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Methodology for the Design of Urban Transportation Interface Facilities

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16. Abstract

Procedures and techniques are described which determine measures of the performance of transit station designs. Categories of measures are defined according to the manner by which they are treated in the design process; as a result of policy, or as measures of performance and economic efficiency. Policy items considered include concessions, advertising, personal care facilities, telephones, acoustics, construction materials, design flexibility, parking facilities, and provisions for the handicapped. Performance measures are associated with passenger processing, passenger orientation, the physical environment safety, and security. The policy and performance considerations along with cost factors are used to specify a systematic transit interchange facility design methodology that is recommended to practicioners.

Comprehensive descriptions of appropriate analytical techniques for the evaluation of transit station designs are provided in the appendices to the report.

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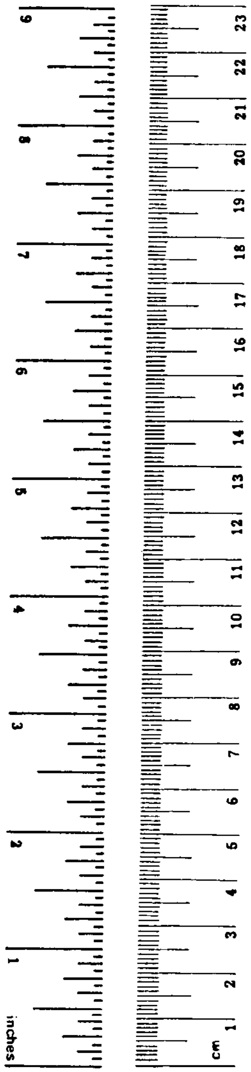
METRIC CONVERSION FACTORS

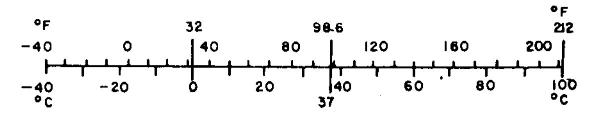
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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 system-analytic approaches. The overall purpose of this research is to investigate a formalized and comprehensive approach for transit station design.

Criteria for evaluating alternative transportation interface facility designs have been identified.* Performance measures were subsequently established for these station design criteria and their utilization within a cost-effectiveness decision framework was shown. In order to use the evaluation framework that has been provided, the transportation analyst must be able to derive explicit values of the performance parameters from the alternative designs. Accordingly, the methodological framework and associated techniques for designing and evaluating alternative transit station facilities are investigated. Specifically, methods for establishing policy for station design and for measuring the performance of functional elements of transit terminals are described.

B. Problem Studied

For the purposes of this study it is assumed that the site for the transit station has been selected during the system development stage. Accordingly, adjacent land use measures, demand estimates, and technological and modal supply information are at hand. The study then addresses the development of a generalized transit interface facility design and evaluation methodology. The methodology uses supply, demand and policy

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*Hoel, L. A., Demetsky, M. J., and Virkler, M. R., Criteria for Evaluating Alternative Transit Station Designs, March 1976.

requirements to design and measure the performance and cost of alternative terminal facilities. The focus is on the development of a set of tools, procedures and guidelines which can be used to establish policy and standards regarding station design, provide performance measures for the appropriate subsystems, and give estimates for the stated cost components. Information and methodology are collected to show a general step-by-step set of procedures for designing new transit stations as well as renovating existing passenger interface facilities.

C. Results Achieved

The important factors and elements that are associated with a transit station design which enter into the terminal analysis process as a result of policy are first identified. These policy related components include concessions, aesthetics, construction materials, design flexibility, parking facilities, and provisions for the handicapped. Guidelines and directions are provided to assist the planner in identifying the important issues which must be considered prior to establishing policy regarding these station features.

Concerning concessions, the policy analysis must determine whether they will enhance the acceptance and usage of a particular transit station. The evaluation of alternative advertising policy options is quite difficult since the negative effects are not quantifiable. Decisions concerning advertising policy will rely on the experience and judgement of the policy makers. In most cases, positive decisions are justified by the projected revenue. The transit station planner should identify the requirements for personal care facilities relative to local building codes, transit planning practice, and local values. A specific policy can then be established because there is little need to look at alternative policies. A minimum number of telephones should be installed and additional units added as needed. Decisions concerning aesthetic and cultural dimensions must be based solely on their value to the total system and the available resources. Various degrees of artistic refinement relative to the associated cost should be considered prior to establishing policy. The selection of construction materials influences not only the aesthetic qualities of stations, but also the safety of patrons, and replacement and maintenance considerations.

Expansion considerations are important in areas where population growth is expected. Joint development will be most appropriate where the transit station is a focal point in an activity center. The number of parking spaces required is determined from the size and nature of the transit demand and the parking requirements for appropriate non-transport activities in the station vicinity. Methodologies are available for estimating the number of travelers who access the system by park-and-ride and kiss-and-ride. The extent of which special facilities are provided to aid the mobility of the elderly and the handicapped will be based on legal requirements and the expected usage of the facility by these special users.

The above considerations summarize the major observations that were determined for the policy variables in the transit station design. This information as presented in the report provides the planner with a basis for showing public officials those areas where policy must be established for transit terminal programs. A review of this material will ensure that each resulting policy arises from a systematic appraisal of its impact on the cost, performance, and social acceptance of the transit station.

The next major thrust of the study deals with the investigation of analytical techniques, including appropriate computer models, for analyzing the performance of important transit interchange facility functions. The specific systems addressed are passenger processing, passenger orientation, the physical environment, security, and safety.

Manual computations which measure walk time, delay time, queue lengths, flow conflicts, and the area per passenger are generally sufficient for evaluating alternative terminal sizes, arrangements, and facilities for accommodating passenger flows. Computer simulations are expensive and difficult and are only warranted in cases where a large number of relatively large and sophisticated facilities are considered. Orientation aids which assist pedestrians in choosing the proper route to their destination have a significant influence on the efficiency of the passenger processing system. Since there are no existing methods for measuring the adequacy of the passenger orientation system of a transit interface facility, an inspection based procedure is developed to assist the designer to improve the orientation aspect by increasing the level of certainty at all decision points.

The elements of the physical environment which are considered in the performance analysis are air quality, air flow rates, temperature, noise, lighting and weather exposure. Manual and computerized techniques are available for designing for air quality, air flow, and temperature. Design standards and techniques are given for noise and lighting.

Alternative variations in security system design can be evaluated in terms of cost vs. service rendered or incidence of crime. Since the impact of a particular security strategy is very difficult to assess, the benefits of, say, more police or surveillance equipment will be a value judgement on the part of the decision maker. Alternative security concepts are shown.

A typical safety study requires a knowledge of all federal and local safety laws (as well as a degree of common sense). Each significant station element must be scrutinized relative to its role and accident potential. After a series of independent reviews by the various interests, a sufficiently safe facility should result.

The final area of terminal performance that must be dealt with is the cost of the facility and its operation. Itemized costs are summed for each component of the total cost. Construction costs are obtained from architectural drawings. Annual operation and maintenance costs are assigned to the station components by extrapolating from recent operating experiences. Finally, the policy and performance analysis methods are combined with the cost considerations to derive a comprehensive transit station design strategy.

A design methodology is provided for application to new station design and evaluation and to station renovation. The procedural method which is described includes the following stages of analysis: data inventory, policy development, generation of trial station design concepts, initial evaluation of concepts, acceptance of policy and design concepts, development of detailed terminal designs, performance and cost evaluation, and design selection. The recommended methodology provides the planner with various options for arriving at a recommended design relative to the manner by which the various station components are developed.

D. Utilization of Results

The results of this research will be used by transportation planners, facility designers, and transit managers who are concerned with renovating existing facilities and future plans for transit systems. The findings can also be applied in the development of acceptable interchange facilities for new transit modes. The research advances the state-of-the-art with a methodology for designing transportation interface facilities.

E. Conclusions

This research provides a systematic and methodology for planning and designing urban transportation interface facilities. It may be applied to both the development of new stations and the renovation of existing terminals. It remains for the research team to demonstrate the application of the procedures to practical terminal design and evaluation problems. During the testing phase it is likely that certain elements in the methodology will become refined and clearer to the practitioner.

PREFACE

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 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*.

This second phase of the study is sponsored by the Department of Transportation Program for University Research, and involves the development of an interface facility design methodology. This report describes a methodology for the design of urban transportation interface facilities. An earlier report identified criteria for the evaluation of alternative transportation station designs and the investigation of an evaluation framework**.

This study examines the appropriate methodological framework and associated techniques for designing and evaluating alternative transit station facilities. Specifically, methods for establishing policy for station design and for measuring the performance of the functional elements of transit terminals are described. The integration of the work completed is contained in a standard terminal design procedure described herein. The final task of this research phase will be an applications guide for planners and designers to apply the methodology in a set of step-by-step procedures.

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*Hoel, L. A. and Roszner, E. S., The Design of Urban Transportation Interface Facilities: State-of-the-Art, December 1975.

**Hoel, L. A., Demetsky, M. J. and Virkler, M. R., Criteria for Evaluating Alternative Transit Station Designs, March 1976.

During the final stage of this research project, Phase III, the methodology will be tested and refined through applications to specific terminal design problems that are associated with the renovation of existing facilities and/or the design of new stations. The findings of this investigation will be interpreted to develop guidelines for planning and evaluating terminal facilities, and to show step-by-step examples of potential solutions to station design problems.

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APPENDICES

I. METHODOLOGY REQUIREMENTS

A. Introduction

This study develops a methodology to be used as a framework for planning, designing, and evaluating transportation modal interchange facilities. Procedures and techniques are selected to provide measures from alternative station designs for criteria that have been established in the first part of this study.(1)

Criteria are classified for the purposes of this investigation according to the manner in which they enter into the terminal analysis process; as the result of policy, or as measures of performance and economic efficiency. These categories for analysis were defined to accommodate and synthesize computer models and manual techniques that have been used or are being investigated for the evaluation of specific functions of transit interface facilities. Table I shows the grouping of typical transit station components. The criteria that were identified in the earlier report are compatible with the areas of analysis given in Table I.

In contrast with the functional subsystems that are used in Table I, a different, but actually complementary strategy for examining transit terminals identifies a set of key elements which encompass a station operation.(2) An example of this alternative approach is given in Figure I. The primary elements shown in Figure I include the following:

1. Station Entry/Exit
2. Interior Entrance/Exit Area
3. Ticketing and Fare Collection Area
4. Platform Entry/Exit Gates
5. Concourse Area
6. Vertical Movement Facilities
7. Platform Area
8. Station Guideway

This type of analysis of key station elements is structured on the identification of a series of functional areas provided in a typical terminal facility to facilitate the movement of passengers. These elements are

TABLE I Transit Station Components

Policy Items

- Concessions
- Advertising
- Personal Care Facilities
- Telephones
- Aesthetics
- Construction Materials
- Design Flexibility
- Parking Facilities
- Provisions for Handicapped

Performance Measures

- Passenger Processing
- Passenger Orientation
- Physical Environment
- Safety
- Security

Cost Analysis

- Fixed Capital Cost
- Operating Cost
- Maintenance Cost
- Policy Related Cost
- User Cost

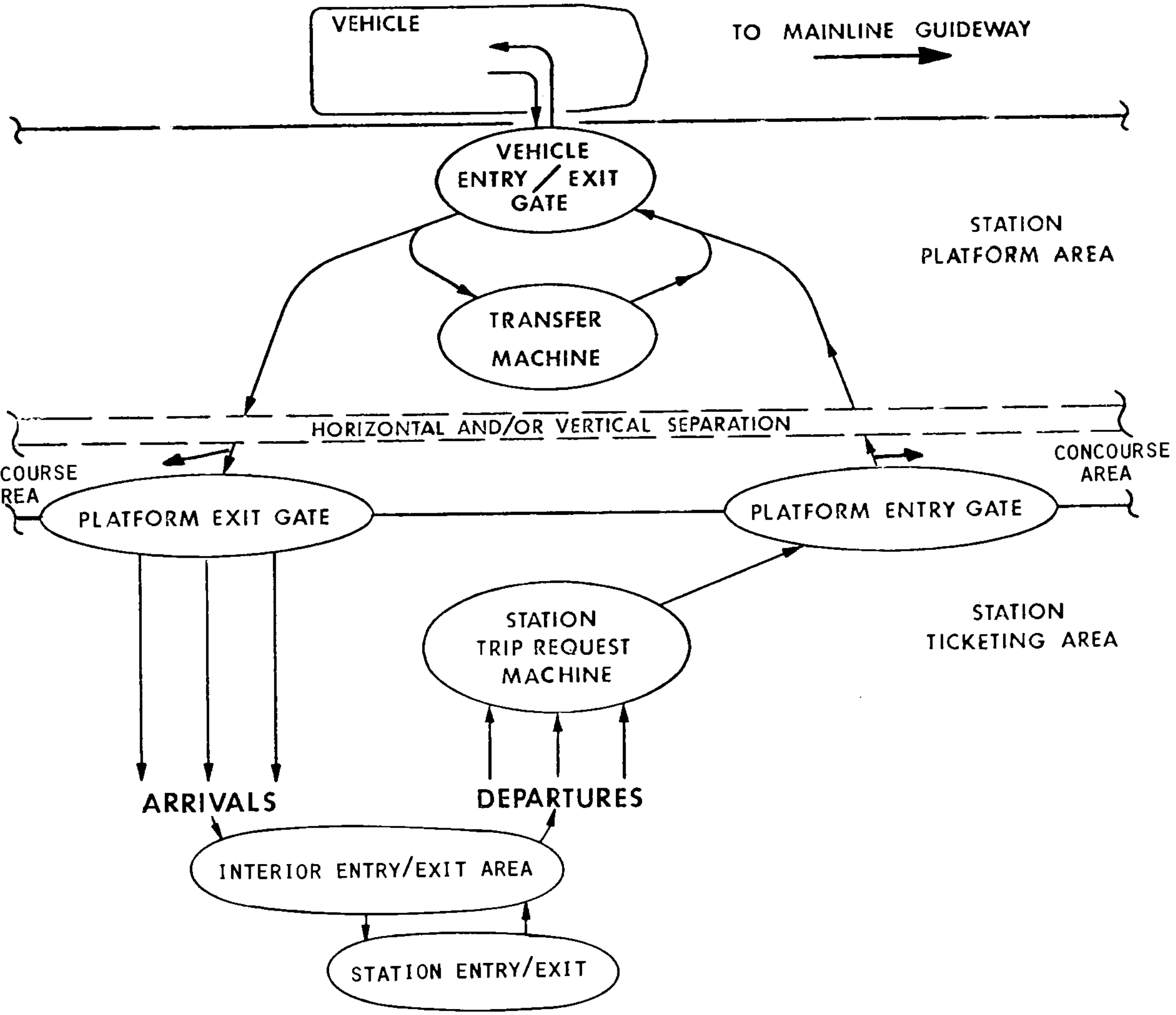


Figure 1 Key Station Elements

typically used in modeling pedestrian flows through terminals, but can be employed to establish alternative spatial configurations as well.

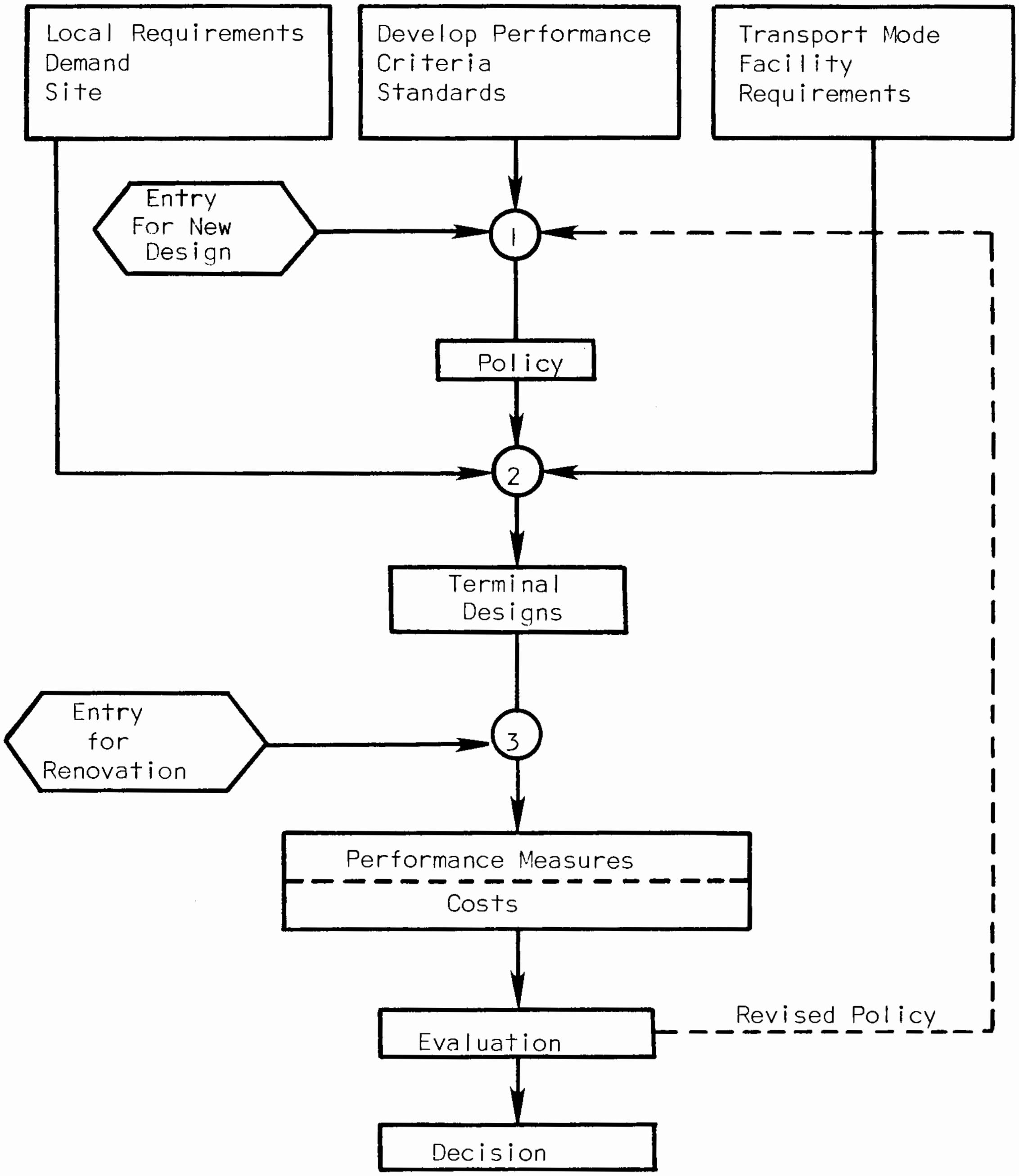
B. Scope of Research

A generalized terminal design and evaluation methodology must provide a means to estimate measures of transit station performance. A comprehensive framework for analyzing transit interface facilities is shown in Figure 2 where evaluation criteria and procedures are employed within a design methodology which uses supply, demand, and policy requirements to design and measure the performance and cost of alternative terminal facilities.

