METHOD FOR DEVELOPMENT OF A MASS TRANSIT EVALUATION MODEL BASED ON SOCIAL SYSTEM VALUES

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This paper describes a method in transportation systems engineering that provides a means of identifying the customers, or decision-makers, and their wants. The method was developed and applied to the hypothetical example of a peoplemover for downtown Los Angeles. The approach couples the methodology of systems engineering with utility theory and survey techniques. It includes steps to identify needs, characterize systems, establish performance criteria, identify decision-makers and their criteria, identify the implementation process, and generate the evaluation model. In the example, 4 basic groups of decision-makers were identified: government technicians, government managers and public officials, local businessmen, and potential riders. Questionnaires, tailored for each group, provided weightings of the decision-maker's influence, delegation of responsibility, criteria from the general down to the component level, and utility data points for all significant component criteria. Results were formulated into a composite value model that was used to generate both a tabular and a computerized evaluation model based on corresponding performance criteria and measures. The method provides identification of the social system decision-makers, their needs and influence, and a meaningful correlation and translation into technical criteria. The research shows the effectiveness of utility curves both as a quantitative measure of performance for a given criteria and as a means of combining worths of multidimensional criteria.

•THE DISTINGUISHING characteristic of a social system, such as mass transit, is by definition its intimate involvement with people, or, more specifically, the existence of a complex, multiple customer. This paper summarizes a method, developed during research for a dissertation in the field of transportation systems engineering, that provides a means of identifying these customers (or decision-makers) and their wants during the implementation process and provides results that can be meaningfully translated into technical terms.

The objective of the research was to develop and demonstrate a model for evaluating mass transit systems that bridges the communication gap between social systems decision-makers and technical systems designers. In other words, the model was intended to convert the criterion of public acceptance to that of technical design. The results are intended to be useful both to those responsible for writing specifications and evaluating subsequent proposals and to those responsible for design and optimization of mass transit systems. Complete results are described elsewhere (1).

Two references provide basic inspiration and a point of departure. The first, by Lifson (2), applies utility and decision theory to system evaluation and establishes the validity of incorporating weighted sets of a single decision-maker's technical utility curves for pertinent design criteria into a value model.

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Utility theory has been the subject of study by economists for more than 200 years and is beyond the scope of this paper for detailed discussion. In brief, economists have established that there exists for individuals a variable quantity, i.e., utility, associated with a quantity of money or other commodities that can be quantitatively measured and formulated on an interval scale; further, that an informed, rational individual will select the alternative that maximizes expected utility in accordance with his expressed preferences.

This concept of incorporating utility curves into a value model has been adopted here; it represents a powerful tool, in that it provides both a quantitative measure of the worth of varying degrees of performance on a given criteria as well as a means of combining on a common reference base the worths of multiple criteria possessing diverse measures of performance. In other words, it is a way of measuring both the desirability of a given apple as well as its worth in comparison with a given orange. Justification of application of utility theory to social systems is provided by Engel (3), who states that consumers do make decisions in a structured way that can be at least partially predicted and that the behavioral motive of maximization of utility is a reasonable approximation. Further, Thiel (4) indicates that, if this is so, the social system utility function will be a linear combination of individual functions.

The second reference basic to this method, by Pardee (5), provides a study of the measurement and evaluation of total transport system effectiveness. This study introduces the ideas of trying to understand the major objectives of all groups affected by transport change, the hierarchical ordering of criteria, and the concept of evaluating potential utility.

A key aspect of the method is the reliance on survey information, based on the belief that the complex of social system decision-makers are able and willing to express their criteria for a system. Thus, direct inputs from the social system are required—not the analyst's estimates or guesses, but the real thing. To provide these inputs a hypothetical example, a people-mover for the downtown Los Angeles area, was postulated, and the informal cooperation of city government officials, employees (from the executive level down to file clerks), and businessmen was solicited and received. Results of research with this example will be summarized. Because of its informal nature, this must be looked on as a pilot study; however, it performs the useful functions of providing initial data for the value model and trying the procedures required by the evaluation method in the real world.

