ATTRACTING LIGHT RAIL TRANSIT RIDERSHIP

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This paper addresses the complex planning considerations for attracting ridership to transit systems, particularly light rail transit systems. Taking the viewpoint of a potential rider, the authors present some observations that lay the foundation for understanding ridership response. Users are not interested in technology per se but in the level of service the system provides. Level of service is a complex combination of many system attributes such as travel time, cost, comfort, and convenience. Different user groups (market segments) make different trade-offs among these attributes. They assign different relative weights or importance to each attribute. To attract maximum ridership, the system should be tailored to the particular needs and constraints of the market segments it is serving. No single system is superior for all market segments. The paper discusses the various level-of-service attributes and their relative importance to different market segments based on empirical evidence and attitude surveys. Although one cannot generalize because different market segments assign different relative weights to level-of-service attributes, the following rank ordering of attributes from most influential to least influential is most typically the case: out-of-vehicle travel time, in-vehicle travel time, cost, comfort, and safety. For work trips, travel time reliability should be added as either the first or second most important attribute. The characteristic convenience is dismissed from this list as being too broad to be specifically and universally defined. The paper goes on to introduce disaggregate, behavioral, travel-demand models as an emerging analytical technique that the transit planner can use to more precisely address the problem of the ridership response of different market segments to different level-of-service packages. Examples of these models are then used to demonstrate how different prototypical households would respond to various technologies under various representative operating policies. Some conclusions are drawn on the situations in which light rail transit would appear to be the most attractive form of public transportation from the rider's point of view, and some suggestions are made on how to improve attraction of light rail transit ridership.

A wide variety of issues must be considered in designing and implementing a light rail transit (LRT) system in an urban area. A partial list of these issues would include the costs and revenues of any potential system, the level of service to be provided to users of the system, and the impacts of the system on the environment of the area. In many cases, there are significant trade-offs among these and other issues, and some difficult design decisions must be made. For example, costs generally rise as service levels are raised. They often rise by more than the increase of revenues associated with new ridership, and a clear trade-off between higher service levels and higher costs (and perhaps deficits) arises.

The role of travel demand modeling (or market assessment) as it applies to evaluating and influencing LRT design lies in making explicit many of the design trade-offs involving service levels, ridership, and revenues. Through modeling of traveler behavior, one can make estimates of responses to service changes that, in turn, yield estimates of revenues, environmental impacts, and profits or deficits.

This paper will address the role of market assessment in LRT systems. It will present some major observations or conclusions to serve as a guide to evaluate markets for public transportation. It will give an overview of the state of the art in

modeling travel demand behavior. And it will present some brief analytical looks at LRT and other modes and draw some conclusions on attracting ridership.

FUNDAMENTAL GUIDELINES FOR DETERMINING TRANSIT RIDERSHIP ATTRACTION

Through 11 points, we will attempt to lay a basic foundation for understanding ridership attraction to LRT or any other public transportation system.

1. Transportation is a means rather than an end in itself.
2. Level of service is a complex combination of the factors or attributes of a system that collectively describe the attractiveness or utility of a particular transportation alternative.
3. Different groups of people, depending on their socioeconomic and locational characteristics will make different trade-offs among level-of-service characteristics.
4. Each market segment can be expected to behave differently from other market segments; therefore, characteristics of unique market segments must be identified.
5. With increasing affluence, high automobile ownership rates, and increasing leisure time, travelers have a choice in selecting travel alternatives and are becoming more discriminating.
6. No single service will be sufficiently attractive to all potential travelers.
7. Level of service is not merely a function of transit technology.
8. Improvements in level of service usually add to operating costs.
9. Marketing a service must accompany providing the service.
10. Traditional transportation planning and travel demand forecasting, which are based on zonal averages and aggregate data, are too crude to give a true idea of the different ridership responses of different market segments.
11. The logical hierarchy of a household's travel decision making and the aspects of travel demand that transit service is likely to influence need to be known.

That transportation is a means rather than an end in itself means that the demand for urban transportation is derived from the traveler's desire to accomplish some other objective (go to work, shop, meet a medical appointment, or visit a friend). Because the trip itself is secondary to the primary purpose for which it is being made, travelers want to make the trip as painless as possible. Travelers are not interested in the technology of a particular transportation system; they are interested in the level of service it provides. The nature of the propulsion, control, suspension, and other subsystems (whether the system has steel wheels or rubber tires or whether it is air cushioned or has coil springs) is of secondary importance to users.

The major level-of-service characteristics include (a) in-vehicle travel time (for line-haul vehicles and access vehicles); (b) out-of-vehicle travel time (walk time, wait time, and transfer time, which are sometimes combined and sometimes separated); (c) cost (perhaps related to traveler's income); (d) time reliability and consistency; (e) comfort; and (f) safety. Concerning item 3, different groups of people will assign different relative weights or importances to each of the level-of-service characteristics in evaluating a transportation alternative. These response groups can be called market segments. Unique market segments can be identified by socioeconomic characteristics, particularly income and automobile ownership; trip purpose; life cycle (age, family status); occupation; transportation-affecting handicaps; and access characteristics, such as distance from transit station.

Because travelers are becoming more discriminating, more attractive service than that of the past must be provided to capture riders.

Because no single service will be sufficiently attractive to all potential travelers, different services need to be tailored to different market segments. For example, office or factory workers who punch time clocks must be at work on time, and therefore time reliability is very important to them; senior citizens visiting a friend are far more interested in not having to walk too far to a transit stop than they are in time

reliability; suburban, upper-income executives want a high-quality transportation service and would be willing to pay for it; young, married, lower-income workers may be much more cost sensitive.

Item 7 mentioned that level of service is not merely a function of the transit technology. It can be influenced greatly by operating policy as well. (Perhaps the most important point of this paper is that simply to specify a technology as light rail transit or personal rapid transit is not sufficient to provide a basis for distinguishing between them. Within each technology there is a wide variety of different "systems" that can be provided; each has very different levels of service, ridership, costs, and environmental impacts.) Furthermore, it is a matter of how the user, not the operator, perceives operating policy. For example, an LRT system may run vehicles between 2 points at 5-min intervals; this 5-min headway is a system variable. However, users do not perceive the headway; they perceive the wait time for the next vehicle after they arrive at a station. A typical assumption is that average wait time is half the headway; however, this is only the case with uniform vehicle arrivals (headways maintained exactly) and with either uniform or random passenger arrivals. In cases in which passengers know the schedules and the schedules are kept, the wait time can be shorter. In cases in which the schedules are not kept, the wait time can be longer as nonuniformity of headway builds up. A recent example on a heavily used bus line in Boston where vehicle bunching occurred showed wait time equal to the headway itself for headways of less than 10 min (13). This distinction between the system variable, headway, and the user variable, wait time, is important. Better reliability or better information systems could lower user wait times while keeping headways constant. Thus different ridership could be attracted to the same headways merely by maintaining better schedule reliability.

In item 8, we mentioned that improvements in level of service usually add to the costs of operating the service. Generally, ridership response is inelastic; that is, a 1 percent change in a level-of-service attribute will produce less than a 1 percent change in ridership and, therefore, revenue. It is important for a transit planner to consider the economic trade-offs of improved service (net cost increases) because economic efficiency is usually the guiding operating objective. In certain instances, however, overriding social objectives (guaranteed mobility to the poor, elderly, and handicapped, for example) may dictate that service improvements should be offered despite negative economic consequences.

