in corners. Construction materials should be durable and economical without sacrificing the needs of the user or attractiveness. Figure 3 illustrates a typical prototype shelter. The critical elements of this shelter are identified in Table 1. The mass-produced shelters currently available are not apt to meet the criteria and considerations discussed above, although modifications to them can lead to a successful program.

In addition to the space available for the shelter, the availability of pavement is also important. While there are sidewalks and pavements in the CBD and other high-activity locations, they are sometimes absent in residential neighborhoods. This should not preclude shelter placement in low-density residential areas without paved walkways. The placement of a shelter should encourage its use and not inhibit pedestrian flows. Therefore, the ideal location is at curbside when wide sidewalks are available, set back across narrow sidewalks, and close to curbside (with a pavement added) when there is no sidewalk. In all cases, there should be provisions for people with mobility limitations so that wheelchairs or walking aids are not hampered.

CONCLUSION

The viability of our transit systems is going to depend not so much on their own technology as on those elements of the system that represent them to the community. A key element that symbolizes transit systems in our cities and communities is the transit shelter, the place where the components of transit service interact. The patron meets the operators and equipment, pays fares, gains information about the system, and forms opinions about the level of service. The operator should intend that such a facility be more than simply wind and weather protection. The role of the transit shelter should be carefully identified through a close analysis of the community and its perceived needs, the patrons themselves, and the system as a whole.

The present approaches to the planning and design of transit shelters have been piecemeal at best and limited in scope. This paper suggests a more systematic, yet flexible, approach, and a methodology that will allow better definition and analysis of the problem and encourage more creative thinking toward the planning and design of transit shelters. By examining transit shelters in the context proposed here, they will have the potential to transcend their identity as simple waiting areas. Shelters could function as indoor-to-outdoor rooms for the transit user in which he or she would not only wait but might also socialize, read, rest, listen, or watch in a safe environment; i.e., transit shelters could become social places oriented to the needs of all the system's patrons, including the elderly, the mobility-limited, the young, the commuter, and the choice rider.

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Role of Simulation Models in the Transit-Station Design Process

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This paper summarizes the ways in which a transit-station simulation model could be developed to function as a more integral part of the design process. It examines in detail the interface of the user with the model. Specific problems dealing with network and spatial representation are discussed, and the model output is matched with the information needs of the designer at the appropriate stages in the design process. The paper concludes with a discussion of the cost-effectiveness of station-simulation models.

Over the past several years, the Urban Mass Transportation Administration (UMTA) has been developing an analytical tool to assist transportation planners and engineers in the design of public transportation facilities. Recently, a pilot version of a computer program to evaluate transit-station designs was tested and evaluated (1). The role of simulation models in the design process was examined in detail, and a number of ideas about the expanded range of analysis possible when computer models are used to supplement more conventional techniques of facility design were developed. This paper summarizes

the ways in which a future version of the simulation model could function as a more integral part of the design process. Basically, the paper focuses on the interface between the user and the model, rather than on the adequacy of the underlying theory and mathematics.

Design is a synthetic process, which places it at the periphery of scientific activity. The acts of designing, manipulating and arranging components, and developing principles of organization cannot be decomposed into a series of easily defined sequential steps, for the process itself requires creativity and imagination. Consequently, tools to aid the process must be flexible and easy to use. They must not present barriers to the process, but should be shortcuts that release the designer from drudge work and give him or her more freedom to exercise imagination and test alternatives.

A conservative approach was used in developing the transit-station simulation model (USS). The model does not attempt to optimize the station or treat the problem deterministically. It uses a Monte Carlo discrete-event simulation procedure with a Markov-type path-choice model (2). The simulation approach presents the designer with a representation of the station, which he or she is free to use as a physical model. Because of the large number of unknown values and the lack of a deterministic theory that would permit the application of mathematical formulas to predict station performance, the computer is used to generate a simulated history of station performance in time. The designer can then study this performance record, modify the design where necessary, and test the design again.

To use the model, it is necessary to translate the physical design for the station into a prescribed mathematical notation that the computer can understand. At present, it is not possible to enter a drawing of the station into the computer memory, although future modifications may permit this. As in any computer model, the assumptions and mathematical rules used by the programmer largely determine the results.

NETWORK CODING AND SPATIAL DESCRIPTION

In abstracting a station design to provide input data for the model, a coding protocol that is based on a network or graphical representation in terms of links and nodes must be used. However, designers, particularly architects, find this notation foreign to their thinking, since they have been trained to think in terms of spaces and sequences of spaces, which are best described by areas and their boundaries. Networks are difficult for architects to conceptualize because of their spatial ambiguity.

