

# COMPARATIVE ANALYSIS AND SELECTION OF TRANSIT MODES

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Current planning of transit systems in many cities requires comprehensive comparisons of alternative transit modes. This paper reviews the state of the art. Important conceptual studies and successful, practical mode comparisons for several cities are pointed out. Serious deficiencies of studies using hypothetical situations and comparing modes through costs only are shown on a diagram typically used in these studies. Methodology for mode evaluation consisting of several steps is presented. Requirements of passengers, operator, and community are defined; then candidate modes are selected through type of right-of-way, technology, and operation. Each mode then is evaluated in terms of monetary costs, other quantitative units, and qualitative values. A summary of the procedure also is presented.

•SELECTING the best combination of transit modes is the central decision in planning new transit systems or expanding of existing transit systems. This decision is important because it not only determines technological, operational, and network characteristics of the planned system but also, through these characteristics, has a direct influence on the role the system will assume in the city's physical, economic, social, and environmental conditions and development. All the factors must be considered in the selection because of their interdependence. This makes the task complex.

It will be shown here that, although some elements of comparison can be quantified and thus compared exactly, many elements are qualitative. Therefore, their evaluation must include qualitative elements and thus certain value judgments. The procedure, then, cannot be defined by a quantitative model, nor can the results of the comparative analysis be expressed by a single quantitative value. After a brief review of recently performed comparative analyses of different modes, this paper presents a general methodology of comprehensive comparative analysis of transit systems. An application of this methodology is also included as an example.

## STATE OF THE ART

A number of studies have compared urban transportation modes or technologies. Most of the studies have been performed for individual cities to select the optimal mode or system. Some have been theoretical studies comparing different modes, usually bus and rail technologies.

One of the most interesting comparisons of modes for individual cities is Leibbrand's study for Frankfurt, Germany, performed in 1961 and presented in a summarized form by Homburger (6). Its recommendations generally were adopted by Frankfurt. A comprehensive comparative analysis of 4 different technologies was performed for the rapid transit system in Manchester, England (2). Another comparison of modes for outlying areas in Boston, including rapid transit extensions and different modes for feeder lines, was reported by Fehr (3). A brief review of these and several related studies is presented by Vuchic and Stanger (12).

Similar studies of mode comparison and selection have been completed recently or currently are under way in a number of U.S. and foreign cities, such as Rochester, New York; Dayton; Buffalo; Los Angeles; Edmonton; Miami, Florida; Honolulu; and Pittsburgh.

In theoretical studies of this problem, a rather popular, although incorrect, method has been to compare modes on the basis of direct monetary costs only. In some cases passenger travel time was included with the claim that the analysis is based on total costs. This obviously violates 1 of the basic principles of transportation system evaluation: that all monetary and nonmonetary, direct and indirect impacts of each system must be considered. In urban transportation such factors of service quality as availability, reliability, comfort, and convenience have a major impact on modal choice. Moreover, an analysis of transporting 10,000 to 20,000 persons/h by private automobiles without considering the impact of the multilane freeways required for this purpose or the physical impossibility of providing needed parking makes the study results obviously invalid for real cases.

Stimulated by Meyer, Kain, and Wohl (8), those making analyses of transit system costs usually base them on the diagrams of unit costs as functions of passenger volume, such as that shown in Figure 1. This type of diagram is valid only if the analyzed modes have the same service quality (SQ). For example, a bus and trolleybus on the same type of right-of-way (ROW) would have the same SQ. If the modes are different, then its use is incorrect for a number of reasons.

Each mode, represented by a curve, has a different SQ and therefore attracts, under given conditions, a different number of passengers. Rail rapid transit attracts more passengers than does a bus system using busway and streets. Such a bus system, in turn, has a stronger attraction than does a surface bus system. All 3 systems are so different from the automobile in type of service and potential user groups that their plots on the same diagram have no meaning.

