Algorithms for Routing and Scheduling in Demand-Responsive Transportation Systems

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This paper reviews several techniques that have been developed for the routing and scheduling of proposed demand-actuated transportation systems. These routing and scheduling techniques have been used in the computer simulation of these systems. Specifically, attention is directed toward the work at Northwestern University, Westinghouse Air Brake Company, and Massachusetts Institute of Technology. A critical review is made of these techniques, highlighting their differences, similarities, and possible limitations. Specifically, attention is given to (a) the selection of a vehicle for pickup and delivery of passengers; (b) the method of selecting priorities for the pickup and delivery of passengers; (c) the ability to handle groups of passengers with common origins and with or without common destinations; (d) the method of contact and the frequency of communication with individual vehicles; (e) the method of describing the street network characteristics of the area to be served; (f) the location of vehicle terminals; (g) the dispatching policies; and (h) the proposed levels of service. Also included is a discussion of work currently under way in the Transportation Research Department of General Motors Research Laboratories that introduces new techniques for the routing and scheduling of passengers.

•MUCH ATTENTION is being given a relatively new type of urban transportation system. This new system goes under a variety of names such as demand-scheduled bus system (DSB), dial-a-bus, demand-jitney (DJ), computer-aided routing system (CARS), and small bus operations. A variety of methods have been proposed for the routing and scheduling of individual vehicles. Computer simulation has been and is being used to evaluate such systems and to arrive at some operating decisions for a real performance or demonstration project. Each group working in this area has proposed somewhat different algorithms for the routing and scheduling of vehicles.

This paper is intended to bring together the various proposed methods and in a brief summary point out the similarities, differences, and possible limitations. Specifically, attention will be directed toward the following items:

1. The selection of a vehicle for pickup and delivery of passengers;
2. The method of selecting priorities for the pickup and delivery of passengers;
3. The ability to handle groups of passengers with common origins and with or without common destinations;
4. The method of contact and the frequency of communication with individual vehicles;
5. The method of describing the street network characteristics of the area to be served;
6. The location of vehicle terminals;

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7. The dispatching policies; and
8. The proposed levels of service.

Items 1, 2, and 7 are closely related. They are discussed separately in this paper to aid in the understanding of the various algorithms. This review is limited to the work done at Northwestern University, Westinghouse Air Brake Company (WABCO), and Massachusetts Institute of Technology (M. I. T.) (1, 2, 3). Also included is a discussion of work currently under way in the Transportation Research Department at General Motors Research Laboratories.

The success of a demand-scheduled bus system might well lie within the routing and scheduling ability. The operational status of the routing and scheduling algorithm will undoubtedly influence the cost of operation. There may be some trade-offs between the cost of sophisticated routing and scheduling techniques and other costs of operation. In addition to the cost of operation, the routing and scheduling technique used may well influence demand for service. How users are picked up and routed could influence the attitudinal preferences of passengers.

The algorithms discussed have been written in a variety of computer languages on several computers, including equipment manufactured by Control Data Corporation (CDC) and International Business Machine Corporation (IBM), and run under the control of various operating systems.

The Northwestern work was written in the FORTRAN language using the SPURT simulation system for the CDC 6400 computer. The General Purpose System Simulation (GPSS) software was used by WABCO. It is not clear from the reporting of the WABCO work what model of the IBM 360 was used. FORTRAN was used by M. I. T. on the IBM 360/40 and IBM 360/65 computers.

Various items that will be discussed, such as the selection of vehicle for pickup and delivery of a passenger and the method of selecting priorities for pickup and delivery of passengers, are closely related. Such divisions have been made in order to more clearly state what the various techniques are intended to do and will hopefully make them understandable.

The Appendix presents in table form a brief comparison of the various algorithms.