The network-coding protocol often requires many subjective judgments by the analyst. The layout of paths is fairly straightforward, but locating nodes requires more intuition. The most difficult to determine are the link and node characteristics, such as allowable areas for movement and queueing. Consequently, what may be evaluated is not the actual physical dimensions of the station, but an interpretation of the area available.

Often, repeated runs are necessary to debug a station. Nearly all coded stations abort in the initial runs because of link and queue-area overloads, and to eliminate these errors, movement and queue areas must be changed on the input data cards. Since the cases studied have dealt with existing stations that are accommodating flows equal to or greater than those specified in the simulation, it was assumed that the coded areas had been underestimated. However, in dealing with designs for proposed stations, the designer may not be sufficiently confident in his or her knowledge of the operation of the model to determine whether the source of an error is faulty design, faulty coding, or faulty interpretation of the area available.

To remedy the problem of correctly interpreting and coding the stations, several alternative coding schemes were investigated. Of these, the most promising retains the basic link-node network representation and subdivides the station plan into a series of sectors or areas of homogeneous use and simple geometry. Links are drawn across each sector to represent major straight-line movement paths. Nodes occur at sector boundaries and devices. Performance statistics for all links crossing each sector are aggregated to give a level-of-service measure for the sector. Consequently, most of the subjective judgments required by the translation of spaces into the network format are removed, and the designer can evaluate the individual spaces in the station.

ROLE OF SIMULATION MODELS IN THE DESIGN PROCESS

The design of transit stations has been a major concern of transit planners and operators for many years. However, for architects and engineers, transit stations are simply another among many specialized facility types that they design. They are not usually specialists in one facility type, but are trained to deal with specific facilities in a generalized design process.

As a part of their training, designers are taught methods of assembling factual information about their problem. Where this information is not available, they rely on experience and intuition to supply the basic data needed. They rely on synthesis rather than on analysis, and most prefer to spend most of their time on actual design preparation rather than on research and data acquisition. Data collection and analysis are viewed as peripheral activities to the commencement of the design. Consequently, an analytical tool that deals with the evaluation of a fully developed design is of limited usefulness. Once a design has reached a level of detail sufficient for a formal analytical evaluation, all of the important decisions have been made, and revisions cause a considerable loss of time.

Although design processes vary, there are usually four phases into which they can be divided: (a) programming, (b) site analysis, (c) schematic design, and (d) detailed design. For most architectural projects, the design requires less than 15 percent of the total person-hours expended.

Programming and Site Analysis

Programming and site analysis are analytical stages. Programming involves the development of user and client requirements. What functions must be accommodated? What spaces must be provided? How much space is needed? Site analysis involves the inventory of conditions found at the proposed location and includes such items as subsoil conditions, adjacent land uses, traffic, circulation, building regulations, and visual characteristics.

Schematic Design

In the schematic-design phase, the designer begins to assimilate the information that he has acquired and to function as a black box in synthesizing alternative schematics for the facility. These schematics are quite crude, graphically, often no more than scribbled sketches. The designer cycles through a number of ideas, constantly testing and refining the images, working quickly, dealing with the major spaces and design elements, and ignoring unimportant elements entirely.

The resulting drawings are quite diagrammatic and seldom have spaces accurately measured and dimensioned. In this stage the design takes shape as an organizing principle rather than as a set of functional elements.

Detailed Design

Once the organization of the design has been established, it must be reconciled with the site and the program. In the schematic phase, the designer has usually dealt with these aspects internally and impressionistically. In the detailed-design phase, measured drawings are made and individual sections can be worked on and developed separately. This is the point at which the simulation model can currently be used.

USE OF SIMULATION MODELS IN PRACTICE

A simulation model will be used by transit-station designers if it can respond to their needs by (a) saving design time, (b) answering hard questions, or (c) reducing construction costs. Each of these areas is examined below.

Saving Design Time

It does not appear that the use of a simulation model can reduce the time needed to design a new transit station. As an evaluation tool, the model is a means to verify the adequacy of a design, but because of its information requirements, it cannot substitute for intermediate evaluations during the schematic-design phase. Currently, it would be most effective as a tool with which to review completed designs submitted by consultants. Architectural and engineering firms who attempt to use such programs without prior experience will have heavy initial costs in time and computer resources. Consequently, the use of simulation models will be limited to those that are already heavy computer users (perhaps only 10 to 15 percent of all architectural and engineering firms). Coding requirements and machine-processing time will also increase the amount of time needed for station design.

