the deterministic demand at bus stop I between
 successive arrivals of buses.
 ADJ(I) the area distance adjustment factor according to a
 zonal specification.

All of the above variables are self explanatory except for the area distance adjustment factor ADJ(I). Thus, a description of why and how ADJ(I) is sepecified is presented below.

Consider the computer program attempting to develop a bus network system with minimum total travel distance. Undoubtedly it is essential to have a distance matrix indicating the travel distance between all pairs of nodes. There are five techniques to construct the distance matrix through the input data X(I)'s and Y(I)'s. These techniques include straight line technique, zoned straight line technique, zoned straight line with linear relation, rotating zones, and warped network. Wilson³⁴ analyzed all five techniques and suggested the zoned straight line technique most favorable because of its economical computation time and satisfactory prediction accuracy.

The zoned straight line technique is in fact a modified

straight line technique. For the case of straight line technique, the travel distance between node i and node j is

$$d(i,j) = K * \text{SQRT} [(X_i - X_j)^2 + (Y_i - Y_j)^2] \quad (3.1)$$

where K is a constant of transformation. For the case of zoned straight line technique the travel distance model is

$$d(i,j) = K(1,m) * \text{SQRT} [(X_i - X_j)^2 + (Y_i - Y_j)^2] \quad (3.2)$$

where node i is in zone 1 and node j is in zone m. Clearly, these are two similar techniques able to provide better accuracy. The accuracy, in some sense, is roughly proportional to the number of zones. In the computer program of this study,

$$K(1,m) = \text{SQRT} [K(1) * K(m)] \quad \text{and} \quad (3.3)$$

$$K(1) = \text{ADJ}(I), \quad K(m) = \text{ADJ}(J) \quad (3.4)$$

3.4 Models Output

The models output on the supply side gives the optimal network design for the bus route system which include all bus routes as well as their respective bus stops and total travel distance. In addition, under specific conditions of operational policies, the output also contains the cost estimation of the system. Cost estimates include annual vehicle miles, annual vehicle hours, peak hour vehicles, revenue passengers, and total operating cost.

3.5 Sweep Algorithm

The algorithm used to develop the bus route structure, referred to as the sweep algorithm, was originally proposed by Gillett and Miller⁶ as a solution to the general vehicle dispatch problem. This algorithm was modified by the author of this study and applied to the bus route network design. The modified sweep algorithm for developing optimum, or near-optimum, network design is discussed in the following paragraphs.

After the input data, as discussed in Section 3.3, is entered in the computer, program transforms all rectangular coordinates into polar coordinates with transfer station at node number one. The polar coordinates of the transfer station are (0,0). Then all bus stops are sorted into an ascending order according to the magnitude of their polar angles. If two bus stops are with the same polar angle the node with smaller radius will be picked up first. Preliminary direct distance matrix is constructed through the following formulae.

$$A(I,J) = \text{SQRT} [(X(I)-X(J))^2 + (Y(I)-Y(J))^2] \quad (3.5)$$

$$A(J,I) = A(I,J) \quad (3.6)$$

Final distance matrix is determined by some modification of zonal distance adjustment factors to the preliminary direct

distance matrix.

$$A(I,J) = A(I,J) * \text{SQRT} [\text{ADJ}(I) * \text{ADJ}(J)] \quad (3.7)$$

The search for the optimal (near optimal) route structure of the bus network is conducted by the heuristic sweep algorithm and accompanied with a Lin's 3-optimum solution for traveling salesman problem. The sweep algorithm is divided into four versions, forward, backward, alternate forward, alternate backward sweeps. In the forward sweep the nodes are partitioned into routes beginning with the stop that has the smallest angle namely node two. Recall that the stops were renumbered according to the size of their polar-coordinate angles and the transfer terminal is node one. The first route is then formed containing bus stops 2,3,4,.....,J, where J is the last node that can be added without exceeding the vehicle capacity. At this point the subroutine traveling salesman algorithm is called upon to join these points and check the forward distance with distance constraints. The remaining routes are formed following the same manner. The temporary total distance is the sum of the distance for each route.

After the preliminary route structure has been formed from the forward sweep, an attempt to reduce the total travel distance then begins. The procedure is to consider replacing one stop in route K with one or more stops in

route $K+1$ for $K=1,2,\dots,m-1$, where m is the number of routes formed. The replaced stop is left unassigned and to be added to the later formed route. The replacement is made only if the total distance is decreased. The stop to be deleted from route K is obtained by minimizing a function of a radius $R(I)$ and the angle $S(I)$ of each stop in route K . This provides a node that is close to the transferring terminal and also close to the next route. A function that works very well is $R(I)+S(I)*AVR$ where AVR is the average of the radius of all stops. The first stop, say node p , to be included in route K is the stop in route $K+1$ that is nearest to the last node that was added to route K . The second node considered for inclusion in route K is the node in route $K+1$, that is nearest to node p . If one or more nodes are added to route K in this scheme, then the next node in route $K+1$ is also checked to see if it can be included in route K . This process is continued until J is the last node in route $K+1$ that can be added to route K . Node $J+2$ is then checked to see if it can be included in route K . Choosing nodes in this manner may not give the exact optimum solution; however, it is a very fast scheme for selecting the nodes and it produces good results.

The process of deleting one node and adding one or more nodes in route K is continued until no improvement is found

($K = 1, 2, 3, \dots, m$). The X and Y axes are then rotated counterclockwise so the first node becomes the last and so forth. After the rotation of the network, the above procedure of partitioning routes and interchanging nodes between routes is then repeated. Again a minimum total distance is calculated. The process of rotating X and Y axes is continued until all possibilities have been exhausted. Each time a minimum total distance is calculated. The smallest of these minimum provides the heuristic optimal solution.

A second algorithm called the backward-sweep algorithm is exactly the same procedure as the forward-sweep algorithm except it forms the routes in reverse order. At start, route 1 contains nodes $N, N-1, N-2, \dots, L$; route 2 contains $L, L-1, L-2, \dots, M$, and so forth. The third algorithm called the alternate version of forward sweep algorithm is almost identical to the forward sweep algorithm. The forward sweep algorithm terminates the growth of a route when the next stop to be added would cause the load constraint to be exceeded and when the interchange of stop already in the route with a nearby unassigned stop results in no overall improvement in the total distance traveled. The alternate version of forward sweep algorithm, on the contrary always attempts to add the next node, regardless of the capacity

constraint, to the route before the improvement of interchanging nodes is checked. The relationship between backward sweep and the alternate version of backward sweep algorithm is the same as that of forward sweeps.

The alternate versions some times provide better travel distance than originals. Of course, the optimal route structure is the one with the smallest total travel distance among these four candidates. The step-by-step description of the sweep algorithm is provided in Appendix A.

3.6 Operational Cost Estimation

The task of explaining total operational costs as a function of output and characteristics of the system has proven in many cases very difficult. Systems involving large capital expenditures are difficult to model not only because a large part of their costs are fixed, but also because there is a large variation in construction costs from system to system. Cost models for bus system have received more attention because they avoid many of the above-mentioned problems. Fixed costs for bus systems constitute a relatively small portion of the total cost; therefore, by measuring operating costs alone, it is possible to develop a good cost estimate of bus systems.

There have been several different approaches to cost models for bus system, but basically they are all single-equation expressions of cost as a function of output of the system. These models can be primarily categorized into three types, four variables unit cost model, four variables regression model, and slowness function model. The review and comparisons for each of these models can be found elsewhere²⁰. Hurley¹¹ suggested "the unit-cost method of determining parameters appears to be an accurate method when used to predict future costs for the same system" and "the four-variable models is equal to, and usually superior to, the slowness function". Therefore, the computer program utilizes the unit cost model, under some reasonable assumptions, to generate operational cost estimate.

The four-variable unit model has the general form.

$$OC = a*VM + b*VH + c*PV + d*RP \quad (3.8)$$

where OC = annual operational costs

VM = annual vehicle miles

VH = annual vehicle hours

PV = number of peak hour vehicles

RP = annual revenue passengers

a,b,c,d= unit costs for their corresponding variables

According to the data taken in 1970, the national averages for these unit-cost coefficients are as follows:

For public operations;

$$OC = .277VM + 5.700VH + 6527.480PV + .038RP \quad (3.9)$$

For private operations;

$$OC = .187VM + 4.659VH + 3639.050PV + .046RP \quad (3.10)$$

These costs may be increased by 1.07^y , where 1.07 is the inflation factor and y is the number of years from 1970 to the year of estimate.

If no particular specifications are established the magnitude of these four variables will be calculated by the following relationships.

$$VM = (\text{total bus route distance, mile}) * (\text{service frequency, veh/hr}) * (\text{operating hours per day, hr/day}) * (\text{operating days per year, day/yr})$$

$$VH = (\text{vehicle mile}) / (\text{bus average speed, mph})$$

$$PV = \text{number of vehicles in peak hour operation}$$

$$RP = (\text{total number of passengers on all routes for each trip, cap}) * (\text{service frequency, veh/hr}) * [\text{peak hour operation per day} + (\text{operating hours per day} - \text{peak hour per day}) / 2] * (\text{operating days per year})$$

CHAPTER IV

4.0 ATTRACTIVENESS PREDICTION AND SYSTEMS EQUILIBRIUM

As discussed in the previous chapter, the development of the bus route structure and the estimation of operating costs have been obtained by the sweep algorithm and four-variable model respectively. In this chapter the discussion will focus on modeling the systems attractiveness, and on the feedback process used in achieving the equilibrium state of the transportation market.

The same arrangement will be used as in the previous chapter in terms of assumptions, models inputs, model outputs and program development including the behavioral model. The program in this chapter is in fact a simulation model which uses as an input with the network developed from the previous chapter, and generates disaggregate and aggregate measures of attractiveness of the bus system. The operation of the simulator always corresponds to the operation of the sweep algorithm. It terminates only when the aggregated attractiveness does not change from one iteration to another.

4.1 Assumptions

The primary assumption to this simulator is that there are only two significant travel modes in the local transportation market. Except for auto and bus other modes such as car pool, taxi, and bicycle etc will not affect the equilibrium at any state. Therefore, the binary choice model was used to generate disaggregate probabilities of travel.

The second assumption is that, within each income group, the individual incomes are uniformly distributed between the two extremes of the group. This assumption simplifies the cumulative income distribution curve into a combination of straight lines and gives an average income for each group.

The walking time from door-step to the nearest bus stop is assumed uniformly distributed between zero and the maximum walking time. In this study the maximum walking time is assumed a value of eight minutes. The transfer time at the terminal is assumed uniformly distributed between five and ten minutes. The average speed for bus and auto are assumed 15 miles per hour and 25 miles per hour respectively. Stop time at each bus stop is assumed at an average of half minute. The walking time from parking lot

to the office is assumed at an average of three minutes. The parking space is assumed always available for the automobile drivers. The inflation factor is assumed 7% for each year. However, variable values assumed in this paragraph were used in this models of the present study and can be changed if the place requires special modifications.

4.2 Models Input

The primary information required for the simulator is of course the network structure developed on the supply side. The optimal configuration is the one with minimum total travel distance. The optimal route structure is then sorted in the order such that each route starts and terminates at the terminal, node number one. Other parameters essential to the operation of the behavioral model are listed in the following.

ASPEED	: average speed (mph) for auto
BSPEED	: average speed (mph) for bus
TSTOP	: average stop time (minute) at each bus stop
TWALK	: average walking time (minute) from office to parking lot
TPARK	: average parking time (minute)

BMXWK : maximum walking time (minute) from door-step
 to the nearest bus station
 HDWY : expected headway (minute) between successive
 arrivals of buses at the bus stop
 FARE : expected trip charge for each bus trip
 V(I)&P(I) : the table function indicating a culmulative
 distribution of percentage of income levels
 FPARK : parking fare for automobile
 SUBSID : available subsidy from the community
 PROB1 : the initial attractiveness of the bus system
 , obtained either from demand survey or from
 an analogy (refer to Section 1.4)

All the above variables are fairly selfexplanatory
 except for the income level variables. The income level
 variables can easily be understood by an example. Assume a
 community of which 10% of its populaton have annual income
 less than 5000, 10% between 5000 and 10000, 18% between
 10000 and 15000, 30% between 15000 and 20000, 22% between
 20000 and 25000, 9% between 25000 and 40000, and 1% above
 40000. Then V(I)'s are the average values of these income
 groups, in this case, 2500, 7500, 12500, 17500, 22500,
 30000, and 50000 respectively. The P(I)'s are the
 culmulative density for each income group, which are , in

this case, 10%, 20%, 38%, 68%, 90%, 99%, and 100%. The income level variables are used because different income groups have different values for travel time.

