RESEARCH AND PLANNING IN DEMAND-RESPONSIVE TRANSPORTATION

Demand, Supply, and Cost Modeling Framework for Demand-Responsive Transportation Systems

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A comprehensive evaluation framework to aid in the implementation of demand-responsive transportation systems is proposed. The framework consists of demand, supply, and cost models that could be applied at general and detailed levels of decision. General-level models use information from existing demand-responsive operations in the United States and Canada. The models provide estimates of expected ridership, vehicle supply, ridership, and cost of operations as a function of system parameters such as population density, fleet size, fare, travel time, and control center requirements. The use of the models to obtain these estimates is exemplified, and their sensitivity to parametric changes is discussed.

Although the number of demand-responsive transportation systems is increasing in the United States and abroad, little is known about the socioeconomic and demographic parameters that affect the usage level of such a system. In addition, little is known about the manner in which this usage level may be translated in terms of system operating parameters such as fleet size, fare, travel times, and control-center staffing. As a result the initial selection of a service area and the operating parameters of a system are arbitrary decisions based on misleading market feasibility studies or superficial inspection of the service area characteristics.

After the system is in service, the operator attempts to reach a desirable level of service by changing the levels of the key system parameters. The operator may lower the fare and increase the fleet size to increase average ridership or may constrain the service area within geographic boundaries to serve high population densities at a higher quality of service—lower waiting and traveling times. Whatever the case, most of these changes would be performed with no detailed knowledge or analysis of what interactions exist among the parameters and how these interactions affect the performance of a system.

Demand, supply, and cost models that were developed for demand-responsive transportation systems are described in this paper. The models are used to derive estimates of expected ridership, vehicle supply, and cost of operations as a function of key system parameters such as density, fleet size, fare, travel time, and control-center personnel requirements. The models were designed to serve as a planning tool to aid in the preliminary evaluation of potential alternatives for implementing a demand-responsive transportation system. They may also be applied for the initial selection and subsequent monitoring of operating parameters.

The set of demand, supply, and cost models presented is an integral part of an evaluation framework that was developed to aid in decision-making at different levels of implementation. The overall evaluation framework is described, and the application of this framework for 2 levels of analysis is exemplified.

The notation used in this paper is defined below.

Notation	Definition
P	Population of service area
A	Service area size, square miles
R	Average daily ridership
H	Average number of operating hours per day
RPP	Average daily ridership divided by service area population
RPM	Average daily ridership divided by service area size
RPH	Average daily ridership divided by number of daily hours of operation
D	Density or population per square mile
V	Average number of daily operating vehicles in system
VH	(V)(H); also V = 3.73 + 0.058VH
$(VH)^1$	Average number of vehicle-hours per month or 28.55(VH)
PS	Average number of total daily passenger seats in operation or (V)(seats per vehicle)
PSH	Passenger seat-hours or (PS)(H)
FA	Average fare charged to a customer
WT	Average waiting time of a customer
RT	Average time of traveling in vehicle
TT	Total trip time or (WT) + (RT)
T	Type of vehicle used where 1 = taxi, 2 = van, 3 = 13- to 20-passenger bus, and 4 = full-sized transit bus
S	Average traveling speed of vehicles, mph
S^1	Type of service, where 1 = many-to-one, 2 = many-to-few, and 3 = many-to-many
R^1	Average weekly ridership or 6.04R
H^1	Average number of operating hours per week or 6.04H
C_{ma}	Monthly cost of management personnel
C_{dt}	Monthly cost of dispatchers and telephonists
C_{sc}	Monthly cost of secretaries and clerks
C_o	Monthly cost of office and garage space
C_t	Monthly cost of telephone
C_{om}	Monthly cost of office maintenance
C_d	Monthly cost of drivers
C_{go}	Monthly cost of gas and oil
C_i	Monthly cost of insurance
C_m	Monthly cost of mechanic
C_s	Monthly cost of miscellaneous supplies
C_r	Monthly ratio maintenance cost
W_{ma}	Wage rate per hour of managers
W_{sc}	Wage rate per hour of secretaries and clerks
W_d	Wage rate per hour of drivers
W_{dt}	Wage rate per hour of dispatchers and telephonists
W_m	Wage rate per hour of mechanics
C_f	Fuel cost per gallon of gas
M_l	Miles driven per gallon of gas

MODEL DESCRIPTION AND INTEGRATION

An integral part of the evaluation of demand-responsive transportation is a modeling framework that can be used to estimate vehicle supply and ridership based on various service parameters and to delineate resultant costs and revenues for any potential demand-responsive operation. These parameters could be used as input to a profit-loss analysis.

Figure 1 shows the manner in which the sets of models interact and integrate to form an evaluative entity. The development of such a framework follows the actual relations that exist among the parameters. For example, the demand for a demand-responsive system is directly dependent on the vehicle supply and inversely related to the fare structure. As the system supply (measured in terms of fleet size or vehicle-hours) increases, the quality of the service (in terms of less waiting time or total trip time) increases and, thus, the demand should increase. However, as the demand increases, it causes a corresponding decrease in service quality that, in turn, causes the total demand to decrease until an equilibrium is achieved between demand and vehicle supply. Similarly, in an aggregate transportation market, as the demand increases, the cost of providing this service increases; but on a local basis, as the fare structure increases, the demand decreases. If the demand is related to both the fare and the supply, indirect relations exist between the fare structure and the vehicle supply, shown in Figure 1 as a dotted line.

Similar relations exist among system demand, supply, and cost of operations. An increase in vehicle supply and ridership causes an increase in control staff requirements—which affects both capital requirements and operating costs of the system. In addition, miscellaneous incomes that may be obtained from a demand-responsive operation may affect fare levels and, thus, the ultimate profit or loss.

The demand, supply, and cost models provide mathematical descriptions of these major relations. The demand model provides estimates of daily ridership for any given service area as a function of the socioeconomic characteristics of the area and the system variables. The supply model relates a service quality index (such as fleet size and fleet-hours) to other interacting parameters, such as ridership, waiting time, and travel time. Similarly, the cost models relate capital and operating costs as a function of ridership and vehicle supply. The cost and income analysis (based on fares, marketing, rents) leads to the profit-loss analysis.