METHOD

As shown in Figure 1, the method requires a series of steps or tasks to be conducted. The first step, identify needs, provides input data for both step 2 and step 4. The second step, characterize systems, establishes the kinds of transport systems that can satisfy the needs and characterizes them by their functional elements. With this information, step 3, establish performance criteria, is accomplished by determining which technical and economic criteria and measures are appropriate estimators of performance. Step 4, identify decision-makers, is placed at the same level as step 1 to indicate that it may be started concurrently. When the types of decision-makers and the kinds of systems involved are established, step 5, establish decision-makers' criteria, may be conducted. Iterating with this information will permit accomplishment of step 6, establish decision-makers' value models. In step 7, generate a composite decision-makers' value model, the individual group value models are combined, and one composite value model is established. In step 8, relate decision-makers' criteria to technical criteria, the transfer from decision-maker language to technical language is accomplished. With this complete, the decision-makers' composite value model may be interpreted in technical terms and step 9, generate evaluation model, accomplished. A discussion of these steps is given in the sections that follow.

Identify Needs

The general tasks in step 1 are to establish the needs, identify the governmental bodies and funding options involved, and establish the external constraints or environment. Specific tasks include formulation of a listing of requirements—essentially a "shopping list" or preliminary specification; establishment of routes and ridership demand projections; development of an initial list of appropriate government agencies, departments, and points of contact; and establishment of system interfaces.

These tasks were greatly simplified for the hypothetical example of a people-mover in downtown Los Angeles by the availability of a document prepared for the guidance of public and private agencies by the Transportation Committee of the General Plan Advisory Board (6).

For this example, present system interfaces are with the freeways and with sidewalks and building access. A system of peripheral parking structures and people-mover stations located at the freeway off-ramps would appear to provide excellent systems integration. Planning for the future would include interfacing with a proposed second-level pedestrian-way system and with a line-haul rapid transit system.

Characterize Systems

The object in step 2 is to characterize systems by constituents, so as to remain independent of specific designs or concepts. This has been done for people-movers in Figure 2. The terminology of "system," "subsystem," and "component" has been adapted to aid in a hierarchical ordering by increasing level of detail. This provides a consistent methodology that may be paralleled in developing decision-maker criteria; it will also serve later as a vertical framework on which to add horizontally technical and economic criteria and then an integration with the decision-maker value model. It may be seen that the first level serves to characterize the major elements that constitute the people-mover system. Although service and management/operation are not elements of hardware, they need to be treated at the same level as hardware-type elements. The subsystem level provides the next breakdown of elements, serving both to identify available choices and to categorize at greater level of detail. The component level brings us to the final and greatest level of detail.

Establish Performance Criteria

Technical and economic performance criteria, influenced by environmental, physiological, and socioeconomic criteria, would normally form the basis for development of a rational, technical decision-maker's value model. Here they are but one step along the way. The criteria and their measures are listed in a form that parallels the hierarchical ordering of Figure 2 and are primarily assigned at the component level; this seems proper because it is only at this level of detail that a technical specification can be written. A partial sample for the vehicle system is given in Table 1. In contrast to a technical decision-maker's value model, ranges of acceptable values are not assigned here; they will be determined by the social system decision-makers' value model. When technical criteria and/or measures are not readily apparent, assignments are deferred to the decision-makers.

Identify Decision-Makers

Step 4 includes determination of the identity of the social bodies involved plus their influence, or weight, and requires synthesizing or charting the implementation process. Both steps 4 and 5 embody an iterative, gradually expanding process of establishing personal contacts with members of the decision-making agencies, where both direct information and referrals are obtained. The process as it evolved in the hypothetical example should be typical of that for any major city.

Although the task appears formidable at the start, organization relationships are usually available that significantly reduce the problem. In the example, one such organization was the Transportation Committee of the General Plan Advisory Board, an active group meeting weekly that consists of technical staff members of all city agencies concerned with transit planning. Another, the General Plan Advisory Board, a chartered group required to pass upon all major city planning, consists of the managers (or their assistants) from all major departments. It includes all the agencies represented on the Transportation Committee plus several others. These two organizational

Figure 1. Evaluation model for mass transit.