This study focuses on the development of a set of tools, procedures, and guidelines which can be used to establish policy for the items defined in Table I, provide performance measures for the appropriate subsystems, and give estimates for the stated cost components.

Specific performance criteria and standards can be established for any terminal study using the criteria given in the previous report.(1) For the purposes of the discussion it is assumed that the site for the facility has been selected in the system's development stage. Accordingly, adjacent land use measures, demand estimates, and technological and modal supply information are at hand. The methodology is then applied in an iterative fashion to first provide a feasible design and then improve upon it.

There is a tradeoff between the system plan and ultimate terminal requirements. In a hierarchial order, the major planning decisions which must be made prior to the development of specific terminal designs include route or corridor location, the evaluation of alternative terminal sites and, the ultimate selection of specific station locations. A practical planning process that has been recently developed for locating fringe parking lots for express bus transit can be applied to the general case for transit terminal locations.(3) The remainder of this report focuses on the steps in planning and designing transit terminals given a specific



○ Indicates the application of terminal analysis procedures for the following purposes:

1. Establish policy
2. Generate alternative terminal designs
3. Establish performance and cost measures for each alternative

Figure 2 Transit Terminal Analysis

location. The methodology assesses the performance of the important functions of transit station facilities by viewing the terminal as a system of the interacting functional components. Human factors and user perceptions are not explicitly included in the performance analysis because individual needs are reflected by design standards. Accordingly, the analytical techniques employed here relate the performance of terminals to established user and operator requirements.

C. Applications

The potential utility of the procedures developed herein are in application to specific terminal design problems such as the renovation of existing stations, the design of new terminals to accommodate passenger loadings and interchanges among the existing bus and/or rail rapid transit modes, and the design of terminals to accommodate new transit modes for new systems development programs. These three problems can be reduced to two primary applications of the systems' analytic methodology; i.e., the renovation of existing terminal structures, and the design of new modal interchange facilities.

Accordingly, the approach to the renovation problem initially measures the performance and cost parameters for the existing facility. These measures are then evaluated along with the current terminal management policy. Site requirements and demand measures are updated and used in conjunction with the conclusions from the terminal evaluation to recommend improvements regarding policy and the physical terminal facility. This renovation strategy enters the analysis framework shown in Figure 2 at nodal point 3.

The development of a new terminal design to meet stated design standards, modal and site requirements, and expected demand levels is more basic to Figure 2. Here, the planners enter at node I where policy is developed prior to consideration of the facility proper.

The transit station analysis techniques that are subsequently described in this report are first addressed to deal with specific parts of the transit station. Later they are synthesized within the analysis framework stated in Figure 2 to provide a systematic methodology.

II. POLICY ANALYSIS PROCEDURES

A. Introduction

The policy components defined in Table I include concessions, advertising, personal care facilities, public telephones, aesthetics, construction materials, design flexibility, parking facilities, and provisions for the handicapped. The subsequent discussions illustrate how each of these items is dealt with in order to establish initial policy concerning the transit station design.

B. Concessions

Space provided for concessions and businesses within the terminal is a policy issue which must be decided in view of local goals and objectives relative to land use and transportation. As a rule, the larger the station and the more modal interchanges taking place, the more likely will be the availability of non-transport related activities within the terminal environment. Concessions should not interfere with mode-to-mode passenger movements. The ultimate policy concerning concessions must be developed at each facility site or for each system of links and terminals. Some planners have felt that the disadvantages of having concessions far outweigh the advantages. For instance, the residues of chewing gum, candy, and coffee cups may be difficult and expensive to clean up. If improperly designed or controlled, concessions may cause problems in pedestrian flow. It is at least partly for these reasons that Washington METRO station plans do not include provisions for concessions. On the other hand, the color and vitality that can be provided by concessions might bring a special addition to the aesthetics of a station. The potential monetary advantages of renting space for concessions and the convenience provided to station users should also not be overlooked.

The BART system architectural standards call for space for vending machines and a manned concession booth in each station. The Project Architect is responsible to analyze his particular station to determine if any additional facilities are needed above those minimum space allocations. The two basic concession goals the BART system is seeking to fulfill are: (1) to provide facilities and space for concessions required for the convenience of BART system patrons, and (2) to establish vending and manned concession standards which will facilitate a system-wide concession operation.

An objective measure of the feasibility of concession activity in a transit terminal is a comparison of the cost of development including space, utilities, maintenance, and security with expected income. If warranted, additional user costs incurred from increased travel times due to larger distances caused by the concession areas can also be considered. In this context, designs exhibiting alternate concession policies can be run through the analytical process shown in Figure 2 and costs can be compared with expected revenues in each case. Table 2 shows the format of the computations required for the analysis of a typical concession policy.

The important guidelines for the planner regarding terminal concessions is that he should investigate the potential of this element to enhance the usage and acceptance of the facility. This element is closely associated with adjacent land use (i.e., whether it is located in a largely commercial or a residential area) and projected growth.

C. Advertising

Advertising is a means to bring in additional revenue to support the operation of a transit system. The apparent disadvantage is the potential unsightliness of randomly scattered and uncoordinated messages. A list of recommendations concerning advertising policy that was prepared for the Washington Metropolitan Area Transit Authority serves to identify the major issues which must be considered in establishing policy.(4) The primary guideline is that advertising should be sanctioned only if it is controlled by location, content and size. Advertising should not be placed where it detracts from the aesthetics of the station. Also advertising should not be placed close to passenger guide signs and other directional aids.

TABLE 2 Concession Evaluation

	Costs	Revenue
Space Requirements		--
Utility Requirements		--
Maintenance Requirements		--
Security Requirements		--
Projected Rent	--	
Induced Traffic	--	
	Costs	Benefits
Total		

The evaluation of alternative advertising policy options is quite difficult since the costs are not measurable and must be derived solely from judgement. For example, how do we measure the impact of advertising on aesthetics or on the effectiveness of directional aids? Some of the benefits can be directly measured, in terms of revenue, whereas others (e.g., information to visitors) are intangible in terms of revenue less monetary costs involved. Decisions concerning advertising policy will, therefore, be based primarily on the experience and position of the policy makers. In most cases, positive decisions can be justified by the projected revenue.

D. Personal Care Facilities (Restrooms, Aid Stations)

The majority of the considerations given above to concessions apply to restrooms and other personal care facilities. However, this item must be provided whereas the other category is optional. This is so because building codes often specify details of type, number, and location of toilets and aid stations that must be provided in public buildings. Transit agencies usually develop more appropriate standards which coincide with local building practice. The primary measure of this element is the space provided for such facilities and the associated costs.

The alternatives available for restrooms are wide ranging. For instance, the New York City Transit Authority's (NYCTA) policy is to have public toilets at transfer and major stations only. These are all located in the paid area of the station, have an attendant at each, and have provisions for closing the facilities at night. The BART system provides public restrooms, but entrance to them is controlled by an operator in a remote location through television surveillance. The Washington METRO system, however, has selected to provide no public restrooms in their stations. These three approaches differ in terms of cost, convenience and security provided, and reflect local concerns and constraints.
The transit station planner should identify the requirements for personal care facilities relative to local building codes, transit planning practice, and local values. A specific policy can then be established as there is little need to seriously look at alternative policies in this regard.

E. Public Telephones

Pay telephones are a significant part of American culture and are available in almost any public place, with transit terminals being no exception. As a matter of policy public telephones should, therefore, be available at selected places throughout the station. The number should be based on the passenger volumes and nature of the trips passing through the terminal. The Institute for Rapid Transit advises to install a minimum number and make provisions for additional units as experience dictates.(6) The telephones should be located so that they are visible and do not interfere with pedestrian movements.

F. Aesthetics and Cultural Environment

This design element can be employed to provide the traveler with a more pleasant and positive experience at the modal interface facility than would be the case without it. Music, art, open assembly areas, and other artistic features should be considered. The current treatment given to the stations of the Washington, D. C. Metro system attest to the fact that considerable expense can be justified to give transit stations landmark status. One conflict which must be resolved for any transit system is the worth of standardization of designs vs. the worth of tailoring individual station to the neighborhoods in which they are located. The standardization approach has, among others, the advantages of providing familiar surroundings to system users at all access points. However, through designing a station to be compatible with the character of its neighborhood in terms of scale, color, materials, and other attributes, the aesthetic quality of the station might be greatly enhanced.

The addition of artistic refinements to a transit station cannot be justified by objective measures such as a comparison of direct costs and benefits. Decisions concerning aesthetic and cultural dimensions must be based solely on their value to the total system and the available resources. Various degrees of artistic refinement relative to the associated cost should be considered prior to establishing policy.

G. Construction Materials

The selection of construction materials has ramifications not only to the aesthetic qualities of stations, but also to the safety of system patrons, the need for replacement of the materials, and the cost of station cleaning, and maintenance. In terms of safety, different materials have varying characteristics of fire resistance and smoke generation. Hazards may arise from the attachments and bonds used on materials due to forces of wind and seismic disruptions, to aging, or to other factors. Additionally, floor materials differ in their non-slip qualities.

In terms of durability, the expected service lives of materials should be investigated. Considerations would include weathering effects, wearing qualities, changes in material strength, and changes in appearance due to aging effects.

The maintenance characteristics of materials can cause highly varying cleaning, repair and replacement costs. Construction materials should be investigated for their soiling and staining qualities, cleaning requirements, cost of repair, and cost of replacement.

Finally, the aesthetic qualities of construction materials can have a great impact upon the user acceptance and appreciation of the station. Any investigation of the aesthetics of various materials would, of course, be highly qualitative, and rely heavily upon the judgement of the architect/designer.

H. Design Flexibility

This element of a transit interchange facility design relates to the potential for expansion of the facility and/or the joint development with other facilities. For example, if a multi-story building is expanded to more floors, or the transit terminal is integrated with a shopping mall or apartment complex, this consideration applies. The latter, joint development, includes coordinated planning and development of transportation facilities and changes in land use over, under, and in the immediate vicinity (one-half mile radius) of the facility. Both public and private development activity may be accommodated.

Expansion considerations are important in areas where population growth and more intense land use has been forecasted. This would apply primarily to areas outside of the central business district where there is currently an ample supply of open space. Joint development considerations will be most important when the terminal is a focal point in an activity nucleus.

In the long term, initial terminal design considerations associated with expansion and joint development will significantly affect the options that are available regarding renovation. For example, expansion may be constrained by building type and adjacent land uses, while the facility arrangement may be inadequate to handle new line haul modal technology.

I. Parking Facilities

The important issues concerning the provision of parking facilities at transit interchange facilities include the following: number of spaces, mode of operation (i.e., degree of automation), location (i.e., adjacent to or within the station proper), terminal access pathways and vertical movement aids, weather protection, rate structure, and public or private management. These items are summarized in Table 3.

The number of spaces required will be determined from the size and nature of the transit demand and the parking requirements for appropriate non-transport activities in the station vicinity. Since the supply of parking at surburban stations is more critical to mode choice than at terminals in the center city area, some systems may only provide parking for the former. A methodology that has been developed to estimate the demand for express bus-fringe parking operations can be applied to estimate parking needs for transit stations in general.(3,7) This method uses census and travel data along with disaggregate mode choice models. This approach uses a sequence of logit choice models; i.e., the first estimates the number of trips using transit, while the second splits the transit trips according to access mode. Thus, the number of transit users who park n' ride is the relevant parameter for establishing parking requirements.

TABLE 3 Key Parking Facility Variables

1. Type of Demand Served (Transit users/local businesses)
2. Location (i.e., adjacent to or within terminal building)
3. Mode of Operation (Automated devices vs. attendants)
4. Terminal Access (Walkways, elevators, etc.)
5. Weather Protection
6. Fee Structure
7. Public or Private Management

A simplified design aid for estimating rapid transit access mode choice was developed as part of the Southwest Transit Area Coordination Study (STAC).(8) This model provides a diversion curve as shown in Figure 3 to estimate the percentage of commuters from each zone who access the station via walking, park n' ride, and kiss n' ride. This distribution of access mode choices is formulated as a function of distance or zone or orgin to the station.

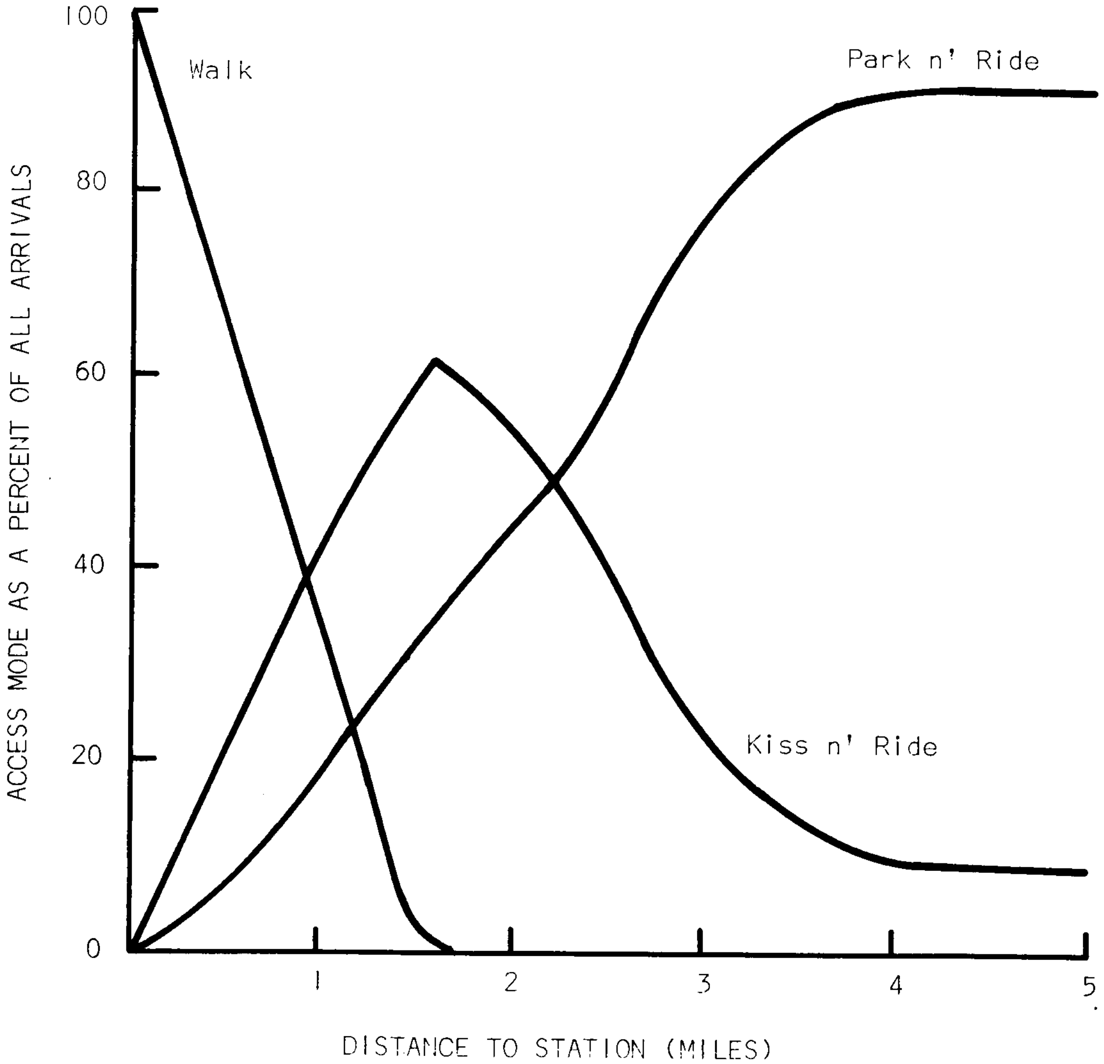
Because parking demand is a component of total transit demand (and not explicitly treated here), it will be assumed to be obtained from prior studies. The impact of policy decisions concerning joint development and concessions that affect parking requirements can be determined by using trip rate analysis for each particular land use. When the total station parking needs are established, the area requirements can be determined. For example, BART space criteria called for 450 to 475 square feet per space.

Alternative parking design concepts which consider items 2 through 7 in Table 3 are considered next. Then, when policy has been established for these items, the detailed engineering design of the parking facility can proceed using established procedures.(9)

Finally, the cost-effectiveness of alternative parking supply strategies are considered. The "costs" include capital costs, labor (operation) costs, maintenance costs and indirect costs such as congestion on local streets, noise, air pollutant emissions and land takings. The benefits gained from parking facilities at transit stations are associated with attracting transit riders who cannot conveniently reach the station by walking or local transit. Revenue will be a function of the parking fee structure and demand. Careful consideration of parking rates is necessary in order to maximize income without discouraging patrons. In many cases, free parking will be necessary, especially in the suburbs.

J. Provisions for the Elderly and Handicapped

In this study the elderly and handicapped passengers have been referred to as "special tripmakers".(1) Devices and design features which aid the mobility of these people have been included in recent transit



Source: Southward Transit Area Coordination Study, Chicago, 1970.

Figure 3 Access Mode Split as a Function of Distance from Home to Stations system designs both independently and as the result of related legislation. This problem is, therefore, a concern to all levels with jurisdiction over transportation systems. One general objective might be to provide the same level of service to the special tripmakers as experienced by the general user group. Specific design objectives for transit stations which are identified with special tripmakers include minimal level changes (or special aids such as elevators), ease of passing through fare collection areas, special facilities to avoid being crowded, locational and directional guides, and the virtual elimination of other physical and psychological barriers. Operational barriers must also be taken into account. For instance, short headway operation in peak periods can cause brief periods of intense crowding and rushing which could be both troublesome and dangerous for special tripmakers. A problem such as this might call for the physical separation of special tripmakers from the rest of the user population. The extent to which special facilities are provided to aid the mobility of the elderly and handicapped can be associated with estimates of the demand for travel by this group at a given site, i.e., a station proximate to a home for the aged would need special considerations; while one located in a surburban area populated by mostly young families might have different standards.