In item 9, we mentioned that marketing service (informing people about it and maintaining a positive image) must accompany providing a good service. Marketing, or creating a positive image, may influence ridership much more than some of the level-of-service variables, and, to a degree, it is much more within the control of an operating transit agency to control.

We have mentioned that zonal averages and aggregate data are too crude to give a transit planner a true idea of the different ridership responses of different market segments. New, more logically structured, analytical techniques are emerging for analyzing travel demand behavior, however. The most promising are disaggregate, behavioral demand models. They are called disaggregate because they deal with the travel decisions and specific influencing circumstances of a sample of individual households rather than zonal aggregates and averages. They are called behavioral because they are causally structured rather than correlatively structured to explain why an individual household member made a particular travel decision. Conceptually, these disaggregate models are far more appealing for explaining travel behavior. Results to date have been extremely encouraging statistically and logically. Because they are behavioral, the models are more readily transferrable from one urban area to another as experience to date in Washington, D.C.; Los Angeles; New Bedford, Massachusetts; Portland, Oregon; and Milwaukee has demonstrated (15). It is much easier to distinguish an individual household's market segment than it is to distinguish the mix of market segments making up an aggregate zone. Each survey observation is for an individual household rather than for many households in a given zone. (Observations for many households involve making a statistically valid, aggregate, zonal observation.) Therefore, these models are much more economical and data efficient to develop and

apply. These disaggregate behavioral formulations hold the key to a better understanding of travel demand behavior and to a determination of the proper set of relative weights of level-of-service characteristics for each market segment. It is not difficult to imagine a time when each urban area will maintain and update a random sample of households and their travel patterns and socioeconomic profiles from home interview surveys. Transit planning agencies then will be able to use that data along with disaggregate models to determine the ridership response to some proposed transit improvement or transportation policy change in much the same way the national consumer response to a new product is forecast by market researchers now.

As a final point, we mentioned that the logical hierarchy of a household's travel decision making and the aspects of travel demand that transit service is likely to influence need to be known. The highest level (longest term) decision a household makes involves land use and residential location. This generally begins with the occupation of the head of the household and encompasses residential location and choice of housing. This level of travel decision will be influenced only by such major changes in the transit system as the construction of a new transit line. A medium-term set of travel or mobility decisions for a household concerns the number of automobiles to own and the usual choice of mode to work. These are highly interrelated decisions as research to date has shown (1). In the medium term (say, the next 3 years), a transit service improvement can be expected to cause a shift in mode choice for work trips and a change in the number and type of automobiles a household owns, but it is unlikely to change the frequency or destination choice of work trips. The shortest term travel decisions involve nonwork trips. A household seldom plans these trips far in advance except in abstract or general terms (for example, to plan to go food shopping once a week). Here, the traditional sequential structure of aggregate travel demand models (trip generation, trip distribution, modal choice, time of day choice, and route assignment) done in an independent sequence of steps seems particularly out of place. A potential traveler decides whether to make a nonwork trip, where a trip should be made, and by what mode and route to arrive at the destination in a simultaneous set of decisions. A model of mode choice alone will not be sufficient to accurately reflect nonwork ridership response to a transit system change; changes in total demand (the term latent demand sometimes is used) and destination choice also must be considered.

These 11 points and their explanations leave us with a framework for how market assessment could influence LRT design and operation. This is shown in Figure 1. A much more detailed and explicit discussion of the techniques for assessing the ridership potential of different transit systems can be found elsewhere (14, 15).

A technology such as LRT is defined here as the basic hardware components of the technology (steel wheel on steel rail, manual operation with block signals, on-line stations, and the like). Using this LRT technology, one creates an LRT system by establishing a network and setting routes and schedules. This "system" forms the basis for demand, cost, and other impacts. If these are not as desired, several changes can be effected. Fares can be set to achieve several objectives, such as maximizing system profitability, subsidizing certain socioeconomic groups, and so on. Operating policy also can be altered to meet different objectives. If these shifts are not sufficient to produce a satisfactory system, then changes in the technology may be appropriate. These could include automation and off-line stations.

In the examples that will appear later in the paper, most of the conclusions will relate to how one operates LRT and other systems from a demand analyst's point of view. But, in some cases, changes in the technology that would allow or facilitate some desired operating options also will be pointed out.

LEVEL-OF-SERVICE COMPONENTS

Now that the concepts of level of service, market segments, and disaggregate analysis have been introduced, let us turn to a comparative look at the individual level-of-service components and the relative weights individuals assign to each.

Attitude Surveys

There are 2 basic data sources or procedures for determining relative weights. One is an attitudinal survey in which individuals are asked to

1. Rank a specified set of level-of-service attributes in order of importance,
2. Rate each level-of-service attribute on a scale from bad to good with respect to current choice of transportation mode, or
3. Compare pairs of attributes by deciding which of a pair is more important (preferably each attribute is tangibly defined in a specific scenario rather than left as an abstract, conceptual term).

From these rankings or comparisons, conclusions can be drawn about relative weights. Figure 2 shows the resulting relative rating scale from a sample of 97 individuals in the Chicago area surveyed by use of the comparison of pairs technique. Problems with this technique are

1. Nonindependence of attributes,
2. Vagueness of definitions,
3. Omission of other subjective variables (comfort, privacy, safety),
4. Lack of quantification or specificity of a variable, and
5. Differences between a respondent's professed attitude or rating of an attribute and actual behavior when confronted with the attribute in operation.

This attitude survey technique is in its formative stages, and refinements are being made all the time. Stopher et al. (2) give a good summary of the state of the art of attitude surveys for determining relative importance of transportation level-of-service characteristics in travel demand prediction. Sommers (3) did some earlier work in the same area and found the rank order of attributes to be time, convenience, comfort, safety, weather reliability, cost, noise, and mechanical reliability. Again, this effort suffers from lack of precise attribute definition and lack of quantification. A national survey was conducted for the National Cooperative Highway Research Program in the late 1960s into traveler attitudes toward modes of travel (4). The 7 most important attributes were found to be safety, reliability, independence, transfers, protection from weather, crowding, and comfort.

These early efforts were, in our opinion, noble but too vague and poorly defined to be conclusive. Some good recent work is being done by Golob and others (5, 6) particularly in correcting the major problem of lack of situation-specific, quantitative definitions of attributes and in applying techniques from the psychological and sociological disciplines to travel demand behavior. The Federal Highway Administration currently is undertaking a large attitudinal survey in the Los Angeles Santa Monica Freeway corridor to try to gain further knowledge of the relative importance of different level-of-service attributes. Many others, including professional market research firms, also are rapidly improving on attitude surveying as it is applied to demand for public transportation service; therefore, although the past experience with attitude surveys has been inconclusive, the future could be promising.

Behavioral Data

A much more successful data source than attitude surveys has been the analysis of actual travel behavior decisions of individuals. The basic data source is the traditional home interview survey (or, sometimes, a telephone survey), which establishes the travel decisions that were made and what the socioeconomic characteristics of the household are. From this basic information, specific data on the times, costs, and other level-of-service characteristics of each transportation alternative available to the individual are assembled, and various statistical techniques are employed to determine what the appropriate relative weights must have been (in each market segment)

Figure 1. Framework for light rail transit market assessment.