The applications of these models can be integrated into an optimization procedure to determine the combinations of parameters that would provide maximum revenue or minimum operating costs (1). For example, the analyst could determine the vehicle supply, operating hours, and fare structure that would generate the highest level of ridership at a given quality of service at minimum operating costs.

To aid in decisions regarding the implementation of a demand-responsive transportation system, the modeling framework should be developed for at least 2 levels of analysis. These are designated as general and detailed levels of analysis in terms of their potential applications, the models that may be developed, and the analytical techniques and data sources that may be used (Table 1).

For the general level, models are developed to provide estimates of demand, supply, and costs for a preliminary evaluation and screening of alternatives. The models not only identify the best service areas for system implementation but also may be used for establishing initial parameters for the operation of the systems. Information from diverse demand-responsive operations in the United States and Canada was used as input for this analysis.

The models developed for the detailed level of analysis are designed to give more accurate and detailed information applicable to a specific service area or ongoing operation. Since ridership and vehicle supply relations are expressed as functions of time of day and origin-destination, decisions can be made as to vehicle routing and scheduling, hours of operation, and arrangement of parameters to meet local conditions. The general models will be more closely related to the socioeconomic profile of the user and nonuser and the attributes of the specific system. Onboard and household surveys from an existing operation should be used as a data source for this modeling effort.

Figure 1. Evaluation framework for demand-responsive transportation systems.

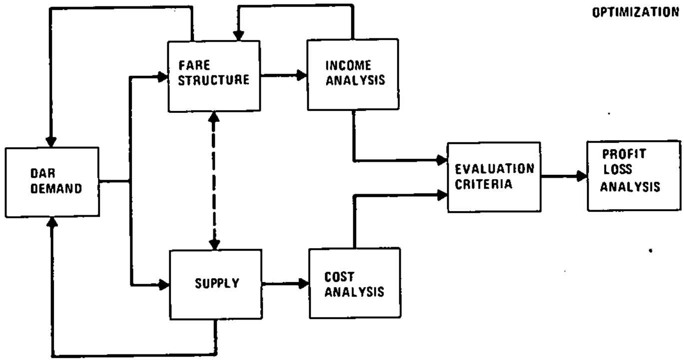


Table 1. General and detailed levels of analysis.

Level	Applications	Models	Analytical Techniques	Data Sources
General (macro)	Preliminary evaluation and screening of alternatives Service area identification index Project ranking Setting of initial operating parameters	Demand, supply, cost Aggregate analysis	Correlation-regression Factor analysis Graphical analysis Response surface optimization	Questionnaire, United States and Canada Census files
Detailed (micro)	Accurate and detail analysis Operational decisions Daily-weekly variations Vehicle routing and scheduling User-nonuser profile Arrangement of parameters	Demand, supply, cost Multiattribute discriminant Utility relations Operational relations	Correlation-regression Clustering and discriminant analysis Utility theory Rating and ranking Response surface optimization	Haddonfield Demonstration, onboard and household surveys

Table 2. Summary of demand-responsive transportation systems.

Service Area	Population	Area (sq mi)	Density	Type of Service	Nature of Service
Little Rock, Arkansas	132,500	53.0	2,500	Taxi-based share-ride	Many-to-many
Davenport, Iowa	100,000	30.0	33	Taxi-based share-ride	Many-to-many
Hicksville, New York	48,075	6.8	7,070	Taxi-based city wide	Many-to-many, many-to-one
Haddonfield, New Jersey	27,481	8.1	3,393	Bus-based city wide	Many-to-many, many-to-one
Columbia, Maryland	18,000	28.0	643	Bus-based city wide	Many-to-few, fixed-route
Buffalo, New York	53,860	3.0	17,953	Bus-based Model Cities	Many-to-many
Batavia, New York	18,000	4.3	4,186	Bus-based city wide	Many-to-many
Ann Arbor, Michigan	10,000	2.3	4,348	Bus-based city wide	Many-to-many
Detroit, Michigan	108,000	9.5	11,368	Bus-based Model Cities	Many-to-many
Columbus, Ohio	37,000	2.5	14,800	Bus-based Model Cities	Many-to-many
Toledo, Ohio	10,000	3.5	2,857	Bus-based Model Cities	Route deviation
La Habra, California	43,000	6.3	6,825	Bus-based	Route deviation
Regina, Saskatchewan	49,000	7.5	6,533	Bus-based feeder service	Many-to-few, many-to-one
Bay Ridges, Ontario	14,000	4.0	3,500	Bus-based feeder service	Many-to-one, many-to-many
Kingston, Ontario	59,000	64.0	922	Bus-based feeder service	Many-to-one
Stratford, Ontario	35,000	7.0	5,000	Bus-based feeder service	Many-to-one

The application of the modeling framework at both the general and detailed levels provides a set of planning tools to deal with all the major elements of system implementation. As a first step in the development of this framework, the results of the general models are presented.

METHOD OF STUDY

Operations of Demand-Responsive Transportation Systems

To obtain the necessary data to develop the general evaluation models, a complete inventory was needed of the operating parameters of existing demand-responsive systems and of the socioeconomic characteristics of the populations of the service areas. The stratification of system parameters was obtained from findings described in numerous reports and professional journals (2, 3, 4, 5, 6) and from questionnaires sent to the managers of existing demand-responsive transit systems.

Table 2 gives a list of the 16 sites from which completed questionnaires were obtained. Because of data reduction problems, complete information was not obtained from all the sites. Therefore, data on operations in Kingston, Stratford, and Hicksville were not included in the models. The models presented will be updated as information is obtained from these and other new significant demand-responsive operations.

A detailed description of these sites is found in other reports and will not be given here, but variability in the data sources is noted. Information was obtained from 3 taxi-based systems and 13 bus-based systems. Service areas vary from about 3 to 65 square miles, and service area population varies from 10,000 to 130,000 people. Four of the sites are in Canada and operate mostly as many-to-one feeder services. Of the remaining 12 American sites, 4 were restricted to Model Cities areas and 8 were providing citywide service. Most of these 12 sites provide many-to-many service.