The diagram implies that it presents costs of different modes for any given passenger volume; thus, in Figure 1, cost per trip  $C$  for a surface bus appears to compare with cost  $B$  for a bus on a busway and street and cost  $A$  for rail rapid transit. The fact is that there cannot be a corridor or served area in the real world in which these 3 modes would have the respective unit costs. If a surface bus line would attract  $P$  passengers in a given area, then a bus on busway and street would attract a volume  $P + \Delta P_1$ , and rail rapid transit would attract a volume of  $P + \Delta P_2$ . Unit cost  $C$  therefore should not be compared with  $B$  or  $A$  but with  $B'$  or  $A'$ , and the criterion is not whether, for example,  $C$  is lower or higher than  $B'$  but whether the cost difference  $B' - C$  is worth the attraction of  $\Delta P_1$  passengers. Incidentally, this cost difference may sometimes be negative, which makes the higher quality mode clearly superior even for volumes below the break-even point. This analysis shows that the break-even point is actually a fictitious concept.

That the diagram is also highly unreliable when it is applied to hypothetical "typical" conditions because of the extreme sensitivity of the curves to the assumptions of the analyst compounds the conceptual deficiency. To change relative positions of curves for different modes by manipulating assumptions of the model is easy. Thus Deen points out in his discussion of the study by Miller et al. (9) that the break-even point varies among different studies from the 2,000 and 5,000 trips/h range to 50,000 trips/h, which is a difference of some 1,000 percent. This characteristic allows use of this methodology to argue in favor of or against any mode. As will be shown later this analysis confuses technologies with modes. Because costs of modes are mostly dependent on their type of ROW, the curves in Figure 1 refer more to types of ROW than to bus and rail technologies. If a bus operated exclusively on a busway were compared with a streetcar, the former would have a cost curve similar to that for rail rapid transit and the latter would have a cost curve that would not be drastically different from that for a surface bus.

Consequently, this type of comparison does not argue so much that rail technology is expensive but that transit modes with high types of ROW have higher unit costs than those with lower types. This is a built-in fallacy in any comparison of facilities on the basis of their costs when their differences in performance are disregarded. A

motorcycle is "superior" to a Volkswagen or a Cadillac if their qualities and the fact that many people do not want to use a motorcycle are ignored. Some of the external factors that should be included in transit system planning have been brought up elsewhere (1).

An excellent critical analysis and a conceptual basis for comparison of transportation modes were given by Kuhn (5). Hill (4) also made a significant contribution to the evaluation methodology. Morlok (10) pointed out the incorrectness of comparisons limited to costs and developed a theoretical framework for comparisons that include several other system characteristics. Manheim (7) developed a set of principles that should be followed in transportation systems analysis. Another critical review of mode comparisons through costs and review of relevant theory was given by Vuchic (11).

The mode evaluation methodology presented in this paper uses a number of concepts and principles developed by Kuhn, Morlok, and others.

## METHODOLOGY FOR MODE COMPARISON AND SELECTION

Each city, area, or corridor to be served by a new transit system has its own characteristics. For selection of the optimal transit mode, it is necessary to define all the conditions, requirements, and constraints designated as conditions set. This set may be considered the demand side of the selection process. On the supply side of the selection process are the transit modes from which the optimal mode should be selected for the specific application.

The methodology for comparison and selection of modes consists of 3 major steps. The first step is defining the conditions set for the planning area. The second step is selecting candidate modes, that is, the modes that may be applicable to the studied case, and making a preliminary design of these modes for the given conditions. The third step is making the comparative analysis and selecting the optimal mode.

## DEFINING THE CONDITIONS SET

Based on the overall transportation policy for the city or individual area and defined goals for the planned system, specific requirements and standards are developed.

To ensure a systematic and comprehensive review of all system characteristics, transit system requirements are classified into 3 groups of interested parties: passengers, operator, and community. Definition of requirements must be done with considerable care because some are difficult to distinguish from others or to define precisely. Also some may be somewhat differently defined, expanded, or deleted in specific cases. However, the framework of this type of analysis has a general validity for virtually all modes of transportation. The more similar the compared modes and their studied applications are, the more precise their comparative analysis can and should be. The requirements most commonly applicable to transit system planning are given in Table 1.