UMTA is currently in the process of developing transit regulations for the elderly and handicapped. Some of the details addressed are:(10)

1. Accessibility
2. Lighting
3. Entrances and exits
4. Interior handrails and stanchions
5. Floors and steps
6. Priority seating
7. Destination route signs
8. Fare boxes, and
9. Public address systems.

The more difficult problem areas relate to (10)

1. The coordination of all sources of transportation for elderly and handicapped persons

2. Levels of service for elderly and handicapped persons, and

3. Funding.

Within the transit terminal are many places where the general transit system details noted above apply plus many other opportunities to improve the mobility of handicapped tripmakers. When considering a certain terminal for accommodations for the elderly and handicapped, the responsible agency must be first alerted to those provisions required by law. Secondly, they can examine various design standards for buildings in general which are developed for accommodating the handicapped. For example, facilities for the handicapped are described in USA Standards Institute A 117.1-1961 "Making Buildings and Facilities Accessible To and Useful By the Physically Handicapped".(6)

K. Summary

Table 4 summarizes the important policy concerns and indicates example measures for analyzing alternative policy statements for each category. Appendix A shows specific policies which were established for certain transit interface facilities or transit systems. The information given in this section provides the planner with a basis for showing public officials those areas where policy is needed for transit terminal programs. Also, a review of the enclosed material will ensure that each resulting policy arises from a systematic appraisal of its impact on the cost, performance, and social acceptance of the transit station.

TABLE 4 Policy Analysis Measures

Policy Areas	Space Reqts.	Maintenance Reqts.	Security Reqts.	Utility Reqts.	Cost	Aesthetic Effects	Effect on Expansion	Reqd. by Law	Income
Concessions	x	x	x	x	x	x	x		x
Advertising		x	x	x	x	x			x
Personal Care Facilities	x	x	x	x	x	x		x	
Public Telephones	x	x	x	x	x	x		x	x
Aesthetics and Cultural Envt.	x	x	x	x	x	x	x		
Construction Materials		x	x		x	x			
Design Flexibility	x		x		x	x	x		
Parking Facilities	x	x	x	x	x	x	x	x	x
Provisions for Handicapped	x	x	x	x	x	x		x	

III. PERFORMANCE ANALYSIS

A. Introduction

In this section analytical techniques, including appropriate computer models, for analyzing the performance of important transit interchange facility functions are investigated. The specific subsystems addressed are passenger processing, passenger orientation, the physical environment, security, and safety.

B. Passenger Processing

The design objectives which are addressed in the analysis of the passenger processing capability are the following:

(1) to provide sufficient space in the basic queueing and movement areas to assure a safe, convenient, and comfortable pedestrian environment,

(2) to provide enough service facilities (e.g., doors, gates, stairs, etc.) to assure a convenient and comfortable pedestrian environment, and

(3) to connect queueing areas, movement areas, and service facilities to assure a secure, continuous, convenient, coherent, and safe pedestrian environment.

The criteria that have been identified for these objectives are summarized in Table 5. Two ways to obtain performance measures for the criteria are through manual computations using steady state queueing formulas, or by implementing more sophisticated computer simulation software.

Manual Techniques

Formulas and procedures are provided in Appendix B for computing the following measures of performance.

1. Total walk time
2. Total delay time
3. Queue lengths
4. Flow conflicts
5. Area per passenger

TABLE 5 Passenger Processing Criteria

	Criteria	Performance Measures
A.	Total walk time	Aggregate travel time
B.	Total delay time in queue	Aggregate waiting time
C.	Total time in system	Aggregate time (travel time + waiting time)
D.	Individual path analysis (origin-destination times)	Unit journey time
E.	Area per person in the space associated with a link	Sq. ft./person on pathway
F.	Number in queue at node	Number of people
G.	Time in queue while traveling from node (a) through node (b)	Unit journey waiting time
H.	Measures of crossing flows	Major and minor flows in area of conflict
I.	Connectivity (directness of path)	Network connectivity measures
J.	Availability of directional information	Type and location
K.	Number of levels	Number of levels
L.	Mechanical aids available	Type (e.g., elevator, ramp, escalator, etc.) and number
M.	Difficulty in navigating fare collection-entrance control area	Type and width (e.g., turnstile, gate, etc.)
N.	Capability of users	Accessible rails, leaning aids.

The steps involved in modeling a proposed transportation interchange facility using the manual method include:

(a) Define the system (Node-Link Network).

(b) Determine pedestrian volumes (through total volume projections).

(c) Select path choice criterion.

(d) Load inbound passengers onto the network.

(e) Load outbound passengers (bulk arrival) onto the network.

(f) Determine walk times and crowding on links.

(g) Determine queueing times and crowding at nodes.

(h) Return to step (d) and adjust path volumes, if necessary, to comply with path choice criterion.

(i) Determine wait times for transit vehicles.

(j) Summarize criteria measures (e.g., walk time, wait time, crowding, etc.).

UMTA Station Simulation Program (USS)

USS was developed by Barton-Aschman Associates, Inc. and Peat, Marwick, Mitchell, and Company for the Urban Mass Transportation Administration (UMTA), and is currently being considered for its utility in the Urban Transportation Planning System (UTPS).(11) The program measures the extent to which design objectives are achieved by estimating:

(a) The time spent walking and the time spent waiting within a station,

(b) The area per person (pedestrian area occupancy) provided in the walking and queueing areas of a station,

(c) The distributions of these variables for comparison with either design standards or level-of-service standards.

Appendix C provides a description of the mechanics of the USS program.

USS Output

The USS program provides 22 reports on the passenger processing performance of a transit station. These reports are listed in Table 6

TABLE 6 USS Output Report Summary

Report Number	Report Description
-	Control Card Images (Parameters and Options)
-	Listing of Types 1-9 Input Data Cards
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	Area Per Person in the Area Associated with Link
16	Number in Queue at Node
17	Required Queue Area for Node
18	People Outside Queue Area at Node
19	Walk Time from Node (A) Through Node (B)
20	Time in Queue from Node (A) Through Node (B)
21	Total Time from Node (A) Through Node (B)
22	Individual Path Analysis

where reports 1 thru 8 are standard output and reports 10 thru 22 can be selected at the option of the user. The output variables are summarized by maximum, minimum, and mean values. The variance and standard deviation of each variable are also given.

USS Cost

Because the USS model is still being refined and documented, no history of application has been established to date and simulation costs are not precisely known. However, the preliminary documentation gives some general estimates of costs for computer processing time. Using an S/360 Model 50 for several runs for networks of 50 links, 30 nodes, and 3 zones, the costs given in Table 7 were obtained. A rough rule-of-thumb for cost appears to be three cents to process a passenger over one link.

Summary

The USS model simulates passenger flows through a transit station and provides selected measures of the aggregate movement. This is an expensive and complex tool and will be used mostly in cases where a large number of evaluations of relatively large and sophisticated facilities are considered. The manual computations are sufficient for most problems.

C. Passenger Orientation

Orientation aids which assist pedestrians in choosing the proper route to their destination have a significant influence on the efficency of the passenger processing system. "Lost" pedestrians tend to create traffic which moves at a relatively slow pace and causes interference with normal flow channels. Measures which have been identified to meet the objective of informing passengers about the layout of the interface facility include directional signs, visibility of the destination, courtesy phones, and information booths.

All of the above are needed to meet the variety of information needs that arise and they fall into two major categories: active and passive. Table 8 describes the characteristics of each.

There are no existing models or methodology for explicitly measuring the adequacy of the passenger orientation system of a transit interface

TABLE 7 USS Run Costs

Simulation Period (Minutes)	Persons Through Station	Check With Checkpoint	Approximate Cost ($)
2	25	Yes	15
5	120	Yes	65
5	150	No	35
5	150	No	40
10	180	No	60
20	380	No	125
20	670	No	165
28	909	No	286*

*This run was done at a commercial S/360 Model 65 Installation (Overnight priority).

TABLE 8 Characteristics of Orientation Aids

Type	Direction of Communication	Examples
Passive	One-way	Directional signs and maps Visibility of destination
Active	Two-way	Courtesy phones Information booths

facility. Accordingly, the following inspection based procedure is recommended for immediate application.

1. Layout terminal system
2. Identify O-D flow channels
3. Place passive and/or active orientation aids
4. Determine total number of decision points along flow paths
5. Determine number of decision points where uncertainty can be expected
6. Establish a level of "orientation certainty"

The above procedure is judgemental but can assist the designer to improve the orientation aspect by increasing the level of certainty at all decision points.

D. Physical Environment

The criteria and corresponding performance measures for the physical environment of transit interchange facilities are given in Table 9. The most advanced approach toward the development of procedures for the evaluation of the physical environment of transit stations is given in the Subway Environmental Design Handbook which was developed under contract for UMTA.(12) The purpose of this handbook project was to develop a set of tools for the analysis of subway environmental control systems. Two types of computational tools were produced. The first approach consists of a set of manual methods to estimate subway air flows and temperature to aid in formulating initial subway environmental control strategies. The second approach is the use of the Subway Environmental Simulation (SES) Model which provides for a detailed evaluation of the aerodynamic and thermodynamic properties of the subway environment.

Temperature, Air Velocity, Air Pressure

The manual techniques mentioned above can aid the designer by providing rough estimates of air temperature, air velocity, and pressure changes to be expected in a station. These methods were derived from the same handbook study which produced the SES model.

TABLE 9 Terminal Environmental Design Criteria

	Criteria	Performance
(a)	Odors and odorants	Number of persons to which the concentration of odors would be unpleasant
(b)	Suspended aerosols and particulates	Coefficient of extinction for transmitted light
(c)	Inflow air rates	Cubic feet per minute, per person
(d)	Air discharges	Points which are affected
(e)	Air velocity	Feet per minute
(f)	Pressure changes	Pounds per square inch, per second
(g)	Thermal comfort	"Relative Warmth Index" or "Heat Deficit Rate"
(h)	Noise	Decibles
(i)	Lighting	Illumination level in foot-candles
(j)	Weather exposure	Percent of terminal area exposed to outside weather

Ref: "Criteria for Evaluating Alternative Transit Station Designs."

The SES is a high speed digital computer model which can continuously evaluate the piston action air flows created by a series of trains traveling through a subway system having interspersed stations and ventilation shafts. This type of dynamic simulation is required to determine air flows and heat flows in the complex geometrical configurations of subway stations because these flows cannot be solved analytically.

Generally, the SES program would be most useful to a designer for comparison and trade-off evaluation of alternative design concepts, and for the final stage of the iterative design process. The solution techniques used in the SES program use existing knowledge of dynamics, thermodynamics, aerodynamics, and empirical data derived from scale model and full scale testing. For purposes of introduction, the manual and computerized techniques are briefly described in Appendix D for their role in the terminal study methodology. At the time of the writing of this report, Volume II of the Handbook, which includes both the user's and the programmer's manuals for the Subway Environmental Simulation, were not available and, hence, the SES model was not ready for general use. A brief description of the computer model is given along with the manual techniques because of its potential as a design aid as well as the insight into the problem that an understanding of it provides.

For the purposes of evaluating the physical environment of the terminal facility, the Handbook provides methods for establishing certain human environmental criteria which can be used to judge the acceptability of a given design. Because each individual study must be responsive to new federal and local regulations concerning criteria, the environmental standards that apply will be established at the policy level. The following are the criteria addressed by the Handbook:

Temperature
Humidity
Air Quality
High Air Velocity
Rapid Pressure Change

In order to meet the human environmental criteria certain environmental control equipment is required. The functional requirements that are obtained by the SES or manual procedures must be translated by the design engineers into equipment systems. The associated equipment needs are as follows: ventilation systems, cooling system, heating systems, isolation systems, and tracking exhaust systems.

Lighting

The two major considerations in lighting design are illumination and brightness. Illumination is the "density of luminous flux incident on a surface; the quotient of the flux divided by the area of the surface, when the flux is uniformly distributed." Luminous flux might be referred to as the cause, and illumination the effect or result. The unit of illumination, when the foot is the unit of length, is the footcandle (fc). A footcandle is equivalent to the illumination on a surface one square foot in area on which a flux of one lumen is uniformly distributed.(13)

Brightness, on the other hand, is the luminous intensity in a given direction per unit of (projected) area. A surface has brightness due to light emitted, reflected, or transmitted by the surface. If either brightness or brightness differences within the visual field are sufficiently high, the effect will be glare, with its resulting annoyance, discomfort, or loss in visual performance.(13)

The major objective of most interior lighting designs is the provision of a recommended maintained general illumination level. Brightness induced glare often is not a primary consideration of designers since they are more concerned with providing for the minimum standards of illumination rather than preventing brightness levels or brightness differences from exceeding quantities which could cause glare. However, both should be considered in the design of a modal interchange facility. Descriptions of suggested standards for illumination and brightness are given in Appendix E, along with brief examples of calculations available for determining these values.

Noise

A substantial amount of data involving noise sources and noise abatement procedures applicable to transportation interface facilities has been accumulated.(14) This data is applied to predict noise levels in a terminal facility, given specific sources (e.g., trains, ventilation equipment, human activity, etc.) and characteristics of the noise abatement properties of the station area (e.g., walls, acoustic ceiling materials, rail pads, acoustic parapets, etc.). The empiric data for this analysis consists of three types. The first type deals with the noise sources, the second with abatement of noise at its source, and the third with the reduction in the transmission.(14)

The calculations involved in predicting noise levels are additive, while recognizing that the decibel scale is logarithmic. For any given area of a station, empiric data dealing with the level of the noise from the major sources within the surrounding area is collected. Next, the effects of proposals for reducing noises at their sources are subtracted from this total. Finally, any reductions in noise expected from provisions to lessen the transmission of noise are taken into account. The resultant total is the estimate of noise levels to be expected in the area under study.(14) Appendix F provides suggested standards for noise in rapid transit stations, as stated by the Institute for Rapid Transit.

Weather Protection

A measure of the weather protection provided by a transportation interface facility derives primarily from the functional area of the facility that is exposed to weather. This functional area is that which accommodates movement by system patrons, exclusive of parking lots. Exposure to weather is defined as the lack of complete enclosure by roof and walls.

E. Security

The effectiveness of transit security is reflected by how it is perceived by the public, and by the actual number of occurrences of criminal activity.(15) The former measure, the perception of security, is unclear and basically unquantifiable. The latter measure can be obtained from accurate records on crime, but guarded interpretation is required. For example, a recent study of a selected city found that the non-transit robbing rate averaged 954 robberies per 100,000 residents, while a comparative statistic for transit riders was 332 per 100,000 persons.(15) In this case it is difficult to decide whether the two statistics are really comparable because the transit population is continually changing as the residential population is relatively constant.

The development of a methodology to evaluate the security of transit interface facilities is thus quite difficult due to the complex nature of the measures of performance. This conclusion is supported by a recent workshop on the subject of transit security evaluation which stated a need for research on techniques to apply benefit-cost analysis to transit.(16)

At present only general guidelines such as the following are available for establishing system security objectives.

1. Make the system surveillable,
2. Reduce waiting time, and
3. Ensure rapid response to security incidents.

A security system can be incrementally built (or evaluated) using the available security methods, procedures, and apparatus to focus on the objectives. Alternative variations in security system design can be evaluated in terms of cost vs. service rendered or incidence of crime (e.g., incidence per 100,000 riders). Since the impact of a particular security strategy has been shown to be very difficult to assess, the benefits of, say, more police personnel or sophisticated surveillance equipment will primarily be a value judgement on the part of the decision maker.

Security Concepts

Although station design cannot eliminate the desire to commit crime, the belief that a crime will be successful can be lessened. Three basic ways to deter crime by creating an atmosphere which counters basic felonous acts have been identified.(17)

1. Deterrence, making the situation such that a potential crime cannot be successfully initiated;
2. Thwarting, providing means for stopping a crime once it is initiated; and
3. Apprehension, providing means to aid in the capture of the violator after the criminal act is completed.

The last two approaches, thwarting and apprehension, greatly increase the perceived security of a station to users.

If crimes have succeeded at a location in the past, the probability of another similar crime occurring there in the future is greatly increased. Conversely, if crimes have not succeeded at a location in the past, the probability of a similar attempt in the future is decreased.(18) Accordingly, the results of attempted crimes will affect future attempts, and the number of attempted crimes over a period of time will affect the users' perceived security.

Security Methods

The security methods that can be implemented at transportation interface facilities are associated with either station policy or station design. Firstly, deterrence to crime can be affected through several measures including:

1. Provision of extra personnel in areas of potential crime.
2. Provision of security guards or police in areas of potential crime.
3. Publicity concerning selected countermeasures.
4. Elimination of potential hiding places.
5. Precautions regarding surrounding land use.
6. Detection of potential offenders.

Secondly, the probability of thwarting a crime can be enhanced through the basic station design. Some of the attributes of stations applicable to this strategy are:

1. Reduce the number of separate, non-intervisible spaces.
2. Sustain passenger volumes (it is assumed that the higher the passenger volume, the higher the likelihood of someone viewing the criminal act and aiding or calling for aid).
3. Reduce the number of levels of the station buildings.
4. Use at-grade stations.

Attributes of specific areas of stations which are also applicable to hindering criminal acts include:

1. Provision of courtesy, or emergency, phones.
2. Short distances from station agents' booths.
3. Short distances to major user paths.
4. High degree of user visibility (including direct visual contact, use of visual surveillance devices, and illumination).
5. Provision of security guards or police.
6. Exact fare devices.

Finally, the ability to apprehend those who commit criminal acts can involve both the station and apprehension after successful flight. Some characteristics of stations applicable to this area of enforcement are:

1. Number of exits.
2. Avenues of escape (modes and directions).
3. Provision of security guards or police.
4. Closed circuit television surveillance.
5. Hidden cameras.
6. Alarms.

Accordingly, there are many potential security and protection strategies that can be instituted at a given transit interchange facility. Each security program should be systematically developed to meet local objectives. Specific station security policies will likely be influenced by previous criminal activity, passenger volume levels, and local population characteristics.

