A DECISION MODEL OF A "MANY-TO-FEW" DIAL-A-BUS SYSTEM

A Dissertation Submitted to the University of Manitoba in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS		i
LIST OF TABLES		iv
LIST OF FIGURES		v
CHAPTER 1 -	INTRODUCTION	1
1.1	Environment for Demand Responsive Transit	1
1.2	Concept of Demand Responsive Transit	3
1.3	Thesis Objective	5
1.4	Problem to be Addressed	6
CHAPTER 2 -	DEMAND RESPONSIVE SYSTEM MODELLING	9
2.1	Reason for Modelling	9
2.2	Review of Conducted Modelling Projects	10
2.2.1	Northwestern University	11
2.2.2	Westinghouse Air Brake Company	13
2.2.3	Massachusetts Institute of Technology	15
CHAPTER 3 -	MODELLING METHODOLOGY	18
3.1	Approach	18
3.2	System Components	20
3.2.1	Demand	21
3.2.2	Supply	21
3.2.3	Communications	21
3.2.4	Operator	24
3.2.5	User Service	24
3.3	Problem Quantification	25
3.3.1	"Real World Inputs"	28
3.3.2	System Demand	32
3.3.3	Travel Orientation	36

CHAPTER 4 -	DECISION MODEL DEVELOPMENT	40
4.1	Phases of Development	40
4.2	Phase 1 - Simulation Model	40
4.2.1	Transhipment Problem	43
4.2.1.1	Hypothetical System Simulation	44
4.2.1.2	Mathematical Formulation	46
4.2.1.3	Mathematical Solution	49
4.2.2	System Simulation in Fort Richmond	54
4.3	Phase 2 - Manual Vehicle Route Assignment	59
4.4	Phase 3 - Analytical Model	66
4.4.1	Definition of System Parameters and State Variables	66
4.4.2	Model Forms	67
4.4.3	Model Estimation Technique	68
4.4.4	Input Data	69
4.4.5	Mean Level of Service Model	69
4.4.6	Vehicle Productivity Time Model	78
CHAPTER 5 -	CONCLUSIONS	84
APPENDIX A -	DERIVATION OF MAXIMUM DEMAND GENERATED FROM THE FORT RICHMOND AREA	88
APPENDIX B -	MPS/360 COMPUTER LISTING FOR HYPOTHETICAL EXAMPLE	90
APPENDIX C -	MANUAL VEHICLE ROUTE ASSIGNMENT	103
APPENDIX D -	STEPWISE MULTIPLE REGRESSION OUTPUT LISTING (MEAN LEVEL OF SERVICE MODEL)	160
BIBLIOGRAPHY		166

LIST OF TABLES

1. Fleet size and Vehicle Passenger Capacity of Existing Demand Responsive Transportation Systems 22

2. Transhipment Technology Table 50

3. Simulation Model Output 57

4. Manual Vehicle Route Assignment Output 64

5. Average Cycle Value per Vehicle 70

6. Statistical Characteristics of the Variables Used in the $\overline{L.S.}$ Model 73

7. Mean Level of Service (Actual and Estimated Values) 76

8. Average Fleet Mean Level of Service 77

9. Vehicle Productivity time (Actual and Estimated Values) 81

LIST OF FIGURES

1.	Section of Fort Richmond Chosen For Decision Model	29
2.	Land Use and Demographic Characteristics	30
3.	Link Travel Times	31
4.	Residential Area Covered by Demand Centroids	33
5.	Typical Weekday Demand Distribution	35
6-A	Demand Density = 180 per square mile	37
6-B	Demand Density = 20 per square mile	38
7.	Phases of Decision Model Development	41
8.	Hypothetical Network Configuration	45
9.	Tabular Form of the Transhipment Model	48
10.	Flow of Supply for Hypothetical Network	52
11.	Relationship Between Simulation Stage, Computer Runs and Subruns	55
12.	Flow of Supply Unit for Simulation	60
13.	Manual Vehicle Route Assignment	61
14.	Simple Correlation Matrix (Linear Form)	72
15.	Relationship Between Mean Level of Service and Vehicle Fleet Size	79
16.	Relationship Between Vehicle Productivity Time and Vehicle Fleet Size	82

CHAPTER ONE

INTRODUCTION

1.1 Environment for Demand Responsive Transit

New trip desire patterns have been generated as a result of the low density suburban development that has taken place in the last decade. In these areas, transportation is a more critical problem than in the central city areas because of the greater distances of travel associated with all purposes of tripmaking. The virtual elimination of the pedestrian mode and the almost entire reliance on the automobile has been generally experienced in these areas. Not only is the automobile the most attractive alternative, it also receives little competition since standard forms of public transportation usually have to face the most adverse conditions possible by having to provide mobility to the people in these low density suburban areas.

To provide the necessary mobility, suburban dwellers have largely relied upon personal transportation. A great deal of energy and resources have been expended on the development of urban highways. Although these highways initially served their intended function, heavy traffic congestion during peak hours has invariably developed in most major urban centres. It has become increasingly apparent that highways alone cannot do the job. Rapidly growing automobile travel has led to increasing demands for more space to accommodate their movement and storage requirements in the central business areas of the city.

A number of multi-component integrated public transportation systems have been proposed by transit planners in an attempt to de-emphasize the role of the automobile as a "people-mover". A transit system which would relieve some of the traffic congestion along major arterial thoroughfares is the major goal of all of these proposals. Although urban travel is characterized by a number of diversified trip origins, destinations and purposes, the home-work trip interchange is one of the most significant and the major contributor to the problem of traffic congestion. In Winnipeg, more than one third (1) of the total morning peak hour trips are destined to the downtown area.

The public transit system is, basically, radially oriented to the downtown area. Such transit routes can generally be broken down into three service portions: the collection and distribution service within the low density suburban regions, the line-haul service which links the suburban developments and the downtown area, and the collection and distribution service in the relatively concentrated, high density downtown area. Because of the dispersed nature of the suburban dwellers, the transit service within these areas has usually been deemed inadequate to provide the necessary mobility requirements. It is within these particular areas that a demand responsive type of transit service could satisfy the transportation needs of the residents.

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1. Winnipeg Transportation Planning Branch, Travel Survey, 1971

In the situation where the journey to work is accommodated by some form of rapid public transportation, commuters are usually forced to first use their automobile to get to the terminal station. This latter feature of the work trip is the prime cause for the continued reliance on the automobile. The rapid transit mode offers a level of service far greater, in terms of travel time, than the automobile could provide. However, getting to the terminal station from the place of residence is a most serious problem that typical fixed-route public transit to date has not been able to solve satisfactorily. Feeder transit systems must offer frequent service along many routes to attract a sizable patronage. Such an operation is uneconomical and usually impossible because of roadway characteristics and network layouts found in a typical low density suburban development. A demand responsive transit system, feeding the terminal station, would provide the degree of mobility, convenience and quality of service necessary to induce the automobile users to the public transportation mode.

1.2. Concept of Demand Responsive Transit

Dial-a-Bus is such a demand responsive transit system. This particular system is a new concept in public transportation service designed to offer the user certain characteristics of automobile and taxi travel at a cost only slightly higher than conventional transit service. Small "mini-bus" vehicles would provide pickup or delivery at the users door-step on demand. Dial-a-Bus, which could be considered the median between conventional transit and

taxi systems, would replace the present fixed route transit service in the area. The Dial-a-Bus vehicle fleet would operate throughout the service area, without regard to any fixed route, serving customers as the service is requested.

Dial-a-Bus users who have a common orientation of travel share the vehicle as in the conventional transit service. However, the vehicle is dispatched like a taxi so that walking to the bus stop and waiting outdoors for the bus to arrive is eliminated. The key to Dial-a-Bus economics is the sharing of rides and the dispatching of vehicles only when service is requested. Since travellers with a common orientation of travel share the vehicle they also share the cost of vehicle operation.

A customer can request service by phoning the dispatch centre from his home indicating his origin, his destination and his preferred pickup time. If a person wishes to make a trip with a destination external to the service area, terminal stations located within or adjacent to the service area boundary provide the transfer points between the fixed-route transit service and the Dial-a-Bus service.

Regular customers could subscribe to the Dial-a-Bus service so that a vehicle would pick up these customers on a daily basis at a prescribed time. Infrequent users would have to contact the dispatch centre each time a pickup is desired. The dispatcher routes the vehicles in the most

direct manner to service the customers requesting service because there are no regular fixed routes. After serving a request for Dial-a-Bus pickup, the vehicle would carry the new customer to the desired destination, probably stopping along the way to collect or deliver other passengers.

Such a demand responsive transportation system would provide the flexibility and adaptability necessary for the travel desires of the low density suburban dwellers.

1.3 Thesis Objective

Until recently, resources allocated to research in urban transportation have usually been highway oriented. Subsequently, there has been relatively little research done in the field of public transportation, other than high volume rapid transit systems. The need for research on new transportation technologies and systems cannot be overstated. Public transportation has played a passive role in urban transportation, but now the seriousness of the transportation problem is apparent to most people. The temporary solutions presented to date by freeways indicates that public transportation offers the most probable source of solution.

At this point, the concept of the Dial-a-Bus system is fairly easy to understand; the difficult aspect is implementing it successfully. Since the costs and risks involved in implementing any new transportation technology are high and usually very uncertain, it is important to be aware of possible operating difficulties and limitations that a system may be subjected to in a proposed area.

The suitability of the proposed site for the project and the proposed operational system should be evaluated before the actual project is begun. Only then, can valid recommendations and predictions about the utility and the role of the transportation system be made. It is the purpose of this thesis to develop a Decision Model that will offer such results and be used as a tool to aid planners in decision making.

1.4 Problem to be Addressed

In all demand responsive transportation system modelling projects conducted at the major research centres, the structure of the model was generally based on the dynamic and stochastic nature of vehicle scheduling and demand generation. However, one facet of operation that has been experienced with existing demand responsive systems, and that has not been given consideration in the research projects is "prebooking" of requests for service. In Bay Ridges, Ontario, 80% of the morning peak period trips to the GO station by the Dial-a-Bus mode are "prebooked" for the whole week.(2) This advanced request for service is usually associated with a trip that is repeated day after day - the work purpose trip for example. This type of request for service introduces a deterministic attribute into the scheduling problem.

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2. Dial-a-Bus, The Bay Ridges Experiment, Ontario Department of Transportation and Communication, August 1971, p.36.

Because of the deterministic property of these requests for service, it is therefore no longer necessary to run a computer in "real time". Real time is defined as the time interval from when the request for service is made to the time when the potential passenger is informed whether service can be provided. During this "real time" period, the computer program tries to allocate a vehicle for this pick-up in the most economical and optimal manner while considering the total system. However, since the person who requested service is waiting for a reply, there is a time constraint on the computer program to provide a solution in the fastest time possible.

This type of request for service offers the greatest possibility for system operation efficiency. The deterministic scheduling program could be run once a day and would generate the tentative routes and schedules for the vehicles for this particular period. There would be no need to accept a suboptimal solution due to time constraints and the optimal vehicle routing and scheduling would be determined beforehand for the next day. Therefore, the basic system then might consist of a listing of vehicle routes that would service the "prebooked" requests with the option of overriding the request by a telephone call on any particular day.

The problem to be addressed in this thesis is to determine the functional and operational characteristics of a demand responsive transportation system that is

subjected to "prebooked" requests for service. These demands will require service to a few common destination points and consequently, the operating demand responsive system will provide a "many-to-few" service. The reason for limiting the scope of the problem to a "many-to-few" operation was to determine what the limitations and upper level of service and system productivity boundaries are for a demand responsive type of transit service in a typical low density suburban area. The upper boundaries that would be determined would, therefore, indicate the optimum potential that an area has for a demand responsive system. An actual operation of this type of transportation service would not be considered a failure if the system did not achieve the goals and objectives that were established on the basis of an intuitive, and usually pessimistic, prediction of the proposed system's operational and functional characteristics. It would be known before implementation what could probably be expected and what the capabilities were of a demand responsive system if "ideal" conditions were prevalent.

A Decision Model will be developed and then applied to indicate the type of guidelines and insights that would be valuable to planners before designing and implementing a demand responsive transportation system in an area. The end product of this model is a decision that can be defined as a course of action chosen from available alternatives for the purpose of achieving the desired result.

CHAPTER TWO

DEMAND RESPONSIVE SYSTEM MODELLING

2.1 Reason for Modelling

One of the major uses of system models is for sensitivity or parametric analysis. It is not uncommon for the systems designer, as the decision-maker, to be presented with point estimates of the uncertain parameters to be used in his analysis. Sensitivity analysis is one method of demonstrating the effects of unknown variances in these parameters and of identifying their crucial elements. The purpose of sensitivity analysis is to show how the results of an analysis change when either the parameters change or the assumptions imposed on a model are altered. Treating the parameters in this way is a meaningful method of decreasing the uncertainty faced by the decision-makers.

The goal behind the development of a Decision Model is oriented toward the actual implementation of a demand responsive transportation system in a community. The basic concept of Dial-a-Bus, which already has been discussed, has been comprehensively examined and expounded in numerous research papers;[3] how this system will react to certain conditions, such as changes in demand levels, also has to be understood. Since the cost associated with an actual demonstration project of reasonable size is quite high, the use of system modelling techniques can provide considerable insight into the operational, functional, and economical feasibility of initiating a Dial-a-Bus system.

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3. The U.S. Department of Commerce has a majority of these reports and documents filed in the National Technical Information Service (NTIS), Springfield, Virginia.

The model will be used as a planning tool in providing some foundations for making decisions regarding the type of system required and the impacts of such a system on the trip-making in the area. Without adequate planning, any implementation will have a very small chance of being successful. Careful evaluations of alternatives must be considered because there is a tremendous amount of resource utilization associated with transportation systems. Suboptimization will often occur where effective system analysis and planning methodologies have not been utilized.

2.2. Review of Conducted Modelling Projects

In the last eight years, a substantial amount of research has been conducted on demand responsive transportation systems. Modelling methodology, facilitated by the computer, was used to evaluate such systems and to arrive at some operating decisions associated with a "real-life" demand responsive transportation system. Different approaches for computing and evaluating the operation and impacts of demand activated vehicles have been proposed by the different research institutes engaged in solving this problem. The research that has been conducted in this field will be reviewed and the general characteristics and methods will be highlighted and criticized where applicable.

The most significant research in demand responsive transportation system computer modelling has been carried out at the institutes discussed below.

2.2.1. NORTHWESTERN UNIVERSITY[4]

The demand responsive system that the Northwestern model simulates is the so-called "many-to-many" system. The vehicles in this system provide service from many origins to many destinations within the area. The method of vehicle allocation is quite simple in theory compared to the models developed by other research institutes. As a request for service is received, the computer program scans the locality near that particular request origin for a vehicle that is available to service the new demand. The vehicle closest to the request origin is the first one selected for consideration. A check is made to see if the new demand can be serviced without violating any of the passenger service guarantees that have been established for those on board the vehicle or for the potential passengers that have already been assigned to be served by this particular vehicle. If a violation of a service guarantee will result from introducing the new demand into the vehicle's tour the next closest vehicle is then considered. If this vehicle cannot satisfy the new demand without a violation of service guarantees, another vehicle is considered. This iterative process may continue until there are no vehicles left in the operating system. At this point, a new vehicle is introduced into the operating system. Because of the nature of this procedure, there is no assurance that any optimization of passenger service or operational efficiency will be obtained. The initial step is an attempt to satisfy a new demand as soon as possible. If the vehicle assigned to service the new demand has passengers already on board, the model will try to pick up

4. Heathington, Kenneth W., et al. "Computer Simulation of a Demand Scheduled Bus System Offering Door-to-Door Service", Highway Research Record, Number 251, pp 26-40, 1968.

this new demand before any further on-board passenger deliveries are made. The two unrealistic assumptions made here are that there is an unlimited source of vehicle supply for system operation and that a person perceives a greater value of time waiting in the comfort of his home than on a vehicle that has increased its circuit travel time in order to satisfy a new demand.

There are two service guarantees that act as constraints in this model. The first is a guaranteed pick-up time of one to five minutes. The other service guarantee is related to the delivery time. This particular guarantee is calculated as some function of the distance between the point of origin and the point of destination. At no time, will any of these constraints be violated. This is an attempt to satisfy all of the system users all of the time.

A very significant limitation of this model is the inability to handle more than one pickup at a single origin point. For example, if there is more than one person to be picked up at a single dwelling, the model will carry out vehicle allocation calculations for each individual person. This may result in having more than one vehicle being allocated to pick up the group of demands at one home. This particular aspect of the model does not satisfactorily represent the "real-life" operation of a demand responsive transportation system.

An important structural component associated with the model is the theoretical street network on which the simulated vehicle operation takes place. This model utilized a simple one mile square grid which was divided into a hundred units or blocks. All streets and avenues are an equal length of one tenth of a mile and travel times on these links were estimated by assuming a constant vehicle speed on all network links.

2.2.2 WESTINGHOUSE AIR BRAKE COMPANY (WABCO) - RESEARCH DIVISION[5]

This model simulates vehicle operation in much the same manner as the Northwestern Model. The vehicle closest to the new demand is considered first and if passenger service guarantees are violated, the next closest vehicle is considered-et cetera. However, the ordering of demand pick-up, that is the vehicle routing through the network, is quite different. Every request for service is assigned a priority value which is based on the distance from the vehicle and the request origin, as well as the total origin to destination distance or passenger desire line. The highest priority for service is given to an unsatisfied demand that has experienced a waiting time of forty minutes. If there are no vehicles available in the operating system after this waiting time guarantee has been exceeded, a new vehicle is introduced into the system and is assigned to immediately pick up this outstanding demand.

Once on board a vehicle, the passenger is assigned another priority value which is based on the waiting time already experienced, the distance from the vehicle to the

5. Study of Evolutionary Urban Transportation. Westinghouse Air Brake Company, Volume 3, February 1968.

destination of that particular passenger, and the total travel time already experienced on board the vehicle. Therefore, where the Northwestern Model always tried to pick up the new demand before delivering passengers on board the vehicle, the WABCO Model operates on the priority basis - demands are picked up or delivered according to the order of priority.

This model was also subjected to a service time constraint. The constraint was based on total service time[6] experienced by a system user. Each user was guaranteed that the total service time would not be greater than six times the direct automobile driving time.[7] However, whereas this guarantee was never violated in the Northwestern Model, the WABCO model only promised that 95% of the system users would not experience a guarantee violation. The method of handling multiple demands at single origins was similar to the Northwestern method. Therefore, "real-life" system operation was not satisfactorily modelled. The street network was a square grid configuration that varied in size from 1 square mile to 5 square miles, depending on the parameters defined in the simulation. Another common characteristic with the Northwestern Model was the assumption of a uniform link travel time for the whole network. A more realistic approach would be to incorporate into the grid, network links that would be classified as "arterial, collector, and local". Traffic flow characteristics associated with these link types would then reflect the travel times to a more realistic degree.

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6. Service time includes at home waiting time and on-board vehicle time.
7. Automobile driving time consisted of the travel time based on a constant 20 M.P.H. speed plus a fixed time of 2 minutes for parking and walking to automobile.

2.2.3 MASSACHUSETTS INSTITUTE OF TECHNOLOGY (M.I.T.)

By far, the most comprehensive and extensive research program into computer modeling of a demand responsive system has been conducted at the Urban Systems Laboratory at M.I.T. The initial research in this field involved model simulation of a "many-to-one" demand responsive system. The service provided was from the door-step of the many residences within the area to a single activity centre. This centre could be a major attraction area for tripmakers, such as shopping centres, recreational centres, or employment institutes, or it could be a terminal station which provided a transfer point between the demand responsive transportation system and a line-haul or rapid transit system.

This particular model was developed in conjunction with what was termed "Project Metran".[8] Project Metran was a research project that involved developing a totally integrated transportation system for an urban area. One section of this project involved the consideration of a mass transit feeder service. The system that was developed was a demand responsive, small bus, transportation service that was called the "Genie" system. From this foundation work, the present "many-to-few" demand responsive system called "Dial-a-Ride" was derived.

In both the Genie system and the Dial-a-Ride System, the model allocates vehicles on the basis of waiting, travel time, service time, and all travel constraints of current vehicle

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8. Hanson,Mark,E., ed. Project METRAN-An Integrated Evolutionary Transportation System for Urban Areas. M.I.T.,Rept.8,1966

passengers. The M.I.T. model assigns a vehicle to service a new demand while attempting to minimize the inconvenience to vehicle passengers, maintain the ability of a vehicle to serve potential new demands, and satisfy the new demand as quickly as possible. However, besides minimizing service times, the model also attempts to maximize vehicle passenger occupancy so that an economical, as well as a functional system operation is simulated.

The minimization of user inconvenience and the maximization of vehicle occupancy are, however, conflicting actions. Inconvenience to system users can be decreased by providing more vehicles to service these users. Maximization of vehicle occupancy cannot be approached if new vehicles are continuously introduced into the system. To accomplish these two objectives, the model utilized an "objective function".[9] An objective function was not used in the Northwestern or WABCO model. Incorporating this kind of function introduced a "system analysis" aspect into the model.

In the M.I.T. Model, the ordering of pick-up and delivery was based on determining an interval in an existing vehicle route in which a new demand could be serviced while minimizing the disruption of service to the passengers on board the vehicle. However, as was previously mentioned, the model also attempts to maximize the passenger load on the operating vehicles so that an economical and a more realistic system is simulated.

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9. This model incorporates aspects of Linear Programming which consists, generally, of an objective function and a set of constraint equations.

With regard to the theoretical street network characteristics associated with the model, the Genie system utilized a rectilinear grid pattern which varied in size from a one-by-one mile square to a three-by-three mile square. However, the Dial-a-Ride system took a completely different approach. A defined network configuration was not used. The distance travelled was based on "airline" distances between the origin and destination points. The argument used in advocating this approach was based on the premise that specific network characteristics and configurations were not essential to facilitate an understanding of the fundamental concepts of demand responsive system simulation.

It appears that simply using the grid network or "airline" distance approach is extremely unrealistic. The most probable solution to this modelling dilemma, one that would relate more to a real-life situation, would be to describe an existing street network and its associated vehicle operating characteristics into the model.

CHAPTER THREE

MODELLING METHODOLOGY

3.1 Approach

Of the many different modelling techniques which could be used, two were considered as most suitable for the Decision Model proposed. These were the simulation and analytic modelling techniques. These techniques will be defined and their scope and limitations discussed in this section.

Simulation methodology is based on the development of a model having artificial events which correspond to events in the "real-world" system. The interrelationships between the artificial elements in the model are equivalent to those interrelationships between elements in the actual system. When these interactions are understood, simulation can be used effectively. However, the cumulative impact over the entire system is usually uncertain. By analysing a model of the actual system, results relevant to the actual system can be obtained. Feeding in a set of input parameters in a simulation model will produce a certain discrete state of the system. This observation will not directly help in predicting the system performance under a set of different parameters because the total system interaction cannot be quantified in this type of system model.

Simulation is therefore a very useful tool with which to analyse the overall implications of altering one of the parameters or inter-event relationships. However, the functional dependence of the system and the elemental framework can only be inferred, when using simulation, by

interpolation between results of different parametric values or by extrapolation beyond the range of results when the parametric change is beyond the range of values used in the model.

An analytic model can generally be described as a set of mathematical equations which represent the results of inter-event system relationships. By solving the equation or equations, an analytic model can provide information on the sensitivity of the system to parametric variation. The drawback of this modelling technique is deriving the form of the equations which make up this model.

The Decision Model developed in this thesis is a synthesis of the analytic and simulation models. The mutually inclusive interface between the two models facilitates the substitution of desirable characteristics of both models within the Decision Model.

Sensitivity analysis, which is a major short-coming of the simulation model, is overcome by interfacing this element with an element of the analytic model which can provide the desirable results. The difficulty in deriving the mathematical form of the analytic model is overcome by interfacing this element with the simulation model. Output from the simulation model was used to validate and calibrate the analytic model. The coefficients and form of the analytical model's equations were determined by analytical analysis and the regression technique of least squares.

The Decision Model that will be developed is based on a "many-to-few" Dial-a-Bus operation. The reason for limiting the scope of the model to represent such an operation was to establish the upper system efficiency and productivity boundaries for the demand responsive transportation system. The "many-to-few" system represents the ideal public transportation system in terms of offering the potential for being the most efficient and productive operation possible. As the dispersion of destinations increases, system efficiency and productivity decreases. The upper boundaries that would be established by the model world, therefore, indicate the optimum potential that an area had for a Dial-a-Bus system. An actual operation of Dial-a-Bus in the area would not be termed a failure if the system did not achieve some intuitive optimistic goals established prior to implementation. It would be known, beforehand, what a system operation was capable of if "ideal" operating conditions were prevalent.

3.2 System Components

A good understanding of the processes at work is absolutely necessary before any attempt can be made to model a system. In order to model the "cause" and "effect" relationships which exist in any system it is necessary to define the components and their interactions with one another. The basic components that are necessary in understanding the framework of a demand responsive transportation system are discussed below.

3.2.1 Demand

The most significant system component is the demand. In an actual operational system, a demand or request for service is transmitted by telephone from the origin to the dispatching centre. Information that is included in this request for service is transmitted by telephone from the origin to the dispatching centre. Information that is included in this request for service is the location of that particular demand, the trip destination, the size of group requesting service and the preferred pick-up time. This basic information is usually then organized in the format best suited for the manual or computer dispatching phase.

3.2.2 Supply

The vehicles or the supply that will be used to satisfy the demands is another system component. The size, in terms of passenger seating capacity, can vary from 8 to 42. The fleet size and vehicle passenger capacity of major demand responsive transportation systems presently in operation are listed in Table 1.[10]

3.2.3 Communications

Changes in state of the operating status of a vehicle must be known by the dispatching centre. This type of information includes the position of the vehicle in the network at certain time intervals, whether there has been a vehicle breakdown, unexpected traffic congestion that a vehicle is experiencing, and variations in operating conditions due to weather.

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10. Metropolitan "Symposium Discusses New Transit Concepts", Vol. 69, No.1 (January/February 1973).

SITE	NUMBER OF VEHICLES	VEHICLE PASSENGER CAPACITY
Regina, Saskatchewan	2	15
	1	17
	1	23
	5	42
Bay Ridges, Ontario	5	11
	1	23
Stratford, Ontario	4	35
Haddonfield, New Jersey	8	17
Columbia, Maryland	4	19
	2	10
	2	8
Batavia, New York	4	23
	1	10
Detroit, Michigan	5	9
Columbus, Ohio	4	19
Ann Arbor, Michigan	3	10
Mansfield, Ohio	1	14

FLEET SIZE AND VEHICLE PASSENGER CAPACITY OF EXISTING DEMAND RESPONSIVE TRANSPORTATION SYSTEMS

TABLE I

In the dispatcher-vehicle communication phase, a two-way radio, either direct voice or digital, is the medium for information flow. Investigation of traditional voice radio dispatch techniques has shown that a human dispatcher using direct voice communication could handle approximately 100-200 demands per hour, or about 5-10 vehicles.[11] Digital transmission systems, which make more efficient use of frequency channels, could transmit messages for 180 vehicles per hour if a computer was used for dispatching.[12]

Communication in the customer-dispatcher phase utilizes the telephone as the medium for information flow. Direct voice or digital communication is used to relay information about a request for service and whether this request can be satisfied. The communication system set-up for the Regina Telebus system is typical of existing major demand responsive systems. The dispatch centre contains a multi-line telephone board connected through normal exchange facilities for user calls. There is also a connection for tape

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11. Ward, John, Vehicle Communications for a Dial-A-Ride System, M.I.T. Report USL-TR-70-15, December 1970, Cambridge Massachusetts, p. 1.

12. Ibid, pp 1-2.

recording messages when the centre is closed. The radio equipment is typical two-way equipment. All vehicles receive all messages sent out. This aspect of the communication system is not the most desirable. The radio traffic, especially in peak periods, is quite heavy and the continuous noise that vehicle users are subjected to is usually annoying and irritating.

3.2.4. Operator

The function of the system operator is to assign the requests for service to a vehicle in such a manner that total system operation and service to present vehicle passengers and new demands is optimized. Although a computer has generally been recommended for systems having more than 20 vehicles, there are no systems at present that have incorporated the use of a computer into the operation. Another function of the operator is to inform the new demand whether a vehicle is available and when the pickup will probably be made. In the case of a "prebooked" request for service, the operator can give a greater assurance of proposed pickup time. This is due to the fact that this type of service request allows for more time to develop optimal vehicle routing and scheduling.

3.2.5 User Service

In addition to the basic system components described above, service options for the system users should be defined as a system component. An attractive operating policy would be the provision of an option to the user to request a desired level of service. Thus, a demand which

has an additional request for a higher quality, faster, and more reliable service would be given a high priority in the vehicle allocation phase. Although the user service component should be ultimately included in the model, and since the system can operate without such an extraneous component, it was not considered necessary to include the user service component in the model. Although this particular system component was not incorporated directly into the model, a set of curves indicating the level of service provided for a certain demand level when a defined number of vehicles are available is developed in Chapter 4.

3.3 Problem Quantification

Having described the components and their interactions in an operational demand responsive system, the next step in modelling is to quantify these elements. The approach taken to describe the workings of an actual "many-to-few" Dial-a-Bus system was based on the following question, "How would an operator handle the system?" The operator would probably address the following two functions:

1. Try to achieve the most economical utilization of vehicles,
2. Try to satisfy the system users as much as possible.

The first function would be basically a matter of minimum path vehicle assignment. However, user satisfaction has a number of elements. Some of these elements are well-defined while others are no more than subjective concepts of user relevance. For example, the total service time and

user cost are both well defined elements of customer satisfaction that are quantifiable. On the other hand, an element that is very subjective and varies greatly is the relative importance or weight placed on the value of time. How much value does an individual place on the time he spends travelling in a vehicle, waiting to be picked up, or transferring to another mode has been the subject of a great deal of research.[13,14,15] Since these subjective and individualistic effects are quite uncertain, only the quantitative elements associated with the service times will be considered.

The contribution of service times to user satisfaction is clear in general terms but the exact function is not so well defined. A user desires to experience minimum service time at minimum cost. These two functions are, however, conflicting. Lower service times can be achieved by increasing the number of vehicles in the system but, consequently, the cost to the user is increased. Exactly how a user reacts to service times is difficult to generalize but very important for system performance evaluation. Latest arrival time guarantees would be most desirable to the

13. Lane, C.A. "A Behavior Approach to Modal Split Forecasting", Transportation Research, Volume 3, pp 463-480, 1969.

14. Quarmby, D.A. "Choice of Travel Mode for the Journey to Work, Some findings", Journal of Transportation Economics and Policy, Volume 1, No. 3, pp 273-314, Sept. 1967.

15. Wynn, F.H. and Levinson, H.S. "Some Considerations in Appraising Bus Transit Potentials", Highway Research Record, Number 197, 1967.

trip maker that has to arrive at a certain destination before some specified time (catching a plane, for example). Other users may be more interested in the mean service time.[16] The mean service time consideration will be the basis for system performance evaluation in this thesis.

The general aim of minimization of the user costs and user service times within the same framework can be stated as follows:

MINIMIZE THE SERVICE TIME EXPERIENCED BY
ALL SYSTEM USERS WITHIN THE CONSTRAINTS
ON THE FLEET SIZE OPERATING IN THE SYSTEM

In an actual operating system, the number of vehicles would usually be a set amount in the short run. It was for this reason that the number of vehicles available in the system was a constraint and not part of the model objective. If fleet size minimization was the objective, the user service time would have to be the constraint. The reason for developing a model of a Dial-a-Bus system was to determine the functional, operational, and economical characteristics. Therefore, it was considered that the objective chosen would be one that would provide the lowest mean service times within fixed system costs.

Ideally, the model should provide an optimal solution. Although such a solution is theoretically possible it is extremely difficult to formulate and would probably be

---

16. Mean service is defined as the total time (including wait, in-vehicle travel, pick-up and discharge times) that an average system passenger experiences.

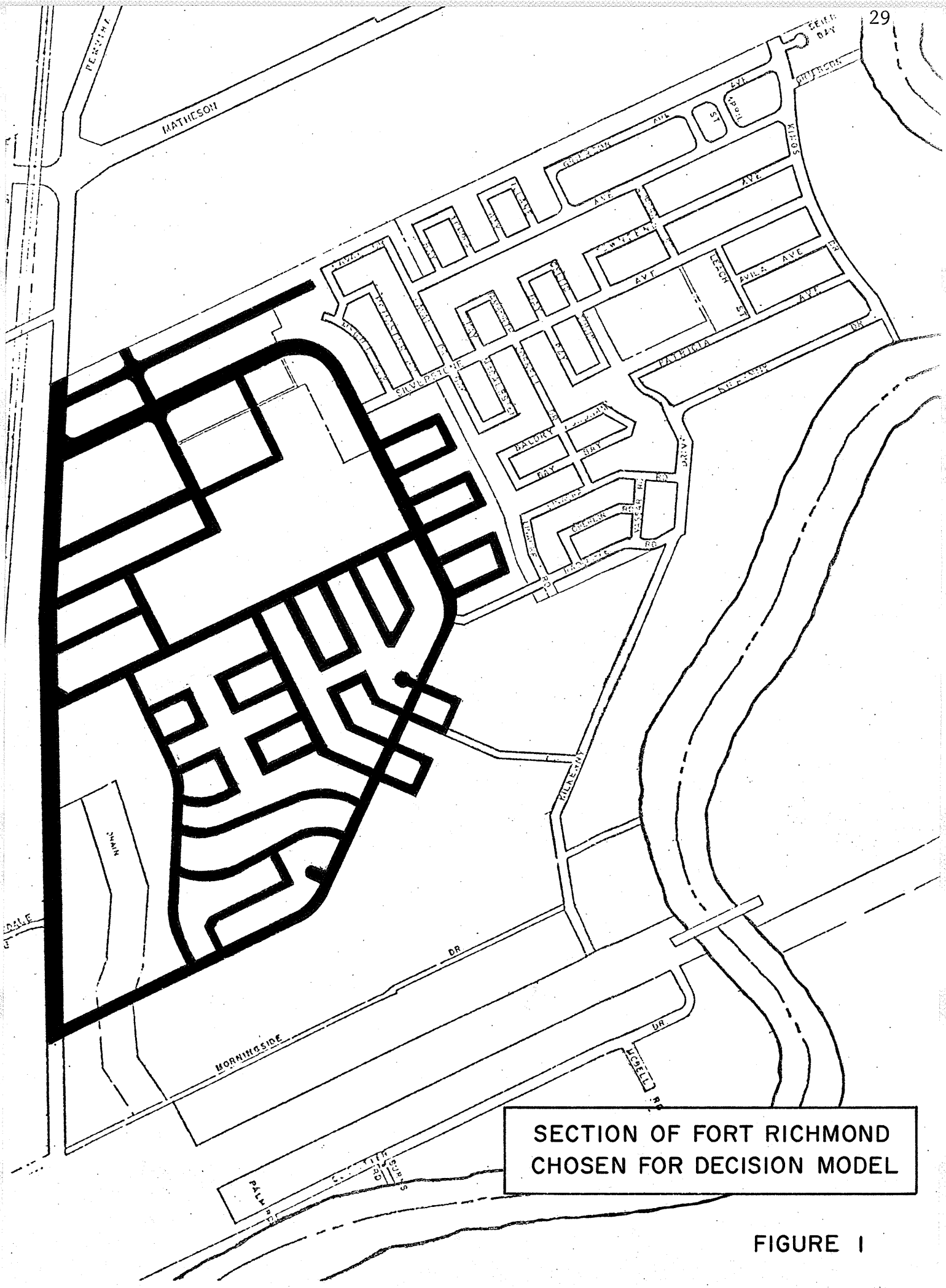
computationally prohibitive to run on a computer. Instead, the principal effort has been to develop a computationally simple model that could be run economically on the computer and produce realistic, but not necessarily optimal, results.

3.3.1 "Real World Inputs"

In order to introduce as much practicality as possible into the model, "real-world" inputs were incorporated into the variables and parameters. The street network configuration of an existing suburban development was used as a basis for establishing the link-node network essential for model functioning. A part of the Winnipeg residential suburb called Fort Richmond was considered and is shown in Figure 1.

Land use and demographic characteristics of this area are listed on Figure 2, which indicates the selected area of Fort Richmond. The locations of the two terminal stations, which are the transfer points between mainline transit and Dial-a-Bus service, are also shown on this figure.

The link-node network and link travel times are shown on Figure 3. Travel times were estimated on the basis of link distance and a constant vehicle speed of 30 miles per hour. Because of the automobile-like operating characteristics of a typical 20 passenger Dial-a-Bus vehicle, there was no distinction made between travel times via different modes. The nature of the function of the real-world network was such that this aspect was characterized within the framework of the model. Assumed grid patterns or other hypothetical link-node configurations were not incorporated into the model, thus avoiding one of the major shortcomings of modelling projects previously conducted.



SECTION OF FORT RICHMOND CHOSEN FOR DECISION MODEL

FIGURE I

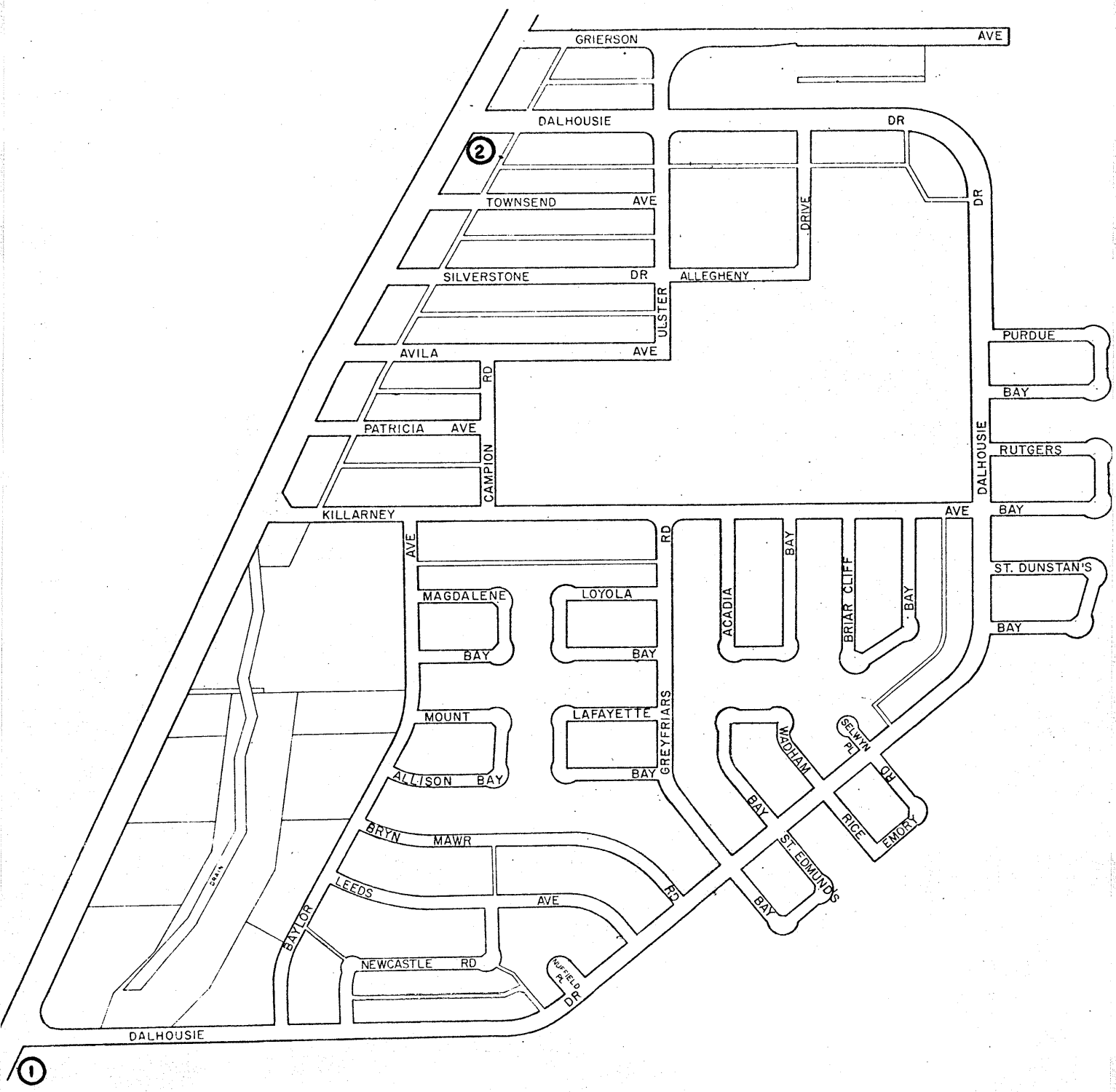
POPULATION = 2486

AREA SIZE = 344.9 RESIDENTIAL ACRES
0.538 RESIDENTIAL SQUARE MILES

DENSITY = 4621 PERSONS/RESIDENTIAL SQ. MILE

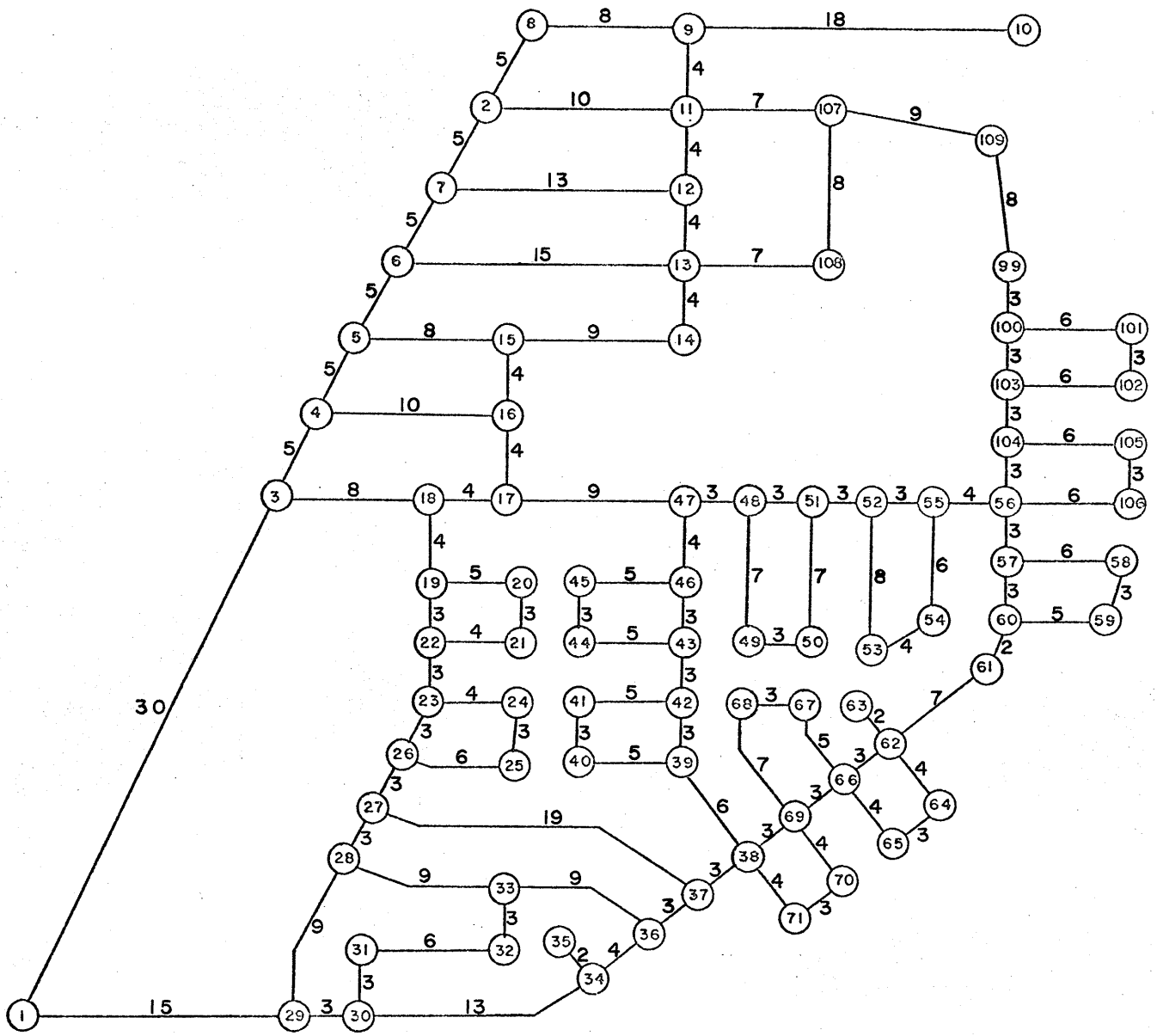
OPEN SPACE AND COMMERCIAL AREAS = 16 % OF TOTAL AREA

DISTANCE BETWEEN TERMINAL STATIONS ① AND ② = 0.91 MILES



LAND USE AND DEMOGRAPHIC CHARACTERISTICS

FIGURE 2



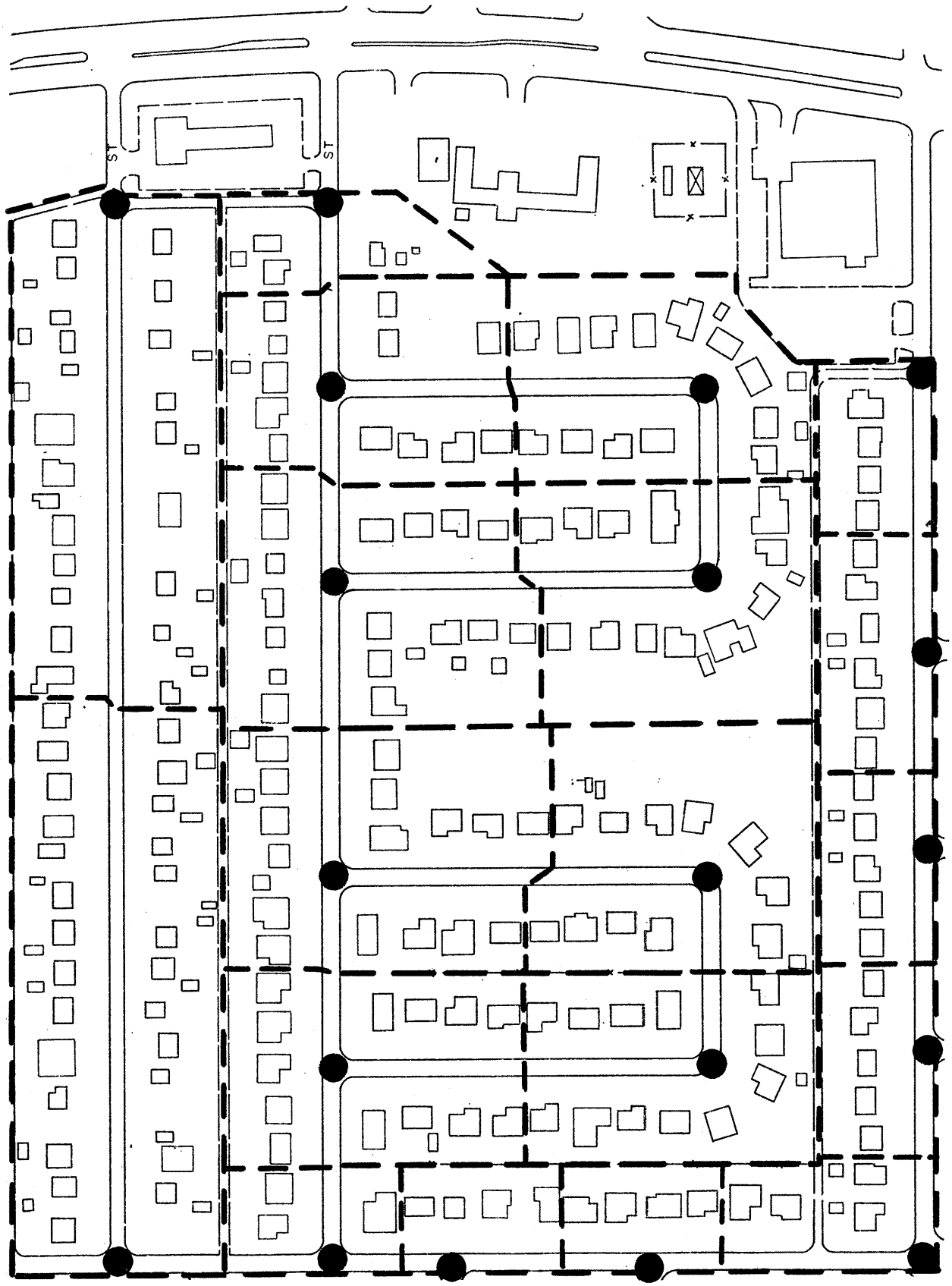
LINK TRAVEL TIMES
(SECONDS)

FIGURE 3

3.3.2 System Demand

The model structure has to allow the demands to enter the system at unique points in the network. In an actual system, the unique point of entry would usually be the place of residence of the person requesting the service. However, because every dwelling unit in the area would be extremely difficult to describe in the computer network modeling phase, a "demand centroid" concept was used. The nodes, which were shown in Figure 3, are usually the intersection points of two or more links. These nodes were assumed to be the locations where demands could be concentrated. Only at these discrete point locations can a demand enter the system. Therefore, these demand centroids can be considered the origin points of the demands. The actual residential area that a demand centroid represents is shown in Figure 4. The black dots indicate the demand centroids while the dashed lines show the centroid boundaries. It is assumed for the purposes of systems modelling, that all demands originating within the "demand shed" are concentrated at its centroid.