4.3 Models Output

The output of the models reflects the impact of the bus system on the demand. It includes statistics of mean travel time ratios and mean probabilities of taking a bus for a trip, both of which are stratified by trip length. The mean probabilities of taking a bus are also given by different income levels. Both probabilities can be considered as the bus system's attractiveness to the society. The overall mean of all individual probabilities is also provided. This mean can be considered as the percentage of total community trips shared by the bus system. Associated with this mean probability, the variance and its 95% confidence interval are also provided. The confidence interval is used to determine if the system is in the equilibrium state. In each iteration if the mean probability falls within the range of the 95% confidence interval of the previous one, the system is considered in the equilibrium state.

4.4 Simulation Model

Following the optimal route structure determined by the sweep algorithm the demand simulator first calculates the probability for each route and the probability for each node. The individual route probability is the total demand on the route divided by the total bus demand of the whole service area. The nodal probability is the number of demand at the particular bus stop divided by the total number of demand along the route. Uniformly distributed random numbers between zero and one are generated and fed into the foregoing cumulative probabilities of the routes and bus stops respectively. Comparisons with the calculated route and nodal probabilities determine the location of the trip origin. The same process is repeated in determining the location of trip destination. The travel distance for this particular trip is calculated separately for different travel modes, private auto and public bus. The travel distance by an automobile is merely the direct travel distance stored in the adjusted zonal straight line distance matrix. The travel distance by using a bus is the sum of the distance from origin to transfer station plus the distance from transfer station to the destination. Of course, if origin and destination are on the same route the

bus travel distance is the absolute value of the difference between distance from origin to transfer and distance from transfer to destination. Because the design of the route configuration is a form of two way loop structure the bus travel distance is always the smallest distance available that a passenger can reach his destination.

When travel distance for bus and auto are determined the demand simulator proceeds to calculate travel times for both modes. The travel time spent by auto is

$$TAUTO = (ADIST/ASPEED) + TWALK + TPARK \quad (4.1)$$

Where TAUTO and ADIST are travel time and travel distance respectively by auto, the other variables are previously defined in Section 4.2. The travel time spent by using the bus is

$$TBUS = (BDIST/BSPEED) + BWK + BWT + TTSTOP + TRANSF \quad (4.2)$$

where TBUS and BDIST are travel time and travel distance respectively by bus. BSPEED is the average speed for bus. BWK is the random walking time from origin to the bus stop which is determined by

$$BWK = R1 * BMXWK \quad (4.3)$$

where R1 is uniformly distributed random number and BMXWK is the maximum walking time from the door-step to the nearest bus stop. BWT is the average individual waiting time at the bus stop. The waiting time has been discussed by Kulash¹⁴

and Hurdle¹⁰. When the bus routes are overlapping and/or with very long route length, the waiting time is a combination of exponential and Gamma distribution. In our case, there are no overlapping routes and the travel distance is not very long. Bakker¹ has suggested the waiting time follows a uniform distribution. If the bus headway is less than ten minutes, the mean BWT is evidently one half of the bus headway because the passengers arrive at the bus stop randomly, paying no attention to the time schedule. If the bus headway is greater than ten minutes, say fifteen minutes, the passengers will recognize the time schedule and arrive at the bus stop on the average of six minutes at 85% confidence interval prior to the bus arrival

TTSTOP is the total time spent in boarding and departing passengers at each stop along this particular bus route. TSTOP is the average stop time at each bus stop.

$$TTSTOP = TSTOP * (N+L) \quad (4.4)$$

where N and L are number of bus stops between origin/destination and transfer station. TRANSF is the transfer time at the terminal station, i.e. node number one. The amount of transfer time is assumed a uniform distribution between five and ten minutes. Up to this stage, both total travel time by auto and by bus are obtained. Using these two values the travel time ratio for

this particular trip can be calculated by taking TBUS divided by TAUTO. The travel time ratio is usually given a terminology "Level of Service" in numerous publications, which has been considered as an indicator of the competitiveness between different modes of transport. In this program, the travel time ratio, level of service, is sorted into classes of trip lengths. The trip lengths are split into six classes, 0-1, 1-2, 2-3, 3-4, 4-5, and 5- miles.

In addition to the determination of travel time ratio, values of TBUS and TAUTO are fed into the binary behavioral model to generate the bus system's attractiveness to the trip maker. The process is described in the following.

Consider the general form of binary behavioral model in Chapter II. Equation 2.3 is

$$P_{ib} = \exp(-B_i) / [\exp(-A_i) + \exp(-B_i)] \quad (4.5)$$

where A_i and B_i are disutility functions of both modes auto and bus for individual trip maker i . If we divided both denominator and numerator by $\exp(-B_i)$, equation 4.5 can be simplified into equations 4.6 or 4.7.

$$P_{ib} = 1. / [1. + \exp(B_i - A_i)] \quad (4.6)$$

$$P_{ib} = 1. / [1. + \exp(Z_i)] \quad (4.7)$$

where Z_i is called the difference disutility function between bus and auto. Substitute equation 2.5 into A_i and B_i the value of Z_i can be determined, and subsequently the

probability P_{ib} is also determined. It is clear that the difference disutility function is

$$Z_i = B_i - A_i \quad (4.8)$$

$$\begin{aligned} &= \{(\text{Cost by Bus}) + V(I) * TBUS\} \\ &\quad + \{(\text{Cost by Auto}) + V(I) * TAUTO\} \end{aligned} \quad (4.9)$$

where $V(I)$ is the trip maker's value of time. Furthermore, equation 4.9 is same as

$$\begin{aligned} Z_i &= \{(\text{Cost by Bus} - \text{Cost by Auto})\} \\ &\quad + V(I) * \{TBUS - TAUTO\} \end{aligned} \quad (4.10)$$

Consider the equation above, cost by bus is nothing but the trip fare charged by the bus company, cost by auto is the perceived auto cost of auto users. If the value of auto cost adopts Winfrey's estimate³⁵, .1687 dollars per mile based on 1970 dollars, equation 4.10 becomes

$$\begin{aligned} Z_i &= \text{FARE} - \text{FPARK} - .1687 * [1.07^{*(n-1970)} * \text{ADIST}] \\ &\quad + V(I) * (TBUS - TAUTO) \end{aligned} \quad (4.11)$$

In this equation, $TBUS$ and $TAUTO$ are known; $FARE$ and $FPARK$ are policy variables; n is the year the program being run; the only unknown is the trip maker's time value $V(I)$. Similar to the generation of trip origin and trip destination, $V(I)$'s are obtained by using Monte Carlo technique to generate an income group corresponding to the individual trip maker. Currently, several different studies have suggested that the time spent on the journey to work is

valued at about one-quarter to one-half of the wage rate²⁸. Accordingly, in this study, the time value is obtained by multiplying the wage rate of the generated income group a factor one third. Consequently, the individual probability, i.e. the bus system's attractiveness to the trip maker i , can be obtained from equation 4.11.

The above process is repeated for one thousand individual trips as the chosen sample size is one thousand. Then statistics of all these attractivenesses are collected according to classes of income level as well as total travel distance. The mean of these attractiveness is also calculated which is the expected percentage of the community's total travel demand serviced by the bus system. The ninety-five confidence interval is also calculated for this mean. The mean of total probabilities is assigned a variable name PROB2 which implies the 'current' bus system's attractiveness, in contrast to the PROB1, the 'previous' attractiveness of the bus system. Recall that PROB1 is among the input data as presented in Chapter III and was determined by either demand survey or analogy method.

Reaching this stage, network configuration, expected operating cost, bus system's attractiveness have been obtained. The next step is to check if the system is in the

equilibrium state.

The values of PROB1 and PROB2 are compared. If they are different the market of course is in the unstable condition and the demand is subject to change. The deterministic demand at each bus, one of the initial input data, is modified by the following relationship.

$$Q(I) = Q(I) * PROB2 / PROB1 \quad (4.12)$$

The 'previous' attractiveness is then dropped and substituted by the 'current' one.

$$PROB1 = PROB2 \quad (4.13)$$

New demands $Q(I)$'s at each bus stop are feedback to the sweep algorithm. The whole process is performed over. Again, current attractiveness PROB2 is generated. Comparison between PROB1 and PROB2 is made. If they are different the whole process will be repeated. The termination of the iterative process occurs only if PROB2 falls within 95% confidence interval of PROB1.

As a result, when the whole process reaches its termination stage, it is assumed that the equilibrium state is reached, that is the supply side and the demand side are in stable condition.

CHAPTER V

5.0 MODEL VALIDATION AND SENSITIVITY ANALYSIS

The basic purpose of these models is to help in the design of bus transit systems. Their validity have to be judged not only by their suitability for a particular situation, but also from the considerations that the model can provide a better system design. In order to test the similarity between the real world system and the model system, it is necessary as a first step to simulate the actual conditions of the existing policies and to examine if the model can give a reasonable correct prediction of the existing system. Having passed the validity the models then can be subjected to a sensitivity analysis by changing the values of policy variables. The sensitivity analysis will provide the users an insight of what and how the variables are significantly affecting the system.

In this chapter the contents are organized in the following manner. The validity of the models is discussed in Section 5.1, in which the models were tested by utilizing a real world example. In Section 5.2 the sensitivity analysis is provided. The effects of several policy variables to the operational cost and system's

attractiveness are also discussed.

5.1 Model Validation

The present research has taken the case of the mid-western section of Arlington County, Virginia for testing the validity of the general bus transit model developed in the foregoing chapters. The area characteristics of this place is described in the following paragraph.

The study area, mid-western section of Arlington County, Virginia, surrounds the proposed east "metro" station on the Rosslyn-Ballston corridor and acts as a catchment area for a bus system feeding the metro station. The boundaries of the designated area are displayed in appendix C. For a conservative measurement the boundaries of the area extend for two miles in the north, west, and south direction from the metro station. The total square mileage of the area is approximately 6.67 (=186 thousand square feet). The area to the east of the metro station is assumed to be serviced by the previous station on the metro corridor. The information obtained from the U.S. census tracts of Arlington shows the study area to be fairly homogeneous. The residential patterns tend to be predominantly single-family with higher density clustering

along the main arterials. Commercial establishments and offices are also clustering along the major route of transportation. The median income of the area is \$13653, slightly higher than the Washington SMSA figure of \$12933. The income group distribution is shown in Table 5.1. 42% of the population within the study area work in Arlington County while 38% commute into the District of Columbia. The remainder of the residents work in the surrounding counties such as Fairfax, Virginia and Montgomery, Maryland. The dominant means of transit throughout the area is one private automobile occupied by only one person. The existing conventional bus network in the area is operated with approximately 20% of the residents using the service.

A new bus network system has been planned for this area. The planned system is a feeder bus system where all bus routes coincide at the metro station. In other words, the metro station is designated as the transfer terminal of the proposed bus network. Including the terminal there are 110 bus stops fairly uniformly distributed in the service area. The plan for the new bus network has been carried out by Walker³³ according to the concept of sweep algorithm. The average level of service obtained in that study was 2.36 and the expected operational cost was approximately three million per year. There was no indication in that study to

TABLE 5.1 Income Cumulative Distribution

Income	≤	≤	≤	≤	≤	≤	≥
(\$/yr)	5000	10000	15000	20000	25000	40000	40000
Percentile	10%	20%	38%	60%	90%	99%	1%

reflect the expected attractiveness to the community.

The rectangular coordinates of all these 110 bus stops were coded, where the metro station was considered bus stop number one, and fed into the computer program. The initial percentage of bus trip was assigned 20%. The fare charge of the system was \$.25 and \$.50 for different runs. The results showed the expected level of service would be about 1.92 and the total operational cost \$2875013. Both figures are fairly close to those of Walker's study. The explanation for the discrepancy in the predicted level of services is that the computer program gives the minimum travel distance by utilizing the traveling salesman algorithm, while Walker's study used linear route structure obtained by Hamiltonian Path Algorithm. The traveling salesman algorithm provided smaller figures of travel time ratio than the Hamiltonian Path Algorithm. Besides, the predicted attractiveness to the community grew up to 34% at equilibrium state while the initialized value was only 20%. 14% of the society's travel will shift from auto to bus, if the bus network is implemented according to this study.

The validity of this model could be better justified if it is applied to an existing bus system network, instead of comparing with another study. However, this was not possible in this study, and it is recommended as a further

research point.

5.2 Sensitivity Analysis

Since the models were constructed with an emphasis on the interaction between supply and demand, many policy variables are incurred.

On the supply side, bus capacity, maximum allowable travel distance, schedule of bus headway, and bus speed are all policy variables. Each of these policy variables is discussed as follows. First, buses with larger capacity allows longer travel length for each route. In this case, less operational cost will be observed because a system with buses of greater capacity can suffice the demand with fewer routes. Second, bus headway and bus speed in this study were not varied in the input information of the models as well as in the sensitivity analysis. The bus speed was assigned an average value of 15 miles per hour and the bus headway was 15 minutes, identical to that of the studied bus system.

