UNIVERSITY RESEARCH

DOT-TST-76-68

CRITERIA FOR EVALUATING ALTERNATIVE TRANSIT STATION DESIGNS

February 1976

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Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration
Office of University Research
Washington, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT-TST-76-68	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CRITERIA FOR EVALUATING ALTERNATIVE TRANSIT STATION DESIGNS		5. Report Date February 1976 6. Performing Organization Code
7. Author(s) Lester A. Hoel, Michael J. Demetsky, Mark R. Virkler		8. Performing Organization Report No. RLES Report No.: CE-4142-101-76
9. Performing Organization Name and Address Department of Civil Engineering University of Virginia Charlottesville, Virginia 22901		10. Work Unit No. 11. Contract or Grant No. DOT-OS-50233
12. Sponsoring Agency Name and Address Department of Transportation Program of University Research 400 Seventh Street, S. W. Washington, D. C. 20590		13. Type of Report and Period Covered Final Interim Report August 1975-December 1975 14. Sponsoring Agency Code TST

15. Supplementary Notes

Monitor: Norman Paulhus, TST-12

16. Abstract

The urban transit interchange facility is described in terms of the important functional facility components and the quality of the station environment. These terminal dimensions are interpreted to establish a list of design objectives which reflect the points of view of the user, the special user (elderly and handicapped) and the operator. The stated objectives are then used to identify quantitative and nonquantitative criteria for the evaluation of alternative urban transportation interface facility designs. A general evaluation framework for analysis of interchange facilities is derived and compared with the basic systems evaluation procedures: effectiveness analysis, benefit-cost analysis, and ranking and rating models. A terminal facility evaluation model with a specific set of measureable criteria is described and discussed with respect to three primary areas of application; i.e., a set of mutually exclusive project designs, an iterative design process, and the analysis of a major design strategy (e.g., modular construction).

An appendix is included which provides a summary description of a number of selected measures in the passenger processing and environmental categories whose quantification is not readily apparent.

17. Key Words Terminal, passenger flows, station environment, criteria, evaluation, effectiveness	18. Distribution Statement Document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	59	

Form DOT F 1700.7 (8-69)

EXECUTIVE SUMMARY

A. Introduction

The planning and design of urban transportation interface facilities represents a critical element in the functioning of a transportation network. This phase of transit system development uses information that is provided from the systems planning stage to select facility components and the spatial configuration and environment of the terminal. The methodology for planning and designing urban transportation interface facilities has been based primarily on "rule of thumb" techniques with little application or systems-analytic approaches. The overall purpose of this research is to investigate a formalized and comprehensive approach for transit station design.

B. Problem Studied

The problem addressed in this report concerns the investigation of alternative criteria for the evaluation of design configurations and internal environments for transportation interface facilities. Criteria selection is associated with passenger flow management, environmental factors, operational efficiency, and user needs. Both quantifiable and non-quantifiable measures of facility performance relative to the cited criteria are considered.

The ultimate interpretation of the individual performance measures into an indicator of total facility performance is accomplished with an evaluation tool such as benefit-cost analysis, cost effectiveness analysis or ranking and rating models. Constraints posed on the applicability of the performance measures must be considered in the selection of an evaluation methodology. The final decision regarding a recommended set of criteria and an appropriate evaluation model requires careful analysis of the advantages and disadvantages of rigorous evaluation models with fewer criteria vs. more criteria with a less structured decision rule.

C. Results Achieved

The urban transit interchange facility is identified by two basic subsystems; passenger processing and environmental. The former includes components which meet the operational objectives of the station; i.e., transit access, egress, and transfer. These elements establish the effective passenger capacity of the terminal design that results from the type and amount of pedestrian movement and staging facilities that are provided. The arrangement of station components is also influential on system performance, and measures such as system coherence, travel time and delay, flow conflicts, queueing, and the availability of alternate routes are important performance indicators. Devices and design features which aid the mobility of the elderly and handicapped should be distinctly considered in the specification of the passenger processing subsystem.

The environmental subsystem of the terminal facility represents those dimensions with which the pedestrian associates his or her comfort and convenience, activity satisfaction, safety, and security needs. These environmental aspects are differentiated from those associated with the passenger processing subsystem in that they are not directly associated with the movement of people but pertain to the physical environment through which they move.

Once the supply side of the terminal system has been identified the demand must be accurately stated because many of the performance measures relative to a station facility depend on the volume of pedestrians being handled. In this respect, area travel data and behavior analysis must be interpreted to specify demand levels for alternative terminal designs.

The terminal dimensions are interpreted to establish a list of design objectives which reflect the points of view of the typical user, the elderly and handicapped, and the operator. In addition to objectives associated with the passenger processing and environmental subsystems, the operating agency is concerned with the economy of the operation and the flexibility of the design (joint development potential and opportunity for expansion).

The stated objectives for the various interest groups are used to identify potential quantitative and qualitative criteria for evaluating alternative transit interchange facility designs. However, before a final set of implementable criteria can be established, the evaluation framework and/or decision rule to which they will be applied must be recognized. Accordingly, an interface facility evaluation framework is recommended after an indepth analysis considers effectiveness analysis, benefit-cost analyses, and ranking and rating models relative to the transit station problem. The resulting evaluation strategy closely resembles a cost-effectiveness evaluation technique which arrays quantitative and non-quantitative criteria in matrix form according to interest group. The tabulations provide raw criteria measures and establish a fundamental decision making framework; for example, the decision maker can review the evaluation matrices for dominance and tradeoffs among the alternatives and "subjectively" select a "best" design in a formal manner.

The resulting transit station design evaluation framework meets all of the objectives for comprehensive evaluation and can ultimately be adapted to apply the ranking and rating decision model. The entire urban transit interchange facility evaluation strategy is summarized by the following steps.

1. Diagnosis of interest groups
2. Objective determination
3. Determination of impact-interest interactions
4. Determination of performance criteria and related measures
5. Establishment of tolerable impact levels for each criteria relative to each interest
6. Specification of a feasible set of alternative designs
7. Preparation of interest evaluation matrices
8. Description of the decision making rule

While the state of knowledge of terminal design and plan criteria and standards permits analytical measures for many considerations, some measures can only be obtained by inspection. Most research into terminal planning models has concentrated on passenger flow analysis, and a majority of the measures associated with the passenger processing criteria can be obtained from the UMTA Station Simulation Program. Many of the environmental measures can be characterized from the design specifications. Other measures can be judged from the prevailing policy that is established to meet the transportation system objectives. The impacts of other features of the design such as orientation aids, barriers to travel, and entry control must be judged by inspection of the design/plan.

The criteria and evaluation strategy recommended for application in evaluating alternative transit interchange facilities can also be interpreted to assist in developing acceptable facilities. This approach involves an iterative process wherein a basic design is created and evaluated relative to established criteria and then incrementally modified until all objectives are satisfied.

This investigation has provided a comprehensive set of criteria for assessing the performance of alternative transit station design configurations. An interest-impact matrix model is recommended for transit station evaluations. The generality of the evaluation framework guarantees the potential for application in numerous terminal design settings.

D. Utilization of Results

The results of this research will be of interest to transportation system planners, facility designers, and transit managers who are concerned with present operations and future plans for rapid transit systems in urban areas. The findings can also be applied by the designers of interchange facilities for new transit modes such as fully automated systems and dual-mode operations.

The research advances the state of the art toward a common methodology based on a systematic approach for evalution of suggested transportation interface facility designs. The new information will eliminate much of the preliminary study required for developing transit interchange facilities, and assure that the primary planning and design objectives are being met.

E. Conclusion

This research provides a framework for the development of a systematic design and planning methodology for urban transportation interface facilities. Important measures of the performance of the passenger processing and environmental sybsystems of a transit station have been identified along with an appropriate evaluation model. In the next phase of the study these results will be utilized to state the requirements for a design and planning methodology for generating and evaluating alternative passenger terminal facilities. This methodology will consider previously developed computer models and ad hoc manual procedures to provide the tools necessary for estimating the performance of urban transit interchange facilities.

FORWARD

This research is a continuation of work begun under a grant from the National Science Foundation to develop and demonstrate methodology for the design of urban transportation interface facilities. Phase I of the research was concerned with the characterization of the state-of-the-art of transit interface design through (1) an extensive literature review resulting in a report titled "The Design of Urban Transportation Interface Facilities: State of the Art" and (2) a 2-day seminar on transit facility design involving representatives of architectural and engineering agencies, transit operators, and researchers. The outcome of Phase I has been the identification of major weaknesses and suggested improvements in facility design methodology.

The second phase is sponsored by the Department of Transportation Program for University Research, and involves the development of an interface facility design methodology. The results of the first task in Phase II are reported herein. Topics include the identification of criteria for the evaluation of design configurations for transportation interface facilities and investigation of alternative evaluation frameworks. The results will be used as part of a systematic design and planning methodology for transit stations in the second task of Phase II.