Security Systems Development

Security systems for transit stations are developed by first identifying the important objectives and then selecting a mixture of available security measures. An example of the integration of transit station design features into security system elements is shown in Figure 4. Here station design features and specific terminal area characteristics are shown relative to their functional role in the security system. The total security system also includes police and surveillance devices. A current issue regarding these latter elements involves the substitution of electronic and mechanical devices for police personnel.

At this stage of knowledge of transit security, it can only be concluded that the system must be tailored to meet the specific requirements of each urban area and station site and that there is a limited set of measures available. An example of the variability of existing transit security systems can be easily seen by just observing the police component. Of 8 transit systems studied, one is policed by a regional law enforcement agency, two by municipal police departments, one policed by a functionally balanced local agency-transit district with shared responsibility, and four by transit police organizations.(19) Thus, specific guidelines for transit station security systems are virtually impossible to establish with the current data on the subject.

For the purposes of a station design/evaluation methodology, an integrated security system is viewed with reference to the following components: station characteristics, area characteristics, police, and surveillance measures. All physical alternatives can be associated with varying degrees of these four basic components.

Security Systems Evaluation

It was pointed out earlier in this discussion that a benefit-cost procedure for security systems evaluation would be desirable, but that less objective strategies must be employed. The approach used to analyze the security systems of BART stations is an example of such a technique.(20) This method, which is described in Appendix G, scores various general and specific station security attributes and provides a summary measure of

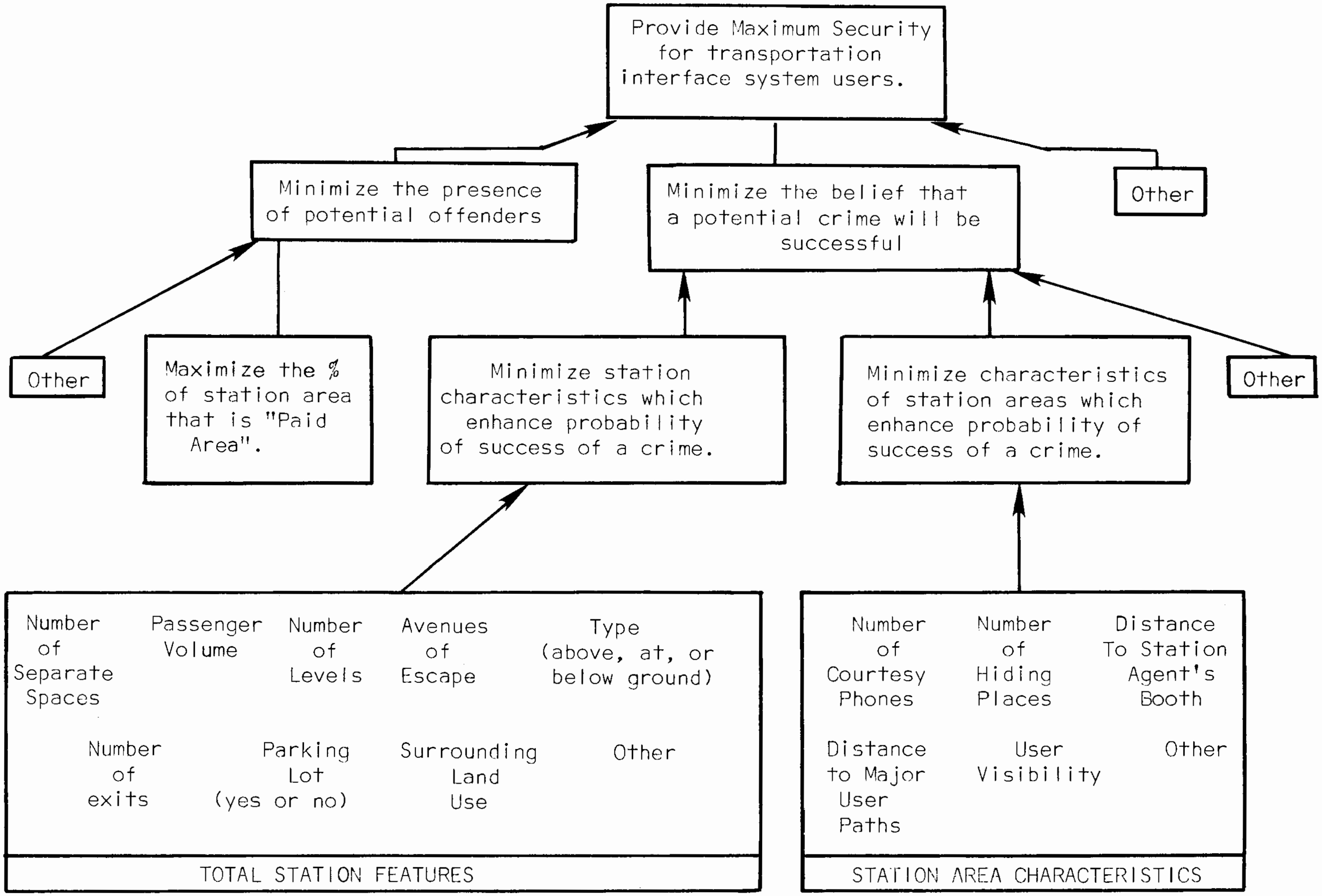


Figure 4 Security System Development in Transit Station Design

total system security. The BART approach has some drawbacks, but is generally implementable for current applications. An effectiveness analysis might be more realistic for the future, since it can evolve into a more sophisticated rating model as the state-of-the-art advances.

F. Safety

A transit interchange facility must provide a safe environment for passengers and employees. Mechanical facilities should meet government safety regulations and exhibit additional safety features that are available. Careful study of the entire station design and components is required in order to eliminate all potential safety hazards.

Accordingly, a typical safety study requires a knowledge of all federal and local safety laws (as well as a degree of common sense). The station design is viewed as a system of nodes and lines. Nodes would represent pieces of mechanical equipment such as turnstiles and escalators and links represent walkways such as stairs, paths, etc. Each significant station element is then scrutinized relative to its role and accident potential. After a series of independent reviews by planners, designers, decision makers, and citizen advisory panels, a sufficiently safe facility should result.

In order to guide terminal developers into assessing the safety of a station design, the Department of Defense standard for the protection of the public from unsafe conditions is documented in Appendix H.(21) This standard is now mandatory for all departments and agencies of the Department of Defense. Accordingly, this standard provides a comprehensive framework for safety analysis of transit interchange facilities.

Safety Analysis Framework

The DOD standards as summarized in Appendix H are implemented within the following analytical framework which is applicable to the transit station problem.

1. Identify hazards and determine any needed corrective actions.

2. Determine and evaluate safety considerations in tradeoff studies (relative to other objectives).

3. Determine and evaluate appropriate safety design and operational requirements.

4. Determine whether the qualitative objectives or quantitative numeric requirements established by the operating authority have been achieved.

The safety systems analysis is further formalized with the statement of particular elements which warrant consideration. An example is given in Table 10 which shows those elements which were used for BART.(20) These features were evaluated using the same approach as is used for the security analysis that is described in Appendix G.

The BART method as given in Reference 15 yields comparisons based on only selected safety considerations. In this respect it is probably inadequate for the general case for which the DOD methodology is recommended. The BART procedure is considered to be an expedient approach that was taken because of the lack of a well structured and recommended procedure such as the DOD standard.

G. Summary

Methods for obtaining measures of the performance of the important functional components of transit stations have been reviewed. The considerations given here along with the methodology described in the Appendices provide transportation planners with the necessary tools to compare the performance of alternative transit terminal designs and design concepts.

TABLE 10 Factors Used in BART Station Safety Analysis

<u>Station Attributes</u>

- Number of Levels
- Passenger Loading Methods
- Local Parking Provided
- Passenger Volume

<u>Station Area Attributes</u>

- Walking distance to:
  - Fire hose and extinguisher
  - Exit or emergency exit
  - Alarm
  - Station Agent's booth
- Unsignaled but marked pedestrian path crossings with vehicle paths

Level changes

- Curbs
- Stairs
- Escalators
- Platform edges

Poorly lighted areas

Areas exposed to rain

IV. AN INTEGRATED PLANNING-DESIGN AND EVALUATION METHODOLOGY

A. Introduction

The policy analysis procedures and performance analysis methods that have been presented provide the analytical components that are required to establish a systematic transit interchange facility design methodology. In this section a comprehensive transit station design strategy that uses these policy and performance analyses along with cost considerations is described.

B. Cost Considerations

Any method that is used to estimate the cost of a proposed transit interchange facility using data from previous experiences must be used with caution. This is so because no two stations are directly comparable and their components are not truly identical. The problem is further complicated due to the fact that the majority of the station experiences that are available to develop an "average" estimator were built at different times and under varying transportation and economic conditions. For example, Table II shows how the first costs of typical stations differ and reinforce the need to treat each station individually and comprehensively.

A basic approach to estimating transit station costs for planning purposes is to define a cost function. Here the total costs associated with a modal interchange facility are summarized in a cost equation such as the one shown below as equation (1).

$$C_t = C_f + C_o \qquad (1)$$

where

C_t = total annual cost

C_f = Annual cost equivalent of first cost

C_o = Annual operation and maintenance cost

TABLE II Selected Station Costs

Station Description	Initial Cost
MARTA Grant St. Station, 3 level aerial, 7 acres 340 parking spaces	$ 8,500,000
MBTA (Boston) North Quincy Station, Park 'N' Ride	2,121,000
Metro (Wash. D.C.) Farragit West Station, underground	31,043,383
New Jersey Journal Square Transportation Center (Jersey City), with administrative offices	85,000,000
BART Embarcadero Station Market Street, 10 story depth, 86 feet down	30,000,000

Source: Department of Research, American Public Transit Association, Washington, D. C.

This equation summarizes the costs of providing and operating a transit interchange facility. These costs arise from the following considerations relative to the transit station.

(1) fixed by original design decisions (e.g., the cost of the land area of the facility),

(2) variable, being dependent upon demand (e.g., the cost of processing people through the facility), or

(3) variable, being dependent upon policy decisions (e.g., the cost of providing security personnel).

Accordingly, itemized costs are summed for each contributing category of the total cost. Construction or first costs can be obtained from architectural drawings which list the design details. Annual operation and maintenance costs can be assigned to the station components by extrapolating recent operating experiences. Alternatives can be identified according to the various policy decisions required to differentiate among them or the various levels of service which are considered.

When level of service is a primary consideration, it may be appropriate to consider the user cost, which can be derived from travel time requirements and an estimate of the user's value of time. Then, tradeoffs between the expense of additional pedestrian travel aids and user costs can be considered to justify the travel aids.

C. A Design Methodology for New Transit Interchange Facilities

Inventory

Initially, input or inventory data must be secured. In the case of the transit interchange facility, the following levels of data are required.

1. Exogenous Design Data
    a. Local site data
    b. Demand data
        Passenger flows
        Vehicle arrivals

c. Supply data

    Interchange modal technology requirements

    Access mode requirements

2. Endogenous Design Data

a. Policy objectives (local & system)

b. User attitudes and preferences

c. Performance standards

d. Cost constraints

According to this typology, the exogenous (or external) data reflect the loads (in terms of passengers and transit vehicles plus local land use) which the facility must sustain. The endogeous data represent further requirements that are established by the planning agency and system user prior to the investigation of actual physical station configurations. Once this preliminary design information is collected and developed, a formalized terminal design/evaluation process is initiated.

Policy Development

The first stage in the station design process concerns the formulation of relevant policy associated with the design, operation, and maintenance of the transit station. Those specific items which comprise the nucleus of policy needs for transit stations have been identified earlier as concessions, advertising, personal care facilities, public telephones, aesthetics and cultural, environmental, construction materials, and provisions for special users (elderly and handicapped). Guidelines to assist the planning agency regarding these policy issues are given in Section II of this report.

Also, certain subsystems that were identified earlier in the section on performance analysis can be approved by policy rather than by the detailed analytical treatment that was given. The subsystems which apply here include passenger orientation, the physical environment, safety, and security. For example, this strategy is appropriate when the only analytic capability available is the USS model or the substitutable manual formulas. All elements except passenger processing are established, and then an iterative procedure is used to obtain an acceptable design relative to the latter criteria. The policy statements and planning data thus provide the necessary background information for generating trial station designs.

Trial Station Design Development

During this stage, architects, planners and engineers collaborate to first generate alternative design concepts and then design facilities which meet the stated requirements and objectives. Design concepts relate those broad considerations which account for major differences in terminals such as multi-level vs. single level, underground vs. above-ground, exclusive shopping mall zones, automated pedestrian movement aids, alternative limits on paid areas, etc. After specific design concepts are agreed upon by the design team, detailed facility designs can be prepared.

Evaluation I

At this stage the effectiveness of each design as resulting from policy, design concepts, and initial component selection and layout is evaluated. This evaluation of "trial station designs" is intended primarily to resolve issues regarding policy and design concepts. That is, a first stage of iteration around policy and design concepts should be conducted until specific policy and design concepts are established. Evaluation criteria mainly include cost measures but some preliminary performance analyses apply. The effectiveness analysis framework that is described in Reference 1 is used to make comparisons among the alternative design approaches.

Develop Detailed Terminal Designs

When an acceptable design basis consisting of certain policy statements and design concepts has been established, alternative physical facility components and layouts can be tested. It is at this point that those variable details of transit stations associated with optimal passenger processing and user acceptance are considered. And, as stated earlier, the analyst has the option of also considering variations in the design relative to the physical environment, passenger orientation aids, safety, and security at this point, if they have not already been established as a matter of policy.

Evaluation II

The detailed terminal facility designs are evaluated in terms of performance and cost. It is in this phase that the available computerized and manual techniques associated with pedestrian flows and orientation, the physical environment, safety, and security are applied to obtain measures of effectiveness for alternative station designs. The performance and cost measures obtained are interpreted with the effectiveness model to select the "best" alternative. When the results of the evaluation indicate where design improvements are warranted and feasible, changes are made and new designs developed. This iterative process is repeated until a specific design is selected.

Summary

The stages in the transit interface facility design methodology are summarized in Figure 5. Figure 6 further identifies the various elements of concern at the appropriate places in the procedural method. This strategy integrates the important study findings concerning design objectives, criteria and measures within an evaluation framework with the judgmental, analytical and computerized methods available for developing and analyzing various station designs.

D. A Methodology for Transit Station Renovation

The procedural method that has been given for the design of new transit terminals can also be utilized for station renovation. The primary difference in these two applications of the methodology is that the station renovation study begins with the execution of Evaluation I and Evaluation II phases given the inventory data, policy, and design detail as shown in Figure 7. Once the existing facility is evaluated, the findings are employed to develop new policy and to redesign the facility. From this point on, the standard procedure is followed.