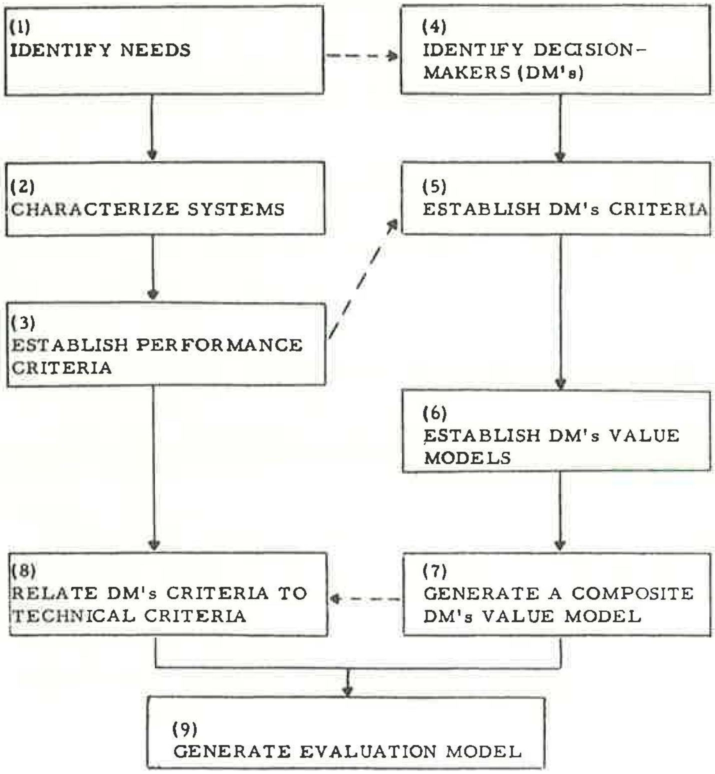
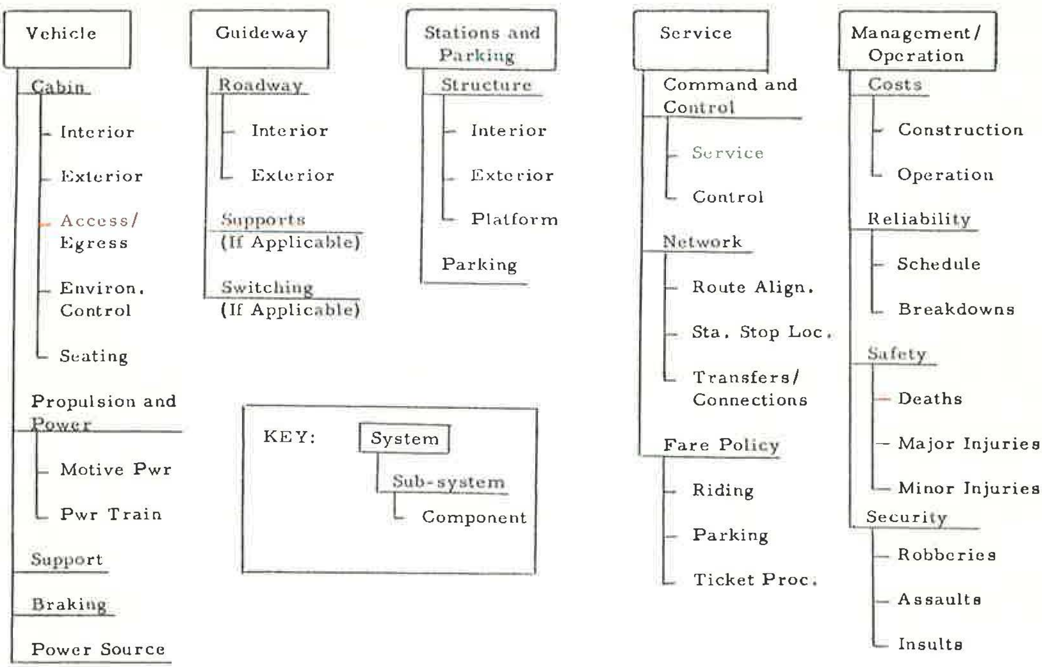