The following major data items were requested in the questionnaires sent to the 16 sites:

1. Competition, major trip generators, and service objectives—(a) type and extent of competition within the service area, including public, private, and special systems, (b) fare structure of other systems, (c) special trip generators or peculiarities of the service area warranting specific treatment, and (d) service objectives and the degree of attainment of these objectives;
2. Demand and supply—(a) type of service being provided, (b) number and type of vehicles and available passenger seats, (c) average ridership, waiting time, riding time, and vehicle-hours for an average weekday and for Saturday and Sunday, and (d) peak-hour ridership; and
3. Economics—(a) capital costs of equipment (vehicles and communications) and basis of acquisition, (b) cost of support facilities, operating personnel, miscellaneous maintenance, office equipment, and taxes, and (c) annual total revenues from fares, leases, advertisements, and other miscellaneous items.

Model Building and Applications

The data items were reduced to perform a correlation and stepwise multiple linear regression analysis to develop 3 basic types of models:

1. A demand model relating variations of the ridership parameters (daily ridership, ridership-persons, ridership-square miles, ridership-hours of operation) with key operating parameters (population, area, fare, wait time, fleet size, hours of operation);
2. A supply model in which either total trip time or fleet size is expressed as a function of the other parameters, including daily ridership; and

3. A cost model relating each major cost component of a demand-responsive system to the estimated levels of ridership and vehicle supply.

After development of these 3 models, they were solved simultaneously to obtain the best estimates of daily ridership, vehicle supply, and monthly revenue and cost.

The procedure used to obtain the estimates can also be used in the application of the models to any particular area. Since each regression equation represents the best estimate of the dependent variable for given values of travel time, density, service type, and fare, demand and supply equations were solved simultaneously to obtain estimates of ridership and fleet size. The monthly revenue curve was then generated by multiplying the average number of days of operation per month by the estimated daily ridership and the corresponding average fare.

Since most of the cost component equations relate individual costs of a demand-responsive system to ridership and fleet size, the total monthly cost of the system was obtained by adding all the individual costs of the systems obtained after substituting the estimated values of ridership and fleet size.

Curves showing the interaction among the variables were also developed to determine the sensitivity of ridership and fleet size to changes in other parameters.

MODEL RESULTS

Demand, Supply, and Cost Models

A summary of the set of equations developed is given in Table 3. In terms of statistical efficiency, all equations were highly significant and yielded estimates that compared favorably with the observations. Most of the correlation coefficients were larger than 0.90; only one was as low as 0.70.

Four types of ridership equations and 2 types of supply equations were developed. The supply equation, in which total trip time is the dependent variable, was developed to enable potential operators to establish system parameters according to the desirable service level. For example, an operator who wanted to ensure that the level of service (i.e., total waiting and riding time) does not exceed 30 minutes could determine the best combination of ridership, vehicle-hours, and density required.

The 12 cost equations are expressed in terms of the major cost elements, excluding the capital cost of the vehicles, radios, and antenna. The capitalization of these costs can be attained according to normal economic procedures, which take into consideration the service life of the vehicles, the market interest rate, and so on. These costs should, of course, be added to the total operating costs obtained from the cost equations.

The equations can be expressed as multidimensional plots or nomographs. This transformation allows the equations to be used with ease and the relative effect of each variable to be apparent. A nomograph for the estimation of ridership per hour of operation is shown in Figure 2. For a service area of 50,000 people, a fleet size of 100 passenger-seats per day and a fare of $0.80, 27 riders/hour of operation is expected. A nomograph for the estimation of vehicle supply is shown in Figure 3. This nomograph will give the best estimate of the number of vehicles required in an operation for different levels of population density, area size, trip time, ridership, and type of service.

Figures 4 and 5 show the cost equation curves. These curves were designed to show the relative contribution of each component of the operating costs; for general use, they could also be translated into nomographs. This is particularly true of the labor costs, which are a function of 2 or more variables, including variations in wage rate.

The costs related to the control center (Fig. 4) illustrate the relative importance of the costs for telephonists, dispatchers, and managers as compared with the remaining costs. For the systems surveyed, costs related to the control center amount to 20 per-

Table 3. Demand, supply, and cost equations.

Type	Equation	Correlation Coefficient
Demand		
Daily ridership	$R = -238.9 + 0.072D + 23.3V + 0.161PSH$	0.99
Ridership/persons	$RPP = 0.00793 - 0.01638FA + 0.00012PS + 0.0000036D$	0.92
Ridership/square mile	$RPM = -51.9 + 0.06D + 1.6V - 145.4FA$	0.87
Ridership/hour	$RPH = 22.6 + 0.0009P + 0.187PS - 72.0FA$	0.94
Supply		
Travel time	$TT = 3.01 + 0.014R - 0.027VH + 0.002D + 3.6S^{1}$	0.84
Vehicles	$V = -4.68 - 0.23TT + 0.012R + 0.70A + 0.0008D + 1.18S^{1}$	0.94
Control-center-related costs		
Management	$C_{ma} = (0.224 + 0.0019R)\ 170\ W_{ma}$	0.92
Dispatchers—telephonists	$C_{dt} = (1.48 + 0.04H' + 0.0002R')\ 170\ W_{dt}$	0.70
Secretaries—clerks	$C_{sc} = (0.001R)\ 170\ W_{sc}$	0.92
Office—garage	$C_o = 129.66 + 0.50R$	0.94
Telephone	$C_t = 28.05 + 0.513R$	0.92
Office maintenance	$C_{om} = -35.41 + 0.393R$	0.91
Vehicle-related costs		
Drivers	$C_d = (VH)'\ W_d$	NA
Gas and oil	$C_{go} = (VH)'\ SC_f/(MI)$	NA
Insurance	$C_i = -1318 + 117V + 471T$	0.80
Mechanics	$C_m = (-69.25 + 1.38VH + 32.39T)\ W_m$	0.92
Miscellaneous supplies	$C_s = -204 + 7VH + 10T$	0.92
Radio maintenance	$C_r = 67.4 + 4.61V$	0.93

Figure 2. Nomograph for estimating ridership per hour of operation.