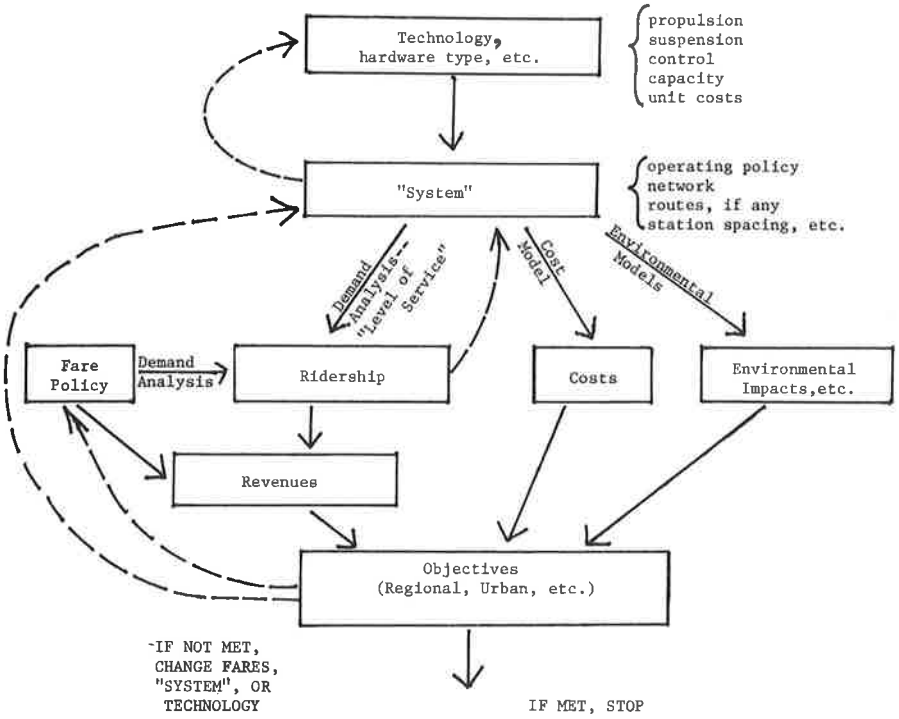
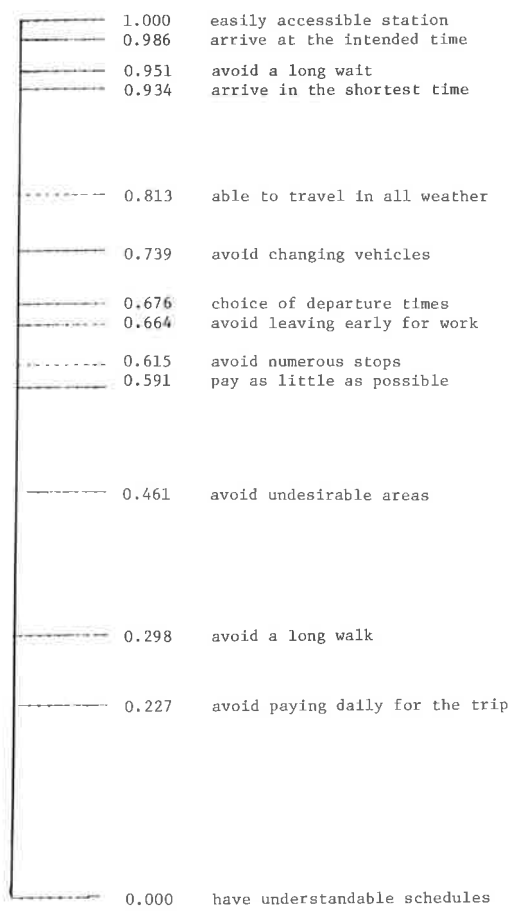


Figure 2. Relative rating of level-of-service attributes from a sample of 97 Chicago-area individuals (2).



to have led to a particular choice. The calibration procedure produces best estimates of what these weights or coefficients are, and it gives some idea of the uncertainty or standard error in estimating each. Conventional, aggregate, modal-split models are calibrated on such data as are the disaggregate, behavioral models referred to previously.

These analyses of actual behavior generally are limited to those level-of-service attributes that are readily quantifiable (most notably various categories of travel time and cost), but the analyses are quite conclusive and consistent in their results. One min of out-of-vehicle travel time (walking, waiting, and transfer time) has anywhere from 1.5 to 10 times the importance of 1 min of in-vehicle travel time depending on the market segment. Disaggregate models estimated on Netherlands data indicate a generally less dramatic ratio of out-of-vehicle time weight to in-vehicle time weight than do models estimated on American data (7). This, perhaps, may be indicative of the American pace of life and desire to make progress.

There is evidence to suggest that, within out-of-vehicle time, certain market segments would distinguish between walking and waiting time. The Netherlands data indicate that walking time is more burdensome than waiting time. Certainly one would expect that this same conclusion would apply to the elderly or for non-time-critical trip purposes. There is some evidence from Boston data, however, that, for work trips, walk time is weighted as less burdensome than wait time (8). This result probably reflects the inclusion of time uncertainty or reliability considerations in the wait time coefficient, however, together with the American desire to make progress.

Although elasticity varies dramatically depending on market segment, the existing split to transit, and the value of the attribute in question, elasticities are generally less than -1.0 for both types of time. (Elasticity of transit ridership to a particular service attribute is defined as the percentage of change in transit riding resulting from a 1 percent change in that service attribute.) The elasticity of transit ridership to out-of-vehicle time would run about twice that for in-vehicle time, based on a few typical calculations, with -1.0 and -0.5 respectively not atypical for a suburb to central business district (CBD) trip. Elasticities for both attributes are greater when the existing market share of transit is small.

Generally, most market segments are not as sensitive to cost as they are to time. Typical elasticities of transit ridership to cost are in the -0.1 to -0.4 range. Elasticities to monthly paid or billed costs are lower than elasticity to out-of-pocket costs. A general conclusion from this fact is that, if fares are increased, ridership will decrease but not by as great a percentage; thus total revenues will increase.

For a work-trip model across all socioeconomic groups, a 1-dollar fare change will have the same effect as a 30-min change in in-vehicle travel time, implying a value for (in-vehicle) time of 2 dollars/h. Again, however, it should be stressed that these relative weights or elasticities cannot be generalized. They will vary significantly depending on market segment. Elasticities will further vary significantly with situation.

Conclusions on Level-of-Service Components

Behavioral data analysis gives one a fairly good grasp of the relative importance of out-of-vehicle time, in-vehicle time, and cost. Attitude survey results would indicate that travel time reliability might be even more important than any of these 3, at least for work trips for certain occupation groups. This, in our opinion, is believable, and offers the transit planner the greatest marketing leverage of any of the level-of-service attributes. If schedules are reliably maintained and the traveling public knows this, then the share of the work trip market captured by transit will be significant. Light rail transit should be better able to maintain schedules relative to buses because of separate right-of-way, limited traffic interaction, and less susceptibility to changes because of weather conditions, but it is probably faced with much more difficulty in maintaining schedules than the grade-separated, exclusive right-of-way service provided by conventional rapid transit.