Figure 2. Systems characterization.



relationships significantly helped to make this task tractable, the first as a gathering point of the technicians involved in transit planning and the second as a gathering point of executive approval of transit planning. The Transportation Committee is thus a working, technical arm of the General Plan Advisory Board and a perfect entry point into the implementation process. From the committee it was possible to branch out into contacts with all pertinent agencies on the board and to related city council and public committees. Cooperation at all points of contact in this study was received without official endorsement, and the amount of thought and time freely given attests to the worth of the results. This voluntary cooperation also attests to the acceptability of the procedure to the social system decision-makers.

It became apparent that 4 basic groups of social system decision-makers existed: the technicians (i.e., Transportation Committee and other agency staff members), the government officials (councilmen, board chairmen, department managers, etc.), local businessmen and property owners (this being a downtown business district, residents were not significant), and riders (primarily employees and shoppers). Just as a thread of relationships was found to exist between various city agencies, a similar arrangement was found in the business community. Identification of these 4 basic groups of decision-makers pointed the way to establishment of a survey methodology consisting of 3 distinct approaches and associated questionnaires (the approach to the officials also served in slightly modified form for the local businessmen). A straightforward approach is used in determining decision-maker influence weights by simply asking them. Therefore, the technicians and government officials were asked to weight on a scale of 0 to 10 the importance in the process of implementing the project of various groups and organizations (including their own). There was no problem of reluctance by the participants to answer (anonymity was promised, however). Results were remarkably consistent, both within the 2 groups and between them.

The final product included both a flow chart of the implementation process (unfortunately, too detailed for clear reproduction here) and identification and weighting of the decision-makers, Table 2. Some 23 discrete bodies were identified. The weights given in the table, normalized to a base of 10, were aggregated and applied to the criteria in the next step.

Establish Decision-Makers' Criteria

An initial hierarchical chart of criteria is prepared for incorporation into questionnaires. The object is to be inclusive and to decompose criteria from the general level into the specific to a level where they may be converted to measurable technical performance and to obtain weightings at each level. In parallel with the designations for the system elements of system, subsystem, and component, these criteria levels are designated general criteria, subcriteria, and component criteria. Using the hierarchical ordering of Pardee (5) as a starting point, modifications were made to account for a difference in philosophy regarding multiple use of the same criteria and to clarify terminology for the social system's decision-makers. The resulting criteria and ordering were to be verified by direct questioning of the decision-makers. The final result provides the basis for derivation of value models in the next steps.

As an example of ordering to increasing level of detail until a measurable level is attained, Figure 3 shows the breakdown for convenience. It may be seen that neither the general criterion, convenience, nor the first of its subcriteria, schedule (convenience), possesses measurable quantities to which degrees of value, or worth, may be assigned; the component of schedule, rush-hour frequency, can, however, be readily evaluated in terms of waiting time, ranging from zero (or on demand) upward. At this level, the decision-maker is asked to weight, on a 0 to 10 scale, the value to him of given lengths of waiting time and a utility curve obtained. Criteria presented in the questionnaires in this form are self-explanatory because lower levels serve to explain the higher levels. It is important to make every effort to include all appropriate criteria at all levels. Superfluous criteria will drop out automatically by receiving low weights from the decision-makers. Similarly, criteria placed at a lower level than they should be will automatically receive higher weightings equivalent to their proper level.