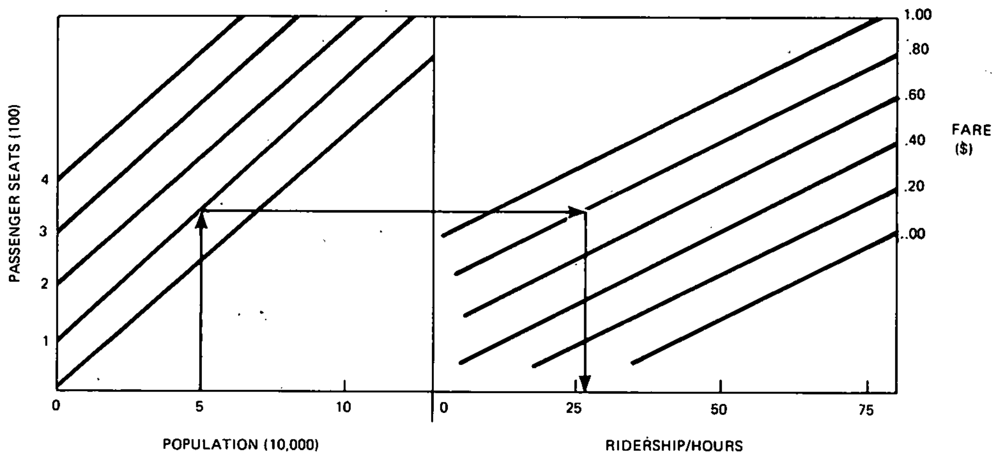


Figure 3. Nomograph for estimating vehicle supply.

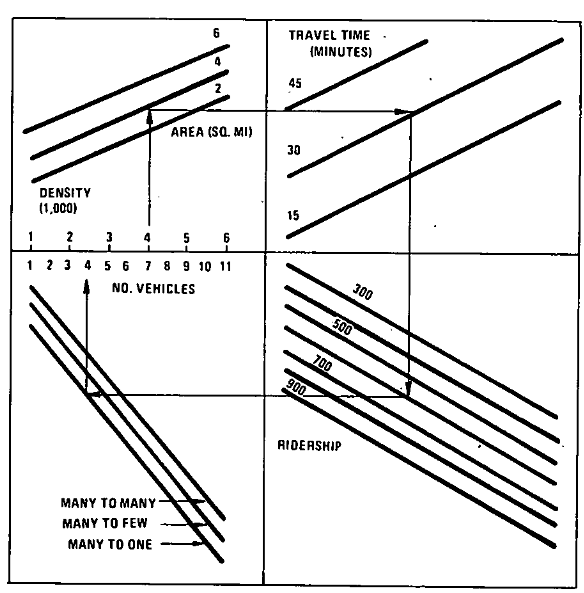


Figure 4. Control-center-related costs versus ridership.

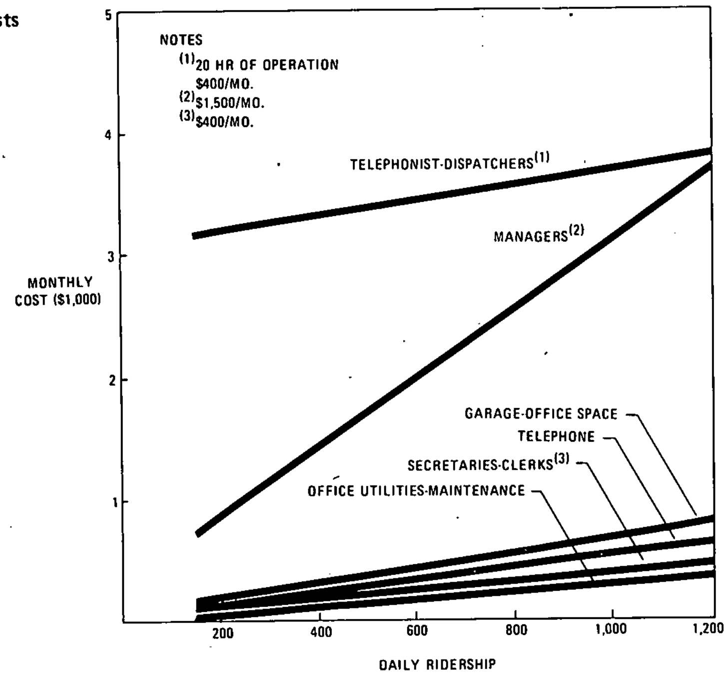
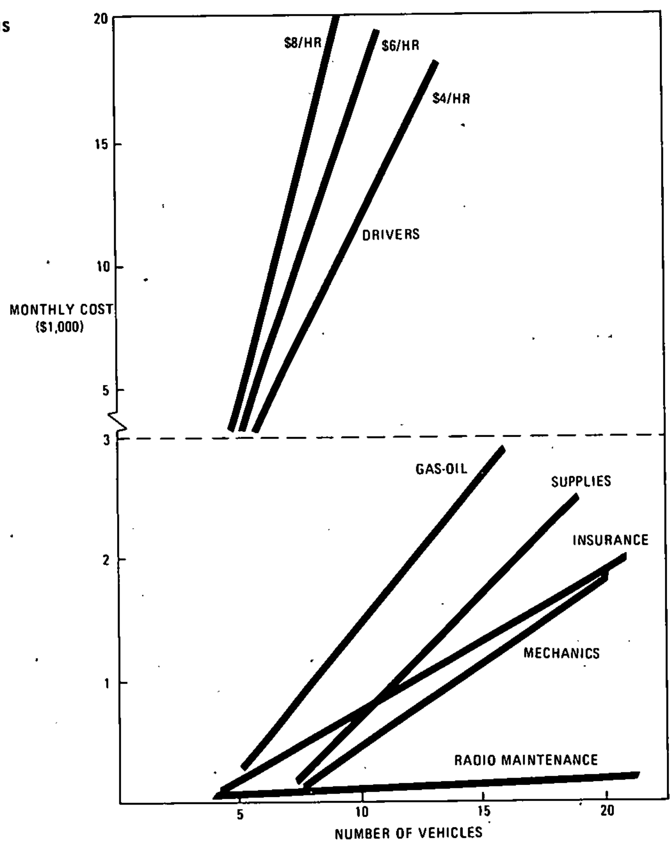


Figure 5. Vehicle-related costs versus fleet size.



cent of the total cost of implementing and operating a demand-responsive transportation system. Of this, the cost of telephonists, dispatchers, and managers amounts to 15 percent of the total cost.