Safety should be downplayed as an important determinant of travel choice. This is certainly not to say that the ultimate in safety standards should not be strived for, but rather that the importance of safety as suggested by attitude surveys is more an instinctive response than it is a well-calculated distinction of one form of transit's being safer than another. All forms are relatively safe, and few riders choose one mode over another for safety reasons. (An exception perhaps is the concern of individuals with their personal safety from crime in urban areas such as Philadelphia and Chicago. This however, is more the exception than the rule.)

Comfort and convenience are attributes that vary the most from one attitude survey to another. This indicates that they are clearly functions of how carefully and specifically they are defined. Comfort is obviously a consideration in today's transit ridership competition with the automobile and should be strived for and publicized in marketing. Exactly how important a determinant of ridership it is still is subject to some conjecture, but it is probably worth maximum consideration until its importance is determined more decisively. Even though we are guilty of the same abstract definition error that we criticized attitude surveys for making, we rank comfort slightly lower than cost as the fifth greatest determinant of ridership based on the information available.

Convenience has been defined by various sources (1, 5, 9) as including number of transfers, ease of access to stations, crowding conditions, privacy, independence from schedule or choice of departure times, avoidance of walking, shortest travel time, reliable arrival time, safety, mechanical reliability, weather protection amenities, baggage-handling facilities, low cost, avoidance of traveling in undesirable areas, probability of getting a seat, easy-to-understand schedules, avoidance of having to pay daily, ability to obtain information from system representatives, and having refreshments or newspapers on board. As such, it covers a multitude of considerations, some of which are actually encompassed in the other level-of-service variables, some of which are difficult to define, and most of which have never been satisfactorily calibrated. It is suggested that the all-encompassing term convenience be abandoned in favor of more specific consideration of the many individual qualities that make it up.

DISAGGREGATE DEMAND MODELS

To analyze the demand responses to LRT and other transportation systems, one needs to use travel demand models that are sensitive to the transportation system attributes that affect potential travelers.

These models must capture the decision-making process of travelers as they weigh different transportation alternatives and incorporate these factors into the model. As discussed under fundamental guidelines in this paper, traditional aggregate demand models are usually neither policy sensitive nor behavioral. Disaggregate models, however, offer much more promise.

Recall that disaggregate behavioral models are those fitted to the observed travel behavior of a sample of individual households in an urban area and are based on the alternative choices that each household sees.

Let us consider 2 sample households. Household A has an income of 8,000 dollars, has 4 children, owns 1 car, and lives a 1-min walk from an LRT line. The breadwinner works downtown. The observed travel choice for the work trip from this household is transit, and it is easy to see many reasons why. Among them are the relatively easy access to transit, the importance of cost, and the high probability of other demands for the family car. Household B has an income of 15,000 dollars, has no children, and lives 1 mile (1.6 km) from the nearest transit line. The breadwinner works at a suburban office park. The observed travel choice for this household is the automobile, and once again, there are many reasons why this is a rational choice for this household.

There are several points that can be illustrated by this example. The first is the advantage of disaggregate models (which use the data at the household level) over aggregate models (which group together all households in a zone or other geographical area.)

Assume that households A and B are in the same zone, which is a not unreasonable occurrence. This zone would then produce 1 transit trip and 1 automobile trip. The average household characteristics for this zone would be an income of 11,500 dollars, 2 children, and about a 0.5-mile (0.8-km) walk to transit. An aggregate model would predict a 50 percent chance of using transit for this average set of household characteristics (if it was a perfect "fit"), but this is a considerably less strong model than one based on the actual household data. The 50 percent probability seems too high for those average characteristics because of the 0.5-mile (0.8-km) walk, if nothing else. The model also is somewhat unstable, because household A might still choose transit even if its income were 10,000 dollars and household B would still choose the automobile even if its income were, say, 20,000 dollars. The average income then would be 15,000 dollars, but the probability of using transit still would be 50 percent—a very wide variation. The disaggregate model clearly seems to be better in this case.

Another point that this example can demonstrate is the use of market segmenting to improve the power of one's forecasts. Aggregate models in general must assume that all households have exactly the same weights with respect to all the attributes of travel choices (waiting time, walking time, travel time, and the like). This is, of course, not literally true. The elderly certainly weight walking time higher than do other groups, and blue-collar workers who punch a time clock weight time reliability higher than do workers who do not punch a clock. These variations in age, life cycle, socioeconomic status, and the like often are averaged completely out of aggregate models because, even though there may have been considerable variation within the zone, there is often no significant variation in the average of these characteristics from one zone to another and, hence, no way to fit a model to them. Disaggregate models based on individual households can and do incorporate these variables that have long been ignored in travel forecasting even though their importance has been recognized. Thus, in disaggregate models, the different behavior of different market segments can be captured.

A third merit to disaggregate models is transferability. A disaggregate model is based on individual household behavior and is not dependent on any zone system or zone size. Thus it has none of the drawbacks that aggregate models based on zonal averages have when transferred from, say, one urban area to another. If it can be shown that a certain market segment in one urban area will respond to a particular set of level-of-service variables the same way that market segment in another area will respond when faced with the same set of travel choices, then these models can be transferred freely without the expensive and time-consuming calibration required with aggregate models. As alluded to earlier, the experience of Cambridge Systematics in transferring models based on Washington, D.C., to New Bedford, Massachusetts; Portland, Oregon; Milwaukee; and Los Angeles has been positive and has required almost no adjustments in any case. Table 1 gives a comparison of coefficients (relative weights) for the 3 level-of-service variables of particular interest and the same modal-choice model specification (work trips, all socioeconomic groups combined) as calibrated separately on Washington, D.C.; New Bedford; and Los Angeles data. As can be seen, the coefficients are remarkably similar. All but 1 are statistically significant (that is, the t-statistics are larger than 1). A t-statistic is the ratio of the coefficient value to the standard error of estimation of that coefficient. In simple terms, if the standard error is as large as the coefficient, one cannot conclude that the coefficient is statistically significantly different from 0. That is, the inclusion of that variable does not clearly improve the explanation capabilities of the model. It is important to point out that low t-statistics should not necessarily eliminate a variable from a model, however. One must first decide whether a variable is logically a causal variable. If it has a low t-statistic, it may mean that there is a large uncertainty over the predicted value, not necessarily that it should be removed.

Given the arguments in favor of disaggregate behavioral demand models, we now can turn to some example applications that show how these models can be used in evaluating LRT and other transit systems.

THE MULTINOMIAL LOGIT MODEL

Translating some of the earlier arguments into mathematical terms, one can express the utility of a particular travel alternative i to a household in market segment t, U_i^t, as some combination of suitably weighted level-of-service values.

$$U_i^t = \sum_k \theta_k^t X_{ki}$$

where

X_{ki} = value of the k th level of service attribute of alternative i, and
θ_k^t = the relative weight that market segment t would assign to level-of-service attribute k.

In addition to the level-of-service variables, utility of a particular travel alternative also is some function of the socioeconomic characteristics of household t (income and automobile ownership).

$$U_i^t = \sum_k \theta_k^t X_{ki} + \sum_\ell \beta_\ell^t A_\ell^t$$

where

A_ℓ^t = value of ℓ th socioeconomic characteristic of household t, and
β_ℓ^t = weight assigned to ℓ th socioeconomic characteristic.