### Passenger Requirements

#### Availability

The requirement of availability, without which the population cannot use a transit system, has 2 facets: locational (closeness to system terminals) and temporal (frequency of service). For good availability users must have both reasonably close terminals and high frequency of service. Because of cost constraints, trade-offs between the 2 facets must be made. At one extreme is a dense network with low frequency; such a system is not available for long intervals of time. At the other extreme is frequent service to few points; users far from terminals do not have the service unless they use

Figure 1. Comparison of modes based on their costs, disregarding different service quality and passenger attraction.

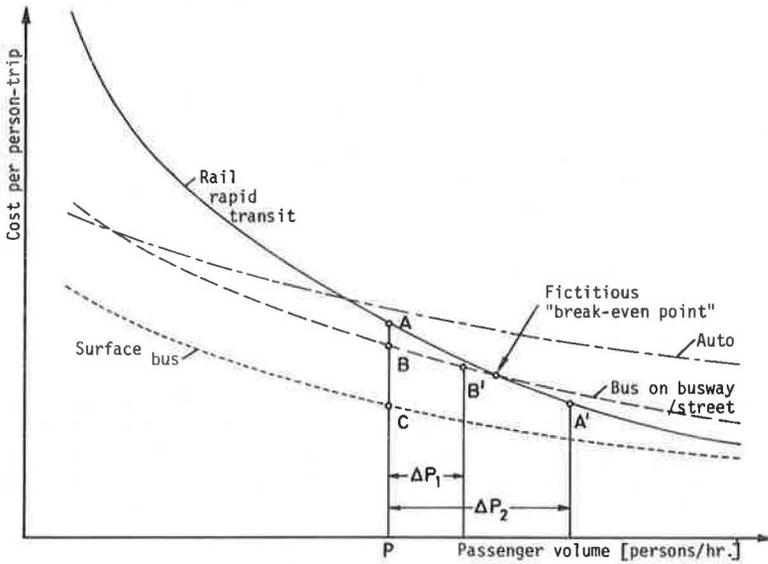


Table 1. Transit system requirements.

Passenger	Operator	Community
Availability	Area coverage	Service quality and passenger attraction
Punctuality	Frequency	Long-range impact
Speed or travel time	Speed	Environmental and energy aspects
User cost	Reliability	Economic efficiency
Comfort	Cost	Social objectives
Convenience	Capacity	
Safety and security	Safety	
	Side effects	
	Passenger attraction	

Table 2. Rating of characteristics of transit modes by right-of-way categories.

Characteristic	Rating		
	Fully Controlled System	Partially Controlled System	Surface Street System
Service quality	Very high	High	Low
Passenger attraction	Very high	High	Low
Image identification	Very good	Good	Poor
Impact on urban form	Very strong	Strong	Weak
Investment cost	Very high	High	Very low
Automation possibility	Full	Partial	None

feeders. Most urban transit lines are a compromise; they provide a certain network density and frequency of service. Naturally, with higher demand both can be increased.

### Punctuality

The important item of punctuality is defined as schedule adherence. The variance from scheduled travel times may result from traffic delays, vehicle breakdowns, or adverse weather conditions. Traffic delays and interference dominate as causes of variance from schedules; therefore, the most significant factor for securing punctuality is control over the system, which means separation of transit ROW from street traffic.

### Speed or Travel Time

The total door-to-door travel time can be composed of 5 parts: access, waiting, travel, transfer, and departure (from transit station to destination) times. Relative weights of these time intervals vary because passengers perceive them differently. Therefore, based on various studies reported in the literature, a factor of 2.0 to 2.5 can be applied to waiting and transfer times to obtain perceived travel time. Relative weight of walking time depends heavily on the attractiveness of the area.

### User Cost

Price of transportation is another important factor for travelers. Transit fare is the most significant portion of it, but other out-of-pocket costs also are included, particularly by commuters. In a broader sense, cost of access by automobile and even its fixed costs (if the automobile is owned only for that purpose) also should be considered.