The next assumption, which also was related to the system demand, was the consideration of spatial demand distribution. Various probability distributions have been used in simulation in order for the random numbers generated to be from a given type of statistical population. For the development phase of the Decision Model, the origin of demands was assumed to be from a uniform distribution



RESIDENTIAL AREA COVERED BY DEMAND CENTROIDS

FIGURE 4

that would be experienced in the morning peak period.

One of the most attractive features of the Decision Model developed is the versatility in being able to incorporate different demand distributions. If a particular demand distribution should be considered more realistic for a real-world demand representation, this input could be easily introduced into the model.

Experience derived from existing demand responsive transportation operations have shown demand distributions to be quite non-homogeneous. Figure 5 shows a typical week-day spatial[17] and chronological[18] distribution experienced in the Bay Ridges Dial-a-Bus Demonstration Project. However, any demand distribution can be used as parameter input to facilitate a detailed sensitivity analysis utilizing the Decision Model developed.

Combining the concept of demand centroids and assuming a uniform demand distribution of 1 demand per 3.5 developed residential acres (180 demands per square mile) for the morning peak hour established one set of input parameters.

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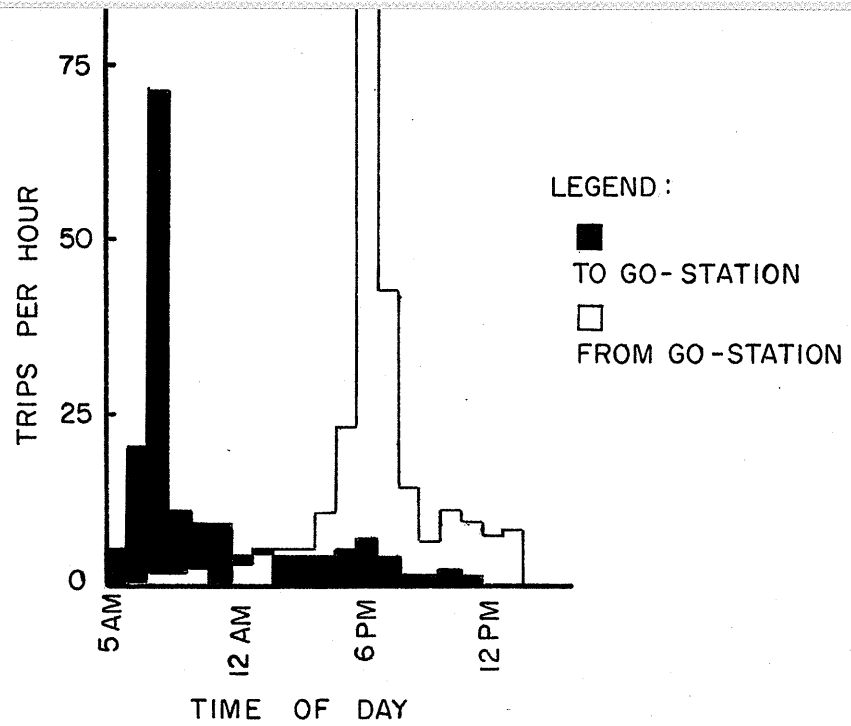
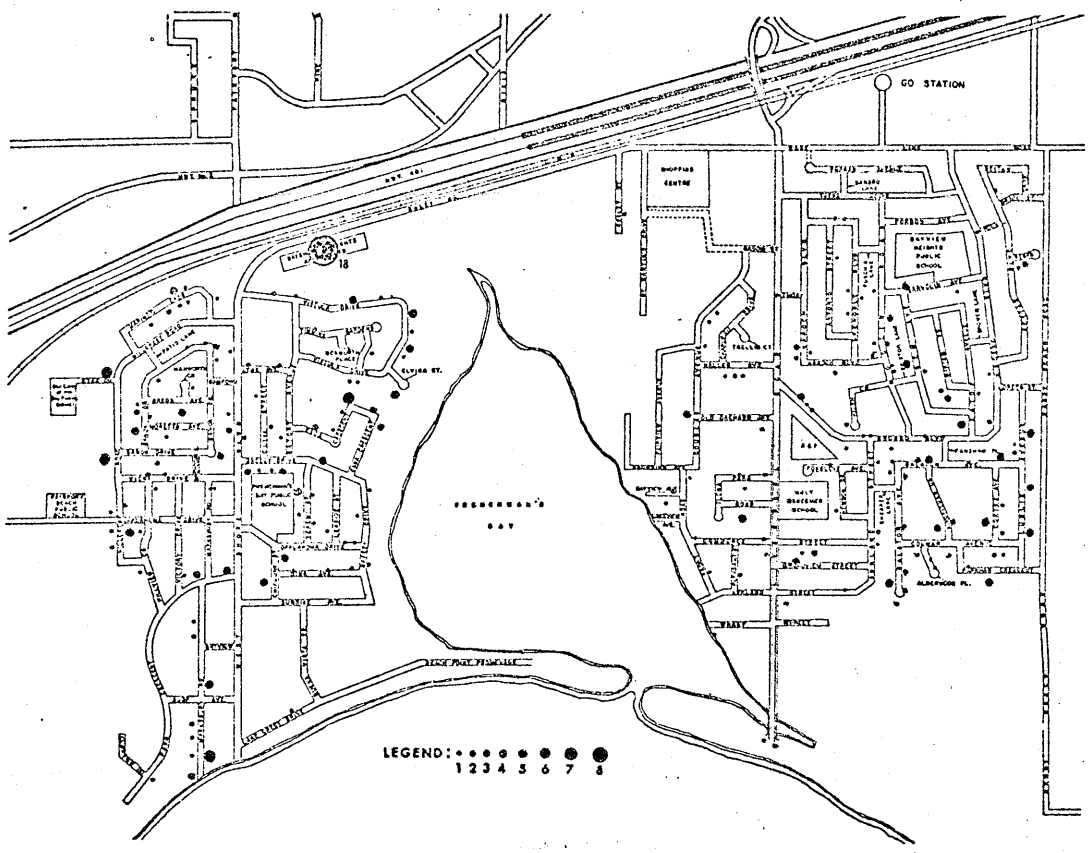
17. Dial-a-Bus, The Bay Ridges Experiment, Ontario Department of Transportation and Communications, August, 1971, p. 37.

18. Bonsall, J.A., The Bay Ridges Dial-a-Bus Experiment, Progress Report No. 1, January, 1971, p. 19



TYPICAL WEEKDAY CHRONOLOGICAL DEMAND DISTRIBUTION



TYPICAL WEEKDAY SPATIAL DEMAND DISTRIBUTION

FIGURE 5

A demand density of 1 per 3.5 acres was considered to be a ridership level that could be anticipated if a demand responsive transit system was implemented in this particular residential area.[19] Figure 6-A and 6-B show the location of demands within the link-node configuration for demand levels of 180 and 20 per square mile respectively. This range of demand levels was used to provide the foundation data for the Decision Model development stage.

To provide a sign convention consistency with that used later in the model development stage, a minus sign before a centroid indicates a demand. As will be shown later, a plus sign indicates the number of supply units available at that node.

3.3.3 Travel Orientation

At this point in the discussion, it is important to note that the collection phase is considered, in this thesis, to act as the strict inverse of the distribution phase. The "collection phase" receives this name because of the fact that the collection of passengers takes place throughout the residential area. These passengers are then delivered to one of two terminal stations where they can transfer to a trunkline transit service. This kind of movement would be primarily experienced during the morning peak period.

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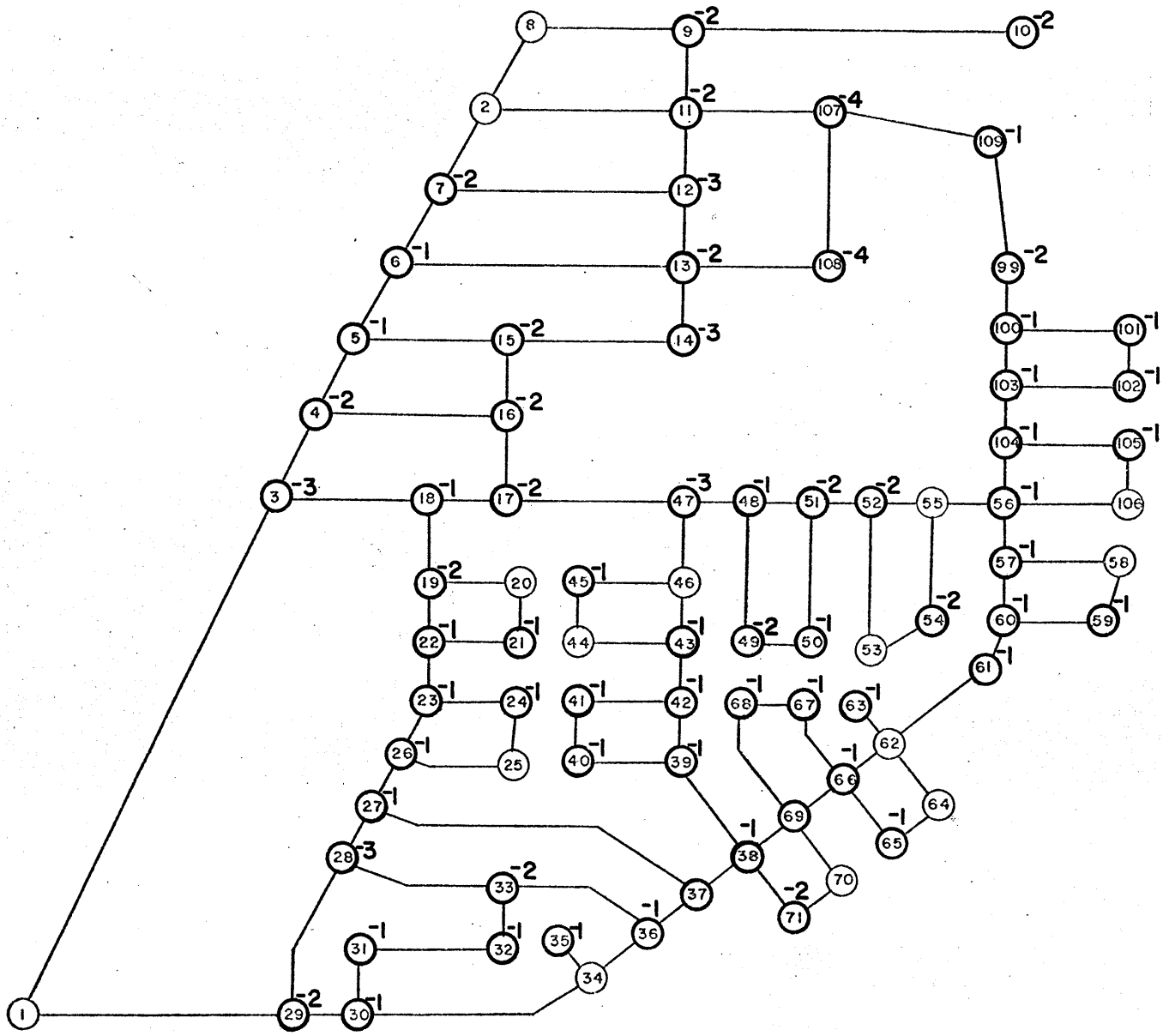
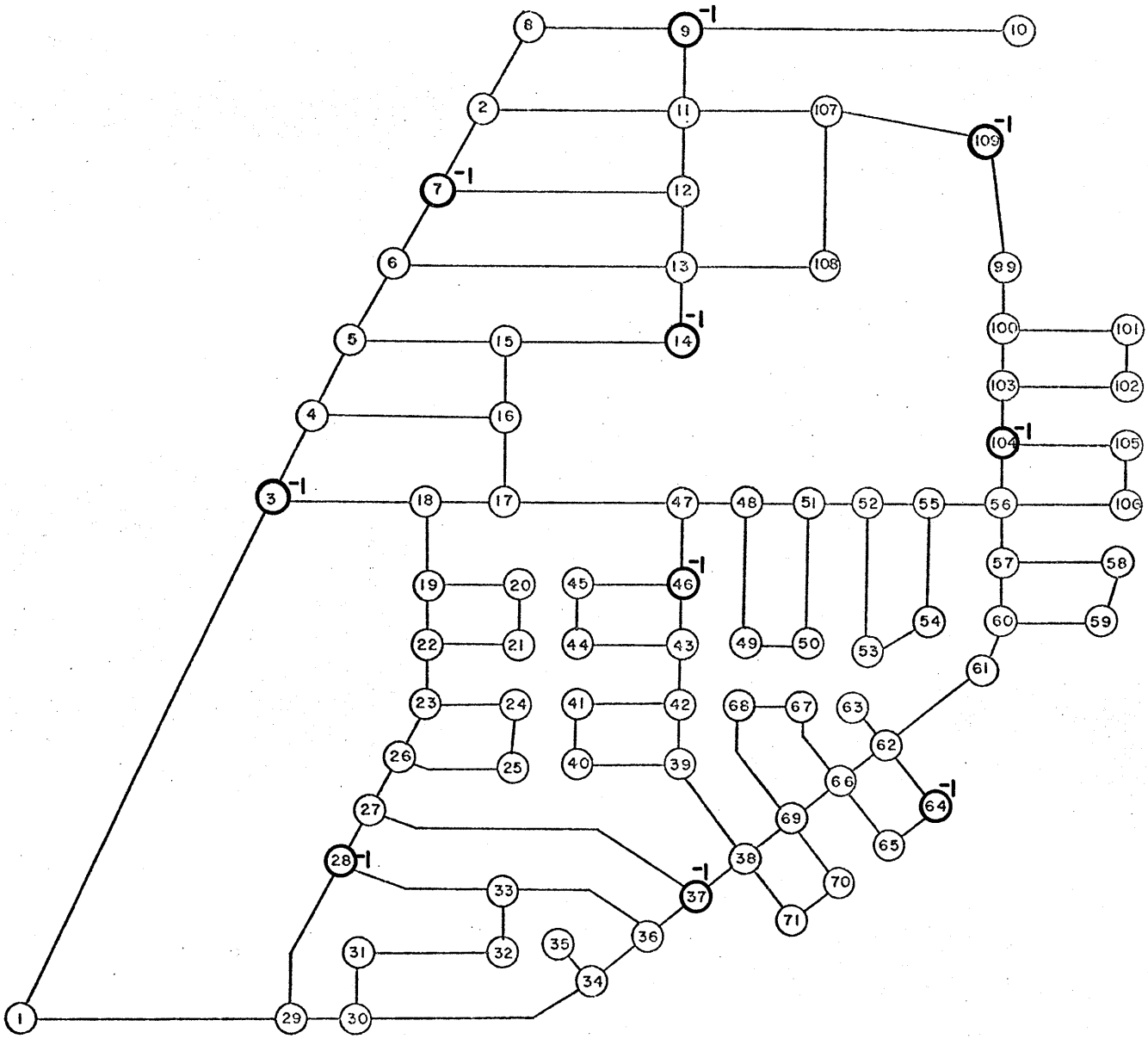
19. Based on the 1971 Winnipeg Transportation Planning Branch Travel Survey, this demand density was obtained by applying a factor to the total trips generated from the Fort Richmond Area. An indepth explanation is located in the appendix of this thesis on page 88.



DEMAND DENSITY = 180 PER SQ. MILE

FIGURE 6-A



DEMAND DENSITY = 20 PER SQ. MILE

FIGURE 6-B

In the "distribution phase", passengers are picked up at the terminal stations and distributed throughout the area according to the places of residence of the vehicle passengers. Only the collection phase of the demand responsive system will be reflected in the Decision Model.

CHAPTER FOUR

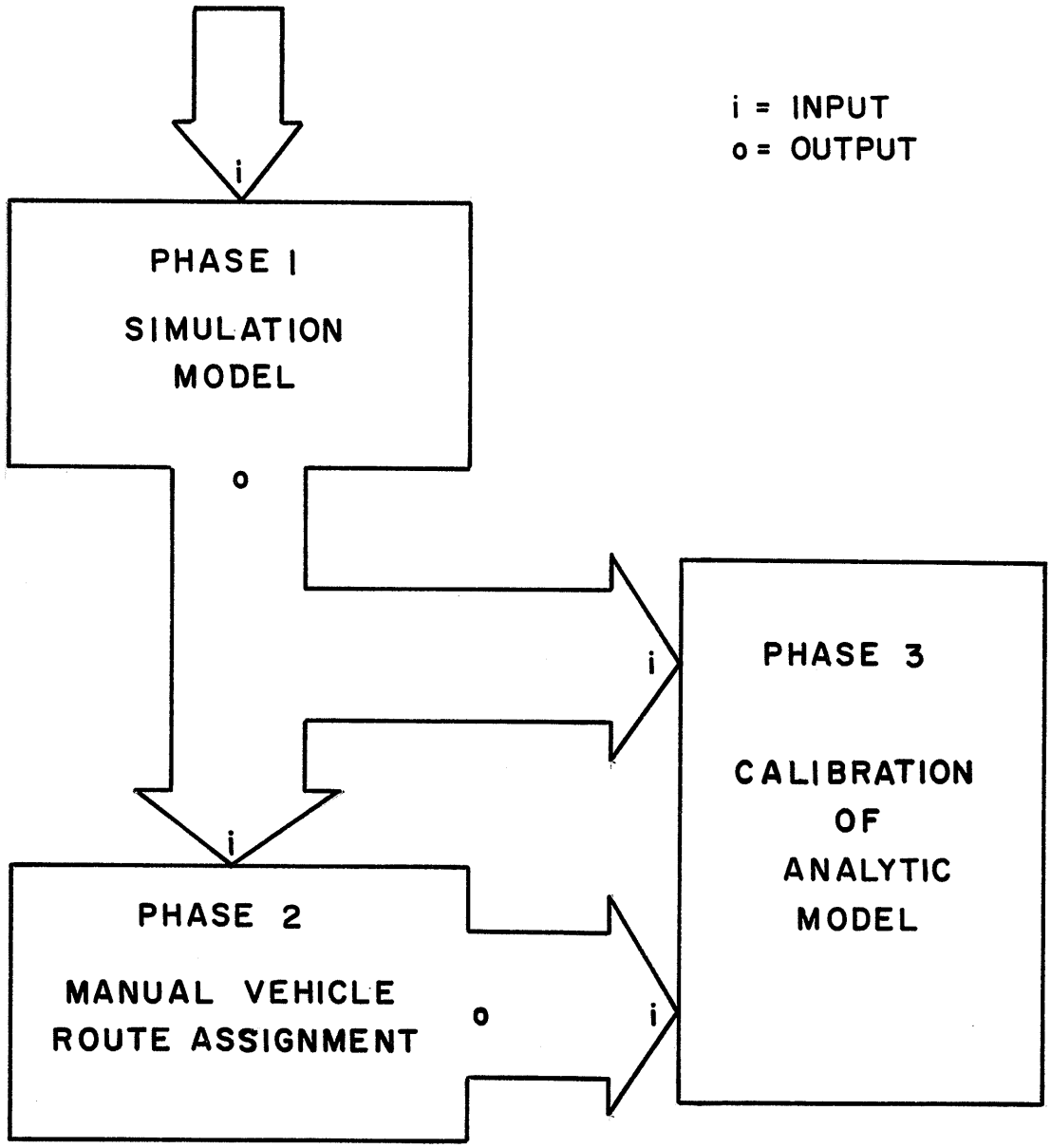
DECISION MODEL DEVELOPMENT

4.1 Phases of Development

The Decision Model development stage is comprised of three distinct phases. These phases and their interconnections are shown in Figure 7. Phase one involves the utilization of a simulation model. Specific input parameters, which were the only external elements in this stage, were fed into the simulation model. The output from this phase is transformed into the input used in phases two and three. Phase two consists of a manual vehicle route assignment operation. On the basis of phase one output considerations, decisions were made manually as to how a vehicle would circulate within the service area picking up passengers and transporting them to the nearest terminal station. Output from this phase was combined with the output from phase one and transformed into input for the third phase of the model development. This phase involved the formulation and calibration of the analytic model. As will be shown later, the analytic model is one of the major components in the Decision Model.

4.2. Phase 1 - Simulation Model

The field of Operations Research (O.R.) is concerned with decision-making for situations which occur in real life. O.R. may be described as the scientific approach to decision-making related to the operation of a "real-world" system. Both industrial and business organizations have widely used O.R. to aid decision making in complex problems. An important characteristic of O.R. is its broad viewpoint and systems analysis approach. Conflicts of interest among



PHASES OF DECISION
MODEL DEVELOPMENT

FIGURE 7

the components of an organization or system are resolved in a way that considers the effects and results on the total system. Usually, O.R. attempts to find the best or optimal solution to the problem under consideration.

A vast number of extremely difficult and complex problems have been solved by utilization of the various techniques that have been developed over the years in O.R. Linear Programming is one such technique. Basically, Linear Programming addresses the problem of allocating limited resources among competing activities in the best or most optimal manner. A mathematical model is used to describe the problem being considered. The model usually attempts to plan the order of activities to facilitate an optimal solution in which all feasible alternatives have been considered and the solution is for the well-being of the total system - not just a few system components.

A special case of the linear programming model is the network optimization model. This particular model most often has been associated with the problem of product distribution. The problem considers the distribution of a product from a source of supply to points where a request for this product is located.

Because of the variety of distribution problems encountered in real life, there have evolved many techniques for network optimization modelling. The one considered most applicable to the problem addressed in this thesis is the "Transhipment Model".

4.2.1 Transhipment Problem

The basic characteristic of the transhipment problem is the distribution of a product from the supply origin to where the product is required, in the most optimal manner This usually involves the minimization of costs to ship a product from origin to destination. In the transhipment model, each point where a demand is located is also permitted to act as an intermediate point for allocation of the product to other demand locations. That is, at one particular time in the distribution activity, a point where a demand for a product is located may actually have more supply units available than are required. At another point in time, however, this excess in supply may be distributed to other demand points. These transhipment points, therefore, may allow for a lower distribution cost than if all supply units had to be distributed to all points in the most direct manner while considering each supply-demand interchange separately.

The characteristics of the general transhipment problem can generally be compared to the operation of a Dial-a-Bus system. The supply must be distributed from its origin to a destination while satisfying the objective of allocation of supply at the minimum cost. The analogy of the Dial-a-Bus system to the transhipment problem is as follows:

THE SUPPLY is the Dial-a-Bus vehicle. Actually, supply units are the individual seats in the vehicle.

THE ORIGIN OF SUPPLY is usually the terminal station or some activity centre within the service area.

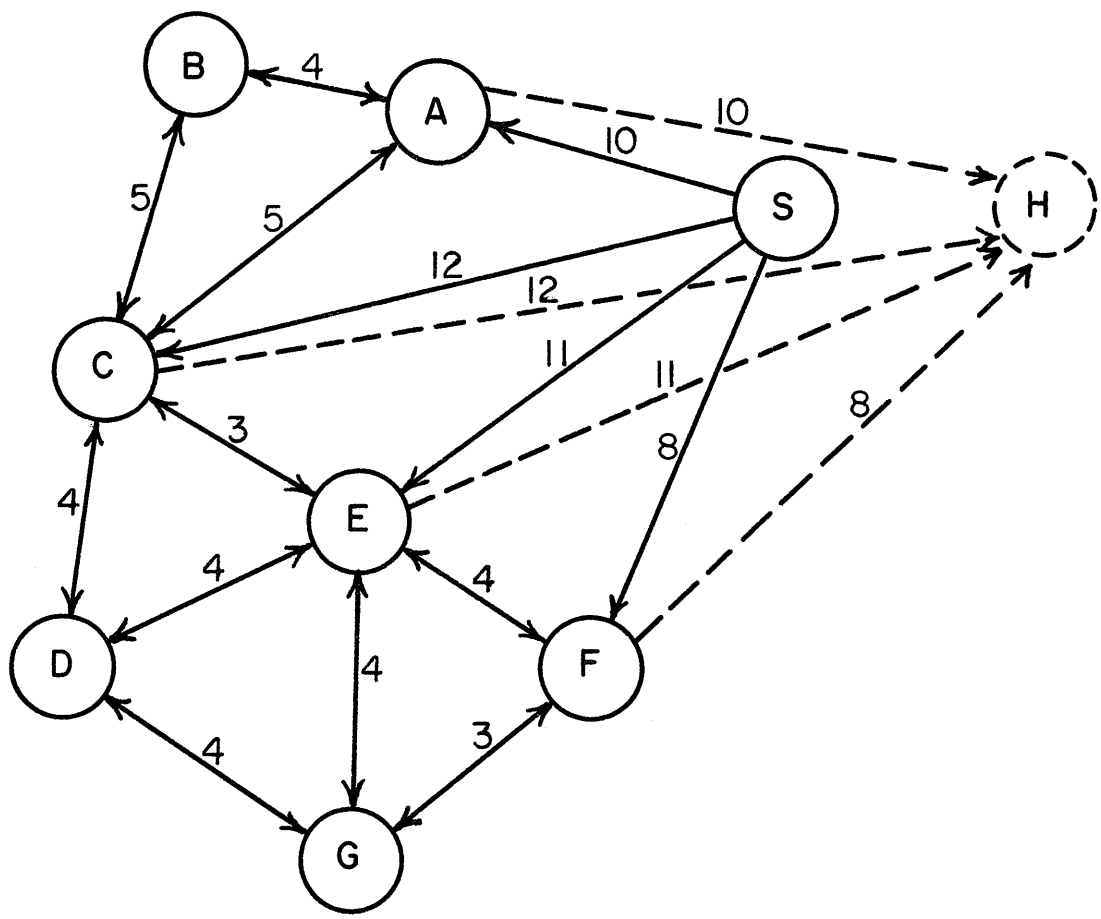
THE OBJECTIVE is to minimize operating cost and user travel time.

4.2.1.1 Hypothetical System Simulation

To provide a basis for better understanding the transhipment model, its applications and its potential, a hypothetical system will be introduced. Figure 8 shows the hypothetical link-node configuration that will be used in this analysis.

There are 3 types of network nodes shown in Figure 8. The "source" or origin of supply node (designated node "S") is the point at which all of the supply is initially located. The "demand centroids" (Nodes "A,B,C,D,E,F, and G") are locations within the network at which point demands are allowed to enter the system. These nodes can also have an excess of supply units allocated through them. These transhipment points, in effect, then become supply nodes. The "sink" or terminal node (designated node "H") is a point in the link-node system through which no supply units can be allocated. However, in simulating a Dial-a-Bus operation, it has been assumed that the "source" and the "sink" nodes are actually one location in the system. That is, at the terminal station there are facilities to store the vehicles until they are demand activated.

In modelling this particular system component, the "source" and the "sink" have to be identified as distinctly separate points. Moreover, a large link penalty has to be assigned so that all the supply is not allocated to the "sink" node in the initial stages of the network optimization process. Theoretically, there is a link travel time of zero



HYPOTHETICAL NETWORK CONFIGURATION

FIGURE 8

associated with the "source" to "sink" interchange since these two nodes are actually one location in the system. The first stage in the network optimation process would be to find a new position for the supply units in the link-node system at the lowest cost. Since the cost or travel time is zero between the "source" and "sink" all of the supply would be allocated to this node. However, the model stipulates the constraint that a "sink" node cannot be a transhipment point. Therefore, the total system supply would be held at this node and an "infeasible solution" would be indicated.

4.2.1.2 Mathematical Formulation

The mathematical model of the transhipment problem is described below. The objective function shown describes the minimization of the total time to allocate the supply to the demands.

$$\text{MINIMIZE} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

where: X_{ij} = flow of supply units from node i to node j

C_{ij} = unit time from node i to j

Z = total time to allocate supply to demand

i = nodes having available supply

j = nodes to which supply is destined

Rather than describing all the constraint equations involved, the mathematical constraint formulations are usually expressed in a concise tabular format. Although the tabular format is comprised of two basic elements, they are usually combined into one matrix. These elements are:

1. the unit cost matrix C_{ij}
2. the supply flow matrix X_{ij}

The mathematical forms of the transhipment model are described in tabular format in Figure 9. The top row is designated for the source with the number of supply units available at that point located in the right-hand "supply" column. In the table, the column at the right is designed for the sink. The number of supply units desired at that point is shown in the "demand" row at the bottom of the table. For the transhipment points, the "supply" values were calculated by using the following equation[20]

$$S_K = T_K + B$$

where: T_K = the supply required at node K

B = the sum of all supply available at all points in the system
= 951

The "demand values for the transhipment points were calculated by using the following equation[21]

$$D_K = B$$

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20. Wagner, Harvey , Principles of Management Science With Applications to Executive Decisions, Prentice-Hall Inc., (Englewood Cliffs, New Jersey: 1970) p.143.

21. Ibid., p. 144.

(source)	A	B	C	D	E	F	G	(sink) H	supply
S	c_{SA} / x_{SA}		c_{SC} / x_{SC}		c_{SE} / x_{SE}	c_{SF} / x_{SF}			951
A	0 / x_{AA}	c_{AB} / x_{AB}	c_{AC} / x_{AC}						851
B	c_{BA} / x_{BA}	0 / x_{BB}	c_{BC} / x_{BC}						901
C	c_{CA} / x_{CA}	c_{CB} / x_{CB}	0 / x_{CC}	c_{CD} / x_{CD}	c_{CE} / x_{CE}			c_{CH} / x_{CH}	751
D			c_{DC} / x_{DC}	0 / x_{DD}	c_{DE} / x_{DE}		c_{DG} / x_{DG}		801
E			c_{EC} / x_{EC}	c_{ED} / x_{ED}	0 / x_{EE}	c_{EF} / x_{EF}	c_{EG} / x_{EG}	c_{EH} / x_{EH}	901
F					c_{FE} / x_{FE}	0 / x_{FF}	c_{FG} / x_{FG}	c_{FH} / x_{FH}	851
G				c_{GD} / x_{GD}	c_{GE} / x_{GE}	c_{GF} / x_{GF}	0 / x_{FF}		651
demand	951	951	951	951	951	951	951	1	

TABULAR FORM OF THE
TRANSHIPMENT MODEL

FIGURE 9

4.2.1.3 Mathematical Solution

The mathematical equations used to represent the objective function and the constraints of the model were represented in a matrix form to facilitate ease in understanding the qualification of the transhipment problem. However, solving the transhipment problem requires the use of the computer. The MPS/360 package computer program was used. The MPS/360 program unlike most previous linear programming packages, includes a linear programming language. In order to solve a linear programming problem, a control program must be written in the MPS/360 control program language. MPS then compiles the program into an executable form so that the "Transhipment Problem" can be solved. The control program reads the required data and then proceeds to solve the problem. The format that the transhipment problem data must be in is shown by the "TECHNOLOGY TABLE" in Table 2. The values on the right hand side indicate whether a node has a supply (positive sign) or a demand (negative sign). The values at the bottom of the Table are the link travel times. The link flow is coded by placing +1 in the origin node row and -1 in the destination node row. There is only one set of +1 and -1 values for each X_{ij} column. A print-out of the computer program output is located in the appendix on page 90.

The optimal supply flow solution for the hypothetical network under the system condition that supply equals demand is as follows:

	x_{SA}	x_{SC}	x_{SE}	x_{SF}	x_{AB}	x_{AC}	x_{AH}	x_{BA}	x_{BC}	x_{CA}	x_{CB}	x_{CD}	x_{CE}	x_{CH}	x_{DC}	x_{DE}	x_{DG}	x_{EC}	x_{ED}	x_{EF}	x_{EG}	x_{EH}	x_{FE}	x_{FG}	x_{FH}	x_{GD}	x_{GE}	x_{GF}	SUDE
S source	1	1	1	1																									951
A	-1				1	1	1	-1																					-100
B					-1			1	1		-1																		-50
C		-1				-1			-1		1	1	1	1	-1			-1											-200
D												-1			1	1	1		-1							-1			-150
E			-1										-1			-1		1	1	1	1	1	-1				-1		-50
F				-1																-1			1	1	1			-1	-100
G																	-1				-1			-1		1	1	1	-300
H sink							-1							-1								-1			-1				-1
	10	12	11	8	4	5	10	4	5	5	5	4	3	12	4	4	4	3	4	4	4	11	4	3	8	4	4	3	

TRANSHIPMENT TECHNOLOGY TABLE

TABLE 2

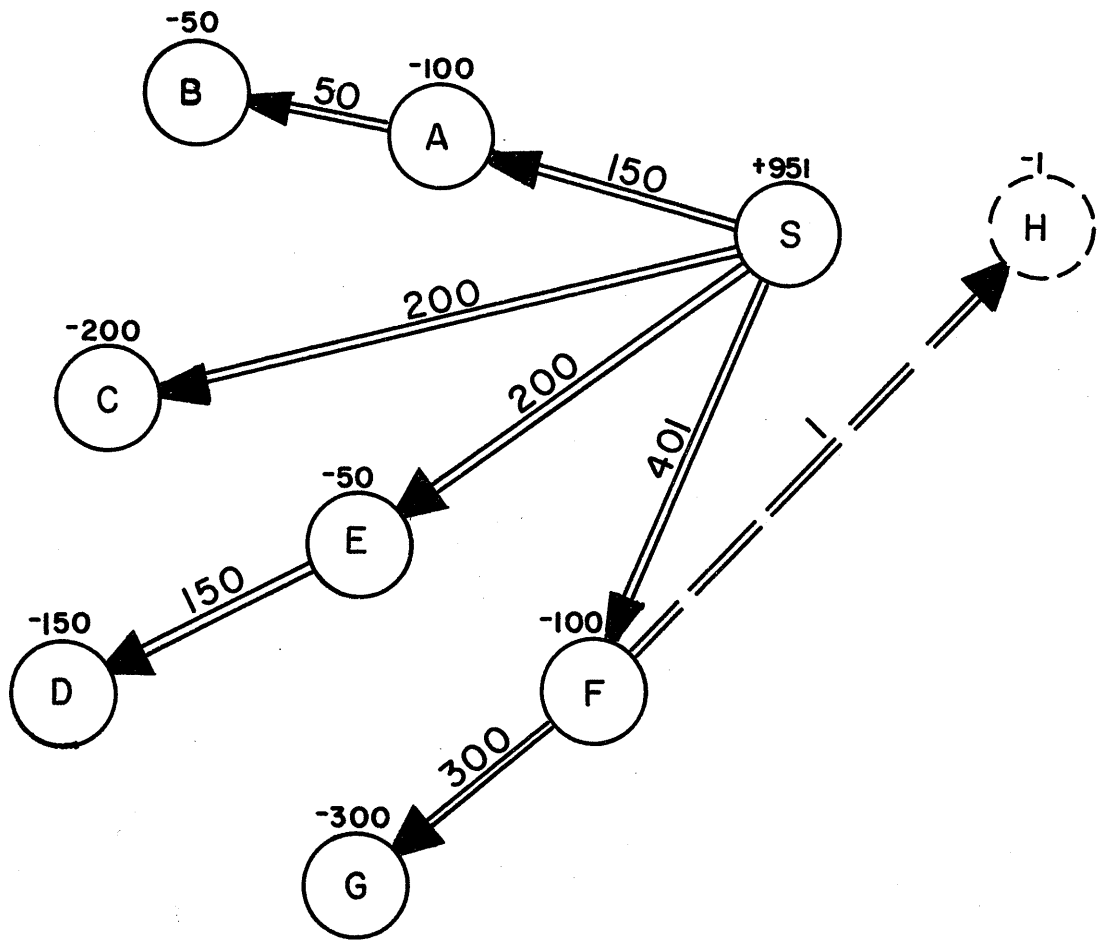
$$X_{SA} = 150 \longrightarrow X_{AB} = 50$$

$$X_{SC} = 200$$

$$X_{SE} = 200 \longrightarrow X_{ED} = 150$$

$$X_{SF} = 401 \longrightarrow X_{FG} = 300 \longrightarrow X_{FH} = 1$$

The flow of supply units is illustrated in Figure 10. The short-comings of the output from this model are quite evident. The model simulates the flow of individual vehicle seats. Once a vehicle seat or supply unit has reached a demand, the computer considers the demand satisfied. This supply-demand pair is deleted from further system consideration and the cost or allocation time associated with the supply flow is added to the total system allocation time. By arbitrarily assigning a -1 demand value at the sink, this problem was somewhat alleviated. The other shortcoming of the transhipment model is the fact that "seats" and not vehicles (which contain integral numbers of seats) are allocated. This simulation or transhipment modeling process and the corresponding input-output data flow was then applied to the real-life situation involving the section of Fort Richmond previously chosen.



FLOW OF SUPPLY FOR HYPOTHETICAL NETWORK

FIGURE 10

By applying these equations, the transhipment model constraint that supply equals demand, at all points within the system to provide system balance, is achieved. If this condition could not be met due to some physical characteristic of the real system, a fictitious or "dummy" supply source would have to be introduced into the system. The physical significance of this condition in the simulation problem relates to the limitation of supply units - the Dial-a-Bus vehicles in the system. If there is a set number of vehicles available and the total number of vehicle seats is less than the number of demands that must be satisfied, a "dummy" source of supply units must be introduced in order to convert the system inequalities into system equalities. The "dummy" source has no effect on the simulation and only facilitates the feasibility condition of the model that total supply equals total demand. The reason why the introduction of a "dummy" source does not affect the simulation is due to the model's objective function, which attempts to minimize total allocation time. The links connecting the "dummy" source node and the actual link-node network are usually given large flow penalties. That is, large link travel times keep the model from allocating the supply units from the "dummy" source node into the system.

4.2.2 System Simulation in Fort Richmond

The link-node configuration, associated with the section of Fort Richmond that was chosen for modelling purposes, and demand centroid quantities for two demand levels (20 demands per square mile and 180 demands per square mile) were coded into the required MPS/360 computer program input format. The MPS/360 program was run for various combinations of supply and demand parameters. These "runs" were categorized into distinct simulation stages on the basis of the various combinations of input parameters. The relationship between simulation stages and computer runs and subruns is illustrated in Figure 11. Two simulation stages were considered in this figure.