For notational convenience, let us drop the superscript t and generalize the definitions of level-of-service variables X to include the socioeconomic attributes A.

$$U_i = \sum_m \theta_m X_{im}$$

The probabilities of choosing one alternative from a set of available alternatives, each of whose utilities are known, can be expressed in many different ways, but the mathematical function

$$P(i:A_t) = \frac{e^{U_i}}{\sum_{jA_t} e^{U_j}}$$

known as the multinomial logit model, is by far the most commonly and successfully used disaggregate demand model form. [Rigorous mathematical derivations of this model and other disaggregate demand models can be found elsewhere (7, 10, 11, 12) but are perhaps beyond the level of interest here.] This particular model form exhibits many favorable properties that make its use desirable. First, the probabilities necessarily sum to 1 as they should. Second, the curve of $P(i:A_t)$ versus U_i has the general shape shown in Figure 3. This curve of "diminishing returns" at both ends reflects known travel behavior quite well. That is, no matter how good (or bad) a service

is, you will never capture (or lose) all of the ridership, and ridership will be most susceptible to diversion to some other alternative in the highly competitive middle range. Third, the logit model is capable of extension to any number of travel alternatives. Finally, the logit form is mathematically tractable, which leads to simplicity in calibrating, transforming, and applying it.

This model, calibrated on Washington, D.C., data and using maximum likelihood estimation techniques, is that with which we are most familiar and most satisfied and that which we will use in the examples.

SOME CASE EXAMPLES ANALYZED

To make analysis simple, only work trips will be considered, and only the mode-choice decision will be simulated. Although the model system generally used in our studies contains a joint automobile-ownership and mode-choice model for work trips and, simultaneously, a model for trip frequency, destination, and mode choice for nonwork trips with automobile availability conditional on the work-trip choice, this set of case studies will serve as an example of the modeling process and will be kept simple for clarity and brevity.

We will consider only 2 modes—automobile and transit. Only 2 socioeconomic market segments will be considered—blue collar and white collar. They are defined as follows:

Segment	Income (1968 dollars)	Automobiles/ Licensed Driver	Household Size
Blue collar	7,000	0.5	4
White collar	12,000	1	1

Market segments for level-of-service variables are defined as shown in Figure 4. Zones are broken into 2 parts. The near subzones are those areas within walking distance of line-haul-system stations. The far subzones are the areas requiring feeder service. The dividing line between the 2 areas is 0.25 mile (0.4 km) from a station; this is commonly called the walk refusal distance in urban areas.

These subzones face different travel choices, of course. Near subzone users are not at all concerned with feeder services, and, in general, are better served than are far subzone users, who generally experience relatively slow travel times (even with good feeder service) and perhaps higher fares and extra transfers.

Returning to the model, we determine the logit model utility equations for automobile and transit as follows:

$$U_{a,b} = 1.19 - 0.00411\ \text{OPTC} - 0.00658\ \text{IVTT} - 0.0879\ \text{OVTTD}$$

$$U_{t,b} = -0.00411\ \text{OPTC} - 0.00658\ \text{IVTT} - 0.0879\ \text{OVTTD}$$

$$U_{a,w} = 1.84 - 0.0024\ \text{OPTC} - 0.0131\ \text{IVTT} - 0.169\ \text{OVTTD}$$

$$U_{t,w} = -0.0024\ \text{OPTC} - 0.0131\ \text{IVTT} - 0.169\ \text{OVTTD}$$

where

$U_{a,b}$ = utility of automobile mode for blue-collar households,
$U_{t,b}$ = utility of transit mode for blue-collar households,
$U_{a,w}$ = utility of automobile mode for white-collar households,
$U_{t,w}$ = utility of transit mode for white-collar households,
OPTC = out-of-pocket travel costs in cents per round trip,
IVTT = in-vehicle travel time in round-trip minutes, and
OVTTD = out-of-vehicle travel time in round trip minutes divided by 1-way distance in miles (kilometers).

This particular model is 1 of the earlier models developed from the Washington, D.C., data base, but it has several less important variables that have been collapsed into the constant term for simplicity. It is a different model specification and is for different market segments than the model results given in Table 1.

It should be emphasized that this model is based on observed travel behavior at the household level and that these utility equations have been used in several studies and have given good results in each.

Several points should be made about this model. One point is that the variable OVTTD in its present form (divided by distance) represents the assumption that the importance of out-of-vehicle time decreases as trip length increases. It says basically that a 10-min wait is much more burdensome for a 1-mile (1.6-km) trip than it is for a 10-mile (16-km) trip. Another point is that the weights of travel time (IVTT and OVTTD) are much higher for the white-collar segment than for the blue-collar segment, which indicates their greater relative importance to the white-collar market segment. Cost is relatively less important to white-collar travelers than to blue-collar travelers. From the ratios of the IVTT and OPTC coefficients, one can infer that the white-collar group values its time at 3.25 dollars/h; the blue collar group values its time at about 0.95 dollars/h.

Using the models presented above, we will examine 4 technologies or systems in a hypothetical corridor as shown in Figure 5.

The highway system consists of an expressway whose average speed is 35 mph (56 km/h) in the peak period and local streets in each zone whose speed is 15 mph (24 km/h).

Automobile operating cost is 10 cents/mile (6.25 cents/km). Out-of-vehicle time for the automobile is 2.5 min for non-CBD trips and 5 min for CBD trips, which reflects the longer walking distances from parking place to eventual destination in the CBD.

Example 1: Light-Rail Transit

An LRT system is proposed for the corridor. Note that this is not LRT, the technology, but LRT, the service, which is characterized by surface operation (sometimes grade separated, sometimes not), close station spacing, low-platform loading, lower average speed than typical rapid transit service, and good area coverage with a heavy orientation to walk-access patronage. Its specific characteristics are as follows:

1. Line length: 6 miles (9.6 km) to CBD,
2. Maximum speed: 50 mph (80 km/h) (grade separated),
3. Station spacing: every $\frac{1}{3}$ mile (0.53 km),
4. Headway: 4 min, and
5. Feeder: fixed-route, fixed-schedule bus with 12-min headways.

The average speed, assuming 3 stops/mile (1.9 stops/km) and 30 s/stop, is 22 mph (35.2 km/h). The percentage of travelers within walking distance of the system in zones 1 and 2 is 29.4 percent; the remainder must use feeder services; 58.8 percent are within walking distance of their workplace in the CBD. The fare policy assumed was 50 cents/trip for LRT and 25 cents/trip on the feeder vehicle.

We now construct the level of service for users of this system. Further defining

Table 1. Comparison of coefficients from work-trip logit-modal-split model estimation on 3 different data bases.

	In-Vehicle Travel Time (round-trip min)		Out-of-Vehicle Travel Time/Distance (round-trip min/1-way miles)		Out-of-Pocket Cost/ Income (round-trip cents/worker dollars per year)	
Data Base	Variable Coefficient	t-Statistic	Variable Coefficient	t-Statistic	Variable Coefficient	t-Statistic
New Bedford	-0.199	-0.4849	-0.1013	-2.903	-87.33	-1.576
Washington, D.C.	-0.0154	-2.67	-0.1600	-4.08	-28.8	-2.26
Los Angeles	-0.01465	-2.25	-0.1860	-4.02	-24.37	-2.07

Note: 1 mile = 1.6 km.