SELECTION OF VEHICLE FOR PICKUP AND DELIVERY OF A PASSENGER

The Northwestern University simulation program specifies methodology for picking up and delivering a given passenger. As a demand for service is received, the Northwestern program scans the location and usage of all of the vehicles that are currently operating in the system. The vehicle that is nearest (by distance) to the origin of the call is the first one selected to be considered for service. This vehicle is then checked to see if the new demand can be serviced without violating any of the passenger service criteria that have been established for passengers already on board or for those passengers that are scheduled to be picked up. If the bus that is nearest the new demand is not able to service the call, then the next nearest bus is selected and is scanned to see if it can service the new demand. After all the buses on the system have been scanned and no bus is found to be able to meet the new demand, then a bus is sent from the terminal to service the call. When a new bus is generated, it then is considered to be in the system and will be considered for any other incoming calls.

Because the closest bus is always the first one to be considered as a possible server, there is really no assurance that any optimization in level of passenger service will be obtained. In fact, at times, passengers will have to remain on the bus an additional time that might otherwise be avoided. However, at no time will any of the established levels of service be violated for any passenger on any bus. Once an individual is assigned to a given bus, he remains assigned to that bus until he is picked up and delivered to his destination.

In the WABCO simulation, a given vehicle (one of three in the service area) makes a pickup or a delivery to serve the waiter or the passenger with the highest priority. For the waiter (the passenger that is to be picked up), a priority is assigned that has an arbitrary value of 110 minus his distance from the vehicle under consideration in grid units minus the waiter's origin to destination (O-D) distance in grid units. A grid unit is a function of the grid density; for example, in an area of 25 square miles and a 20 by 20 grid, the grid unit would have a value of 0.25 mile. For those users already on the bus, "the priority is 100 minus the destination distance in grid units plus one unit for every five minutes of total wait time plus one unit for every 10 minutes of total wait time" (3). If a passenger has been waiting for 40 minutes, including the time that he spent on the vehicle, he is assigned a top priority. The WABCO algorithm uses one additional vehicle designated to handle the longest trips and the longest waiters. This vehicle attempts to handle those passengers that cannot receive service from the other vehicles in the system. A passenger waiting to be picked up will be given a priority relating to the largest value computed by adding his O-D distance in grid units to his waiting time measured by 1 unit for 3 minutes of wait, 1 unit for 2 minutes, and 1 unit for 1 minute of wait time. If this extra vehicle cannot keep up with the task of handling the longer waiters, provision is made for other vehicles to assist by assigning a top priority to those waiting over 50 minutes.

In the M. I. T. CARS project, a vehicle is selected to serve a new demand based on the consideration of waiting time of the new user, his travel time, his overall service time, link constraints, and the travel constraints of all current users. The link constraints are, in effect, the time that a vehicle is due at particular nodes in the tour of the bus. The travel constraints of all current users are waiting time, travel time, and total service time. The new user is assigned to a vehicle that can serve him while inconveniencing "as little as possible" those already traveling and serve the new demand "quickly" and also maintain the ability to serve future demands.

If it is desired to optimize on-system operation or to minimize the cost of operation, it is obvious that the fewer the buses required to service a given demand level, other factors being equal, the more likely it is that cost will be lowered. Thus, if an algorithm is developed that would tend to maximize the occupancy of a given vehicle, then this would seem, on the surface, to reduce the number of vehicles required for that operation. However, it is also obvious that it is somewhat difficult, if not impossible, to minimize the inconvenience to passengers and, at the same time, maximize the occupancy of individual vehicles.

An objective function that incorporated the maximization of bus occupancy and the minimization of user "inconvenience" might be used to solve the dilemma. Given several buses that could serve a new demand, each having about the same inconvenience value but each having a different number of passengers, then the new user would, under the control of the objective function, be assigned to the bus with the largest number of passengers. If the importance that is applied to the maximization of passengers is nonlinear, lightly loaded buses look much worse in proportion to heavily loaded buses, this strategy would likely cause buses to become empty so that they can be removed from the system. A discussion of such an algorithm will appear later in this paper in the discussion of the General Motors Research Laboratories work.