On the demand side, fare structure, parking fare, gasoline price are effective to the measure of system's attractiveness. All these three variables are tested in order to investigate how alternative policies will affect

the bus attractiveness to the society. In addition, the amount of government subsidies plays an important role in the operation of a bus system. Consequently, some tests were carried out to study the effect of alternative amount of subsidies.

Capacity and Distance Constraints Versus Operational Cost

As mentioned in the previous paragraphs, the system operates with larger buses will require less operational cost. In this study two types of buses were chosen. First choice is the bus with 32 seats and maximum allowable travel length of 30000 feet (5.68 miles). Second choice is the bus with 50 seats and maximum allowable travel length of 50000 feet (7.97 miles). The results showed that the system using buses of 32 seats in the case of Arlington County, with fleet size forty buses, will require 3092 thousand dollars operational costs. The system using buses of 50 seats, will require 2473 thousand dollars operating cost. The system with larger buses will indeed operate with less cost.

Capacity and Distance Constraints Versus Attractiveness

From intuitive judgement, decrement in attractiveness should be observed if buses of greater capacity are used. It can be explained that the bus with greater capacity

enables to serve longer route length, and longer route length, of course, will consume longer travel time. The reduction of the attractiveness of the bus system due to its longer travel time is shown in Tables 5.2, 5.3, and 5.4. However, not too surprisingly, the bus capacity does not significantly affect the system's attractiveness. The variation ranges between 0.005 and 0.01. Such a small range of variation can be referred to the structure of the behavioral model. The effects of excess travel time due to greater bus capacity can almost be neglected.

Fare Structure, Parking Price, and Subsidy versus Attractiveness

Presently, many studies have recommended various price mechanisms either to foster the bus system's attractiveness or to suppress the automobile usage. The reduced fare structure and the increased parking charges are frequently discussed. In the present study, the analyses were conducted along those two directions to find out how the system's attractiveness will be affected by the changes of fare structure and parking price. In addition, the amount of subsidy is changed to study its effects on the attractiveness of the system. The results are listed in Table 5.2 through 5.4. Several observations can be drawn

Table 5.2 Attractiveness under 0 Subsidy
and \$.06/mile Auto Cost

	Bus Fare=.00			Bus Fare=.25			Bus Fare=.30			Bus Fare=.50		
	Parking Price			Parking Price			Parking Price			Parking Price		
	.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5		
CP=32	.409	.521	.609	.348	.459	.548	.336	.449	.560	.287	.405	.506
CP=50	.404	.518	.606	.343	.455	.545	.331	.444	.557	.282	.401	.503

Table 5.3 Attractiveness under 250000 Subsidy
and \$.06/mile Auto Cost

	Bus Fare=.00			Bus Fare=.25			Bus Fare=.30			Bus Fare=.50		
	Parking Price			Parking Price			Parking Price			Parking Price		
	.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5		
CP=32	.416	.540	.659	.355	.466	.552	.344	.455	.545	.295	.411	.511
CP=50	.410	.535	.653	.346	.460	.548	.335	.448	.540	.288	.405	.506

Table 5.4 Attractiveness Under 500000 Subsidy
and \$.06/mile Auto Cost

	Bus Fare=.00			Bus Fare=.25			Bus Fare=.30			Bus Fare=.50		
	Parking Price			Parking Price			Parking Price			Parking Price		
	.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5			.50 =1.0 =1.5		
CP=32	.422	.546	.665	.362	.471	.557	.350	.460	.549	.300	.418	.517
CP=50	.418	.536	.655	.355	.462	.551	.340	.452	.543	.291	.409	.509

from the analysis of these data.

Increasing the subsidy to the bus system can increase the system's attractiveness. But the increase in attractiveness grows at a much slower rate than the increase in subsidy. This is shown by comparing the data columnwise in Table 5.2 through 5.4. It tells that the increase in attractiveness by increasing governmental subsidy is not substantial. In Rapp's²⁴ study, he indicated the same conclusion that "the per ride subsidy increases very rapidly when attempting to increase the modal split". These two results are compatible and can be considered as further evidence of models validity. Note that in these tables, bus fares sometimes are simplified approximation numbers. While the assigned subsidy cannot cover the deficit incurred in the system, the difference between deficit and subsidy will be uniformly distributed on the total revenue passengers. In this case, the disutility increases and, consequently, attractiveness decreases. Therefore, when the subsidy cannot cover the deficit, the real bus fare is slightly higher than the numbers shown, and the values of attractiveness in tables are modified numbers.

According to the foregoing observations discussed in the previous paragraph we can state that the system's attractiveness is not sensitive to either the choice of bus

capacity or the amount of governmental subsidy. Consequently, the data in Table 5.2 through 5.4 can be rearranged and simplified to Table 5.5. The numbers obtained in Table 5.5 are the averages of numbers in associated columns of Tables 5.2 through 5.4. The reason why we can do so is that there is no large variations in data within each column.

Tables 5.2 through 5.5 is plotted in Figure 5.1, 5.2, and 5.3. Figure 5.1 shows the family curves representing the relation between parking price and system's attractiveness. All these curves seem to have the same shape, and indicate that higher parking price will increase the bus ridership. Figure 5.2 shows the family curves for the relation between bus fare structure and system's attractiveness. The curves show higher bus fare charges suppress ridership. Because within these two figures curves are parallel to one another in each family, the generalized form is plotted in Figure 5.3. The generalized form is the averages of values in Figure 5.1 and 5.2. The elasticity of attractiveness (P) with respect to fare structure (F), is defined as the percentage of change in attractiveness which results from a one percent change in bus fare. Thus.

$$\text{elasticity} = e' = (\partial P/P) / (\partial F/F) = (F/P) (\partial P/\partial F) \quad (5.1)$$

Table 5.5 Average Attractiveness under the
Perception of \$.06/mile Auto Cost

	Bus Fare=.00			Bus Fare=.25			Bus Fare=.30			Bus Fare=.50		
	Parking Price			Parking Price			Parking Price			Parking Price		
	.50	1.0	1.5	.50	1.0	1.5	.50	1.0	1.5	.50	1.0	1.5
AVG	.413	.533	.641	.352	.462	.550	.339	.451	.549	.291	.408	.507

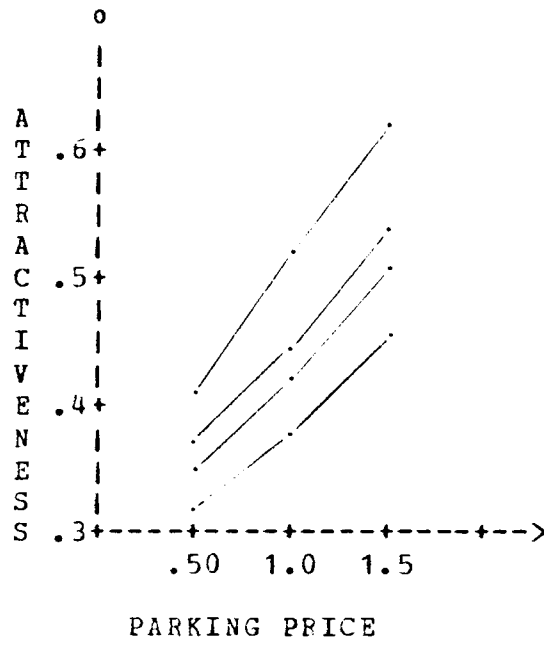


Figure 5.1 Attractiveness Versus Park Price

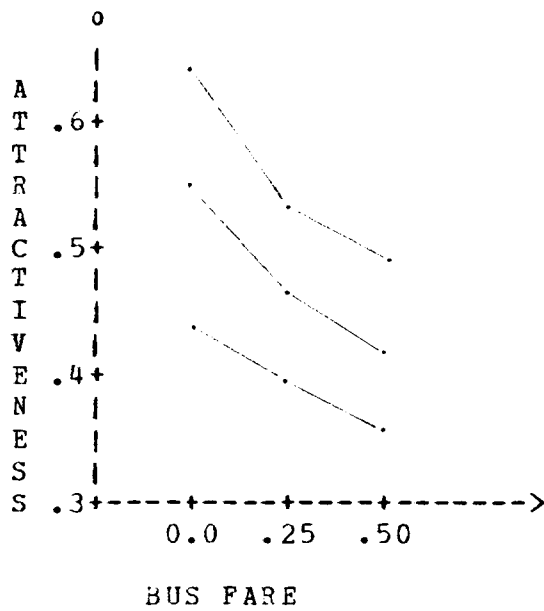


Figure 5.2 Attractiveness Versus Bus Fare

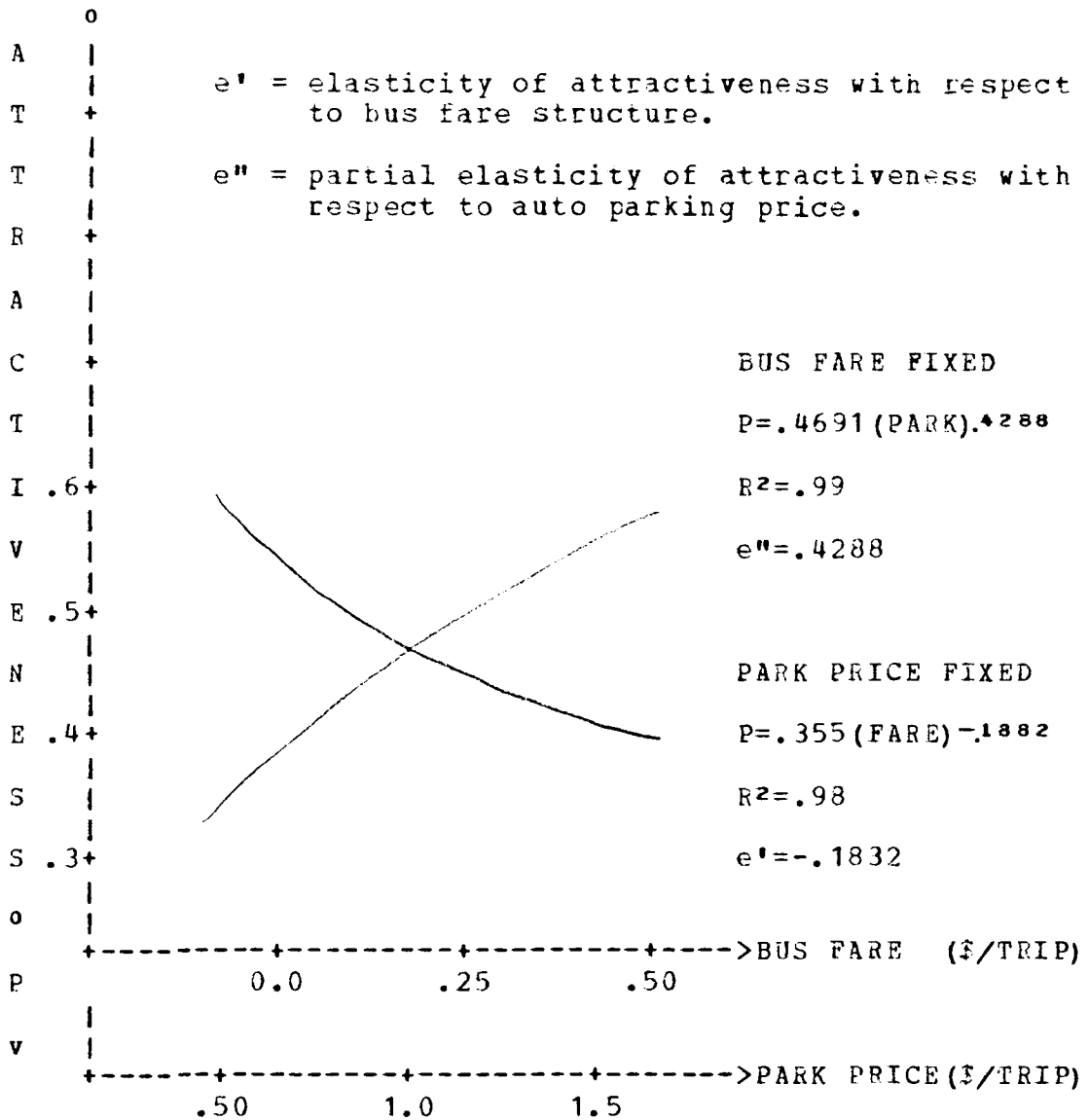


Figure 5.3 Elasticities of Bus Attractiveness

Assuming the attractiveness function to have the following form³⁷.

$$P = a * (f ** b) \quad (5.2)$$

the elasticity e' can easily be derived as below

$$e' = b \quad (5.3)$$

One way to determine the value of elasticity e' is to take the logarithm of equation 5.2 and run the regression analysis for curves in Figure 5.3 in the transformed linear form.

$$\log P = \log a + b \log f \quad (5.4)$$

Using the output data points, the assumed function P has been obtained as

$$P = .355 (\text{Fare})^{-0.1832} \quad R^2 = .98$$

and the elasticity $e' = -.1832$.