Phase III of the project will test and illustrate the application of design methodology in specific case studies. The relevance of the proposed methodology to the practical requirements of the profession will be evaluated through this process.

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I. INTRODUCTION

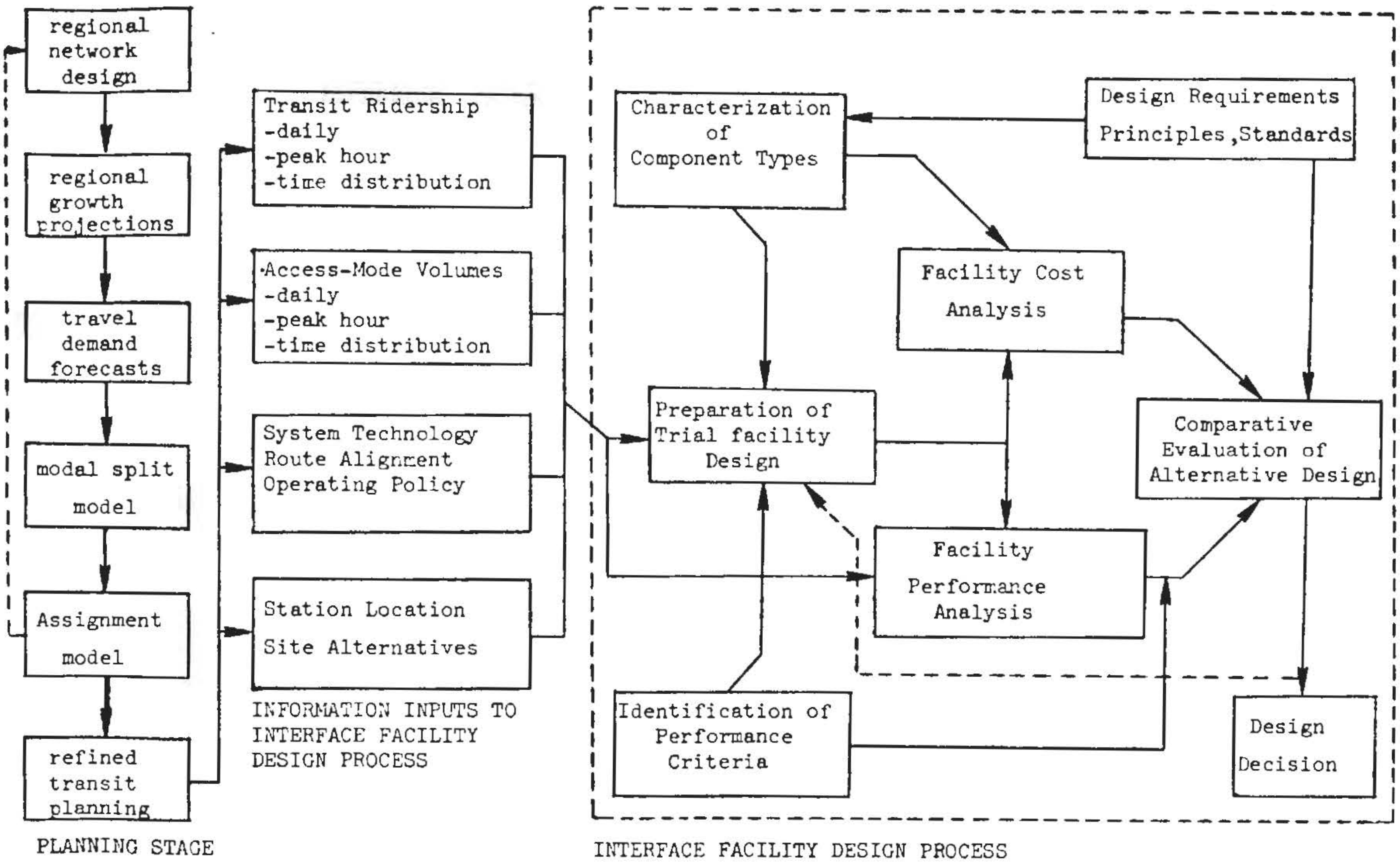
A. Background

Urban Transportation interface facilities represent critical elements in the functioning of a transportation network. This is so because it is at these nodal points that the traveler transfers between modes, and it is well known that travelers assign a much higher disutility to the time spent transferring than the time in the vehicle (up to 2.5 to 1). Accordingly, the ease with which transfers can be accomplished enhances the attractiveness of a transit mode to potential riders. Abrupt transitions and delays at interface facilities can offset service advantages offered by high speeds, frequent service obtained through close vehicular headways, and other advances in line-haul technology and operation. With inadequate interface facilities, line -haul improvements will not reach their full potential impact in meeting the transportation objectives for which they were designed.

B. Problem Statement

The planning and design process, as depicted in Figure 1, furnishes perspective concerning the place of transit interface facility design within this total process. In the initial or planning stage the network structure is fixed and the basic information inputs to the interface facility design process are established: transit line ridership, access mode volumes, the system technology, and the station location. In the terminal design process, facility components are selected and the spatial configuration and environment determined to accommodate passenger flows through the station.

The methodology for planning and designing urban transportation interface facilities has been based primarily on "rule of thumb" techniques with little application of systems-analytic approaches to establish a



Context of the Interface Facility Design Process within the Total Planning and Design Process

Figure 1

design process.* The purpose of this research is to develop and test a system-analytic approach to the interface facility design process shown in Figure 1. The project consists of two parts. Part I is concerned with the development of a methodology including identification of station design criteria, selection of an evaluation framework appropriate to station planning and design, and evaluation of appropriate methods for measuring facility performance, taking account of previously developed computer models and comparing these for appropriateness in various design settings. Part II will be concerned with applications of the methodology to specific sites as tests and illustrations of the procedures developed.

C. Scope

The research described in this report identifies the important elements of transportation interface facilities. These major components are interpreted to define a comprehensive set of terminal design and planning objectives for associated interest groups. Criteria are proposed to provide measures of the performance of alternative terminal facilities relative to the stated planning and design objectives. These criteria are used to develop a general interface evaluation framework which closely resembles an effectiveness model. The potential for this framework to accommodate ranking and rating analysis is demonstrated. Finally, an evaluation model which uses selected measures of performance is recommended for practical application in urban transit station design analysis. This evaluation framework is designed for the general case to consider access-mode, mode-mode, and mode-egress flow patterns. The terminal functions and environment are simulated to handle interchange flows for any transit technology setting.

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* For a comprehensive review of the state of the art of transit station design see: Hoel, L. A. and Roszner, E. S., "Planning and Design of Intermodal Transit Facilities," paper prepared for Transportation Research Board Annual Meeting, January 1976.

II. SYSTEM DEFINITION

A. Primary System Elements

In order that criteria be established for the evaluation of transit interchange facilities, the system must be clearly identified by a set of dimensions which specify performance. In this context, the transit interchange facility can be described in terms of the functional facility components provided to accommodate tripmakers, the general system arrangement, the quality of the station environment, amenities provided to the public, and those special facilities available to meet the needs of the physically handicapped and elderly (special users). These elements that define the transit station facility then identify a physical system for which design objectives and evaluation criteria can be established.

B. Functional Facility Components: Supply and Arrangement

The functional facility components are the total set of elements provided to meet the operational objectives of the station; i.e., modal access, egress and transfer. These components establish the effective passenger capacity of the facility that results from the type and amount of pedestrian movement and staging facilities that are provided. The basic functional facility components are:

1. Internal pedestrian movement facilities and areas (passageways, stairs, ramps, escalators, elevators, moving walks, ramps, etc.);
2. Line haul transit access area (entry control and fare collection, loading and unloading);
3. Components which facilitate movements between the access modes and the interchange facility (ramps, electric doors);
4. Communications (information and directional graphics, public address system); and
5. Special provisions for the elderly and handicapped.

Stating the supply of pedestrian travel facilities and space in terminals does not completely specify the internal transportation system, because various arrangements of these component facilities will experience different measures for aggregate travel times and distances, and queueing. Accordingly, the interchange system arrangement must be considered and the following measures describe the effectiveness of the station layout.

1. System coherence: connectivity, accessibility, continuity.
2. Travel distance, times, and delays.
3. Conflicts (among passenger flows).
4. Security considerations (e.g., isolated paths, dark corners, etc.)
5. Path choice avaiable.
6. Queueing points.

The supply and arrangement of the interchange facility components together establish the passenger processing subsystem of the station.

C. Special Tripmakers

In addition to the facility design considerations regarding typical users, recent transportation systems designs and related legislation reflect a concern for special tripmakers. This group is comprised of those individuals whose ambulatory functions are impaired; particularly the handicapped and elderly. Devices and design features which aid the mobility of these groups are included in the passenger processing subsystem. Typical measures which may be taken include lanes for movement outside of crowds and special level change facilities (i.e., elevators).