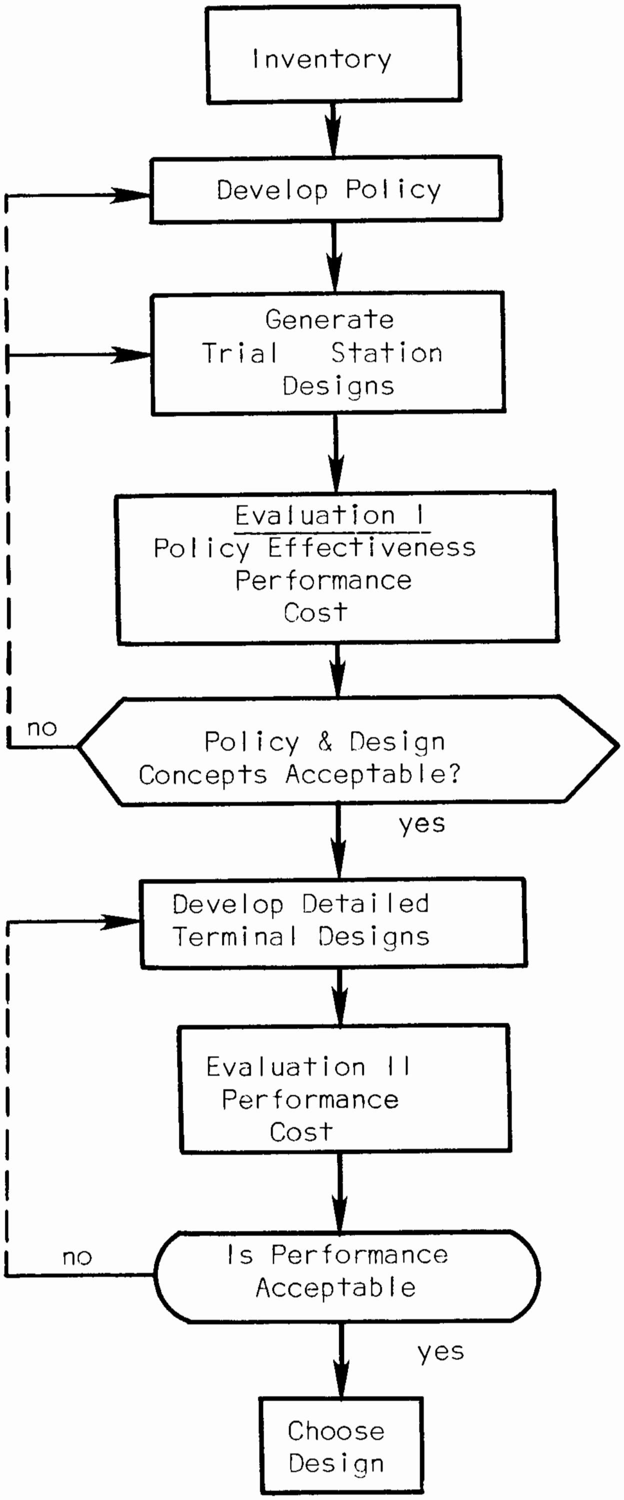


Figure 5 Stages in Transit Station Design Methodology

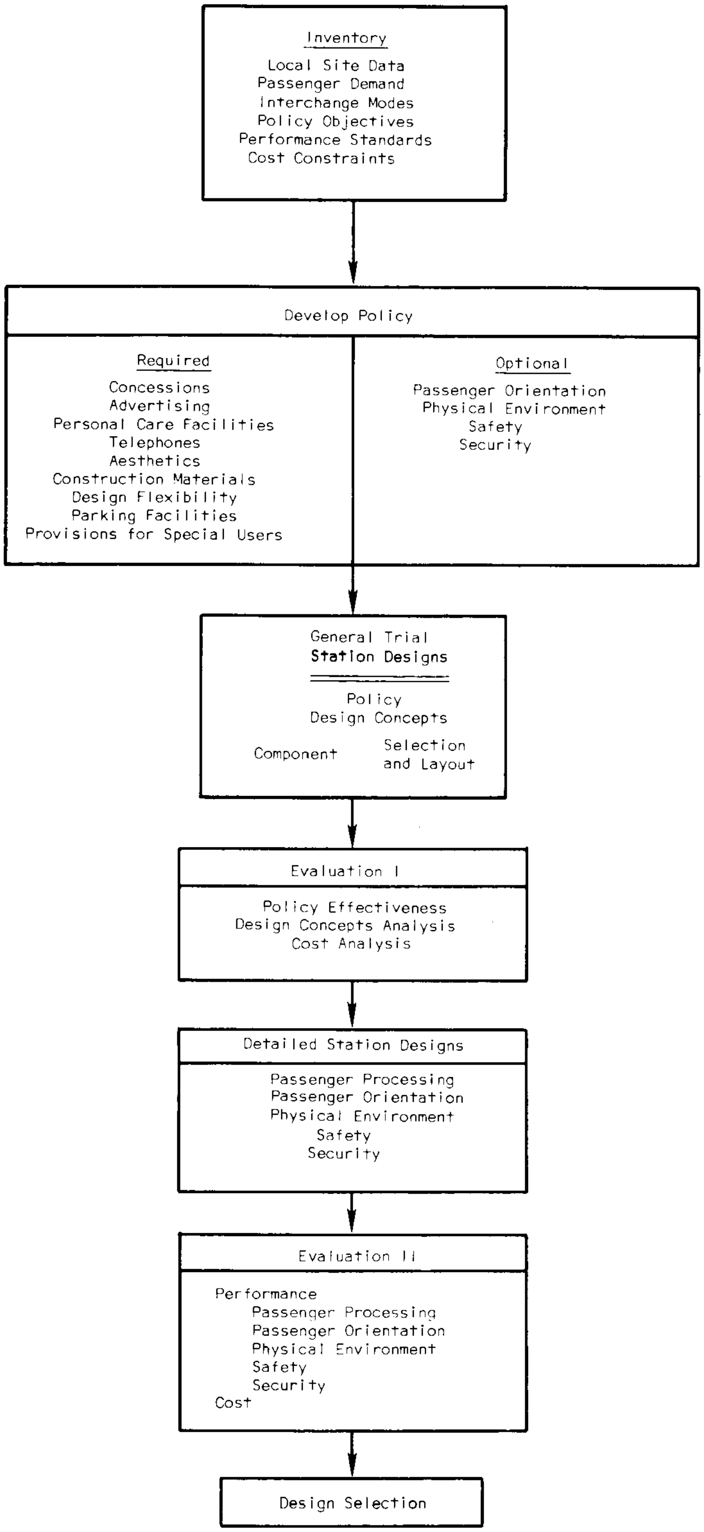


Figure 6 Elements Considered in Transit Station Design Methodology

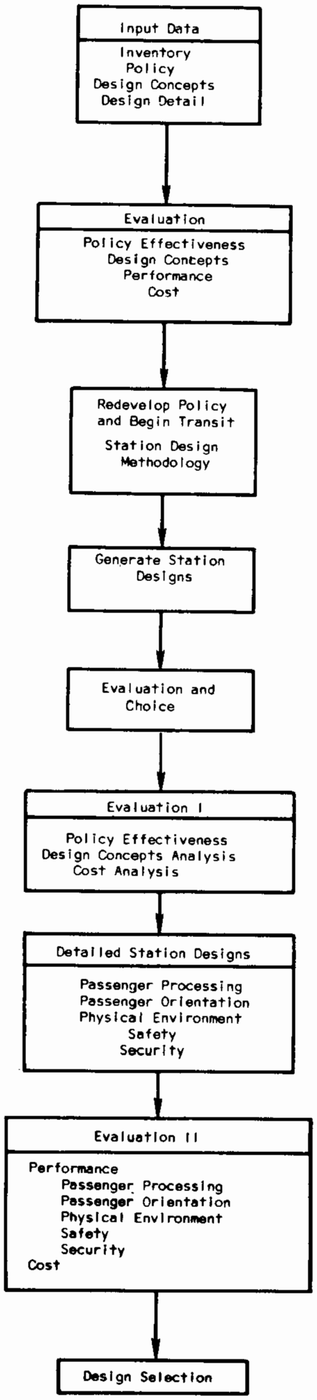


Figure 7 Preliminary Tasks for Transit Station Renovation

V. CONCLUSIONS

A. Summary

This research addressed the problem of establishing a formalized yet flexible, general design methodology to assist the planning and design professions in the development of efficient and acceptable transit terminal designs. The framework that has evolved provides the analyst with various options for arriving at a recommended design relative to the manner through which the various station subsystems are developed. For example, the most basic way to design a station component is to first establish a firm policy concerning cost and performance requirements, and then to select a design which meets the stated criteria. More complex design approaches simulate the performance of alternative subsystem designs to establish the most efficient alternative. Problems, which relate to the interrelationships among the various subsystems, can only be checked through applications of an iterative comprehensive design process which assesses the performance of the entire facility relative to specified measures of performance.

The methodology provided here combines with the evaluation criteria and framework developed in Reference 1 to relate the measures of terminal effectiveness to the objectives of the user, the special user, and the operator. Accordingly, the complete set of methodological procedures for transit station design that have been developed during the course of this study include the following:

(1) Criteria for terminal performance evaluation,
(2) Performance measures for selected criteria,
(3) Methods for obtaining performance measures from alternative design configurations,
(4) Guidelines for establishing policy directly associated with terminal performance,
(5) A practical framework for the analysis of transit stations, and
(6) A practical evaluation framework.

Items 1, 2 and 6 are addressed in the earlier report, while items 3, 4 and 5 have been examined in this report.

B. Conclusions

A comprehensive set of criteria, analytical models, computational techniques, evaluation models, and a general analysis framework have been suggested from this study for transit interface facility design. Accordingly, sufficient information and methodology have been collected to provide a general step-by-step set of procedures for designing new transit stations as well as renovating existing passenger terminals. It remains for the research team to draw upon the study findings and actually demonstrate this general approach to transit station design. Consequently, an application guide is provided as a separate document entitled "A Procedural Guide for Transit Station Planning and Design." This publication translates the research results reported here into simplified language and shows how the general procedures can be implemented by the profession. Finally, the resulting generalized transit station design methodology must be tested and refined during applications to specific design problems.

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APPENDIX A

EXAMPLE POLICY STATEMENTS FOR TRANSIT STATIONS

This appendix provides samples of policy statements from existing transit systems. The purpose is to show current approaches to station policy. These samples are taken from the San Francisco Bay Area Rapid Transit District's Manual of Architectural Standards(1) and New York City Transit Authority Design Guidelines - Station Planning.(2)

New York City Transit Authority

Concessions

Locations

- Not to obstruct passenger flow or interfere with the operation of transit facilities.
- Accessible to normal passenger flow.
- Concessions not permitted on platforms.
- Not to interfere with other concessions or advertising.
- All concessions to be observable by the token agent.

General Requirements

- Automatic vending must be within view of the token agent and is to be grouped in units of an approved modular design.
- All manned concessions and storage areas to be provided with sprinkler systems.
- Concessionaires are to use rubber-tired dollies and hand trucks only rather than steel wheeled which tend to damage stair and floor finishes.
- Areas chosen for concessions are to be designed as part of the total station concept and not as an after-thought.

Advertising

Locations

- Not to conflict with graphics.
- To be treated as elements within the total station design concept.
- To be grouped in selected areas.

Personal Care Facilities: Toilets

Types

- Public toilets for men and women at transfer and major stations only.
- One employees toilet per station.
- Crew room toilets with provisions to suit each specific situation.

General Requirements

- Public toilets shall have an attendant station, supervising both the mens and womens toilets.
- With provisions for closing the facility at night.

Handicapped Requirements

- Each public toilet (mens and ladies) shall have one stall with the following requirements:
  - Width: 3'-0"
  - Depth: 4'-8" minimum 5'-0" preferred
  - Door width: 2'-4" swing out, not to interfere with access to other stalls.
  - Handrails on each interior side of the stall, 33" high and parallel to the floor, 1-1/2" clearance between rail and wall, fastened securely at ends and center of rail.
  - Water closet with seat 20" from the floor.
  - Stall to be identified with appropriate graphics.

Public Telephones

- Public telephones within view of the token agent are to be provided in and outside of the paid areas of the station.
- The telephones shall have a "911" emergency provision.
- One phone to be provided for the hard of hearing and shall be identified with appropriate graphics.

Construction Materials

It is the task of the project architect to propose finishes which are most suitable for a transit environment without sacrificing attractiveness, quality, or passenger comfort. The project architect should be aware that the proper selection of finishes and general aesthetic considerations will provide the passenger with pride for the facility and thereby reduce vandalism.

Properties

Safety

- Incombustible materials
- Adequate anchorage
- Non-slip floors

Durability

- Non-fading
- Weather resistant
- Strong
- Wear resistant
- Impact resistant

Maintenance

- Dense, non-porous
- Acid & Alkali resistant
- Replaceable

Acoustical Materials

Acoustical materials in general are quite delicate and easily tampered with. Thus they should be located only on surfaces that are not accessible to the passenger (i.e., below the platform, ceilings, etc.).

Absorbing Materials

Acoustic absorbing materials shall be nonflammable, durable and washable. Where possible, properly designed perforated panels shall be used to protect the absorbing materials.

Sound Insulating Materials

Sound Insulating Materials shall be nonflammable, durable, and washable.

Energy Conservation Criteria for Above Ground Structures

Walls shall have minimum "U" value of 0.12
Roofs shall have minimum "U" value of 0.12
Where more than 25% of the exposed exterior wall is glass at least one-fourth of all glass surfaces shall be insulating glass or storm sash.

Handicapped

Design Criteria

- Emphasis and consideration shall be given to those facilities which will make the transit system used by the public, accessible to, and useful by the physically handicapped, without sacrifice to the general public.

Application

- The needs of the handicapped are incorporated into the station standards in the following sections:

  exit gates
  graphics
  platform safety edge
  public address system

street entrances
telephones
television surveillance
toilets
escalators
handrails
ramps and gradients
snow melters
stairs - raisers and treads
elevators
lighting
non-slip floor finish

San Francisco Bay Area Rapid Transit District

Concessions

Basic Goals

1. To provide facilities and space for concessions required for the convenience of BART system patrons.
2. To establish vending and manned concession standards which will facilitate a system-wide concession operation.

General Requirements

Concessions should be located in the station core, at the concourse, in either the "free" or "paid" area, or both, depending upon the station plan and local conditions. In addition, certain stations will require concessions in peak-hour only and daytime entrances, where traffic warrants. For the convenience of the passengers and the success of the concessions, they should be immediately adjacent to the traffic flow, but must not obstruct it. No concessions will be allowed on the platforms. No vending machines, other than for newspapers, will be permitted outside the station structure. An authorized concession truck will be allowed in the parking lot at above ground stations.

It is likely that concession requirements and needs will change considerably over a period of years. In order to avoid the haphazard installation of vending machines and concession booths in the future, sufficient and flexible space should be provided at the outset. Therefore, to properly service the public both now and in the future, the project architect should make allowance in his design for as much space for future concession facilities as is practical.

Advertising

Basic Goals

1. To establish an advertising system that is attractive, controlled, tasteful, and in the public interest.
2. To ensure that advertising, by its placement and treatment, does not conflict with station directional and informational signing.
3. To use advertisements as design elements rather than haphazard displays.
4. To provide revenue for the BART District.

General Criteria

1. Advertisements will be permitted only in selected and controlled areas.
2. Advertisements must be carefully located: adjacent to areas of heavy traffic, but out of the direct passenger flow, so that they do not obstruct or retard such flow.
3. Advertisements must be so placed that they cannot easily be defaced or damaged.
4. To assure variety and freshness, no permanent installations will be permitted (except for certain built-in display cases, in which displays will be regularly changed).

Specific Criteria

1. Glass-enclosed, built-in, locked display cases may be used for certain types of advertisements.
2. Poster advertising may be permitted in certain controlled locations.
3. Space should be provided for built-in display cases to be used in conjunction with special entrances to BART stations. Such cases will be designed to station standards, and should be included only as requested by owners of the adjacent stores in conjunction with their special entrances.

Restrooms

General

Each station will have at least one staff toilet and one men's and one women's toilet for the public. Each such public toilet will accommodate only one user at a time and will be locked when not in use, with entry controlled by the station agent. Public toilet rooms must be located within the "paid" area. Staff toilets should also be located in the "paid" area when possible.

Basic Goals

1. To provide toilet room facilities for BART personnel and patrons.
2. To minimize maintenance, operation, vandalism and security requirements.
3. To standardize toilet room accessories throughout the BART system.
4. To standardize plumbing fixtures and fittings.

Public Telephone Service

Public telephones should be provided both in "free" and "paid" areas of each passenger station with connection to local Pacific Telephone exchange.

1. Number and location of sets will be determined in consultation with the Pacific Telephone Co. Total number will be based on passenger volumes. A minimum of two sets should be provided in both the "paid" and the "free" areas at the station core.
2. Terminal cabinet should be located in the station auxiliary electrical room or other wire closet (not in the train control room). Conduit shall be as required for the number of telephones plus expansion. It should not be combined with BART district equipment or BART system telephones.

Materials and Finishes

The purpose of this section is to specify basic requirements and criteria which have been established for finish materials to be used in public areas of all BART stations, to the end that the quality level and maintenance requirements of such materials will be consistent throughout the BART system. It is intended that project architects shall have the freedom to propose materials best suited to the environment and design of the individual stations, provided that they meet the performance standards specified in this section.

Basic Goals

A. Safety

1. Fire Resistance and Smoke Generation - To reduce hazard from fire by using materials with minimum burning rate and smoke generation characteristics for station finishes, consistent with code requirements.

2. Attachment - To eliminate hazard from dislodgement due to wind or siesmic forces, aging or other causes, by using proper attachments and adequate bond strength.

3. Non-Slip - To increase pedestrian safety by using floor materials with non-slip qualities.

B. Durability - To provide for long and economical service by using materials with wear, strength and weathering qualities consistent with their initial and replacement cost and their location in the station. The materials must maintain their good appearance throughout their useful life.

C. Ease of Maintenance

1. Cleaning - To reduce cleaning costs by using materials which do not soil or stain easily, which have surfaces that are easy to clean in a single operation, and on which minor soiling is not apparent.

2. Repair or Replacement - To reduce maintenance costs by using materials which, if damaged, are easily repaired or replaced without undue interference with the operation of the BART system.

D. Aesthetic Qualities - To create a feeling of warmth, attractiveness and good quality in the stations, and to provide a pleasant and comfortable atmosphere for the patrons, recognizing that the proper atmosphere will not only encourage the use of the BART System but will also instill pride and respect, with a resultant decrease in abuse.

Parking Facilities

Basic Goals

1. To provide for the safety of BART patrons while arriving and departing from the station site.

2. To establish traffic circulation patterns and routes which will allow convenient, rapid vehicular and pedestrian movement, both within the station site and on adjacent roads.

3. To provide easy access to, and egress from, parking facilities.

Traffic Modes

1. BART System patrons will arrive at, and depart from, the station in four basic ways or modes. The modes, in order of priority for convenience and directness of routing, are as follows:
    a. Pedestrian
    b. Bus
    c. Kiss-and-ride (patrons are dropped off or picked up by private automobile or taxi)
    d. Park-and-ride (patrons park at the station site, and pick up their cars on their return)
2. The maximum possible separation between modes of transportation in the station area should be provided, in the following order of priority:
    a. Between pedestrian and other modes.
    b. Between public and private transportation.
    c. Between kiss-and-ride and park-and-ride.

APPENDIX A

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APPENDIX B

MANUAL CALCULATIONS FOR ANALYSIS OF PASSENGER FLOWS

The manual calculations described in this section provide measures of mean walk speeds and queueing delays. These procedures address the same design objectives as does the USS model.

System Definition (Nodes and Links)

It is not mandatory to define a transit station in terms of nodes and links for a manual analysis of passenger processing. However, it does provide an effective bookkeeping system and renders an overview of the entire facility. In this method nodes represent service devices (e.g., doors, fare collection devices, etc.), path decision points, or system origin/destination points. Associated with each node is either an inbound (accessing the major line-haul vehicles) or an outbound queue.

Links represent connections between two nodes and are defined by the pair of connected nodes. A link may accommodate one-way or two-way flows. Also, each link has a defined movement area and length. The movement area of any two links may overlap, causing a flow conflict. This conflict is called a shared area. Volumes within shared areas must be added together in order to determine a level of service.

A zone is a node at which pedestrians enter or leave the network. Unlike the USS model, a separate zone is required only at each entrance or exit to the station (e.g., doorway, train door, bus stop, etc.), regardless of the number of modes providing movement from or to that point.

The queueing area associated with a node is an area designated as such. For the first iteration it is assumed that the queue area associated with a node is contained entirely within the movement areas of the links to which it belongs. Finally, just as movement areas of links may be shared, queueing areas may also overlap.

Passenger Flow Dimensions

Volumes

In this model, the volumes from all modes other than transit enter the station at uniform rates. These volumes are predicted from demand models, adjusted for peak period flow, and further adjusted to reflect peaking within that time period.

The passenger flows departing transit vehicles are determined using a method which reflects the discrete nature of the transit vehicle arrivals. The important consideration for passenger disembarking characteristics is that the flow rate is not uniform throughout the peak period. Rather, the exit pathways immediately adjacent to the stopped vehicle operate at capacity until all pedestrians have left the platform.

Walk Time

The total walk time on a link is a function of the type of link (i.e., flat or stairs), link length, density of pedestrians on the link, and presence of conflicting flows. Unlike the USS model, this manual method does not involve subtracting the length of the destination node queue from the length of the link to determine an "effective link length." Although the USS procedure provides more accurate results, it involves more calculations than a manual method warrants. Also, the difference in walk time using the actual link length rather than the effective link length are generally quite small relative to queueing delays.

Time in Queue

All queueing is modeled at the nodes of the pedestrian network. Queueing occurs at doors, fare collection gates, vehicle doors, escalators, and other devices. The two basic assumptions used to model queueing behavior are:

(1) The number of arrivals or persons served per unit time is random, and

(2) The numbers are Poisson distributed.(1)

Means of finding or estimating the mean service times necessary for application of the queueing model are discussed in the section describing the USS model.