THE METHOD OF ORDERING THE PICKUP AND DELIVERY OF PASSENGERS

The Northwestern simulation package attempts to pick up new passengers as early as possible. That is, if a vehicle has one passenger already on board, the vehicle will attempt to pick up the new user before the delivery is made. The simulation package tries all combinations of scheduling the pickup of the new passenger as well as the delivery to his destination. The simulation package will choose the first position in the queue in which the pickup can be made and not violate any of the other levels of service guaranteed. The destination is handled in exactly the same manner, in that it is placed first in the queue in which it will fit without violating any of the other levels of service for the other passengers. Nothing is done to ensure that there is an optimum scheduling of the new passenger onto the vehicle. That is, the new demand (passenger) is scheduled to be picked up as soon as possible and will be delivered as soon as possible within the established constraints of the other passengers assigned to the vehicle. This, of course, means that someone who is already on the bus may have to wait until someone else is picked up and delivered before he himself will reach his destination.

The WABCO simulation operates on the priority basis. A passenger is picked up or delivered in the order of his priority. This priority is established in the manner that has been previously discussed.

In the M. I. T. CARS project the ordering of pickup and delivery is based on finding a point in the existing tour of a bus (the route the bus follows while picking up and delivering users) that will minimize the disruption of service to all current users. The function to be minimized is one involving projected pickup and delivery times of each current user and the link constraints of the bus's tour before and after the proposed pickup and delivery. There are 3 possible infeasible solutions to the pickup and delivery problem: (a) For a tour there are positions for the origin and destination that do not violate the link constraints but violate one or more of the service guarantees for the new demand; (b) for a tour it is possible to insert the new demand so as to satisfy its own service guarantees but at least one of the link constraints for that tour will be violated; and (c) solutions (a) and (b) are combined.

THE ABILITY TO HANDLE GROUPS OF PASSENGERS WITH COMMON ORIGINS AND WITH OR WITHOUT COMMON DESTINATIONS

The Northwestern simulation package does not specifically handle multiple origins or destinations. If multiple origins or destinations are to be handled, they would have to be treated as individual destinations. For example, if there were 3 people desiring to make a trip together from a common origin, this would be treated in the simulation as 3 separate demands for service. Also, each destination would be treated separately. Thus, there would be 3 destinations used by the simulation package. Three people, perhaps of one family, desiring to have the same destination might have to use more than one vehicle to obtain the service.

The WABCO report does not specify its method of handling multiple origins and destinations. It would seem from the report that they treat multiple origins and destinations in the same manner as the Northwestern simulation package.

In the M. I. T. formulation of the problem, a demand may consist of more than one person and is referred to as a passenger group. It would appear that for each passenger group there is a unique origin and destination. As a matter of fact, an example is given: "If two distinct demands have a common origin but not a common destination, the formulation represents their origin as two different non-negative integers which may or may not be sequential" (2). Associated with the formulation would be a list transforming these integers into some graphical representation of the pickup and delivery points. The possibility then exists that more than one bus would have to be used to satisfy the demand for travel from this one origin.

The system should be able to handle groups of passengers with a common origin and with or without a common destination. If this service is to be provided in off-peak periods where families might be using this service to attend movies, go shopping, or simply take a trip to visit the neighbors or relatives, then it is highly unlikely that a given family would desire to split into 2 or more vehicles for the trip. An algorithm to handle this situation would not be difficult to develop.

THE METHOD OF CONTACT AND THE FREQUENCY OF COMMUNICATION WITH INDIVIDUAL VEHICLES

The Northwestern simulation package assumes continuous contact with all vehicles operating on the system. There was no proposal as to the methods of contacts as far as electronic equipment is concerned. Essentially the WABCO report also assumed automatic vehicle monitoring. WABCO, having problems with the General Purpose Systems Simulations (GPSS) programs, used a negative time feature to account for automatic vehicle monitoring. The WABCO report suggested the possibility of 2-way radio communications as a means of achieving this constant monitoring of the vehicle on the system.