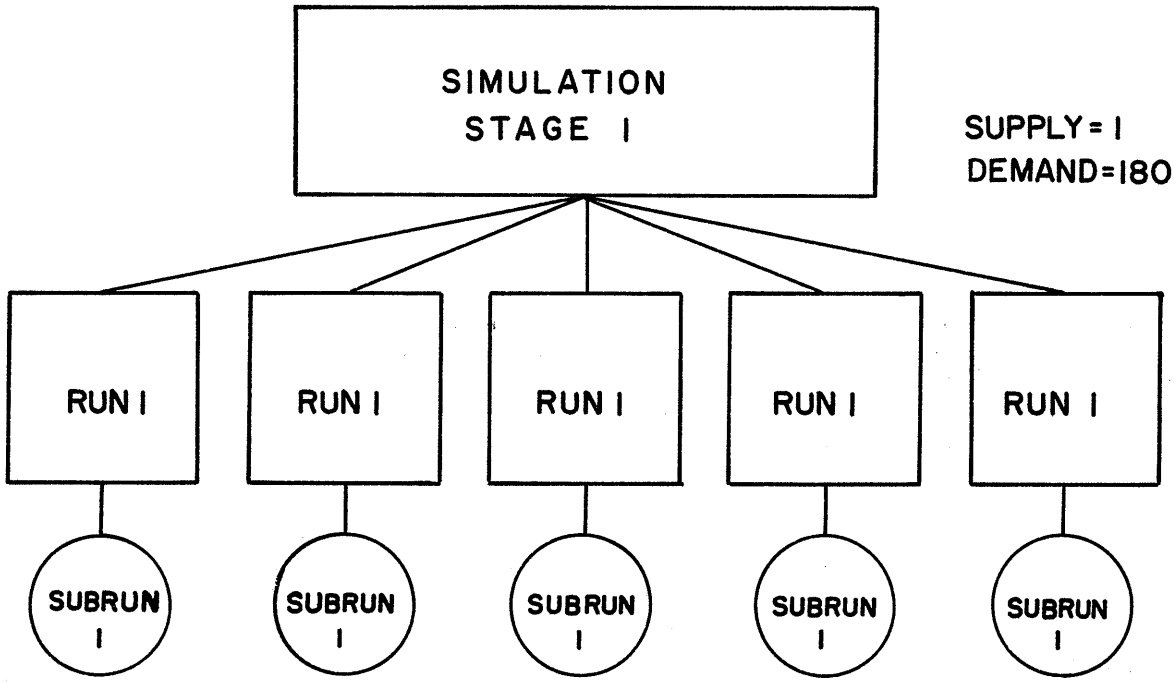
1. DEMAND = 180 per square mile
   SUPPLY = 1 set of 22 supply units (22 "seats")

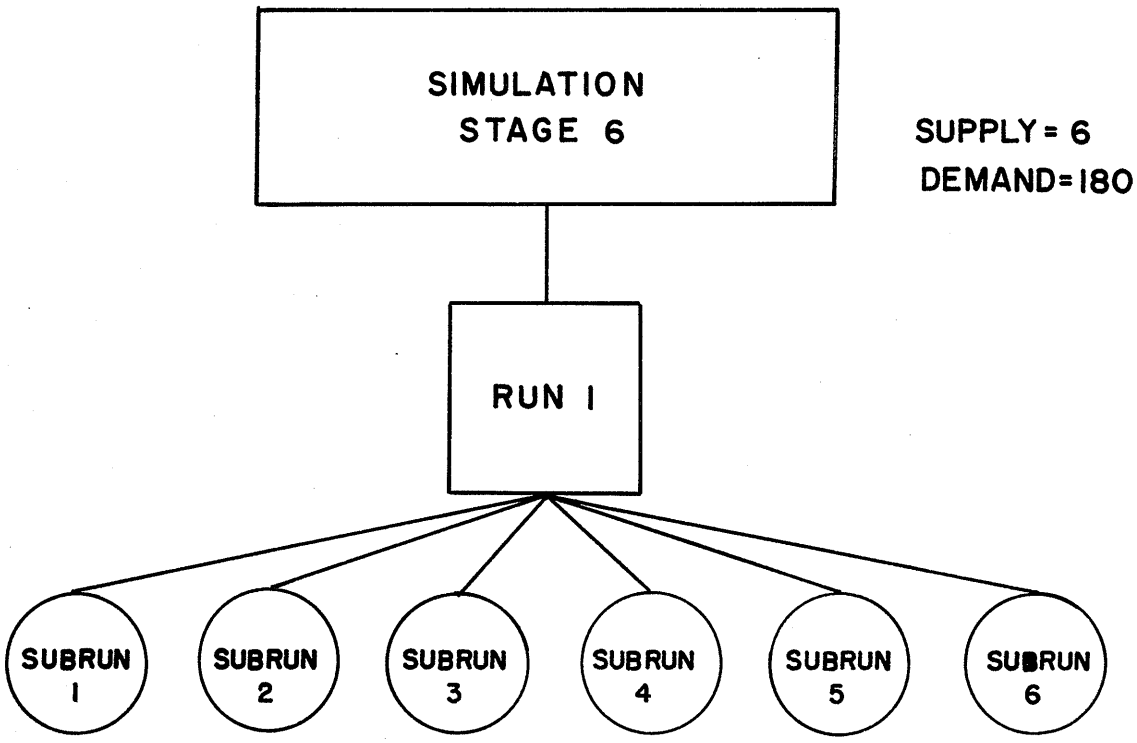
2. DEMAND = 180 per square mile
   SUPPLY = 6 sets of 22 supply units (132 "seats")

In this figure, each square indicates a computer run. The number of runs required in a simulation stage was determined by the following equation.

$$\text{NUMBER OF RUNS} = \frac{\text{TOTAL SYSTEM DEMAND}}{(\text{SUPPLY INCREMENTS})(22)}$$

Each sub-run, indicated by a circle, represents a supply set of 22 units. These sets, as will be shown in phase two, represent Dial-a-Bus vehicles.





RELATIONSHIP BETWEEN SIMULATION STAGE, COMPUTER RUNS AND SUBRUNS

FIGURE 11

Phase one output is summarized in Table 3. The column headed " $\Sigma\Sigma C_{ij} X_{ij}$ " indicates the total allocation or "flow" time required for the movement of supply units to demands. For simulation Stage 1, only one increment of 22 supply units was available to be allocated for this particular computer run. At a demand density of 180 per square mile, there were 98 demands to be satisfied. Since in Run 1 there were 22 supply units and 98 demands, a dummy node containing 76 supply units was required to satisfy the supply-demand system balance constraint. The allocation time for this run was 752 seconds or 12.53 minutes. The right-hand column in Table 3 indicates that the demands satisfied in Run 1 were located at 16 centroids. After the demands that were satisfied in Run 1 were deleted from the system network, a new set of 22 supply units was made available to the system, and the MPS/360 program was run for the second time. A dummy node with 54 supply units was also introduced in this run. The allocation time in Run 2, however, had two components - the time to satisfy the 22 demands chosen in computer Run 2 plus the allocation time in Run 1. In the situation where there is more than one set of supply units available to the system (and therefore, more than one subrun per run), the order of supply unit set introduction determines which subrun allocation times will be cumulated. For example, each run in Simulation Stage 3 has 3 subruns (3 sets of supply units) Therefore, the allocation times in Run 2 were calculated by cumulating the values of both Run 1 and Run 2 for subruns with similar numbers.

SIMULATION STAGE	INCREMENTS OF 22 SUPPLY UNITS AVAILABLE	COMPUTER RUN	SUBRUN	$\Sigma\Sigma c_{ij}x_{ij}$	NO. OF DEMANDS SATISFIED	NO. OF DEMAND CENTROIDS SERVICED
1	1	1	1	752	22	16
		2	1	1174	22	15
		3	1	2266	22	8
		4	1	2949	22	16
		5	1	3276	10	4
2	2	1	1	752	22	16
			2	422	22	8
		2	1	1844	22	15
			2	1105	22	16
		3	1	1432	10	4
3	3	1	1	752	22	16
			2	422	22	8
			3	1092	22	15
		2	1	1322	9	4
			2	699	11	6
			3	2010	12	11
4	4	1	1	752	22	16
			2	422	22	8
			3	1092	22	15
			4	683	22	16
		2	1	749	10	4
5	5	1	1	752	22	16
			2	422	22	8
			3	1092	22	15
			4	683	22	16
			5	327	10	4
6	6	1	1	752	22	16
			2	422	22	8
			3	1092	22	15
			4	918	12	11
			5	570	9	4
			6	277	11	6

SIMULATION MODEL OUTPUT

TABLE 3

SIMULATION STAGE	INCREMENTS OF 22 SUPPLY UNITS AVAILABLE	COMPUTER RUN	SUBRUN	$\Sigma\Sigma c_{ij}x_{ij}$	NO. OF DEMANDS SATISFIED	NO. OF DEMAND CENTROIDS SERVICED
7	9	1	1	428	10	8
			2	363	12	7
			3	172	11	4
			4	271	11	3
			5	669	10	6
			6	410	12	7
			7	474	10	8
			8	446	12	6
			9	327	10	4
8	1	1	1	382	10	10
9	2	1	1	202	5	5
			2	109	5	5
10	3	1	1	40	3	3
			2	94	3	3
			3	172	4	4
11	4	1	1	40	3	3
			2	125	3	3
			3	49	2	2
			4	92	2	2
12	5	1	1	18	2	2
			2	48	2	2
			3	68	2	2
			4	80	2	2
			5	92	2	2

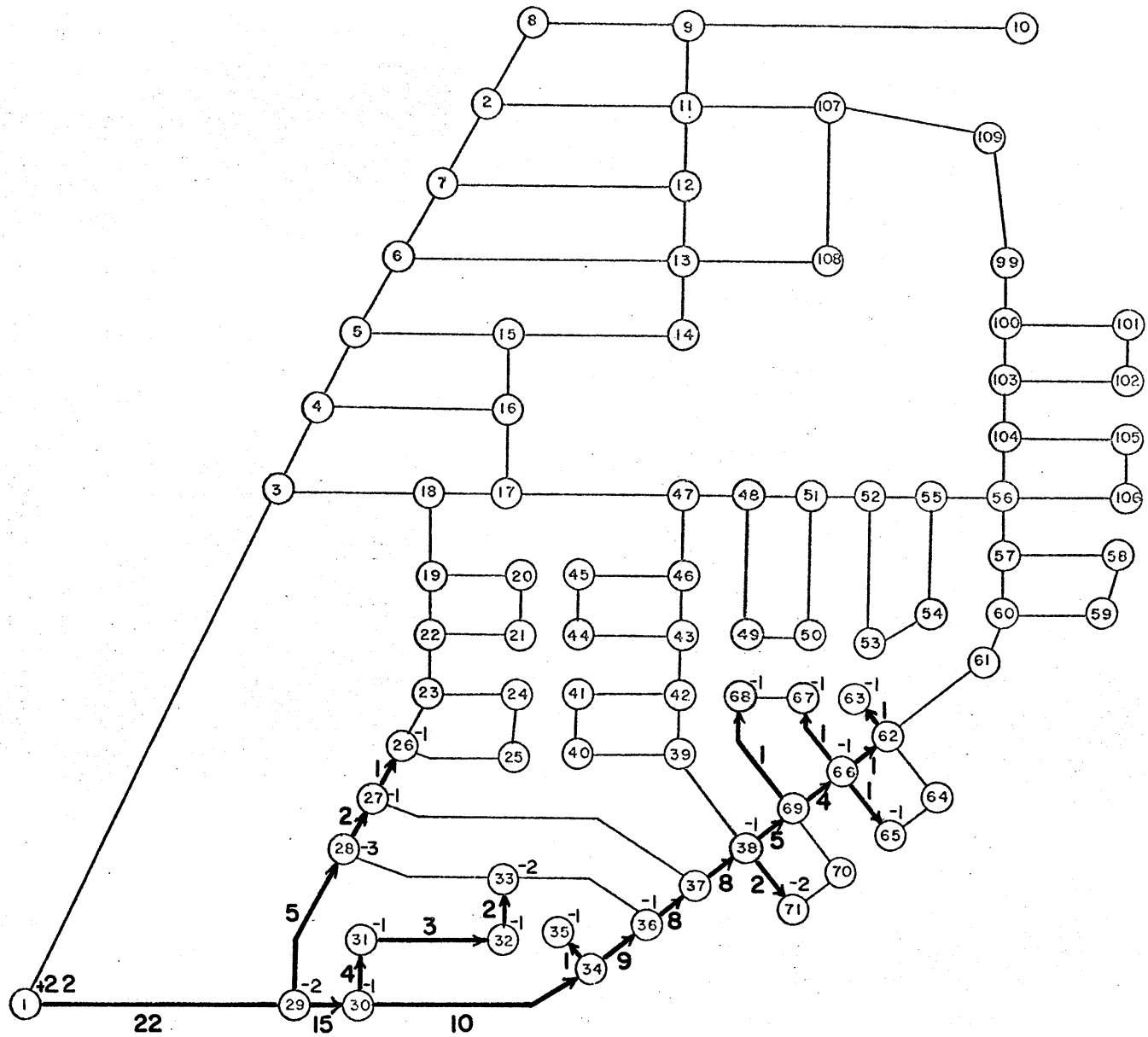
SIMULATION MODEL OUTPUT

TABLE 3 (CONTINUED)

4.3 Phase 2 - Manual Vehicle Route Assignment

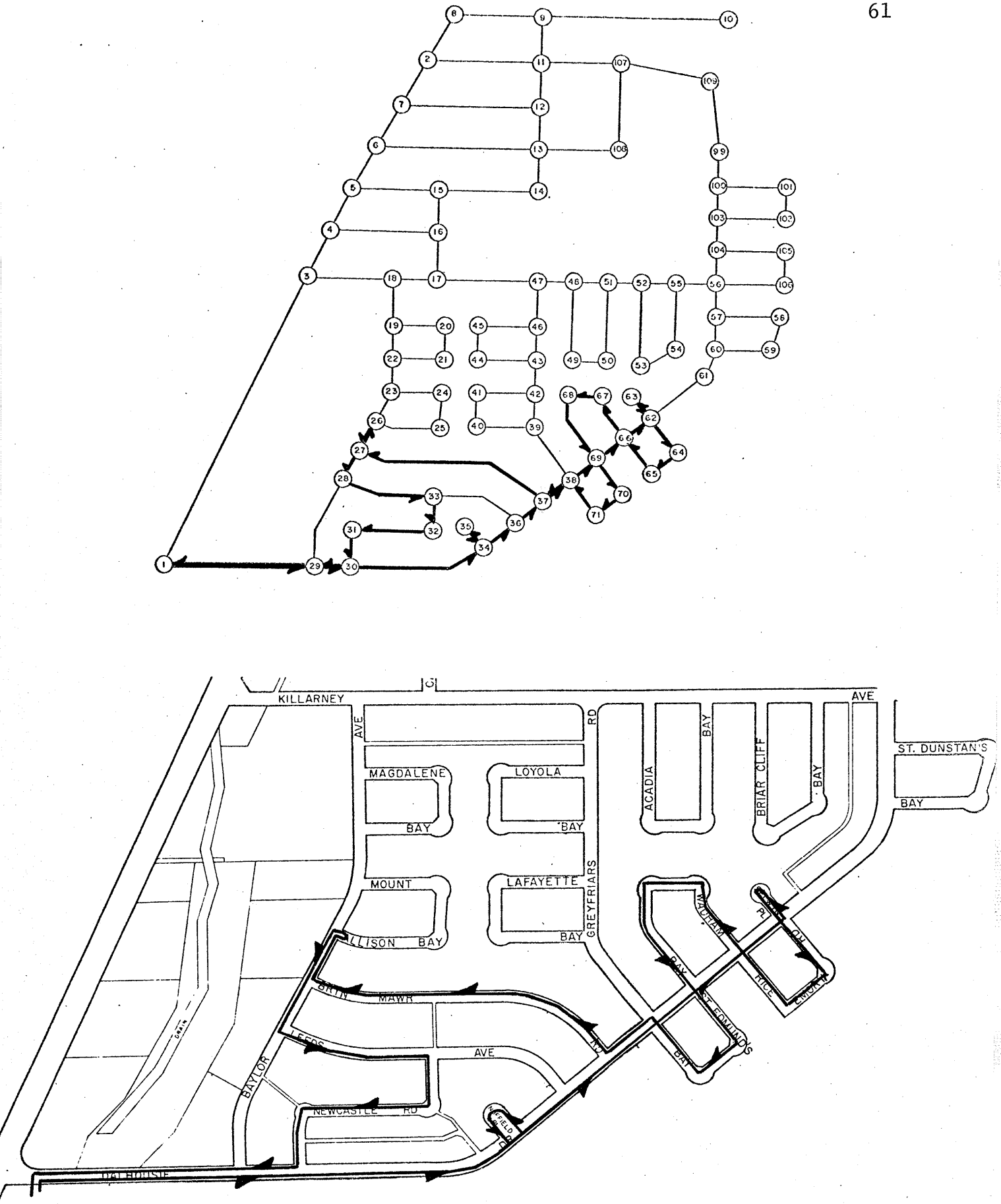
Based on the minimum path supply allocation decisions generated by the MPS/360 computer program in Phase 1, the flow for a set of supply units, which actually simulated the movement of 22 'vehicle seats', was considered for determining the most likely route a 22-passenger vehicle would take to pick up the same demands that were satisfied in a subrun. An example of the simulated flow of 'vehicle seats', as generated in Phase 1 by the MPS/360 Transhipment Model Program, is shown in Figure 12. The manual vehicle routing,derived on the basis of 'vehicle seat' flow decisions as summarized in Figure 12, is shown on Figure 13 for both a link-node and an actual street network. This particular route begins and ends at 'Terminal Station 1'. In this phase of the Decision Model development, the sets of 22 supply units represent 22-passenger vehicles. Each simulation stage was divided into one or more computer 'cycles'. A cycle is defined as the movement of all available vehicles from the terminal stations, picking up passengers ,and then returning to the stations where the passengers are discharged. A cycle is not considered to be complete until all vehicles are back at the terminal stations and ready for further operation. The number of cycles in a particular simulation stage can be calculated by the following equation:

$$\text{NUMBER OF CYCLES PER SIMULATION STAGE} = \frac{\text{TOTAL SYSTEM DEMANDS}}{(\text{AVAILABLE VEHICLES} \times 22)}$$



FLOW OF SUPPLY UNITS FOR SIMULATION

FIGURE 12



MANUAL VEHICLE ROUTE ASSIGNMENT

FIGURE 13

As can be seen, this equation is identical to the one used to calculate the number of computer runs required per simulation stage.

The next step after the manual route assignment, was to calculate the service time experienced by each passenger. This calculation considered waiting, pickup delay, vehicle travel, and terminal discharge delay time. The direct automobile travel time from the demand origin to the terminal station was also estimated for each demand satisfied. A ratio of the service time over direct auto driving time indicated the level of service experienced by each system user. These three values were generated for every passenger serviced in this phase of the development of the Decision Model.

The passenger travel time calculations were based on the following assumptions:

- traveling speed of 30 M.P.H. for auto and Dial-a-Bus vehicles.

- pickup delay time of 15 seconds per vehicle stop regardless of the number of passengers boarding at a stop(or demand centroid).

- passenger discharge delay time at the terminal of 2 minutes regardless of number of passengers alighting from the vehicle.

- passengers serviced in the first cycle do not perceive a waiting time component in their total service time.

The last assumption will be explained in more detail. Vehicles in the first cycle of demand pickups are scheduled to leave the terminal station (supply source) in order that

the waiting time that would be experienced by passengers picked up in the latter part of the vehicle tour be offset by picking up passengers earlier than the requested pickup time in the initial part of a vehicle tour. This was considered a realistic assumption because the average passenger pickup time variance (the time interval between initial and final passenger pickup) was within approximately 4 minutes for all vehicle tours.

The output from Phase 2 is summarized in a figure-table format. The vehicle route that was assigned manually is shown on the link-node network figure while the service time, the direct auto travel time, and the level of service experienced by the vehicle passengers is listed in the table. Every vehicle tour has a figure-table summary. The mean level of service ($\overline{L.S.}$) experienced by the passengers on each vehicle and the vehicle productivity time (P_T), which is the time required for a vehicle to complete a cycle (in seconds), is shown above the table. This portion of the Phase 2 output is located in Appendix C. The mean level of service and the vehicle productivity time for every vehicle considered in this phase is listed in Table 4. Simulation stages 1 to 7 relate to a demand level of 180 per square mile while stages 8 to 12 relate to a demand level of 20 per square mile.

SIMULATION STAGE	CYCLE NUMBER	VEHICLE NUMBER	MEAN LEVEL OF SERVICE	VEHICLE PRODUCTIVITY TIME
1	1	1	4.9	407
	2	1	16.1	778
	3	1	63.7	1314
	4	1	35.4	1859
	5	1	101.4	2104
2	1	1	4.9	407
		2	7.2	251
	2	1	16.0	943
		2	12.5	796
	3	2	48.3	1041
3	1	1	4.9	407
		2	7.2	251
		3	4.3	416
	2	1	9.4	749
		2	21.7	526
		3	15.2	691
4	1	1	4.9	407
		2	7.2	251
		3	4.3	416
		4	3.9	425
	2	2	21.5	376
5	1	1	4.9	407
		2	7.2	251
		3	4.3	416
		4	3.9	425
		5	2.7	125
6	1	1	4.9	407
		2	7.2	251
		3	4.3	416
		4	2.9	312
		5	1.4	222
		6	3.3	155

MANUAL VEHICLE ROUTE ASSIGNMENT OUTPUT

TABLE 4

SIMULATION STAGE	CYCLE NUMBER	VEHICLE NUMBER	MEAN LEVEL OF SERVICE	VEHICLE PRODUCTIVITY TIME
7	1	1	2.5	136
		2	3.2	75
		3	5.3	75
		4	2.5	88
		5	2.3	100
		6	2.4	140
		7	2.2	144
		8	2.2	138
		9	2.7	125
8	1	1	6.4	1812
9	1	1	2.4	496
		2	9.3	462
10	1	1	3.0	143
		2	2.2	219
		3	2.0	429
11	1	1	3.0	143
		2	1.3	230
		3	1.8	140
		4	1.2	161
12	1	1	2.1	59
		2	2.1	117
		3	1.4	148
		4	1.2	157
		5	1.2	161

MANUAL VEHICLE ROUTE ASSIGNMENT OUTPUT

TABLE 4 (CONTINUED)

4.4 Phase 3 - Analytical Model

The term 'analytical model' is used here to describe a set of equations which represent the results of a series of system component relationships. After determining the most suitable form and solving for the equation coefficients, the analytical model will be used to provide information on the sensitivity of the proposed demand responsive transit system for the selected area of Fort Richmond to parametric variation.

The reason for developing the analytic model was to be able to estimate the mean level of service that would be provided by a certain number of vehicles at a certain demand level and the average time that it would take for a certain number of vehicles operating at a certain demand level to complete a passenger pickup and discharge tour. The manual vehicle route assignment phase consumed a great deal of time. To minimize the necessity for undertaking such an extensive analysis for each set of input parameters to be considered, the analytic model, in conjunction with the simulation model, will prove to be a valuable systems planning tool.

4.4.1 Definition of System Parameters and State Variables

The initial step in formulating the analytic model was to define the system parameters and the system state variables.

SYSTEM PARAMETERS

D = demand level

V = vehicle fleet size (supply)

DEPENDENT SYSTEM STATE VARIABLES

$\overline{L.S.}$ = mean level of service experienced by system users (per cycle)

P_T = average vehicle productivity time (per cycle)

INDEPENDENT SYSTEM STATE VARIABLES

ΣCX = total supply to demand allocation time

S_T =average cumulative number of vehicle stops to pick up passengers (per vehicle per cycle)

P_S = average cumulative number of vehicle passengers (per vehicle per cycle)

4.4.2 Model Forms

Three basic mathematical forms for the model were considered. These were the linear form, the logarithmic form, and the exponential form. Two exponential functions considered were 'square' and 'square root'. The models in this analysis had the following functions:

$$Y = f\ (Xn, Xn^2, Xn^{1/2}, \log Xn)$$

$$\log Y = f\ (Xn, Xn^2, Xn^{1/2}, \log Xn)$$

$$Y^2 = f\ (Xn, Xn^2, Xn^{1/2}, \log Xn)$$

$$Y^{1/2} = f\ (Xn, Xn^2, Xn^{1/2}, \log Xn)$$

4.4.3 Model Estimation Technique

The various models, whose functions were described above, were estimated by means of stepwise multiple regression. Stepwise multiple regression is a statistical method for analyzing the relationship between a dependent variable (**Y**) and a set of independent variables (**X1, X2, ... Xn**). Another important function performed by stepwise multiple regression is the selecting of the indepent variables to enter the regression equation in the order of their importance. The criterion of importance is based on the reduction of sums of squares. The independent variable most important in this reduction at a given 'step' is entered.

The relationships between the variables and the corresponding regression coefficients and constants for each of the models were determined by this technique. Equation validation, statistical inference tests, and stability analysis are briefly discussed in the following sections. An analysis of the accuracy of model estimation based on 'observed results', which are actually the outputs from the simulation and vehicle route assignment phases, will be conducted to determine the model's reliability.

4.4.4 Input Data

Phase one and two outputs are combined in Table 5 to give the desired input data for phase three. Some of the headings used in the phase one output listing in Table 3 do not correspond to the headings in Table 5. What was termed a 'computer run' in phase one is now a 'cycle' and a 'subrun' is now associated with the identification of a particular vehicle. As referred to in the simulation phase, the terms 'number of demands satisfied' and 'number of demand centroids serviced' now correspond to 'passengers picked up' and 'number of stops' respectively.The output data from phases one and two were related to individual subruns or vehicles. Because the objective in developing the analytic model was to be able to estimate mean level of service and average vehicle productivity time for the entire fleet, individual subrun or vehicle values were averaged on a per cycle basis. The values listed in Table 5, therefore, were derived from phase one and two outputs and constitute the required input data format to be used in this phase.

4.4.5 Mean Level of Service Model

The first step in developing the mean level of service model was to examine the simple correlation matrix.[22] The existence of a strong relationship indicates a potential variable that should enter the regression equation. Investigation of the simple correlation matrix for each of the model forms considered indicated the following:

22. The correlation coefficient (r) is a measure of the association between two variables. The matrix gives the correlation coefficients for all combinations of variables.

SIMULATION STAGE	CYCLE NUMBER	NUMBER OF VEHICLES AVAILABLE	MEAN LEVEL OF SERVICE	VEHICLE PRODUCTIVITY TIME	PASSENGERS PICKED UP	NUMBER OF STOPS	$\Sigma\Sigma c_{ij}x_{ij}$
1	1	1	4.9	407	22	16	752
	2	1	16.1	778	44	31	1174
	3	1	63.7	1314	66	39	2266
	4	1	35.4	1859	88	55	2949
	5	1	101.5	2104	98	59	3276
2	1	2	6.0	329	22	12	587
	2	2	14.3	869	44	28	1475
	3	2	48.3	1041	54	32	1432
3	1	3	5.4	358	22	13	755
	2	3	15.4	622	34	20	1344
4	1	4	5.1	500	22	14	737
	2	4	21.5	496	32	16	1486
5	1	5	4.6	325	20	12	655
6	1	6	4.0	283	17	10	672
7	1	9	2.8	113	11	6	396
8	1	1	6.4	1812	10	10	382
9	1	2	5.9	479	5	5	156
10	1	3	2.4	264	3.3	3.3	102
11	1	4	1.8	169	2.5	2.5	77
12	1	5	1.6	128	2	2	61

AVERAGE CYCLE VALUE PER VEHICLE

TABLE 5

- The linear form gave the highest correlations between the dependent and independent variables. The simple correlation matrix for this model form is shown in Figure 14.

- Independent variables which have a high correlation ($r \geq 0.860$) with the dependent variable are: ΣCX, S_T, S_T^2, P_S, and P_S^2.

- These particular independent variables also had an extremely high intercorrelation. As can be seen in Figure 14, intercorrelation coefficients ranging from 0.931 to 0.996 indicate how strong these interrelationships are.

Usually, a group of independent variables with high intercorrelations are not used together in a single regression equation because of the possibility of statistical degeneracy. However, as will be shown, incorporating all of these independent variables into the regression equation generated the most reasonable, statistically sound, and significant model.

In the initial stage of the analysis, all independent variables were considered. Variables that did not contribute to the reduction of sums of squares were rejected. The statistical characteristics and the order of entry into the regression of all variables contributing a reduction of sum of squares greater than 0% are shown in Table 6. The computer output

	$\overline{L.S.}$	ΣCX	ΣCX^2	$\Sigma CX^{\frac{1}{2}}$	Log CX	S_T	S_T^2	$S_T^{\frac{1}{2}}$	Log S_T	P_S	P_S^2	$P_S^{\frac{1}{2}}$	Log P_S
$\overline{L.S.}$	1.000	.868	.678	.784	.555	.860	.870	.794	.658	.879	.898	.797	.637
ΣCX	.868	1.000	.872	.964	.759	.974	.931	.950	.847	.986	.939	.956	.837
ΣCX^2	.678	.872	1.000	.931	.645	.742	.831	.897	.731	.821	.853	.786	.823
$\Sigma CX^{\frac{1}{2}}$	.784	.964	.931	1.000	.884	.938	.825	.977	.944	.952	.830	.989	.945
Log CX	.555	.759	.645	.884	1.000	.743	.567	.865	.966	.750	.568	.875	.972
S_T	.860	.974	.742	.938	.743	1.000	.954	.971	.859	.994	.948	.958	.832
S_T^2	.870	.931	.831	.825	.567	.954	1.000	.861	.692	.948	.996	.842	.658
$S_T^{\frac{1}{2}}$	.794	.950	.897	.977	.865	.971	.861	1.000	.954	.967	.854	.992	.936
Log S_T	.658	.847	.731	.944	.966	.859	.692	.954	1.000	.857	.686	.951	.992
P_S	.879	.986	.821	.952	.750	.994	.948	.967	.857	1.000	.949	.966	.841
P_S^2	.898	.939	.853	.830	.568	.948	.996	.854	.686	.949	1.000	.843	.658
$P_S^{\frac{1}{2}}$	.797	.956	.786	.989	.875	.958	.842	.992	.951	.966	.843	1.000	.949
Log P_S	.637	.837	.823	.945	.972	.832	.658	.936	.992	.841	.658	.949	1.000

SIMPLE CORRELATION MATRIX (LINEAR FORM)

FIGURE 14

STEP	VARIABLE ENTERING	T-VALUE ENTERING	T-VALUE AT FINAL STEP	REG.COEF. ENTERING	REG. COEF. AT FINAL STEP	F-LEVEL ENTERING	MULTIPLE CORR. COEF. ENTERING*	% S.S. REDUCED IN THIS STEP
1	P_S^2	9.129	7.589	0.009	0.085	83.344	0.898	80.6%
2	S_T^2	-4.013	-7.023	-0.094	-0.221	81.194	0.943	8.9%
3	S_T	1.993	3.938	0.695	5.783	63.914	0.951	1.9%
4	P_S	-3.577	-2.480	-3.282	-2.323	82.554	0.971	3.7%
5	ΣCX	-2.198	-2.198	-0.020	-0.020	81.889	0.976	1.1%

* ADJUSTED FOR DEGREES OF FREEDOM

STATISTICAL CHARACTERISTICS OF THE VARIABLES

USED IN THE $\overline{L.S.}$ MODEL

TABLE 6

listing is located in Appendix D.

The t-value[23] for each regression coefficient in the final step was greater than 2.02. Regression coefficients significantly different from zero at the 95% confidence level have t-values in excess of 2.02. To examine the effect of each variable in entering the equation, the F-level[24] entering was considered. Only when the variable S_T was entered into the regression did the F-level lower. A relatively constant F-level value for the other four variables indicated that these variables were very significant in improving the multiple correlation coefficient, which was 0.976 in the final step.

The equation selected, on the basis of stepwise multiple regression analysis, for the 'mean level of service' model is:

$$\overline{L.S.} = -4.38 + 0.08P_S^2 - 0.22S_T^2 + 5.78S_T - 2.32P_S - 0.02\Sigma CX$$

23. The t-value is defined as the ratio of the regression coefficient to its standard error. This statistic is a standard used to determine the probability that the coefficient computed using the sample has a value close to the coefficient that would be computed if the entire universe were considered.
24. The F-level is a statistical index used to determine the probability that only chance factors caused the improvement in the multiple correlation coefficient resulting from adding a variable. Lowering the F-level increases the probability that the improvement in correlation was caused by chance factors.

where:

$\overline{L.S.}$ = mean level of service experienced by system users (per cycle)

P_S = average cumulative number of vehicle passengers (per vehicle per cycle)

S_T = average cumulative number of vehicle stops to pickup passengers (per vehicle per cycle)

The main objective in developing this model is to generate estimates of the mean level of service that would be experienced at various parameter levels. A comparison between the 'actual' and the 'estimated' mean level of service at demand levels of 20 and 180 per square mile and fleet sizes ranging from 1 to 9 vehicles is shown in Table 7. The residuals[25] range from 0.1 to 13.5. On examining the residuals, a bias in the model was discovered. The model tends to overestimate the mean level of service values within the $\overline{L.S.}_{ACT}$ range of 4.6 to 6.4. However, this bias was found not to be as serious as was thought originally. Considering the basic use of the model, which is to estimate the mean level of service experienced at various fleet sizes, average fleet values were calculated for each fleet of vehicles. By the process of averaging the mean level of service, the bias for overestimating some values was minimized. The average fleet mean level of service for actual and model estimated values are listed in Table 8. The estimated mean level of service for the entire fleet, when compared to the corresponding

25. Residual = $\overline{L.S.}_{EST} - \overline{L.S.}_{ACT}$

DEMAND LEVEL	No. OF VEHICLES	CYCLE	$\overline{L.S.}_{ACT.}$	$\overline{L.S.}_{EST.}$	RESIDUAL
180/sq.mi.	1	1	4.9	6.9	2.0
		2	16.1	2.6	-13.5
		3	63.7	59.6	- 4.1
		4	35.4	44.9	9.5
		5	101.4	96.7	- 4.8
	2	1	6.0	11.9	5.9
		2	14.3	18.5	4.2
		3	48.3	50.1	1.8
	3	1	5.4	8.8	3.4
		2	15.4	16.2	0.8
	4	1	5.1	9.0	3.9
		2	21.5	15.5	-6.0
	5	1	4.6	8.0	3.4
	6	1	4.0	3.3	-0.7
	9	1	2.8	0.7	-1.1
20/sq.mi	1	1	6.4	9.1	2.7
	2	1	5.9	6.4	0.5
	3	1	2.4	3.5	1.1
	4	1	1.8	1.9	0.1
	5	1	1.6	0.9	-0.8

MEAN LEVEL OF SERVICE
(ACTUAL AND ESTIMATED VALUES)

TABLE 7

DEMAND LEVEL	NO. OF VEHICLES	$\overline{L.S.}_{ACT}$	$\overline{L.S.}_{EST}$	% RESIDUAL*
180/sq.mi.	1	44.5	42.2	5%
	2	22.8	26.8	17%
	3	10.4	12.5	20%
	4	13.3	12.3	8%
	5	4.6	8.0	74%
	6	4.0	3.3	18%
	9	2.8	0.7	39%
20/sq.mi.	1	6.4	9.1	42%
	2	5.9	6.4	8%
	3	2.4	3.5	45%
	4	1.8	1.9	6%
	5	1.6	0.9	43%

$$* \quad \% \text{ RESIDUAL} = \frac{\overline{L.S.}_{EST.} - \overline{L.S.}_{ACT}}{\overline{L.S.}_{ACT.}} \times 100\%$$

AVERAGE FLEET MEAN LEVEL OF SERVICE

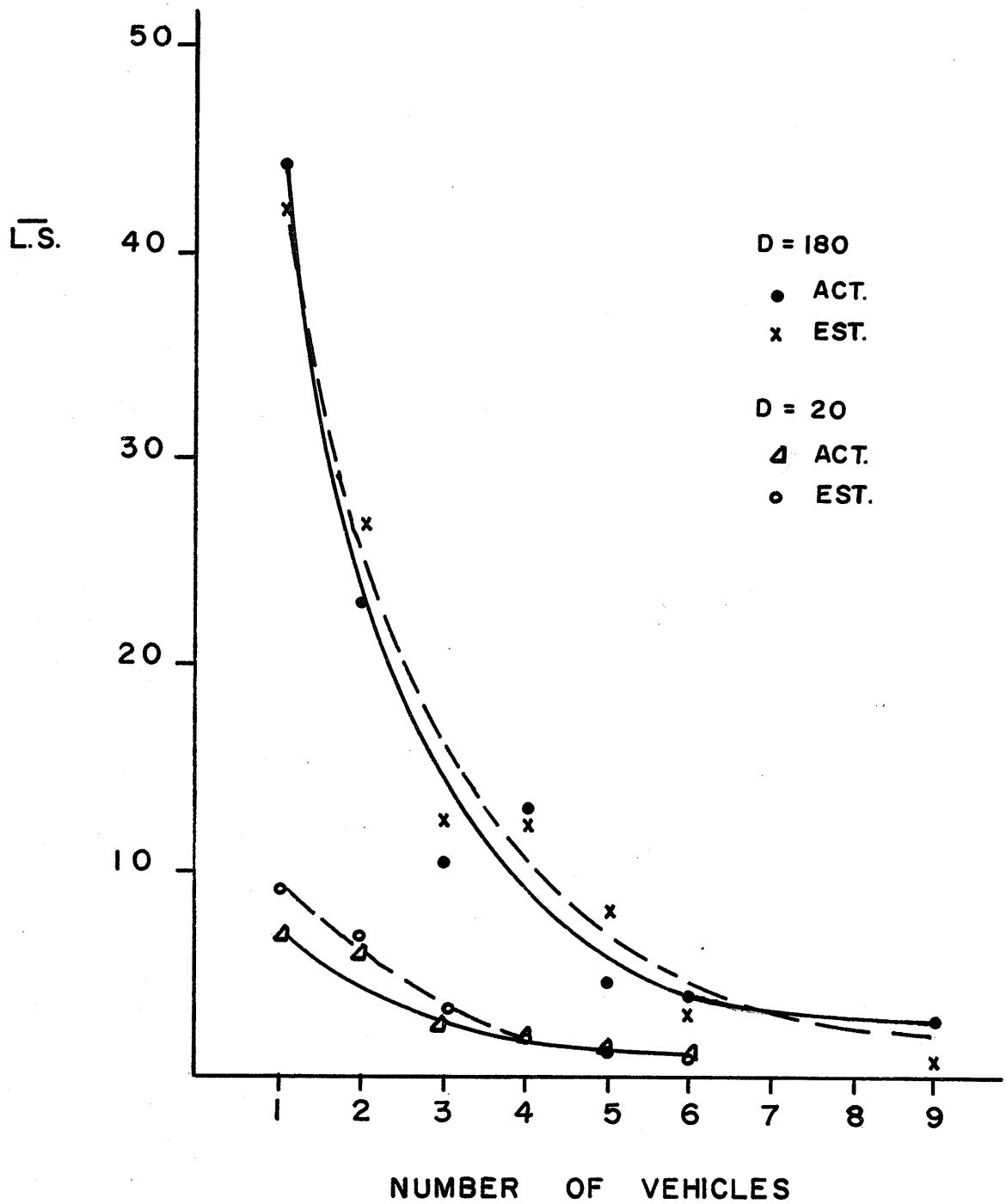
TABLE 8

actual values proved to be accurate to within 10% for 33% of the cases; within 20% for 58% of the cases; and within 45% for 91% of the cases. The effect of fleet size on the mean level of service experienced at demand levels of 20 and 180 per square mile is shown in Figure 15. Both $L.S._{ACT}$ and $L.S._{EST}$ values are represented. The best fitting curve between point estimates also improved the accuracy between the estimated and actual values.

4.4.6 Vehicle Productivity Time Model

In comparison to the mean level of service model, the vehicle productivity time model was relatively easy to develop. Based on the simple correlation matrix analysis for each model considered, the logarithmic form had the highest correlation coefficients between the dependent and independent variables. Independent variables with an unusually strong relationship with the dependent variable were $S_T^{1/2}$ (r = 0.967), $\log S_T$ (r = 0.988), $P_S^{1/2}$ (r = 0.962), and $\log P_S$ (r = 0.984).

However, when the stepwise multiple regression analysis was run, only the variable $\log S_T$ satisfied the statistical inference tests and the sum of squares reduction criteria. This particular variable entered the regression equation at the first step reducing the sum of squares by a substantial 97.6%. The multiple correlation coefficient, which was the same as the simple correlation coefficient in this case, was 0.988 and a t-value of 22.796 indicated that the regression coefficient was significantly different from zero at the 97.5% confidence level.



RELATIONSHIPS BETWEEN MEAN LEVEL OF SERVICE AND VEHICLE FLEET SIZE

FIGURE 15

The equation selected, on the basis of stepwise multiple regression analysis , for the 'vehicle productivity' model is:

$$\log P_T = 1.238 + 1.175 \log S_T$$

or

$$P_T = 1.238\ S_T^{1.175}$$

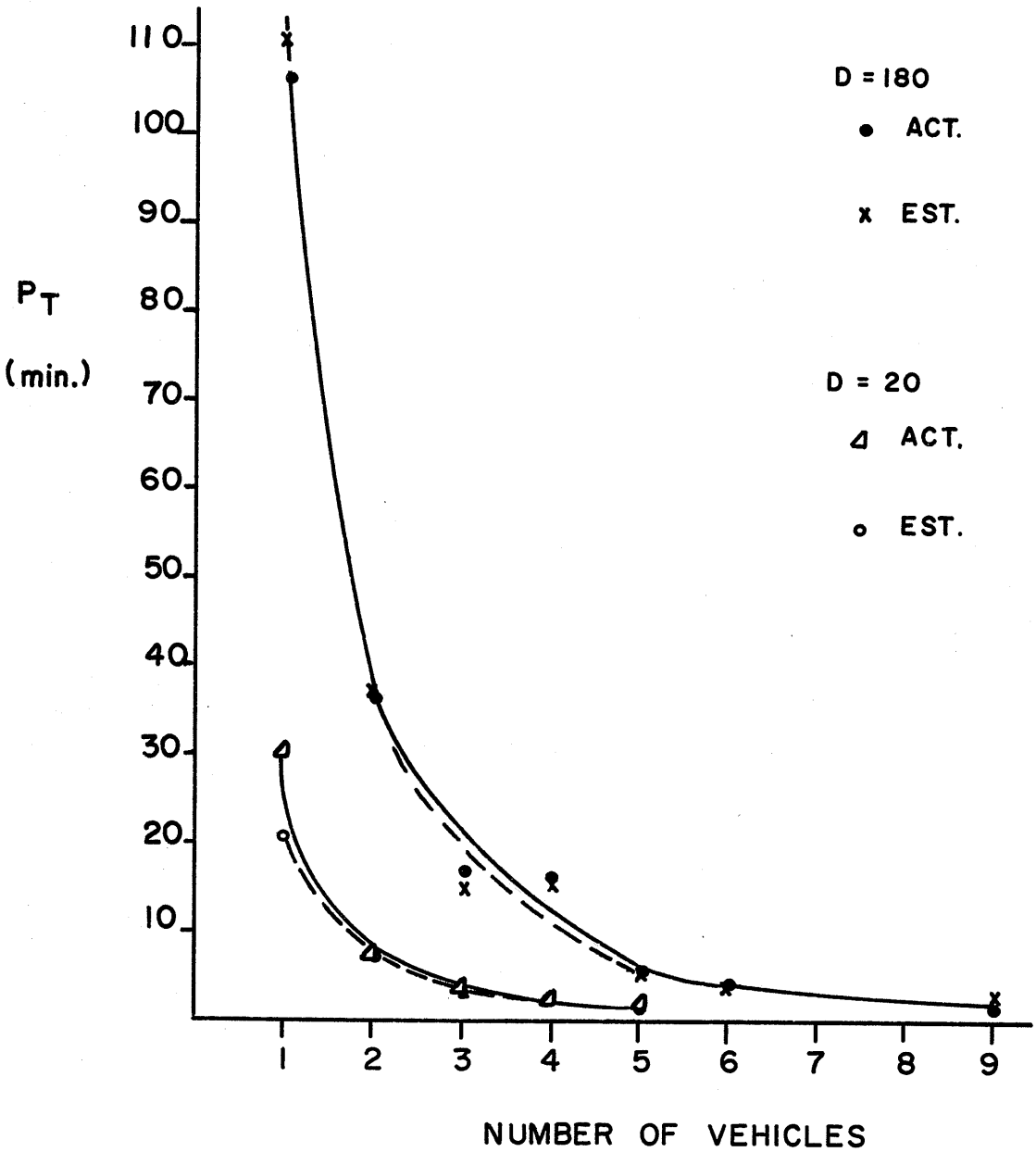
The first equation facilitated the 'linear' transformation requirement for a proper regression analysis. Therefore, the latter equation is the true form of the vehicle productivity time model.