Validity of survey results was ensured by using the scaling rules set down by Torgerson (7) in the questionnaires: First, stable estimates of the scale values can be obtained via repeated judgments (over multiple judges); second, the origin and the unit of measure are specified. Responses of subjects within the groups were combined using the mean of ratings assigned. Questionnaires are developed and tailored to the type of decision-maker with respect to method of application, size, content, and terminology. In the study, all groups were questioned on weightings of general criteria, government and business officials were permitted to indicate delegation of lower level criteria (a proper and useful reduction of effort), and both technician and rider questionnaires (300 copies distributed to city employees as representative riders) carried the questioning process down to the lowest levels of detail. The resulting master chart of decision-maker criteria is shown in Figure 4. Weightings of relative importance on a 0 to 10 scale were obtained at all levels—general criteria against each other, subcriteria relative to each other for given general criteria, etc. Although these criteria were established for the specific transit mode of people-movers, they should generally apply to most forms of mass transit.

Establish Decision-Makers' Value Models

Before proceeding, a few definitions are in order. A value model is defined by Lifson (2) as a representation of the value system that motivates the design effort. Lifson defines utility as the scalar measure of relative contribution to success. The objective function in an evaluation model may be considered simply as an aggregation of weighted utility functions.

The equation for the objective function is essentially a methodical aggregation of weights from each criterion level. These criteria levels are subscripted and weights indicated as follows:

Level	Subscript	Weight
Decision-maker	j	w_j
General criteria	ji	w_{ji}
Subcriteria	jik	w_{jik}
Component criteria	jikl	w_{jikl}

These weights are relative weightings, summing to 1. If $f(y)_{jikl}$ represents a single decision-maker's utility function for the measureable performance of component criterion, the objective function for the composite set of general criteria is given by

$$U = \sum_{j=1}^{m} w_j \left(\sum_{i=1}^{n} \left(w_{ji} \sum_{k=1}^{o} \left(w_{jik} \sum_{l=1}^{p} w_{jikl} \cdot f(y)_{jikl} \right) \right) \right)$$

Results of this step consist of tables of weights and utility points or curves for all key decision-makers and all levels of criteria. Based on the survey of delegation of responsibility, 9 complete sets of such data were assembled for the example. These data are used in the next step.

General Composite Decision-Makers' Value Model

In step 7 the tables of criteria weightings and utility points representing the key decision-makers are integrated into one composite value model representing the social system. Integration is conducted in accordance with the delegations and weightings of decision-makers determined in step 4, the criteria obtained in step 5, and the criteria weightings and utility points determined in step 6.

The composite decision-makers' weights for general criteria are given in Table 3. Results, when arranged on an ordinal scale, agree quite well with those of rider surveys summarized by ABT Associates (8). Composite weights at the subcriteria and component level plus component-level utility curves are given in the original reference.

Table 1. Sample tabulation of technical and economic performance criteria.

Constituent	Technical Criteria	Measures
System: Vehicle		
Subsystem: Cabin		
Component		
Interior		
Windows	Size	Percentage of sides
Material	*	*
Capacity	Capacity	Passengers
Parcel space	Storage volume	Cubic feet per passenger
Exterior	*	*
Access/egress	Doorway dimensions	*
Environment control	Comfort	Temperature, relative humidity
Air	Odor	*
Lighting	Intensity	Average footcandles
Noise	Intensity	Average decibels
Seating	Type	Bucket, bench
	Hip room per passenger	Inches
	Leg room per passenger	Inches
	Direction	Forward, aft, in, out
	Vibration of passenger	g's

*To be provided by decision-makers.

Table 2. The decision-makers and their weights.

Decision-Makers	Weights
Southern California Rapid Transit District Board/Manager	0.589
Southern California Rapid Transit District Technical Staff	0.510
Technical Review Committee	0.467
General Plan Advisory Board	0.485
Transportation Committee of GPAB	0.424
Chamber of Commerce/Central City Association	0.478
Southern California Automobile Club	0.282
City Planning Commission	0.488
Board of Public Works	0.528
Board of Public Utilities	0.374
Municipal Art Commission	0.235
Council Industry and Transportation Committee	0.462
Council Planning Committee	0.548
Council State, County, and Federal Affairs Committee	0.497
Council Finance Committee	0.492
City Administrative Office	0.184
City Council	0.588
Mayor	0.553
State Office of Intergovernmental Relations	0.202
Los Angeles County	0.356
Southern California Association of Governments	0.307
U. S. Department of Transportation	0.580
Public riders	0.371

Figure 3. Hierarchical ordering of convenience.