However, the use of a simulation model can save significant time in the redesign or retrofitting of existing stations where the designer begins with a completed plan. The coding becomes much simpler and the simulation results can be verified in the field. In such applications, the model can provide the designer with a means to recreate conditions in the existing station without lengthy field observations. Flows can be sampled and used to calibrate the simulation, for which conditions can then be varied to recreate a variety of operating modes. The use of a simulation model also permits a reduction in data collection for the existing station. Finally, the program itself can be used as a manipulable sketch-planning model.

Answering Hard Questions

Because the job requires a complete facility plan, regardless of information gaps, the designer is frequently forced to make assumptions and resort to intuition. In many cases, however, assumptions and intuition fail to provide the correct answers, and facilities may later be deficient. In certain critical areas, such mistakes can be costly or even tragic. The model should be used in those critical areas for which there are no ready solutions or standards. Three areas of station-design uncertainty in which USS could provide answers to hard questions are (a) safety, (b) area requirements, and (c) trade-offs between devices and space.

Safety

Designers need better information on how stations function during emergencies. For example, subway fires occur with sufficient frequency to require designs that explicitly consider evacuation. Other mishaps, such as stalled trains, collisions, and flooding, may also require simultaneous evacuation of all of the trains or vehicles in a station. The station designer usually has no firsthand knowledge of the physical design requirements for evacuations and may have to use existing space and exit standards that may or may not be adequate.

In some systems there are design-performance specifications that specify the maximum time in which to evacuate a fully loaded train. Those for the Southeastern Pennsylvania Transportation Authority, for example, specify that "The circulation system should permit the total capacity of a loaded train to exit from the station in 4 min" (3). These standards also contain capacity guidelines and minimum dimensions, but give no guidance in determining the compliance of a station design with the 4-min evacuation standard.

A simulation model could be used to evaluate station performance in an evacuation, with some modifications from normal operating requirements. The station-evacuation mode would permit the user to start the simulation with fully loaded transit vehicles in the station, alter gates and inbound links from pedestrian entrances to permit passengers to flow out of the station, and introduce a higher than normal desired mean walking speed and the ability of individuals to backtrack on one-way links as needed. Rather than specifying a period to be simulated, the user would specify a maximum simulation period and terminate the program as soon as all individuals had exited from the station or when the maximum period had elapsed. The outputs would specify how many individuals remained in the station at each time interval and where they were located.

Area Requirements

The determination of space requirements for a facility is accomplished during the programming phase. Architects and designers generally begin schematic designs with the required areas known. Currently, the simulation model tests the adequacy of spaces under passenger flows, but not until the detailed design is under way. The most important spatial element in transit-station design is the platform size, but since link-node coding protocol requires the disaggregation of platforms into subareas for analysis, platforms cannot be easily modeled by simulations that rely on network representation.

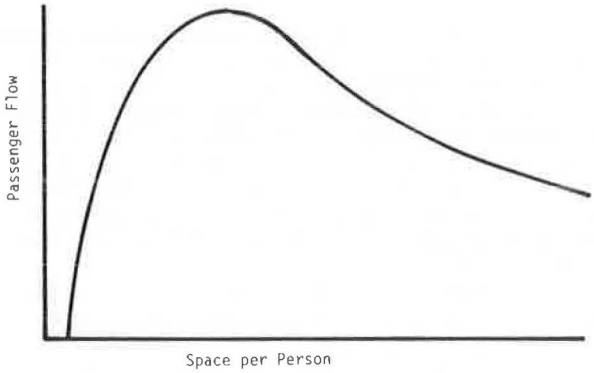
Essentially, the designer needs an initial estimation of the station areas required prior to the schematic-design preparation. A simulation model could be solved for these areas for given passenger flows and service-level requirements. From the passenger flows, the model could be used to calculate the required movement and queue areas. This mode of operation would permit the designer to code and simulate the transit station early in the schematic-design phase while using only a minimum of information (primarily link and node locations). A set of default-device characteristics would also simplify the initial coding.

By helping the designer to determine the areas at the beginning of the schematic-design phase with minimum information inputs, the model could provide data for the station design before major decisions have been made.