M. I. T. looked into 2 possibilities: (a) continuous location of the vehicle and (b) discrete location of the vehicle. Under continuous location, the vehicle path would be monitored at all times during the simulation and thereby allow instant reassignment of the vehicle to pick up or deliver passengers. The feeling was that if vehicle monitoring is continuous, it may be possible to improve the routing policies by using intermediate assignments of new demands between vehicles. Under a system where only the discrete location of the vehicle is known, one does not have the capability of making an intermediate assignment or reassignment because the precise location of the vehicle is only known when passengers are either picked up or delivered.

The ability to communicate with the vehicle on demand is important to the efficient operation of the system. New users could be assigned vehicles and those vehicles rerouted if vehicles could be located when desired. If, on the other hand, an assignment cannot be made based on the vehicles' current locations, then the new user may suffer a delay in both his pickup and mean destination arrival time. Current users' travel time would likely be increased because a less desirable vehicle, in the sense that the vehicle had to be diverted to a greater extent, was assigned to pick up the new user. The operator or system suffers because the assigned vehicle may be required to travel farther out of the way thus increasing vehicle mileage and lowering the demand per hour that a vehicle can serve. The net result for the system would be an increase in operating cost.

The communication between the vehicle and control center will, in general, be non-voice in an operational system. Vehicle location would be through the transmission by the control center of a coded signal, a different code for each vehicle; the vehicle would respond with a signal that may indicate the vehicle position. Routing information could also be transmitted by a coded signal causing a display or printout of where the vehicle is to go if the vehicle is being rerouted or how to get to the next stop in its tour. The vehicle might transmit a signal to the control center on arrival at a stop.

Voice communication would only be used in special cases, e.g., vehicle breakdown, passenger illness, or driver illness, because of the time required to transmit the routing information and the cost of the personnel at the control center that would be involved.

THE METHOD OF DESCRIBING THE STREET NETWORK CHARACTERISTICS OF THE AREA TO BE COVERED

The Northwestern package used a simple, 1-mile square grid. This grid was in turn divided into 100 basic units that represented intersections of blocks. Equal travel times were assumed on all links of the network.

The WABCO simulation also used a square grid. Their square grid ranged from a 1- by 1-mile square up to 5 by 5 miles. However, the grid unit size varied from one-tenth to one-quarter mile. As with the Northwestern simulation, the WABCO origin and destination points occur at grid intersections. The link travel time appeared to be uniform over the entire area.

The M. I. T. work of an earlier date, primarily the METRAN work, was based on a rectilinear grid of from 1 by 1 mile to 3 by 3 miles (4). The current work (2) discusses a network that is based on airline distances between points, using the reasoning that the specific street network under study is not pertinent to a grasp of the fundamental algorithmic concepts.

It would seem that the idea of simply describing a grid system with all of the links having the same travel time, or using airline distances, is very unrealistic. At a very minimum, a network description should be made in which one would be able to describe at least the major arterial street system by zone or by areas within the area to be serviced. This would conform more closely to present techniques used in the assignment package of most transportation plans. In, for example, certain areas in which there is limited access to river crossings, this would be a definite constraint on the scheduling and operation of a demand-type service. Therefore it would seem that, to have any accuracy or relate to a real-life situation, some form of existing street network should be described to the simulation program.

THE LOCATION OF VEHICLE TERMINALS

All 3 simulation studies locate the vehicle terminals in the middle or center of the study area. All 3 simulation projects use only one terminal from which to generate or dispatch vehicles.

The location of the terminal or terminals is very important to the performance of the system. If only one terminal is used, then the pickup time guaranteed will be a function of the time required for a vehicle to travel from that terminal to the most distant (in time) point in the area. For most areas this will be the corners. In a 2- by 2-mile area and with a vehicle traveling at an average velocity of 20 mph, the time for the trip might be 6 minutes, which seems to be a reasonable waiting time. On the other hand, if the area is 6 by 6 miles, the travel time for the same vehicle might be expected to be 18 minutes. If 6 minutes is the desired and, therefore, guaranteed pickup time, then something must be done. It is unlikely that the velocity of the vehicle could be increased to 60 mph, leaving only the possibility of additional terminals. Where these terminals will be located and the exact number required will be a function of the area to be served, i.e., shape and size, the level of demand, and the distribution function of the demand.