Subsequently, the 'partial elasticity', or the 'partical (cross) elasticity of bus attractiveness with respect to the automobile parking price' is determined following the same approach to e' . The function P was obtained as

$$P = .4691 (\text{Park Price})^{.4288} \quad R^2 = .99$$

and the elasticity $e'' = .4288$

Comparing the magnitudes of e' and e'' , we can conclude that increasing the parking price provides a more efficient way to increase the bus system's attractive than cutting

down the transit fare. The former is more than twice as much efficient as the latter because e'' is greater than twice e' . The negative sign for e' is nothing but the decline trend of the attractiveness with respect to fare. As a result, the various results show that the most effective way to foster the bus ridership is to increase the auto parking charge. Other auto costs although are not included in this study, could produce effective results in attracting people to use bus transit. These costs may be toll price, automobile tax etc.

Perceived Running Cost Versus Attractiveness

The attractiveness of a bus system generated from the behavioral model is based on one assumption that 'the modal split is determined by the consumer's perception of time and money'. The auto running cost of 6 cents per mile has been used in the behavioral model. The value \$.06/mile definitely is not the real auto running cost. However, people always consider their trip fare as out-of-pocket money only; they 'think' their automobile running cost is nothing but the fuel expense. Therefore, the 'perceived auto running cost' generally excludes the cost of engine oil, maintenance, tires, insurance, and depreciation etc.

If we are using the models to simulate the existing

situation in order to demonstrate the model's validity, no doubt the perceived running cost should be used.

However, as stated before, the perceived running cost is not the real running cost. The real running cost includes more items such as depreciation, maintenance etc. Winfrey³⁶ made a very detailed listing of all items in real running cost determination. The average value he figured out is approximately 25 cents per mile on a calculated 1977 dollar base. The great gap between the real (25 cents) and perceived (6 cents) running cost is due to mostly to depreciation and maintenance which have been neglected by most people. Deleuw, Cather/STV gave a conservative figure for the national average of the true auto running cost. The figure is 18.6 cents per mile when auto is traveling urban area with an average speed of 25 mile per hour.

Both the foregoing two auto running costs are much higher than the perceived one in the behavioral model. Some additional computer runs were made by substituting the perceived auto running cost to the real auto running cost. Fortunately, the system's attractiveness goes up markedly with the increase of auto running cost. Tables 5.6 and 5.7 contain the results of new attractivenesses with different perception of auto running cost. Tables 5.3, 5.5, and 5.6 are data of attractiveness based on 500,000 subsidy

Table 5.6 Attractiveness Under 500,000 Subsidy
and \$.25/mile Auto Cost

```

+=====+=====+=====+=====+
| Bus Fare=.00 | Bus Fare=.25 | Bus Fare=.30 | Bus Fare=.50 |
+-----+-----+-----+-----+
| Parking Price | Parking Price | Parking Price | Parking Price |
+-----+-----+-----+-----+
|=.50|=1.0|=1.5|=1.5|=1.0|=1.5|=1.5|=1.0|=1.5|=1.5|=1.0|=1.5|
+-----+-----+-----+-----+
|CP=32|.590|.717|.764|.539|.647|.732|.525|.635|.724|.475|.563|.692|
+=====+=====+=====+=====+

```

Table 5.7 Attractiveness Under 500,000 Subsidy
and \$.186/mile Auto Cost

CP=32	.552	.724	.501	.690	.478	.665	.428	.655
Bus Fare=.00	Bus Fare=.25	Bus Fare=.30	Bus Fare=.50					
Parking Price	Parking Price	Parking Price	Parking Price					
=.50	=1.0	=1.5	=.50	=1.0	=1.5	=.50	=1.0	=1.5

assumption. We can see, from the comparison of these three tables, that Winfrey's auto running cost will increase the system's attractiveness by ten per cent and Deleuw's auto running cost will increase the system's attractiveness by about 5 per cent. Therefore, the traveler's perception of auto travel cost will significantly affect the system's attractiveness. Based on this result it should be realized that informing the people the real cost of operating an automobile is a very effective tool to foster the bus system's attractiveness.

Trip Length and Income Level Versus Attractiveness

The simulation output gives statistical data on some additional variables such as trip length and income level. The general shapes of the relationship between those independent variables and attractiveness are drawn in Figure 5.4 and 5.5. From Figure 5.4 we realize that maximum bus usage are observed within the range of trip length between three and four miles. When trip length is longer the attractiveness drops rapidly. From Figure 5.5, we realize that the income level will not strongly affect the system attractiveness unless the income level exceeds certain level. Beyond that level the attractiveness drops rapidly.

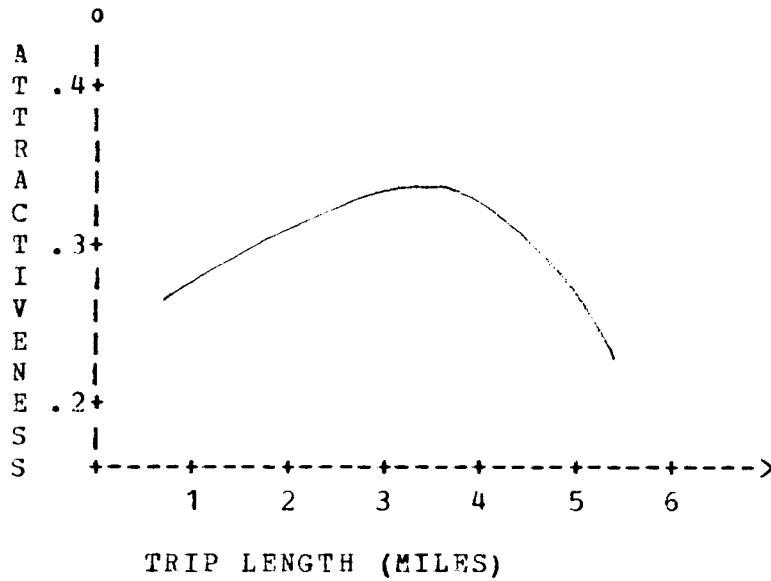


Figure 5.4 Attractiveness Versus Trip Length

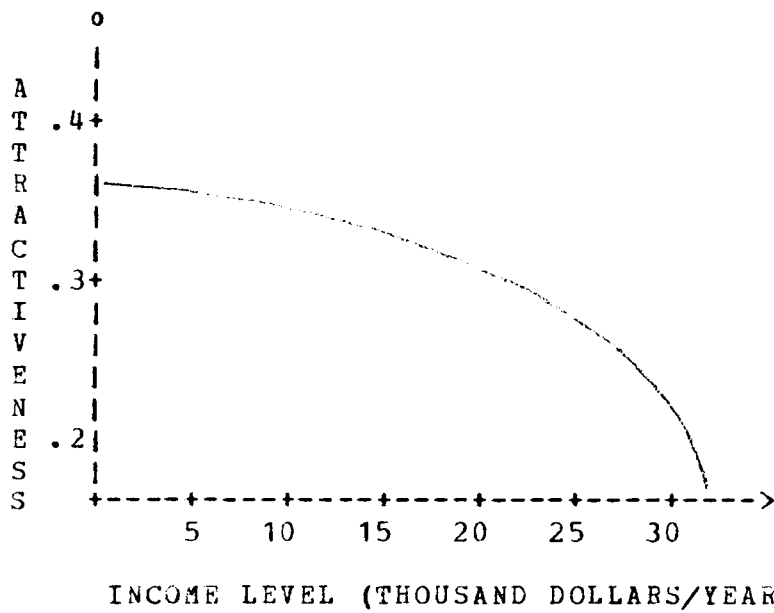


Figure 5.4 Attractiveness Versus Income Level

CHAPTER VI

6.0 CONCLUSION AND RECOMMENDATION

The whole study can be summarized as follows.

1. The route structure developed by sweep algorithm (and traveling salesman 3-optimum solution) is the most economical design as far as the total travel distance is concerned.
2. Utilizing larger buses for the system will permit longer route length and, in turn, less number of routes. Under this condition, the operational cost will be decreased while attractiveness stays fairly the same. In other words, the bus capacity is sensitive to operational cost, but insensitive to system's attractiveness.
3. Subsidy is not an efficient way to increase buses attractiveness. The attractiveness increases very slowly while large amount of subsidy is added in.
4. Increasing auto cost is the most effective way to obtain better buses attractiveness. The term auto cost is not restricted to parking price only. All related expenses to auto trip making can be included in this term.
5. The second best way to increase bus attractiveness is to educate drivers to realize the difference between the

actual and the perceived auto running cost. The actual running cost is four to five times as much as the perceived auto running cost.

6. Decreasing transit fare is not as effective as the foregoing two methods. Yet the transit fare structure is sensitive to the system's attractiveness.
7. The models provide a network structure of minimum total travel distance (or, minimum total travel time). The test for the model at Arlington County provides a satisfactory compatibility between models output and Walker's study. The model may be better justified by a real world implementation.

Several recommendations for future researches are listed in the following.

1. The computer output gives the route configuration design. The design is displayed sector by sector surrounding the terminal station. All routes are given in two-way loop form. No linear route is designed. However, in the real world case, some linear routes are still essential albeit they consume more travel time and distance. Future research is recommended to put some nodal priority weight in forming the routes such that the developed system will not consider the economic efficiency only.
2. The sweep algorithm will perform better if it is applied to the metropolitan level. In that case, the system should be modified to multi-terminal station or multi-vehicle dispatching point. Perhaps partitioning process can be used to cut down the size of the routing problem.
3. The socio-economic factors play an important role in the bus route design. The demand level at high income residential area is much lower than that at lower income area. The passenger demand at each bus stop is assigned as input data in this study. In fact, this demand distribution to bus stops doesnot necessarily be linear as assumed in the feedback process of the developed program. A demand distribution function that allocates

passengers to bus stops in a specific service area is another recommendation to further research.

4. The behavioral model used in this study is restricted to binary case. Multiple modes behavioral model can be added to improve the model's applicability, such as including walk, bicycle, taxi, kiss-and-ride etc.
5. As mentioned in Chapter 1, the mass transit market behaves in an interactive manner. In order to simulate this particular characteristic, the behavioral demand model included a policy variable, the measure of travel time on each mode, from the supply side. The measures of travel time is dependent on the bus route configuration and will affect the attractiveness on the demand side. However, in addition to the route configuration design, spacing of bus stops, service frequency on each route, maximum route distance etc are all policy variables on the supply side which have been unchanged through all iterations in the model. In fact, the system's attractiveness varies with these policy variables. A recommendation for the future research would be how to determine the optimal spacing between bus stops, the optimal frequency, and the optimal route length on each route based on the objective function of maximizing the bus system's attractiveness.

LIST OF REFERENCES

1. J.J.Bakker, "Transit Operating Strategies of Service", Transportation Research Record 606, 1976, pp 1-5
2. R.G.Coyle, and M.J.Martin, "Case Study: The Cost Minimization of Refuse Collection Operation", Operations Research Quarterly, Vol. 20, Special Conference Issue, April 1969, pp. 43-56.
3. J.D. Foulkes, W. Prager, and W.H. Warner, "On Bus Schedules", Management Science, Vol. 1, 1954, pp.41-48.
4. T.J. Gaskell, "Bases for Vehicle Fleet Scheduling" Operations Research Quarterly, Vol. 18, no. 3, Sept. 1967, pp.281-295.
5. P.M. Ghare, W.C. Turner, L.R. Fources, "Transportation Routing Problem - A Survey" AIIE Transactions, Vol. 6, no. 4, pp. 283-300.
6. B.E. Gillett and L.R. Miller, "A Heuristic Algorithm for the Vehicle Dispatch Problem", Operations Research, no. 22, pp. 340-349.
7. R.H. Gonzalez, "Solution of the Traveling Salesman Problem by Dynamic Programming on Hypercube", Interim Tech. Report, no. 18, Operations Research Center, M.I.T.
8. F.S. Hiller and G.J. Lieberman. Operations Research, 2nd ed., Holden-Day, Inc., 1974.
9. M. Held and R.M. Karp, "The Traveling Salesman Problem and Minimum Spanning Tree: Part II", Mathematical

Programming 1, pp.6-25,1971.