### Comfort

Comfort is a difficult concept to define because it encompasses many qualitative factors. Paramount are the availability of a seat and quality of ride (affecting users' ability to read and write). The physical comfort of the seat itself, naturally, enters in as do the geometry of the vehicle entrances and exits, width of aisles, presence of air-conditioning, jerk and noise levels, image of patrons relative to users' self-image, and the degree of privacy offered, to name a few.

### Convenience

Comfort is related to the vehicle, and convenience is related to the overall system. No transferring is a convenience. Good off-peak service, clear system information, well-designed and protected waiting facilities, and sufficient and close parking (if required) also are user conveniences. Evaluation of conveniences is predominantly qualitative.

### Safety and Security

Passenger safety and security, which consist of prevention of passenger accidents and protection of passengers from crime, are measured by statistical records of accidents and crime incidents on the system.

## Operator Requirements

### Area Coverage

Primary transit area coverage generally is measured as the area within 5-min walking distance from transit stations and stops. In examining area coverage, however, network extensiveness, provision of access modes (which increase the coverage beyond the 5-min limit), and central business district (CBD) distribution should be considered.

### Frequency

Frequency is expressed by the number of vehicle departures per unit of time. It is sometimes believed that for commuters frequency is not important. Although its significance is greater for riders during off-peak hours, it also seriously affects regular riders. For example, there are no residential areas in which 1, 2, or 3 departures during the whole 2-h peak period would be convenient for all potential users. Short, regular headways are an essential element of attracting all categories of passengers.

### Speed

Although passengers are more sensitive to transfer and waiting than to travel times, they also do want to have high travel speed on the line. The operator is particularly concerned with high commercial speeds on the lines because they affect fleet size, labor costs, fuel, maintenance, and above all, attraction of passengers. Several speeds used in transit systems analysis are defined as follows:

1. Travel speed is the 1-way average speed of vehicle including stops;
2. Commercial speed is the average speed including terminal times;
3. Platform speed is the overall average speed, including travel to and from garages;
4. Paid time speed is the average speed based on a driver's paid time.

### Cost

Although cost is often given an unjustifiably high relative weight, it is the most important single factor to the operator. In most cases 3 aspects of costs are analyzed: investment cost, operating cost, and revenue. All 3 aspects vary greatly with local conditions and system characteristics as well as with time because of inflation. In evaluation, unit costs rather than total costs of individual modes should be compared.

### Capacity

Two different capacities can be defined for a system: way capacity and terminal capacity. Terminal capacity, which is capacity of stations along the line, governs because it is smaller in all cases except when vehicles from a line-haul section branch out into several terminals. Such cases have limited applications for urban transit lines.

### Safety

The operator must pay great attention not only to security but also to operational safety of the system. Considerable cost and reduction of speed or capacity are often applied to guarantee a high degree of operational safety of transit.

## Side Effects

System effects on the nonusers and the environment for which the operator is responsible include immediate physical impacts such as aesthetics, noise, and air pollution as well as long-range impacts such as attractiveness of CBD and stimulation of desired land use patterns in outlying areas.

## Passenger Attraction

The number of passengers a transit line carries is the most important single indicator of its success and its role in urban transportation. The attraction is obviously a function of the type and quality of service, but there is also an additional factor, probably best described as system image, that can be important. System image is difficult to define, but it is composed of such aspects as the simplicity of the system, reliability, frequency and regularity of service, and physical characteristics of facilities.

## Community Requirements

Items included in this category are generally self-explanatory. However, in each specific case they must be defined and analyzed carefully because they vary more with local conditions than do such quantitative items as speed or frequency.

## DEFINING TRANSPORTATION MODES

There is a common tendency to identify the concept of transit mode with technology. This is incorrect because such a definition does not make a distinction between a streetcar and rapid transit or a shoppers' shuttle and a "freeway flyer" bus. As explained elsewhere (13), 3 basic characteristics define a transit mode: ROW, technology, service, and operation.

Despite the widespread practice of classifying modes by technology only, type of ROW mostly determines the basic characteristics of modes. For example, a streetcar system is more similar to surface bus than to a rapid transit system. Or, it may be easier to compare buses operating exclusively on busways with Westinghouse Transit Expressway than it is to compare buses on busways with buses operating partially on controlled ROW and partially on streets.