A comparison of actual and estimated vehicle productivity times, listed in Table 9, indicates the high level of accuracy achieved by this model. The residuals in this table were given in minutes to better indicate the significance of this accuracy. Figure 16 shows the effect of fleet size on vehicle productivity time. The point estimates were obtained by calculating the average vehicle productivity time for the entire fleet, to satisfy all system demands. The curves for both the actual and estimated values are very close-fitting. As is shown in this figure, the model estimates that a single vehicle operating within the section of Fort Richmond chosen for this analysis, under a 'many-to-few' service would take 111.9 minutes

DEMAND LEVEL	NO. OF VEHICLES	CYCLE	$P_{T_{ACT}}$ (SEC.)	$P_{T_{EST}}$ (SEC.)	RESIDUAL (MIN.)
180/sq.mi.	1	1	407	450	+0.72
		2	778	979	+3.35
		3	1314	1277	-0.62
		4	1859	1923	+1.07
		5	2104	2085	-0.32
	2	1	329	321	-0.13
		2	869	865	-0.07
		3	1041	1149	+1.80
	3	1	358	353	-0.08
		2	622	585	-0.62
	4	1	500	485	-0.25
		2	496	450	-0.77
	5	1	325	321	-0.07
	6	1	283	259	-0.40
	9	1	113	142	+0.48
20/sq.mi.	1	1	1812	1259	-9.22
	2	1	479	515	+0.60
	3	1	264	270	+0.10
	4	1	169	151	-0.30
	5	1	128	139	+0.18

VEHICLE PRODUCTIVITY TIME
(ACTUAL AND ESTIMATED VALUES)

TABLE 9



RELATIONSHIP BETWEEN VEHICLE PRODUCTIVITY TIME AND VEHICLE FLEET SIZE

FIGURE 16

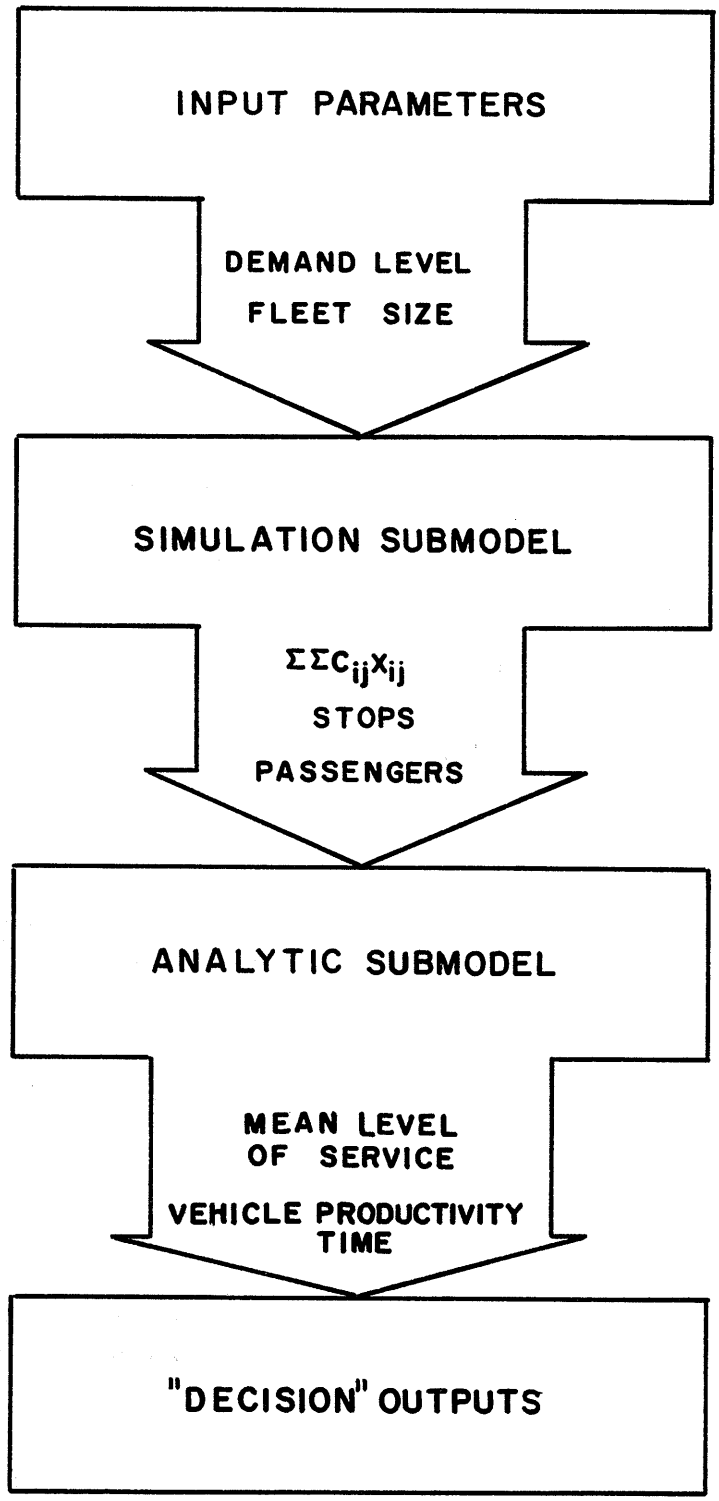
(1.87 hours) to satisfy all system requests for service at a demand level of 180 per square mile and 21.0 minutes to satisfy all system requests for service at a demand level of 20 per square mile. Five vehicles operating under the same conditions would take 5.4 and 2.3 minutes at the demand levels of 180 and 20 per square mile.

CHAPTER FIVE

CONCLUSIONS

A Decision Model has been developed to be used as a planning tool in the design of a demand responsive transit system. The relationship between the submodels, the flow of information within the model, the required input and the final output is shown in Figure 17. Any combination of the input parameters 'demand level' and'fleet size' can be introduced into the model. The simulation submodel generates the outputs $\Sigma\Sigma C_{ij} X_{ij}$, the number of stops made per vehicle and the number of passengers picked up per vehicle on the basis of the set of input parameters chosen by the planner. The output from the simulation submodel is then fed into the analytic submodel. The analytic submodel estimates the 'mean level of service' and the 'vehicle productivity time' related to the set of input parameters considered. On the basis of these results, a set of 'decision' outputs is offered to the planner.

Throughout the development phases of the Decision Model, the results obtained have demonstrated the utility of a combined simulation-analytic modelling approach to a complex problem. The model is based on the operation of many-to-few Dial-a-Bus system in a section of Fort Richmond. Deterministic principles are used with regards to the system demand. The assumption that the number and location of all system demands are known beforehand is promoted by the occurence of 'prebooking' for service experienced by existing demand responsive transit systems. Although the demands are generated from a uniform spatial distribution,



DECISION MODEL

FIGURE 17

any distribution would be valid in this model. A range of demand levels originating from the Fort Richmond area from the maximum demand realistically conceivable to a very low demand, ensured that model estimates at any anticipated demand level would be within the accuracy and reliablity levels already established for the model.

Providing for the basic needs and desires of the users at the initial stages of implementation of a Dial-a-Bus system is an important objective of design. To design a system that will be acceptable to the area residents requires an insight into the fundamental operational and functional characteristics of the proposed system before actual implementation. A new public transportation system that does not initially meet many of the needs and desires of the users may experience a trend of decreasing patronage. Later improvements to the system may not be sufficient to induce those persons who initially tried the system and found it deficient in meeting their needs.

Although the model was developed on the basis of some very simplified assumptions, it is felt that a good beginning has been made toward developing a useful tool for transportation planning. By introducing particular input parameters in question, the model can be used to perform a detailed sensitivity analysis on the utility of a Dial-a-Bus operation within an urban area before any demonstration project is implemented. The model provides a focus on rational and realistic policy decisions and the necessary tools for

effective systems planning. However, the final decision is, and always will be when systems modelling is concerned, dependent on good judgment by the systems designers because real-world situations are involved.

APPENDIX A

DERIVATION OF MAXIMUM DEMAND GENERATED FROM THE FORT RICHMOND AREA

DERIVATION OF THE MAXIMUM DEMAND GENERATED FROM THE FORT RICHMOND AREA

For the total residential area:

a.m. peak hour trips(excluding those to the University of Manitoba)

transit = 70
auto = 562 (includes both auto passenger and auto driver)

A factor was developed to estimate the proportion of trips that were generated from the section of Fort Richmond chosen to be modelled.

$$\text{factor} = \frac{\text{size of area chosen for modelling}}{\text{size of entire Fort Richmond area}}$$

$$= \frac{0.538 \text{ residential square miles}}{1.001 \text{ residential square miles}}$$

A.m. peak hour trips generated from the chosen section:

transit = 70 x 0.538 = 38
auto = 562 x 0.538 = 302

It was considered that 20% of the persons presently using the auto mode would be the maximum number that could be induced to the Dial-a-Bus mode if it were available. It was also assumed that 100% of the present transit users would continue to use the public transportation submode (Dial-a-Bus) if it were available.

Dial-a-Bus a.m. peak hour demand:

transit	= 38 x 100%	= 38
auto	= 302 x 20%	= 60
	total	= 98

APPENDIX B

MPS/360 COMPUTER LISTING FOR HYPOTHETICAL EXAMPLE

```
NAME          BUS
ROWS
 N  VALUE
 E  S
 L  A
 L  B
 L  C
 L  D
 L  E
 L  F
 L  G
 L  H
 G  MINA
 G  MINB
 G  MINC
 G  MIND
 G  MINE
 G  MINF
 G  MING
COLUMNS
    XSA       VALUE          2.70000   S                 1.00000
    XSA       A        -     1.00000   MINA              1.00000
    XSC       VALUE          3.10000   S                 1.00000
    XSC       C        -     1.00000   MINC              1.00000
    XSE       VALUE          2.90000   S                 1.00000
    XSE       E        -     1.00000   MINE              1.00000
    XSF       VALUE          2.30000   S                 1.00000
    XSF       F        -     1.00000   MINF              1.00000
    XAB       VALUE          1.20000   A                 1.00000
    XAB       B        -     1.00000   MINB              1.00000
    XAC       VALUE          1.60000   A                 1.00000
    XAC       C        -     1.00000   MINC              1.00000
    XAH       VALUE          2.70000   A                 1.00000
    XAH       H        -     1.00000
    XBA       VALUE          1.20000   A          -      1.00000
    XBA       B              1.00000   MINA              1.00000
    XBC       VALUE          1.60000   B                 1.00000
    XBC       C        -     1.00000   MINC              1.00000
    XCA       VALUE          1.60000   A          -      1.00000
    XCA       C              1.00000   MINA              1.00000
    XCB       VALUE          1.60000   B          -      1.00000
    XCB       C              1.00000   MINB              1.00000
    XCD       VALUE          1.40000   C                 1.00000
    XCD       D        -     1.00000   MIND              1.00000
    XCE       VALUE          1.20000   C                 1.00000
    XCE       E        -     1.00000   MINE              1.00000
    XCH       VALUE          3.10000   C                 1.00000
    XCH       H        -     1.00000
    XDC       VALUE          1.40000   C          -      1.00000
    XDC       D              1.00000   MINC              1.00000
    XDE       VALUE          1.40000   D                 1.00000
    XDE       E        -     1.00000   MINE              1.00000
    XDG       VALUE          1.40000   D                 1.00000
    XDG       G        -     1.00000   MING              1.00000
```

```
    XEC       VALUE          1.20000   C          -    1.00000
    XEC       E              1.00000   MINC           1.00000
    XED       VALUE          1.40000   D          -    1.00000
    XED       E              1.00000   MIND           1.00000
    XEF       VALUE          1.40000   E              1.00000
    XEF       F        -     1.00000   MINF           1.00000
    XEG       VALUE          1.40000   E              1.00000
    XEG       G        -     1.00000   MING           1.00000
    XEH       VALUE          2.80000   E              1.00000
    XEH       H        -     1.00000
    XFE       VALUE          1.40000   E          -    1.00000
    XFE       F              1.00000   MINF           1.00000
    XFG       VALUE          1.20000   F              1.00000
    XFG       G        -     1.00000   MING           1.00000
    XFH       VALUE          2.30000   E              1.00000
    XFH       H        -     1.00000
    XGD       VALUE          1.40000   D          -    1.00000
    XGD       G              1.00000   MIND           1.00000
    XGE       VALUE          1.40000   E          -    1.00000
    XGE       G              1.00000   MINE           1.00000
    XGF       VALUE          1.20000   F          -    1.00000
    XGF       G              1.00000   MINF           1.00000
RHS
    SUDE      S            951.00000   A          -  100.00000
    SUDE      B        -    50.00000   C          -  200.00000
    SUDE      D        -   150.00000   E          -   50.00000
    SUDE      F        -   100.00000   G          -  300.00000
    SUDE      H        -     1.00000   MINA            20.00000
    SUDE      MINB          10.00000   MINC            40.00000
    SUDE      MIND          15.00000   MINE            10.00000
    SUDE      MINF          20.00000   MING            60.00000
ENDATA
```

```
SETUP  PRFILE

TIME =    0.10

 MATRIX1  ASSIGNED TO MATRIX1

 ETA1     ASSIGNED TO ETA1

 SCRATCH1 ASSIGNED TO SCRATCH1
 SCRATCH2 ASSIGNED TO SCRATCH2

 MAXIMUM PRICING NOT REQUIRED - MAXIMUM POSSIBLE   7

 NO CYCLING

     POOLS          NUMBER    SIZE     CORE
 H.REG-BITS MAP                         80
 WORK   REGIONS       9       160     1440
 MATRIX BUFFERS       2      1168     2336
 ETA    BUFFERS       4      2288     9152

                            TOTAL  NORMAL  .FREE.   FIXED BOUNDED
 ROWS     (LOC.VAR.)         17      15       1        1       0
 COLUMNS (STR.VAR.)          28      28       0        0       0

      125 ELEMENTS - DENSITY =  16.33 -     2 MATRIX RECORDS (WITHOUT RHS'

PRIMAL        OBJ = VALUE        RHS = SUCE

TIME =     0.13  MINS.        PRICING    7
 SCALE =     .

   ITER   NUMBER  VECTOR  VECTOR  REDUCED      SUM
  NUMBER  INFEAS   OUT     IN      COST      INFEAS
M    1      13      2      20    3.00000-   1066.00
     2              4      28    1.00000-   1056.00
     3              7      39    1.00000-   1055.00
M    4       8     10      18    2.00000-    935.000
     5              3      26    2.00000-    770.000
     6              6      37    2.00000-    650.000
M    7       2      8      19    2.00000-    360.000
     8              5      34    2.00000-      .
 FEASIBLE SOLUTION

PRIMAL        OBJ = VALUE        RHS = SUCE

TIME =     0.15  MINS.        PRICING    7
 SCALE =     .
 SCALE RESET TO   1.00000

   ITER   NUMBER  VECTOR  VECTOR  REDUCED    FUNCTION
  NUMBER  NONOPT   OUT     IN      COST       VALUE
M    9      11     34      38    1.40000-   3640.80
```

EXECUTED . [illegible] V3- 1

	ITER NUMBER	NUMBER NONOPT	VECTOR OUT	VECTOR IN	REDUCED COST	FUNCTION VALUE
	10		37	21	2.[illegible]-	3440.[illegible]
	11		9	8	2.[illegible]-	3440.80
M	12	4	38	41	.[illegible]-	3200.00
	13		28	22	.[illegible]-	3160.80
	14		39	42	1.[illegible]-	3159.60

OPTIMAL SOLUTION

EXECUTOR. MPS/360 V2-M10

SECTION 1 - ROWS

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVITY
1	VALUE	BS	3159.60000	3159.60000-	NONE	NONE	1.00000
2	S	EQ	951.00000	.	951.00000	951.00000	2.30000-
3	A	UL	100.00000-	.	NONE	100.00000-	.40000
4	B	UL	50.00000-	.	NONE	50.00000-	1.60000
5	C	UL	200.00000-	.	NONE	200.00000-	.60000
6	D	UL	150.00000-	.	NONE	150.00000-	2.00000
7	E	UL	50.00000-	.	NONE	50.00000-	.60000
8	F	BS	100.00000-	.	NONE	100.00000-	.
9	G	UL	300.00000-	.	NONE	300.00000-	1.20000
10	H	UL	1.00000-	.	NONE	1.00000-	2.30000
11	MINA	BS	150.00000	130.00000-	20.00000	NONE	.
12	MINB	BS	50.00000	40.00000-	10.00000	NONE	.
13	MINC	BS	200.00000	160.00000-	40.00000	NONE	.
14	MIND	BS	150.00000	135.00000-	15.00000	NONE	.
15	MINE	BS	200.00000	190.00000-	10.00000	NONE	.
16	MINF	BS	401.00000	381.00000-	20.00000	NONE	.
17	MING	BS	300.00000	240.00000-	60.00000	NONE	.

SECTION 2 - COLUMNS

NUMBER	COLUMN	AT	ACTIVITY	INPUT COST	LOWER LIMIT	UPPER LIMIT	REDUCED COST
18	XSA	BS	150.00000	2.70000	.	NONE	.
19	XSC	BS	200.00000	3.10000	.	NONE	.
20	XSE	BS	200.00000	2.90000	.	NONE	.
21	XSF	BS	401.00000	2.30000	.	NONE	.
22	XAB	BS	50.00000	1.20000	.	NONE	.
23	XAC	LL	.	1.60000	.	NONE	1.2000
24	XAH	LL	.	2.70000	.	NONE	.8000
25	XBA	LL	.	1.20000	.	NONE	2.4000
26	XBC	LL	.	1.60000	.	NONE	2.4000
27	XCA	LL	.	1.60000	.	NONE	2.0000
28	XCB	LL	.	1.60000	.	NONE	.8000
29	XCD	LL	.	1.40000	.	NONE	.2000
30	XCE	LL	.	1.20000	.	NONE	1.4000
31	XCH	LL	.	3.10000	.	NONE	1.6000
32	XDC	LL	.	1.40000	.	NONE	2.6000
33	XDE	LL	.	1.40000	.	NONE	2.8000
34	XDG	LL	.	1.40000	.	NONE	2.2000
35	XEC	LL	.	1.20000	.	NONE	1.0000
36	XED	BS	150.00000	1.40000	.	NONE	.
37	XEF	LL	.	1.40000	.	NONE	2.0000
38	XEG	LL	.	1.40000	.	NONE	.8000
39	XEH	LL	.	2.90000	.	NONE	1.2000
40	XFE	LL	.	1.40000	.	NONE	.8000
41	XFG	BS	300.00000	1.20000	.	NONE	.
42	XFH	BS	1.00000	2.30000	.	NONE	.
43	XGD	LL	.	1.40000	.	NONE	.6000
44	XGE	LL	.	1.40000	.	NONE	2.0000
45	XGF	LL	.	1.20000	.	NONE	2.4000

```
NAME          BUS
ROWS
 N  VALUE
 E  S
 L  DUMMY
 L  A
 L  B
 L  C
 L  D
 L  E
 L  F
 L  G
 L  H
 G  MINA
 G  MINB
 G  MINC
 G  MIND
 G  MINE
 G  MINF
 G  MING
COLUMNS
    XSA       VALUE          2.70000   S                1.00000
    XSA       A        -     1.00000   MINA             1.00000
    XSC       VALUE          3.10000   S                1.00000
    XSC       C        -     1.00000   MINC             1.00000
    XSE       VALUE          2.90000   S                1.00000
    XSE       E        -     1.00000   MINE             1.00000
    XSF       VALUE          2.30000   S                1.00000
    XSF       F        -     1.00000   MINF             1.00000
    XZA       VALUE      99999.00000   A        -       1.00000
    XZA       MINA           1.00000
    XZC       VALUE      99999.00000   C        -       1.00000
    XZC       MINC           1.00000
    XZE       VALUE      99999.00000   E        -       1.00000
    XZE       MINE           1.00000
    XZF       VALUE      99999.00000   F        -       1.00000
    XZF       MINF           1.00000
    XAB       VALUE          1.20000   A                1.00000
    XAB       B        -     1.00000   MINB             1.00000
    XAC       VALUE          1.60000   A                1.00000
    XAC       C        -     1.00000   MINC             1.00000
    XAH       VALUE          2.70000   A                1.00000
    XAH       H        -     1.00000
    XBA       VALUE          1.20000   A        -       1.00000
    XBA       B              1.00000   MINA             1.00000
    XBC       VALUE          1.60000   B                1.00000
    XBC       C        -     1.00000   MINC             1.00000
    XCA       VALUE          1.60000   A        -       1.00000
    XCA       C              1.00000   MINA             1.00000
    XCB       VALUE          1.60000   B        -       1.00000
    XCB       C              1.00000   MINB             1.00000
    XCD       VALUE          1.40000   C                1.00000
    XCD       D        -     1.00000   MIND             1.00000
    XCE       VALUE          1.20000   C                1.00000
```

```
    XCE       E          -    1.00000    MINE          1.00000
    XCH       VALUE        3.10000    C             1.00000
    XCH       H          -    1.00000
    XDC       VALUE        1.40000    C          -  1.00000
    XDC       D            1.00000    MINC          1.00000
    XDE       VALUE        1.40000    D             1.00000
    XDE       E          -    1.00000    MINE          1.00000
    XDG       VALUE        1.40000    D             1.00000
    XDG       G          -    1.00000    MING          1.00000
    XEC       VALUE        1.20000    C          -  1.00000
    XEC       E            1.00000    MINC          1.00000
    XED       VALUE        1.40000    D          -  1.00000
    XED       E            1.00000    MIND          1.00000
    XEF       VALUE        1.40000    E             1.00000
    XEF       F          -    1.00000    MINF          1.00000
    XEG       VALUE        1.40000    E             1.00000
    XEG       G          -    1.00000    MING          1.00000
    XEH       VALUE        2.90000    E             1.00000
    XEH       H          -    1.00000
    XFE       VALUE        1.40000    E          -  1.00000
    XFE       F            1.00000    MINF          1.00000
    XFG       VALUE        1.20000    F             1.00000
    XFG       G          -    1.00000    MING          1.00000
    XFH       VALUE        2.30000    F             1.00000
    XFH       H          -    1.00000
    XGD       VALUE        1.40000    D          -  1.00000
    XGD       G            1.00000    MIND          1.00000
    XGE       VALUE        1.40000    E          -  1.00000
    XGE       G            1.00000    MINE          1.00000
    XGF       VALUE        1.20000    F          -  1.00000
    XGF       G            1.00000    MINF          1.00000
RHS
    SUDE      S          401.00000    DUMMY       550.00000
    SUDE      A          -  100.00000    B        -   50.00000
    SUDE      C          -  200.00000    C        -  150.00000
    SUDE      E          -   50.00000    F        -  100.00000
    SUDE      G          -  300.00000    H        -    1.00000
    SUDE      MINA         20.00000    MINB         10.00000
    SUDE      MINC         40.00000    MIND         15.00000
    SUDE      MINE         10.00000    MINF         20.00000
    SUDE      MING         60.00000
ENDATA
```

```
SETUP  PBFILE

TIME =    0.19

 MATRIX1  ASSIGNED TO MATRIX1

 ETA1     ASSIGNED TO ETA1

 SCRATCH1 ASSIGNED TC SCRATCH1
 SCRATCH2 ASSIGNED TC SCRATCH2

 MAXIMUM PRICING NOT REQUIRED - MAXIMUM POSSIBLE   7

 NO CYCLING

     POOLS          NUMBER    SIZE     CORE
 H.REG-BITS MAP                          84
 WORK   REGIONS       9       168      1512
 MATRIX BUFFERS       3      1072      3216
 ETA    BUFFERS       4      2288      9152

                          TOTAL  NORMAL  .FREE.   FIXED BOUNDED
 ROWS     (LOG.VAR.)        18      15       1       2       0
 COLUMNS  (STR.VAR.)        32      32       0       0       0

       138 ELEMENTS - DENSITY =  15.33 -     2 MATRIX RECORDS (WITHOUT RHS'


PRIMAL        OBJ = VALUE        RHS = SUDE

TIME =     C.23  MINS.        PRICING    7
 SCALE =     .

   ITER   NUMBER  VECTOR  VECTOR  REDUCED      SUM
  NUMBER  INFEAS   OUT     IN     COST      INFEAS
M    1      13      2      21   3.00000-   1066.00
     2              8      44   1.00000-   1065.00
M    3      1C      7      41   2.00000-    900.000
     4              9      26   2.00000-    780.000
     5              4      23   2.00000-    660.000
     6              5      27   2.00000-    600.000
M    7       2     10      46   2.00000-    240.000
     8             11      20   2.00000-      .
 FEASIBLE SOLUTION

PRIMAL        OBJ = VALUE        RHS = SUDE

TIME =     C.25  MINS.        PRICING    7
 SCALE =     .
 SCALE RESET TC   1.00000

   ITER   NUMBER  VECTOR  VECTOR  REDUCED    FUNCTION
  NUMBER  NONOPT   OUT     IN     COST       VALUE
M    9       8      6      22   99999.8-   .55E+08
```

EXECUTOR. MPS/360 V2-M10

	ITER NUMBER	NUMBER NONOPT	VECTOR OUT	VECTOR IN	REDUCED COST	FUNCTION VALUE
M	10	4	20	24	.80000-	.55E+08
	11		26	25	.60000-	.55E+08
	12		44	47	1.20000-	.55E+08
M	13	1	21	19	.20000-	.55E+08

OPTIMAL SOLUTION

EXECUTOR. MPS/360 V2-M10

SOLUTION (OPTIMAL)

TIME = 0.26 MINS. ITERATION NUMBER = 13

...NAME...	...ACTIVITY...	DEFINED AS
FUNCTIONAL	55001004.6000	VALUE
RESTRAINTS		SUDE

EXECUTOR. MPS/360 V2-M10

SECTION 1 - ROWS

NUMBER	...ROW..	AT	...ACTIVITY...	SLACK ACTIVITY	..LOWER LIMIT.	..UPPER LIMIT.	.DUAL ACTIVIT
1	VALUE	BS	55001004.6000	55001004.6000-	NONE	NONE	1.00000
2	S	EQ	401.00000	.	401.00000	401.00000	99996.30000
3	DUMMY	BS	.	550.00000	NONE	550.00000	.
4	A	UL	100.00000-	.	NONE	100.00000-	99999.00000
5	B	UL	50.00000-	.	NONE	50.00000-	100000.20000
6	C	UL	200.00000-	.	NONE	200.00000-	99999.00000
7	D	EQ	150.00000-	.	150.00000-	150.00000-	100000.40000
8	E	UL	50.00000-	.	NONE	50.00000-	99999.00000
9	F	UL	100.00000-	.	NONE	100.00000-	99998.60000
10	G	UL	300.00000-	.	NONE	300.00000-	99999.80000
11	H	UL	1.00000-	.	NONE	1.00000-	100000.90000
12	MINA	BS	150.00000	130.00000-	20.00000	NONE	.
13	MINB	BS	50.00000	40.00000-	10.00000	NONE	.
14	MINC	BS	200.00000	160.00000-	40.00000	NONE	.
15	MIND	BS	150.00000	135.00000-	15.00000	NONE	.
16	MINE	BS	200.00000	190.00000-	10.00000	NONE	.
17	MINF	BS	401.00000	381.00000-	20.00000	NONE	.
18	MING	BS	300.00000	240.00000-	60.00000	NONE	.

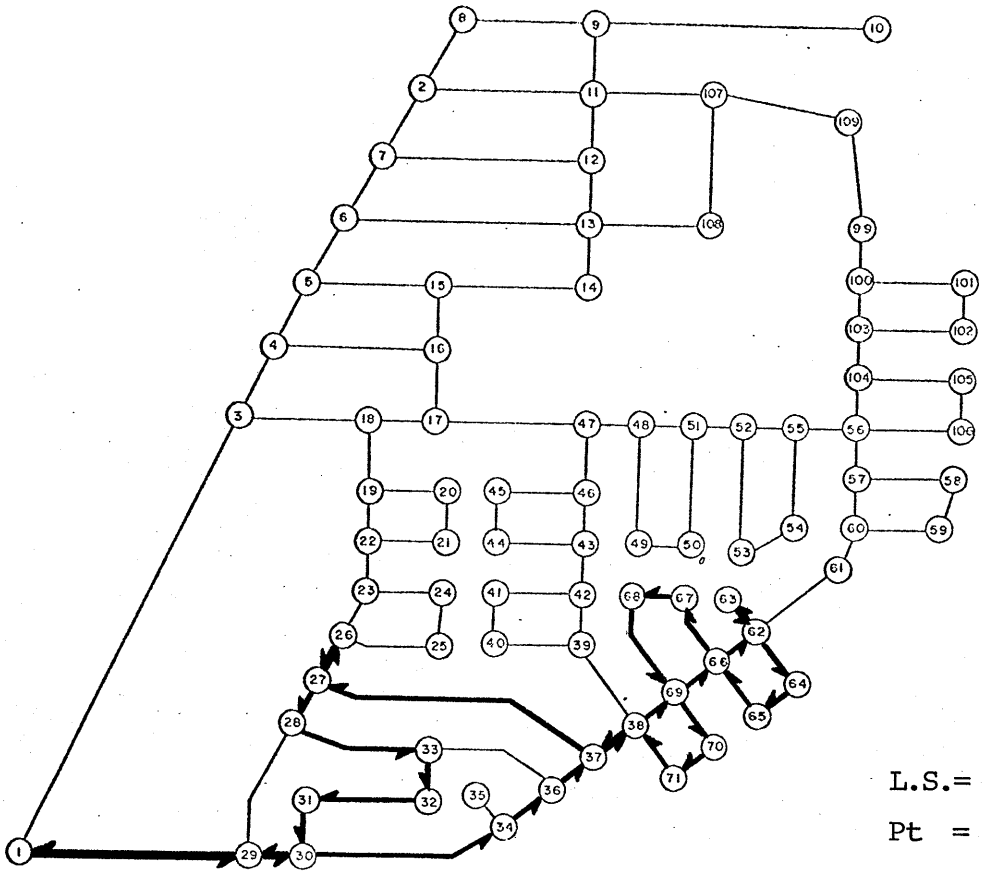
SECTION 2 - COLUMNS

NUMBER	COLUMN	AT	ACTIVITY	INPUT COST	LOWER LIMIT	UPPER LIMIT	REDUCED COST
19	XSA	BS	.	2.70000	.	NONE	.
20	XSC	LL	.	3.10000	.	NONE	.40000
21	XSE	LL	.	2.90000	.	NONE	.20000
22	XSF	BS	401.00000	2.30000	.	NONE	.
23	XZA	BS	150.00000	99999.00000	.	NONE	.
24	XZC	BS	200.00000	99999.00000	.	NONE	.
25	XZE	BS	200.00000	99999.00000	.	NONE	.
26	XZF	LL	.	99999.00000	.	NONE	.40000
27	XAB	BS	50.00000	1.20000	.	NONE	.
28	XAC	LL	.	1.60000	.	NONE	1.60000
29	XAH	LL	.	2.70000	.	NONE	.80000
30	XBA	LL	.	1.20000	.	NONE	2.40000
31	XBC	LL	.	1.60000	.	NONE	2.80000
32	XCA	LL	.	1.60000	.	NONE	1.60000
33	XCB	LL	.	1.60000	.	NONE	.40000
A 34	XCD	LL	.	1.40000	.	NONE	.
35	XCE	LL	.	1.20000	.	NONE	1.20000
36	XCH	LL	.	3.10000	.	NONE	1.20000
37	XDC	LL	.	1.40000	.	NONE	2.80000
38	XDE	LL	.	1.40000	.	NONE	2.80000
39	XDG	LL	.	1.40000	.	NONE	2.00000
40	XEC	LL	.	1.20000	.	NONE	1.20000
41	XED	BS	150.00000	1.40000	.	NONE	.
42	XEF	LL	.	1.40000	.	NONE	1.80000
43	XEG	LL	.	1.40000	.	NONE	.60000
44	XEH	LL	.	2.90000	.	NONE	1.00000
45	XFE	LL	.	1.40000	.	NONE	1.00000
46	XFG	BS	300.00000	1.20000	.	NONE	.
47	XFH	BS	1.00000	2.30000	.	NONE	.
48	XGD	LL	.	1.40000	.	NONE	.80000
49	XGE	LL	.	1.40000	.	NONE	2.20000
50	XGF	LL	.	1.20000	.	NONE	2.40000

APPENDIX C

MANUAL VEHICLE ROUTE ASSIGNMENT OUTPUT

SIMULATION 1 CYCLE 1 VEHICLE 1

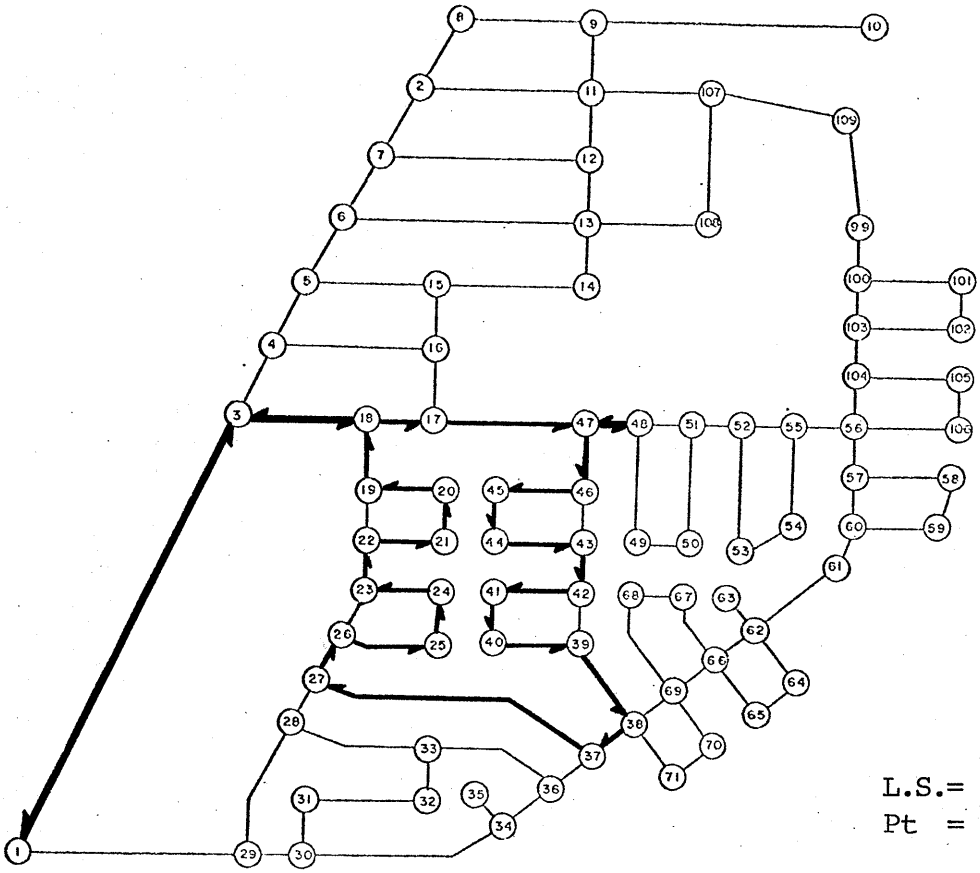


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

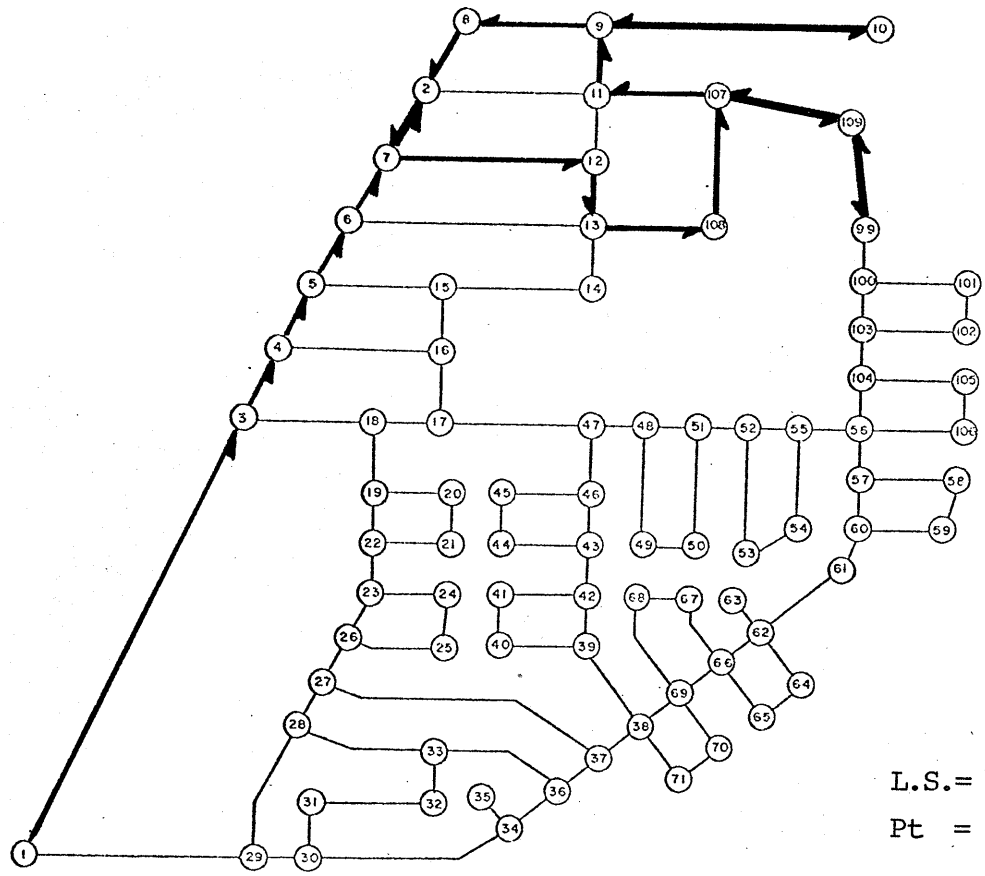
SIMULATION 1 CYCLE 2 VEHICLE 1



L.S.= 16.1
Pt = 778

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	909	42	21.6
2	17	909	42	21.6
3	48	882	64	13.8
4	47	864	61	14.2
5	47	864	61	14.2
6	47	864	61	14.2
7	45	840	62	13.6
8	43	817	54	15.1
9	42	799	51	15.7
10	41	779	56	13.9
11	40	761	53	14.3
12	39	741	48	15.4
13	24	686	37	18.5
14	23	667	33	20.2
15	22	649	36	18.0
16	21	630	40	15.8
17	19	607	39	15.6
18	19	607	39	15.6
19	18	588	38	15.4
20	3	565	30	18.8
21	3	565	30	18.8
22	3	565	30	18.8

SIMULATION 1 CYCLE 3 VEHICLE 1

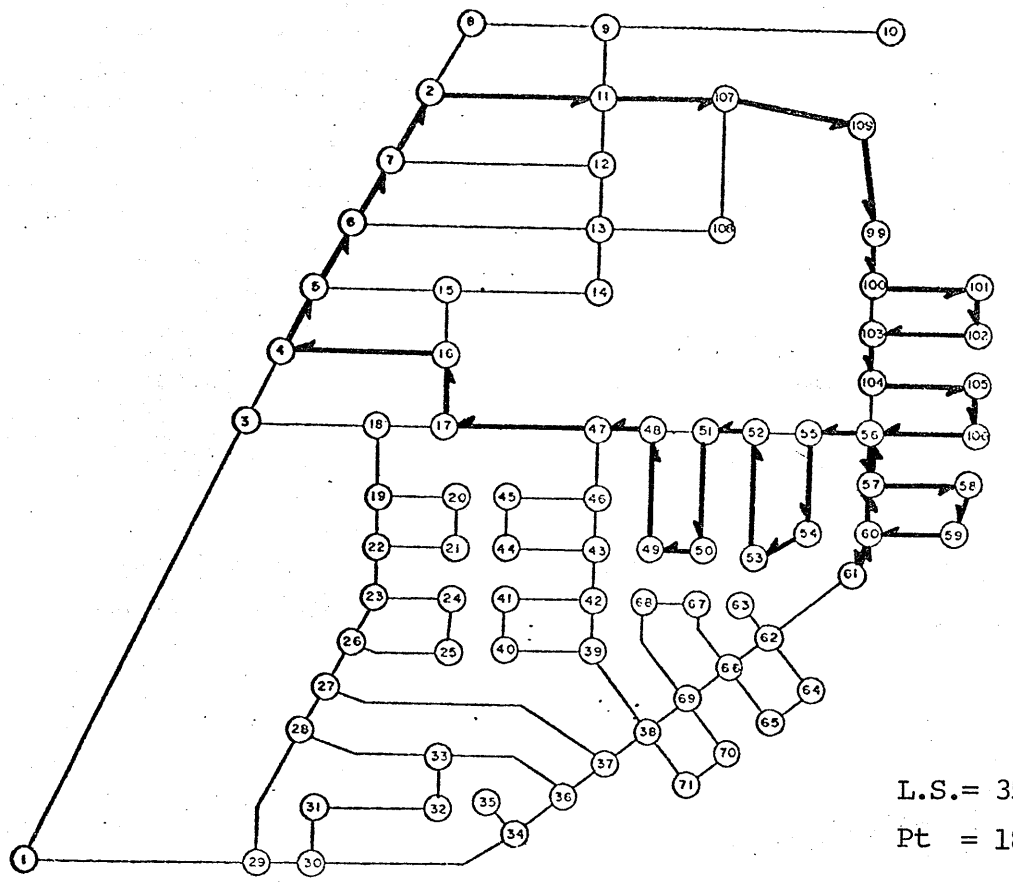


L.S.= 63.7

Pt = 1314

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	1335	5	267.0
2	7	1335	5	267.0
3	12	1307	14	93.4
4	12	1307	14	93.4
5	12	1307	14	93.4
6	108	1281	25	51.2
7	108	1281	25	51.2
8	108	1281	25	51.2
9	108	1281	25	51.2
10	99	1241	34	36.3
11	99	1241	34	36.3
12	109	1218	26	46.8
13	107	1194	17	70.2
14	107	1194	17	70.2
15	107	1194	17	70.2
16	107	1194	17	70.2
17	11	1172	10	117.2
18	11	1172	10	117.2
19	10	1135	31	36.5
20	10	1135	31	36.5
21	9	1102	13	85.7
22	9	1102	13	85.7