10. V.F. Hurdle, "Minimum Cost Schedules for a Public Transportation Route", Transportation Science, Vol. 7, no. 2, pp.109-157.
11. J.W. Hurley and R.L. Siegel, "A Cost Forecasting Model for Bus Transit Operation", Modeling and Simulation, Vol. 7, Proceedings of the Seventh Annual Pittsburgh Conference, April 26-27, 1976, pp. 427-432.
12. M. Iri, T. Morigaki, S. Moriguti, and M. Yabe, "A Network Model for Commuter Transportation", J. of Operations Research Society of Japan, Vol. 10, no. 3-4, June 1968, pp.108-124.
13. W.S. Jewell, "Allocation of Route Service in a Transportation Network", Paper delivered at the 4th International Symposium on the Theory of Traffic Flow, Karlsruhe, Germany, June 17-20, 1968.
14. D.J. Kulash, "Routing and Scheduling in Public Transportation Systems", Ph.D. thesis, M.I.T. March 1971.
15. W. Lampkin and P.D. Saalmans, "The Design of Routes, Service Frequencies, and Schedules for a Municipal Bus Undertaking: A Case Study", Operations Research Quarterly, vol. 18, no. 4, Dec. 1967, pp.375-397.
16. C.A. Lave, "A Behavioral Approach to Modal Split

- Forecasting", Transportation Research, Vol. 3, no. 4, Dec. 1969, pp.463-480.
17. E.L. Lawler and D.E. Wood, "Branch and Bound Methods; A Survey", Operations Research, Vol. 14, no. 4, pp. 699-719, 1966.
 18. S.Lin, and B.W. Kernighav, "An Effective Algorithm for the Traveling Salesman Problem", Computer Science Tech. Report, no. 1, Bell Labs, April 1972.
 19. J.D. Little, K.G. Murty, D.W. Sweeney, and C. Karel, "An Algorithm for the Traveling Salesman Problem", Operations Research, no. 11, pp.972-989, 1963.
 20. J.H.Miller and J.C.Rea, "Comparison of Cost Models for Urban Transit" Highway Research Record, no. 435, 1973, pp. 11-20.
 21. J.F. Pierce, "On the Truck Dispatching Problem: Part I", Cambridge, Scientific Center, IBM Data Processing Division, July 1967.
 22. R. Pratt, "A Utilitarian Theory of Travel Mode Choice", Highway Research Record no. 322, 1970, pp. 40-53.
 23. D.A.Quarmby, "Choice of Travel Mode for the Journey to Work", Journal of Trasport Economics and Policy, Vol. 1, no. 3, 1967, pp.273-314.
 24. Rapp and Gehner, "Criteria for Bus Rapid Transit Systems in Urban Corridors: Some Experiment with an Interactive

- Graphic Design System", Research Report no. 72-1, Seattle, Washington, Urban Transportation Program, University of Washington, April 1973.
25. R.Seshagiri, R.Narasimhan, S.L.Mehndiratta, and B.K. Chanda, "Computer Generated Time-Table and Bus Schedules for a Large Bus Transport Network, Transportation Science, Vol. 3, no. 1, Feb. 1969, pp. 69-85.
 26. R.W. Simpson, "A Review of Scheduling and Routing Models for Airline Scheduling", AGIFORS Meeting, Broadway, England, Oct. 1969.
 27. P.R.Stopher, "Derivation of Values of Time From Travel Demand Models", Transportation Research Record, no. 587, 1976, pp.12-18.
 28. P.R.Stopher, "Application of Value of Travel Time to Economics Evaluation of transport Investment Alternatives", Transportation Research Record, no. 587, 1976, pp 19-23.
 29. P.R.Stopher and A.H.Meyburg, Urban Transportation Modeling and Planning Lexington Books, 1975.
 30. T.C. Thomas and G.I. Thompson, "The Value of Time for Community Motorist as a Function of Their Income Level and Amount of Time Saved", Highway Research Record, no. 314, 1970, pp.1-19.
 31. V.R.Vuchic and G.G.Newell, "Rapid Transit Interstation

- Spacings for Minimum Travel Time, Transportation Science, Vol. 2, no. 4, Nov. 1968, pp. 303-339.
32. V.R.Vuchic, "Rapid Tansit Interspacings for Maximum Number of Passengers", Transportation Science, Vol. 3, no. 3, Aug. 1969, pp. 214-232.
33. Victoria Walker, "Bus Route Structure Design in Small Urban Area". Forthcoming Major Paper, Virginia Polytechnic Institute and State University.
34. S.L.Warner, Stochastic Choice of Mode in Urban Travel, A Survey of Binary Choice, Evanston, Illinois, Northwestern University Press, 1962.
35. N.H.M. Wilson, J.M.Sussman, H.K.Wang, and T.Higonnet, "Scheduling Algorithms for a Dial-A-Ride System", Urban System Lab. Tech. Report no. 70-13, Cambridge, M.I.T., March 1971.
36. R. Winfrey, "Economic Analysis for Highway", 1969.
37. M.Wohl and B.V. Martin, Traffic System Analysis for Engineers and Planners, McGraw-Hill, New York, 1967.

APPENDIX A

STEP-BY-STEP DESCRIPTION OF MODEL OPERATIONS

If location J is in a given route and location $J+1$ cannot be added to it, then location $J+2$ is not checked. The notation in the body of the paper is assumed. Instead of relabeling the locations, we let $K(2)$ denote the location with the smallest angle, $K(3)$ denote the location with the second smallest angle, and so forth.

Step 1. Evaluate the polar coordinates for each location with the depot at $(0,0)$. Let $An(I)$ represent the angle and $R(I)$ the radius for location $I, I=2,3,\dots,N$.

Step 2. Determine $K(I)$ for $I=2,3,\dots,N$ such that $An(K(I))$ is less than or equal to $An(K(I+1))$.

Step 3. Begin the first route with $J=2$ and $SUM=Q(K(2))$.

Step 4. Increment the angle by making $J=J+1$.

Step 5. If $SUM+Q(K(J)) > C$, go to step 7.

Step 6. Augment the route with location $K(J)$ by making $SUM=SUM+Q(K(J))$. If $J=N$, then go to step 16. If not, then go to step 4.

Step 7. Calculate the minimum distance $D1$ for the route by means of traveling-salesman algorithm. Check the distance constraint. If the distance capacity is exceeded, then eliminate $K(J-1)$ from the route. Make $SUM=SUM-Q(K(J-1))$ and $J=J-1$. Check the distance constraint again. Continue this procedure until the

distance constraint is satisfied.

Step 8. Determine JJX so that $K(JJX)$ is the nearest location to $K(J-1)$ and not in a route. Find JII so that $K(JII)$ is the nearest location to $K(JJX)$ and not in a route. Likewise determine I so that $R(K(I)) + A_n(K(I)) * AVR$ is a minimum for all locations in the route. Let KII denote this I. Determine the minimum distance D2 for the route with $K(JJX)$ added to the route and $K(KII)$ deleted from it.

Step 9. If D2 not greater than D and the load constraint is satisfied, then go to step 11. Otherwise go to step 10.

Step 10. Record the route and start a new route by setting $SUM = Q(K(J))$. Go to step 4.

Step 11. Evaluate the minimum distance D3 for starting at 1, traveling through locations $K(J)$, $K(J+1), \dots, K(J+4)$ and ending at $K(J+5)$. Determine the distance D4 for traveling through the same locations, except eliminate $K(JJX)$ and inject $K(KII)$. If $K(JJX)$ is not $K(J)$, $K(J+1), \dots$, or $K(J+4)$, then go to step 10. If $D1 + D3 < D2 + D4$, then go to step 13. Otherwise, go to step 12.

Step 12. Place $K(JJX)$ in the route and remove location $K(KII)$. Go to step 4.

Step 13. Evaluate the minimum distance $D5$ for the route with $K(JJX)$ and inject $K(KII)$ substituted for $K(KII)$. If $K(JJX)$ and $K(JII)$ are not $K(J)$, $K(J+1)$, ..., or $K(J+4)$, then go to step 10. If $D5 < D$ and the load constraint is satisfied, then go to step 14. Otherwise, go to step 10.

Step 14. Determine the minimum distance $D6$ for starting at 1, traveling through locations $K(J)$, $K(J+1)$, ..., $K(J+4)$, and ending at $K(J+5)$, with $K(JJX)$ and $K(JII)$ excluded and $K(KII)$ included. If $D1 + D3 < D5 + D6$, then go to step 10. Otherwise, go to step 15.

Step 15. Place $K(JJX)$ and $K(JII)$ in the route and eliminate $K(KII)$ from the route. Go to step 4.

Step 16. Evaluate the minimum distance for the route and check the distance constraint. If not satisfied, then go to step 17. If satisfied, then that set of routes is complete. Check to see if another set of routes is needed. If no more are needed, then go to step 19. Otherwise go to step 18.

Step 17. Delete one from the route ($J=J-1$). go to step 10.

Step 18. Increment the angle by one location, i.e. start with $K(3)$ for the second set of routes. Go to step 2.

Step 19. End of route structure design.

Step 20. Transform the above route structure into the route structure matrix. Set the route structure matrix to be $ITT(K, NN)$ where K stands for the number of routes and NN stands for the number of stops in route K . Start from $ITT(I, J)$ go to step 23.

Step 21. Set $I=I+1$ and $J=0$ in order to start a new route.

Step 22. $J=J+1$.

Step 23. If $ITT(I, J)=1$ the route is started at terminal location number one. Record the route structure. Otherwise go to step 22.

Step 24. If $I=K$ every route has been sorted to start at node one, go to step 25. Otherwise go to step 21.

Step 25. Evaluate the total demand on each route. Set $SBDQ(I)=0$, $I=1$. $SBDQ(I)$ stands for the total demand on route I .

Step 26. $I=I+1$, $J=0$.

Step 27. $J=J+1$.

Step 28. $SBDQ(I) = SBDQ(I) + Q(ITT(I, J))$. If $J < NN$ go to step 27. If $J = NN$ and $J < K$ go to step 26. Otherwise go to step 29.

Step 29. Determine the total system's demand $SSBQ$.

The SSBQ is the sum of all SBDQ(I)'s, $I=1, \dots, K$. Evaluate the probability for each route which is $PBRT(I) = SBDQ(I) / SSBQ$, $I=1, 2, \dots, K$.

Step 30. Evaluate the probabilities for each node J along route I. Set $L = ITT(I, J)$, $PBOG(I, J) = Q(L) / SBDQ(I)$ for all $I=1, \dots, K$, $J=1, \dots, NN$.

Step 31. Generate a uniformly distributed random number B. Set $I=1$.

Step 32. $I=I+1$.

Step 33. If $B - PBRT(I)$ not greater than 0 the route of trip origin is determined. Otherwise set $B = B - PBRT(I)$ go to step 32.

Step 34. Generate another random number B. Set $J=1$ go to step 36.

Step 35. $J=J+1$.

Step 36. If $B - PBOG(I)$ not greater than 0 the node of origin is determined. Let $IO = ITT(I, J)$. Otherwise set $B = B - PBOG(I)$ go to step 35.

Step 37. Follow the same process from step 31 through 36, generate the destination of the trip. Let $ID = ITT(I, J)$.

Step 38. Evaluate the bus travel distance ODPT from origin to transfer station. The distance is the sum of all distances between bus stops that the traveler

has to pass.

Step 39. Evaluate the bus travel distance $DDPT$ from the transfer station to the destination. The distance is the sum of all distances between bus stops that the traveler has to pass.

Step 40. The total bus travel distance is the sum of the distances in step 39 and step 40. $BDIST = ODPT + DDPT$. If IO and ID are on the same route $BDIST$ is the shortest travel distance the bus has to travel between two bus stops.

Step 41. The auto travel distance is the direct distance in the distance matrix. Let $ADIST$ represent the total travel distance by auto then $ADIST = A(IO, ID)$.

Step 42. Determine the total bus travel time $TBUS$. $TBUS$ is the sum of walking time to/from bus stop, waiting time at bus stop, transfer time at terminal, and on bus time plus the total stop time at each stop.

Step 43. Determine the total auto travel time $TAUTO$. $TAUTO$ is the sum of vehicle running time plus the parking time and walking time from office to parking lot.

Step 44. Generate a random number B to determine the income level. Set $MMS = 1$ go to step 46.

Step 45. $MMS = MMS + 1$

Step 46. If $B-P(MMS)$ not greater than 0 the income level is determined. Otherwise go to step 45.

Step 47. Evaluate the travel time ratio between mode bus and auto. Let $ALOS$ represent travel time ratio then $ALOS = TBUS/TAUTO$

Step 48. Evaluate the attractiveness of bus for this particular travel. Let $PROB$ denote this attractiveness. $PROB = 1./ (1. + \exp(FARE - ACOST*ADIST - V(MMS)*(TBUS-TAUTO)*.2/HOUR))$ where $FARE$ is the bus fare charge per trip, $ACOST$ is the auto running cost per mile. $V(MMS)$ is the yearly income of this traveler. $HOUR$ is the assumed working hours for a year.