Queue Size

The size of a particular queue is of concern when it is possible that the floor area provided each pedestrian is insufficient for the desired level-of-service. Level-of-service has earlier been defined as a function of floor area per pedestrian in the waiting area. Therefore, one would divide the available floor area by the number of persons queued and compare this statistic with the level-of-service descriptions for queueing.

Application of the Manual Techniques

Node-Link Network

When a station layout is proposed, a drawing is used to trace likely pedestrian paths, both inbound and outbound. Next, nodes representing queueing devices and zones where people enter or leave the system are identified.

These paths, nodes, and zones are then interpreted to define links which are described by the following measures.

(a) type (i.e., level, upward stairs, downward stairs),
(b) length,
(c) movement type (i.e., shared area with other flows, one-way flow, two-way flow),
(d) minimum effective width of path (subtracting at least two feet for impedances such as columns or newsstands and subtracting an additional 18 inches if walls are present beside the path, also subtracting two feet if the path is a sidewalk with curb on one side).

The travel time associated with each link is determined individually.

Pedestrian Volumes

As stated earlier, pedestrians entering the station from street level to access the line-haul system are assumed to arrive at a uniform rate during a peak 15 minute design period. However, since "micro-peaking" (temporary higher volumes) within this design period is likely to occur, an additional adjustment factor is used in order to avoid over-capacity situations which could last for several minutes at a time.(2) Although each individual transit station may have different micro-peaking characteristics, a surge factor of 1.5 is recommended by Fruin as being suitable for application to the 15 minute peak design volume.(3) Therefore, if a peak 15-minute inbound volume of 1000 pedestrians (4000 ped./hour) is used, this would be multiplied by the 1.5 surge factor to arrive at the volume to be applied to the proposed design (1500 pedestrians, 6000 ped./hour). The surge factor of 1.5 should be sufficiently conservative to avoid most serious over-capacity situations. Note that this surge factor is for application to inbound (accessing the major line-haul system) volumes. Outbound volumes will be dealt with later.

Path Choice

The path choice criterion used by the planner varies according to the characteristics of the facility under study. If the design of the station is simple in terms of paths (i.e., there is only one path available) there is no problem of path choice. However, if there are more than one path available and none provides less disutility to the traveler, individual path choice criteria may be difficult to resolve. Also, if there are ancillary facilities available on alternate paths, path choice may not be apparent. Finally, if a particular path offers certain movement aids (e.g., elevators, escalators, moving sidewalks, etc.), no method for determining path choice may be obvious.

Several methods are available for modeling path choice. Wardrop's Principles of trip assignment are applicable here.

(a) the trip times on all routes used will be equal and less than those which would be experienced by a single pedestrian on any unused route.

(b) the average journey time of all pedestrians will be a minimum.

Using an iterative process, pedestrians are assigned to alternative paths so that these criteria are met.(4)

If ancillary facilities are present and it is anticipated that they will draw a sizable portion of pedestrian traffic, an internal origin-destination projection study may be necessary. Finally, if a particular path offers movement aids, it may be necessary to compare paths on the basis of certain disutilities rather than simply total route travel time.

The path selection criteria used by handicapped and elderly persons are different from other travelers. In general, these groups would have to be studied separately.(5)

Walk Speed

The values for both walk speed and area per pedestrian are determined from the pedestrian volume and effective width of the walkway. For a level (± 5 degree slope) walkway:

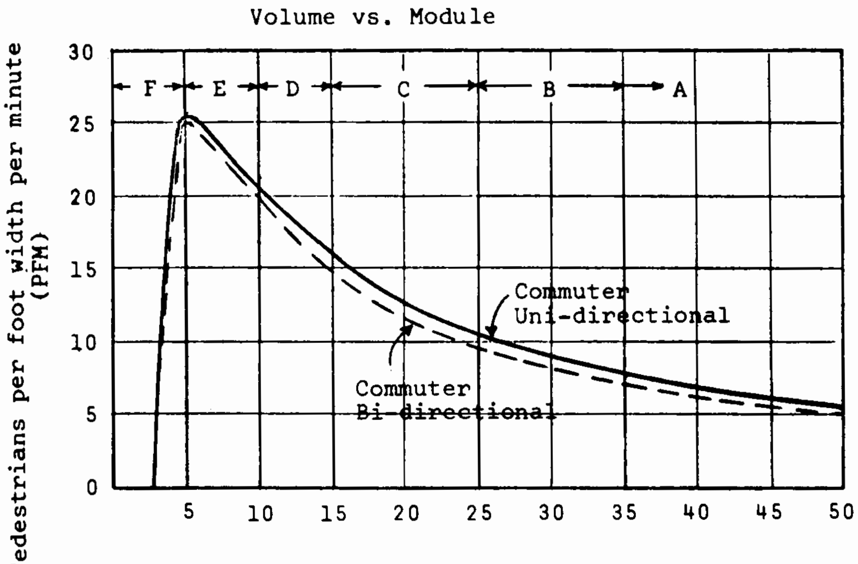
Step 1 - Divide the Pedestrian Volume (ped./min.) by the effective width of the walkway (ft.) to obtain Pedestrians per Foot Width per Minute (PFM).

Step 2 - Using Figure B.1, determine Module (M, square feet area per pedestrian) from PFM. When doing this, ignore module values less than 5 $ft.^2/ped.$ as this represents forced flow. Note that flow direction (one-way or two-way) must be specified.

Step 3 - Using Figure B.2, determine walking speed (ft./min.) from Module. This represents space mean speed and would be the value used in determining walk time for a link.

As an example, consider a walkway 23 feet wide. Walls are present on both sides so that the effective width is 20 feet. The design volume for the link (including the surge factor) is 240 ped/min. Flow is uni-directional.

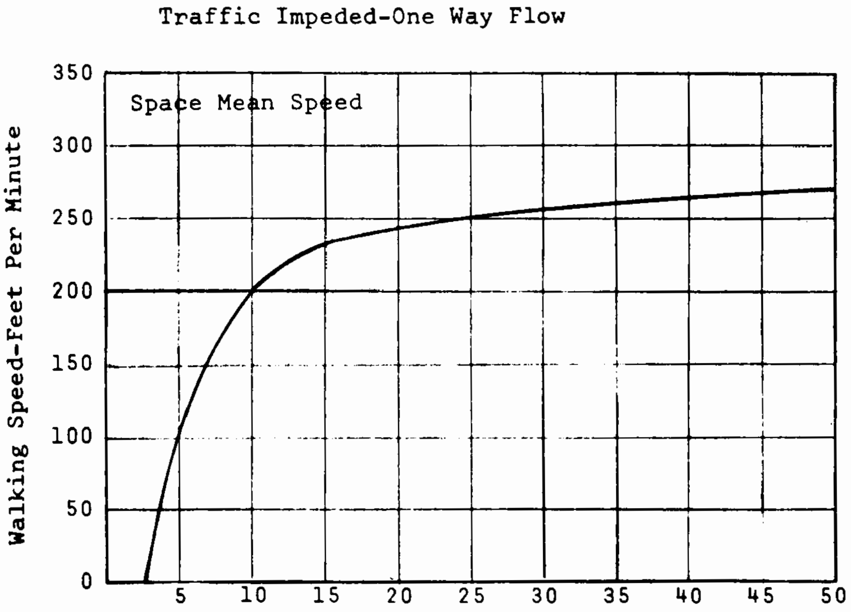
The volume per foot (PFM) is equal to 240/20 or 12 pedestrians per foot per minute. Using Figure B.1, a Module value of approximately 21 $ft.^2/ped.$ is found. Using Figure B.2, the Module value yields a walk speed of about 248 ft./min.



Module - (m) - Square feet area per pedestrian

Source: Reference 2

Figure B.1 Level of Service Standards for Walkways



Module - (m) - Square feet area per pedestrian

Source: Reference 2

Figure B.2 Pedestrian Speed on Walkways

Since Flow Volume (F) equals average speed (S) divided by average density (M) this can be checked:

$$F = S/M \qquad \text{(B.1)}$$

$$12\ (\text{ped/ft.})/\text{min.} = (248\ \text{ft./min.})/(21\ \text{ft.}^2/\text{ped})$$

$$12\ (\text{ped/ft.})/\text{min.} = 11.8\ (\text{ped/ft.})/\text{min.}$$

The procedure for measuring walk speed and area per pedestrian for stairs is identical. For upward movement on stairs use Figures B.3 and B.5. For downward movement use Figures B.3 and B.4. It should be noted that when minor reverse flow occurs on stairways, the effective width should be reduced by 30 inches (one pedestrian lane).(2)

Elevators are treated in a similar manner to walk links. Table B.1 provides data on both their theoretical and nominal capacities.

Queueing

Queues in a transit station are of two types; single-channel (one service device) or multi-channel (more than one service device). For a single channel queue, the parameters under consideration are:(1)

The expected number in the queue, L_q, is

$$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} \qquad \text{(B.1)}$$

The expected number in the system (queue and service), L, is

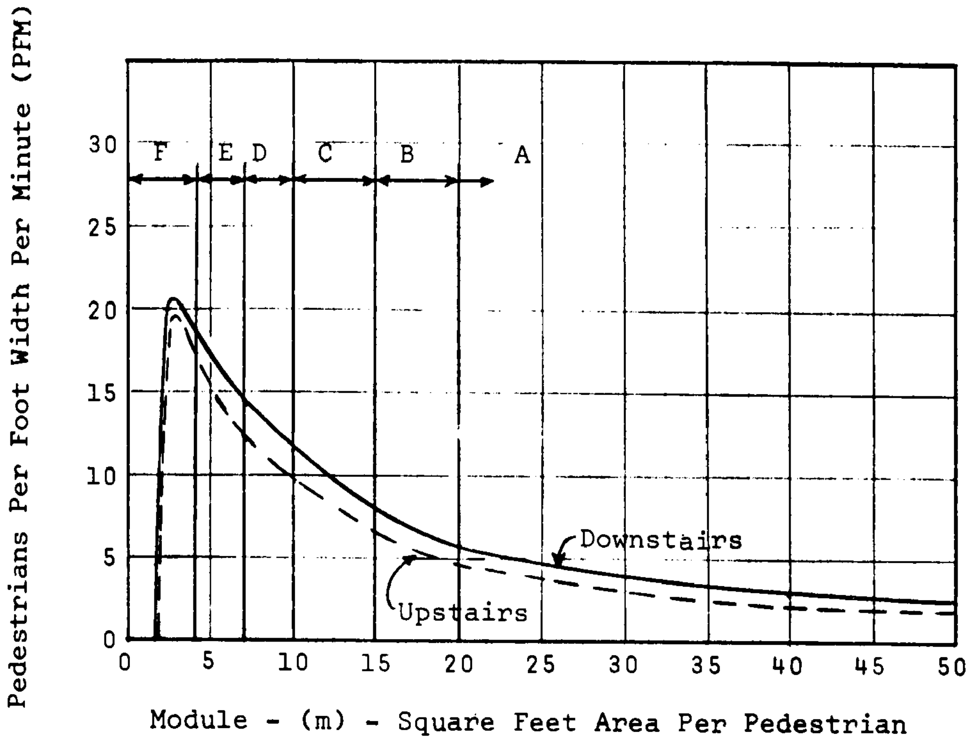
$$L = \frac{\lambda}{\mu-\lambda} \qquad \text{(B.3)}$$

The expected time in the queue, W_q, is

$$W_q = \frac{\lambda}{\mu\ (\mu-\lambda)} \qquad \text{(B.4)}$$

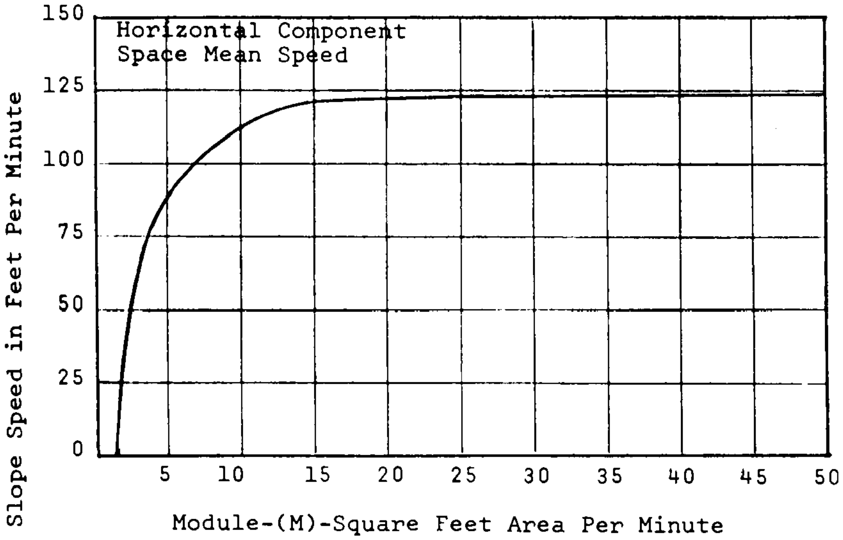
The expected time in the system, W, is

$$W = \frac{1}{\mu-\lambda} \qquad \text{B.5)}$$



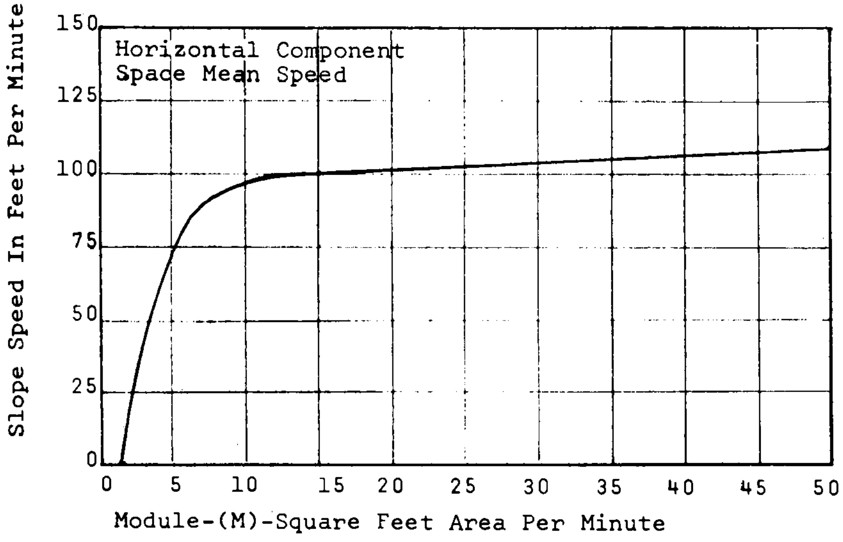
Source: Reference 2

Figure B.3 Level of Service Standards for Stairways


Traffic Impeded-One Way Flow

Source: Reference 2

Figure B.4 Pedestrian Speed Downstairs


Traffic Impeded-One Way Flow

Source: Reference 2

Figure B.5 Pedestrian Speed Upstairs

TABLE B.1 Theoretical and Nominal Escalator Capacities

Width at Hip (Inches	Width at Tread (Inches)		Maximum Theoretical Capacity Persons/Hour	Nominal Capacity Persons/Hour	Nominal Capacity Persons/ Minute
32	24	(1)	5,000	3,750	63
		(2)	6,700	5,025	84
48	40	(1)	8,000	6,000	100
		(2)	10,700	8,025	133

(1) incline speed 90 feet per minute, 58 steps per minute.

(2) incline speed 120 feet per minute, 89 steps per minute.

Source: Reference 2

where: λ = arrival rate, pedestrians/unit time

μ = service rate, pedestrians/unit time

Similar expressions are available for multi-channel queues. Let k equal the number of channels(1):

The probability of an empty system, P_o, is

$$P_o = \frac{1}{\left[\sum_{n=0}^{k-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \left(\frac{1}{k!}\;\frac{\lambda}{\mu}\right)^k \left(\frac{k\mu}{k\mu - \lambda}\right)} \qquad \text{(B.6)}$$

The expected number in the queue, L_q, is

$$L_q = \frac{\mu\ (\lambda/\mu)^k\ P_o}{(k - 1)\ !\ (k\mu - \lambda)} \qquad \text{(B.7)}$$

The expected number in the system, L, is

$$L = L_q + \lambda/\mu \qquad \text{(B.8)}$$

The expected time W_q in the queue is

$$W_q = \frac{\mu\ (\lambda/\mu)^k\ P_o}{(k - 1)\ !\ (k\mu - \lambda)^2} \qquad \text{(B.9)}$$

The expected time W in the system is

$$W = W_q + 1/\mu \qquad \text{(B.10)}$$

From the above equations the parameters of interest in queueing (e.g., average delay, total delay, etc.) can be determined at each queueing point.

Bulk Arrivals

Where bulk arrivals occur (e.g., a train discharging passengers on a platform), the pedestrian facilities will be used at their capacity until all arrivals are serviced. Therefore, when treating these types of arrivals, the passenger processing parameters of interest are determined by treating the paths as operating at full practical capacity.(2)

Bulk Departures

When treating bulk departures (e.g., the system users about to enter a train, pedestrians waiting to board an elevator) a mean waiting time of one-half the average headway will generally be used. However, if the situation is such that many of those waiting may not board due to capacity limitations, this method would not be suitable. Instead, a dynamic simulation would probably be required.

Furthermore, it should be noted that if transit headways are sufficiently large (e.g., greater than 20 minutes) the assumed mean waiting time of one-half the headway would probably be an over-estimation. This would be due to user's timing their arrivals because they are aware of when the next vehicle is due to arrive.

APPENDIX B

REFERENCES

1. Shamblin, James E. and Stevens, G. T., Jr., Operations Research: A Fundamental Approach, McGraw-Hill Book Company, New York, 1974.

2. Fruin, John J., Pedestrian Planning and Design, Metropolitan Association of Urban Designers and Environmental Planners, New York, New York, 1971.

3. General Motors Transportation Systems Division, "Parametric Design of Dual Mode Stations," prepared for Third Intersociety Conference on Transportation, Atlanta, Georgia, July 1975.

4. Hutchinson, B. G., Principles of Urban Transport Systems Planning, Scripta Book Company, Washington, D. C., 1974.

5. Barton-Aschman Associates, Inc., Transit Station Simulation User's Guide, prepared for U. S. Department of Transportation, Urban Mass Transportation Administration, Office of Transit Planning, Washington, D. C., January 1975.