SIMULATION 1 CYCLE 4 VEHICLE 1

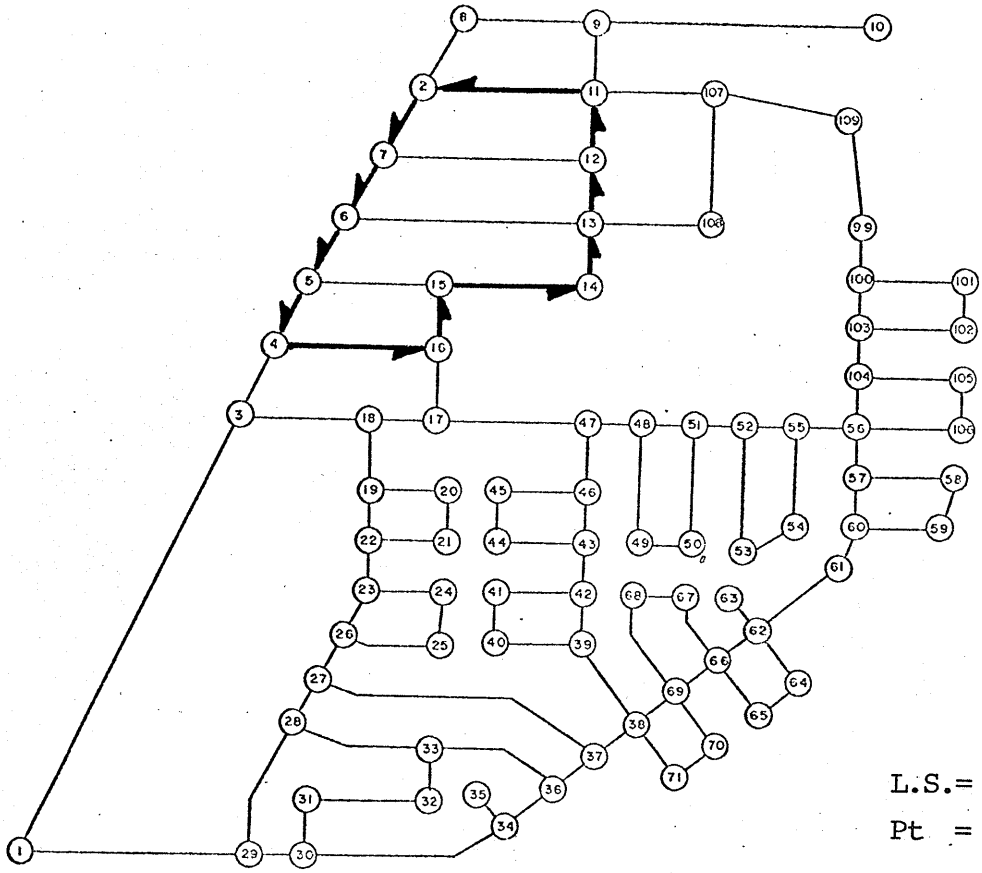


L.S.= 35.4

Pt = 1859

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	100	1880	37	50.6
2	101	1859	43	43.2
3	102	1841	46	40.1
4	103	1820	40	45.7
5	105	1796	49	36.7
6	59	1760	57	30.9
7	61	1738	54	32.3
8	60	1721	52	33.2
9	57	1703	49	34.9
10	56	1685	46	36.7
11	54	1660	56	29.7
12	54	1660	56	29.7
13	52	1633	53	30.8
14	52	1633	53	30.8
15	51	1615	52	31.1
16	51	1615	52	31.1
17	50	1596	59	27.1
18	49	1578	56	28.2
19	49	1578	56	28.2
20	16	1537	30	51.3
21	16	1537	30	51.3
22	6	1502	10	150.2

SIMULATION 1 CYCLE 5 VEHICLE 1

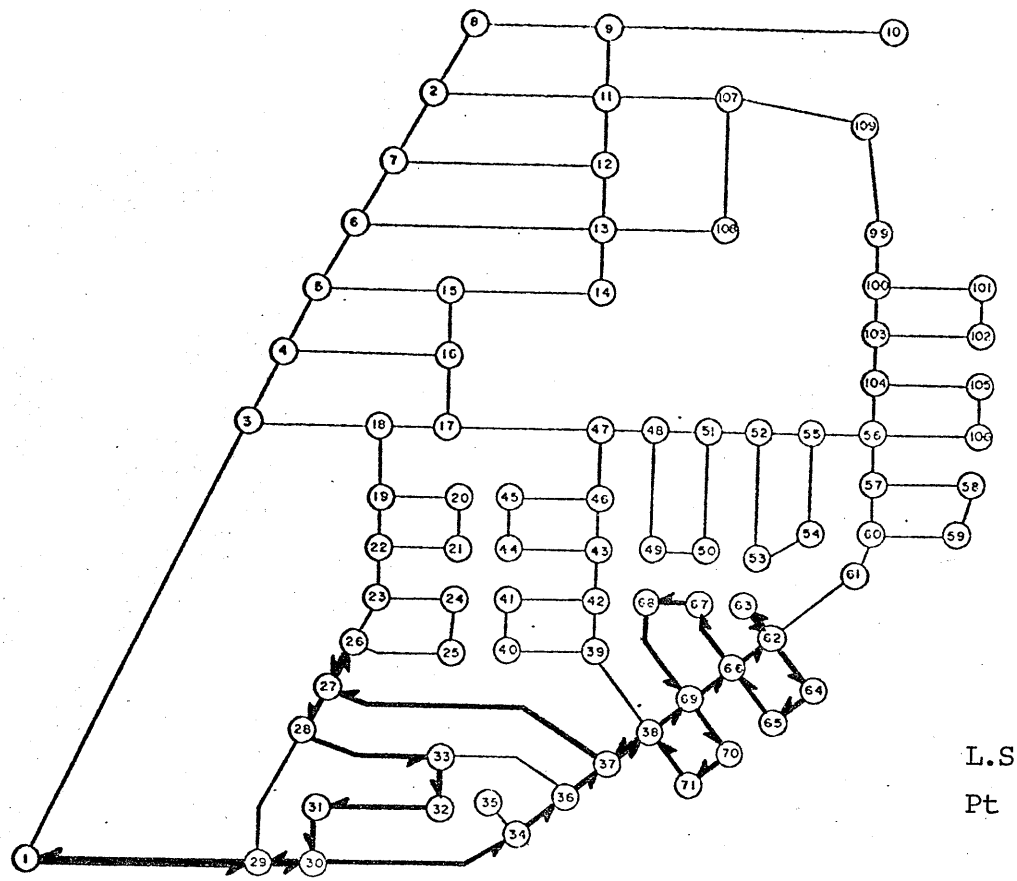


L.S.= 101.4

Pt = 2104

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	5	2125	15	141.6
2	4	2105	20	105.3
3	4	2105	20	105.3
4	15	2076	23	90.1
5	15	2076	23	90.1
6	14	2052	22	93.4
7	14	2052	22	93.4
8	14	2052	22	93.4
9	13	2033	18	112.9
10	13	2033	18	112.9

SIMULATION 2 CYCLE 1 VEHICLE 1

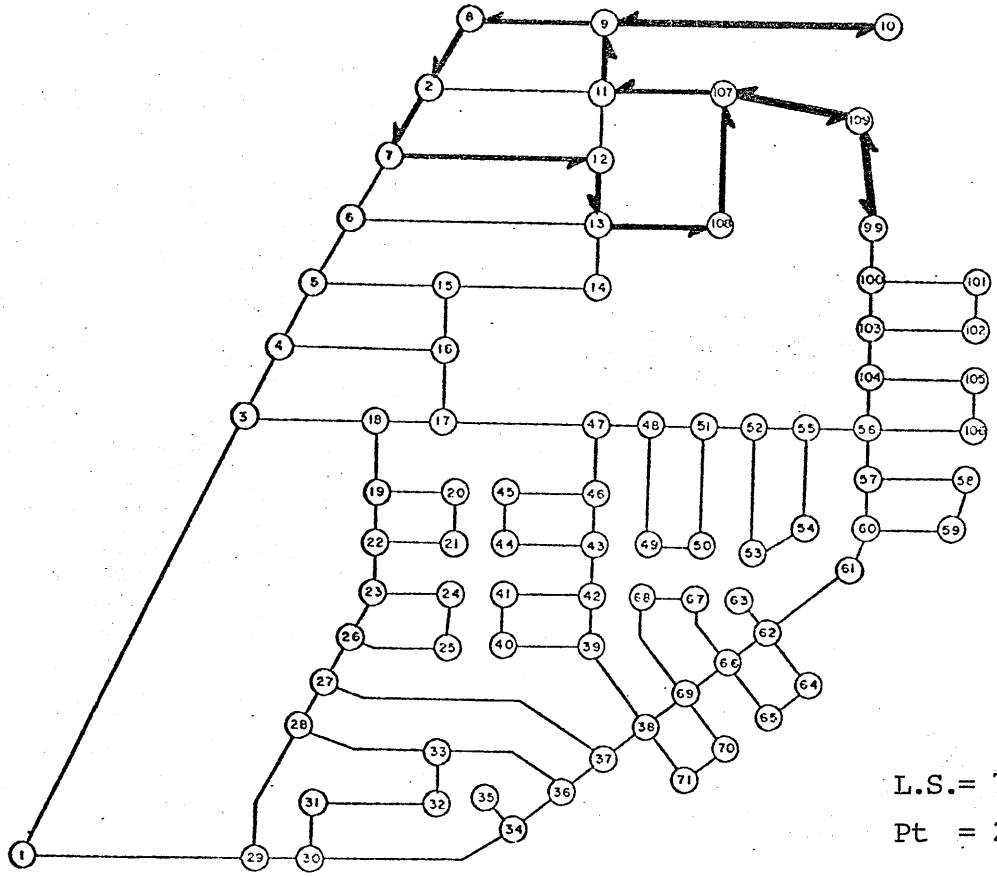


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

SIMULATION 2 CYCLE 1 VEHICLE 2

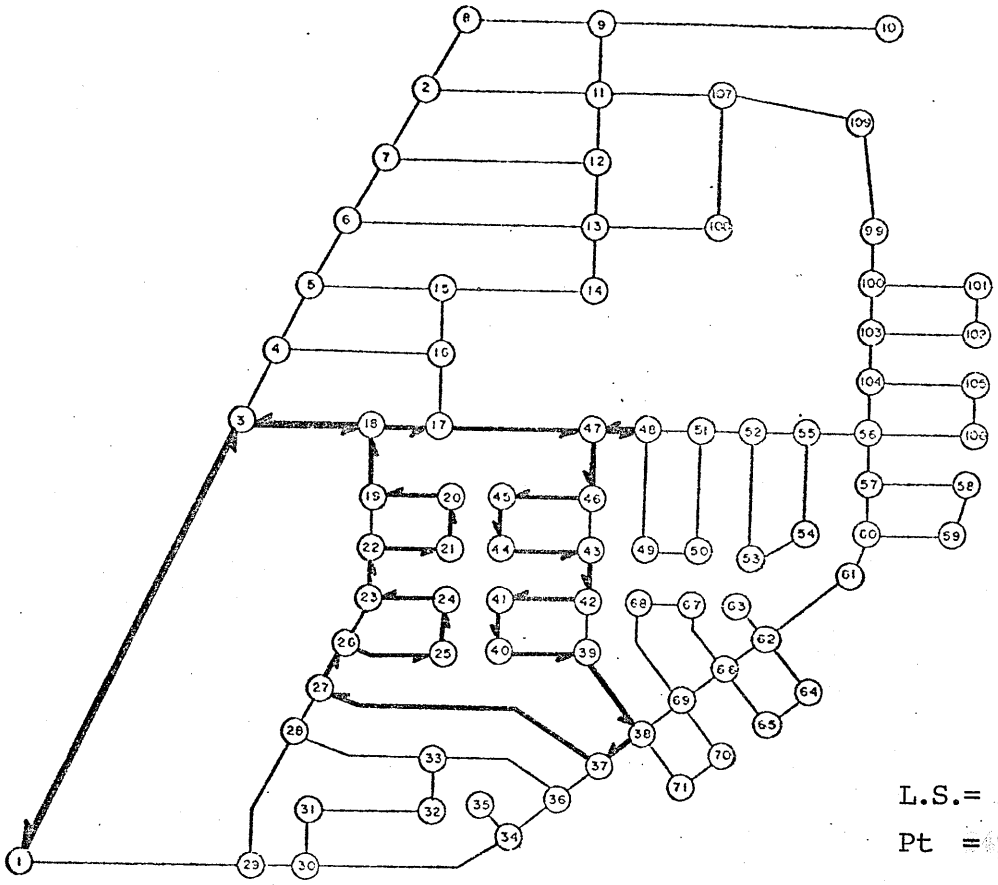


L.S.= 7.2

Pt = 251

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	246	5	49.3
2	7	246	5	49.3
3	12	218	14	15.6
4	12	218	14	15.6
5	12	218	14	15.6
6	108	192	25	7.7
7	108	192	25	7.7
8	108	192	25	7.7
9	108	192	25	7.7
10	99	152	34	4.5
11	99	152	34	4.5
12	109	129	26	5.0
13	107	105	17	6.2
14	107	105	17	6.2
15	107	105	17	6.2
16	107	105	17	6.2
17	11	83	10	8.3
18	11	83	10	8.3
19	10	46	31	1.5
20	10	46	31	1.5
21	9	13	13	1.0
22	9	13	13	1.0

SIMULATION 2 CYCLE 2 VEHICLE 1

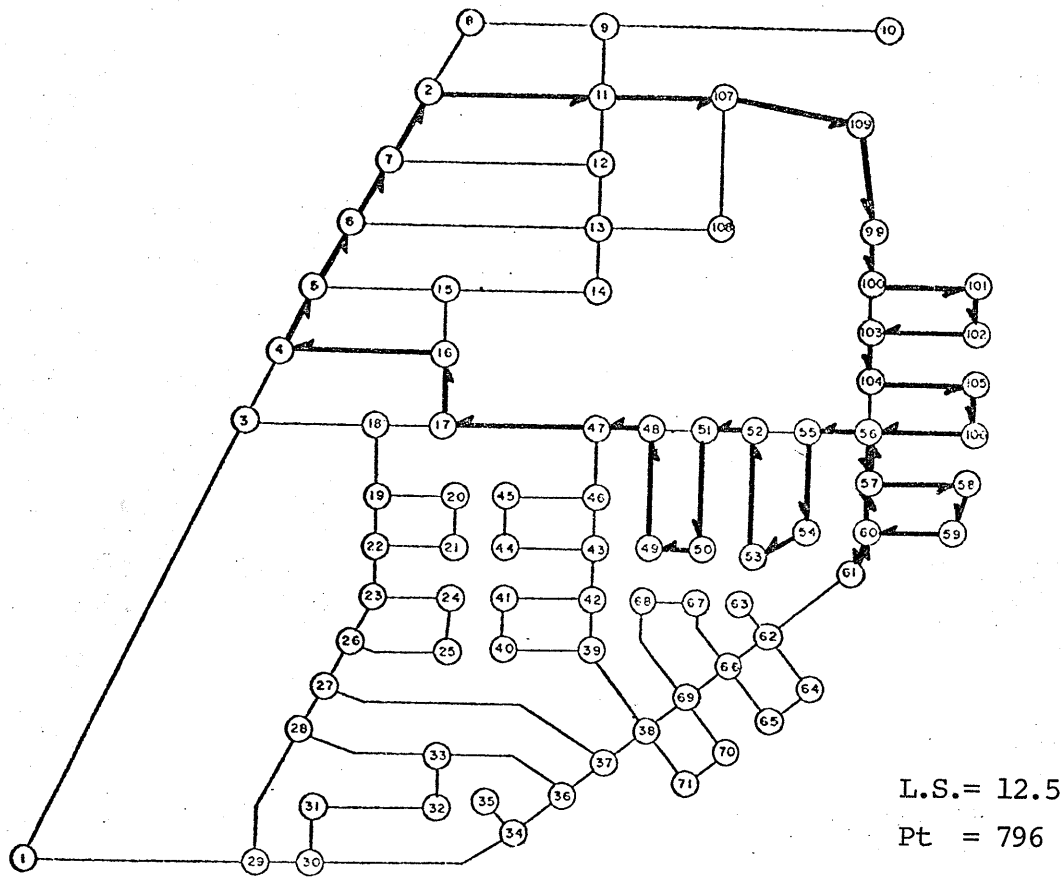


L.S.= 16.0

Pt = 943

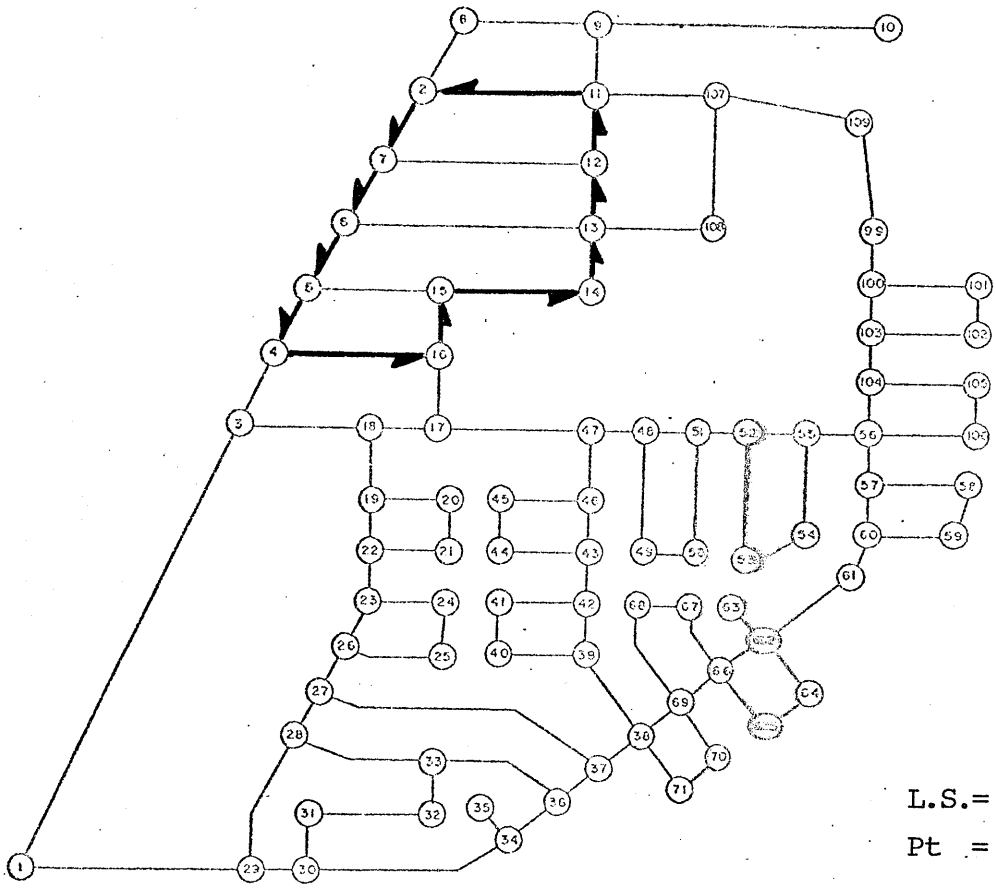
ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	909	42	21.6
2	17	909	42	21.6
3	48	882	64	13.8
4	47	864	61	14.2
5	47	864	61	14.2
6	47	864	61	14.2
7	45	840	62	13.6
8	43	817	54	15.1
9	42	799	51	15.7
10	41	779	56	13.9
11	40	761	53	14.3
12	39	741	48	15.4
13	24	686	37	18.5
14	23	667	33	20.2
15	22	649	36	18.0
16	21	630	40	15.8
17	19	607	39	15.6
18	19	607	39	15.6
19	18	588	38	15.4
20	3	565	30	18.8
21	3	565	30	18.8
22	3	565	30	18.8

SIMULATION 2 CYCLE 2 VEHICLE 2



ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	649	5	129.8
2	7	649	5	129.8
3	12	621	14	44.4
4	12	621	14	44.4
5	12	621	14	44.4
6	108	595	25	23.8
7	108	595	25	23.8
8	108	595	25	23.8
9	108	595	25	23.8
10	99	555	34	16.3
11	99	555	34	16.3
12	109	532	26	20.3
13	107	508	17	30.0
14	107	508	17	30.0
15	107	508	17	30.0
16	107	508	17	30.0
17	11	486	10	48.6
18	11	486	10	48.6
19	10	449	31	14.5
20	10	449	31	14.5
21	9	416	13	32.1
22	9	416	13	32.1

SIMULATION 2 CYCLE 3 VEHICLE 2

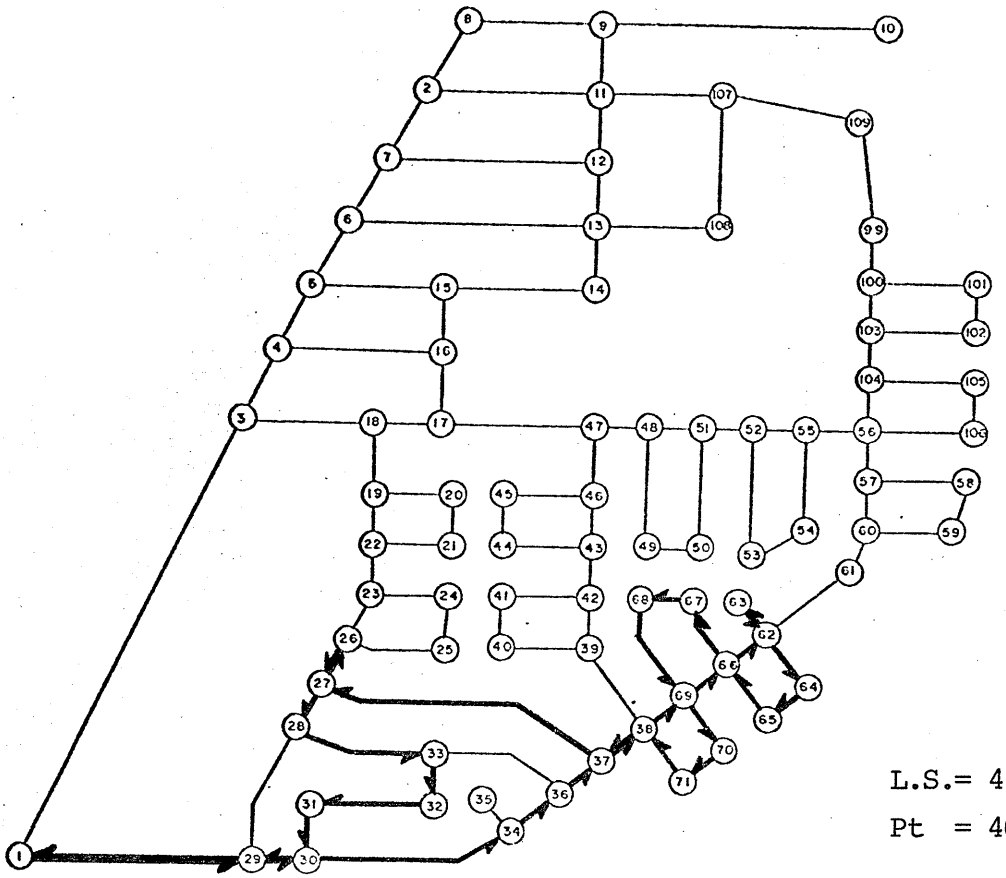


L.S.= 48.3

Pt = 1041

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	5	894	15	59.7
2	4	874	20	43.7
3	4	874	20	43.7
4	15	845	23	36.7
5	15	845	23	36.7
6	14	821	22	37.4
7	14	821	22	37.4
8	14	821	22	37.4
9	13	802	18	44.6
10	13	802	18	44.6

SIMULATION 3 CYCLE 1 VEHICLE 1

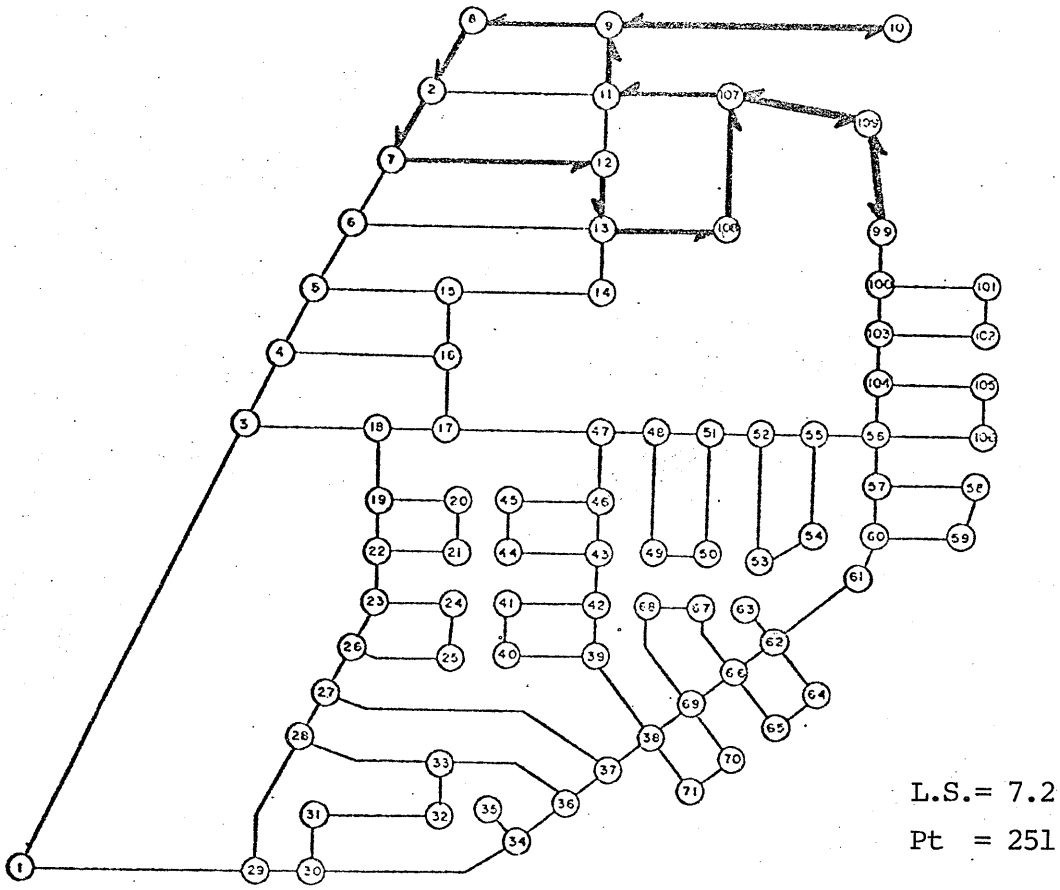


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

SIMULATION 3 CYCLE 1 VEHICLE 2

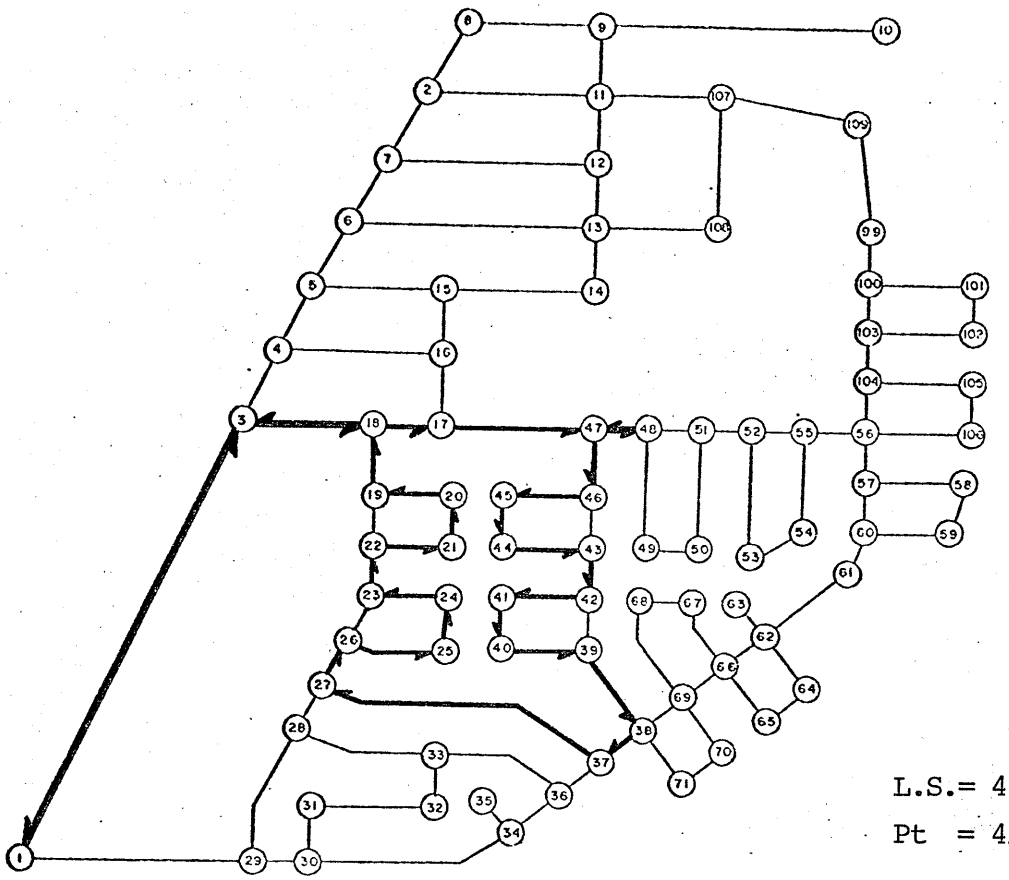


L.S.= 7.2

Pt = 251

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	246	5	49.3
2	7	246	5	49.3
3	12	218	14	15.6
4	12	218	14	15.6
5	12	218	14	15.6
6	108	192	25	7.7
7	108	192	25	7.7
8	108	192	25	7.7
9	108	192	25	7.7
10	99	152	34	4.5
11	99	152	34	4.5
12	109	129	26	5.0
13	107	105	17	6.2
14	107	105	17	6.2
15	107	105	17	6.2
16	107	105	17	6.2
17	11	83	10	8.3
18	11	83	10	8.3
19	10	46	31	1.5
20	10	46	31	1.5
21	9	13	13	1.0
22	9	13	13	1.0

SIMULATION 3 CYCLE 1 VEHICLE 3

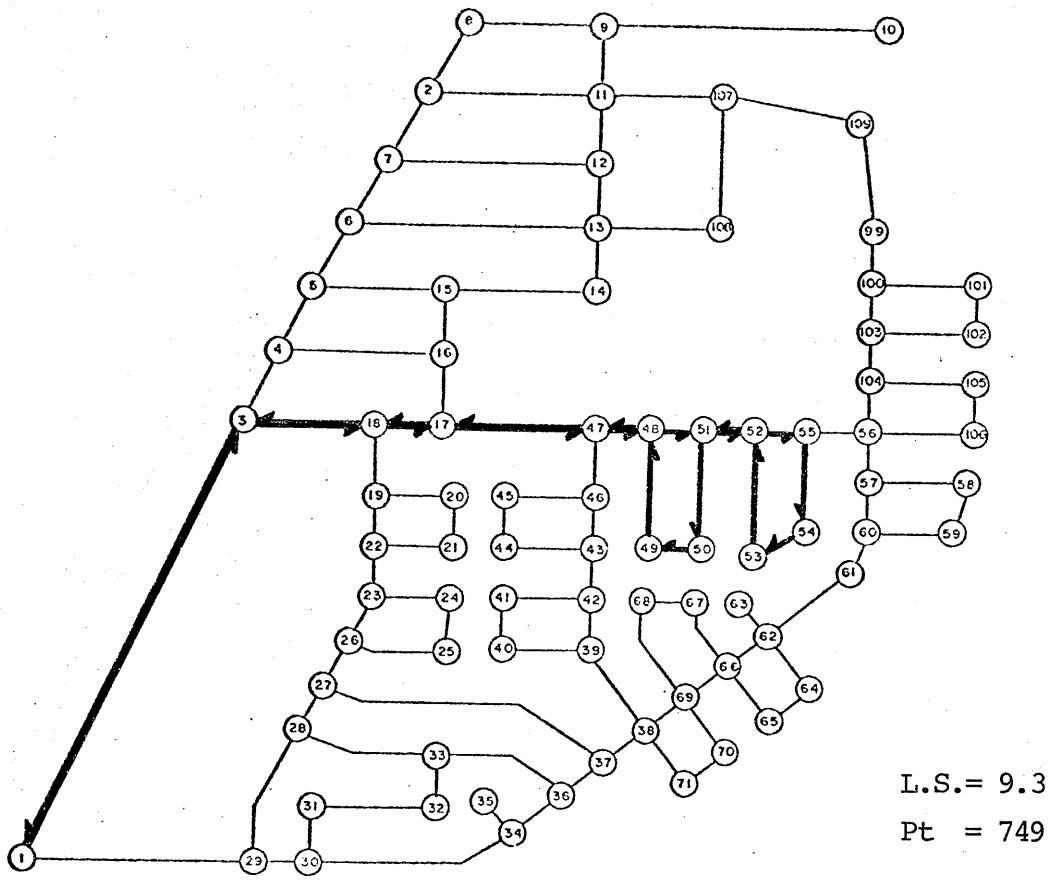


L.S.= 4.3

Pt = 416

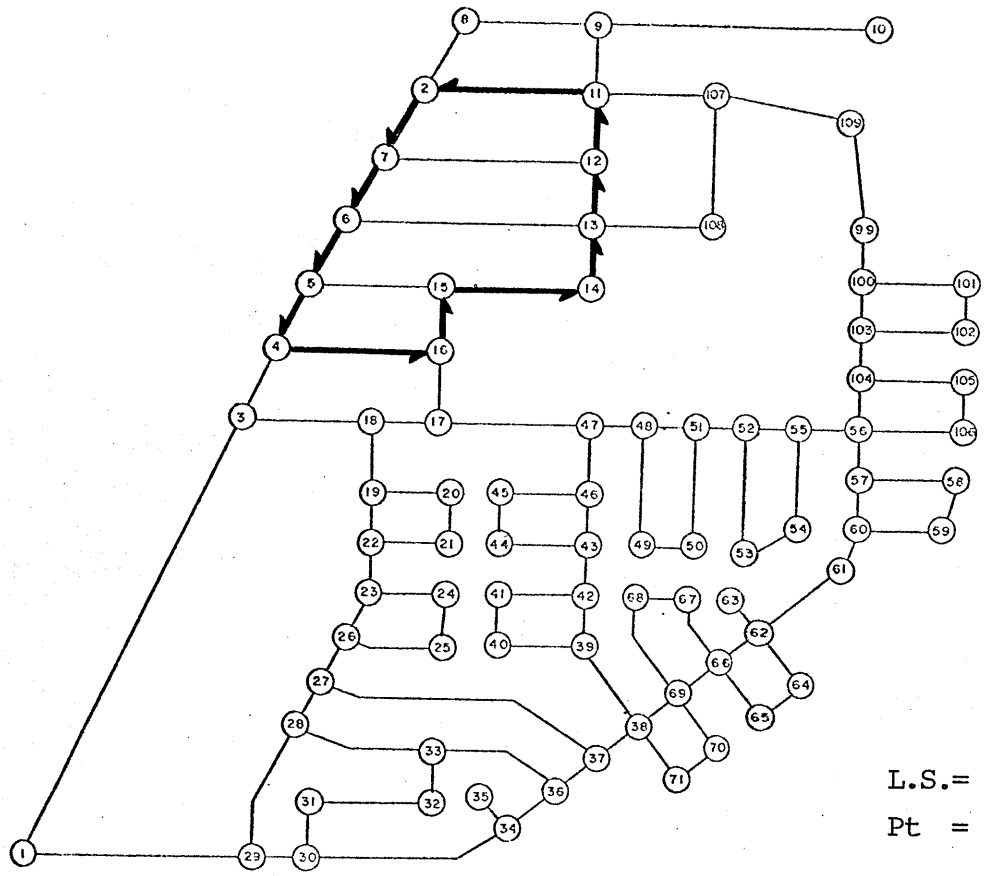
ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	374	42	8.9
2	17	374	42	8.9
3	48	347	64	5.4
4	47	329	61	5.4
5	47	329	61	5.4
6	47	329	61	5.4
7	45	305	62	4.9
8	43	282	54	5.2
9	42	264	51	5.2
10	41	244	56	4.4
11	40	226	53	4.3
12	39	206	48	4.3
13	24	151	37	4.1
14	23	132	33	4.0
15	22	114	36	3.2
16	21	95	40	2.4
17	19	72	39	1.8
18	19	72	39	1.8
19	18	53	38	1.4
20	3	30	30	1.0
21	3	30	30	1.0
22	3	30	30	1.0

SIMUALTION 3 CYCLE 2 VEHICLE 1



ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	54	703	76	9.3
2	54	703	76	9.3
3	52	676	70	9.6
4	52	676	70	9.6
5	51	658	67	9.8
6	51	658	67	9.8
7	50	636	74	8.6
8	49	618	61	10.1
9	49	618	61	10.1

SIMULATION 3 CYCLE 2 VEHICLE 2

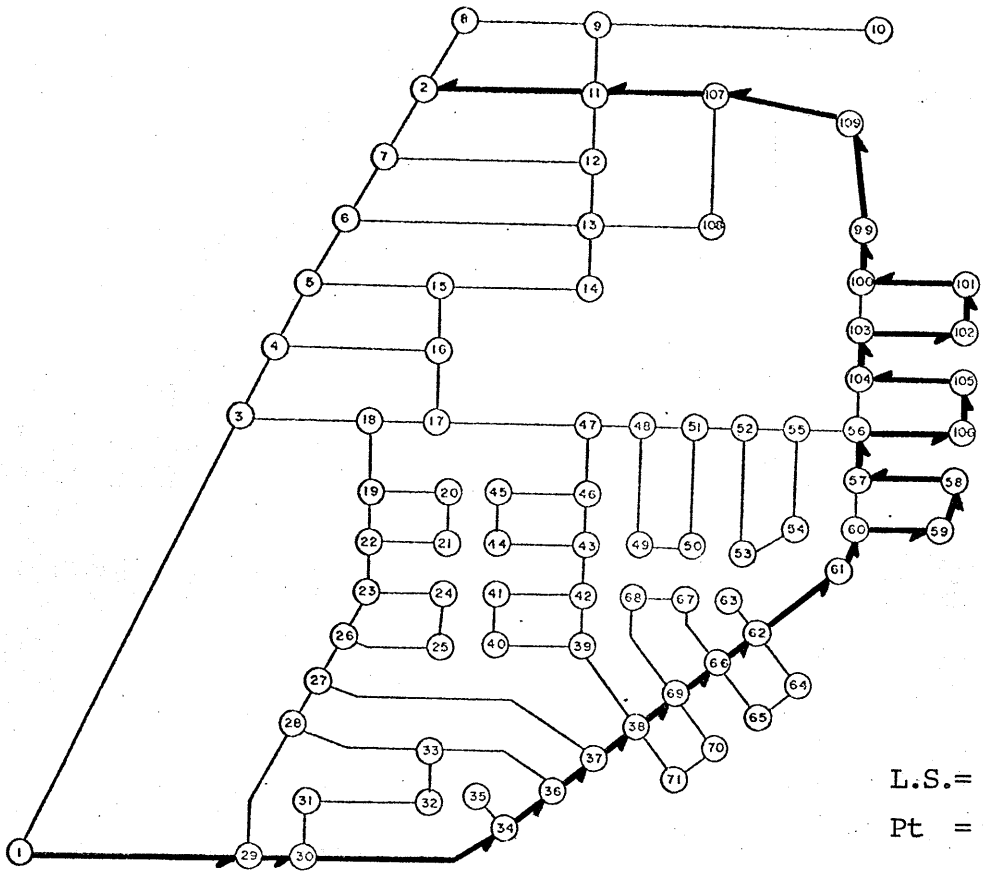


L.S.= 21.7

Pt = 526

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	6	521	10	52.1
2	5	501	15	33.4
3	4	481	20	24.1
4	4	481	20	24.1
5	16	455	27	16.8
6	16	455	27	16.8
7	15	437	23	19.0
8	15	437	23	19.0
9	14	413	22	18.8
10	14	413	22	18.8
11	12	394	18	21.9

SIMULATION 3 CYCLE 2 VEHICLE 3

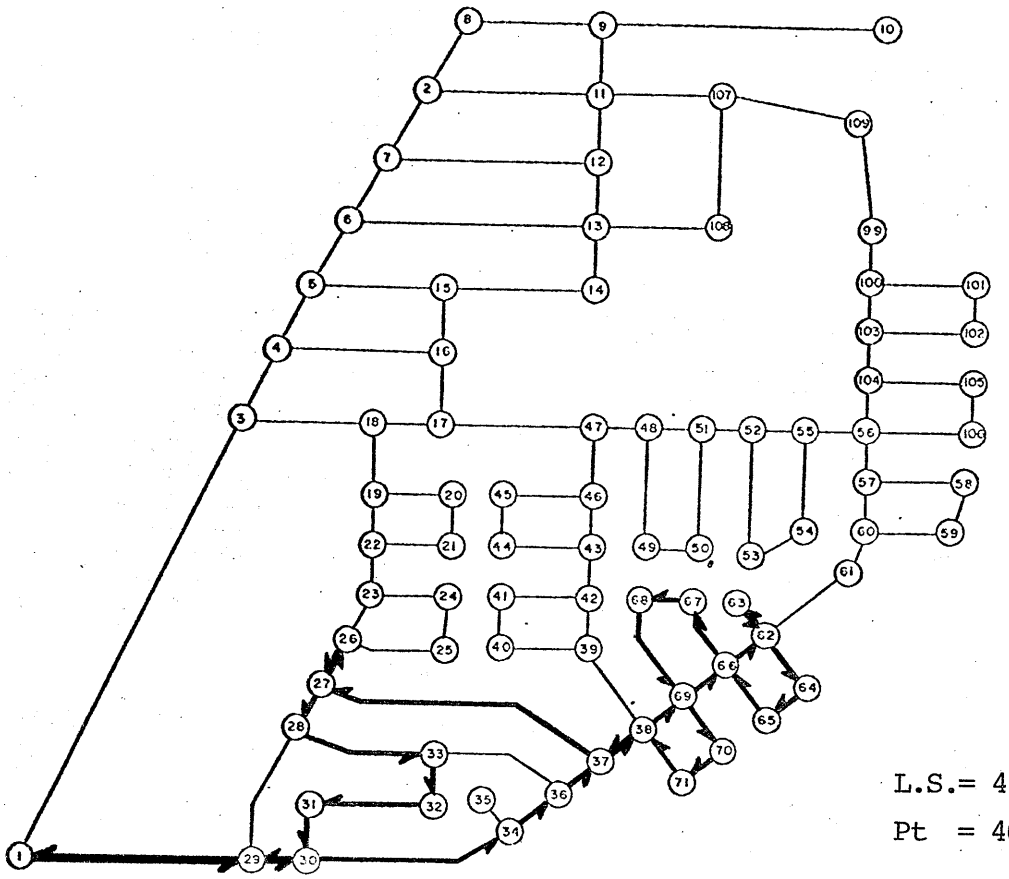


L.S.= 15.2

Pt = 691

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	61	805	54	14.9
2	60	788	52	15.1
3	59	768	57	13.5
4	57	744	49	15.2
5	56	726	46	15.8
6	105	702	49	14.3
7	104	681	43	15.8
8	103	663	40	16.5
9	102	642	46	14.0
10	101	624	43	14.5
11	100	596	37	16.1
12	99	585	34	17.2