Step 49. Collect the statistics of travel time ratio versus trip length bus attractiveness versus trip length and income level.

Step 50. If $NSAMPLE < 999$ go to step 31.

Step 51. Evaluate the expected operational cost. $VM = BSTDD * 60 / HDWY * OHPD * ODPY$; $VH = VM / BSPEED$ $PV = PASSG * (60 / HDWY) * (PKHPD + (OHPD - PKHPD) / 2) * ODPY$ where $BSTDD$ is system's total travel distance per headway. $HDWY$ is the bus headway. $OHPD$ is operating hour per day. $ODPY$ is operating days per year. $BSPEED$ is the average bus speed. $PASSG$ is the system's total

demand per headway. PKHPD is the peak hour per day.

Step 52. Operational Cost = $(.227VM + 5.7VH + 6527.48PV + .038RP) * (1.07^{**} (YEAR-1970))$

Step 53. Evaluate deficit and subsidy. deficit = operational cost - revenue passengers * trip fare. If deficit is less than or equal to subsidy go to step 55.

Step 54. Distribute the difference between deficit and subsidy on all passengers and re-evaluate the system's attractiveness.

Step 55. Check if the PROB1 is within the 95% confidence interval of PROB2. If it is go to step 56. If not modify all nodal demand by $Q(I) = Q(I) * PROB2 / PROB1$; and then set $PROB1=PROB2$ go to step 3.

Step 56. Stop.

APPENDIX B

PROGRAM LISTING

```

C  N IS THE NUMBER OF LOCATIONS INCLUDING THE DEPOT.
C  XD IS THE DISTANCE CONSTRAINT FOR EACH VEHICLE.
C  XLD IS ADDED DISTANCE PER STOP
C  CP IS THE LOAD CAPACITY FOR EACH VEHICLE.
C  THE DEPOT IS AT LOCATION 1.
C  X(I) , Y(I) IS RECTANGULAR COORDINATES FOR LOCATION I.
C  Q(I) IS THE DEMAND FOR LOCATION I.
COMMON A(110,110) , IROUT(110)
  DIMENSION R(250) , S(250) , K(250) , SS(250) , MK(250) , NT(250) , KK(250)
  X,X(250) , Y(250) , Q(250) , IT(300) , ITT(300) , QQZ(50) , DQZ(50) ,
  * KKZ(50) , BQD(50) , BQZ(50) , KZ(50)
  DIMENSION KMZ(50) , SBDQ(50) , IITT(50,300) , BDQR(50) , SUMP(7) , VSP(7) ,
  XKLM(7) , AVGSP(7) , VARSP(7) , PBRT(50) , SRQ(50) , PBOG(50,300) ,
  XPPEB(50) , C(6) , CC(6) , NSH(6) , PB(6) , SPB(6) , AVG(6) , VAR(6) , APG(6) ,
  ZVPG(6)
  DIMENSION V(7) , P(7)
  DIMENSION IITTT(50) , ADJ(110)
  DATA PROB1/.2/
  DATA BMXWK/8./
  DATA FREQ/15./
  DATA ASPEED,BSPEED/22.,13.2/
  DATA TSTOP/.5/
  DATA TWALK,TPARK/3.,2./
  DATA FARE,FPARK/.5,1.0/
  DATA V/2000.,7500.,12500.,17500.,22500.,30000.,50000./
  DATA P/.1,.2,.38,.68,.9,.99,1.0/
  DATA PUBLIC,SUBSID/1.,500000./
  DATA PKHPD,OHPD,ODPY,VEHN/6.,18.,300.,40./
  DATA YEAR/1977./
  DATA TRANF/7./
  ILM = 1
254 FORMAT ('
?      ')
  WRITE(6,254)
  READ (5,255) N,XLD
255 FORMAT (I5, F10.2)
  READ(5,800) CP,XD
800  FORMAT(F5.0,F10.2)
  NJN=N
  AVQ = 0
  DO 1 I = 1,N
  READ (5,256) X(I) , Y(I) , Q(I) , ADJ(I)
256 FORMAT (2F10.0,F10.1,F10.2)
  1 AVQ = AVQ + Q(I)
  AVQ = AVQ/(N-1)
  XD=1.3*XD
  XX= X(1)
  YY = Y(1)

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```

      WRITE (6,258) N,CP,XD,XLD,X(1), Y(1)
258  FORMAT (' NUMBER OF POINTS IS ',I5/' LOAD CAPACITY IS ',F12.6/
C' DISTANCE CONSTRAINT IS ',F12.6/' EXTRA DISTANCE PER STOP IS '
C,F12.6/' DEPOT AT ',F12.6,' AND ',F12.6)
      KLN = 1
      KV = 0
      BSTDD=9999999.

C
C  CHANGE TO POLAR COORDINATES WITH DEPOT AT ORIGIN
      WRITE (6,200)
200  FORMAT (' ',18X,'X(I)', 8X,'Y(I)', 6X,'DEMAND', 6X,'RADIUS',
1 7X,'ANGLE',/)
538  MM = 1
      PROB=0.
      SPROB=0.
      DO 315 I=1,300
315  IT(I)=0
      STAUTO=0
      BSTD = 10000000.
      RMAX = 0
      SUMR = 0
      DO 2 I = 2,N
      R(I) = SQRT((X(I) - XX)**2 + (Y(I) - YY)**2)
      S(I) = ATAN2(Y(I) - YY,X(I) - XX)
      SUMR = SUMR + R(I)
      IF(ILM.GT.1) GO TO 5001
      WRITE (6,257) I,X(I), Y(I), Q(I), R(I), S(I)
257  FORMAT (8X,I3,5(2X,F10.4))
5001 IF(RMAX- R(I)) 66,2,2
      66 RMAX = R(I)
      2 CONTINUE
      GO TO (1000,2000,3000,4000),ILM
1000 WRITE (6,1001)
1001 FORMAT ('1 FORWARD SWEEP ALGORITHM')
      GO TO 5000
2000 WRITE (6,2001)
2001 FORMAT ('1 BACKWARD SWEEP ALGORITHM')
      GO TO 5000
3000 WRITE (6,3001)
3001 FORMAT ('1 FORWARD SWEEP ALGORITHM CHECKING J+2 LOCATION')
      GO TO 5000
4000 WRITE (6,4001)
4001 FORMAT ('1 BACKWARD SWEEP ALGORITHM CHECKING J+2 LOCATION')
5000 CONTINUE
      AVR = SUMR/(N-1)
      DO 81 I = 1,N
      DO 81 J = I,N
      A(I,J) = SQRT (1.*((X(I) - X(J))**2 + (Y(I) - Y(J))**2))

```

```

      **SQRT(ADJ(I)*ADJ(J))
81  A(J,I) = A(I,J)
      K(1) = 1
      K(N+1) = 1
C
C  ARRANGE IN ASCENDING ORDER
21  J = N
      KOU = 0
      SUMD = 0
      DO 67 I = 2,N
        K(I) = I
67  SS(I) = S(I)
      5 XMAX = -1000000. * (-1) ** ILM
      DO 3 I = 2,J
        IF(ILM .EQ. 2 .OR. ILM .EQ. 4) GO TO 551
        IF(SS(I) - XMAX) 4,3,3
551  IF(SS(I) - XMAX) 3,3,4
      4  XMAX = SS(I)
        II = I
      3  CONTINUE
        IB = K(II)
        K(II) = K(J)
        K(J) = IB
        B = SS(II)
        SS(II) = SS(J)
        SS(J) = B
        J = J - 1
        IF(J-2) 6,6,5
      6  CONTINUE
C
C  FORMING ROUTES
11  J = 2
      M = 1
      KCECK = 0
      N1 = 0
      N2 = 0
      LX = 0
      JJ = 2
      SUM = Q(K(2))
      MM = MM + 1
12  J = J + 1
45  IF(SUM + Q(K(J)) - CP) 13,13,14
13  SUM = SUM + Q(K(J))
      KCECK = 0
      IF(J .EQ. N) SUMQ = SUM
792 IF(J-N) 12,27,27
14  CONTINUE
      IF(ILM .LE. 2) GO TO 714

```

```

      IF ( J+1 .GE. N) GO TO 714
      IF (SUM + Q (K(J+1)) -CP) 713,713,714
713  IB = K(J+1)
      K(J+1) = K(J)
      KCECK = 0
      K(J) = IB
      SUM = SUM + Q (K(J))
      J = J + 1
714  JJJ = J - 1

C
C   CHECKING NEXT LOCATION
C   FINDING TWO NEAREST POINTS
C   KII IS LOCATION IN ROUTE WITH 'SMALLEST' RADIUS AND LARGEST ANGLE
C   JJX IS IN ROUTE CLOSEST TO JII NOT IN THE ROUTE
328  F = 1000000
      DO 40 I = JJ, JJJ
      EFG = R (K(I)) - S (K(I)) * AVR
      IF (F - EFG) 40,40,48
48   F = EFG
      KII = I
40  CONTINUE
      RX = 1000000000
      DO 346 I = 1,4
      JX = J - I
      IF (JX .LT. 2) GO TO 346
      IF (R (K(JX)) / AVR - .7) 346,346,347
347  J5 = J + 6
      IF (J5 - N) 363,363,364
364  J5 = N
363  DO 348 II = J, J5
      IF (A (K(JX), K(II)) - RX) 349,348,348
349  RX = A (K(JX), K(II))
      JJX = JX
      JII = II
348  CONTINUE
346  CONTINUE

C
C   TEST7
      IF (KCECK .GT. 0) GO TO 374
      KOUNT = 1
      DO 320 I = JJ, JJJ
      KOUNT = KOUNT + 1
320  IROUT (KOUNT) = K(I)
      IROUT (1) = 1
      IROUT (KOUNT+1) = 1
      CALL TRAVS (KOUNT, DIST)
      DIST = DIST + (KOUNT - 1) * XLD
      IF (DIST .GT. XD) GO TO 76

```

```

DO 716 I = 1,KOUNT
716 KK(I) = IROUT(I)
374 CONTINUE
SUMQ = SUM
IF(RX .GT. 100000) GO TO 75
C
RRX = R(K(JII))
JIX = JII
DO 334 I = J,JIX
IF(R(K(I)) - RRX) 334,334,335
335 RRX = R(K(I))
JII = I
334 CONTINUE
42 IF(SUM + Q(K(JII)) - Q(K(KII)) -CP) 44, 44,75
C
44 JY = 5
IF(JY-(N-JJJ)) 324,322,322
322 JY = N - JJJ
324 JZ = JY + 1
IF(KCECK .EQ. 1) GO TO 375
DO 321 I = 2,JZ
321 IROUT(I) = K(JJJ+I-1)
IROUT(1) = 1
CALL BTS (JY,DIST2)
375 CONTINUE
KCECK = 0
C
IF(JII -JJJ + 1 .GT. JY) GO TO 443
DO 332 I = 2,JZ
332 IROUT(I) = K(JJJ+I-1)
IROUT(1) = 1
IROUT(JII-JJJ+1) = K(KII)
CALL BTS (JY,DIST3)
C
KOUNT = 1
DO 331 I = JJ,JJJ
KOUNT = KOUNT + 1
331 IROUT(KOUNT) = K(I)
IROUT(1) = 1
IROUT(KOUNT+1) = 1
IROUT(KII - JJ + 2) = K(JII)
CALL TRAVS (KOUNT,DIST1)
DIST1= DIST1+ (KOUNT - 1) * XLD
IF(DIST1 .GT. XD) GO TO 443
C
EFG = AVR * (Q(K(JII)) - Q(K(KII))) / AVQ
IF(EFG+DIST + DIST2 - DIST1 - DIST3) 443,443,326
326 DIST = DIST1

```



```

DO 717 I = 1,KOUNT
717 KK(I) = IROUT(I)
SUMQ = SUM
JJ1 = JJJ - 1
SUM = SUM + Q(K(JII)) - Q(K(KII))
JI = K(KII)
DO 51 I = KII,JJ1
51 K(I) = K(I+1)
IF(JII .NE. JJJ + 1) GO TO 274
K(JJJ) = K(JJJ + 1)
K(JJJ + 1) = JI
GO TO 275
274 K(JJJ) = K(JII)
K(JII) = JI
275 J = J - 1
DIST2 = DIST3
KCECK = 1
GO TO 12

```

C

```

443 MAX = 1000000
IF(J5 - J .LT. 3) GO TO 75
DO 420 I = J,J5
IF(I - JII) 421,420,421
421 IF(MAX - A(K(I),K(JII))) 420,422,422
422 JKK = I
MAX = A(K(I),K(JII))
420 CONTINUE
IF(SUM + Q(K(JII)) + Q(K(JKK)) - Q(K(KII)) .GT.CP) GO TO 75