APPENDIX C

UMTA STATION SIMULATION MODEL

This Appendix introduces the planner to the basic concepts that are applied by the UMTA Station Simulation Model (USS). The user is referred to the source documentation to facilitate implementation.*

System Definition (Nodes and Links)

For USS a transit station is defined in terms of nodes and links. Nodes represent service devices (e.g., doors, fare collection gates, etc.), path decision points, or system origin/destination points (e.g., entrances, subway car doors, etc.). Associated with each node is either an inbound queue (i.e., destined to a transit vehicle loading platform) or an outbound queue (e.g., destined to the parking lot, street, feeder bus, etc.).

A link connects two nodes and is defined by the pair of nodes (a and b) which it connects. The pair may be ordered, representing flow from (a) to (b), or may be unordered, representing flow in both directions. Each link has a defined movement area and a length, the distance from (a) to (b). The movement area of any two links may overlap or cross, causing a flow conclict. This conflict is modeled by designating the overlap or intersection as a shared area for each of the links involved.

A zone is a node at which pedestrians either enter or leave the network. A separate zone (node) is used to designate each mode and line interfacing with a station, facilitating the specification of transit vehicle characteristics.

The queue area associated with a node is defined to be contained entirely within the movement areas of the links to which it belongs. That is, for inbound flow from (a) to (b), the queue area for node (b) is totally contained in the area of the (a) to (b) link if the (a) to (b)

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*Software Systems Development Program; Transit Station Simulation User's Guide, UMTA, 1975 (Draft Document) link represents the only inbound flow into node (b). Also, queueing areas may be overlapping, just as movement areas of links may be shared.

The pedestrian network of a transit station can be modeled with a maximum of 500 links, 300 nodes, and 30 zones. An example of certain key station elements that are defined by a node and link network is shown in Figure C-1.

Passenger Flow Dimensions (USS)

Volumes

In USS arrivals by all modes other than transit vehicles are considered to enter the station by the walk mode. This includes bicycling, drop off, park and ride, taxi and other similar modes. Arrival by transit vehicle is modeled by a zone inside the (stopped) vehicle to allow for the effects of vehicle door closing times on inbound and outbound passengers.

Arrivals by the walk mode occur at a uniform rate. Therefore, if the design volume at an entrance is 1800 pedestrians/hour (equal to 30 ped./min.), one arrival will occur at that entrance every two seconds of the simulation time. Arrivals are randomized by stochastic assignment of desired walk speed. Person arrivals by a transit mode are generated when a vehicle arrives at the station. The delay these passengers would experience upon exiting the vehicle would include the time required by any vehicles already present to clear the loading/unloading area. The number of people alighting at a particular station is determined from specified O-D volumes and the profile of station activity.

Each person arrival is assigned a set of individual attributes which include:

(1) Destination in Station
(2) Desired Walk Speed
(3) Handicapped Status
(4) "Red Flag" Status*

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*Traced throughout journey in station.

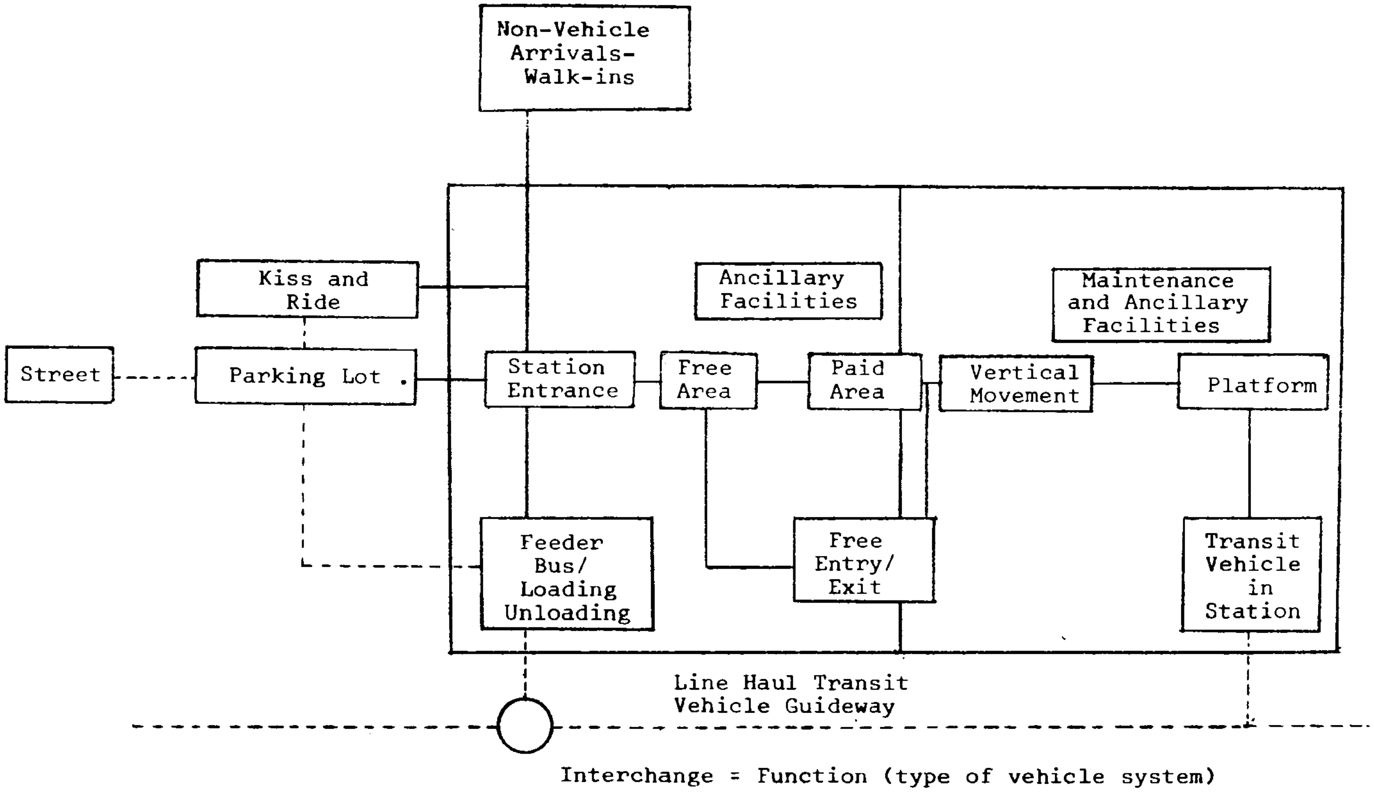

Figure C.1 Station Elements Represented by Nodes and Links for USS

(6) Time Entered Station
(7) Person Identification Number
(8) Other Recordkeeping Variables.

The following data is recorded at discrete intervals for each individual as he passes through the station network:

(1) Total time in queue
(2) Total Time spent walking on last link
(3) Next event (enter queue, leave queue, or path decision)
(4) Time of next event
(5) Last node passed through
(6) Next node
(7) Other data collection variables

The sum of the changes in the above data on individuals is used to produce output reports.

Walk Time

An individual's walk time on a link is a function of link length, desired walk speed, density of pedestrians on the link, presence of conflicting flows, and the length of the queue. If no congestion or queueing is present, walk time on a link would equal the link length divided by the desired walk speed. If congestion or queueing exists, the procedure used by USS is to subtract the queue length from the link length to determine the movement length, determine the individual's walk speed as a function of congestion in the effective movement area, and calculate walk time as equal to the movement length divided by the individual's walk speed. At the time he reaches the end of the queue, he is placed into a "queued events list" to await processing through the queue.

Time in Queue

Queueing in a transit station generally occurs at doors, fare collection devices, vehicle doors, and escalators. To model queueing the USS model uses the queueing discipline assumption of "first-in, first-out," in which pedestrians are serviced in the same order in which they arrive.

The default distribution the USS program uses to measure service time is the negative exponential. However, the user may specify an empirically derived distribution. The latter might be preferred if service times are a function of arrival pattern or passenger attributes.

In order to use the negative exponential distribution the mean service time must be specified. For fare collection devices, turnstiles, and other similar facilities the user must find some source by which to estimate the mean service time. For doors and narrow channels the USS documentation suggests a method developed by J. J. Fruin to determine mean service time, $\bar{S}$, which is shown below:

$$\bar{S} = w \frac{N_1}{N_1 + N_2} \frac{HALL}{60} \tag{C.1}$$

where:

w = doorway width in feet

HALL = capacity in persons per minute per foot width of device

N_1 = number approaching door from analysis link

N_2 = number approaching door from opposing link

The stochastic service time, S, is computed using the function:

$$S = - \bar{S} \ln (R) \tag{C.2}$$

This is the formula for the negative exponential distribution when R is a positive random number less than one.

Path Choice

The factors which influence an individual's path choice via USS are:

(a) passenger attributes, such as desired destination and handicap status,

(b) the length of queues, where a choice among possible paths is available, and

(c) the types of activities that can be reached on alternate paths.

These factors are incorporated into a probabilistic model to simulate an individual's path choice at decision points. The Path choice is based upon travel time to the destination zone, relative congestion, and queueing on the alternative links connected to the decision point, or user-specified probabilities of path choice. The user-specified probabilities are used to model passenger diversion (possibly including backtracking) to ancillary facilities. The model also takes into account paths that will not accept handicapped persons.

It is assumed that all passengers will not select the minimum time (or minimum distance) path through the station. The degree to which passengers are constrained to take shorter paths is determined by an input parameter.

Transit Vehicle Loading

The following variables control the transit vehicle loading model of the USS program:

1. Design hour profile of available capacity (i.e., vehicle capacity minus through passengers).
2. Minimum door open time.
3. Door open extension time (to allow each arrival to board)
4. Maximum door open time.

The number of persons who would board a vehicle, N, would be:

$$N = \min(W, O, A) \tag{C.3}$$

where:

W = number of persons waiting to board

O = number of persons who could board subject to maximum door open time

A = available capacity

The available capacity would be specified as a function of time in the design hour profile of available capacity.

The user may specify either a gap distribution (time between vehicle departures and arrivals: e.g., for PRT vehicles) or the user may specify a headway distribution (time between arrivals) to model vehicle arrivals.

The Elevator Model

The USS program models elevators as links with doors on each end and a fixed travel time. The design data which controls the program is similar to that for the transit vehicle model. These variables are:

(1) Mean headway or design hour profile of mean headway.
(2) Distribution specifying random variation in headways.
(3) Minimum, extension, and maximum door open times.
(4) Distribution of person capacity of elevator.

Statistical Distributions

To model walk speeds, vehicle headways, and device service times the USS program provides the following theoretical and empirical distributions:

(1) Negative exponential, Erlang, and Normal distributions to simulate arrivals.
(2) Walk speed cumulative distribution function.
(3) Cumulative arrivals vs. time.
(4) Area occupancy vs. probability of selecting walk speed for corridors.
(5) Area occupancy vs. probability of selecting walk speed for stairs.
(6) Area occupancy vs. mean walk speed for corridors.
(7) Area occupancy vs. mean speed for stairs.

Provisions are made for user-supplied functions if the default distributions are unsuitable.

APPENDIX D

ENVIRONMENTAL ANALYSIS: TEMPERATURE, AIR QUALITY, AND AIR FLOW

Computer Analysis

The organization of the dynamic simulation provided by the SES model is shown in Figure D.1.* The train performance subprogram continuously determines, for all trains in the system:

(1) location (ft.),
(2) speed (mph),
(3) acceleration (mph/sec),
(4) aerodynamic drag on vehicle (lbs),
(5) heat rejection (But/sec),
(6) power demand (amps/motor), and
(7) tractive effort (lbs/motor).

The aerodynamic subprogram uses these parameters to compute continuously, for each line segment and ventilation shaft segment, the values of:

(1) air flow (cfm)
(2) air velocity (fpm), and
(3) pressure rise across all fans which are in operation (in. w.g.)

The temperature/humidity subprogram uses the computed air flows and train-heat release data to calculate, for each line subsegment and ventilation shaft subsegment, the values of temperature (in °F) and humidity ratio (lb/lb).

The air velocities computed in the aerodynamic subprogram are reinput into the train performance subprogram and are used to calculate the air flows adjacent to the trains. This is then used to calculate the vehicle aerodynamic drag.

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*Subway Environmental Design Handbook, Vol. I: Principles and Applications, Associated Engineers, for UMTA, 1975.

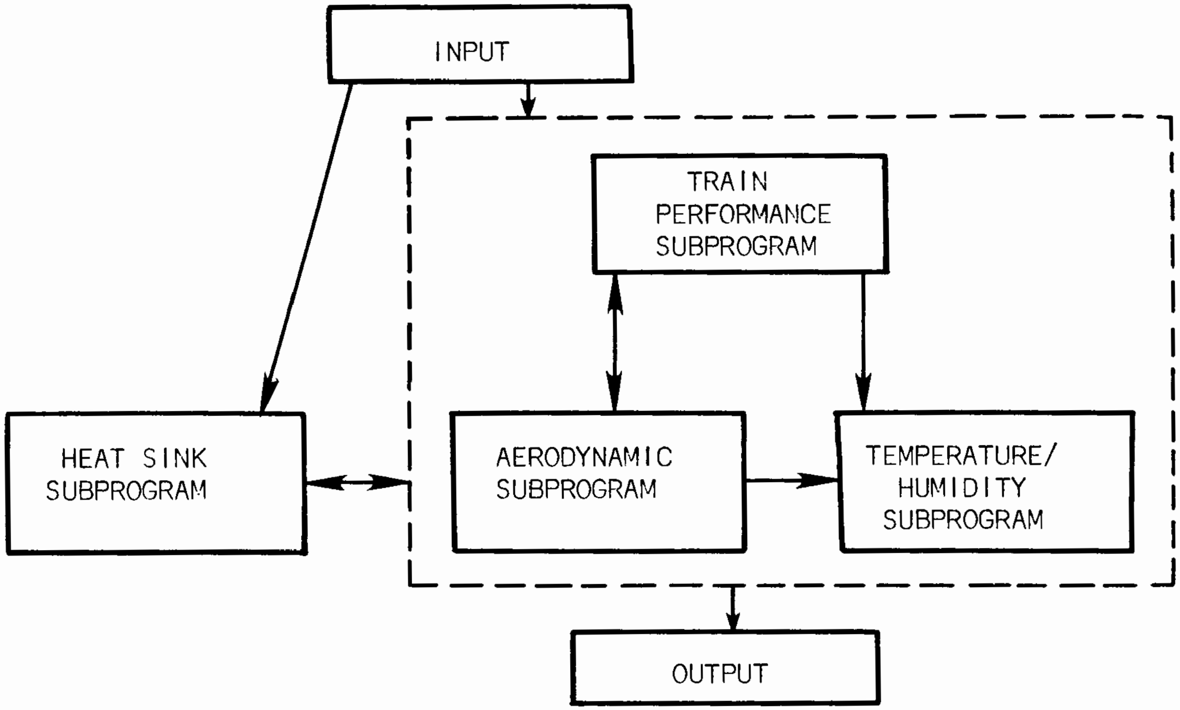

Figure D.1 Organization of the Subway Environmental Simulation Model

The subway ventilation and heat load computations from these subprograms, along with data concerning the thermal properties and daily and annual changes in ambient (outside) conditions, are used in the heat sink subprogram to compute the long-term conduction of heat between the subway air, the structure, and the soil surrounding the subway.

For the purpose of the terminal design methodology, the SES model can be used to estimate the following distinct performance measures.

Air Inflow	cubic feet per minute per person
Air Velocity	feet per minute
Thermal Comfort	"relative warmth index" or "heat deficit rate"

The first two performance measures, cu. ft./min./person and ft./min. are rather straight forward. However, the two that apply to the criterion of thermal comfort are more complex. The Relative Warmth Index (RWI) is applicable to warm environments and the Heat Deficit Rate (HDR) is applicable to cool environments. Both are derived from the equation of human heat balance:

$$M \pm C \pm R - E - W \pm S = 0 \tag{D.1}$$

where: M = metabolic rate
C = net convective heat exchange rate
R = net reactive heat exchange rate
E = evaporative heat loss rate
W = net external mechanical work performed
S = storage rate of body heat

The methods used in determining the RWI and the HDR measures are discussed thoroughly in the Subway Environmental Design Handbook and representative values of both are discussed with regard to the determination of desired standards.

Manual Techniques

A method is given in the Subway Environmental Design Handbook to estimate the functional requirements for the environmental control equipment. The basic steps that are suggested are:

1. Establish the human engineering criteria.
2. Establish the physical and operating data base for the system.
3. Establish the ambient design conditions.
4. Establish the heat gain for the subway.
5. Reduce the heat gains for the subway.
6. Compute the heat loss (or gain) to the heat sink.
7. Compute the ventilation ratio required.
8. Compute the ventilation rate, if any, induced by the underplatform exhaust system.
9. Compute air velocities.
10. Compute heat gain (or loss) convected into the subway by the ventilation air.
11. Compute the net heat gain (or loss) for the station module.
12. Compare the cooling and heating level with the resources of the system.
13. Isolate station public areas from the tunnel.
14. Check design for emergency and other criteria.

These steps are iterated until an acceptable design results. This strategy is also appropriate for evaluating a specific design. The actual techniques required for the calculation are given in Chapter 3 of the handbook. An example calculation is provided in the handbook to illustrate the techniques.

APPENDIX E

DESIGN FOR ILLUMINATION AND BRIGHTNESS

There are two primary methods for designing illumination systems. The method most often used to estimate the number and type of lamps or luminaries, or both, which yield a certain average illumination level over a particular interior is the lumen method. It provides an average footcandle value for the area under study through a relatively simple formula. The second, termed the point-by-point method, while being more accurate in some cases, involves more complex computations. In general, it is used when a relatively small number of direct-type luminaries are employed.(1)

The Lumen Method(1)

This method is based upon relationships between light distribution characteristics of luminaries, luminaire mounting height, and room characteristics. The six basic steps of the lumen method are as follows:

(1) Determine the required level of illumination.
(2) Select the lighting system and luminaries.
(3) Determine the coefficient of utilization.
(4) Estimate the maintenance factor.
(5) Calculate the number of lamps and luminaries required.
(6) Determine the location of the luminaries.