THE DISPATCHING POLICIES

In the Northwestern simulation package, when all of the vehicles on the grid cannot service an incoming call, then and only then is a new vehicle dispatched from the terminal to service this call. This vehicle will not be dispatched until after all of the other vehicles have been rejected.

The WABCO simulation designates a special (extra) vehicle that handles particular situations. When WABCO's 3 vehicles on the system cannot service a given demand for service, then the extra vehicle handles this individual demand. Each individual demand that cannot be serviced by the other vehicles is assigned a special waiting time measured by 1 unit for 3 minutes of wait, 1 unit for 2 minutes, and 1 unit for 1 minute of wait time. Once the extra vehicle is on its way to pick up a passenger and if there is a new demand located on the way to this origin, he also will be picked up. Essentially, the extra vehicle uses an algorithm that is designed to handle the longest trips and those waiting the longest.

In the CARS project a bus is dispatched if, and only if, none of the other vehicles in the system can service the demand. When a demand is made on the system, the vehicles are scanned to determine which vehicles can satisfy the demand. If none of the vehicles can satisfy the demand, that is, if guarantees will be violated for the new user or current users, then a new vehicle is dispatched from the station.

In regard to the dispatching policies, given that there are no vehicles on the system that can service the demand, then a vehicle from a terminal nearest to the incoming call should be dispatched to service the call. However, there might be some merit to having one or more vehicles that could be responsible only for servicing those calls that occur in an extreme situation and could not be serviced by any of the vehicles on the system. Also there might not be any additional vehicles available for dispatching in the terminals. If the scheduling algorithms work properly and everything is performing as it should, then it would seem that only very rarely would a situation such as this occur. An application of a sensitivity analysis would allow for evaluation of the number of times an extra vehicle designated only for handling extreme cases would be required.

THE PROPOSED LEVELS OF SERVICE

The Northwestern simulation package had 3 items included in the level of service—a minimum and maximum pickup time, and a maximum travel time. The minimum pickup time was automatically set at 1 minute; from the time that an individual placed his call he was assured that a vehicle would not pick him up for at least 1 minute. The maximum pickup time guaranteed the passenger that he would be picked up before a specified time limit has elapsed. The maximum pickup time was arbitrarily chosen to be 6 minutes. The maximum travel time was a linear function.

$$\text{Max travel time} = \begin{cases} K\,n, & \text{for } n \le n' \\ T + e\,n, & \text{for } n > n' \end{cases}$$

where

n = the number of links between origin and destination (a link is 1 block long);
n' = a control parameter constant set equal to 10 links;
K = a control parameter constant that equals 1 minute per link;
T = a control parameter constant that equals 5 minutes; and
e = a control parameter constant that equals one-half minute per link.

The 3 levels of service were guaranteed to each individual demand for service. At no time were any of these levels of service violated. That is, 100 percent of the demand would be assured these levels of service.

The WABCO guaranteed service time dealt with an assured total time that includes the waiting time. This time varied from 2 times the automobile driving time to 6 times the automobile driving time. The automobile driving time was assumed to be based on a 20-mph average speed plus a fixed value of 2 minutes. In the WABCO simulation each passenger was not guaranteed that he would have a given "phone to destination" time. However, in the simulation runs, 95 percent of all passengers were served within the guaranteed time.

The M. I. T. simulation work originally was for a square 2 by 2 miles and with a grid street pattern; this apparently was for the "many-to-one" algorithm. Vehicle speed was 15 mph between stops, each vehicle had a capacity to hold 6 passengers, the waiting time constraint was 15 minutes, and there was a time constraint for travel time that was a function of the distance of the trip. The assumed time for unloading and loading of passengers was 10 seconds. Results were not given for the "many-to-many" algorithms in this current report (2), although one would expect that the time constraints and the criteria used for calculating travel time would probably not change.