```

C

```

KOUNT = 1
JZ = 6
IF(JII - JJJ + 1 .GE. JZ) GO TO 75
IF(JKK - JJJ + 1 .GE. JZ) GO TO 75
IF(JZ - (N - JJJ + 1)) 435,436,436
436 JZ = N - JJJ
435 DO 431 I = 2,JZ
IF(I .EQ. JKK - JJJ + 1) GO TO 431
KOUNT = KOUNT + 1
IROUT(KOUNT) = K(JJJ + I - 1)
431 CONTINUE
IROUT(JII - JJJ + 1) = K(KII)
IROUT(1) = 1
JT = KOUNT - 1
CALL BTS(JT,DIST5)

```

C

```

KOUNT = 1
DO 430 I = JJ,JJJ
KOUNT = KOUNT + 1

```

```

      IROUT(KOUNT) = K(I)
430  CONTINUE
      IROUT(1) = 1
      KOUNT = KOUNT + 1
      IROUT(KOUNT + 1) = 1
      IROUT(KII - JJ + 2) = K(JII)
      IROUT(KOUNT) = K(JKK)
      CALL TRAVS (KOUNT,DIST4)
      DIST4= DIST4+ (KOUNT - 1) * XLD
      IF (DIST4 .GT. XD) GO TO 75
C
      IF (DIST + DIST2 - DIST4 - DIST5) 75,433,433
433  DIST = DIST4
      DO 718 I = 1, KOUNT
718  KK(I) = IROUT(I)
      SUM = SUM + Q(K(JII)) + Q(K(JKK)) - Q(K(KII))
      SUMQ = SUM
      M5 = JJJ + 4
      JI = K(KII)
      JM = K(J)
      IF (KII .EQ. JJJ) GO TO 794
      JJ1 = JJJ - 1
      DO 434 I = KII, JJ1
434  K(I) = K(I+1)
      K(JJJ) = K(JII)
      JJJ = JJJ + 1
      K(JJJ) = K(JKK)
      K(JKK) = JI
      IF (JII .EQ. J) GO TO 793
      K(JII) = JI
      K(JKK) = JM
      GO TO 793
794  K(J) = K(JII)
      K(KII) = K(JKK)
      JJJ = JJJ + 1
      K(JII) = JM
      K(JKK) = JI
793  CONTINUE
      KCECK = 2
      GO TO 12
C
C  DELETING ONE FROM ROUTE
76  JJJ = JJJ - 1
      KOUNT = KOUNT - 1
      J = J - 1
      SUM = SUM - Q(K(J))
      GO TO 328
C

```

C ACCEPTING THE ROUTE

```

75 SUMD = SUMD + DIST
   KT = JJJ - JJ + 2
   DQZ(M) = DIST
   QQZ(M) = SUMQ
   KZ(M) = KT
   DO 536 I = 1,KT
   KOU = KOU + 1
536 IT(KOU) = KK(I)
   LX = 0
   M = M + 1
   SUM = Q(K(J))
   JJ = J
20 IF(KLN-1) 30,31,30
31 IF(KV-KOUNT) 32,30,30
32 KV = KOUNT
30 CONTINUE
   IF(J-N) 12,27,27
27 KOUNT = 1
   JJJ = J
   IROUT(1) = 1
   DO 82 I = JJ,J
   KOUNT = KOUNT + 1
82 IROUT(KOUNT) = K(I)
   IROUT(KOUNT + 1) = 1
   CALL TRAVS (KOUNT,DIST)
   DIST = DIST + (KOUNT - 1) * XLD
   IF(DIST - XD) 83,83,97
97 J = J + 1
   GO TO 76
83 CONTINUE
   QQZ(M) = SUMQ
   KZ(M) = KOUNT
   DQZ(M) = DIST
   DO 537 I = 1,KOUNT
   KOU = KOU + 1
537 IT(KOU) = IROUT(I)
   SUMD = SUMD + DIST
   IF(BSTD - SUMD) 530,531,531
531 NM = N + M
   BSTD = SUMD
   DO 532 I = 1,NM
532 ITT(I) = IT(I)
   DO 533 I = 1,M
   BQD(I) = DQZ(I)
   BQZ(I) = QQZ(I)
533 KKZ(I) = KZ(I)
   MZ = M

```

```

530 CONTINUE
C
C   INCREMENTING THE ANGLE
      KLN = 2
      IF(MM      - KV) 61,50,50
61  XMIN = 100000000.
      DO 62 I = 2,N
      IF(S(K(I)) - XMIN) 63,62,62
63  XMIN = S(K(I))
      MI = K(I)
62  CONTINUE
      S( MI ) = 3.14529 - ABS(S( MI )) + 3.14529
      GO TO 21
50  CONTINUE
      WRITE (6,5002)
5002 FORMAT (///' BEST SOLUTION IS')
      IB = 0
      DO 534 I = 1,MZ
      IA = IB + 1
      IB = IB + KKZ(I)
C
C   MEMORIZE THE ROUTE STRUCTURE
      SBDQ(I)=0
      IF(BSTD-BSTDD) 524,526,525
524  BSTDD=BSTD
      KRT=MZ
      IDUM=ILM
526  KMZ(I)=KKZ(I)
      NNNN=IB-IA+1
      DO 527 J=1,NNNN
527  IITT(I,J)=ITT(IA+J-1)
      SBDQ(I)=BQZ(I)
      BDQR(I)=BQD(I)
525  CONTINUE
534  WRITE (6,719) I,BQZ(I),BQD(I), (ITT(J),J=IA,IB)
719  FORMAT (/' ROUTE',I5,' HAS LOAD',F10.2,' WITH DISTANCE ',F10.2,
1 ' IS' / 28(1X,I3))
      ILM = ILM + 1
      WRITE (6,84) BSTD
84  FORMAT(///' TOTAL DISTANCE IS',F15.5)
      GO TO 521
      IF(ILM .LE. 4) GO TO 538
521  CONTINUE
      WRITE(6,1002)
1002 FORMAT('1FINAL OPTIMAL ROUTE STRUCTURE')
      DO 541 I=1,KRT
      NNNN=KMZ(I)
541  WRITE(6,719) I,SBDQ(I),BDQR(I), (IITT(I,J),J=1,NNNN)