Each element in the vehicle-related costs (except radio maintenance) increases significantly with an increase in the number of operating vehicles per day (Fig. 5). However, the drivers are the most expensive element, amounting to about 60 percent of the total costs. The remaining vehicle-related costs amount to another 15 percent of the total costs. The remaining 5 percent of the costs are capital costs for the purchase of vehicles, radios, and other control-center equipment.

Illustration and Sensitivity Analysis

The demand and supply equations were solved simultaneously to illustrate the model results and the sensitivity of these results to changes in system parameters. Except as noted, the following assumptions can be made:

Item	Assumption
Population	32,000
Service area, square miles	8
Density, people/square mile	4,000
Service	Many-to-many
Vans, 4-year life, 8 percent interest (no salvage value)	$8,000
Radios, 6-year life, 8 percent interest (no salvage value)	$500
Antenna, 6-year life, 8 percent interest (no salvage value)	$5,000
Wage rates/hour	
Drivers	$5
Mechanics	$5
Wage rates/month	
Dispatchers and telephonists	$600
Secretaries	$500
Managers	$1,500

Effects of Fare and Travel Time

Figures 6 and 7 show the expected ridership and vehicle supply for the previously stated assumptions as functions of fare and total trip time. Daily ridership decreases significantly with an increase in fare and decreases slightly with an increase in total trip time. For example, for a decrease in travel time of 30 minutes, the ridership increases by approximately 200/day. This increase in ridership necessitates an increase of 8 vehicles, which affects the cost of operation significantly. The interaction of these 2 variables is shown in Figure 8.

Figures 9 and 10 show monthly revenue and costs as functions of fare and trip time. The revenue and cost curves reflect the functional relations existing among the operating parameters. That is, as fare increases, revenue increases to an optimum point, after which ridership begins to decrease. As shown in Figure 10, low fares result in high ridership, which requires a large fleet and high monthly costs. Levels of ridership, supply, and monthly costs have been delineated for 3 fare values corresponding to values of optimum revenue.

Figure 11 shows a comparison of revenue and costs for a trip time of 30 minutes and the previously stated assumptions. An additional cost curve is shown relating the effect of reductions in wage rates on the total monthly cost. The curve for the low wage rates was obtained by using the following values:

Figure 6. Effect of fare and travel time on daily ridership.

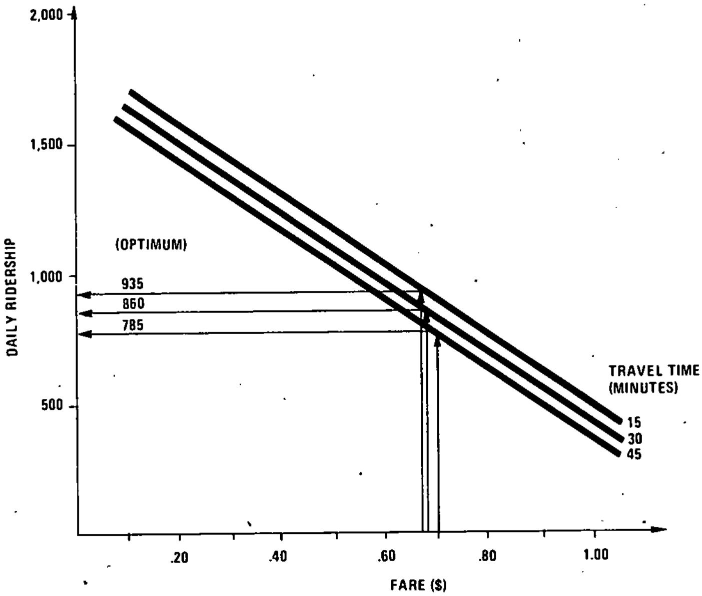


Figure 7. Effect of fare and travel time on fleet size.

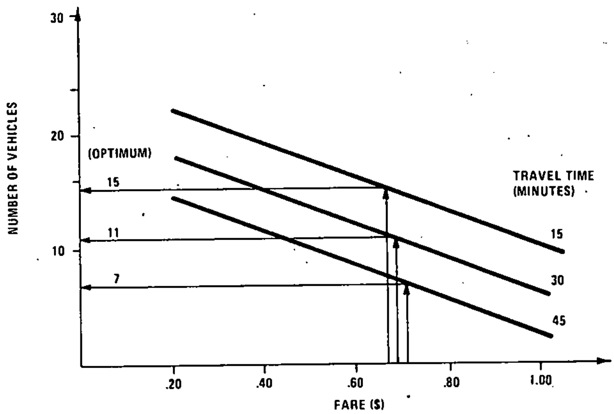


Figure 8. Effect of fleet size and travel time on daily ridership.

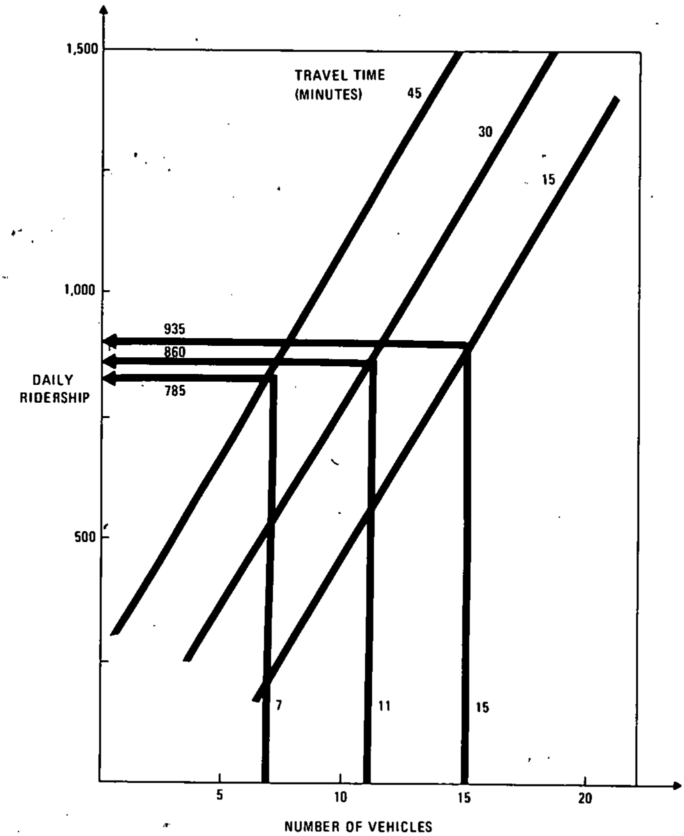


Figure 9. Monthly revenue as a function of fare and travel time.