It is difficult at this point in time to put definite values on the various levels of service. In fact, an in-depth evaluation needs to be made to ascertain what levels of service would be compatible with the majority of potential users of a demand-scheduled service. This is presently being done (5), and it is hoped that after an evaluation is made absolute quantitative values can be attached to the various levels of service. It can easily be argued that different times of day would require different levels of service, different types of trip purposes would require different levels of service, and different geographic areas of operation might also require different levels of service. The point to be made is that levels of service depend on a variety of factors and these levels of service need to be evaluated in terms of the many influencing factors.

THE GENERAL MOTORS RESEARCH LABORATORIES SIMULATION

The General Motors Research Laboratories simulation will try to add to the development of a demand-responsive system simulation procedure. They are using a real city with its associated street network and travel data. The travel data are based on survey data, trip origins and desinations, of the case study city. The street network is also for the case study city and was coded from maps of the city. The network is divided into 2 network types, primary and zonal or secondary. The primary network contains the major streets in the city and the zonal boundaries. The zonal network contains the streets within each of the neighborhoods that the system will serve. Each zone covers an area of about one square mile. A minimum path routine may be used to determine the route and travel time between stops to pick up and/or deliver passengers. System performance or service level is in general maintained through system constraints such as waiting time and travel time guarantees that must be met for both current users as well as the new demand.

The selection of a vehicle to pick up new demands will be based on a function similar in many respects to that developed by M. I. T. The current function includes 4 weighted criteria as of this writing. These criteria are as follows:

1. An attempt to minimize the increase in travel and waiting time to those presently assigned to the system;
2. The desire to keep the waiting time of the new demand to a minimum and an attempt to minimize travel time for the new demand;

3. A parameter that aids in operations of the system and that if used exclusively would minimize the deviation of a vehicle from a given path; and
4. A parameter that will aid in reducing the number of buses in the system.

The weighted summation of the quantities relating to these criteria is, in effect, the cost (in time) of providing service. A cost increase is experienced if the new demand is assigned to a bus under consideration and should, it seems, be minimized on a system-wide basis.

The value used for the weights may be arrived at by various means. Clearly, once the system performance levels were set, the necessary values for the weights to make the system cost the least to the user could be determined.

On the other hand, if one were to consider the desires of the potential customer, by survey, then the weights and system constraining limits could be established and used to determine system performance. Presently work (5) is under way at the General Motors Research Laboratories that will provide quantitative measures of these values.

Using the function, all possible points in a bus's tour will be investigated to determine where the new demand might be picked up and delivered while meeting the guarantees provided current users. Then, that bus and those positions in the bus's tour that result in the minimum value for the function will be used for the demand.

For purposes of the simulation, the location of any bus may be assumed to be found automatically by sending a coded signal to the bus; this would cause the onboard radio equipment to respond. The returning signal is then analyzed and the bus location is determined.

The size of the current study area is approximately 36 square miles. Because of the desire to be able to pick up a new demand within 5 or 10 minutes after a request for service, and the average speed on the street network is not likely to be greater than 20 mph, it becomes apparent that 1 station or terminal located in the center of the city will not suffice. At a speed of 20 mph, it would require 0.21 hour or 12.6 minutes to travel to the corner of the area from the center. Therefore, there will be more than one terminal if either the 5- or 10- minute pickup service guarantee is used.

The only time a new bus will be sent from the terminal or dispatched is when none of the buses currently in the area can service a new demand because of violation of user guarantees. In this case, a stored bus will be dispatched from the nearest terminal to the demand.

One problem that has received little apparent attention is how buses are taken out of the system. Several questions need to be asked: What criteria could be used to determine when a bus is to be returned? How does one get the bus sent back?