D. The Station Environment

The environmental quality of a transit station is represented by those dimensions with which the pedestrian associates his or her comfort and convenience. These environmental aspects are differentiated from those given in the previous section on functional performance in that they are not directly associated with the movement of people but pertain to the physical environment through which they move. Amenities are activity points within this non-movement oriented environment. These latter considerations are not explicitly needed to perform the functional mission of the station, but their availability enhances the place status of the terminal environment. The physical personification of the environment-amenity elements include:

1. The physical environment (lighting, air quality, temperature, aesthetics, cleanliness, music, etc.).
2. Non-transport businesses and services (private concessions such as newspaper stands, coffee shops, barber shops and other small businesses and services).
3. Restrooms and lounges; first aid stations; public telephones.
4. Weather protection.
5. Other.

The terminal environment can also be described relative to safety and security conditions. Typical safety standards incorporated into the design include fire prevention and accident reduction measures. Security provisions are employed for protection against crime and vandalism.

The stated environmental, amenity, safety, and security dimensions establish the environmental subsystem of the transit interchange facility. The performance of the passenger processing and environmental sybsystems contribute to the overall effectiveness of a station plan and design.

E. Demand and Level of Service

The success of the transit interchange in performing its transportation mission is directly related to the extent to which the supply of the functional facility components balances the travel demand at this node (terminal junction). Explicit supply and demand measures for both normal and special users are needed. Specifically, pedestrian flow between each access mode/access point (egress mode/egress point) and line-haul mode by number of passengers and time of day should be established.

The total demand at a terminal is associated with its locational-area attributes (i.e., density, market area, income levels, sex distribution, etc.) and the level of service provided by the total transit system (time, cost, comfort, etc.). Alternative station designs which provide for high levels of terminal service should be evaluated for larger demands than those designs offering less service. In this regard, performance measures of the interchange system must be compatible with the transportation service measures that are used in estimating travel demand. Theoretically, the terminal analysis model should be integrated with travel demand models to ensure an equilibrium analysis.

Area travel data that is used to evaluate multi-modal systems can be employed to infer demand levels for alternative terminal designs. Examples of level of service formulations established for the passenger processing subsystem and the environmental subsystem include the following:

1. Design (D)

   LS_D = f (size, amount and design characteristics of component facilities; aggregate and specific)

2. Planning (P)

   LS_P = f (distance, volume/capacity, queues)

3. Environmental Quality (E)

   LS_E = f (comfort, convenience, security, safety)

4. Special Accomodations (A)

   LS_A = f (amount of special facilities)

An aggregate service quality index can be derived from the above measures to identify a given design.

$$QI = f\ (LS_D, LS_P, LS_E, LS_A)$$

This index can be interpreted to identify the proper demand level that can be expected to use a facility.

III. OBJECTIVES AND CRITERIA FOR TERMINAL DESIGN

A. System Objectives

The ultimate goal of the terminal design process is to provide the best possible level of service under the governing financial and design constraints. Accordingly, a set of design and planning objectives which account for the performance of the terminal facility is needed. Subsequently, a set of criteria will be derived from the objectives so as to explicitly measure the total performance of a terminal facility.

The following is a list of station design objectives which associate the points of view of the user, the special user (elderly and handicapped) and the operator with the interface facility.

B. Passenger Processing Objectives

User

1. Minimize travel impedances (time, distance)
2. Minimize delays (queues)
3. Minimize conflicts (crossing movement paths)
4. Minimize crowding
5. Minimize disorientation
6. Maximize safety
7. Maximize reliability
8. Provide for efficient fare collection
9. Minimize level changes

Special User

1. Eliminate level changes
2. Reduce fare collection barriers
3. Avoid crowding
4. Eliminate physical barriers
5. Provide locational guides

Operator

1. Maximize equipment reliability
2. Efficiently control entry

3. Maximize safety
4. Efficiently process flows
5. Provide adequate space

C. Environmental Objectives

User and Special User

1. Provide comfortable ambient environment (heat, noise, air quality)
2. Provide adequate lighting
3. Provide clean surroundings
4. Ensure an aesthetically pleasant environment (including provision of music, art, etc.)
5. Provide for personal comfort
6. Provide services and concessions
7. Provide adequate weather protection
8. Provide adequate security

Operator

Provide proper security

D. Fiscal Objectives

In addition to the objectives associated with the functional and environmental elements of the terminal, the operating agency is concerned with the economy of the operation and the potential for expanding the facility. In this respect the following objectives are stated.

1. Minimize maintenance, cleaning and replacement needs
2. Obtain an efficient return on incremental investment
3. Receive adequate income from non-transport activities
4. Utilize energy efficiently
5. Minimize total cost
6. Exploit joint development potential
7. Provide opportunity for expansion

E. Criteria Development

The terminal planning, design, and economy objectives that have been given for the respective interest groups are translated into a set of measures which explicitly describe terminal facility performance. Table 1 lists a set of generalized objectives without reference to interest. The purpose for this step is to eliminate duplication where similar objectives are given for various interests, and to facilitate the development of a set of mutually exclusive criteria. Specific criteria are stated for each of the generalized objectives in Table 1 along with appropriate performance measures. Additional descriptive information concerning design standards and documentation for certain criteria are given in the Appendix.

The comprehensive criteria given in Table 1 must be closely examined to establish a list of mutually exclusive measures which can be used in practice. For example, it is desirable to provide a comprehensive evaluation with as few criteria as necessary. This implies only one criterion per objective and, possibly, combining objectives without sacrificing the sensitivity of the evaluation. Limitations on the number of criteria being considered in an evaluation are justified by feasibility and relevance considerations for each criterion.[1] There are two practical aspects to the feasibility question. First, the more factors, the higher the costs of data collection, analysis, and forecasting. Second, the more complex the information, the more difficult the choice process becomes. The relevancy issue pertains to how well the criteria associate with a particular plan and show a real sensitivity of difference among alternatives. Finally, the nature of the particular decision making rule used in the evaluation process may also place constraints on the usefulness of certain criteria. Because of this latter factor, an evaluation framework for urban terminal facilities must be considered prior to recommending a finalized set of criteria for planning applications.

Table 1: Objectives, Criteria, Measures

OBJECTIVE	CRITERIA	PERFORMANCE MEASURES
1. Minimize Travel Impedances (differentiate between accessing and egressing flows)	Total walk-time Total time in system Individual path analysis (origin-destination times)	Aggregate travel Time Aggregate time Unit journey time
2. Minimize Crowding on Links	Area per person in the space associated with a link	Sq. ft./person on pathway
3. Minimize Queues	Total delay time in queue Number in queue at node Time in queue while travelling from Node (A) through Node (B)	Aggregate waiting time Number of people Unit journey waiting time
4. Minimize Conflicts	Measures of crossing flows	Relative volumes (major and minor flows)
5. Minimize Disorientation	Connectivity from Node-Link network (directness of path) Availability of directional information	Network connectivity measures Type and locations
6. Maximize Safety	Safety features on mechanical facilities Elimination of design hazards	Special safety features
7. Maximize Reliability of System Components	Back-up facilities in case of breakdown	Present or not present
	Inspection procedures	Frequency and type
8. Provide for Efficient Fare Collection and Entry Control	Attraction to robbery or vandalism	Type of collection (credit card, token, cash, exact fare, other) also, safeguards provided
	Inconvenience, or disutility to user due to method	Time required for purchasing tokens, making change, waiting, etc. at the fare collection area
	Technology used	Passenger processing rate; ability to keep non-payers out
9. Minimize Level Changes	Number of levels Mechanical aids available	Number of levels Type (elevator, ramp, escalator, etc.) and number
10. Eliminate Physical Barriers	Difficulty in navigating fare collection-entrance control area	Type and width (turnstile, gate, etc.)
	Capability of users	Accessible rails, leaning aids

OBJECTIVE	CRITERIA	PERFORMANCE MEASURES
11. Provide Sufficient Space	Station size	Square feet
12. Provide a Comfortable Ambient Environment	Odors and odorants	Concentration not to be unpleasant to any considerable number of persons
	Suspended Aerosols and particulates	Coefficient of extinction for transmitted light
	Inflow of air	Cu. ft./min. per person
	Air contaminants	Concentrations, e.g., parts per million (ppm)
	Discharges from equipment rooms and control centers	Points affected
	Air velocity - public areas	Not to exceed 1,000 fpm
	--through sidewalk gratings	Not to exceed 500 fpm
	--passageways during emergencies	Not to exceed 2,700 fpm
	Rapid pressure change	If change is greater than 0.10 psi, change rate not to exceed 0.06 psi/sec.
	Thermal comfort	"Relative Comfort Index" (inc. termperature, humidity, etc.)
	Noise, Underground Station:	
	Platform level, trains entering and leaving	Max. of 80 dBA
	Platform level, trains passing through	Max. of 85 dBA
	Platform level, trains stationary	Max of 67 dBA
	Platform level, only station ventilation system operating	Max of 55dBA
	In station attendants' booth	Max of 45 dBA
	Train room reverberation time	1.6 to 2.0 sec.
	Noise, Above Ground Station:	
	Platform level, trains entering and leaving	Max of 70-75 dBA
13. Ensure Adequate Lighting	Passenger stations, surface, and passenger loading areas must be well lit.	Illumination levels (foot-candles)
	Maintenance factors, brightness ratios, glare, reflectance, and emergency lighting.	