## Selection of Types of Right-of-Way

Types of transit system ROW can be classified into the following 3 basic categories:

1. Fully controlled (grade-separated) ROW, which is used by rapid transit;
2. Partially controlled ROW, which is used by semirapid transit; and
3. Surface street with mixed traffic, which is used by surface transit.

The 3 categories of ROW have a major influence on the type of transit system operation and its SQ. Thus category 3 transit vehicles, which share the same facilities with other traffic and have to stop along the way, can never be competitive with the private automobile either in speed or in overall SQ, regardless of technology used. Category 2 is typically represented by light rail transit and has considerably higher speed, reliability, and capacity than category 3. The highest SQ in all respects is provided by category 1 but at the highest investment cost. This factor usually limits the extent of network of this category and requires supplementing by other modes. Often the alternatives considered are a smaller network of a high type of system with feeders or a larger network of a lower type of system. Many factors influence the choice

between the 2, but the basic trade-off is between higher quality of operation with the former and fewer passenger transfers with the latter. Better area coverage is advantageous but only if the SQ remains above a certain level. If it does not remain above a certain level, then passenger attraction may be reduced. The possibility of upgrading the lower type of system to a higher type of system is also an important consideration in planning.

The most important characteristics of the 3 ROW categories of transit modes are given in condensed form in Table 2.

A particularly important factor in selecting the ROW category is passenger attraction, which is a direct function of SQ, that is, competitiveness of the transit system with private automobile. Category 3 requires the lowest investment cost but also offers the lowest SQ; category 1 represents the highest investment cost and SQ package of the 3 categories.

The influence of SQ on passenger attraction is shown in Figures 2 and 3. Figure 2 shows the conventional diversion curve, which has modal split (or distribution of traffic between 2 highways) as a function of the ratio (or difference) of their travel times (or costs). Figure 3 shows the same type of diversion curve as a function of transit SQ, which includes such elements as reliability, comfort, convenience, and the like, in addition to travel time and cost. An increase in the total volume of travel with increasing SQ also is shown. Assuming that automobile travel has a certain fixed SQ for the given direction of travel, the share of transit travel increases with its SQ. Because SQ is strongly dependent on ROW category, domains of each category can be plotted along the abscissa with some overlap as shown. Thus the diagram shows conceptually the different volumes of passengers attracted by each category of transit mode.

The selection of the ROW category thus is closely related to the overall characteristics of the transit system and its anticipated relationship with other modes and the economic, social, and other goals of the city. It is therefore not only a technical but also a high-level planning and political decision.

### Selection of Technology and Type of Operation

Another step in comparative analysis and mode selection focuses on technology of modes. If all modes are divided into the 3 general technological categories of rail, highway (bus), and the other technologies between these 2, then classification of individual modes by technological and ROW categories is as given in Table 3.

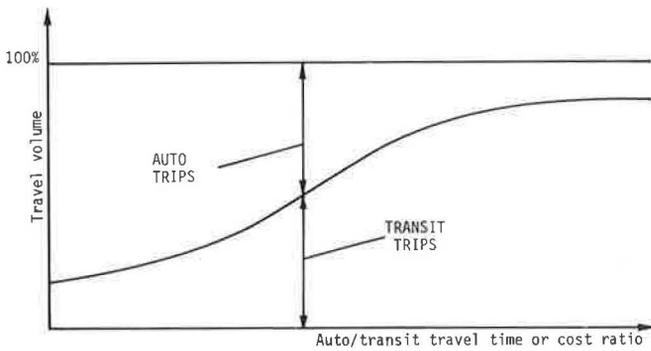
Type of operation, which is related to technology, includes such factors as frequency of service and vehicle capacity; express, skip-stop, and local running; and interconnection of lines. These features usually are selected together with technology.

Comparative analysis of different technologies and operations within the same ROW category is based mostly on a deeper analysis of specific technical and operating system characteristics and somewhat less on overall system impact. The analysis therefore is predominantly technical. It is better defined and more quantitative than that of ROW categories, yet it is far from simple. It must include a great number of quantitative and qualitative factors, and it must evaluate all of them.