SIMULATION 4 CYCLE 1 VEHICLE 1

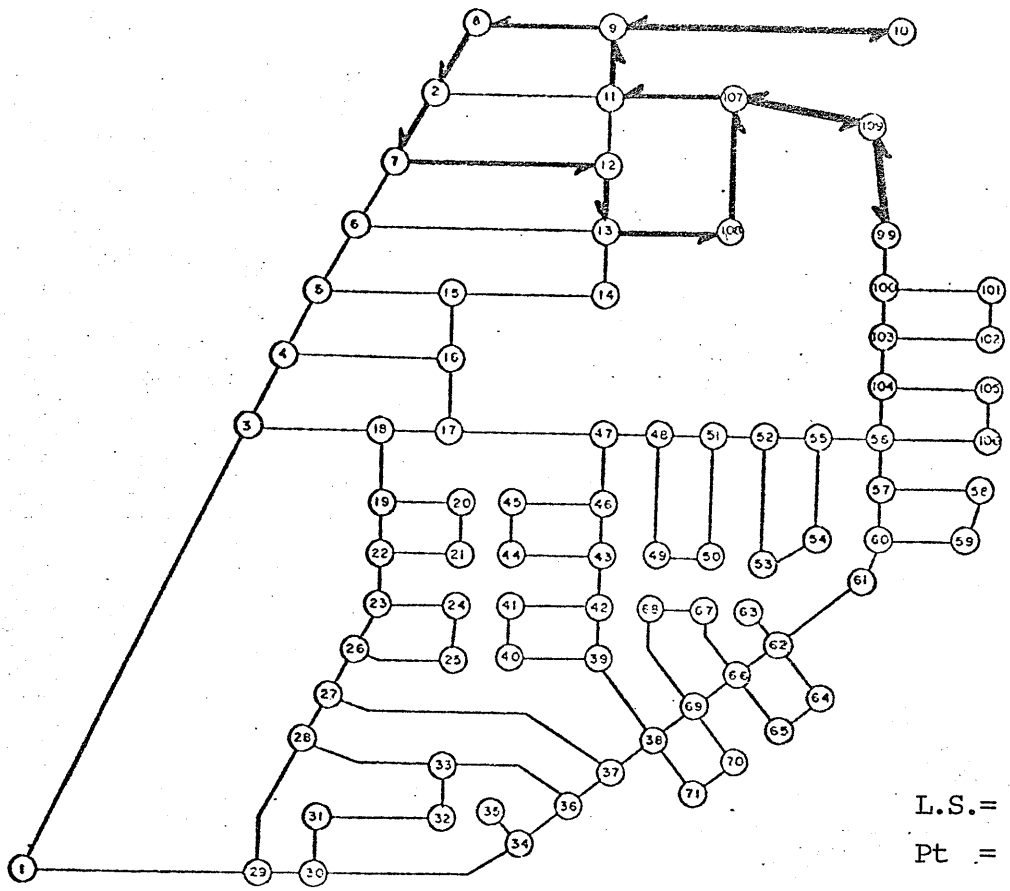


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

SIMULATION 4 CYCLE 1 VEHICLE 2

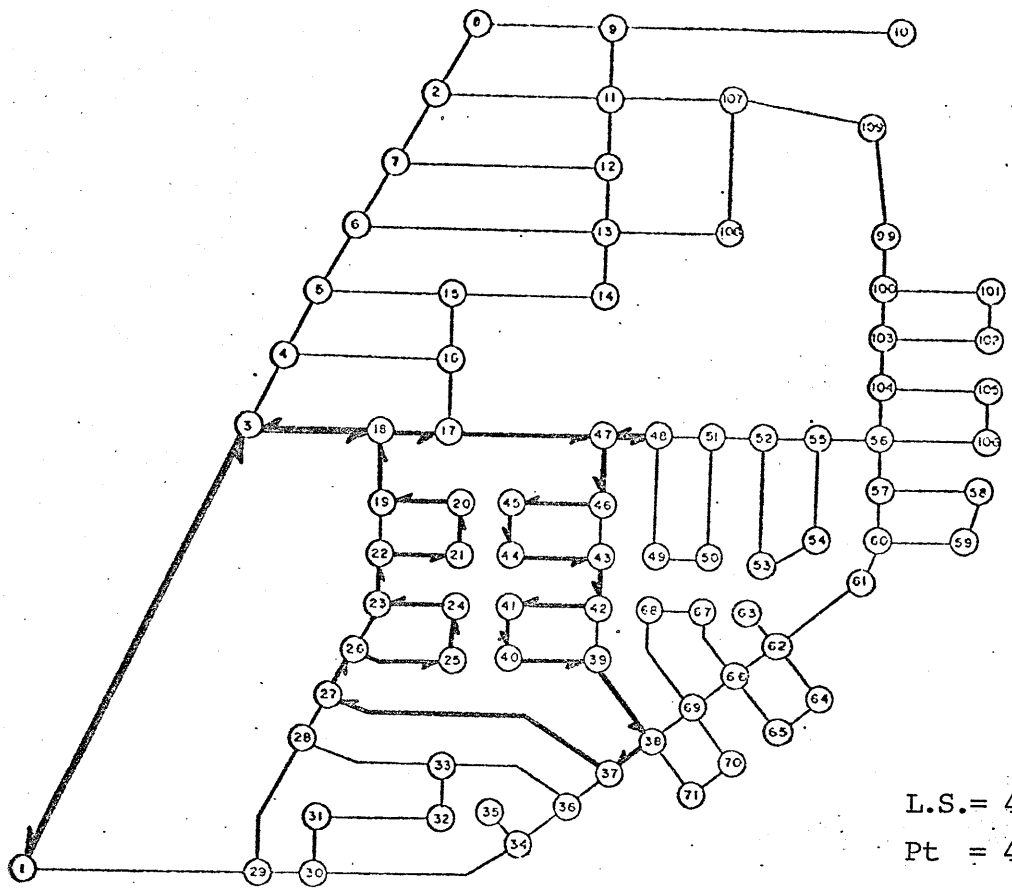


L.S.= 7.2

Pt = 251

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	246	5	49.3
2	7	246	5	49.3
3	12	218	14	15.6
4	12	218	14	15.6
5	12	218	14	15.6
6	108	192	25	7.7
7	108	192	25	7.7
8	108	192	25	7.7
9	108	192	25	7.7
10	99	152	34	4.5
11	99	152	34	4.5
12	109	129	26	5.0
13	107	105	17	6.2
14	107	105	17	6.2
15	107	105	17	6.2
16	107	105	17	6.2
17	11	83	10	8.3
18	11	83	10	8.3
19	10	46	31	1.5
20	10	46	31	1.5
21	9	13	13	1.0
22	9	13	13	1.0

SIMULATION 4 CYCLE 1 VEHICLE 3

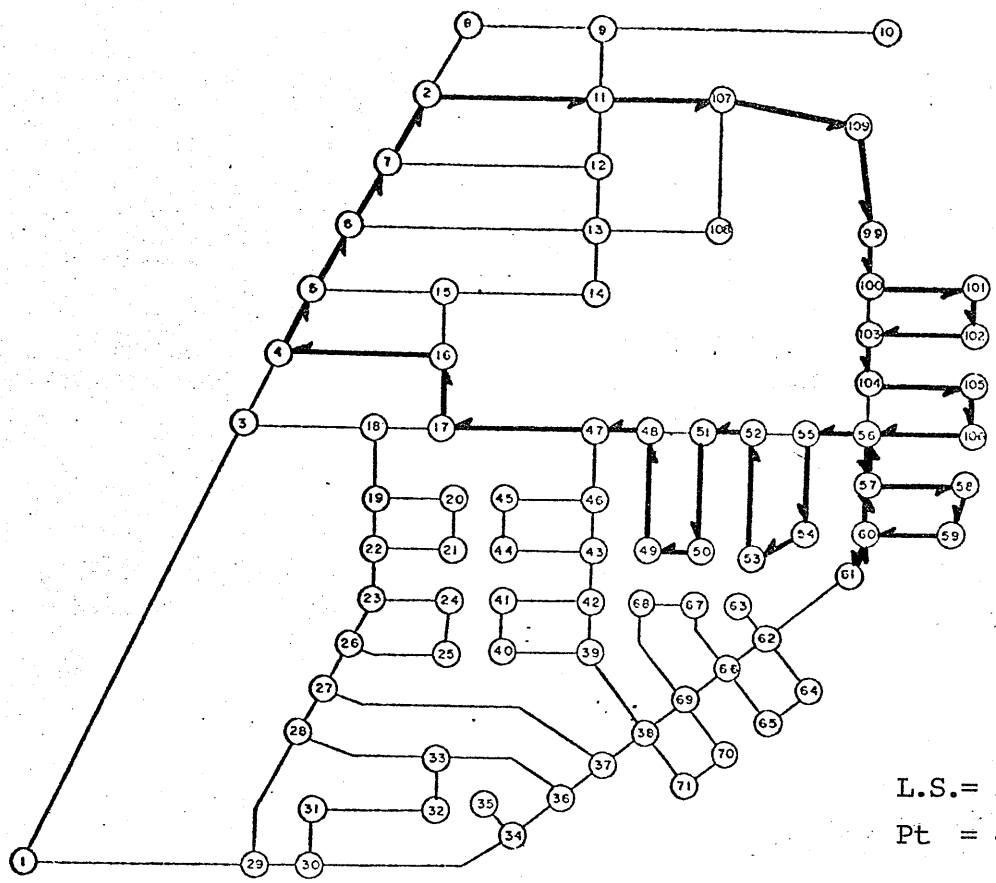


L.S.= 4.3

Pt = 416

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	374	42	8.9
2	17	374	42	8.9
3	48	347	64	5.4
4	47	329	61	5.4
5	47	329	61	5.4
6	47	329	61	5.4
7	45	305	62	4.9
8	43	282	54	5.2
9	42	264	51	5.2
10	41	244	56	4.4
11	40	226	53	4.3
12	39	206	48	4.3
13	24	151	37	4.1
14	23	132	33	4.0
15	22	114	36	3.2
16	21	95	40	2.4
17	19	72	39	1.8
18	19	72	39	1.8
19	18	53	38	1.4
20	3	30	30	1.0
21	3	30	30	1.0
22	3	30	30	1.0

SIMULATION 4 CYCLE 1 VEHICLE 4

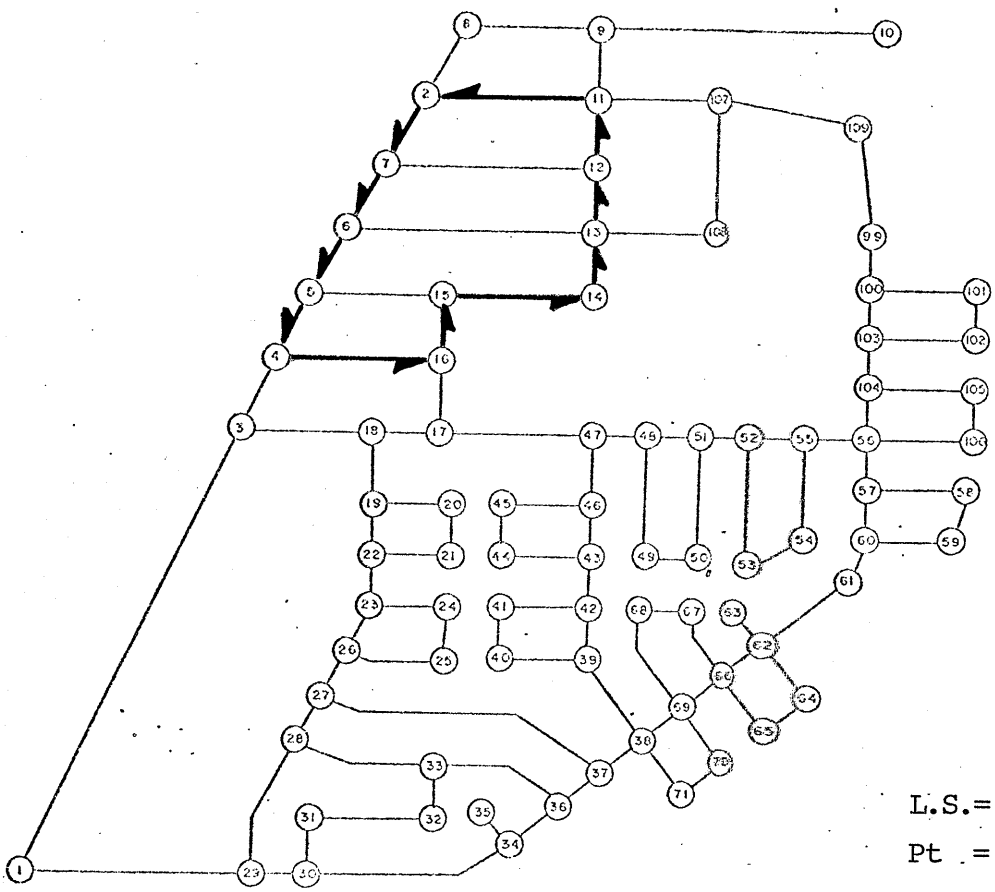


L.S.= 3.9

Pt = 425

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	100	388	37	10.5
2	101	367	43	8.5
3	102	349	46	7.5
4	103	328	40	8.2
5	105	304	49	6.2
6	59	268	57	4.7
7	61	246	54	4.5
8	60	229	52	4.4
9	60	229	52	4.4
10	56	193	56	4.2
11	54	168	56	3.0
12	54	168	56	3.0
13	52	141	53	2.7
14	52	141	53	2.7
15	51	123	52	2.4
16	51	123	52	2.4
17	50	104	59	1.8
18	49	86	56	1.5
19	49	86	56	1.5
20	16	45	30	1.5
21	16	45	30	1.5
22	6	10	10	1.0

SIMULATION 4 CYCLE 2 VEHICLE 2

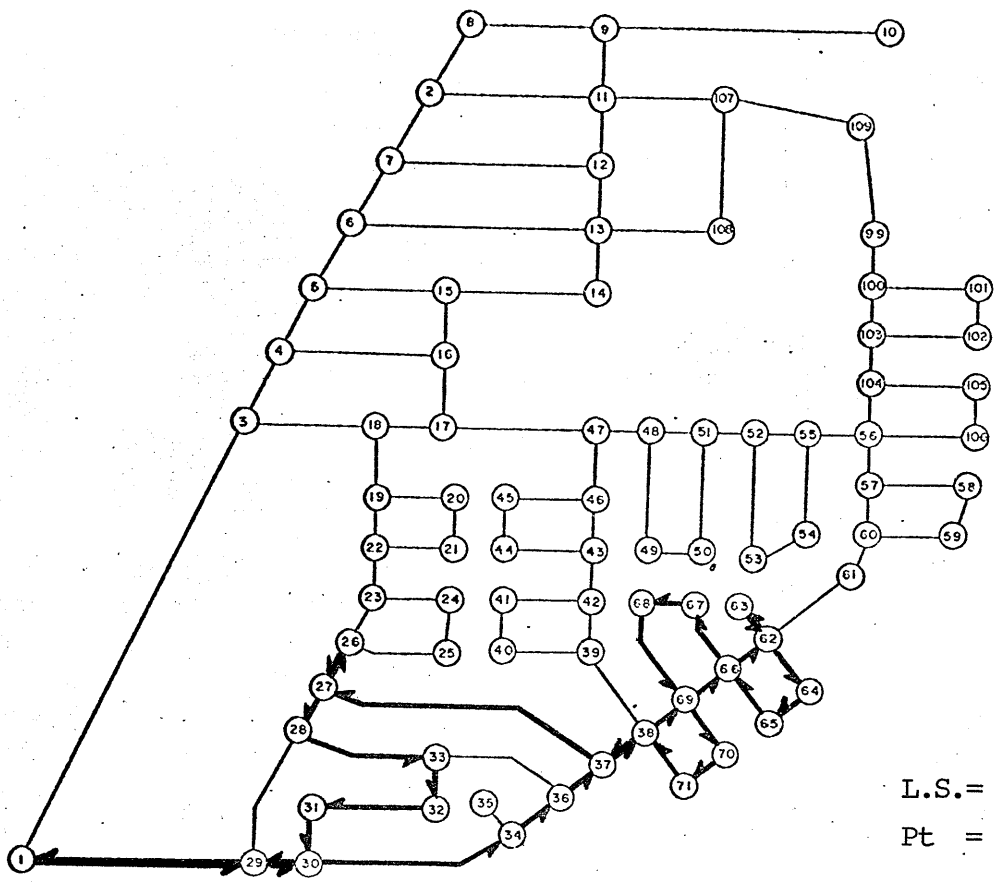


L.S.= 21.5

Pt = 376

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	5	491	15	32.8
2	4	471	20	32.6
3	4	471	20	23.6
4	15	442	23	19.2
5	15	442	23	19.2
6	14	418	22	19.1
7	14	418	22	19.1
8	14	418	22	19.1
9	13	399	18	22.1
10	13	399	18	22.1

SIMULATION 5 CYCLE 1 VEHICLE 1

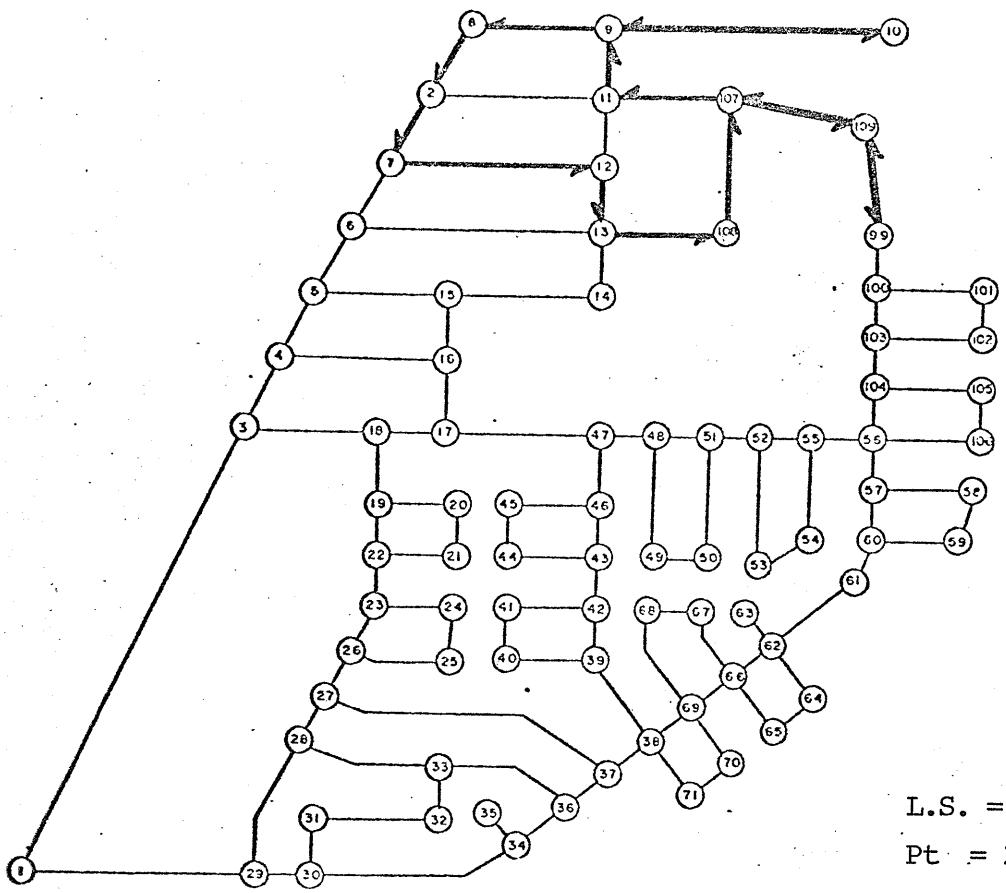


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

SIMULATION 5 CYCLE 1 VEHICLE 2

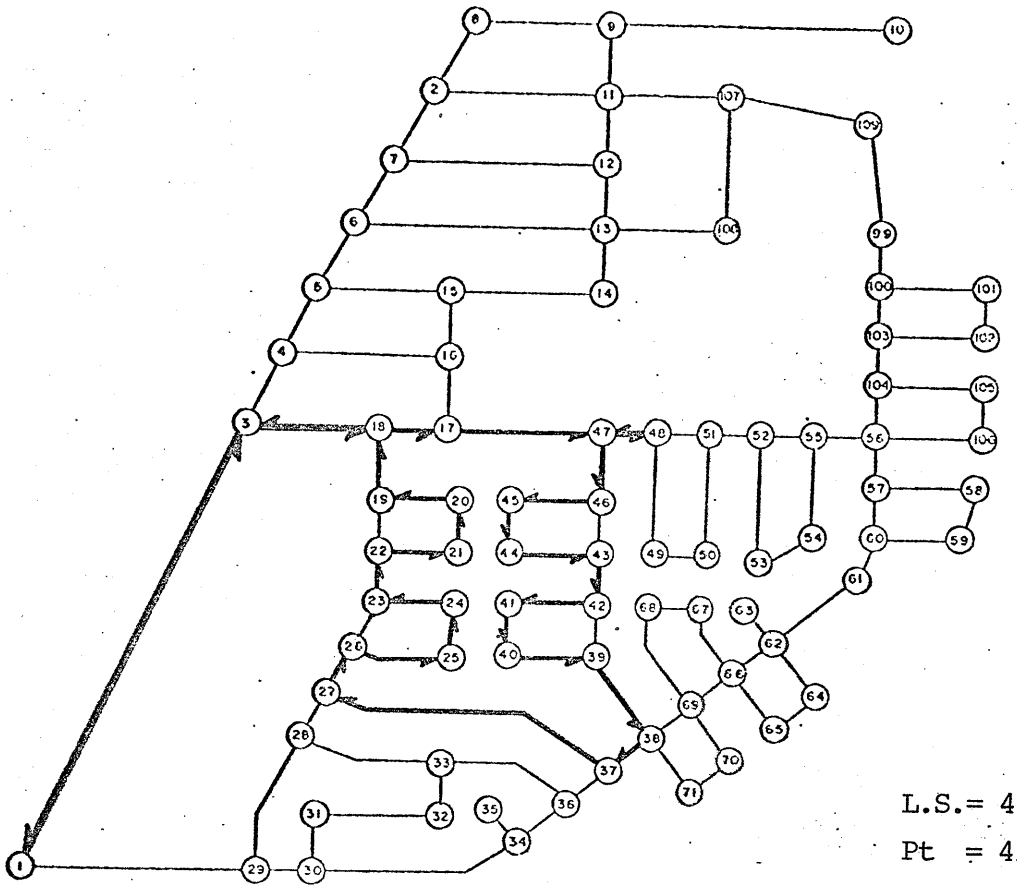


L.S. = 7.2

Pt = 251

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	246	5	49.3
2	7	246	5	49.3
3	12	218	14	15.6
4	12	218	14	15.6
5	12	218	14	15.6
6	108	192	25	7.7
7	108	192	25	7.7
8	108	192	25	7.7
9	108	192	25	7.7
10	99	152	34	4.5
11	99	152	34	4.5
12	109	129	26	5.0
13	107	105	17	6.2
14	107	105	17	6.2
15	107	105	17	6.2
16	107	105	17	6.2
17	11	83	10	8.3
18	11	83	10	8.3
19	10	46	31	1.5
20	10	46	31	1.5
21	9	13	13	1.0
22	9	13	13	1.0

SIMULATION 5 CYCLE 1 VEHICLE 3

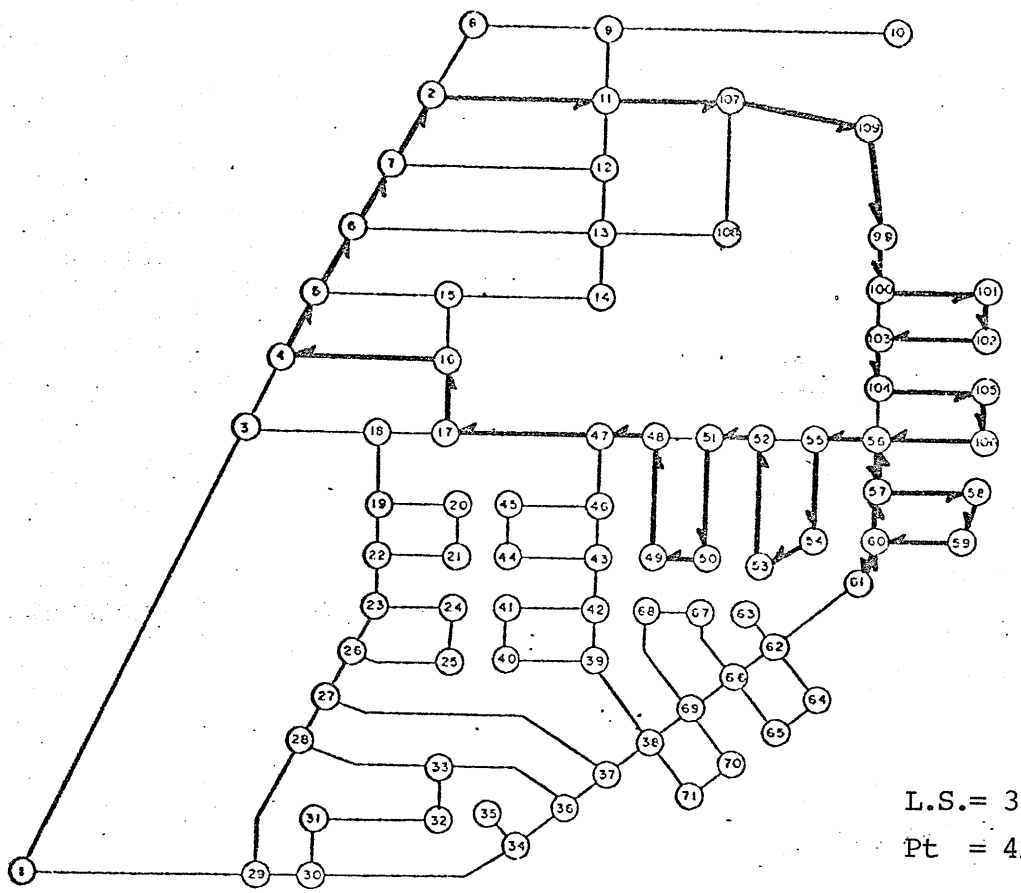


L.S.= 4.3

Pt = 416

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	374	42	8.9
2	17	374	42	8.9
3	48	347	64	5.4
4	47	329	61	5.4
5	47	329	61	5.4
6	47	329	61	5.4
7	45	305	62	4.9
8	43	282	54	5.2
9	42	264	51	5.2
10	41	244	56	4.4
11	40	226	53	4.3
12	39	206	48	4.3
13	24	151	37	4.1
14	23	132	33	4.0
15	22	114	36	3.2
16	21	95	40	2.4
17	19	72	39	1.8
18	19	72	39	1.8
19	18	53	38	1.4
20	3	30	30	1.0
21	3	30	30	1.0
22	3	30	30	1.0

SIMULATION 5 CYCLE 1 VEHICLE 4

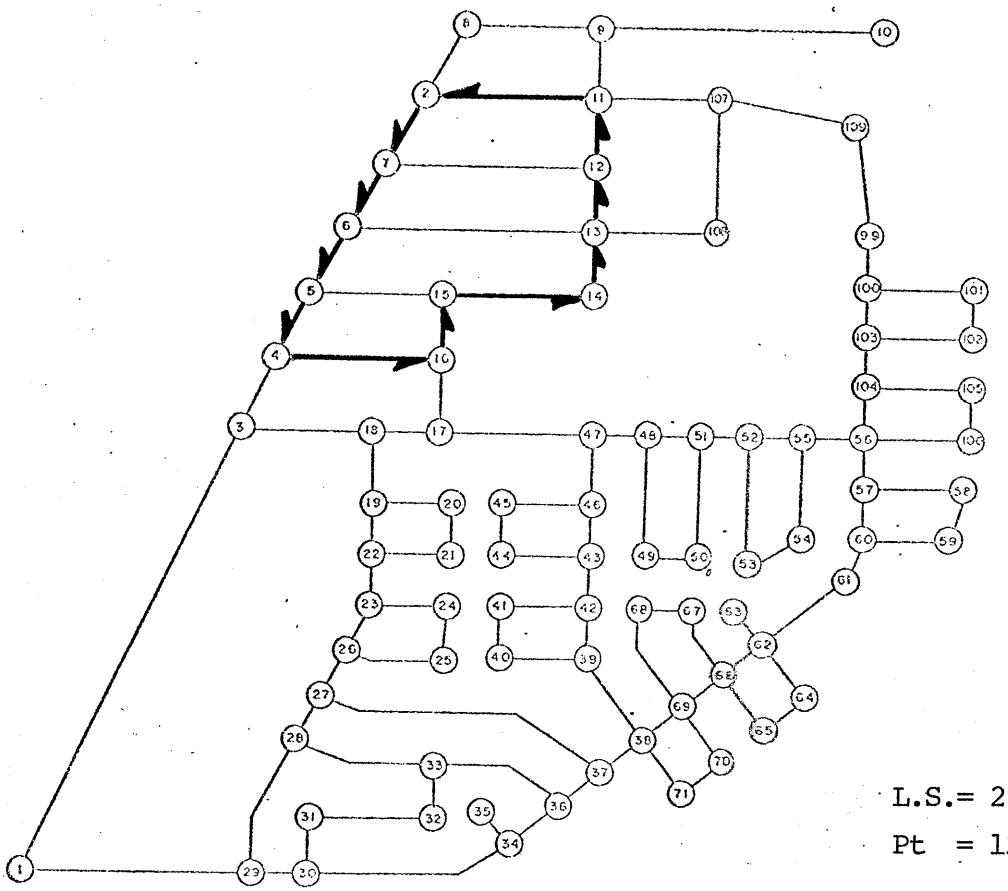


L.S.= 3.9

Pt = 425

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	100	388	37	10.5
2	101	367	43	8.5
3	102	349	46	7.5
4	103	328	40	8.2
5	105	304	49	6.2
6	59	268	57	4.7
7	61	246	54	4.5
8	60	229	52	4.4
9	60	229	52	4.4
10	56	193	56	4.2
11	54	168	56	3.0
12	54	168	56	3.0
13	52	141	53	2.7
14	52	141	53	2.7
15	51	123	52	2.4
16	51	123	52	2.4
17	50	104	59	1.8
18	49	86	56	1.5
19	49	86	56	1.5
20	16	45	30	1.5
21	16	45	30	1.5
22	6	10	10	1.0

SIMULATION 5 CYCLE 1 VEHICLE 5

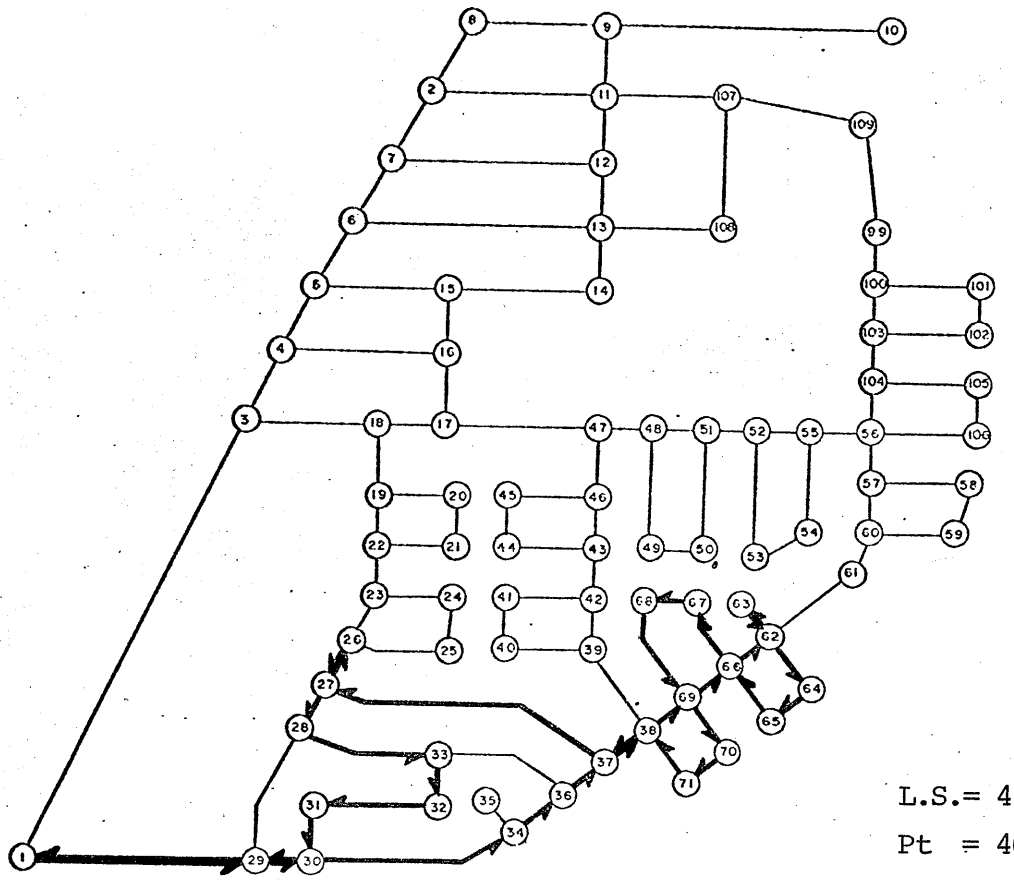


L.S.= 2.7

Pt = 125

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	5	110	15	7.3
2	4	90	20	4.5
3	4	90	20	4.5
4	15	61	23	2.7
5	15	61	23	2.7
6	14	37	22	1.7
7	14	37	22	1.7
8	14	37	22	1.7
9	13	18	18	1.0
10	13	18	18	1.0

SIMULATION 6 CYCLE 1 VEHICLE 1

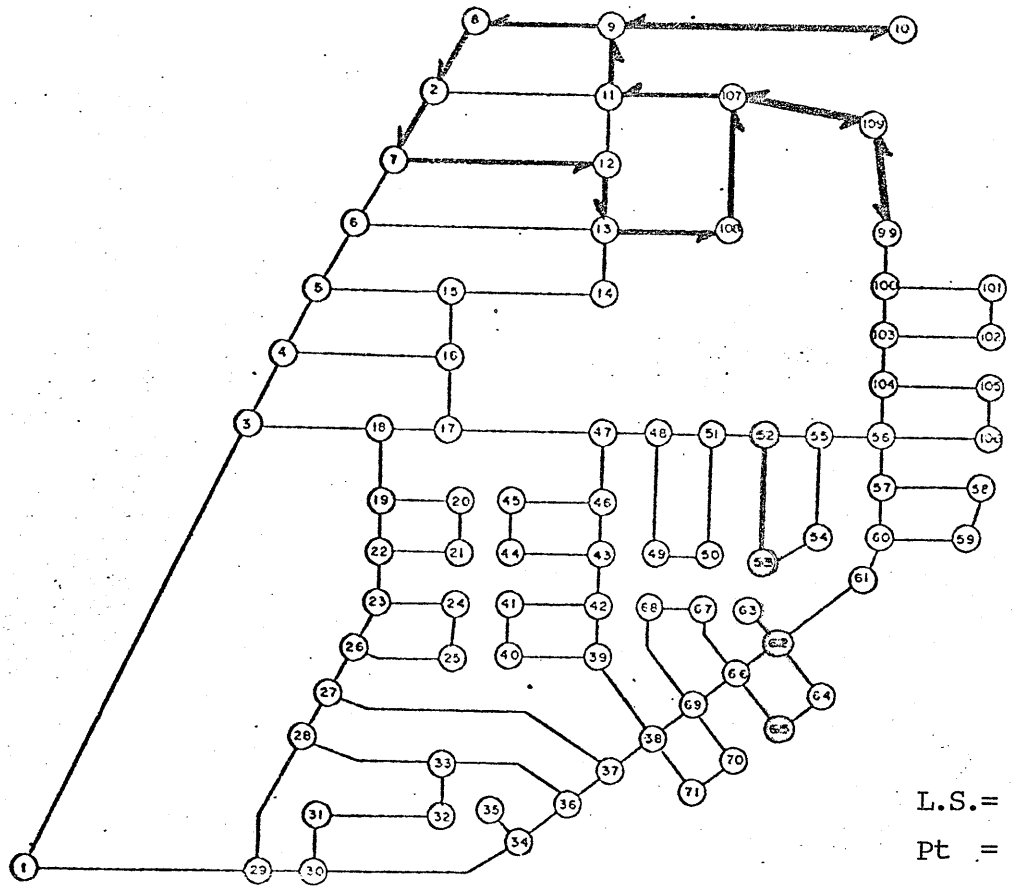


L.S.= 4.9

Pt = 407

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	35	373	34	10.3
2	36	352	36	9.8
3	63	320	53	6.0
4	65	296	52	5.7
5	66	277	48	5.8
6	67	257	53	4.8
7	68	239	52	4.6
8	71	210	46	4.6
9	71	210	46	4.6
10	38	191	42	4.6
11	26	151	30	5.0
12	27	133	27	4.9
13	28	115	24	4.8
14	28	115	24	4.8
15	28	115	24	4.8
16	33	91	31	2.9
17	33	91	31	2.9
18	32	73	28	2.6
19	31	52	22	2.4
20	30	34	19	1.8
21	29	15	15	1.0
22	29	15	15	1.0

SIMULATION 6 CYCLE 1 VEHICLE 2

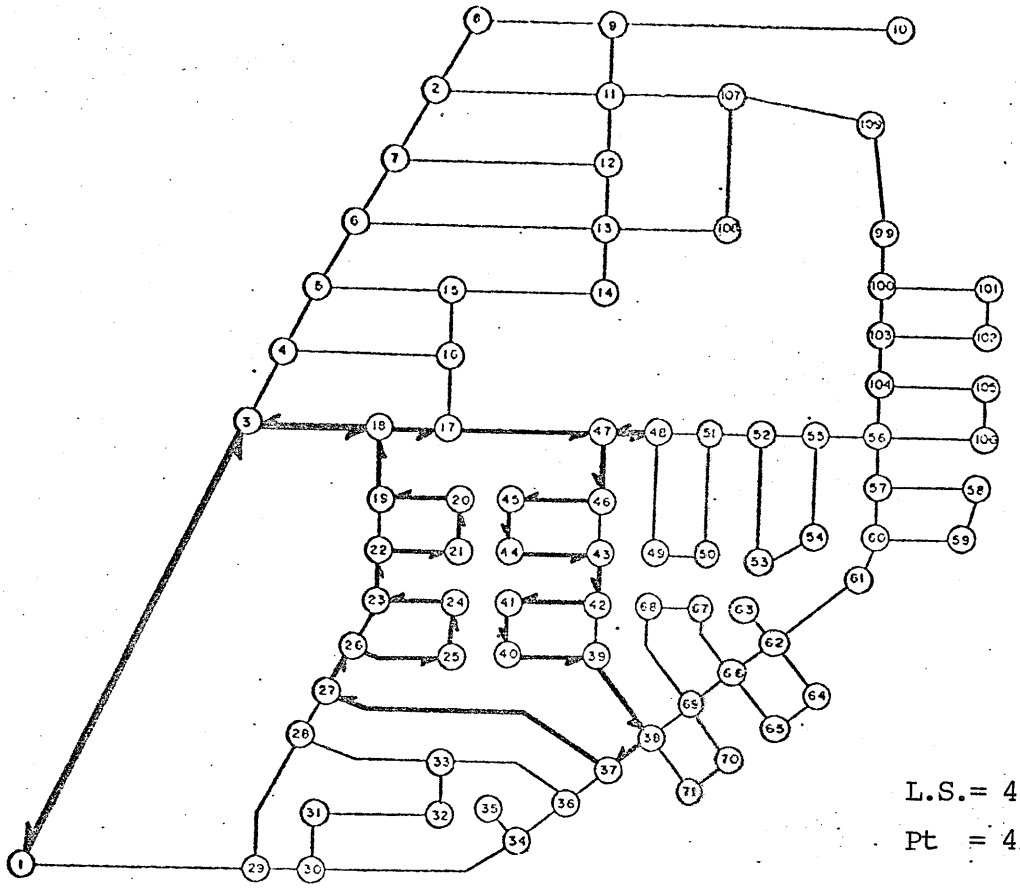


L.S.= 7.2

Pt = 251

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	246	5	49.3
2	7	246	5	49.3
3	12	218	14	15.6
4	12	218	14	15.6
5	12	218	14	15.6
6	108	192	25	7.7
7	108	192	25	7.7
8	108	192	25	7.7
9	108	192	25	7.7
10	99	152	34	4.5
11	99	152	34	4.5
12	109	129	26	5.0
13	107	105	17	6.2
14	107	105	17	6.2
15	107	105	17	6.2
16	107	105	17	6.2
17	11	83	10	8.3
18	11	83	10	8.3
19	10	46	31	1.5
20	10	46	31	1.5
21	9	13	13	1.0
22	9	13	13	1.0

SIMULATION 6 CYCLE 1 VEHICLE 3

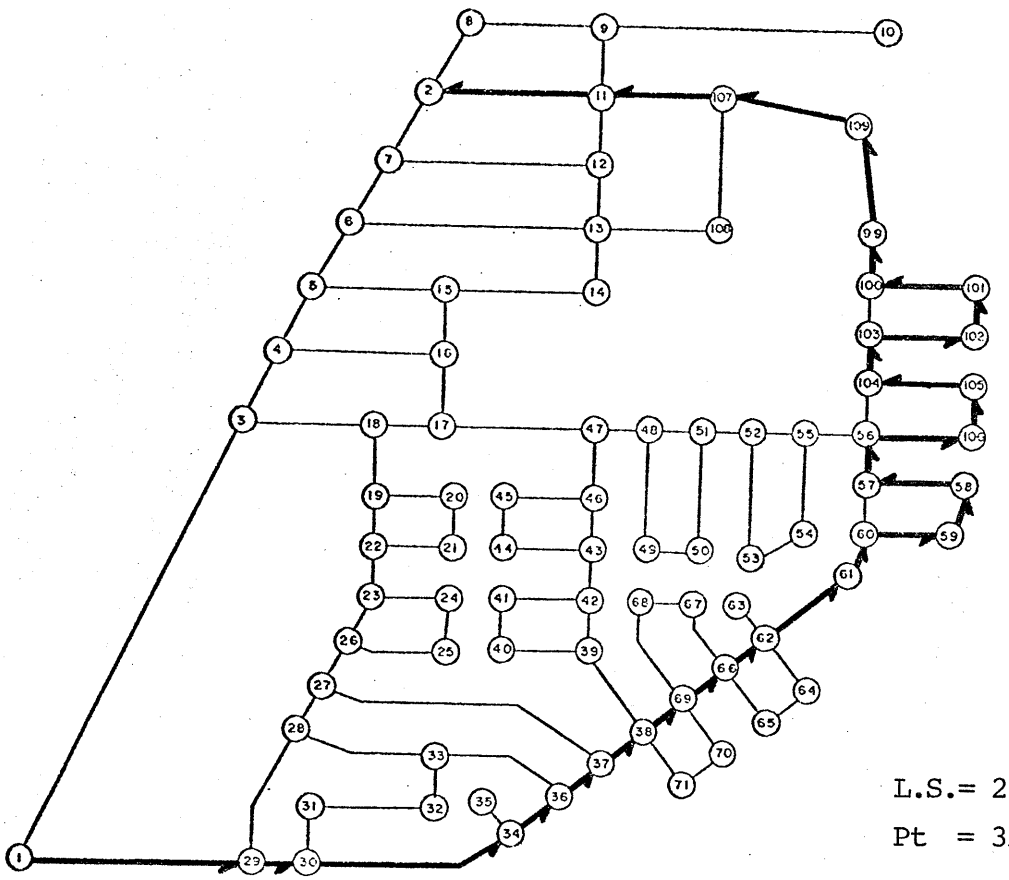


L.S.= 4.3

Pt = 416

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	374	42	8.9
2	17	374	42	8.9
3	48	347	64	5.4
4	47	329	61	5.4
5	47	329	61	5.4
6	47	329	61	5.4
7	45	305	62	4.9
8	43	282	54	5.2
9	42	264	51	5.2
10	41	244	56	4.4
11	40	226	53	4.3
12	39	206	48	4.3
13	24	151	37	4.1
14	23	132	33	4.0
15	22	114	36	3.2
16	21	95	40	2.4
17	19	72	39	1.8
18	19	72	39	1.8
19	18	53	38	1.4
20	3	30	30	1.0
21	3	30	30	1.0
22	3	30	30	1.0