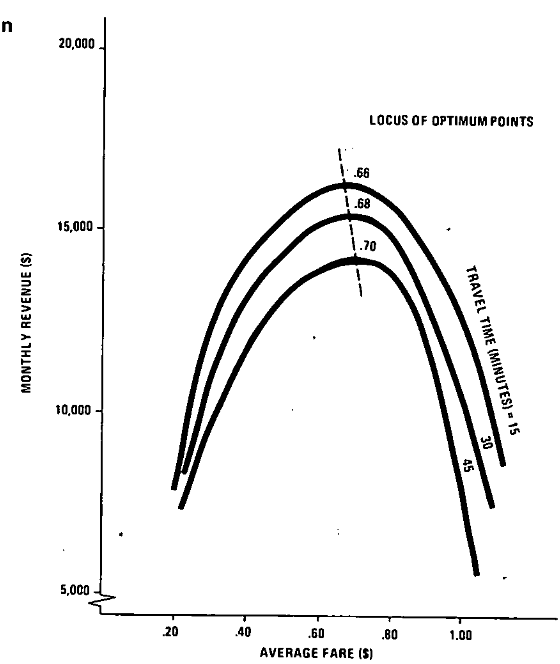


Figure 10. Monthly cost as a function of fare and travel time.

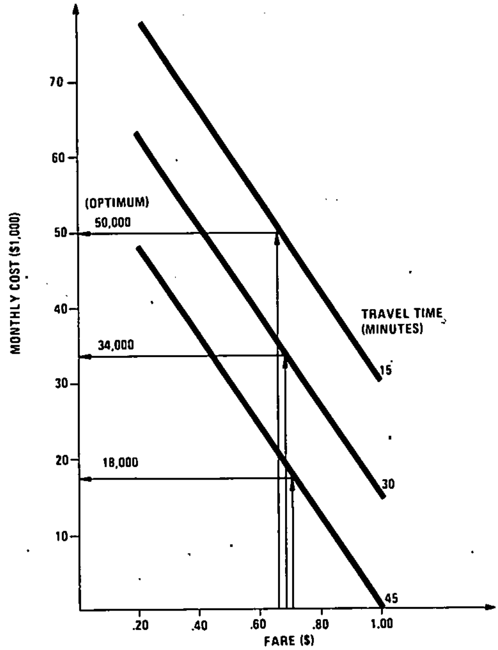
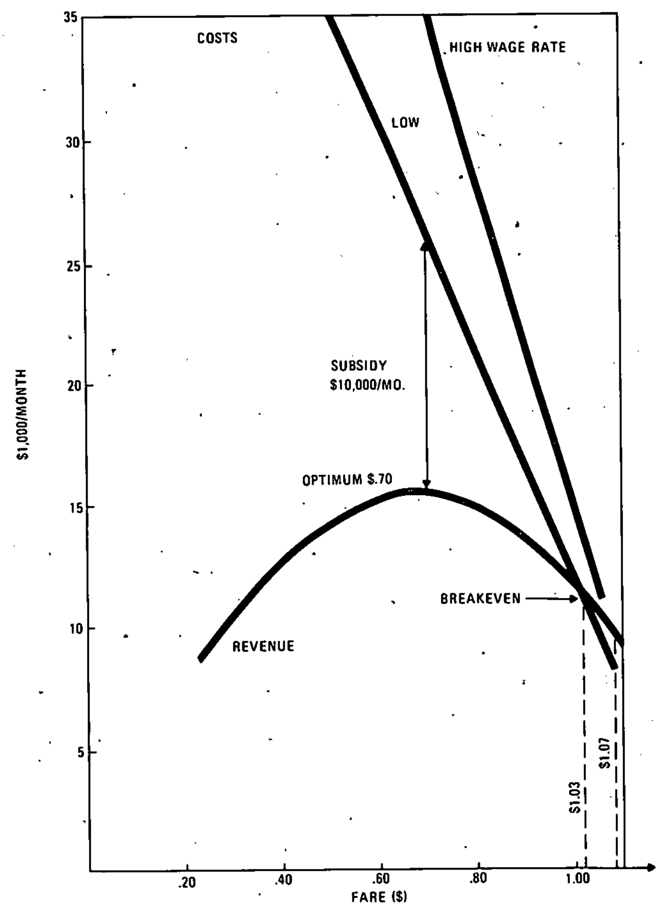


Figure 11. Comparison of monthly revenues and costs.



Item	Value
Wage rates/hour	
Drivers	$3.50
Mechanics	$3.50
Wage rates/month	
Dispatchers and telephonists	$500
Secretaries	$500
Managers	$1,000

The point of optimum revenue obviously does not correspond to minimum operating costs. If the objective is to operate at low subsidy or profitable levels, high fares must be charged and will result in low ridership, low vehicle supply, and thus a low level of service. Low fares result in high ridership, large vehicle supply, and thus a high level of service.

The optimum revenue of $15,000/month is obtained by charging $0.70/ride (Fig. 11). This results in a monthly cost of $25,000 or $10,000 of required subsidy or external incomes. Break-even conditions occur at a fare of about $1.03/person. A final factor to note from Figure 11 is the sensitivity of the costs to changes in wage rates. A decrease in wage rates reduces the subsidy level by half at optimum conditions, but reduces the break-even fare level by only $0.04. Thus, the effect of decreased wage rates is much more significant at lower fare levels because these low fares result in incrementally higher ridership and vehicle supply levels.

Effects of Fare and Density

An important factor in the implementation of a demand-responsive transportation system is the population density of the service area under consideration. As shown in Figures 12 through 15, for a trip time of 30 minutes and the aforementioned assumptions, population density has a high correlation with levels of ridership, vehicle supply, revenues, and costs. For example, at a fare of $0.60, an increase in density of 2,000 people/square mile results in an additional 1,200 riders/day, which requires 14 additional vehicles for service. The monthly revenue increase from the fare box is approximately $36,000, and the costs increase about $52,000.