OBJECTIVE	CRITERIA	PERFORMANCE MEASURES
14. Provide for Personal Comfort	Rest rooms must be provided.	Uniform Building Code of International Conference of Building Officials local building codes, facilities per sq. ft. of floor area, or facilities per station user/peak hr.
	Rest areas must be provided.	State law, local ordinance, local building codes, sq. ft. of rest area/sq. ft. of floor area, sq. ft. of rest area per system user/peak hr., or seats in rest area per system user/peak hr.
	Benches, water fountains, etc.	Number provided
15. Provide a Clean and Pleasant Environment	Station finish materials: general, floors, walls, ceilings, doors, and miscellaneous metals	Materials and construction methods
	Provision for art displays, graphics, and visual features.	Location and size of these provisions
16. Provide Supplementary Services	Advertising	Type, size, location
	Concessions	Type, size, location
	floor space allocated-	Sq. ft. allocated
	% of total floor space-	%
17. Provide Protection from Weather	Terminal area exposed	% terminal area exposed
18. Provide Adequate Security	Size of security force	Number of personnel
	Number of levels of terminal	Number of levels
	Avenues of escape (train, bus, auto, foot) from terminal area	Type and number of directions for each destination
	Number of exits from terminal	Number of exits
	Separate spaces (separate non-intervisible spaces)	Number delineations
	Accessibility to station agent's booth and major user paths	Distance of discrete areas from station agent's booth and major user paths
	Paid area	Percentage of floor area that is part of "paid area"
	Surveillance and security patrols	Number of areas not subject to frequent security patrols or constant surveillance inclusive of parking lots

OBJECTIVE	CRITERIA	PERFORMANCE MEASURES
	Alarm provisions	Number of areas away from major user paths, not subject to constant surveillance from Kiosk or remote camera, or not serviced by alarms by emergency phones
19. Minimize Maintenance, Cleaning, and Replacement Needs	Maintenance Cleaning-surfaces Cleaning-concessions	Size and cost of maintenance force
20. Account for Total Cost Initial Operation Security Other	Allocated funds Subsidy required Public investment Private investment	Dollars
21. Obtain an Efficient Return on Incremental Investment	Additional benefits or objectives met beyond base cost (no frill design)	Benefit-cost ratio (assuming benefits are convertible to dollars)
22. Obtain Adequate Income for Non-transport Activities 1. Businesses 2. Advertisements	Cost of facilities vs. income received	Break even or profit, loss must be avoided
23. Operate with Efficient Energy Utilization	Total and incremental energy requirements	Kilowatt hrs.
24. Provide for Joint Development Potential within Station Boundaries	Compatibility with community planning and land use goals Special zoning % area non-transport	Policy evaluation (Will be a function of location)
25. Provide Design Flexibility	Expansion potential vertical, horizontal Passenger processing, other activity Modular components	Floor space, local land costs, area around station, zoning ordinances

IV. FACILITY EVALUATION FRAMEWORK

A. The Evaluation Problem

The criteria that have been specified in Table 1 provide either quantitative or descriptive measures of objective attainment. These measures can be used to evaluate designs for new and existing terminal facilities.

Evaluation is defined as a process which operates on two sets of information - information about actions and information about values - to assess the relative desirability of each alternative.[2] The specific requirements for a comprehensive evaluation are stated in a recent study[3] and those which are appropriate here include:

1. Indicate the differential incidence of impacts resulting from different alternatives,
2. Highlight the tradeoffs among alternatives,
3. Operate on qualitative as well as quantitative information,
4. Treat uncertain and incomplete information, and
5. Recognize that different interests place different relative values on different objectives and impacts.

A general evaluation model which meets the above requirements concerning group interests and the type of information considered is derived and compared with the basic systems evaluation procedures: effectiveness analysis, benefit-cost analysis, and ranking and rating models.[1,4]

B. A General Interface Facility Evaluation Model

For data processing and analysis purposes, terminal facility performance criteria are categorized according to interest-impact considerations as shown in Table 2. Here the impacts are defined relative to the 25 objectives listed in Table 1 (assuming 1 criteria for each objective). The entries in Table 2 denote typical impact-interest interactions. Nine impacts of the passenger processing system affect the user and 10 the special user; while only 2 affect the operator. Both the user and special user are concerned with 7 environmental impacts, while the operator only considers one. On the other hand only the operator is directly involved with the economy and design measures.

Table 2 Impact - Interest Matrix

Impact	User	Special User	Transit System Operator
Passenger Processing			
1. Travel Impedances	X	X	
2. Crowding	X	X	
3. Queueing	X	X	
4. Conflicts	X	X	
5. Orientation	X	X	
6. Safety	X	X	
7. Reliability	X	X	
8. Fare Collection and Entry	X	X	X
9. Level Changes	X	X	
10. Barriers, physical		X	
11. Station size			X
Environmental			
12. Ambient Environment	X	X	
13. Lighting	X	X	
14. Rest Areas	X	X	
15. Aesthetic Quality	X	X	
16. Services	X	X	
17. Weather	X	X	
18. Security	X	X	X
Economy			
19. Maintenance Costs			X
20. Total First Cost			X
21. Incremental Cost			X
22. Income			X
23. Energy Requirements			X
Design Flexibility			
24. Joint Development			X
25. Design Flexibility			X

Once the relevant criteria and associated impact groups are established for a facility design problem an evaluation matrix for each interest group can be constructed as shown by Tables 3, 4 and 5. The entries in this model are performance measures for each alternative for the various criteria as rated by each specific evaluator group. Tables 3, 4, 5 indicate multicriteria objectives - the general case. These tabulations provide raw criteria measures and establish a basic decision making framework. For example, the decision maker can review Figures 3, 4, 5 for dominance and tradeoffs and subjectively select a "best" design or, at least, reduce the total set of criteria by eliminating those which do not show significant variance among the alternatives. The various tradeoffs which may be considered include tradeoffs among impacts, tradeoffs among interests and tradeoffs among alternatives.

The model as given thus far only presents relevant criteria to the decisionmaker in a manner which facilitates comparisons among alternatives. This general interface facility evaluation model closely parallels the cost-effectiveness evaluation technique which separates the criteria into two categories, costs and measures of effectiveness.(1) Costs are defined in terms of all the resources necessary to provide, operate, and maintain the facility, and effectiveness is the degree to which an alternative achieves certain other design objectives. The impacts can be arranged according to impacted groups. The total information is listed for the decisionmaker so that he can choose that plan which best suits the interests which he represents. This methodology relies on intuition, judgement, and experience of the analyst for a decision. An example application of this philosophy toward the evaluation of intercity transportation terminals is given in reference 5 where it is referred to as an impact-incidence matrix.

C. Benefit-Cost Evaluation

Other commonly used evaluation tools establish decision rules for choosing among alternatives. Although such strategies are designed to provide relatively objective decisions, they create certain problems as will be shown in discussion of the two most widely used decision

Table 3 User Evaluation Matrix

Criteria	Performance Measures				
	Alternative				
Subsystem/category: Measure	1	2	-	-	n
Passenger Processing					
1:1	$e_{1:1,1}$	$e_{1:1,2}$			$e_{1:1,n}$
1:2					
i:1					
i:k	$e_{i:k,1}$				$e_{i:k,n}$
9:t					
Environmental					
12:1					
12:2					
18:1	$e_{18:1,1}$				
:					
18:m					

$e_{i:k,z}$ = performance measure for <u>zth</u> alternative regarding measure k in objective category <u>i.</u>

Table 4 Special User Evaluation Matrix

	Performance Measures				
Criteria	Alternative				
Subsystem/Categore: Measure	1	2			n
Passenger Processing					
1:1	$e_{1:1,1}$				$e_{1:1,n}$
1:2					
i:1					
i:k	$e_{i:k,1}$				
10:z					
Environmental					
12:1					
12:2					
18:1					
:					
18:m	$e_{18:m,1}$				$e_{18:m,n}$

$e_{i:k,z}$ = performance measure of zth alternative regarding measure k in objective category $\overline{i}$.

Table 5 Operator Evaluation Matrix

	Performance Measures				
Criteria	Alternative				
Subsystem/Criteria: Measures	1	2			n
Passenger Processing					
8 11	$e_{8,1}$	$e_{8,1}$			$e_{8,1}$
Economy					
19 20 21 22 23	$e_{19,1}$				$e_{23,n}$
Design					
24 25	$e_{24,1}$				

$e_{i,z}$ = performance measure of <u>zth</u> alternative relative to objective/criterion i.

rule-evaluation methods: benefit-cost analysis and the ranking and rating procedure.