SIMULATION 6 CYCLE 1 VEHICLE 4

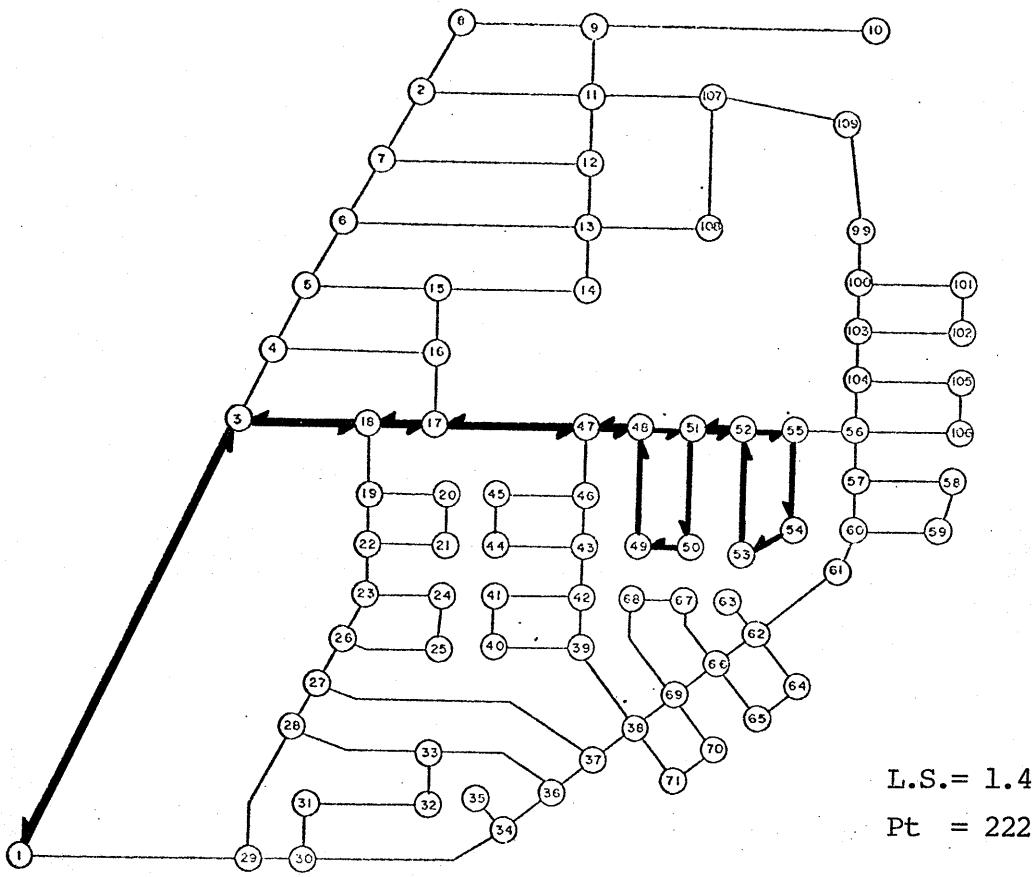


L.S.= 2.9

Pt = 312

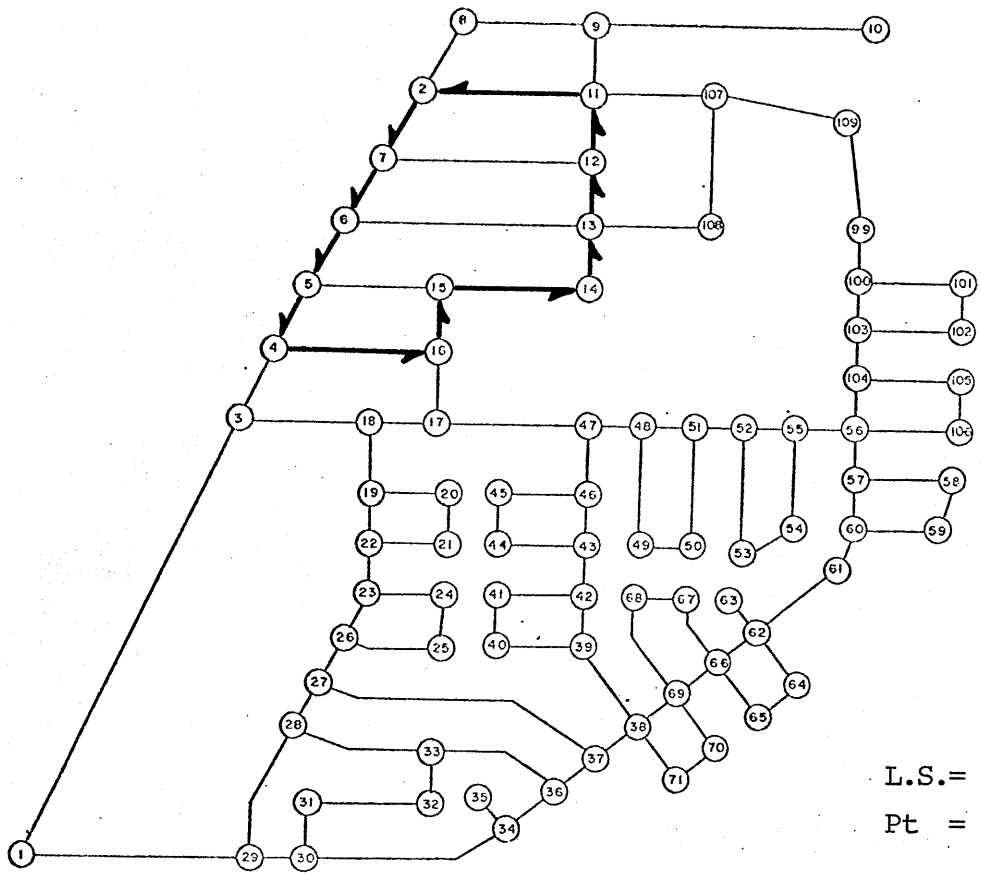
ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	61	254	54	4.7
2	60	237	52	4.5
3	59	217	57	3.8
4	57	193	49	3.9
5	56	175	46	3.8
6	105	151	49	3.0
7	104	130	43	3.0
8	103	112	40	2.8
9	102	91	46	1.9
10	101	73	43	1.6
11	100	45	37	1.2
12	99	34	34	1.0

SIMULATION 6 CYCLE 1 VEHICLE 5



ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	54	146	76	1.9
2	54	146	76	1.9
3	52	119	70	1.7
4	52	119	70	1.7
5	51	101	67	1.5
6	51	101	67	1.5
7	50	79	74	1.0
8	49	61	61	1.0
9	49	61	61	1.0

SIMULATION 6 CYCLE 1 VEHICLE 6

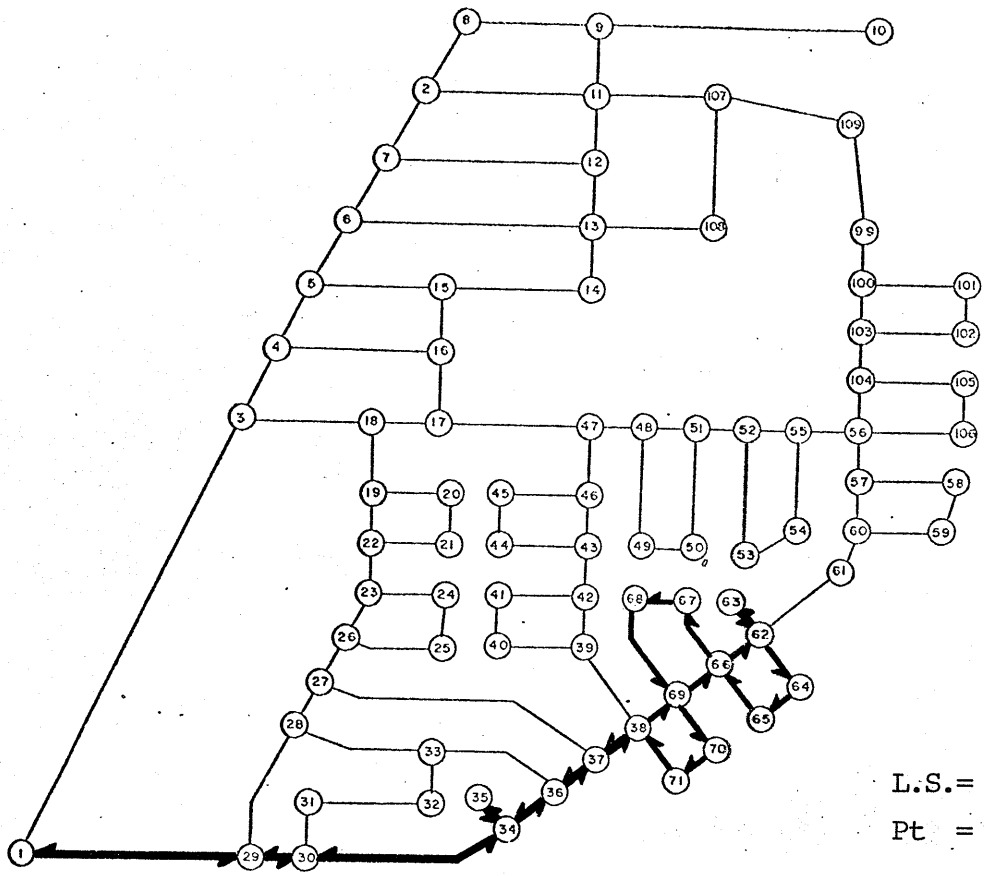


L.S.= 3.3

Pt = 155

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	6	145	10	14.5
2	5	125	15	8.3
3	4	105	20	5.2
4	4	105	20	5.2
5	16	79	27	2.9
6	16	79	27	2.9
7	15	61	23	2.6
8	15	61	23	2.6
9	14	37	22	1.6
10	14	37	22	1.6
11	13	18	18	1.0

SIMULATION 7 CYCLE 1 VEHICLE 1

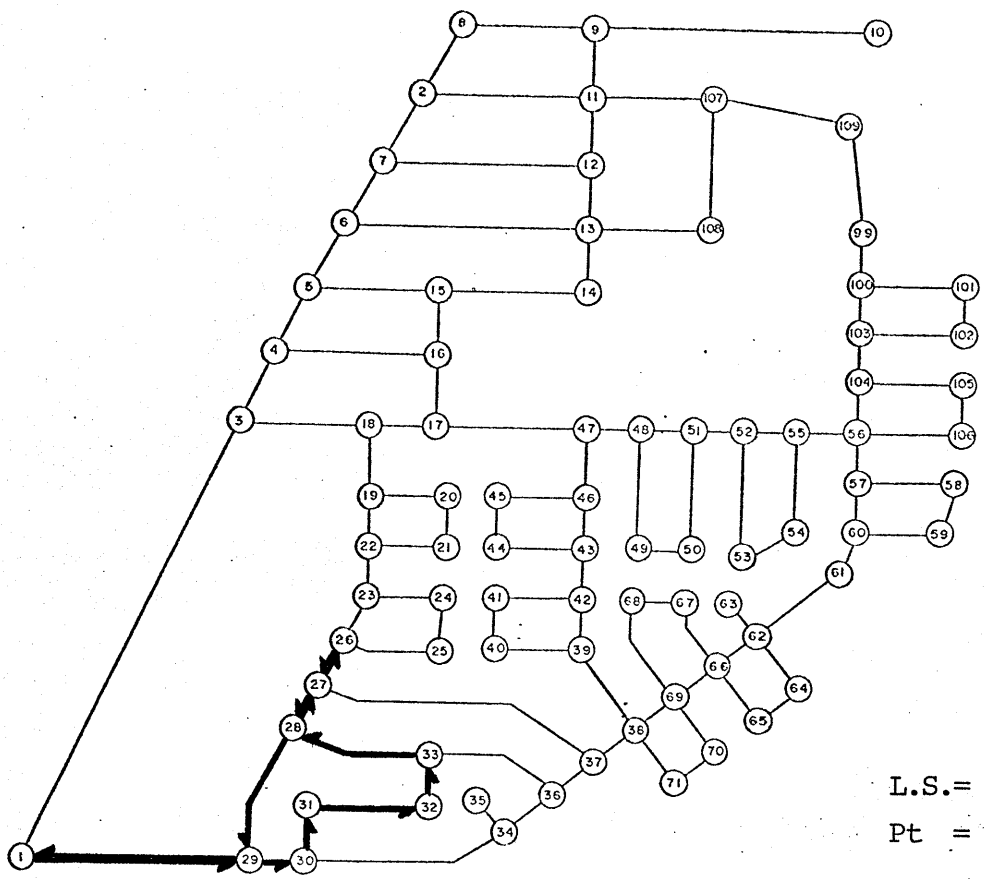


L.S.= 2.5

Pt = 136

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	63	202	53	3.8
2	65	178	52	3.4
3	66	159	48	3.3
4	67	139	53	2.6
5	68	121	52	2.3
6	71	92	46	2.0
7	71	92	46	2.0
8	38	73	42	1.7
9	36	52	36	1.4
10	35	33	33	1.0

SIMULATION 7 CYCLE 1 VEHICLE 2

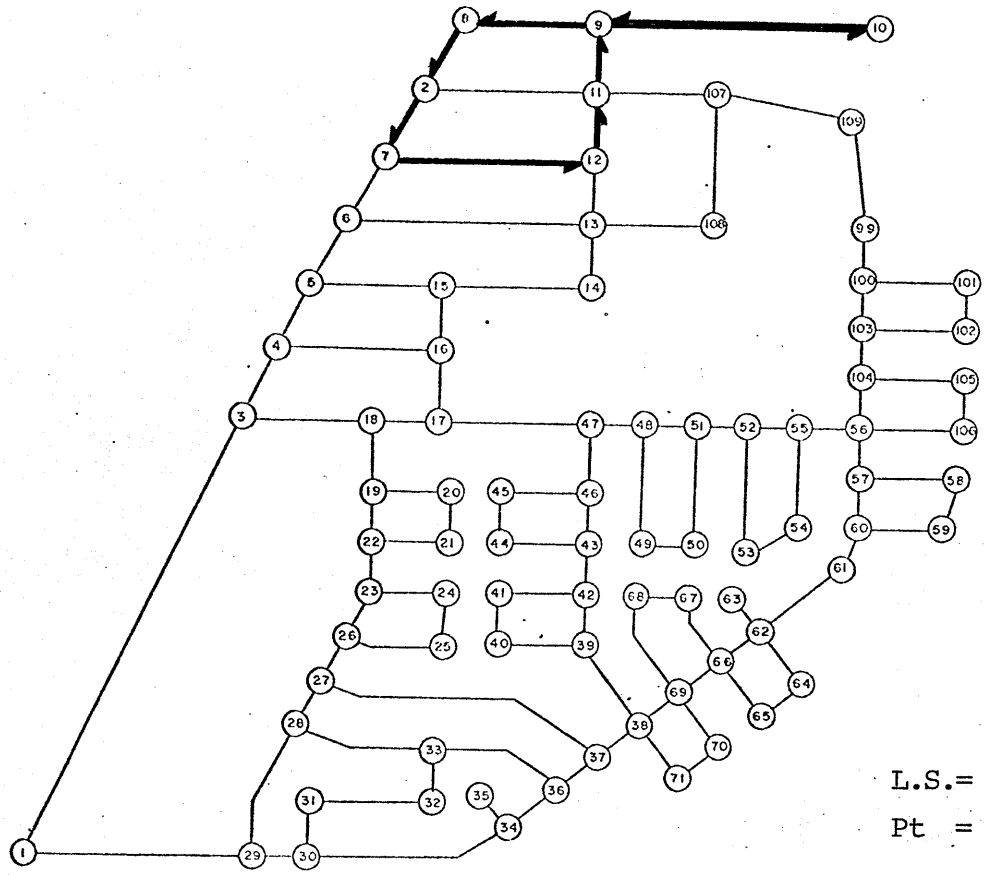


L.S.= 3.2

Pt = 75

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	30	162	19	8.5
2	31	144	22	6.5
3	32	123	28	4.4
4	33	105	31	3.4
5	33	105	31	3.4
6	26	75	30	2.5
7	27	57	27	2.1
8	28	39	24	1.6
9	28	39	24	1.6
10	28	39	24	1.6
11	29	15	15	1.0
12	29	15	15	1.0

SIMULATION 7 CYCLE 1 VEHICLE 3

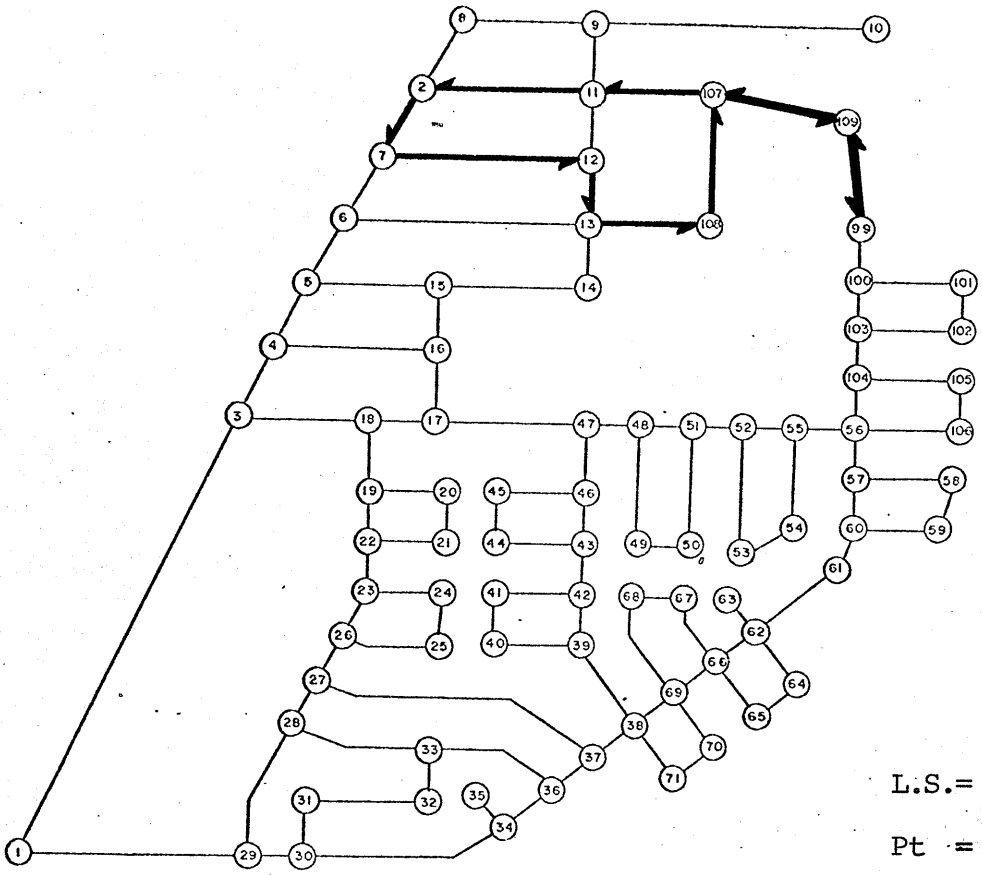


L.S.= 5.3

Pt = 75

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	130	5	26.0
2	7	130	5	26.0
3	12	102	14	7.3
4	12	102	14	7.3
5	12	102	14	7.3
6	11	83	10	8.3
7	11	83	10	8.3
8	10	46	31	1.5
9	10	46	31	1.5
10	9	13	13	1.0
11	9	13	13	1.0

SIMULATION 7 CYCLE 1 VEHICLE 4

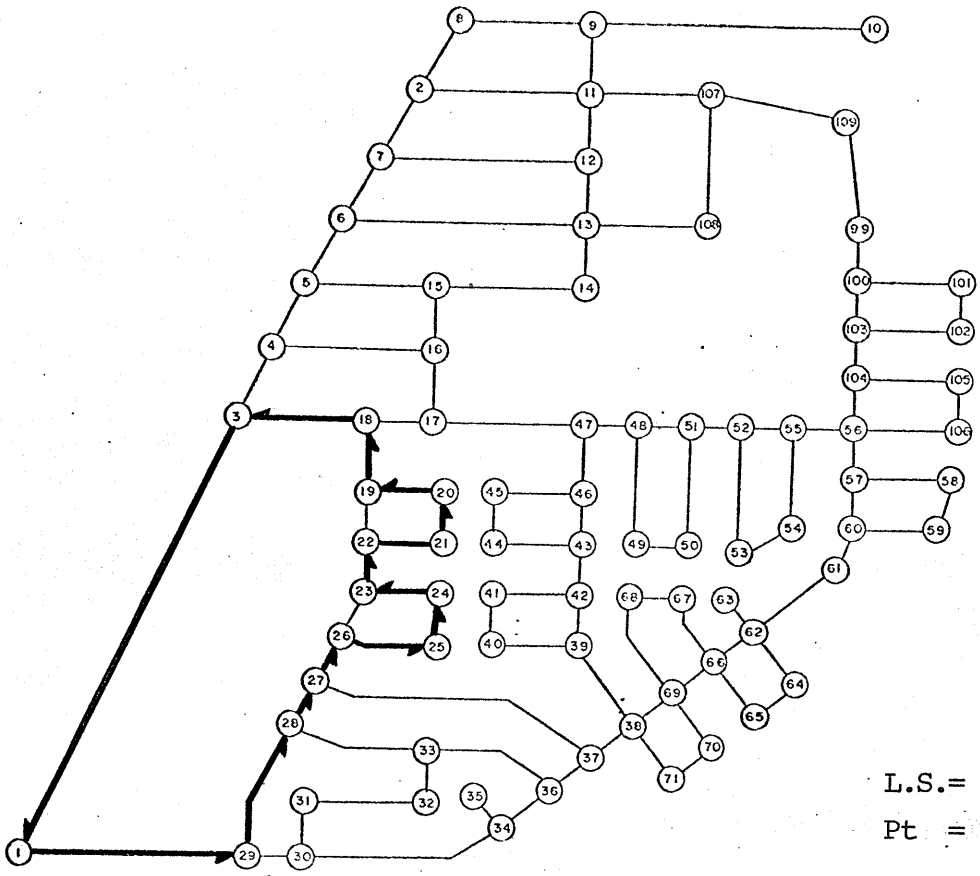


L.S.= 2.5

Pt = 88

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	108	103	25	4.1
2	108	103	25	4.1
3	108	103	25	4.1
4	108	103	25	4.1
5	99	64	34	1.9
6	99	64	34	1.9
7	109	41	26	1.6
8	107	17	17	1.0
9	107	17	17	1.0
10	107	17	17	1.0
11	107	17	17	1.0

SIMULATION 7 CYCLE 1 VEHICLE 5

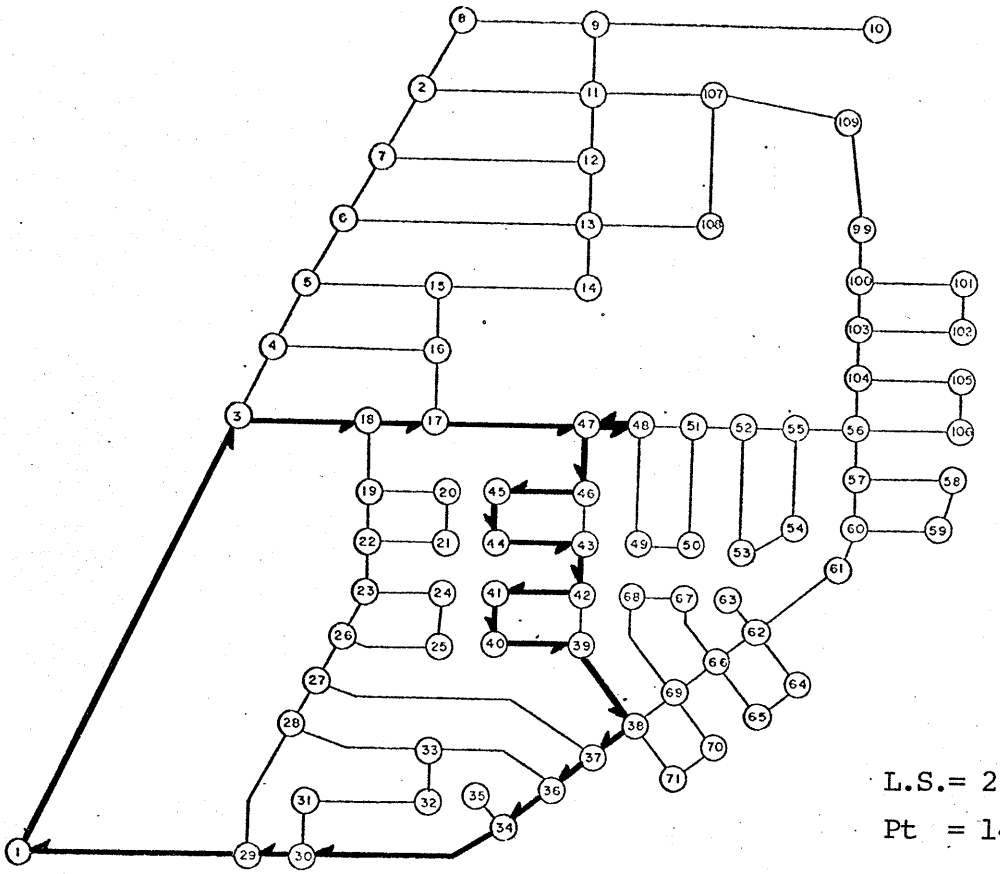


L.S.= 2.3

Pt = 100

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	24	151	37	4.1
2	23	132	33	4.0
3	22	114	36	3.2
4	21	95	40	2.4
5	19	72	39	1.8
6	19	72	39	1.8
7	18	53	38	1.4
8	3	30	30	1.0
9	3	30	30	1.0
10	3	30	30	1.0

SIMULATION 7 CYCLE 1 VEHICLE 6

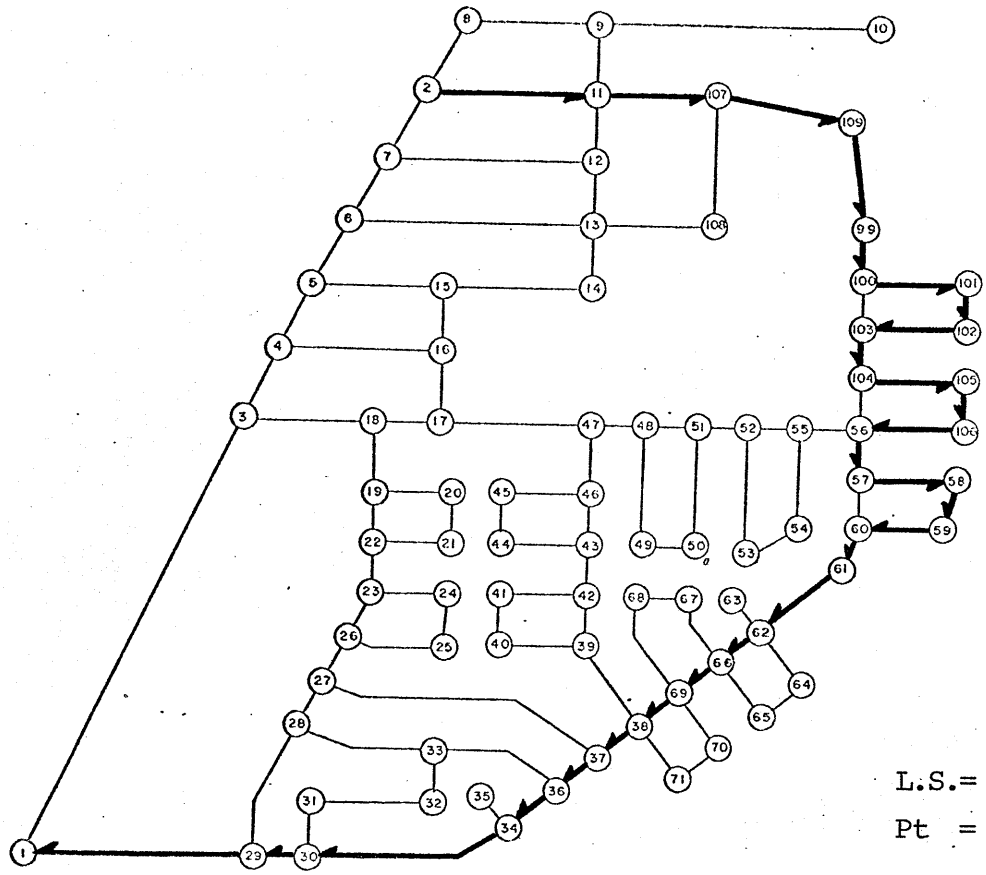


L.S.= 2.4

Pt = 140

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	17	200	42	4.8
2	17	200	42	4.8
3	48	173	64	2.7
4	47	155	61	2.5
5	47	155	61	2.5
6	47	155	61	2.5
7	45	131	62	2.1
8	43	114	54	2.1
9	42	96	51	1.9
10	41	86	56	1.5
11	40	68	53	1.3
12	39	48	48	1.0

SIMULATION 7 CYCLE 1 VEHICLE 7

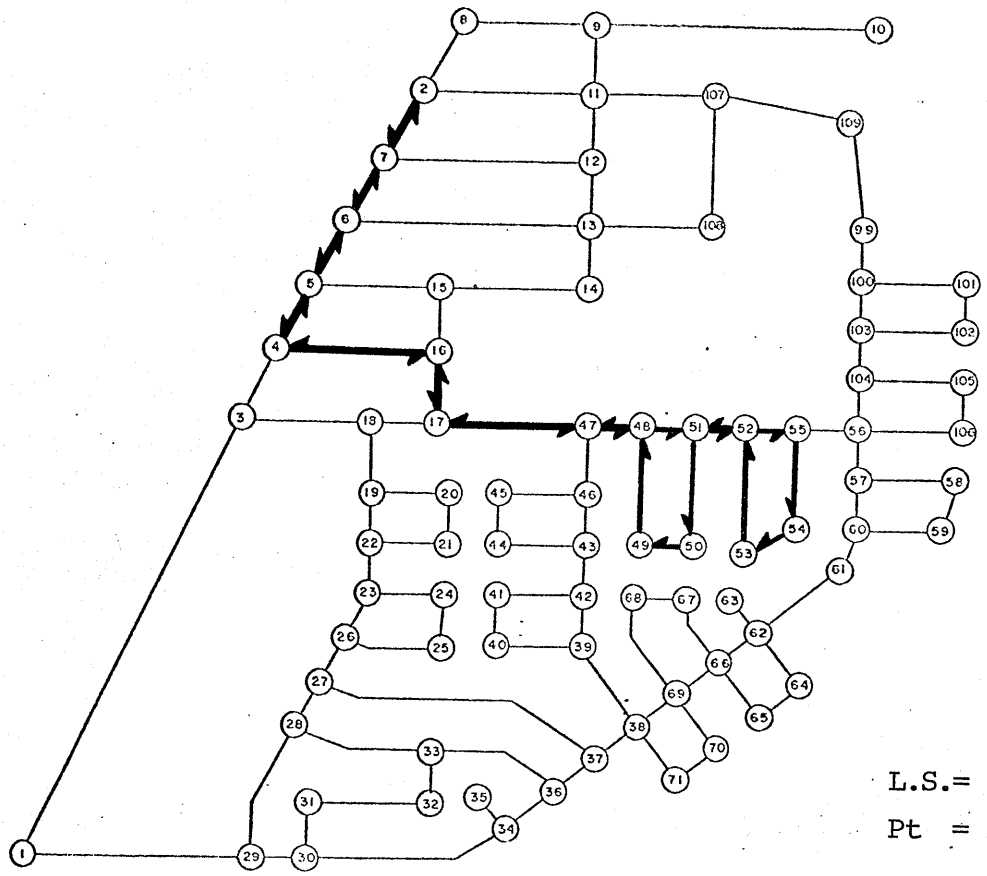


L.S.= 2.2

Pt = 144

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	100	292	75	3.2
2	101	221	81	2.7
3	102	203	78	2.6
4	103	185	72	2.6
5	105	161	75	2.2
6	56	137	66	2.1
7	57	119	63	1.9
8	59	95	65	1.5
9	60	75	60	1.2
10	61	58	58	1.0

SIMULATION 7 CYCLE 1 VEHICLE 8

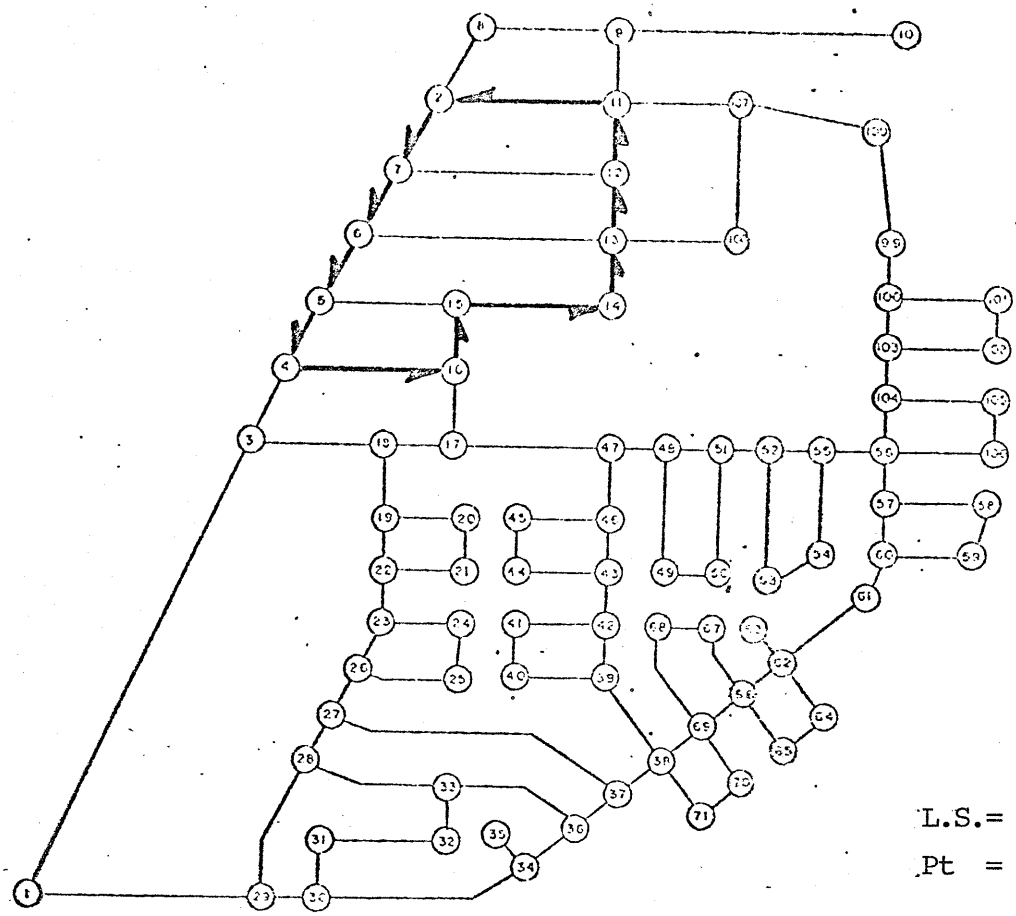


L.S.= 2.2

Pt = 138

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	54	168	56	3.0
2	54	168	56	3.0
3	52	191	53	2.7
4	52	141	53	2.7
5	51	123	53	2.4
6	51	123	52	2.4
7	50	104	59	1.8
8	49	86	56	1.5
9	49	86	56	1.5
10	16	45	30	1.5
11	16	45	30	1.5
12	6	10	10	1.0

SIMULATION 7 CYCLE 1 VEHICLE 9

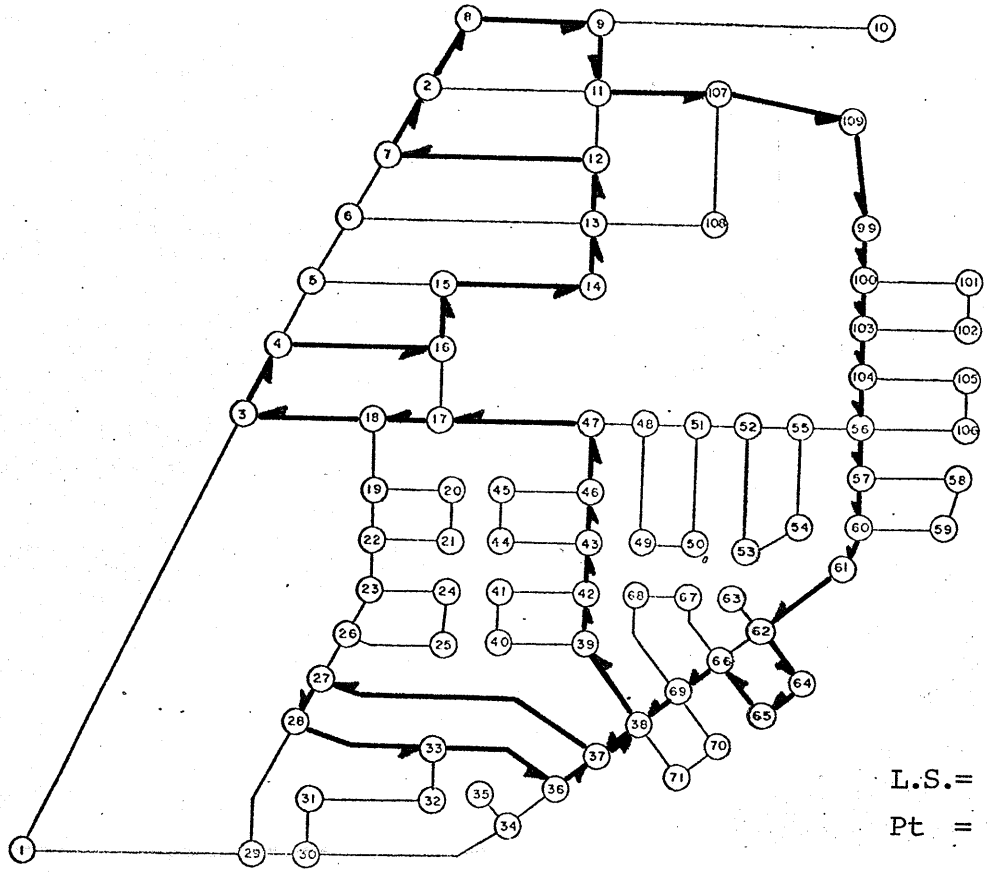


L.S.= 2.7

Pt = 125

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	5	110	15	7.3
2	4	90	20	4.5
3	4	90	20	4.5
4	15	61	23	2.7
5	15	61	23	2.7
6	14	37	22	1.7
7	14	37	22	1.7
8	14	37	22	1.7
9	13	18	18	1.0
10	13	18	18	1.0

SIMULATION 8 CYCLE 1 VEHICLE 1

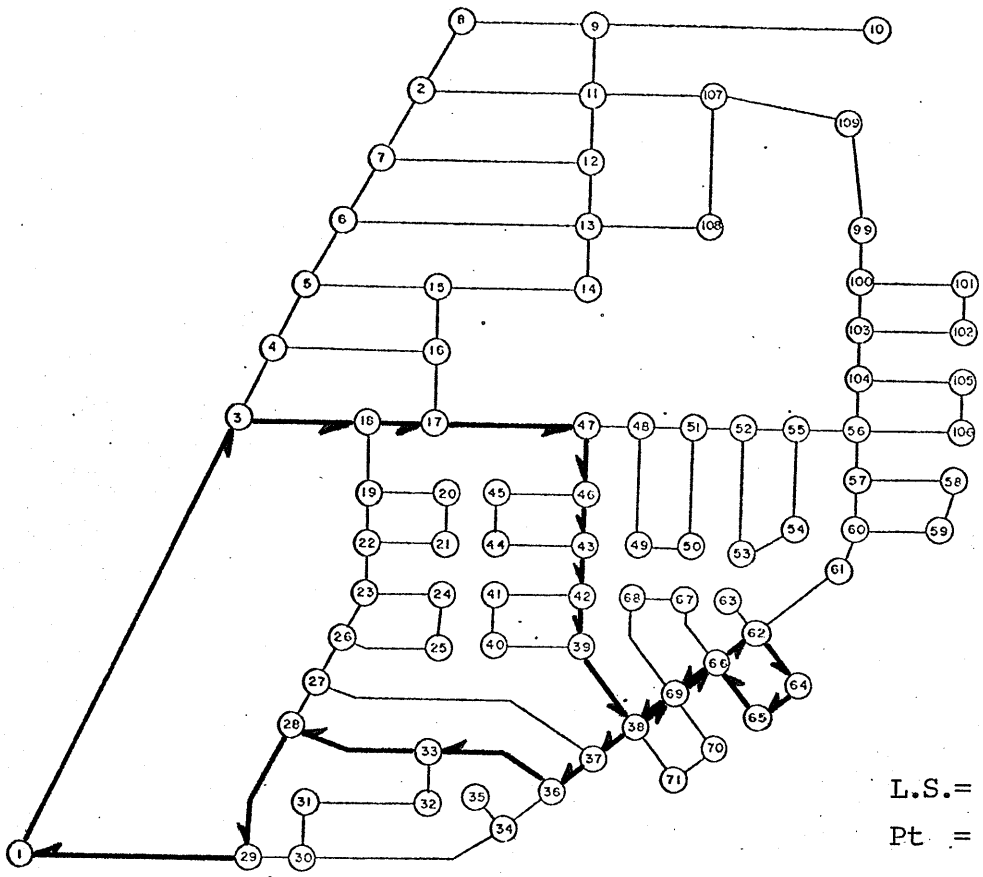


L.S.= 6.4

Pt = 1812

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	9	350	13	26.9
2	109	315	26	12.1
3	104	283	43	6.6
4	64	246	78	3.2
5	28	194	52	3.7
6	37	157	68	2.3
7	46	124	50	2.5
8	3	84	25	3.4
9	14	41	22	1.9
10	7	5	5	1.0