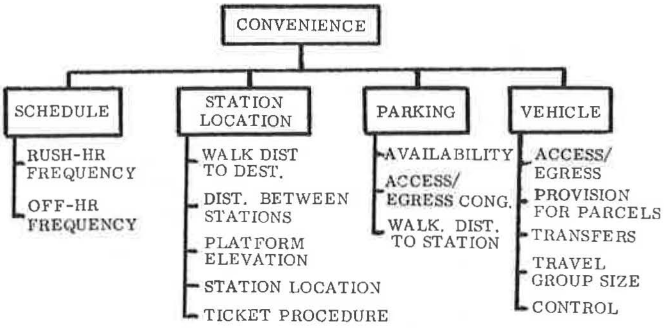
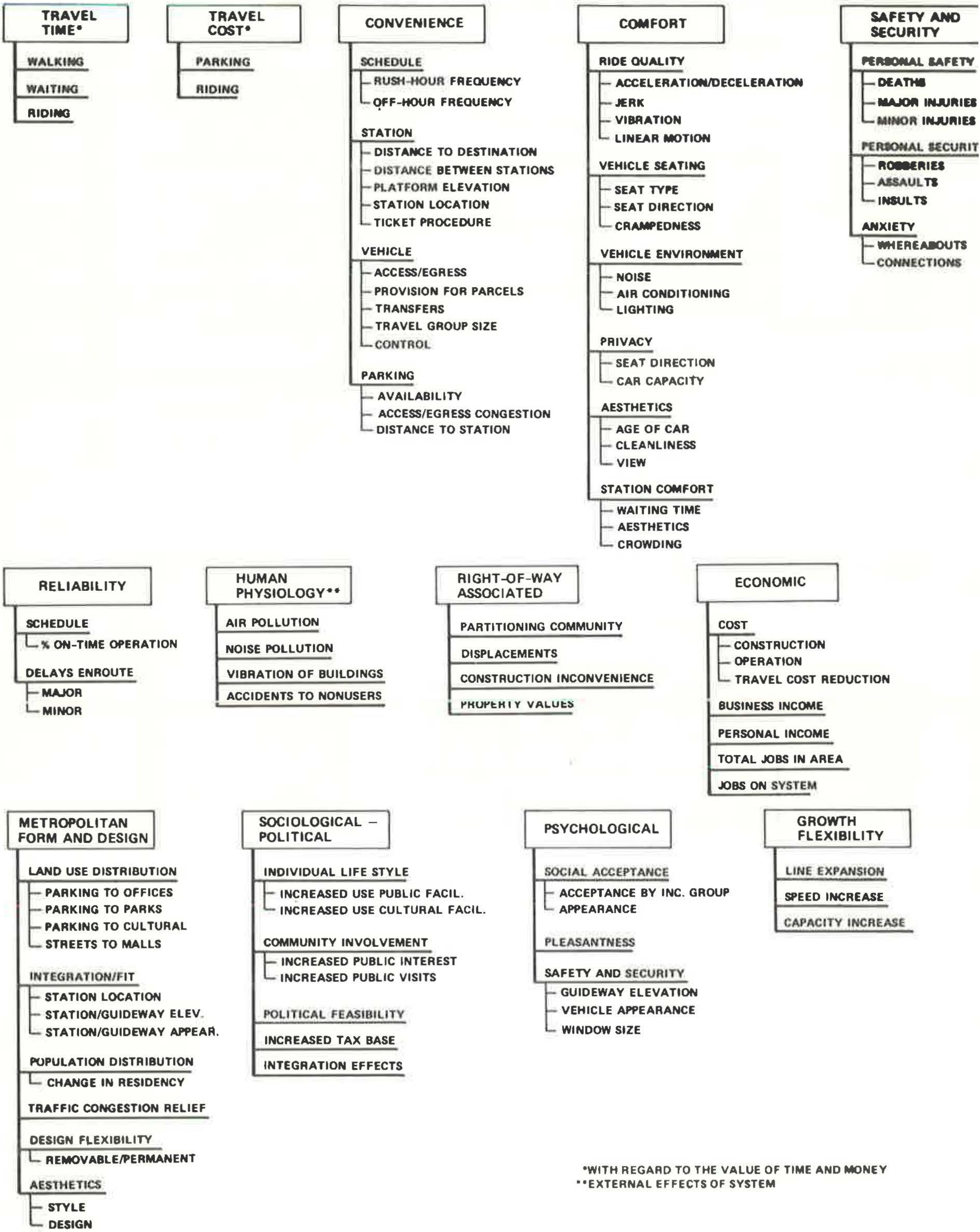