Figure 3. Curve of $P(i:A_t)$ versus U_i.

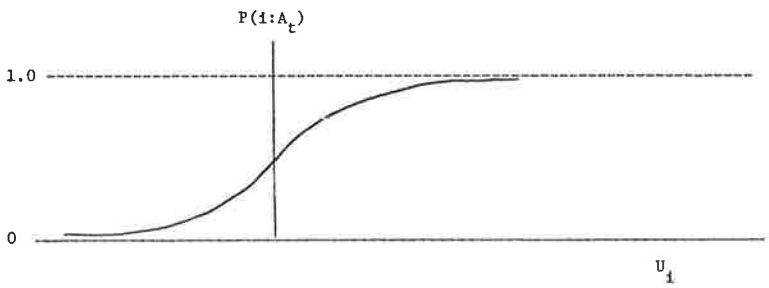


Figure 4. Market segments for level-of-service variables.

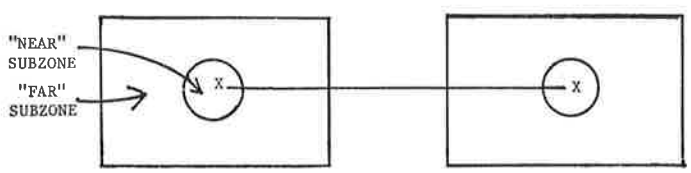
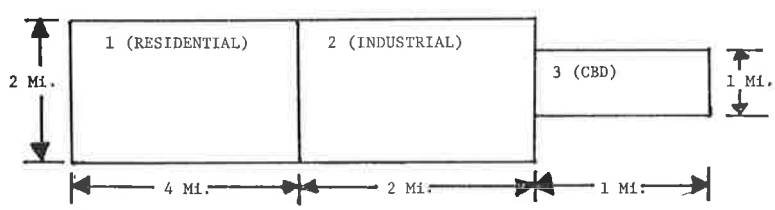


Figure 5. Hypothetical corridor.



Note: 1 mile = 1.6 km.

market segments based on their station-access characteristics results in 4 basic types of trips: near-near, near-far, far-near, and far-far subzone combinations for each zone pair. The level of service for the subzone combinations and the specific time assumptions made for each link of the zone 1 to zone 3 trip are shown in Figure 6.

Obviously, the percentage of trips in each category is affected by station spacing. The closer the station spacing is, the more trips there are that have one or both ends within walking distance of a station, but the slower the travel time becomes if all station stops are made. Demand analysis can help to make this design trade-off. When the demand models are applied, the flows given in Table 2 result for this LRT system.

Several issues are readily apparent from this table. The transit modal split is higher when walk access to the transit station is possible (near subzones). Transit share of the longer CBD-destined trip is greater because of the defraying of the out-of-vehicle time component and the transit fare over a longer distance and because of the higher parking cost and out-of-vehicle time associated with taking an automobile to the CBD. Blue-collar transit ridership is higher than white-collar ridership is, which is to be expected for anything other than superior service. It is also interesting that white-collar ridership drops off more steeply than blue-collar ridership does for far subzone trips because of the greater sensitivity (higher demand weight) to access travel times.

The policies one might use to increase this system's ridership would be quite different for the 2 groups as well. A drop in fare to 25 cents/ride for LRT and free transfer to feeder increase blue-collar ridership by much more than they do white-collar ridership as can be seen by the data given in Table 3.

However, policies that involve raising fares and providing a better level of service affect white-collar ridership more favorably than they do blue-collar ridership.

How would LRT modal split vary with walking distance to and from stations? Figure 7 shows the transit modal share versus the combined walking time at origin and destination for a 1-way trip from zone 1 to zone 2 (near-near subzone). If, for example, a 10-min walk at either end of the trip were assumed instead of a 3.3-min walk, then the modal share would drop from 17.3 percent to about 12 percent for blue-collar workers and from 7.2 percent to about 3.5 percent for white-collar workers. This would be about 50 percent loss of white-collar ridership and about 30 percent loss of blue-collar ridership, which is quite dramatic. White-collar-group sensitivity to walking time would be greater than that for the blue-collar group, as expected.

Example 2: Commuter Rail Transit

A commuter rail system for the corridor might have the following characteristics:

1. Line length: 6 miles (9.6 km) (short for such operations),
2. Maximum speed: 50 mph (80 km/h),
3. Station spacing: every 1.5 miles (2.4 km),
4. Headway: 20 min, and
5. Feeder: none in zones 1 or 2, same as for LRT in zone 3 (CBD).

The average speed of this system is 35 mph (56 km/h) assuming each stop takes 45 s. We assume the walk refusal distance here to be 0.5 mile (0.8 km) and that the park-and-ride option is available because there is no feeder bus operation. The dependence on park-and-ride for access to the station from beyond 0.5 mile (0.8 km) is a greater burden on the blue-collar potential transit users than it is on the white-collar potential transit users because this access mode requires either restricting the use of the family car or owning an extra car. With these additional automobile ownership effects accounted for in the constant term of the utility equations, the mode shares for transit become as shown by the data given in Table 4. (Automobile ownership was 1 of the variables in the original specification of the model used here, but it was collapsed into the constant term by using a regional average value of automobiles owned per household to simplify the model presented here.) In Table 4, the wait time was assumed to be 5 min

Figure 6. Zone 1-zone 3 light rail transit trips.

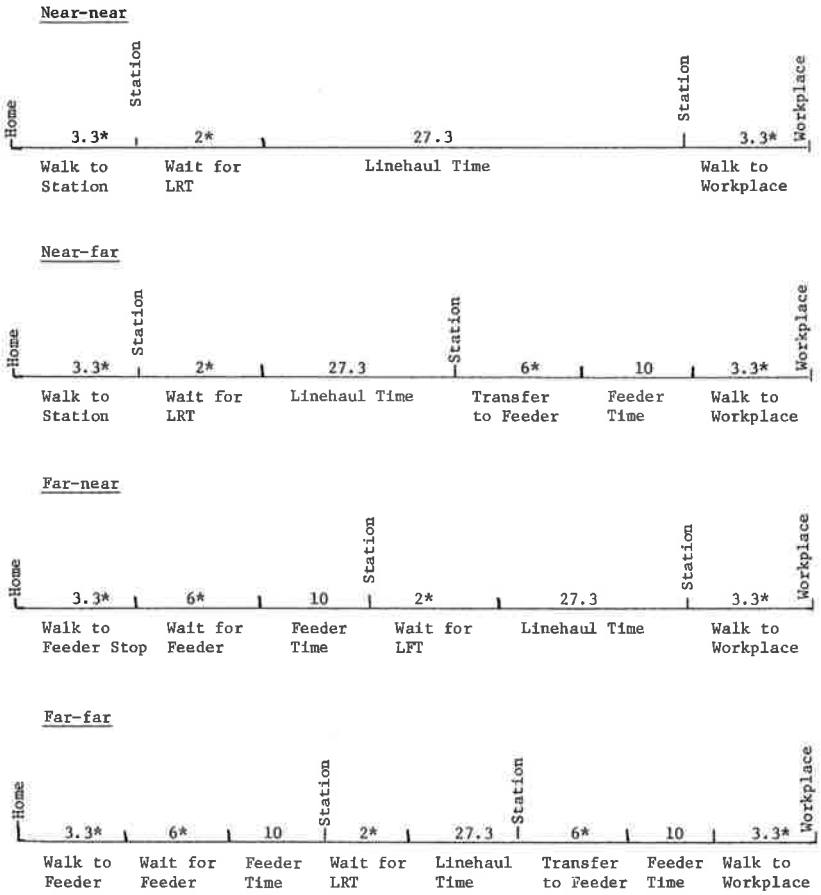


Table 2. Modal shares.