```

```

WRITE(6,84) BSTDD
C ARRANGE ALL ROUTES START AT TERMINAL
C
DO 561 I=1,KRT
  NNNN=KMZ(I)
  DO 564 L=1,NNNN
564   IITTT(L)=IITT(I,L)
  DO 562 L=1,NNNN
  IF (IITTT(L).EQ.1) GO TO 563
562   CONTINUE
563   IITT(I,1)=1
  NNNN1=NNNN-1
  DO 565 J=1,NNNN1
  LJ=L+J
  IF (LJ.GT.NNNN) LJ=LJ-NNNN
565   IITT(I,J+1)=IITTT(LJ)
561   CONTINUE
  WRITE(6,1003)
1003  FORMAT('1REORDERED OPTIMAL ROUTE STRUCTURE')
  DO 566 I=1,KRT
  NNNN=KMZ(I)
566   WRITE(6,719) I,SBDQ(I),BDQR(I),(IITT(I,J),J=1,NNNN)
  PASSG=0
  DO 390 N=1,I
390   PASSG=PASSG+SBDQ(N)
  WRITE(6,84) BSTDD
  DO 7000 I=1,7
  SUMP(I)=0
  VSP(I)=0
  KLM(I)=1
7000  PPDB(I)=0
  DO 6047 I=1,6
  C(I)=0
  CC(I)=0
  PB(I)=0
  SPB(I)=0
  AVG(I)=0
  APG(I)=0
  VAR(I)=0
  VPG(I)=0
6047  NSH(I)=1
  WRITE(6,399)
399   FORMAT('1')
C
C
C   USE EVENT SIMULATION FIND TRAVEL TIME RATIO AND PROBABILITY
C   OF MODE CHOICE BETWEEN AUTO AND BUS.
C

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C      PROBILITY OF EACH ROUTE
      SSBQ=0
      DO 6001 I=1,KRT
6001   SSBQ=SSBQ+SBDQ(I)
      DO 6002 I=1,KRT
6002   PBRT(I)=SBDQ(I)/SSBQ
C      PROBABILITY OF EACH NODE IN EACH ROUTE
      DO 6003 I=1,KRT
      NROUT=KMZ(I)
      SRQ(I)=0
      DO 6004 J=1,NROUT
      L=IITT(I,J)
6004   SRQ(I)=SRQ(I)+Q(L)
      DO 6005 J=1,NROUT
      L=IITT(I,J)
      PBOG(I,J)=Q(L)/SRQ(I)
6005   CONTINUE
6003   CONTINUE
C
C      GENERATE DEMAND ORIGIN IN WHICH NODE AND ROUTE
      LOS=0
      LX=65539
6060   CALL RANDU(LX,LY,B)
      LX=LY
      LOS=LOS+1
      I=1
6006   IF (B-PBRT(I)) 6008,6008,6007
6007   B=B-PBRT(I)
      I=I+1
      GO TO 6006
6008   CALL RANDU(LX,LY,B)
      LX=LY
      J=1
6009   IF (B-PBOG(I,J)) 6011,6011,6010
6010   B=B-PBOG(I,J)
      J=J+1
      GO TO 6009
6011   IO=IITT(I,J)
      MII=I
C
C      FIND THE DISTANCE FROM ORIGIN TO TEANSFER POINT
      ODPT=0
      NNNN=J-1
      DO 6019 L=1,NNNN
6019   ODPT=ODPT+A(IITT(I,L),IITT(I,L+1))
      REV=BDQR(I)-ODPT
      IF (REV.LT.ODPT) ODPT=REV
      L=L-1

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      IF (KMZ (I) -J.LT.L) L=KMZ (I) -J
C      GENERATE DESTINATION AND DISTANCE BETWEEN DESTINATION AND DEPOT
6031 CALL RANDU (LX,LY,B)
      LX=LY
      I=1
6012 IF (B-PBRT (I) ) 6013,6013,6014
6014 B=B-PBRT (I)
      I=I+1
      GO TO 6012
6013 CALL RANDU (LX,LY,B)
      LX=LY
      J=1
6015 IF (B-PBOG (I,J) ) 6017,6017,6016
6016 B=B-PBOG (I,J)
      J=J+1
      GO TO 6015
6017 ID=IITT (I,J)
      DDPT=0
      NNNN=J-1
      DO 6018 N=1,NNNN
6018 DDPT=DDPT+A (IITT (I,N) ,IITT (I,N+1) )
      REV=BDQR (I) -DDPT
      IF (REV.LT.DDPT) DDPT=REV
      N=N-1
      IF (KMZ (I) -J.LT.N) N=KMZ (J) -J
      BDIST=DDPT+ODPT
      IF (I.EQ.MII) BDIST=ABS (DDPT-ODPT)
      ADIST=A (IO,ID)

C
C      DETERMINE TRAVEL TIME RATIO
      TAUTO=(ADIST/ASPEED) +TWALK+TPARK
      CALL RANDU (LX,LY,R2)
      LX=LY
      BWK= R2*BMXWK
      IF (FREQ-10) 6023,6024,6024
6023 BWT=FREQ/2.
      GO TO 6025
6024 CALL RANDU (LX,LY,B)
      LX=LY
      BWT=B*5.
6025 TTSTOP=TSTOP* (N+L)
      IF (I.EQ.MII) GO TO 6026
      GO TO 6027
6026 NL=N-L
      TTSTOP=TSTOP*IABS (NL)
6027 TBUS=BWK+BWT+TTSTOP+ (BDIST/BSPEED) +TRANF
      ALOS=TBUS/TAUTO
      STAUTO=STAUTO+TAUTO

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C
C      FIND THE PROBABILITY OF MODE CHOICE
C
      CALL RANDU (LX,LY,B)
      LX=LY
      MMS=1
7005  IF (P(MMS).GE.B) GO TO 7003
      MMS=MMS+1
      GO TO 7005

C
C      TAKE MODE SPLIT STATISTICS ACCORDING TO INCOME LEVEL
      DATA AUTO$/.06/
7003  Z=FARE-((AUTO$/52.8)*ADIST)+(V(MMS)*(TBUS-TAUTO)*.3/115200.)
      *-FPARK
      ZZ=EXP(Z)
      PDB=1./(1.+ZZ)
      PROB=PROB+PDB
      SPROB=SPROB+(PDB*PDB)
6029  PPDB(MMS)=PPDB(MMS)+PDB
      SUMP(MMS)=SUMP(MMS)+PDB
      VSP(MMS)=VSP(MMS)+(PDB*PDB)
      KLM(MMS)=KLM(MMS)+1
      AVGSP(MMS)=SUMP(MMS)/KLM(MMS)
      VARSP(MMS)=(VSP(MMS)-(SUMP(MMS)*SUMP(MMS)/KLM(MMS)))/(KLM(MMS)-1)

C
C      TAKE LOS AND M.S. STATISTICS ACCORDING TO TRIP LENGTH
      IDST=BDIST/52.8
      IDST=IDST+1
      IF (IDST.GT.6) IDST=6
      C(IDST)=C(IDST)+ALOS
      PB(IDST)=PB(IDST)+PDB
      CC(IDST)=CC(IDST)+(ALOS*ALOS)
      SPB(IDST)=SPB(IDST)+(PDB*PDB)
      NSH(IDST)=NSH(IDST)+1
      AVG(IDST)=C(IDST)/NSH(IDST)
      APG(IDST)=PB(IDST)/NSH(IDST)
      VAR(IDST)=(CC(IDST)-((C(IDST)**2)/NSH(IDST)))/(NSH(IDST)-1)
      VPG(IDST)=(SPB(IDST)-((PB(IDST)**2)/NSH(IDST)))/(NSH(IDST)-1)
      IF (LOS.LT.999) GO TO 6060

C
      PRINT 6101
6101  FORMAT('1'//40X,'STATISTICS BY TRIP LENGTH (IN MILES)'//32X,
      *'0-1',10X,'1-2',10X,'2-3',10X,'3-4',10X,'4-5',10X,'5-')
      WRITE(6,6102) (AVG(IDST),IDST=1,6)
6102  FORMAT('/' MEAN TRAVEL TIME RATIO ',6(8X,F5.2))
      WRITE(6,6103) (VAR(IDST),IDST=1,6)
6103  FORMAT(6X,' (VARIANCE) ',15X,7(F6.3,7X))
      WRITE(6,6104) (APG(IDST),IDST=1,6)

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6104 FORMAT(/' PROB OF TAKING BUS',12X,6(F5.2,8X))
      WRITE(6,6103) (VPG(IDST),IDST=1,6)
      PRINT 6105
6105 FORMAT(//, 40X,'STATISTICS BY INCOME LEVEL (IN THOUSAND DOLLARS
*PER YEAR) '/32X,'0-5',10X,'5-10',8X,'10-15',8X,'15-20',8X,
*'20-25',8X,'25-30',8X,'30-')
      WRITE(6,6106) (AVGSP(MMS),MMS=1,7)
6106 FORMAT(/' MEAN PROBABILITY',15X,7(F5.2,8X))
      WRITE(6,6103) (VARSP(MMS),MMS=1,7)
      PROB2=PROB/LOS
      PARM=ALOG((1/PROB2)-1)-FARE
      SPROB2=(SPROB-(PROB**2/LOS))/(LOS-1)
      COS=LOS
      CONFD=1.64*SQRT(SPROB2)/SQRT(COS)
      CONFD1=PROB2-CONFD
      CONFD2=PROB2+CONFD
      WRITE(6,6107)
6107 FORMAT(40X,'*****')
      WRITE(6,6108)
6108 FORMAT(40X,'*',50X,'*',/,40X,'*',50X,'*')
      WRITE(6,6109) PROB2,SPROB2,CONFD1,CONFD2
6109 FORMAT(40X,'*      MEAN PERCENTAGE OF BUS TRAVEL IS ',F8.5,4X,'*',
*/40X,'*      WITH VARIANCE',21X, F7.5,4X,'*',/40X,
**      95% CONFIDENCE INTERVAL ',4X,F6.5,'-',F6.5,4X,'*')
      WRITE(6,6108)
      WRITE(6,6107)
      HSPEED=BSPEED*60/52.8
      VM=(BSTDD/52.8)*(60/FREQ)*OHPD*ODPY
      VH=VM/HSPEED
      PV=VEHN
      RP=PASSG*(60/FREQ)*(PKHPD+(OHPD-PKHPD)/2)*ODPY
      OC1=(.227*VM+5.7*VH+6527.48*PV+.038*RP)*(1.07** (YEAR-1970))
      OC2=(.187*VM+4.659*VH+3639.05*PV+.046*RP)*(1.07** (YEAR-1970))
      OCT = .862*VM*(1.07** (YEAR-1970))
      WRITE(6,399)
      WRITE(6,600)
600  FORMAT(20X,'EXPECTED OPERATING COSTS ARE',///)
      WRITE(6,601) OC1,OC2,OCT
601  FORMAT(10X,'FOR PUBLIC OPERATION, OPERATING COST IS',F15.2,/,
*10X,'FOR PRIVATE OPERATION, OPERATING COST IS',F15.2,/,10X,'TOTAL
*OPERATING COST IS',F15.2)
      REVENU =RP*FARE
      IF(PUBLIC.EQ.1) GO TO 391
      DEFICI =OC2-REVENU
      WRITE(6,610)
610  FORMAT(10(/),20X,'THE SYSTEM IS PRIVATELY OWNED',///)
      WRITE(6,611) VM,VH,PV,RP
611  FORMAT(10X,'ANNUAL VEHICLE MILES',F15.2,/,

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*10X,'ANNUAL VEHICLE HOURS',F15.2,/,
*10X,'PEAK HOUR VEHICLES ',F15.2,/,
*10X,'REVENUE PASSENGERS ',F15.2)
  WRITE(6,612)REVENU,FARE,DEFICI
612  FORMAT(///,10X,'ANNUAL REVENUE ',F15.2,' BASED ON ',F15.2,' DOLLAR
*S PER TRIP',///,20X,'YEARLY DEFICIT OF THE SYSTEM',F15.2)
  GO TO 392
391  DEFICI =OC1-REVENU
  WRITE(6,613)
613  FORMAT(10(/),20X,'THE SYSTEM IS PUBLICLY OWNED ',///)
  WRITE(6,611)VM,VH,PV,RP
  WRITE(6,612)REVENU,FARE,DEFICI
392  IF(DEFICI .LE.SUBSID ) GO TO 386
  FARE=FARE + ((DEFICI -SUBSID )/RP)
  PROB2=1/(1+EXP(FARE+PARM))
  WRITE(6,614)FARE,SUBSID,DEFICI
614  FORMAT(10(/),10X,'BECAUSE THE DEFICIT EXCEEDS ITS SUBSIDY THE FARE
* PER TRIP IS INCREASED TO',F10.6,' IN ORDER TO BALANCE THE INSUFF
*ICIENT SUBSIDY; OTHERWISE, SUBSIDY ',F15.2,' BE INCREASED TO ',/,
*15X,F15.2)
  WRITE(6,615) PROB2
615  FORMAT(///,10X,'THE ADJUSTED ATTRACTIVENESS OF THE SYSTEM BECOMES '
*,F10.5,' AND FEEDBACK PERFORMS')
386  N=NMN
  DO 384 I=1,N
384  Q(I)=Q(I)*PROB2/PROB1
  PB1UP=PROB1+CONFD
  PB1LOW=PROB1-CONFD
  IF(PB1LOW.GT.PROB2) GO TO 621
  IF(PB1UP.GE.PROB2) GO TO 385
  WRITE(6,399)
621  PROB1=PROB2
  ILM=1
  KV=0
  KLN=1
  BSTDD=99999999999.
  GO TO 538
385  CONTINUE
383  STOP
  END
  SUBROUTINE TRAVS (N,DIST)
  COMMON A(110,110),K(110)
  DIMENSION KK(110),KKK(110)
C 3 OPT NEW PROGRAM
  N1 = N+1
  DO 34 I = 1,N1
34  KKK(I) = K(I)
51  IF(N-3) 54,54,53

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53 N1 = N-1
   N3 = N-3
5 DO 12 KOUNT = 1,N
   DO 32 IK = 1,N3
   K1 = IK + 1
   DO 32 IJ = K1,N1
   D1 = A(K(IK),K(IJ+1)) + A(K(1),K(IJ))
   D = A(K(1),K(IJ+1)) + A(K(IK),K(IJ))
   IF (D1 - D) 6,6,7
6 IA = 8
  D = D1
  GO TO 17
7 IA = 2
17 IF (D+A(K(IK+1),K(N)) - A(K(1),K(N)) - A(K(IK),K(IK+1)) - A(K(IJ),K(IJ+
   *1)) + .001) 9,32,32
32 CONTINUE
   IB = K(N)
   N1 = N-1
   DO 13 I = 1,N1
13 K(N-I+1) = K(N-I)
   K(1) = IB
12 CONTINUE
   GO TO 2
9 DO 19 I = 1,N
19 KK(I) = K(I)
   IJ2 = IJ+2
   K1 = IK+1
   K(N) = KK(IJ+1)
   KO = 0
   IF (IJ2 - N) 36,36,37
36 DO 20 I = IJ2,N
   KO = KO + 1
20 K(KO) = KK(I)
37 DO 21 I = K1,IJ
   KO = KO + 1
21 K(KO) = KK(I)
   K(N) = KK(IJ+1)
   IF (IA-8) 18,15,18
15 DO 22 I=1,IK
   KO = KO+1
22 K(KO) = KK(I)
   GO TO 14
18 DO 25 I= 1,IK
   KO = KO+1
25 K(KO) = KK(IK+1-I)
14 CONTINUE
   DO 35 I = 1,N
35 KKK(I) = K(I)

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      GO TO 5
2  CONTINUE
54 CONTINUE
      DIST = A(KKK(N),KKK(1))
      DO 30 I = 2,N
30  DIST = A(KKK(I-1),KKK(I)) +DIST
      RETURN
      END
      SUBROUTINE BTS (N,BOUND)
      COMMON A(110,110), K(110)
      DIMENSION MM(10,10),T(10,10), IT(10), KK(10)
C  BRANCH METHOD FOR TRAVELING SALESMAN PROBLEM WITH ONE SERVER
      DO 21 I = 1,N
      DO 22 J = 1,N
22  MM(I,J) = 0.
21  IT(I) = 0.
      IT(N+1) = N+1
      T(1,1) = 0.
      IT(1) = 1
      BOUND = 100000.

C
      JJ = 1
      I = 1
1  I = I+1
      II = I-1
      DO 25 L = 1,II
      IF (IT(L)) 25,25,26
26  MM(I,IT(L)) = 1
25  CONTINUE
12  DX = 100000.
      DO 2 J = 2,N
      IF (MM(I,J) .EQ. 1) GO TO 2
      T(I,J) = T(I-1,JJ) + A(K(JJ),K(J))
      IF(T(I,J) .GT. BOUND) GO TO 8
      IF (DX .LT. T(I,J)) GO TO 2
      DX = T(I,J)
      KZ =J
2  CONTINUE

C
      IF (DX .GT. 10000) GO TO 24
11  IT(I) =KZ
      JJ = KZ
      MM(I,JJ) =1
      IF(I.LT. N) GOTO 1
      GO TO 28

C
24  I = I-1
      IF (I.EQ.1) GO TO 13

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      DX= 100000
      DO 27 L = 2,N
      IF (MM(I,L) .EQ.1) GO TO 27
      IF (T(I,L) .GT. DX) GO TO 27
      DX = T(I,L)
      JJ =L
27  CONTINUE
      DO 29 L = 1,N
29  MM(I+1,L) =0
      IF (DX .GT. 10000) GO TO 24
      IT(I) = JJ
      MM(I,JJ) =1
      IF (I .LT. N) GO TO 1
C
28  I = I+1
      T(I,1) = T(I-1,JJ) + A(K(JJ),K(I))
      IF (T(I,1) .GT. BOUND) GO TO 24
      J = I
      BOUND = T(I,1)
      IF (N+1 - I) 36,35,36
35  DO 34 L = 1,I
34  KK(L) = K(IT(L))
36  CONTINUE
      8 IT(I) = J
      GO TO 24
      13 DO 342 I = 1,N
342 K(I) = KK(I)
      RETURN
      END

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DEMAND/SUPPLY EQUILIBRIUM IN DESIGNING BUS
ROUTE OF SMALL URBAN AREA

by
Chaushie Chu

ABSTRACT

Mass transit bus systems can be characterized by two aspects, supply and demand. As in most system, the supplier objective is to minimize the system total cost yet maximize its attractiveness to the users.

The present study applied this concept to a bus system in small urban area by minimizing the total operational costs and maximizing the system's attractiveness to the riders. The total operational costs are reduced by designing a route-network which will yield a minimum total bus travel distance within the physical and economic constraints. On the demand side, a measure of attractiveness is constructed based on the probability that a person will ride a bus given a certain level of service of the bus system and a cost figure for using the private automobile.

The main purpose of this work is to find the

equilibrium point of the demand and supply of a bus transit system so that decisions on some policy variables such as bus capacity, maximum route length, bus fare, parking price etc., can be interactively determined.