Step 1. Determine the Required Level of Illumination

The Subcommittee on Design Standards, Technical and Operations Committee of the Institute for Rapid Transit, has suggested the following standards for subway stations.(2) If these standards are judged to be unsuitable for the modal interface facility being designed, handbooks and manuals are available which list many of the more common seeing tasks, along with the illumination level that should be provided for each.(1)

Passenger Stations

Location	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

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

Parking Areas

Location	Recommended Minimum Maintained Illumination Levels (fc)
Self-parking	2
Pedestrian walkways	3
Entrance and exit roadways	2

The illumination on all entrance and exit roadways shall be graduated up or down to the illumination level of the "feeder" street or highway.

Transit Rights-of-Way and Storage

Location	Recommended Minimum Maintained Illumination Levels (fc)
Underground	1.5
Entrances and exits within 300 feet of portal	
(night)	1.5
(day)	10
On grade and aerial structures	0.5
Underground special trackwork areas	3
Yard and other special trackwork areas	2
Transit vehicle storage areas	1

Operations Central Control Building

Central Control Area

Lighting depends on the type of panels. General lighting should be designed to complement panel lighting and should be capable of being dimmed.

General illumination	100*
Face of Control Panels (vertical)	150*
Rear of Control Panels (vertical)	10
Dispatch Desks (horizontal, desk level)	50
Emergency Lighting	3

*Illumination levels should be variable ± 50 percent of levels indicated.

Step 2. Select the lighting system and luminaries.

Lighting systems are classified as:

1. Direct
2. Semi-Direct
3. General Diffuse or Direct-Indirect
4. Semi-Indirect
5. Indirect

The choice of lighting system and luminaries to be used will generally depend upon the seeing tasks to be performed and the characteristics of the area to be illuminated.

Step 3. Determine the coefficient of utilization.

The coefficient of utilization is the ratio of the lumen reaching the working plane to the total lumens generated by the lamps. This factor takes into account the efficiency and distribution of the luminaire, its mounting height, the room proportions, and the reflection factors of walls and ceiling. Tables are then used which translate these variables into a factor which represents the coefficient of utilization.

Step 4. Estimate the maintenance factor.

The maintenance factor is used to represent three elements of maintenance. These elements are: the loss in light output, or depreciation, of the lamp over time; the loss in illumination through accumulated dirt on the reflection or transmitting surfaces of the luminaire and the lamps; and the loss of reflected light through the accumulation of dirt on walls and ceilings.

The quantitative values for a maintenance factor are generally determined through a qualitative description of the conditions present and are also dependent upon the type of luminaire used. Maintenance factors are generally considered to fall within three types of conditions:

1. Good Maintenance Factor - where atmospheric conditions are good, luminaires are frequently cleaned, and lamps are replaced systematically.
2. Medium Maintenance Factor - where less clean atmospheric conditions exist, luminaire cleaning is fair, and lamps are replaced only after burnout.
3. Poor Maintenance Factor - where atmosphere is quite dirty and equipment is poorly maintained.

Since these descriptions are subject to variable interpretation and do not describe a complete set of possible conditions; care should be taken in evaluating existing and anticipated conditions. Furthermore, reference 2 suggests that an average maintenance factor for use in all areas of subway stations other than offices should not exceed 0.65.

Step 5. Calculate the number of lamps and luminaries required.

The number of luminaries and lamps required is calculated from the following formulas:

$$\text{Number of Lamps} = \frac{\text{Footcandles} \times \text{Area}}{\text{Lumens per Lamp} \times \text{Coeff. of Utilization} \times \text{Maintenance Factor}} \quad \text{(E-1)}$$

$$\text{Number of Luminaries} = \frac{\text{Number of Lamps}}{\text{Lamps per Luminaire}} \quad \text{(E-2)}$$

It should be noted that for any given lighting system design, Equation E-1 can be rearranged to estimate the illumination, in footcandles, for that design.

Step 6. Determine the location of the luminaires.

Luminaire location will be dependent upon several factors which, among others, include the general architecture, size of bays, type of luminaire, and position of previous outlets. In order to provide relatively uniform distribution of illumination, it is necessary to insure that the spacings between luminaires do not exceed certain limits. These limits are generally related to the mounting height of the luminaire (e.g., maximum spacing = S x mounting height, where the value of S is related to the type of luminaire).

The Point-by-Point Method(1)

While the lumen method is based upon the average light flux effective throughout an area, the point-by-point method is based upon the amount of light which will be produced at specific points in the area. The following types of light sources are used in this approach:

(1) Point Source - Illumination is inversely proportional to the square of the distance from source. An incandescent lamp, alone or in an enclosing globe, is usually considered as a point source.

(2) Line Source of Infinite Length - Illumination is inversely proportional to the distance from source. A continuous row of flourescent fixtures would approach this condition when the distance from the source is sufficiently short.

(3) Surface Source of Infinite Area - Illumination does not change with distance. This condition could be approached, at sufficiently short distances, by a large luminous panel or a ceiling lighted by totally indirect means.

(4) Parallel Beam of Light - Illumination does not change with distance. At sufficiently short distances, this condition can be approached by searchlights, spotlights, and other similar beam-producing devices.

Since no sources are perfectly point, infinite line, infinite surface, or parallel beam types, care must be taken when applying the illumination-distance relationships.

After the type of light source has been defined, trigonometric relationships and empiric data on candlepower distribution can be used to determine the illumination at any point on a floor, wall, ceiling, or other surface.

Brightness Calculations(1)

The brightness of a reflective surface can be measured in terms of footlamberts and, for a surface, would be equal to the footcandles incident on the surface multiplied by the reflection factor of the surface. Reference 2 suggests the following standards for brightness ratios:

(1) Typical brightness ratio between stairs, escalators, etc., to general platform or mezzanine areas should be approximately - 2/1

(2) Station interiors should have luminance ratios typically not to exceed

Wall to floor	- 3/1
Wall to ceiling	- 1/3
Luminous coffers to walls and/or adjacent horizontal surfaces	-10/1
Luminaires to adjacent surfaces	-20/1

(3) Elevated Stations (at night) Exterior Areas

Wall to floor	No limit set
Wall to ceiling	No limit set
Luminaires to adjacent surfaces	-40/1

(4) Substations, switchrooms and control rooms should have luminance ratios not to exceed:

Wall to floor	- 3/1
Wall to ceiling	- 1/3
Luminaires to adjacent surfacew	-20/1

Luminaires in control rooms in particular should be so positioned that no reflected glare from meter faces or cathode ray tube monitoring screens meets the operator's eyes while at his normal operating position. Non-specular glass should be used on meter faces.

(5) Small areas for accent, design interest, or message purposes, such as for station identification, safety or guidance, will be allowed to have brightness ratios in excess of the preceding criteria.

APPENDIX E

REFERENCES

1. Westinghouse Electric Corporation, Lighting Handbook, Bloomfield, New Jersey, 1953.

2. Institute for Rapid Transit, Guidelines and Principles for Design of Rapid Transit Facilities, May 1973.

APPENDIX F

SUGGESTED STANDARDS FOR NOISE LEVELS*

Noise in Underground Stations

Platform level, trains entering and leaving	80 dBA
Platform level, trains passing through	85 dBA
Platform level, trains stationary	67 dBA
Maximum train room reverberation time	1.6 to 2 sec.
Platform level, only station ventilation system operating	55 dBA
In station attendants' booths	45 dBA

Noise in Above-Ground Stations

Platform level, trains entering and leaving	70-75 dBA

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*Institute for Rapid Transit, Guidelines and Principles for Design of Rapid Transit Facilities, May 1973.

APPENDIX G

BART SECURITY ASSESSMENT PROCEDURE

In order to measure the environmental qualities of BART stations, including security, the Institute of Urban and Regional Development, University of California, Berkeley, used certain indicators to measure the non-quantifiable effects of station design.* These indicators were of two types: General Station Indicators (GSIs) and Specific Station Indicators (SSIs). GSIs were defined as indicators which may be attributed to specific areas of, or paths through, a station (e.g., distance to station agent's booth, user visibility, etc.).

Three assessment methods were used in the BART study which are applicable to security: General Station Score (GSS), Mean Cell Score (MCS), and Mean Major Pedestrian Path Cell Score (MMPPCS). The GSS is based upon scales of the General Station Indicators. The scale used in the BART study is shown below:

Indicator	Score
Station elevation	
Surface	2
Subway	1
Aerial	2
Number of levels (including street level)	
Two	3
Three	2
Four	1

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*Institute of Urban and Regional Development, University of California, Berkeley, BART-I: Traveler Behavior Studies, Part II, Volume II, BART Traveler Environment: Environmental Assessment Methods for Stations, Lines, and Equipment; Final Report to Metropolitan Transportation Commission, Berkeley, California, May 31, 1973.

Indicator	Score
Passenger volume (estimated ADT for 1975)	
0 - 10,000	1
10 - 25,000	2
More than 25,000	3
Line situation	
Through	1
Transfer	1
Terminal	2
Trip attraction/generation	
Attractor	1
Generator	3
Balanced	2
Predominant land use immediately surrounding station	
Surburban	
residential	3
commercial	2
mixed	2
Urban	
residential	2
commercial	1
mixed	1
Industrial	1
Freeway	1
Vacant, rural, or agricultural	1
Land use density immediately surrounding station	
Low	3
Medium	2
High	1
Parking	
No	2
Yes	1

Indicator	Score
Number of paid-area exits	
One	3
Two	2
Three or more	1

The General Station Score of a particular station for security would then be the sum of its scores in each individual category (the higher the score, the better the security). The scale used for the Mean Cell Score in the BART study is shown below:

Indicator	Score
Walking distance from nearest station agent's booth	
0 - 20 ft.	5
20 - 50 ft.	4
50 - 100 ft	3
100 - 200 ft.	3
More than 200 ft.	1
Walking distance from nearest major user path	
0 - 20 ft	3
20 - 50 ft.	2
50 - 100 ft.	1
More than 100 ft.	0
Walking distance from nearest courtesy phone	
0 - 5 ft.	3
5 - 20 ft.	2
20 - 50 ft.	1
More than 50 ft.	0
Paid area	1
Visible and indirect footpath from jajor user path	1
Visible and within 200 ft. of station agent's booth, or visible by closed circuit TV	1
Area with obviously poor lighting	-5
Area which could be used as a hiding place	-5

To score security, a rectangular grid (the scoresheet) is overlaid on a "Rational User Path Diagram" (RUPD). The RUPDs are plan diagrams which show the locations, directions, and relative volumes of the paths between station subdestinations.

The cells of each scoresheet which are at least half occupied by station property are outlined. The value of each security indicator is determined for each cell, the sum of these being the cell score. The Mean Cell Score is equal to the total of cell scores, divided by the number of cells. The BART study used cells ranging in size from 5 feet on a side to 25 feet on a side, dependent upon the type of area under study.

To determine the Mean Major Pedestrian Path Cell Score, the cell scores for each cell traversed by a "major pedestrian path" are added together, then divided by the total number of cells on the path. It was stated in the study reference that since the MMPPCS focuses upon major pedestrian paths, it should be more representative than the MCS in simulating users' perceptions of the most active station areas.

APPENDIX H

DEPARTMENT OF DEFENSE SAFETY STANDARD*

I. Definitions

(a) Hazard - Any real or potential condition that can cause injury or death to users or personnel, or damage to or loss of equipment or property.

(b) Hazard Level - A qualitative measure of hazards stated in relative terms. For the purposes of this standard, hazard levels are defined: Conditions such that human error, environment, design characteristics, procedural deficiencies, or subsystem or component failure or malfunction:

Categore I - Negligible

. . . will not result in personal injury or system damage

Category II - Marginal

. . . can be counteracted or controlled without personal injury or major system damage.

Category III - Critical

... will cause personal injury or major system damage, or will require immediate corrective action for personal or system survival.

Category IV - Catastrophic

. . . will cause death or severe injury to persons, or system loss.

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*Military Standard, "System Safety Program for Systems and Associated Subsystems and Equipment: Requirements for Department of Defense, United States of America," MIL-STD-882, July 1969. In Safety in Urban Mass Transportation: The State-of-the-Art, Highway Research Board Task force on Urban Mass Transportation Safety Standards, Division of Engineering, National Research Council, Washington, D. C., September 1973.

2. System Safety Criteria and Considerations

System designs and operational procedures developed by the designer or operator should consider, but not be limited to the following:

(a) Avoiding, reducing, or eliminating significant hazards identified by analysis, design selection, material selection, or substitution. Composition of hydraulic fluid, solvent, lubricant, or other hazardous material shall provide optimum safety characteristics.

(b) Controlling and minimizing hazards to users, personnel, equipment, and material which cannot be avoided or eliminated.

(c) Isolating hazardous substances, components, and operations from other activities, areas, users, personnel, and incompatible materials.

(d) Incorporating "fail-safe" principles where failures would disable the system or cause a catastrophe through injury to users, personnel, damage to equipment, or inadvertent operation of critical equipment.

(e) Locating equipment components so that access to them by personnel during operation, maintenance, repair, or adjustment shall not require exposure to hazards such as chemical burns, electrical shock, cutting edges, sharp points or toxic atmospheres.

(f) Avoiding undue exposure of personnel or users to physiological and psychological stresses which might cause errors leading to mishaps.

(g) Providing suitable warning and caution notes in operations, maintenance, and repair instructions; and distinctive markings on hazardous components, equipment, or facilities for personal protection.

(h) Minimizing severe damage or injury to users, personnel, and equipment in the event of an accident.

3. Hazard Levels

The hazard levels, Category I (Negligible); Category II (Marginal); Category III (Critical); and Category IV (Catastrophic) as defined in Section I, shall be used as a qualitative measure of a system's hazards. These categories may be further defined, if desired.

4. System Safety Precedence

Actions for satisfying safety requirements in order of precedence are specified below:

(a) Designing for minimum hazard - The major effort throughout the design phases shall be to select appropriate safety design features; e.g., fail safe, redundancy.

(b) Safety devices -known hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices.

(c) Warning devices - Where it is not possible to preclude the existence or occurrence of an identified hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be standardized within like types of systems.

(d) Special procedures - Where it is not possible to reduce the magnitude of an existing or potential hazard through design or the use of safety and warning devices, the designer or operator shall develop special procedures. Precautionary notations shall be standardized.

5. Design Criteria/Specifications

When design criteria specified by the operating agency is proved inadequate in regard to safety, the designer shall report the deficiency and recommend corrective actions with supporting evidence to the operating agency.

6. Analyses

Analyses are performed to identify hazardous conditions for the purpose of their elimination or control. Analyses shall be made to examine the system, subsystems, components and their interrelationships, to include logistic support, training, maintenance, and operational environments. The analyses shall be accomplished to do the following:

(i) Identify hazards and determine any needed corrective actions.

(ii) Determine and evaluate safety considerations in tradeoff studies.

(iii) Determine and evaluate appropriate safety design requirements.

(iv) Determine and evaluate operational, test, and logistic safety requirements.

(v) Determine whether the qualitative objectives or quantitative numeric requirements established by the operating authority have been achieved.

Qualitative and/or quantitative analyses will be performed as specified by the operating agency. These analyses shall be revised when changes are made in components, subsystems, or total systems.

A qualitative analysis would provide a technical assessment of the relative safety of a system design. A quantitative analysis would provide a numerical assessment of the relative safety of a system design by determining: the probability of occurrence of critical or catastrophic hazards, and the calculated system, subsystem, or equipment numeric requirement risk level.

(a) Preliminary hazard analysis - A preliminary analysis shall be performed as the initial task during the design of a system. This analysis shall be a comprehensive, qualitative study. Such information shall be used in the development of safety criteria to be imposed in performance or design specifications. Areas to be considered shall include, but not be limited to, the following:

(1) Isolation of energy sources.

(2) System environmental constraints.

(3) Compatibility of materials.

(4) Use of pressure vessels and associated plumbing, fittings, mountings, and hold-down devices.

(5) Safe operation and maintenance of system.

(6) Training and certification pertaining to safe operation and maintenance of the system.

(7) Egress, rescue, survival, and salvage.

(8) Fire ignition and propagation sources and protection.

(9) Environmental factors such as equipment layout and lighting requirements and their safety implications in manual systems.

(10) Fail safe design considerations.

(11) Safety from a vulnerability and survivability standpoint, e.g., fire suppression systems, subsystems protection, and system redundancy.

(12) Protective clothing, equipment, or devices.

(13) Human error analysis of operator functions, tasks, and requirements.

(b) Subsystem hazard anaylsis - This is an expansion of the preliminary hazard analysis. It shall be performed to determine, from a sefety consideration, the functional relationships of components and equipments comprising each subsystem. Such analysis shall identify all components and equipments whose performance degradation or functional failure could result in hazardous conditions. The analysis should include a determination of the modes of failure and the effects on safety when failures occur in subsystem components.

(c) System hazard analysis - The designer shall conduct reviews or studies which define the safety integration and interface requirements of the total system. Analyses shall be performed of subsystem interfaces to determine the safety problem areas of the total system. Such analyses shall include, but not be limited to, review of subsystems interrelations for:

(1) Compliance with safety criteria.

(2) Possible independent, dependent, and simultaneous failures that could present a hazardous condition.

(3) Insuring that normal operation of a subsystem cannot degrade the safety of another subsystem or the total system.

(d) Operating hazard analysis - Analyses shall be performed to determine safety requirements for users, personnel, procedures, and equipment used in maintenance, support, storage, operations, emergency escape, egress, resuce, and training during all phases of the intended use as specified in the system requirements. Engineering data, procedures, and instructions developed from the engineering design and initial test programs shall be used in support of this effort. Results of these analyses shall provide the basis for:

(1) Design changes where feasible to eliminate hazards or provide safety devices, and safeguards.

(2) The warning, caution, special inspections, and emergency procedures for operating and maintenance instructions, including emergency action to minimize personal injury.

(3) Identification of a hazardous period time span and actions required to preclude such hazards from occurring.

(4) Special procedures for servicing and maintaining the system.

7. Action on Identified Hazards

Action shall be taken to eliminate or minimize hazards revealed by anaylses or related engineering efforts. Catastrophic and critical hazards shall be eliminated or controlled. If these hazards cannot be eliminated or controlled to a specified probability of occurrence, the alternative controls will be immediately presented to the operating agency for resolution.

8. Training

Safety information on approved methods and procedures will be included in instruction lesson plans and examinations for the training of system (operator and maintenance) personnel. Protective devices and emergency equipment will be identified and included in training.

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