Table 3. Composite weightings of general criteria.

Criteria	Composite Weight
Travel time	0.945
Travel cost	0.808
Convenience	1.033
Comfort	0.827
Safety and security	0.900
Reliability	0.927
Human physiology	0.727
Right-of-way	0.574
Economic	0.808
Metropolitan form and design	0.831
Sociopolitical	0.584
Psychological	0.719
Flexibility	0.273

Figure 4. Master chart of decision-maker criteria.



A typical set of utility curves, for travel time, is shown in Figure 5. These curves show the value of utility curves in indicating worth of varying quantities of a given criterion measure. While the weightings indicated only a small difference in worth of the 3 subcriteria, the figure shows that this worth depends on how much time is being considered. ABT Associates discussed research that found that 2 minutes of waiting or walking time is equal to the disutility of 5 minutes of riding time; this is very close to what the curves of Figure 5 show.

Relate Decision-Makers' Criteria to Technical Criteria

The way has been prepared for step 8 by step 2, which characterized the systems hierarchically and provided a vertical framework; by step 3, which established technical performance criteria and added horizontally to the framework; and by steps 5 through 7, which identified decision-maker criteria in a corresponding hierarchy (including conversion of subjective measures to technical measures during preparation of utility curves in the previous step). The construction is completed in this step with the addition and correlation of decision-maker criteria.

As may be seen in Table 4, the correlation is usually obvious. Some decision-maker component criteria are associated with more than one system component; for example, linear motion (a component criterion of ride quality) relates to both vehicle motive power and to support. Matching of a few of these criteria is judgmental. In both instances, placement is not critical; however, inclusiveness of all appropriate criteria somewhere in the matrix is important. (Although double-counting is not a consideration here, it is guarded against in the final step, generation of evaluation model.)

Generate Evaluation Model

The evaluation model is presented in the original reference in 2 forms, tabular and computerized. The tables provide points of worth for corresponding measures of performance, requiring only the addition by an evaluator of columns to rate alternatives under consideration. The points are derived from the weighted utility curves that were related to component criteria in the previous step. Maximum points (i.e., highest points for each criterion) were summed and normalized to a base of 100. Thus, a "perfect" design would receive 100 points of worth. Points of worth for each subsystem and system are obtained by summing maximum points for appropriate components and subsystems respectively. Values for the people-mover systems were as follows: vehicle, 20; guideway, 13; stations and parking, 8; service, 36; and management/operation, 23. The order of importance seems logically consistent.

A small sample portion of the tabular model is given in Table 5. As an example of the table's use, the interior component would be evaluated on the aspects of windows, material, capacity, and parcel space. Window size of a particular design would be compared against the range of sizes given and points assigned accordingly; in a specification, a size resulting in the maximum points would be specified. Some points, such as those for capacity, represent the combination of 2 decision-maker utility curves (in this example, privacy aspects of capacity with convenience aspects of travel group size). Points of worth for the style and design aspects of exterior represent half of the total allocated; the remaining half has been assigned to similar aspects for the guideway. It will be noted that, although some criteria still require judgmental opinion by the evaluator, measures have been provided that serve to confine the judgment within fairly narrow limits.