Because all the system parameters increase significantly with an increase in population density, care should be used in the selection of a service area. The optimum revenue curves are shifted to a higher fare level as population density increases. This causes break-even conditions to occur at prohibitive fare levels. Therefore, under certain circumstances, depending on the desired level of service to be attained, to operate in areas having lower population densities might be propitious in order to keep system size and cost at a minimum.

Consideration for Future Applications

Those who are considering implementing a demand-responsive transportation system and who desire to use these models for preliminary evaluation and selection of system parameters should be aware of the limitations of the models and the types of adjustments needed to account for local conditions.

In terms of specific limitations, the models were developed by using a statistical analysis of existing demand-responsive transportation systems, which differ in terms of demographic characteristics and types of operation. Therefore, the analysis attempts to account not for direct cause and effect relations among the variables but for true functional relations. Estimates obtained from these equations should be used in light of the peculiarities of the study areas used for analysis. For example, ridership estimates of more than 1,000 obtained from a large fleet size and high fares usually refer to a taxi-based operation.

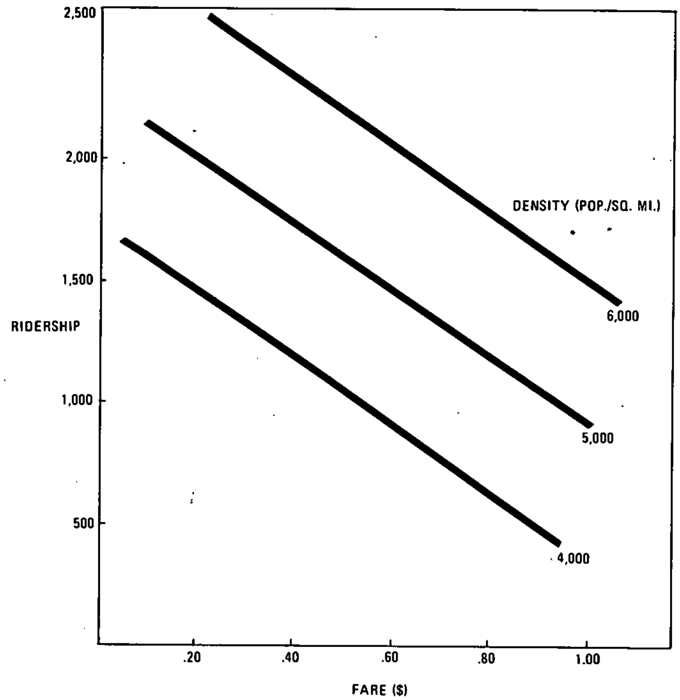


Figure 12. Effect of fare and density on daily ridership.

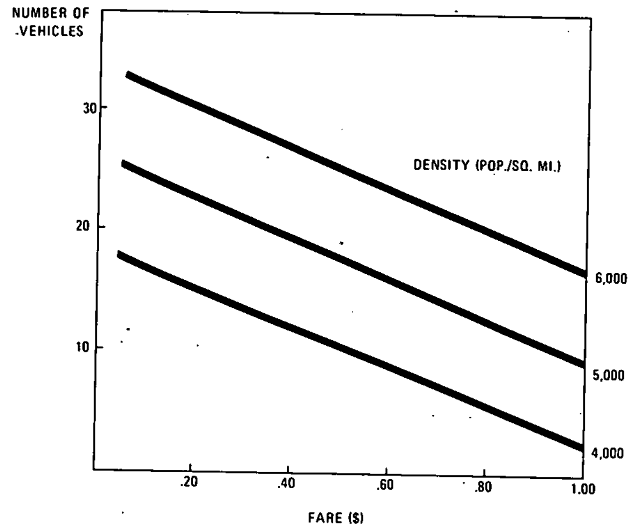


Figure 13. Effect of fare and density on fleet size.

Figure 14. Monthly revenue as a function of fare and density.

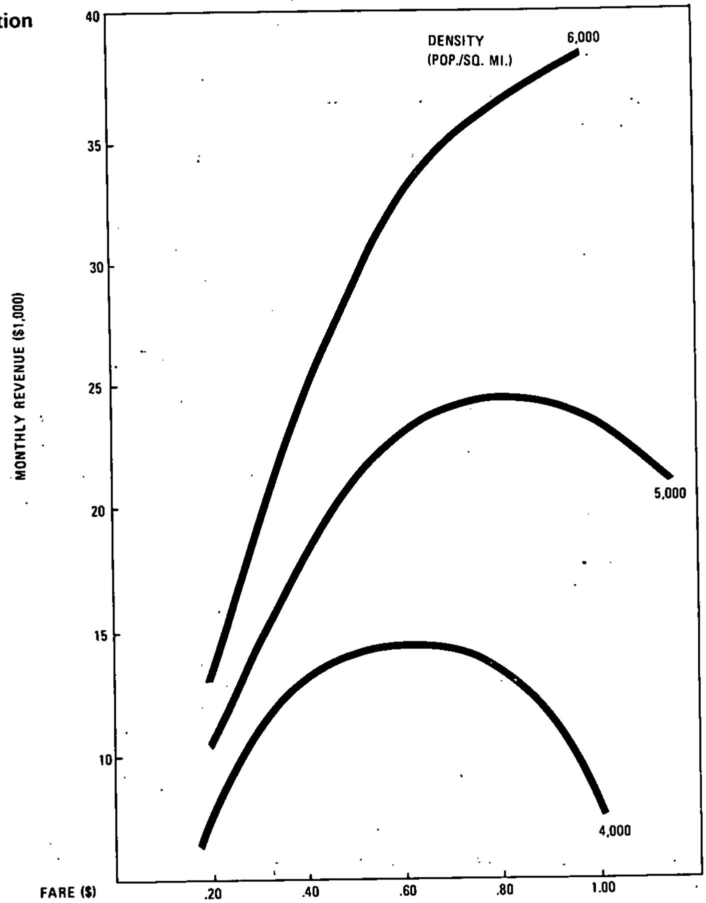
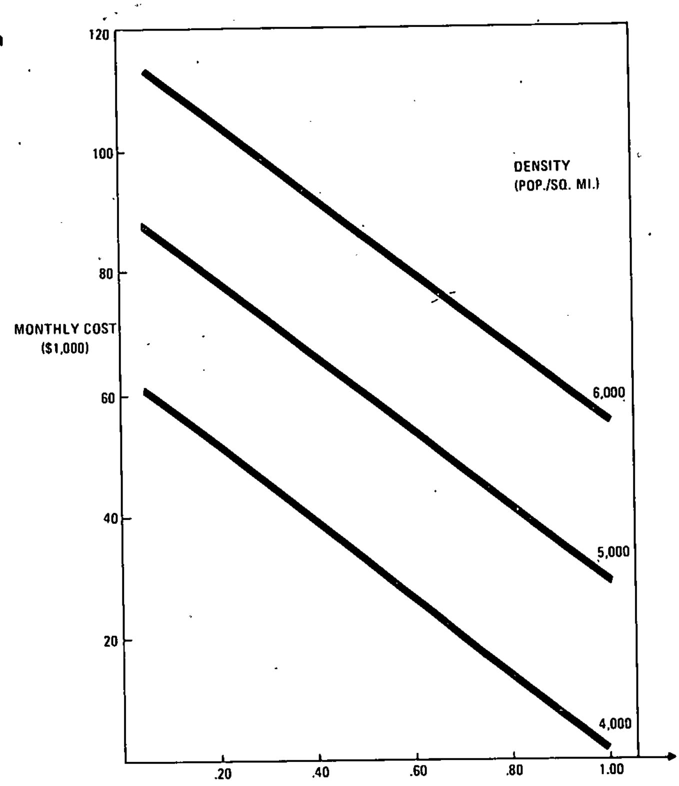