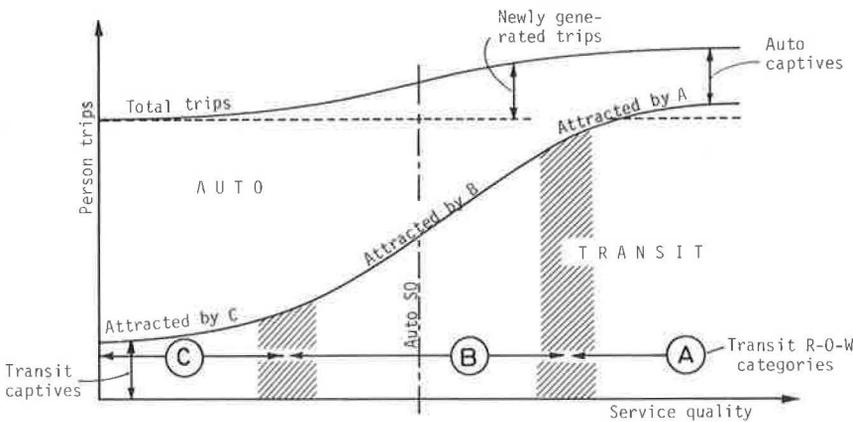
### Definition and Preoptimization of Candidate Modes

In each specific case of transit mode selection, the planner must decide which modes to consider. Based on an examination of the conditions set for the planned system and personal knowledge of characteristics of different types of ROW, transit technologies, and operations, the planner selects those modes that conceivably may satisfy the defined requirements. The more expertise and experience the planner has, the more precise his or her choice will be and the fewer candidate modes he or she will select. Thus, in no case will an experienced transit planner compare such drastically different modes as buses on streets with rapid transit, people movers with minibuses, or demand-

**Figure 2. Standard automobile-transit, modal split-diversion curve.**



**Figure 3. Travel volume and modal split as functions of transit service quality and right-of-way category.**



**Table 3. Classification of transit modes.**

Right-of-Way Category	Technology		
	Rail Guided	Rubber Tired Guided and Other Modes	Highway
Fully controlled system	Regional rail transit <sup>a</sup> Rapid transit <sup>a</sup> Light rapid transit	Rapid transit Monorail People movers <sup>b</sup> Personal rapid transit	Bus on busway only <sup>b</sup>
Partially controlled system	Light rail transit <sup>a</sup>	Dual-mode systems <sup>b</sup>	Bus partially on busway
Surface street system	Streetcar	Trolleybus	Surface bus <sup>a</sup>

<sup>a</sup>Widely used.    <sup>b</sup>Currently not in operation.

**Table 4. Summary of comparative analysis for Lindenwold Line and Shirley Busway.**

Requirement	Rating	
	Lindenwold Line	Shirley Busway
<b>Passengers</b>		
Availability	Good	Poor
Speed or travel time	Good	Very good
Reliability	Very good	Poor
User cost	Good	Very good
Comfort	Good	Poor
Convenience	Good	Fair
Safety and security	Very good	Good
<b>Operator</b>		
Area coverage	Good	Very good
Frequency	Very good	Very poor
Speed	Very good	Poor
Investment cost	Very poor	Fair
Operating cost	Good	Fair
Capacity	Good	Poor
Side effects	Good	Fair
Passenger attraction	Very good	Good
<b>Community</b>		
System impact	Very good	Good

responsive transit with rail transit. The conditions-set-making application of the respective former modes likely will not be suitable for the use of the respective latter modes.

When the candidate modes are selected, each must be preoptimized, that is, its network, specific technology, and operation must be determined so that they are compatible with the given conditions. This preoptimization is necessary because different characteristics of modes make their optimal employment different. For example, rapid transit, light rail transit, and buses on busways each would have its own optimal station locations and connections with other modes.