SIMULATION 9 CYCLE 1 VEHICLE 1

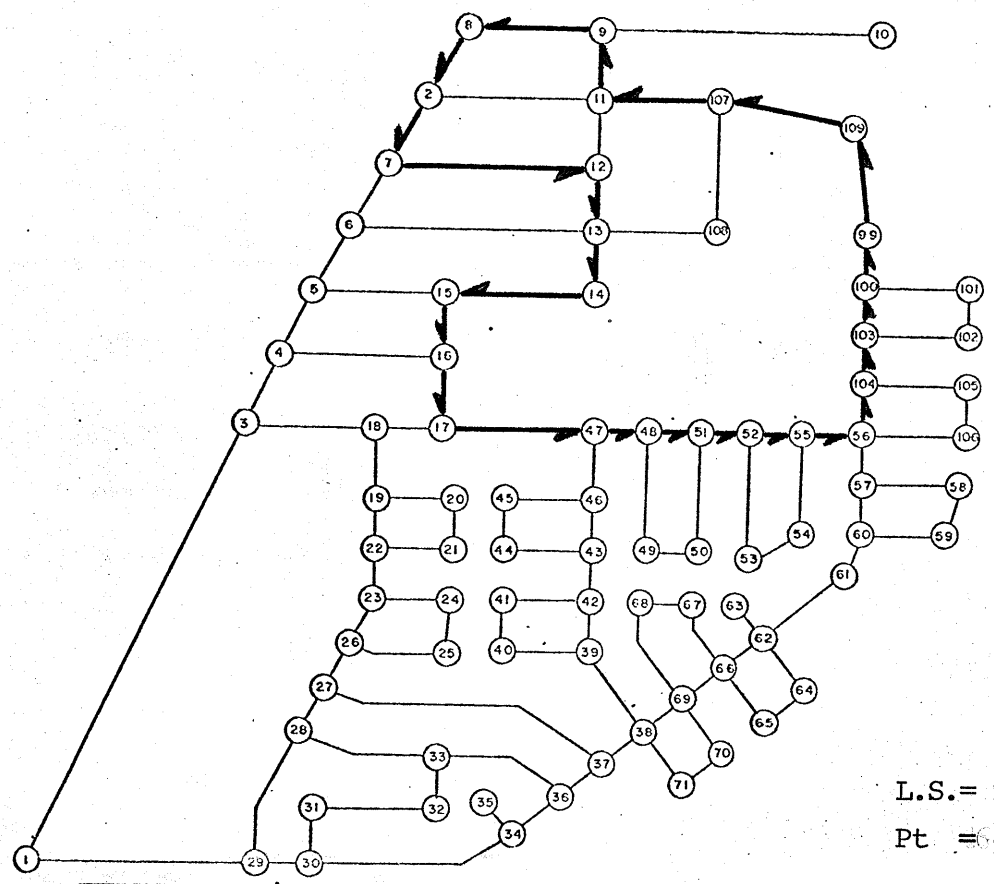


L.S.= 2.4

Pt = 496

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	3	158	30	5.3
2	46	133	56	2.4
3	64	91	54	1.7
4	37	60	38	1.6
5	28	24	24	1.0

SIMULATION 9 CYCLE 1 VEHICLE 2

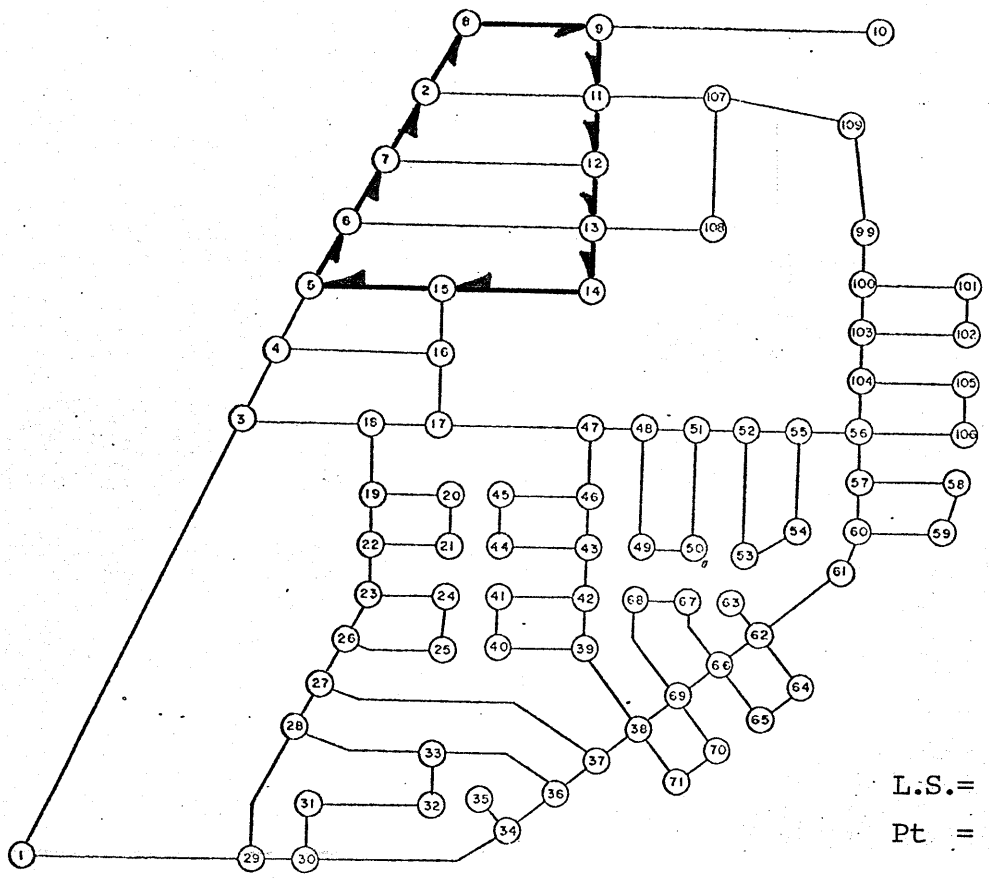


L.S.= 9.3

Pt = 462

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	7	176	5	35.2
2	14	140	22	6.4
3	104	80	43	1.9
4	109	48	26	1.8
5	9	13	13	1.0

SIMULATION 10 CYCLE 1 VEHICLE 1

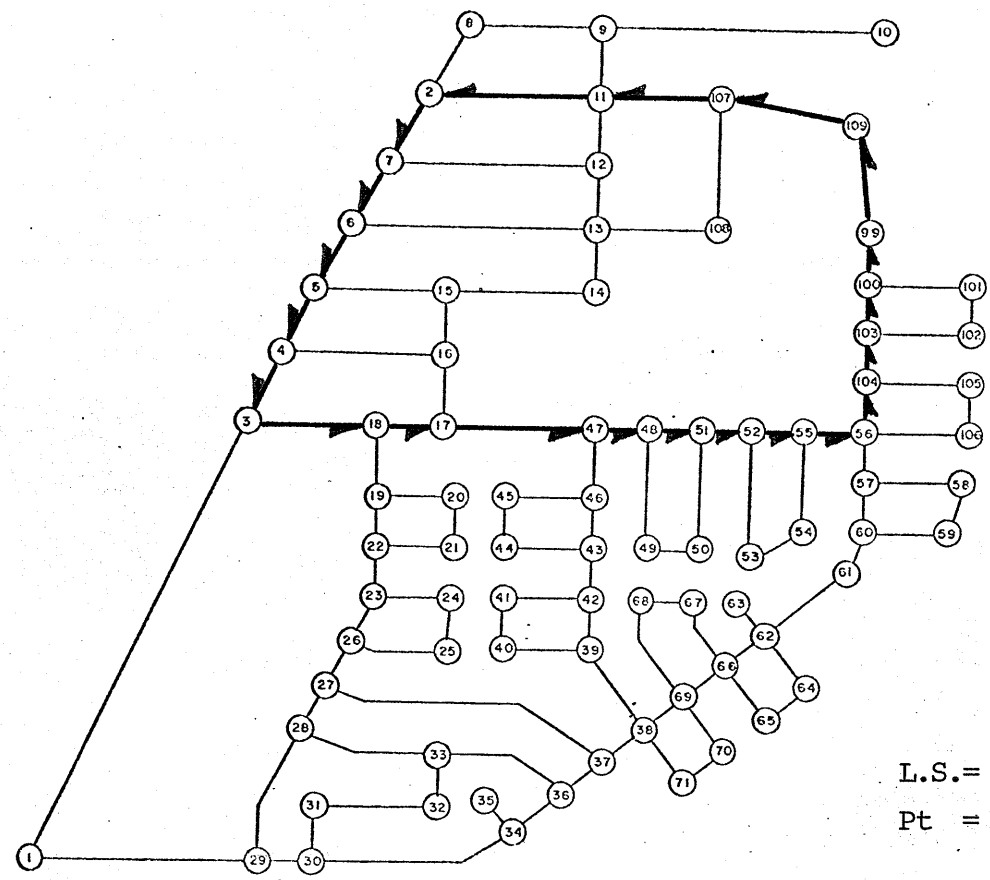


L.S.= 3.0

Pt = 143

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	9	78	13	6.0
2	14	47	22	2.1
3	7	5	5	1.0

SIMULATION 10 CYCLE 1 VEHICLE 2

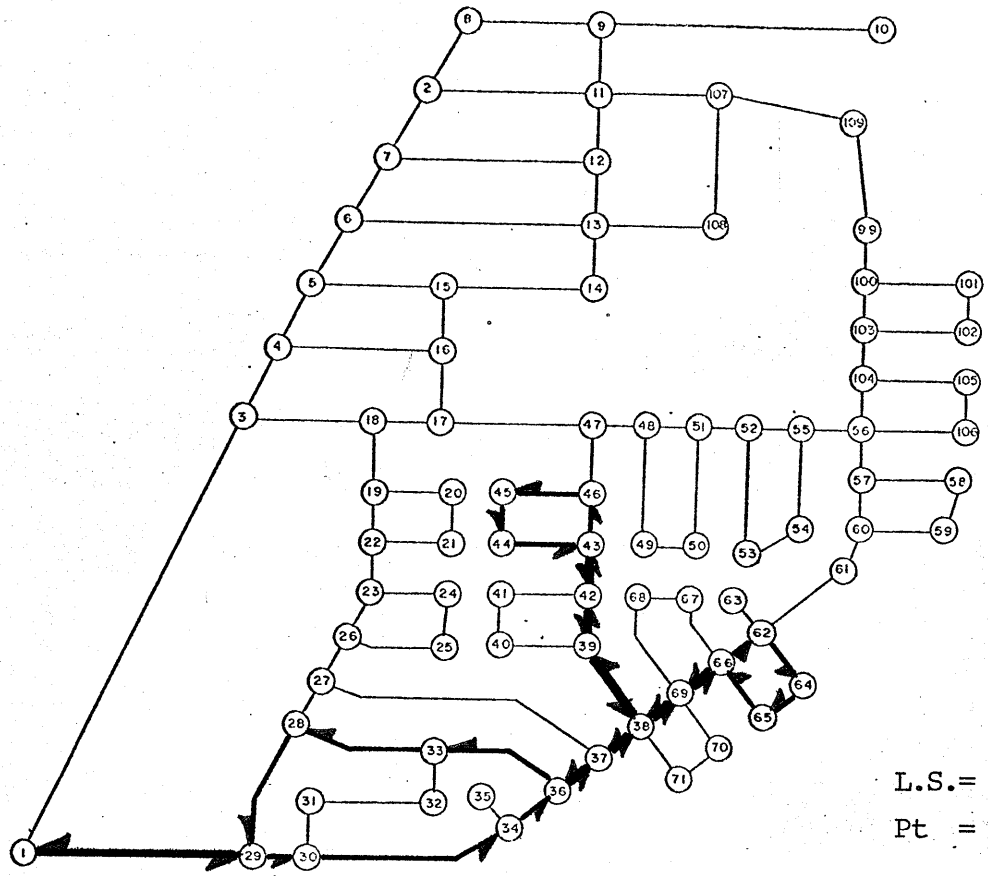


L.S.= 2.2

Pt = 219

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	3	110	25	4.4
2	104	58	43	1.3
3	109	26	26	1.0

SIMULATION 10 CYCLE 1 VEHICLE 3

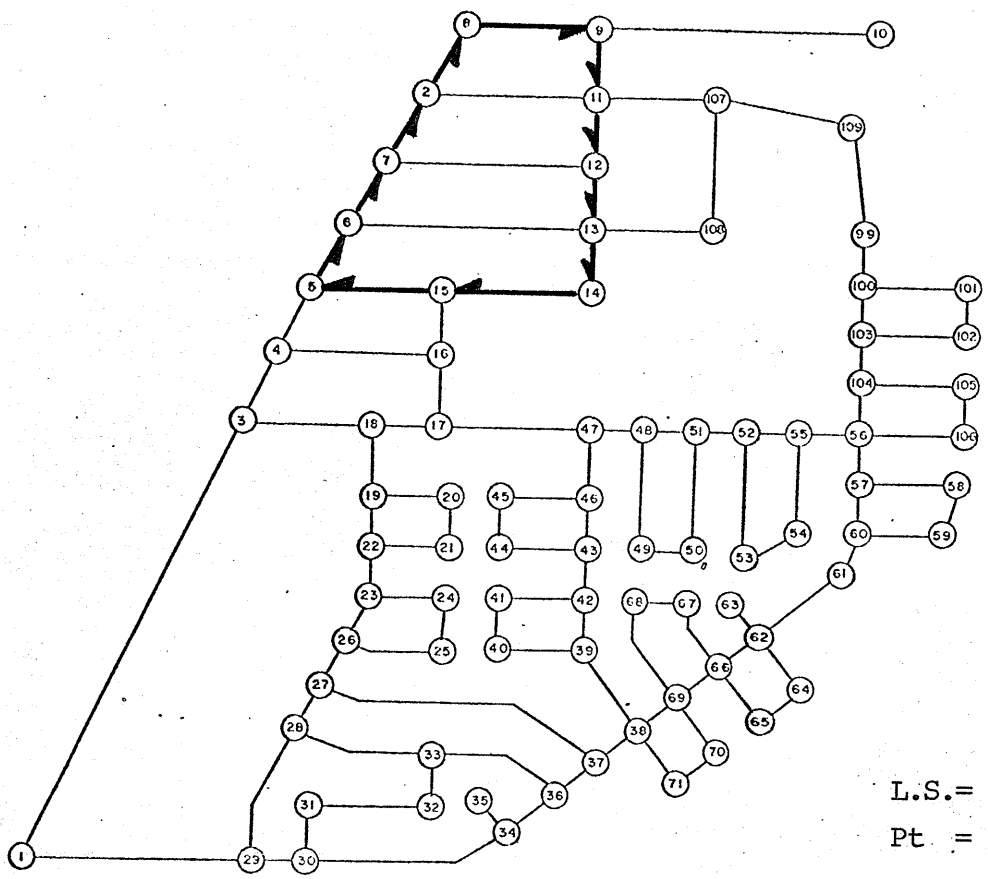


L.S.= 2.0

Pt = 429

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	64	152	54	2.8
2	46	121	56	2.2
3	37	78	38	2.1
4	28	24	24	1.0

SIMULATION 11 CYCLE 1 VEHICLE 1

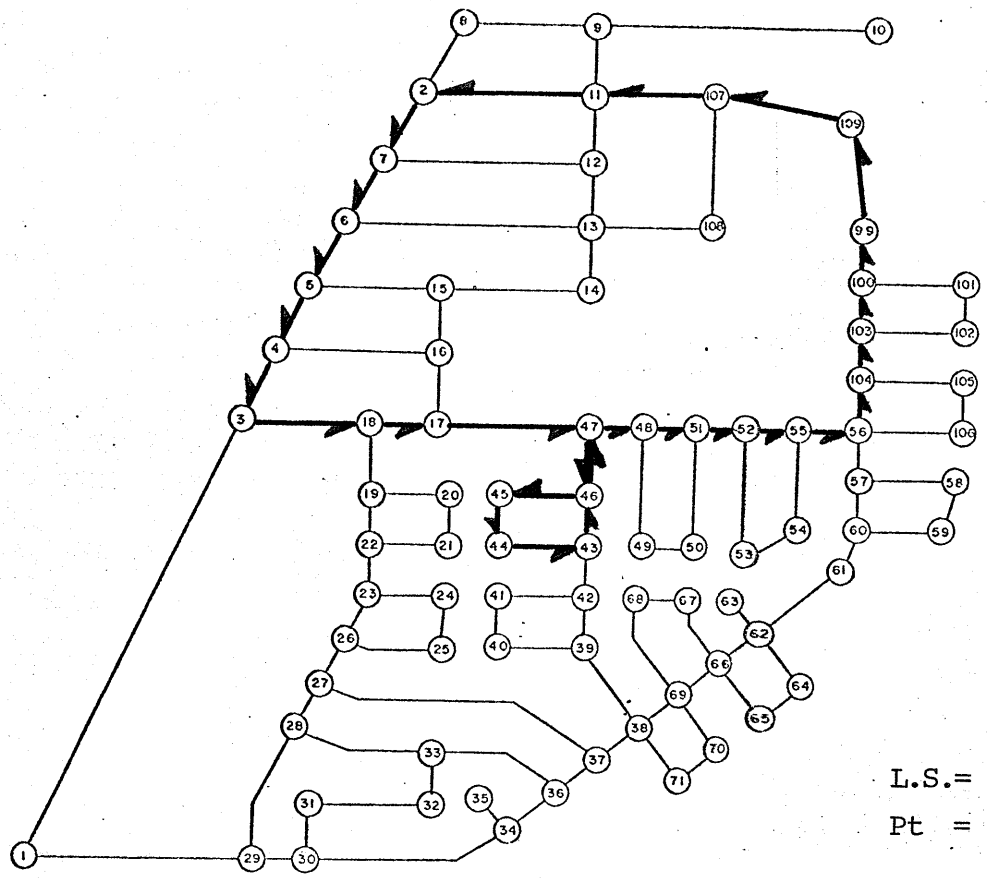


L.S.= 3.0

Pt = 143

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	9	78	13	6.0
2	14	47	22	2.1
3	7	5	5	1.0

SIMULATION 11 CYCLE 1 VEHICLE 2

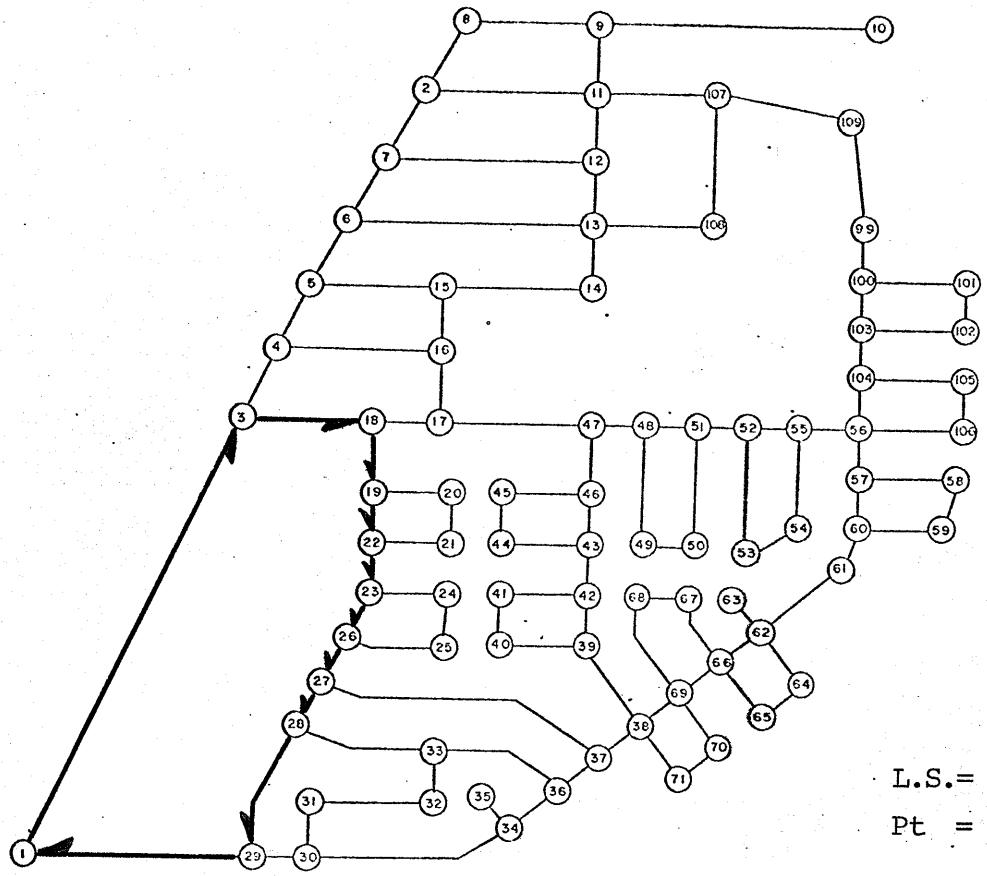


L.S.= 1.3

Pt = 230

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	46	96	56	1.7
2	104	58	43	1.3
3	109	26	26	1.0

SIMULATION 11 CYCLE 1 VEHICLE 3

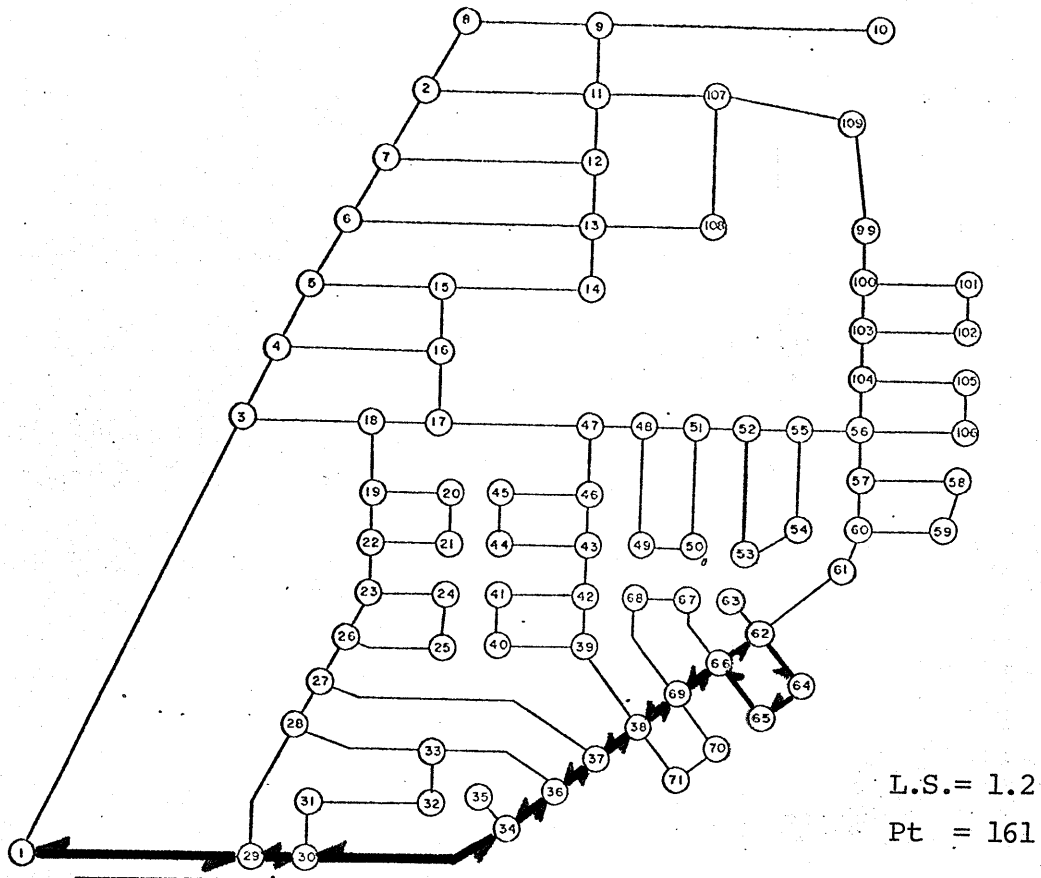


L.S.= 1.8

Pt = 140

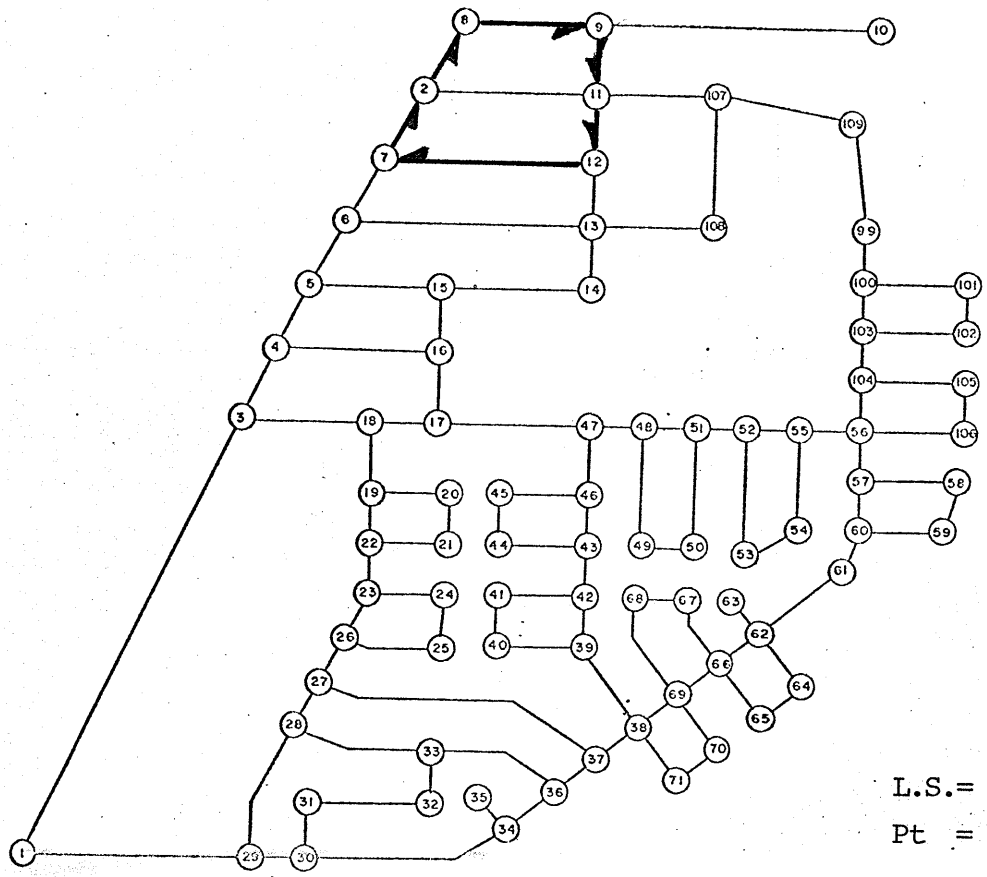
ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	3	65	25	2.6
2	28	24	24	1.0

SIMULATION 11 CYCLE 1 VEHICLE 4



ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	64	69	54	1.3
2	37	38	38	1.0

SIMULATION 12 CYCLE 1 VEHICLE 1

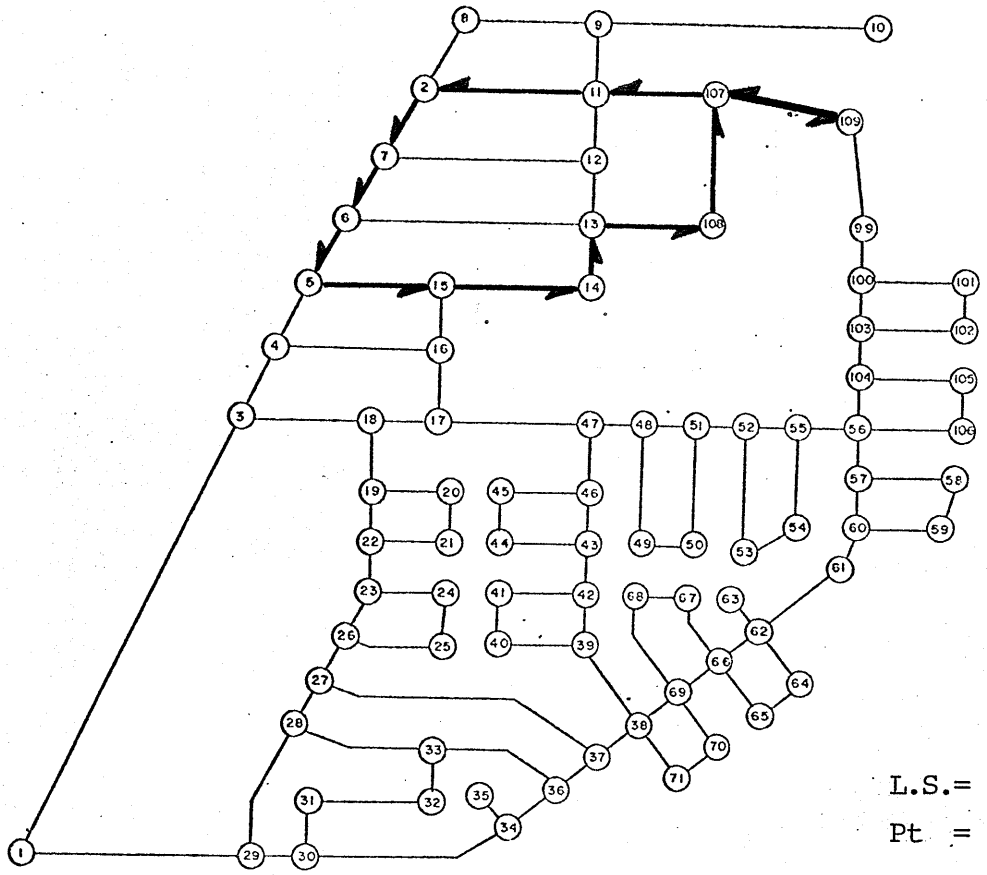


L.S.= 2.1

Pt = 59

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	9	41	13	3.1
2	7	5	5	1.0

SIMULATION 12 CYCLE 1 VEHICLE 2

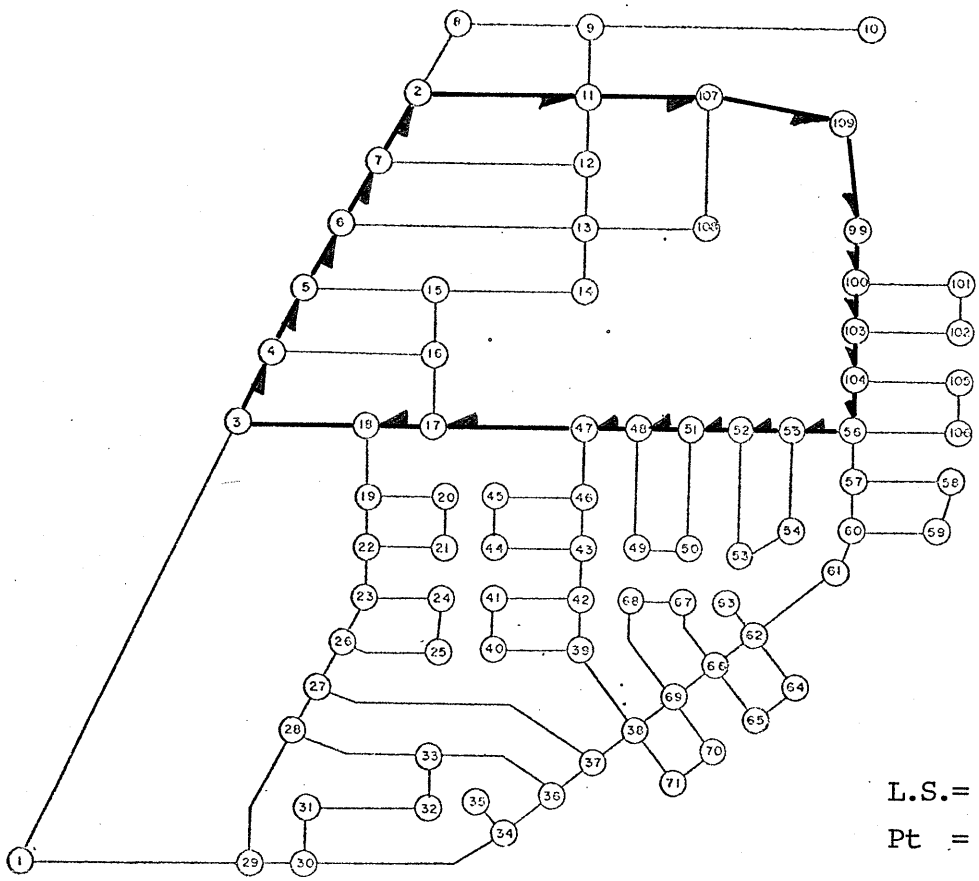


L.S.= 2.1

Pt = 117

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	14	69	22	3.1
2	109	26	26	1.0

SIMULATION 12 CYCLE 1 VEHICLE 3

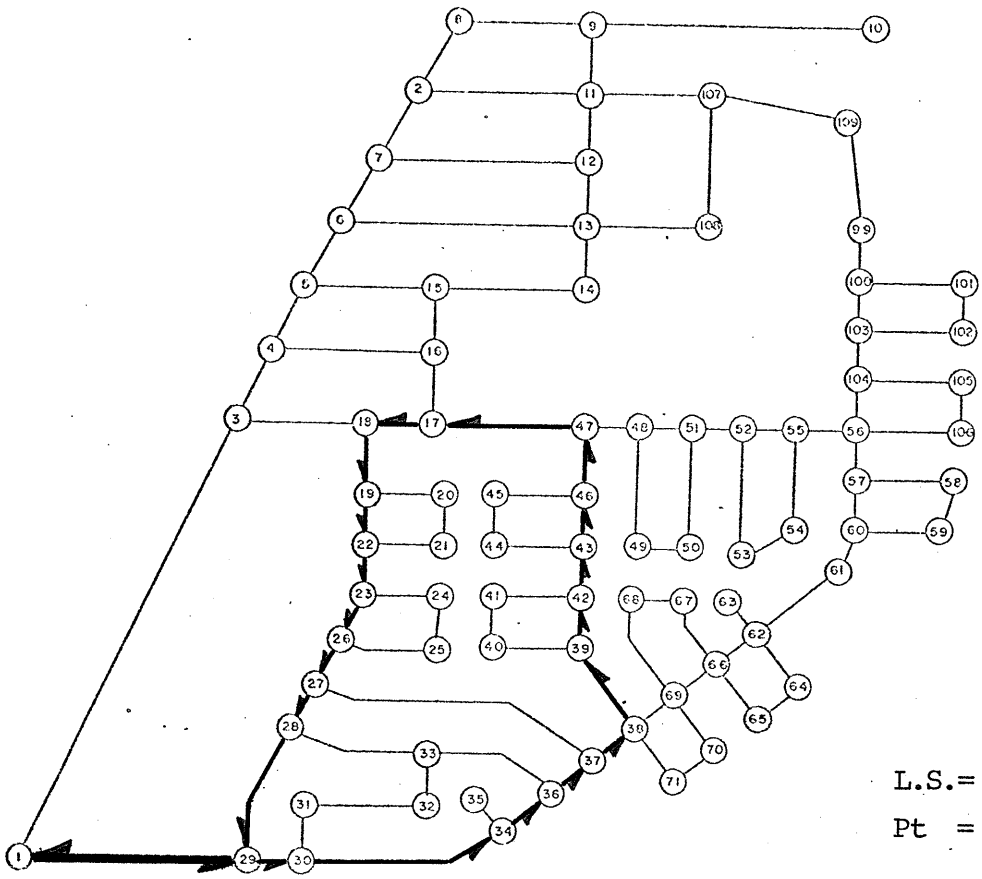


L.S.= 1.4

Pt = 148

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	104	80	43	1.9
2	3	25	25	1.0

SIMULATION 12 CYCLE 1 VEHICLE 4

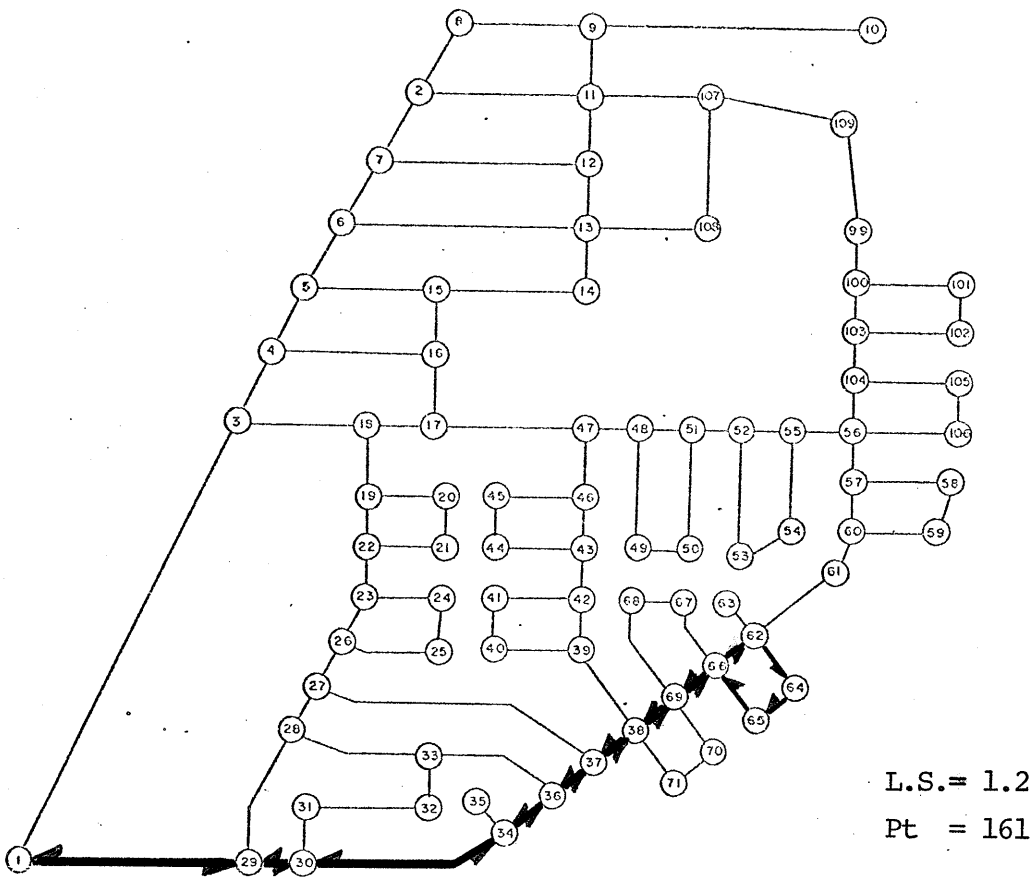


L.S.= 1.2

Pt = 157

ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	46	78	56	1.4
2	28	24	24	1.0

SIMULATION 12 CYCLE 1 VEHICLE 5



ORDER OF PICK-UP	DEMAND CENTROID	PASSENGER SERVICE TIME	DIRECT AUTO TRAVEL TIME	LEVEL OF SERVICE
1	64	69	54	1.3
2	37	38	38	1.0

APPENDIX D

STEPWISE MULTIPLE REGRESSION OUTPUT LISTING (MEAN LEVEL OF SERVICE MODEL)

STEP 1

VARIABLE ENTERED.....16 P_S^2

SUM OF SQUARES REDUCED IN THIS STEP.... 10618.070
PROPORTION REDUCED IN THIS STEP..... 0.806

CUMULATIVE SUM OF SQUARES REDUCED..... 10618.070
CUMULATIVE PROPORTION REDUCED..... 0.806 OF 13166.078

FOR 1 VARIABLES ENTERED
MULTIPLE CORRELATION COEFFICIENT... 0.898
(ADJUSTED FOR D.F.)..... 0.898
F-VALUE FOR ANALYSIS OF VARIANCE... 83.344
STANDARD ERROR OF ESTIMATE..... 11.287
(ADJUSTED FOR D.F.)..... 11.287

VARIABLE NUMBER	REGRESSION COEFFICIENT	STD. ERROR OF REG. COEFF.	COMPUTED T-VALUE
16	0.00872	0.00096	9.129
INTERCEPT	3.46845		

STEP 2

VARIABLE ENTERED.....12 S_T^2

SUM OF SQUARES REDUCED IN THIS STEP.... 1168.893
PROPORTION REDUCED IN THIS STEP..... 0.089

CUMULATIVE SUM OF SQUARES REDUCED..... 11786.961
CUMULATIVE PROPORTION REDUCED..... 0.895 OF 13166.078

FOR 2 VARIABLES ENTERED
MULTIPLE CORRELATION COEFFICIENT... 0.946
(ADJUSTED FOR D.F.)..... 0.943
F-VALUE FOR ANALYSIS OF VARIANCE... 81.194
STANDARD ERROR OF ESTIMATE..... 8.520
(ADJUSTED FOR D.F.)..... 8.730

VARIABLE NUMBER	REGRESSION COEFFICIENT	STD. ERROR OF REG. COEFF.	COMPUTED T-VALUE
16	0.04363	0.00873	4.999
12	-0.09413	0.02346	-4.013
INTERCEPT	4.31575		

STEP 3

VARIABLE ENTERED.....11 S_T

SUM OF SQUARES REDUCED IN THIS STEP.... 249.219
PROPORTION REDUCED IN THIS STEP..... 0.019

CUMULATIVE SUM OF SQUARES REDUCED..... 12036.176
CUMULATIVE PROPORTION REDUCED..... 0.914 OF 13166.078

FOR 3 VARIABLES ENTERED
MULTIPLE CORRELATION COEFFICIENT... 0.956
(ADJUSTED FOR D.F.)..... 0.951
F-VALUE FOR ANALYSIS OF VARIANCE... 63.914
STANDARD ERROR OF ESTIMATE..... 7.923
(ADJUSTED FOR D.F.)..... 8.329

VARIABLE NUMBER	REGRESSION COEFFICIENT	STD. ERROR OF REG. COEFF.	COMPUTED T-VALUE
16	0.04522	0.00816	5.545
12	-0.10991	0.02321	-4.736
11	0.69549	0.34905	1.993
INTERCEPT	-1.30806		

STEP 4

VARIABLE ENTERED.....15 Ps

SUM OF SQUARES REDUCED IN THIS STEP.... 485.281
PROPORTION REDUCED IN THIS STEP..... 0.037

CUMULATIVE SUM OF SQUARES REDUCED..... 12521.457
CUMULATIVE PROPORTION REDUCED..... 0.951 OF 13166.078

FOR 4 VARIABLES ENTERED
MULTIPLE CORRELATION COEFFICIENT... 0.975
(ADJUSTED FOR D.F.)..... 0.971
F-VALUE FOR ANALYSIS OF VARIANCE... 82.554
STANDARD ERROR OF ESTIMATE..... 6.158
(ADJUSTED FOR D.F.)..... 6.651

VARIABLE NUMBER	REGRESSION COEFFICIENT	STD. ERROR OF REG. COEFF.	COMPUTED T-VALUE
16	0.08356	0.01245	6.711
12	-0.21636	0.03480	-6.218
11	6.34026	1.60104	3.960
15	-3.28226	0.91750	-3.577
INTERCEPT	-5.45483		

STEP 5

VARIABLE ENTERED..... 8 ΣCX

SUM OF SQUARES REDUCED IN THIS STEP.... 149.479
PROPORTION REDUCED IN THIS STEP..... 0.011

CUMULATIVE SUM OF SQUARES REDUCED..... 12670.934
CUMULATIVE PROPORTION REDUCED..... 0.962 OF 13166.078

FOR 5 VARIABLES ENTERED
MULTIPLE CORRELATION COEFFICIENT... 0.981
(ADJUSTED FOR D.F.)..... 0.976
F-VALUE FOR ANALYSIS OF VARIANCE... 81.889
STANDARD ERROR OF ESTIMATE..... 5.563
(ADJUSTED FOR D.F.)..... 6.183

VARIABLE NUMBER	REGRESSION COEFFICIENT	STD. ERROR OF REG. COEFF.	COMPUTED T-VALUE
16	0.08567	0.01129	7.589
12	-0.22136	0.03152	-7.023
11	5.78303	1.46844	3.938
15	-2.32338	0.93670	-2.480
8	-0.01973	0.00898	-2.198
INTERCEPT	-4.37953		

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