Figure 15. Monthly cost as a function of fare and density.



The models also do not reflect unique demographic, social, and economic characteristics of the community and of the potential users of the system. The only measure of socioeconomic level used in the models was the total population of the service area, the size, and thus the density. Therefore, although the models can be applied to any specific area to obtain estimates of expected ridership, on the basis of aggregate indexes, no mechanism in the models accounts for specific individuals (the poor, the aged) who have a strong propensity to use the system.

Within the context of these limitations, analysis of the models has shown that significant relations exist among ridership, vehicle supply, and various demographic and system parameters. Similarly, significant relations exist among operating costs, ridership, and vehicle supply. That is, even at the general level, where ridership data are expressed on an average daily basis, significant statistical relations exist among parameters.

To apply the equations effectively, the analyst should be aware of these limitations and make adjustments based on the following considerations:

1. Is there a high percentage of residents with a propensity (percentage over 55, under 20, unlicensed) to use a demand-responsive system?
2. Is there a large trip generator, such as a shopping center, high-speed line station, hospital, or schools, that would affect the incidence of ridership?
3. What other transportation modes are available within the area, and what percentage and type of market do they capture?
4. Is it possible to allocate services to institutions, such as day care centers and senior citizens' homes?
5. According to the traffic-generating characteristics of the area, at what daily hours is it better to operate modes such as many-to-many or many-to-one?
6. Is there a potential to offset the cost of operating a system in the service area by supplementing fare-box revenue by paying low wages to operators or providing package delivery?

CONCLUSIONS AND RECOMMENDATIONS

A comprehensive evaluation framework to aid in the implementation of demand-responsive transportation systems has been proposed. The framework consists of demand, supply, and cost models that could be applied at general and detailed levels of decision. General-level models were developed by using information from existing demand-responsive operations in the United States and Canada. The application and sensitivity of the models to key system parameters were also illustrated.

It was concluded that the set of demand, supply, and cost models fulfilled the objectives of the general level of analysis. These 3 models can be used as planning tools to aid in the preliminary evaluation of potential alternatives for implementing a demand-responsive transportation system. They may also be used for the initial selection and subsequent monitoring of operating parameters. The models perform these functions by providing estimates of expected ridership, vehicle supply, revenue, and cost of operations as a function of system parameters such as population density, fleet size, fare, travel time, and control-center requirements.

The research in demand, supply, and revenue-cost modeling for a demand-responsive transportation system is in its infancy. This study could be expanded to improve analysis at the general level or to develop more accurate and widely applicable models for decisions at the detailed level. Critical research areas regarding the modeling of demand-responsive systems include

1. Expansion of the general models by incorporating demographic and socioeconomic indexes to better represent the tendency of the residents of given areas to the system;
2. Development of models that will accurately reflect differences in operating systems and modes such as bus-based versus taxi-based and many-to-many versus many-

to-one and that will account for other variations in usage such as average weekday, Saturday, and Sunday travel;

3. Development of demand and supply models for detailed analysis that are behavioristically oriented and, thus, sensitive to profiles of users and nonusers and their attitudes toward the system's attributes; and
4. Development of an optimization procedure that will integrate the demand, supply, and cost models to identify operating parameters that will maximize ridership, give the most favorable arrangement of vehicle supply, and minimize cost of operation.

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Analytic Model for Predicting Dial-A-Ride System Performance

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Previous development work on dial-a-ride (DAR) has focused principally on defining the supply side of the system. Detailed computer simulation models that have been developed at M.I.T. and the Ford Motor Company (1, 2) relate the quality of service to the number of vehicles operating and the level and distribution of demand for the service. At the early stages of development and investigation of the general potential of the system, this was appropriate because detailed and realistic simulation was necessary to determine these fundamentals of operation. During this phase, different assignment algorithms were tested and, for the best set, calculations were developed between level of service as a key output measure and number of vehicles, vehicle speed, pickup and delivery time, ridership, and distribution of ridership as key input parameters. This basis that was then formed for detailed costing of DAR systems related cost per vehicle, cost per operator-hour, control costs, and operating costs to important output measures such as cost per passenger trip and cost per passenger-mile.

At this stage the supply side of the system was quite well defined, and the analyst was able to make reliable statements such as, "If a dial-a-ride system is to be implemented to serve 200 passengers per hour at a mean level of service of 2.5 in a 10 square mile area, then x vehicles will be required and the average cost per trip