The benefit-cost procedure lists all of the benefits and costs from each alternative plan, places them on a common metric scale (usually dollars), totals the values in each list, and then measures the (economic) efficiency of the plan. The most favorable alternative becomes that which gives the highest ratio of benefits to cost. Generally, this method is used in an incremental fashion where plans are considered in the order of increasing cost beginning with the existing situation or the lowest cost alternative.

Bacause the benefit cost method works only with costable impacts, subjective criteria must be omitted from the evaluation unless they are costed. Since it is difficult to specify many of the important considerations of an interchange facility analysis in monetary units, it appears that the benefit-cost procedure is not suitable for the evaluation of transit station designs.

D. Ranking and Rating Methods

In sharp contrast with the inherently narrow benefit-cost approach, subjective plan ranking and rating procedures have been developed to account for the intangible consequences of alternatives. After the criteria are identified, alternative facilities are rated to the extent to which they contribute to the attainment of the stated objectives. For elements wherein objective measurements are feasible, they are used to establish ratings. Otherwise, a subjective grade is used as an index to the extent to which a standard is met (e.g., a score on a 10 point scale). Since the ultimate measure generated by this procedure is a "total score" or "worth" for each facility being evaluated, all ratings must ultimately be measured in similar units. Thus, the objective measures must be mapped onto a numerical scale which is consistent with the subjective evaluations. A common strategy is to develop utility measures for each criteria.

Next, weights for the different criteria which rank their relative importance are established. A method which uses only a single set of weights is unrealistic because different groups have different values and objectives and, if they really understand the issues, they will never reach agreement on a single set of weights unless they have already reached agreement on a course of action.[6] In the final step, the ratings are multiplied by the weights and summed to provide a "total score" or "worth" for each alternative.

E. Shortcomings of Ranking and Rating Approaches

The benefit-cost measure of economic efficiency can be included as one of the critieria which are considered in the ranking and rating model, thus showing the relative sophistication of the latter method. Theoretically the ranking and rating strategy meets the requirements for the desired multi-objective evaluation of the transit interchange. However, the subjective judgements required in rating, ranking, and weighting the criteria create a major problem. Typically, psychometric procedures can be used, but they require resources that are usually beyond the capability of the typical transportation planning agency and consume a considerable amount of time. Furthermore, no matter how much caution is exercised in applying the method, the validity of the ultimate weights and scores can always be questioned due to the many assumptions needed to quantify the unquantifiable. When the multifaceted decision is viewed relative to a single index, the sensitivity of the various measures is lost in the aggregation process.

F. Application of Ranking and Rating to Station Evaluation

The ranking and rating strategy can be applied to the basic facility evaluation model which was stated earlier. It is shown below that the ranking and rating model only extends the basic model by providing a decision rule when the earlier development remains the same. The additional requirements include the development of weights for each criteria by interest groups, and establishing a common metric for all performance measures, i.e., a utility index. The ultimate ranking and rating model is described by the following equations which establish a "score" for each alternative.

$$U_i^k = \sum_j^z w_j^k U_{ij}^k \qquad (1)$$

where

U_k^k = Utility score of ith alternative for interest group k(k = 1, 2 or 3)

w_j^k = weight assigned to criteria j by interest group k,

U_{ij}^k = Utility score for criteria j, alternative i, by group k.

Now if the criteria are combined and weighted according to a few important categories, a more manageable model will result that includes less measures, each of which incorporates any possible number of the original performance considerations.

$W_l^k = \sum w_j^k$ For all j in category l, l = 1, lll, m.

$V_{il}^k = \sum_j U_{ij}^k$

k = 1, 2 or 3
i = alternative number
m = reduced number of criteria categories

Then

$$U_i^k = \sum_1^m W_l^k V_{il}^k \qquad (2)$$

For the 3 interest groups defined in this study, the ranking and rating operation on the basic model will provide the decision matrix shown as Table 6. The information provided in Figure 6 must be further summarized among interest groups to render an objective choice. Weights which indicate the relative influence of each interest group must be defined.

Let Y_k = relative impact of group k and $\sum_1^3 Y_k = 1$

then

$$Z_i = \sum_k^3 Y_k U_i^k \quad \text{all } i \qquad (3)$$

Table 6 Summary of Group Evaluations

Group \ Alternative	1	2	3		n
1	U_1^1	U_2^1	U_3^1		U_n^1
2	U_1^2	U_2^2	U_3^2		U_n^2
3	U_1^3	U_2^3	U_3^3		U_n^3

The choice as best design is that design i for which Z_i as computed by Equation 3 is highest as compared with the same index for the other plans with which it has been compared.

G. Summary

At this stage in the investigation of a transit interface facility evaluation model, the state of the art can be advanced with the implementation of a basic model for tradeoff analysis as described by Tables 3, 4, and 5. This framework meets all of the objectives for comprehensive evaluation and can later be adapted to apply the ranking and rating decision model if the situation warrants this. Accordingly, a specific terminal evaluation model has evolved which includes the following steps:

1. Diagnosis of interest groups,
2. Objective determination,
3. Determination of impact-interest interactions,
4. Performance criteria determination (for each objective),
5. Specification of measures for performance criteria,
6. Establishment of tolerable impact levels for each criteria relative to each interest,
7. Specification of a feasible set of alternative designs,
8. Preparation of interest evaluation matrices,
9. Description of the decision making rule (tradeoffs and dominance analysis).

V. THE TERMINAL FACILITY EVALUATION MODEL

A. The Model

This section focuses on the development of explicit interest-evaluation matrices according to the format outlined by Tables 3, 4, and 5. Table 7 is a terminal user evaluation matrix derived from Table 1 and Tables 8 and 9 are similar evaluation frameworks for the special user and the operator.

B. Estimation of Performance Measures

The criteria listed in Tables 7, 8, and 9 can be used to compare alternative transit station designs. Table 1 and the Appendix provide alternative measures and definitions for these criteria. Also, Hoel and Roszner(4) have documented the important practices regarding design principles and standards for transit stations. Sufficient information is therefore available in summary form for the planner and/or decision-maker to educate himself or herself to the meaning, scope and explicit nature of each of the operational criteria. They can then select those measures which are most appropriate to the transportation objectives, study them in depth, and obtain related information for the alternatives under consideration.

The information requirements for the station design and plan evaluation depend primarily on the objectives (criteria) that are associated with a particular design problem. The criteria used in Tables 7, 8, and 9 use either objective measures on some metric scale (i.e., time, temperature, noise) with clearly defined standards, objectives measures relative to some subjective standard (passenger occupancy space, orientation aids, concessions), or subjective judgements related to some subjective standard (safety, security; pleasantness). In most cases, the nature of the criteria will establish the manner in which design sensitive measures can be obtained. While the state of the art of knowledge of the terminal design and plan criteria and standards permits analytical measures for many considerations, a certain set of measures can only be obtained via inspection of the terminal design and plan. Where analytical measures apply to a

Table 7 Terminal User Evaluation Matrix

Criteria	Impact Measures				
	Alternative				
	1	2			n
1. Total walk time					
2. Total time in system					
3. Route Travel Times					
4. Area per person					
5. Total delay time					
6. Number in queue					
7. Crossing flows					
8. Connectivity					
9. Orientation aids					
10. Safety features					
11. Design hazards					
12. Back up facilities					
13. Inspection procedures					
14. Number of levels					
15. Mechanical level change aids					
16. Odor concentration					
17. Suspended aerosols and particulates					
18. Inflow air rate					
19. Air contaminants					
20. Air discharges					
21. Air velocity					
22. Pressure changes					
23. Thermal comfort					
24. Noise					
25. Lighting					
26. Personal comfort facilities					
27. Cleanliness					
28. Pleasantness					
29. Advertising					
30. Concessions					
31. Weather exposure					
32. Security					

Table 8 Terminal Special User Evaluation Matrix

Criteria	Impact Measures				
	Alternative				
	1	2			n
1. Total walk time					
2. Total time in system					
3. Route travel times					
4. Area per person					
5. Total delay time					
6. Queue length					
7. Crossing flows					
8. Connectivity					
9. Orientation aids					
10. Safety features					
11. Design hazards					
12. Back up facilities					
13. Inspection procedures					
14. Number of levels					
15. Mechanical and ramp level change aids					
16. Fare collection-entry barriers					
17. Physical barrier to certain travelers					
18. Odor concentration					
19. Suspended aerosols and particulates					
20. Inflow air rate					
21. Air contaminants					
22. Air discharges					
23. Air velocity					
24. Pressure changes					
25. Thermal comfort					
26. Noise					
27. Lighting					
28. Personal comfort facilities					
29. Cleanliness					
30. Pleasantness					
31. Advertising					
32. Concessions					
33. Weather exposure					
34. Security					

Table 9. Terminal Operator Evaluation Matrix

Criteria	Impact Measures				
	Alternative				
	1	2			n
1. Fare Collection and Entry Control					
2. Station Size					
3. Security					
4. Maintenance and Repair					
5. Cleaning Requirements					
6. Funds Available					
7. Funds Required					
8. Income (Non-transport Activity)					
9. Incremental Return (relative to low cost alternative)					
10. Energy Requirements					
11. Joint Development Provisions					
12. Expansion Potential					

given criterion, alternate techniques are available for estimating the magnitude for a particular station design. Currently available analytical techniques which are concerned with station functions rather than the environmental issues operate at 3 levels[4]:

1. Characterization of system components in deterministic contexts; e.g., capacity,
2. The modeling of the component system characteristics in probabilistic contexts; e.g., walking speed, service time, path choice, and
3. Systems analysis, i.e., simulation models.