CONCLUSIONS

The following conclusions appear valid:

1. It has been verified in the application studied that the method provides (a) identification of the social system decision-makers, along with their needs and influence in the process of implementation, and (b) correlation of their criteria with technical performance criteria.

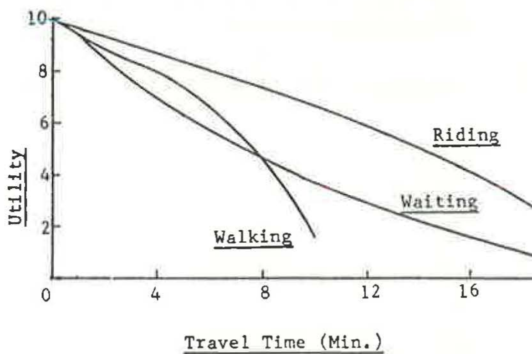
Table 4. Sample of final performance criteria.

			Decision-Maker Criteria							
			Convenience	Comfort					Metropolitan Form and Design	Psychological
Constituent	Performance Criteria	Measure	Vehicle	Ride Quality	Vehicle Seating	Vehicle Environment	Privacy	Aesthetics	Aesthetics	Safety and Security
System: Vehicle Subsystem: Cabin Interior										
Windows	Size	Percentage of sides								Window size
Material	Ability to hold appearance	Clean-dirty						Cleanliness		
Capacity	Capacity	Passengers	Travel group size				Capacity			
Parcel space	Storage volume	Cubic feet per passenger	Parcel provision							
Exterior	Style	Old fashioned-modern							Style	
	Design	Simple-complex							Design	
	Appearance of age	Perceived age						Age of car		
	Appearance of weight	Perceived mass								Vehicle appearance
Access/egress	Ease of access/egress	Method of entry	Access/egress							
Environment control										
Air	Comfort	Temperature, relative humidity				Air-comfort				
	Odor	CFM air per passenger				Air-odor				
Lighting	Intensity	Average foot-candles				Lighting				
Noise	Intensity	Average decibels				Noise				
Seating	Type	Bucket-bench			Seat type					
	Hip room per passenger	Inches			Cramped-hip					
	Leg room per passenger	Inches			Cramped-legs					
	Direction	Forward, aft, in, out			Seat direction					
	Vibration of passenger	g's		Vibration						

Table 5. Evaluation model part 1, vehicle cabin.

Constituent	Performance Criteria	Measure	Points of Worth
System: Vehicle			20.079
Subsystem: Cabin Interior			11.080
Windows	Size	<30 percent of side area	0.104
		30 percent of side area	0.428
		40 percent of side area	0.874
		>50 percent of side area	0.394
Material	Ability to hold appearance	Spotless	0.672
		Clean but discolored	0.463
		Discolored and dirty	0.088
Capacity	Number of passengers	1 passenger	0.350
		2 passenger	0.405
		4 passenger	0.685
		8 passenger	0.583
Parcel space	Storage volume per passenger	0 cubic feet	0.231
		2 cubic feet	0.473
		4 cubic feet	0.234
Exterior	Style	Old fashioned	0.030
		Modern	0.674
		Futuristic	0.244
	Design	Simple	0.674
		Average complex (auto)	0.380
		Complex	0.068
	Appearance of age	New	0.379
		<2 years	0.334
		<4 years	0.279
		>4 years	0.208
	Appearance of weight	Massive	0.601
		Like auto	0.670
		Light weight	0.838
		Flimsy	0.231
Access/egress	Ease of access/egress	Duck	0.457
		Duck and slide over	0.330
		Enter erect	0.880

Figure 5. Utility of travel time.



2. The effectiveness of utility curves as both a quantitative measure of performance value for a given criterion and as a means of combining worths of multidimensional criteria has been shown.

3. Although initiation of a mass transit system may in many, if not all, instances be a political decision, the method of evaluation described here can help to guide this decision. Further, the method should enhance potential for implementation—i.e., the potential for completion of the system from planning to financing to public approval and use—by ensuring that the final system design meets the weighted needs of the social system decision-makers.

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