Zone Pair	Subzone Combination	Zone Trips (percent)	Share of Transit Mode (percent)	
			Blue Collar	White Collar
1-2	Near-near	8.6	17.3	7.2
	Near/far	41.5	10.1	3.0
	Far-far	49.9	5.7	1.2
	Total	100.0	8.5[a]	2.5[a]
1-3	Near-near	17.2	34.0	16.1
	Near/far	53.6	24.5	9.4
	Far-far	29.2	16.9	5.2
	Total	100.0	23.0[a]	0.3[a]

[a]Total mode share is the weighted average where percentages of trips in each subzone combination are the weights.

Table 3. Modal shares after a 25-cent/ride drop in fare for light rail transit and free transfer to feeder service.

Zone Pair	Subzone Combination	Zone Trips (percent)	Share of Transit Mode (percent)	
			Blue Collar	White Collar
1-2	Near-near	8.6	20.5	8.1
	Near/far	41.5	14.5	3.8
	Far-far	49.9	10.1	1.7
	Total	100.0	12.8[a]	3.1[a]
1-3	Near-near	17.2	38.7	17.8
	Near/far	53.6	32.8	11.6
	Far-far	29.2	27.4	7.3
	Total	100.0	32.2[a]	11.4[a]

[a]Total mode share is the weighted average where percentages of trips in each subzone combination are the weights.

Figure 7. Effect of walk time on LRT modal share for a trip from zone 1 to zone 2 with walk access used.

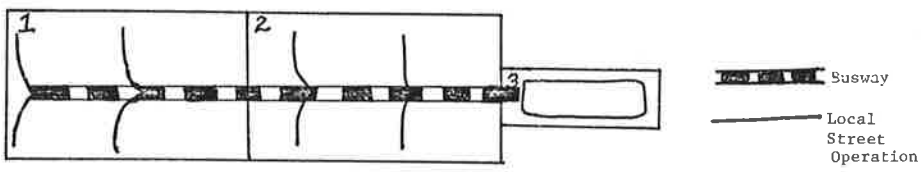


Table 4. Modal shares with additional automobile ownership.

Zone Pair	Subzone Combination	Zone Trips (percent)	Share of Transit Mode (percent)	
			Blue Collar	White Collar
1-2	Near-near	6.9	11.1	2.7
	Near-far	19.3	0	0
	Far-near	19.3	3.4	7.0
	Far-far	54.3	0	0
	Total	100.0	1.4[a]	1.5[a]
1-3	Near-near	13.7	30.0	12.0
	Near-far	12.5	24.1	9.6
	Far-near	38.7	6.7	16.5
	Far-far	35.1	5.2	11.7
	Total	100.0	11.5[a]	13.3[a]

[a]Total mode share is the weighted average where percentages of trips in each subzone combination are the weights.

even though the headway is 20 min because commuter rail schedules usually are reliably maintained. Users may be expected to know the schedule and arrive accordingly.

Commuter rail service can carry no trips destined to areas without feeder service even though it carries trips originating in areas with no feeders. Its share of long, white-collar trips is roughly comparable to that of the LRT systems examined, but its share of all other types of trips is less than half the LRT shares. Generally, modal shares from the far subzones for white-collar workers are high because of their increased automobile availability and free and easy parking. Moreover, walking time is out-of-vehicle time and white-collar workers have assigned a particularly heavy weight to that form of travel time.

The fares assumed for this commuter rail operation (75-cent base fare) are lower than usual; a fare increase would drive away more blue-collar users than white-collar users.

Example 3: Express Bus System

An express bus system for the corridor could operate with the following characteristics (Figure 8):

1. Line length: 6 miles (9.6 km),
2. Stations: none on expressway,
3. Headway: 12 min on each "route,"
4. Feeder: integrated with line-haul service, and
5. Cruise speed: 50 mph (80 km/h).

Each route operates as a local bus service on streets in its origin zone and then enters the busway for a nonstop run to the CBD where it again traverses local streets for distribution.

The average speed of this system is 50 mph (80 km/h) (line haul) because no stops are made; the feeder portion speed is 12 mph (19.2 km/h). Because there are no line-haul stations, the near-far subzone distinction does not exist; all users board on the feeder portion of the routes. Because there are no intermediate stops on the line-haul portion, intracorridor passengers must go into the CBD and back out again to use the service, which is a relatively unattractive option. The fare is assumed to be 75 cents/ride.

The express bus modal shares turn out to be as follows:

	Share of Transit Mode (percent)	
Zone Pair	Blue collar	White collar
1-2	4.5	0.9
1-3	34.7	21.3

In general, express bus modal shares would be high for trips focused on a particular destination area served by express bus and low otherwise. For CBD-bound trips, the service is good and the mode share is higher than it is for LRT service, particularly for white-collar trips. Note that, to the extent that white-collar trips are often more CBD-oriented than are blue-collar trips, the differential effects between the 2 groups may be even stronger than a simple examination of mode shares might show.

Example 4: Conventional Rail Rapid Transit

A conventional rail rapid transit system might have the following characteristics:

1. Line length: 6 miles (9.6 km),
2. Stations: every 1.5 miles (2.4 km),
3. Headway: 4 min, and
4. Feeder: fixed-route, fixed-schedule bus with 12-min headways.

The system is very similar to LRT except for station spacing. With a 50-mph (80-km/h) top speed and 30-s stops, the average speed is 39 mph (62.4 km/h). This system is clearly at a trade-off point with LRT. Fewer stations would produce a higher speed, but fewer riders would be within walking access of the system. A large majority would be forced to use the relatively unattractive feeder service.

The modal shares for this system turn out to be as shown by the data given in Table 5. The information in Table 5 ignores park-and-ride and kiss-and-ride options, which could increase ridership (white-collar ridership particularly); the same holds true for the LRT system and the express bus system examined above.

As might be anticipated the modal shares are generally lower overall than they are in the LRT example but higher for those close enough to the station to walk. Because the principal difference between the rail rapid transit system and the light rail transit system is increased speed versus longer station spacing, it would appear here that the numbers favor closer station spacings at the sacrifice of speed because the travel time minutes spent, both in the vehicle and out of the vehicle, in gaining access to the stations are so burdensome. Were the near-far percentages different, this might not be the case.

Total demand and trade-offs of service levels with operating costs are also factors. If trip density is great enough that the conversion of modal splits to actual ridership volumes leads to crowded cars, either more cars (lower headways) or larger cars (rail rapid transit) would need to be provided. If ridership volumes are very low in relation to rail rapid transit car capacity, the planner might consider going to LRT.