Therefore a terminal design characterization is limited by the degree of modeling and analytical capability available for the criteria. Most research into terminal planning models has concentrated on passenger flow analysis and a majority of the measures associated with passenger processing criteria can be obtained from the UMTA Station Simulation program (USS), which is the most advanced model of its type developed to date. This model is currently in the testing stage for application and user documentation is being prepared. The program is available with the Urban Transportation Planning System package (UTPS) and the model provides the output shown in Table 10.

Many of the environmental measures can be characterized deterministically from the design specifications for the facility. Air control, acoustics, lighting, temperature, etc. can be included here. Other measures can be judged from the prevailing policy that is established to meet the transportation system objectives. For example, safety and security controls will be established by the funds allocated and program established toward their benefit. The impacts of other features of the design such as orientation aids, barriers to travel and entry control must be judged by inspection of the design/plan. Sources of measurement for the set of relevant criteria that have been defined are summarized in Table 11. The listed sources of measurement range from objective measures and costs to subjective plan inspection and policy review to indicate that research is needed regarding a more efficient and objective criteria measurement and assessment methodology.

Table 10 UMTA Station Simulation Model (USS) Output

1. Link Statistics in Numeric Order
2. Link Statistics in Ascending Order by Occupancy
3. Node Statistics in Numeric Order
4. Node Statistics in Descending Order by Usage
5. Total Walk Time for Station
6. Total Time in Queue for Station
7. Total Time in System for Station
8. Overall Station Impedance by Access/Egress Mode
9. Link Occupancy Report
10. Number of Arrivals at Link
11. Number of Departures from Link
12. Number in Movement on Link
13. People from Other Links that Compete on Link
14. Total People in the Area Associated with Link
15. Number in Queue at Node
16. Required Queue Area for Node
17. People Outside Queue Area at Node
18. Walk Time from Node (A) Through Node (B)
19. Time in Queue from Node (A) Through Node (B)
20. Total Time from Node (A) Through Node (B)
21. Individual Path Analysis

Table 11 Criteria Measurement

	CRITERIA	SOURCE OF MEASUREMENT
1.	Total Walk Time	UMTA Station Simulation Model (USS)
2.	Total Time in System	USS
3.	Route Travel Times	USS
4.	Area Per Person	USS
5.	Total Delay	USS
6.	Queue Length	USS
7.	Flow Conflicts	USS, Plan Analysis
8.	Connectivity	USS, Plan Analysis, Network Analysis
9.	Orientation Aids	Inspection
10.	Safety Features	Inspection
11.	Design Hazards	Inspection
12.	Back-up Facilities	Inspection
13.	Inspection Procedures	Policy (Terminal Management)
14.	Number on Levels	Inspection of Plan & Design
15.	Mechanical and Ramp Level Change Aids	Inspection of Plan & Design
16.	Fare Collection-Entry Barrier	Inspection of Plan & Design
17.	Physical Barrier to Special Users	Inspection of Plan & Design
18.	Entry Control	Inspection of Plan & Design
19.	Station Size	Estimated Demand
20.	Odor concentration	Design Specifications
21.	Suspended Aerosols and Particulates	Design Specifications
22.	Inflow Air Rate	Design Specifications
23.	Air Discharges	Design Specifications
24.	Air Velocity	Design Specifications
25.	Pressure Changes	Design Specifications
26.	Thermal Comfort	Design Specifications
27.	Noise	Design Specifications
28.	Lighting	Design Specifications
29.	Personal Comfort Facilities	Policy
30.	Cleanliness	Design Standards, Terminal Management
31.	Pleasantness	Amenities provided, i.e., music, art, etc.
32.	Advertising	Policy
33.	Concessions	Policy
34.	Weather Exposure	Inspection
35.	Security	Policy and Plan Analysis
36.	Maintenance & Repair	Design Experience
37.	Cleaning Requirements	Design Experience
38.	Funds Available (Budget) vs Funds Required	Program, Ownership
39.	Income (Non-transport Activity)	Policy
40.	Incremental Return (Relative to Low Cost Alternative)	Cost Analysis
41.	Energy Requirements	Design Standards
42.	Joint Development Provisions	Policy Option
43.	Expansion Potential	Policy Option

The preceeding development relates to procedure and method for evaluating mutually exclusive terminal designs. The evaluation framework can also be interpreted to assist in generating an acceptable facility design.

C. Design Sensitivity Analysis

The application of the model summarized by Tables 7, 8, and 9 and 11 to generate an acceptable terminal design is now considered. This is envisioned to be an iterative process whereby a basic design is created and evaluated relative to established criteria and then incrementally modified until all of the objectives are satisfactorily met. This strategy is referred to as the "sufficient design" approach because it guarantees that all criteria are met wherever feasible. This integration of the design and evaluation processes is warranted since the selection of an alternative design from a mutually exclusive set does not necessarily guarantee a satisfactory design. It should be recognized, however, that a sufficient design approach or algorithm can be used to improve upon the best of a set of designs.

This design strategy requires that a set of algorithms, models, etc. be available so that the effects of slight changes in a design can be noted with minimum effort on the part of the analyst. This methodology requires a detailed specification of the terminal design and plan and the establishment of relationships among the various criteria. When the above is accomplished, the analyst will be able to methodologically alter his plan relative to the design factors, which are reflected in the criteria in Table 11, until the facility objectives are met.

D. Conclusions and Recommendations

This investigation of evaluation criteria and procedure for urban transit station facilities has resulted in a comprehensive set of criteria for assessing the performance of alternative design configurations. These criteria are measurable to various degrees of certainty and objectivity, but always measurable. Due to the differences in the nature and units of the criterion measures a structured decision rule for comparing alternatives has been determined to be infeasible for practical applications. An interest-impact matrix model was designed and recommended for transit station evaluations. It was shown that the recommended approach closely resembled the effectiveness analysis technique in structure. It was also shown that the suggested model can be extended to include the ranking and rating decision rule.

The results of this investigation provide a framework for the development of a design and evaluation methodology for urban transportation interface facilities. The generality of the evaluation framework guarantees the potential for application to numerous terminal design problems. The desired methodology can address such problems as the comparison of alternative architectural approaches toward a given facility and/or the refinement of a basic design to satisfy all the objectives. In addition, this methodology will be designed to also evaluate alternative design, planning and policy options. Typical issues of this type include:

1. Single level vs. multilevel facilities
2. Benefits of modular construction
3. Impact of alternative energy sources
4. Major system arrangement ideas
5. Policy toward concessions

Only after the testing of the framework in an actual design situation or, preferably, on a recently constructed facility, can a concise and operational set of criteria be validated.

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APPENDIX

CRITERIA MEASUREMENTS AND DESIGN SPECIFICATIONS

A number of criteria that have been suggested in this report have been investigated in-depth elsewhere. This appendix provides a summary description of a number of selected measures in the passenger processing and environmental categories whose quantification is not readily apparent. The criteria appear under their corresponding objective from Table 1 and those criteria with which most planners are familiar are included for clarity in crossreferencing Table 1.

Objective 1: Minimize Travel Impedances

Criteria: Total walk-time.
Total time in system.
Individual path analysis (origin-destination times).

Objective 2: Minimize Crowding on Links

The following level of service definitions have been recommended for pedestrian systems (1):

Descriptions for Walkways

Level of Service	Occupancy and Flow	Qualitative Description
A	Occupancy = 35 ft^2/person or more Flow = 7 PFM* or less	Sufficient area is provided for pedestrians to freely select their own walking speed, to bypass slower pedestrians, and to avoid crossing conflicts with others.
B	Occupancy = 25-35 ft^2/person Flow = 7-10 PFM	Sufficient space is provided to select normal walking speed, and to bypass other pedestrians in primarily one-directional flows. If reverse-direction or crossing movements exist, minor conflicts will occur, slightly lowering mean speeds and potential volumes.
C	Occupancy = 15-25 ft^2/person Flow = 10-15 PFM	Freedom to select individual walking speed and to freely pass others is restricted. If cross movements and reverse flows exist, there will be a high probability

*PFM = Pedestrians per foot width of walkway, per minute.