The current function attempts to get buses out of the system by making the assignment to lightly loaded buses less attractive given that all of the other parameters are nearly the same in value. In other words, if 2 buses can serve a new demand and the cost of this service is the same for the combined parameters (new user, current users, and operator), then the new user will be assigned to the more heavily loaded of the 2 buses. Without the additional parameter the objective function would tend to uniformly load all buses causing more to be in the system at any given time than necessary. In addition to the parameter in the objective function, a constraint is used to return buses to the terminal at the end of given times; i.e., after 4 hours on duty making pickups and deliveries.

The simulation is written in the IBM PL/I language using the Interim Time Sharing System (ITSS) as installed on the IBM 360/67 computer at General Motors Research Laboratories. The machine was picked because it supports IBM 2250 graphic terminals that will be used to monitor and interact with the simulation. The PL/I language was chosen because there was no other real choice; fortunately, one can do things in PL/I that are either difficult or impossible in other high-level languages.

CONCLUSIONS

A review has been made of the work that has been done by 4 organizations: Northwestern University, Westinghouse Air Brake Company, Massachusetts Institute of Technology, and General Motors Research Laboratories. There are many similarities among the various algorithms as there are differences, which demonstrates that there is yet much to be learned in the area of demand-bus type systems.

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Appendix

The following tabulations give a brief comparison of the algorithms discussed.

	PICKUPS AND DELIVERY	PRIORITY FOR PICKUP AND DELIVERY
NORTHWESTERN UNIVERSITY	Starting with the closest bus review for possible assignment, if not possible, look at the next closest	First bus that can provide the required service. Meet both user and the new demand guarantees.
	No objective function	
WABCO	Starting with the closest bus review for possible assignment, if not possible, look at next closest.	Priority based upon distance from bus and O-D distance for pickup. Priority based upon distance from bus to destination and total time.
	No objective function	
MIT	Review of all vehicles is made to determine which vehicle can 'best' serve the new demand.	Concurrent with the review of all buses a review of positions in the tour of each bus is made. Those positions that minimize the objective function are saved.
GMRL	Review of all vehicles is made to determine which vehicle can 'best' serve the new demand.	MIT uses two terms without 'weights'. GMRL function uses four terms with weights for each.

	LEVELS OF SERVICE	GROUP HANDLING	VEHICLE SIZE
NORTHWESTERN UNIVERSITY	Guaranteed service. One to five minute pickup and a guaranteed delivery time that is a function of distance between the origin and destination (O-D).	None	3 - 8 seats
WABCO	Guaranteed service.	Not clear	5 - 20 seats
MIT	Guaranteed pickup and delivery time. On bus time two to three times auto travel time.	Passenger units which may be more than one person.	6 - 10 seats
GMRL	Guaranteed pickup and delivery time.	Passenger units	Under study

	NETWORK DESCRIPTION	LOCATION OF TERMINAL (vehicle)	VEHICLE CONTACT (Loc. and Com.)
NORTHWESTERN UNIVERSITY	Rectilinear Grid one square mile link length = .1 mile	One at center of grid.	Continuous (assumed)
WABCO	Rectilinear Grid (1 x 1 to 5 x 5 mile) link length = .1 to .25 miles	One at center of grid.	On demand
MIT	Airline (direct movement from stop to stop) up to at least a 3 x 3 mile area	One at center of service area	At discrete intervals or continuous
GMRL	Real city streets 4000 nodes and 10,000 + one way links	A function of 1. Demand level 2. Size of area 3. Pickup guarantee	On demand

	DISPATCHING POLICY	BUS REMOVAL
NORTHWESTERN UNIVERSITY	As needed, once a bus is in the system it stays. Demand constant.	No
WABCO	Up to three buses served most demands. A fourth bus was needed to serve long trips and waiters.	No
MIT	As needed, once a bus is in the system it stays. Demand constant.	No
GMRL	Buses will be sent as needed.	The objective function will attempt to remove unneeded buses. Also buses will be removed on periodical basis; i.e., after four hours duty.