The results of the 4 basic examples are as follows:

		Transit Modal Splits (percent)			
Zone Pair	Market Segment	Light Rail Transit	Commuter Rail Transit	Express Bus	Rail Rapid Transit
1-2	Blue collar	12.8	1.4	4.5	6.6
	White collar	3.1	1.5	0.9	1.6
1-3	Blue collar	32.2	11.5	34.7	20.7
	White collar	11.4	13.3	21.3	7.8

CONCLUSIONS

There are several areas that this paper has attempted to deal with. A primary one has been to show that LRT and other systems have patterns of level of service that vary quite widely for different trips and evoke different ridership responses.

Typical LRT service offers good, relatively evenly distributed service to a CBD and to on-line stations. Therefore, it would be more appropriate for a corridor with heavy intracorridor riding rather than a major CBD focus. Particularly when combined with some kind of feeder bus service, it provides good area coverage at the sacrifice of speed and would appeal to blue-collar workers who are more cost sensitive than time sensitive. It is designed to operate together with walking access or, perhaps, with feeder bus access, but probably not as much with park-and-ride because users who could afford the higher automobile ownership levels required for park-and-ride would find the slower speeds and frequent stops unappealing.

Commuter rail operations provide good service to the CBD and on-line stations although, with their typically sparse feeder service, the on-line intermediate stations do not serve many destinations. The lack of access at the residential end of a trip

Figure 8. Express bus system in hypothetical corridor.

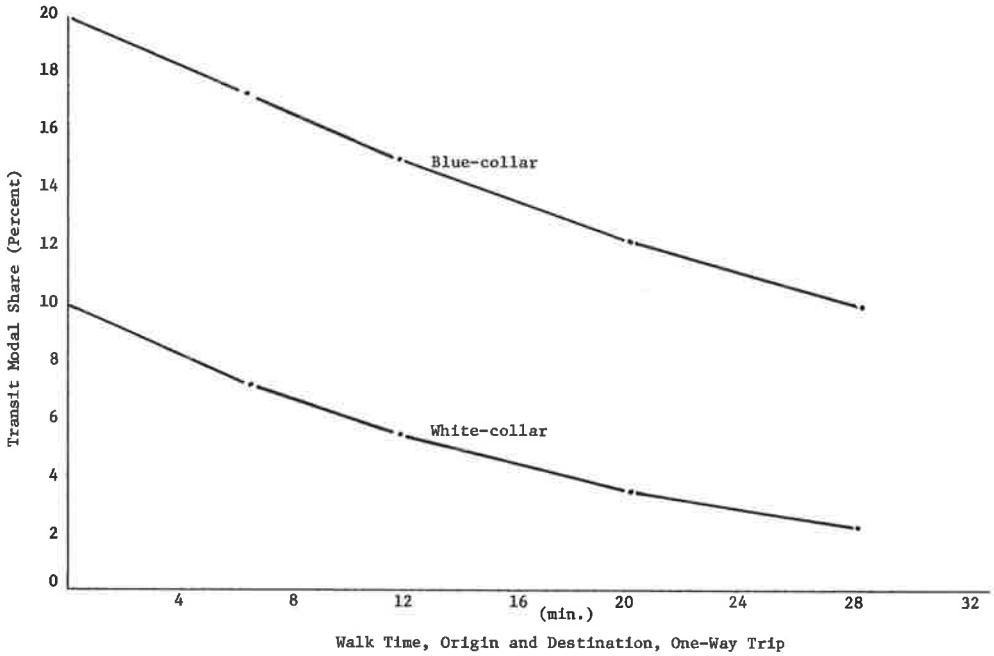


Table 5. Modal shares for conventional rail rapid transit.

Zone Pair	Subzone Combination	Zone Trips (percent)	Share of Transit Mode (percent)	
			Blue Collar	White Collar
1-2	Near-near	0.4	18.0	7.9
	Near/far	12.2	10.6	3.3
	Far-far	87.4	6.0	1.3
	Total	100.0	6.6[a]	1.6[a]
1-3	Near-near	1.7	36.0	19.7
	Near/far	29.1	26.1	10.9
	Far-far	69.2	18.1	6.2
	Total	100.0	20.7[a]	7.8[a]

[a]Total mode share is the weighted average where percentages of trips in each subzone combination are the weights.

generally is a bias against lower income groups, who would still require a car to be able to use this transit system. Commuter rail service would appear to appeal to longer distance, white-collar workers who want premium quality service (fast and reliable) and are willing and able to pay for it.

An express bus operation gives very good service (better than almost any other mode) to a major destination focal point such as the CBD, but it gives almost no service to intermediate areas. To the extent that white-collar trips are more heavily CBD oriented and blue-collar work trips are more heavily oriented to non-CBD industrial areas, this has differential effects on traveler groups as well.

Conventional rail rapid transit has service levels similar to LRT. It has higher speeds as soon as one gets to the system, but the system is less accessible to people because of its generally greater station spacing. Those who can use a car for access are more favored in this system than in LRT with its more frequent stations because access to the station by walking does not matter to them—they use their cars.

In any comparison between light rail transit and heavy rail transit, the transit planner or operator must trade off total demand, capacity, headway, station spacing, capital costs, and operating costs both from a demand and a cost point of view. Some of the levels of service specified in the examples in this paper may be prohibitively costly given the ridership volumes, for example. However, these examples should demonstrate the kind of trade-offs that need to be explored in evaluating alternative transit systems.

What does this imply for LRT? Several conclusions can be drawn. LRT as a technology has the flexibility to offer service levels comparable to all the other modes examined. There is no reason why LRT could not operate in the way the express bus, commuter rail transit, and rail rapid transit systems were assumed to operate.

There are certainly situations in which the service patterns that are commonly associated with these other modes are desired, but that does not automatically mean that that technology must be selected. LRT operating in an express-bus-type service pattern could be more reliable, less costly, produce less pollution, and allow more flexibility to change operating policy than a bus system could in some cases; thus it should be considered as an option in early analysis.

A study that only considered LRT operating in its typical way and an express bus system in its typical way could easily miss the most cost-effective mode-service combination. This is what was meant by our statement that a technology is not a system.

This paper has shown, hopefully, that many systems can offer many service levels in different implementations; therefore it only remains for this paper to emphasize again the issues involved in choosing the service levels a transit system should give.

If an area is very CBD oriented or if that is a regional goal, express-type service very well may be reasonable. If transit is being implemented in a highly white-collar area, commuter-rail-type service may be appropriate, and a generally expensive feeder system need not be run at a high level. If an area has many intracorridor trips, then a typical LRT or rail rapid transit service pattern may be in order. There are many reasons to believe that the costs and flexibility of LRT will make it as useful a transit option in this country as it has been in other countries. We have tried to show in this paper the many ways in which LRT can be used to provide different level-of-service patterns.

It is the level of service provided by a system, not the technology, that is of primary importance to attracting ridership. This concept, and the models that have been built around it, can provide many insights into LRT system design and operation in urban implementations. This paper has reviewed some of these issues briefly and simply. But hopefully it has explained what we feel is a key role for demand analysis in planning transit systems.

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