Level of Service	Occupancy and Flow	Qualitative Description
		of conflict and frequent adjustment of speed and direction would be required to avoid contact. There is reasonably fluid flow.
D	Occupancy = 10-15 ft^2/person Flow = 15-20 PFM	The majority of persons would have their normal walking speeds restricted and reduced. There would be difficulty in bypassing slower-moving pedestrians and avoiding conflicts. Pedestrians involved in reverse-flow and crossing movements would be severely restricted and multiple conflicts would occur. There is some probability of intermittently reaching critical density, causing momentary stoppage of flow.
E	Occupancy = 5-10 ft^2/ person Flow = 20-25 PFM	Virtually all have their normal walking speeds restricted. At the lower end of this range forward progress would only be made by shuffling. Insufficient area would be available to bypass slower-moving pedestrians. Extreme difficulty would develop for those attempting reverse-flow and cross-flow movements. The design volume approaches the capacity of the walkway and frequent stoppages and interruptions of flow would result.
F	Occupancy = 5 ft^2/person or less Flow = Variable up to 25 PFM	All individual walking speeds are restricted and forward progress is only made by shuffling. There is frequent, unavoidable contact with others. Reverse or crossing movements are impossible. Flow is sporadic.

Descriptions for Queueing[1]

Level of Service	Occupancy (ft^2/person)	Qualitative Description
A	13 or more (average inter-person spacing is 4 ft. or more)	Free Circulation Zone-space is provided for standing and free circulation through queueing area without disturbing others.
B	10-13 (average inter-person spacing is 3 1/2 - 4 ft.)	Restricted Circulation Zone-space is provided for standing and restricted circulation through the queueing area without disturbing others.
C*	7-10 (average inter-person spacing is 3 - 3 1/2 ft.)	Personal Comfort Zone-space is provided for standing and restricted circulation through the queueing area by disturbing others.
D**	3-7 (average inter-person spacing is 2-3 ft.)	No Touch Zone-space is provided for standing without personal contact with others, but circulation through the queueing area is severely restricted, and forward movement is only possible as a group
E***	2-3 (average inter-person spacing is 2 ft. or less)	Touch Zone-space is provided for standing but personal contact with others is unavoidable. Circulation within the queueing area is not possible.
F****	2 or less (close contact with surrounding persons)	The Body Ellipse-space if approximately equivalent to the area of the human body. Standing is possible, but close unavoidable contact with surrounding standees causes physical and psychological discomfort. No movement is possible

*Level of Service C is within the range of personal comfort body buffer zone established by psychological experiments.

**Fruin states that based on psychological experiments, this Level of Service D should not be recommended for long-term periods of waiting.

***Fruin states that Level of Service E can only be sustained for short periods of time without physical and psychological discomfort and that the only recommended application would be for elevator occupancy.

****Fruin states that in large crowds, at Level of Service F, panic is possible.

Descriptions for Stairways

Level of Service	Occupancy and Flow	Qualitative Description
A	Occupancy = 20 ft^2/person or more Flow = 5 PFM* or less	Sufficient area is provided to freely select walk speed and to bypass other slower-moving pedestrians. No serious difficulties will be experienced with reverse flows.
B	Occupancy = 15-20 ft^2/person Flow = 5-7 PFM	At stairway level-of-service B, representing a space approximately 5 treads long and 3 to 4 feet wide, virtually all persons may freely select locomotion speeds. However, in the lower range of area occupancy, some difficulties would be experienced in passing slower-moving pedestrians. Reverse flows would cause minor traffic conflicts.
C	Occupancy = 10-15 ft^2/person Flow = 7-10 PFM	At stairway level-of-service C, representing a space approximately 4 to 5 treads long and about 3 feet wide, locomotion speeds would be restricted slightly, due to an inability to pass slower-moving pedestrians. Minor reverse-traffic flows would encounter some difficulties.
D	Occupancy = 7-10 ft^2/person Flow = 10-13 PFM	At stairway level-of-service D, representing a space approximately 3 to 4 treads long and 2 to 3 feet wide, locomotion speeds are restricted for the majority of persons, due to the limited open tread space and an inability to bypass slower-moving pedestrians. Reverse flows would encounter significant difficulties and traffic conflicts.
E	Occupancy = 4-7 ft^2/person Flow 13-17 PFM	At stairway level-of-service E, representing a space approximately 2 to 4 tread lengths long and 2 feet wide, the minimum possible area for locomotion on stairs, virtually all persons would have their normal locomotion speeds reduced, because of the minimum tread length space and inability to bypass others. Intermittent stoppages are

*PFM = Pedestrians per foot width of stairway, per minute.

Level of Service	Occupancy and Flow	Qualitative Description
		likely to occur, as the critical pedestrian density is exceeded. Reverse-traffic flows would experience serious conflicts. This level-of-service would only occur naturally with a bulk arrival traffic pattern that immediately exceeds available capacity.
F	Occupancy = 4 ft^2/person Flow = Variable, up to 17 PFM	At stairway level-of-service F, representing a space approximately 1 to 2 tread lengths long and 2 feet wide, there is a complete breakdown in traffic flow, with many stoppages. Forward progress would depend on movement of those in front.

Objective 3: Minimize Queues

Criteria: Total delay time in queue
Number in queue at node
Time in queue while traveling from Node (a) through Node (b)

Objective 4: Minimize Conflicts

Criteria: Measures of crossing flows

Objective 5: Minimize Disorientation

Criteria: Connectivity from Node-Link network (directness of path). This can be derived from network connectivity analysis. Availability of directional information.

Objective 6: Maximize Safety

Criteria: Safety features on mechanical facilities. Elimination of design hazards.

Objective 7: Maximize Reliability of System Components

Criteria: Back-up facilities in case of breakdown.
Inspection and maintenance procedures.
Alternatives available.

Objective 8: Provide for Efficient Fare Collection and Entry Control

Criteria: Attraction to robbery or vandalism.
Means to prevent non-payees from entering.
Inconvenience or disutility to user due to method

Objective 9: Minimize Level Changes

Criteria: Number of levels
Mechanical aids available

Objective 10: Eliminate Physical Barriers

Criteria: Difficulty in navigating fare collection-entrance control area.

Certain provisions have been suggested specifically to aid the handicapped (2). They apply to both fare transaction and entry gates.

(a) No person who is unable to do so in reasonable comfort or with minimal inconvenience to himself and other passengers should be required to pass through a channel narrower than 32 inches, from outside the transit station until he is in the transit vehicle. At least one fare collection system meeting this standard should be provided at each set of entry gates within every major pathway.

(b) Passengers who need such clearance to operate (or cause to operate) an alternative means of admission to the paid area of the station should have a system provided which would enable them to do so. Special entrance devices such as gates, extra-width turnstiles, or limited-use doorways should be under the direct or remote visual supervision of an attendant, but should preferably not require any special action by him to admit most elderly or disabled passengers.

(c) Difficulties encountered in exiting the system should not be greater than those encountered in entering.

(d) If gates are required, a disabled person should be capable to activate or manually operate this gate by himself.

Criteria: Capability of Users

Certain design standards have been suggested to aid the handicapped and the elderly.[2] These include the provision of:

A. General

(1) Ramps (in place of stairs or steps)
(2) Elevators
(3) Special entrance and exit on board transit vehicle or provided on ramp to decrease level change (powered or non-powered)
(4) Contrasting color for level change
(5) Contrasting floor texture for level change
(6) Contrasting lighting for level change

B. Boarding and Disembarking Vehicles

(1) Maximum Vertical Change = 2"
  (a) at least one ent./exit on each side of vehicle must meet this requirement.
  (b) max. time for this provision to be put into function- 10 seconds.
(2) At boarding, max. length of ramp with upward slope = 30'.
(3) Discontinuity of level between platform floor and vehicle interior floor greater than 1" should be clearly marked by contrasting color, changes in floor texture, and/or lighting.
(4) Passenger should be able to reach platform from which he can board without propelling himself up or down a verticle level change of 2 ft.
(5) Facilities should be provided which allow passenger to enter or exit without self-propelled level changes so as to minimize departure time from the entry or exit pathway used by most passengers. A person using such a pathway should not be required to travel more than 50% further than the distance travelled by other passengers. Special facilities should be placed or designed so as not to interfere with the use of other powered or non-powered means of level change by persons who do not require special mobility services. Exception: special level change devices might cause some minimum delay for other pax. using a given entry or exit pathway, provided the delay is limited to the actual time of boarding, use, and disembarking.

(6) No passenger entering the system should be required to use a moving stairway in order to reach a boarding platform, nor any other device which requires the passenger to board or debark from a surface, seat or platform while it is in motion.