## EVALUATING AND SELECTING A MODE

Each candidate mode now must be evaluated with respect to each requirement. The type and depth of evaluation that are reasonable and practical with respect to data availability and objectivity of evaluation of qualitative aspects must be determined. The evaluation of each parameter can be expressed in 1 of 3 basic ways (5):

1. Dollars as measure units (mostly costs);
2. Other quantitative units (for example, passenger time in hours); and
3. Qualitative evaluation (for example, comfort, system image, aesthetics, impact on development pattern).

To derive an overall evaluation of different modes expressed by a single quantitative criterion, one would have to make 2 highly subjective and therefore controversial steps. First, all parameter evaluations would have to be quantified, and second, their relative weights would have to be assumed. Although this can be done with reasonably satisfactory results in some rather simple cases, this is seldom the case in transit system evaluations. The reader, analyst, or decision maker usually will get a better picture of compared modes through a complete list of evaluated items than through a single number based on numerous subjective values that often cannot be traced down.

An example of this method of comparative analysis of transit modes is presented in an abbreviated form elsewhere (12). This complex comparison of a rapid transit line (Lindenwold Line) with an express bus service (Shirley Busway), that is, modes from 2 different ROW categories, was performed through analysis of the previously defined requirements. However, because the comparison was made for 2 different conditions set with different reliability of data, a direct comparison of quantitative measures could have led to a misinterpretation of numerical values. The summary of the comparison, given in Table 4, therefore contains only a simple qualitative evaluation of each characteristic of the 2 modes; the text of the study provides a description of analysis of each characteristic supported by all relevant quantitative data.

The study separated differences caused by local conditions from those caused by inherent characteristics of rail and bus technology and from those resulting from the different types of operations (regular transit on the Lindenwold Line and commuter transit on the Shirley Busway). This detailed analysis of individual characteristics explains the major differences between the 2 systems (such as higher investment cost but higher SQ passenger attraction of the Lindenwold Line) much more clearly than a comparison limited only to cost and travel time could explain.

A further discussion of the characteristics of different modes is available elsewhere (13).

## SUMMARY OF METHODOLOGY

In summary, the procedure for comparative analysis and selection of transportation modes consists of 8 major steps.

1. Based on urban transportation policy, develop goals for the transit system.
2. Define conditions for the area to be served.
3. By using results from the preceding steps, define specific requirements and standards for the planned system.
4. Select type of ROW for candidate modes.
5. Select technologies and operational characteristics for candidate modes.
6. Preoptimize candidate modes.
7. Evaluate candidate modes.
8. Compare evaluation results and select optimal mode.

These steps usually are not quite distinct and discrete. For example, goals for the transit system depend somewhat on the conditions in the served area, and ROW, technologies, and operational characteristics of transit modes are interdependent. The steps show the general sequence of the procedure, but considerable interaction and feedback among them always exist.

## SUMMARY AND CONCLUSIONS

Comparative analysis of transit modes is a complex problem. A widespread tendency is to simplify this process even to the extent that a single item (usually cost) of peak-hour operation is used as the only evaluation criterion. Considerable literature exists on thresholds of individual technologies, which often do not recognize the importance of ROW characteristics that strongly influence service quality. This tendency for simplification, in combination with pursuit of an incorrect objective in transit system planning (such as to provide the minimum cost system), has led to many incorrect decisions.

Different transit modes must be compared in a systematic manner and on a comprehensive basis by using many different factors. The methodology presented in this paper facilitates the comparison by classifying transit systems first by their type of ROW, then by technology and type of operation. Although the methodology is not and cannot be exact because of certain qualitative elements, it produces much clearer and more realistic results than do simplistic comparisons based on system costs only. The most serious errors in these simplistic studies, particularly those based on hypothetical models, are their numerous, largely unrealistic assumptions and their failure to consider differences in service quality and the resulting differences in passenger attraction. These are often far from negligible.

That further work and experiences with the methodology presented here will bring additional improvements should be expected. However, these improvements should not be expected in the form of quantification of individual parameters and mechanization of the evaluation procedure, which often are accompanied by a reduced understanding of systems. Rather, the improvements should be made in further formalization of the systematic methodology and comprehensive approach, which will require a much better understanding of transit systems, their operations, and their role in urban transportation than is presently the case.

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