<u>Objective 11: Provide Sufficient Space</u>

Criteria: Square feet available

<u>Objective 12: Provide a Comfortable Ambient Environment</u>

Criteria: Odors and odorants
It has been suggested that the concentration of odors and odorants should not reach levels which are unpleasant, annoying, irritating or otherwise unacceptable to any considerable number of persons or to the public.[3]

Criteria: Suspended Aerosols and Particulates

It has been suggested that the concentration of suspended aerosols and particulates should not produce a coefficient of extinction for transmitted light (the proportion loss of light for each meter a beam of light travels) greater than 0.0006 per meter (six ten-thousandths per meter).[3]

Criteria: Inflow of Air

It has been advised that the minimum effective inflow of air from above the surface (of a subway terminal) into the stations and tunnels should be 7.5 CFM per person. Such inflow need not be by any direct pathway, but may be accomplished by diffusion and mixing in the system air mass. Much greater inflows than this minimum often will be necessary to meet other criteria.[3]

Criteria: Air Contaminants

It has been suggested that air contaminants not exceed the "threshold limit values" for industrial exposure set by the Committee on Threshold Limits of the American Conference of Governmental Industrial Hygienists (ACGIH).[3]

Criteria: Discharges from Equipment Rooms and Control Centers

It has been advised that all discharges from equipment rooms and control centers (of subway terminals) should be to points above the surface.[3]

Criteria: Air Velocity

It has been suggested that air velocities should have maximums dependent upon location and conditions, of:

Public Areas
Air velocities in the public areas of the subway system should not exceed 1,000 FPM.

Sidewalk Gratings
Air velocities through sidewalk gratings should not exceed 500 FPM.

Emergency Conditions
During emergency conditions, air velocities in any emergency egress passage way of the subway system should not exceed 2,200 FPM.[3]

Criteria: Rapid Pressure Change

It has been advised that whenever the total local air pressure within the subway system, including the vehicle interiors, changes more than 0.10 PSI, neither patrons nor employees shall be exposed to an air pressure change rate which exceeds 0.06 PSI per second.(3)

Criteria: Thermal Comfort

The "Relative Comfort Index is explained thoroughly in Reference 3. It is a function of:

--Metabolic Rate, M(kcal/hr./sq. m.)
--Clothing, I_{cw}
--Relative Air Velocity, V_{a+d} (fpm)
--Air Temp., t_a (°F)
--Relative Humidity, RH (%)
--Radiant Heat, H (kcal./hr./sq. m.)

Criteria: Noise and Vibration

The criteria for noise is explained thoroughly in Reference 4.

Objective 13: Ensure Adequate Lighting

Criteria: Illumination Levels, Foot-candles (fc)

The criteria for illumination is explained thoroughly in Reference 4. The recommended levels are:

Passenger Stations	Recommended Minimum Maintained Illumination Levels (fc)
Platform, subway	20
Platform, under canopy, surface and aerial	15
Uncovered platform ends, surface	5
Mezzanine	20
Ticketing area - turnstiles	30
Passages	20
Stairs and escalators	25
Fare collection kiosk	100
Concessions and vending machine areas	30
Elevator (interior)	20
Above ground entry to subway (day)	30
(night)	10
Washrooms	30
Service and utility rooms	15
Electrical, mechanical and train control equipment rooms	20
Storage areas	5

Surface Passenger Loading Areas	Recommended Minimum Maintained Illumination Levels (fc)
Bus loading platforms	5
Streetcar loading platforms	5
Bus and streetcar loops	2
Kiss and ride areas	5

Objective 14: Provide for Personal Comfort

Criteria: Rest Rooms
Rest Areas

Objective 15: Provide a Clean and Pleasant Environment

Criteria: Station finish materials:
general, floors, walls, ceilings, doors, and miscellaneous metals

The following guidelines have been suggested for station finish materials.(4)

General--

During the selection of station finish materials, it is important that a cleaning program be considered and possibly developed as the materials are being selected. The cleaning and maintenance program is directly related to the selection of finish materials and has a considerable effect on the total cost of the operating transit system. Maintenance problems are usually simplified through the use of as few different materials as possible.

Floors

Floors in heavy wear areas should have a wear surface separate from the structural slabs to facilitate replacement.

Floors should have a dense, low absorption and soil resistant surface that provides good traction for pedestrians.

Non-slip materials at platform edges and on stair nosings should be used to improve safety.

Floor drains should be installed adjacent to outside walls in below grade structures to prevent seepage water from spilling over large floor areas, causing a slipping hazard.

Walls

Walls should be of a dense dirt resistant, polished, enamelled or glazed surface to reduce cleaning and maintenance costs.

Exterior walls in below grade structures should have a cavity between the structural wall and finish wall to avoid moisture damage to the station finish in the event of ground-water infiltration. Drainage holes should be provided at the bottom of the cavity.

Walls should be started on a floor base to facilitate floor cleaning.

Ceilings

Ceilings must be designed to be resistant to damage or soiling and be easily cleaned. Where suspended ceilings are used of the tile or pan type construction, the minimum floor to ceiling height should be 9' - 0" to discourage damage by vandals. This type of construction must also include a suspension system sufficiently rigid to resist air flows and pressures resulting from train operations within the rapid transit tunnels. Ceilings offer an effective means of controlling noise levels within the subway station areas, and the designer should therefore give serious consideration to the use of ceiling materials designed for the attenuation of sound.

Doors

Doors should be faced with plastic or other damage resistant material to reduce maintenance costs.

Miscellaneous Metals

Handrails and metal trim should be of stainless steel, anodized aluminum, or other low maintenance material.

Criteria: Provision for art displays, graphics, and visual features.

Objective 16: Provide Supplementary Services

Criteria: Advertising
Concessions
Floor space allocated
% of total floor space

Reference 5 provides an in-depth study of advertising and concession policy considerations for the Washington metropolitan Area Transit Authority. The following items represent a summary of the major recommendations of that study.(5)

ADVERTISING RECOMMENDATIONS

1. Adopt a policy in favor of limited and controlled advertising.

2. A minimum number of locations should be made available for the advertising program.

3. The operator should handle the entire advertising program with in-house personnel.

4. The program should be under the control and administration of an Advertising Manager.

5. Guidelines for control and administration of the program should be written and formulated immediately.

6. Advertising, wherever it is used, should be designed to supplement the basic architecture of the system.

7. Aesthetics should take precedence over revenue in the program.

8. Standard sized advertisements should be used in the program.

9. The program should attempt to serve the needs of both the local and national advertiser.

10. No advertising should appear on the coffered walls of any station.

11. No advertising should appear on any station platform, or in any passageway in the system, or between the tracks in any station.

12. No advertising should appear on any escalator wall, and there should be no merchandise display window in the system.

CONCESSIONS RECOMMENDATIONS

1. Adopt a policy in favor of limited and controlled concessions.

2. A minimum, rather than a maximum, number of locations should be made available for the concessions program.

3. Handle the entire concessions program with in-house talent.

4. The concessions program should be under the control and administration of a Concessions Manager.

5. Guidelines for control and administration of the program should be written and formulated early in a station plan.

6. Functional service should take precedence over revenue in the concessions program.

7. A uniform style and size of concession stand should be sought.

8. All concession stands should be located in the mezzanines of selected stations. No concession should be placed on any station platform.

9. Concession stands should be placed outside the normal flow of traffic.

10. Concession stands should be designed into the station plans wherever possible.

11. No concession stand should restrict the view of the station attendant.

12. Concessions (except telephones) should be limited to those stations with a projected annual volume of 5 million passengers, or more.

Objective 17: Provide Protection from Weather

Criteria: Terminal area exposed

Objective 18: Provide Adequate Security

It would be possible to consider security as simply a function of station design, but since the provision of security patrols and surveillance might differ from one type of station design to another, it is more proper to measure security as a function of design, surveillance, security patrols, and alarm provisions.[6]

Design Features

Criteria: Number of Levels - the greater the number of levels the greater the security risk.[6]

Criteria: Avenues of Escape - the greater the number of possible means of escape, the greater the security risk.[6]

Avenues of escape

-- train
-- bus
-- auto
-- foot

Criteria: Number of Exits - the greater the number of exits, the greater the assailants opportunity to escape.[6]

Criteria: Separate Spaces - the greater the number of separate non-intervisible spaces in a station, the greater the opportunity for an assailant to find an unobserved location. Also his prospective victim would have a decreased opportunity to obtain aid due to the distribution of station users.[6] Number of separate, non-intervisible spaces including:

--Rest Rooms
--Rest Areas, non-intervisible
--Telephones or vending machines, non-intervisible
--Concessions, non-intervisible
--Any area of low illumination
--Parking Lot

Criteria: Accessibility to station agent's booth and major user paths: Distance of discrete areas (such as vending machine area or telephone area) from station agent's booth or major user paths.(6)

Criteria: Paid Area

The paid area is generally more restricted, controlled and active and therefore would be considered more secure.(6)

Criteria: Surveillance and Security Patrols

Number of areas not subject to frequent security patrol or constant surveillance, inclusive of parking lots.

Criteria: Alarm Provisions

Number of areas away from major user paths, not subject to constant surveillance from kiosk or remote camera, not serviced by emergency phones, inclusive of parking lot.

Objective 19: Minimize Maintenance, Cleaning and Replacement Needs

Criteria: Maintenance
Cleaning-surfaces
Cleaning-concessions

The sale of gum, candy, food, and coffee has caused severe cleaning problems at some stations.(7)

APPENDIX REFERENCES

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