Device Versus Space Trade-Offs

In most instances, devices such as turnstiles and esca-

Figure 1. Relation between passenger flow and space per person.



lators produce queues during periods of maximum use, and additional areas must be constructed to accommodate these queues. Alternatively, the addition of more turnstiles or such devices could reduce the queue-area requirements. Simulation models could permit the designer to make this kind of analysis, and, to make this analysis even more useful, the model could include a comparison capability between configurations. This could be achieved in two ways: First, the program could produce aggregate reports of the movement and queue areas required for the entire station. This would provide a simple means for comparing alternative station designs. Alternatively, the program could accept several station plans as input, compare them internally, and produce comparison statistics. The second alternative reduces work for the user but would probably be neither sufficiently flexible nor cost-effective.

Reducing Construction Costs

The single most important use of any design tool, particularly with regard to transportation facilities, is in reducing construction costs. Because of the high costs of these facilities, it is desirable to minimize both the total area required and the number of devices such as escalators, turnstiles, and elevators. In general, the area requirements for a station are determined during the programming stage, prior to the development of schematic designs. Station designers usually begin with an estimate of passenger flows. Most often, they also need to know the hourly variations and the peak expected volumes and use these volumes to apply space standards, such as those developed by Fruin (4), to determine the required areas and widths for generic space types (hallways, platforms, stairways, and such), which serve as a program for schematic-design development.

There is some uncertainty in using these space standards. These standards are generally mean rates or averages derived from observed data, but often there is a large associated variance. Area standards can also be associated with levels of service, as by Fruin (4) and Pushkarev and Zupan (5). The designer must assume that the areal standard is applicable, and determine the appropriate level of service. Because of the uncertainties in determining spacial requirements for a transit-station facility, the designer may tend to overdesign it and provide too much space to compensate for possible errors in space estimates. Most designers are comfortable with designs that have an overabundance of space, since, once a completed facility is found to be undersized, there is seldom a possibility to add additional space economically. Indeed, because of the serious problems caused by inadequate space in transit stations, the current emphasis in simulation modeling of stations is in locating undersized areas.

The overdesign of stations could be reduced with more accurate estimates of spatial requirements. A simulation model could provide this information: This is one of its most useful applications. It is relatively easy to run several simulations, reducing the areas each time, to determine the minimum area required. However, this requires an iterative approach, and many runs may be needed to optimize the station. In addition, the program currently requires a fairly specific initial estimate of space requirements, which is time-consuming. For stations coded with a large number of links and nodes, the process of comparing results and incrementally reducing areas may also be time-consuming.

The present simulation model is better suited to detecting portions of stations that are underdesigned. The program operation draws attention to areas that have movement blockages and overflowing queue areas. Consequently, optimization of the station design is not an explicit program function although, in a crude sense, it is possible. Figure 1 shows the relation between pedestrian flow and space per person for walkways. If one assumes that there is a similar relation between passenger throughput and area per person, there will be a theoretical maximum station size for any given passenger volume. It is improbable, however, that station design can be specified and modeled as an optimization problem, although several previously mentioned program capabilities could increase the usefulness of a simulation model in minimizing transit-station cost. The most important of these are (a) program-generated area requirements and (b) the incorporation of level-of-service indicators.

POTENTIAL COST-EFFECTIVENESS

The UMTA station-simulation program is still in a developmental state and is not yet ready for release to the planning community. However, the program is a unique tool with considerable potential for station designers. Although only a few new fixed-guideway transit systems are under construction or planned for the near future, tremendous cost savings are possible. Currently, for example, escalators cost about $60 000 so that the elimination of one escalator per station in a 10-station system could save more than the cost of developing the program. Rapid-transit stations cost from $3 000 000 for surface stations to $12 000 000 or more for underground stations with construction costs alone ranging from about $650/m^2 ($60/ft^2) for the surface stations to several thousand dollars per square meter (several hundred dollars per square foot) for the underground ones. Thus, even small reductions in station area have a major impact on system costs.

Although few large transit stations will be constructed in the foreseeable future, hundreds of existing stations need modernization and rehabilitation. Major portions of the rapid-transit systems in Boston, New York, and Chicago were constructed more than 50 years ago (some are nearly 75 years old) and are still in use. A station-simulation model could be a widely used and vital tool for planners rehabilitating existing transit stations, if it were flexible and responsive to user needs.

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Rehabilitation of Suburban Rail Stations

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This paper reports the results of a study of the feasibility of rehabilitating underused suburban railroad stations. Seventy-seven stations on eight commuter lines in New Jersey were surveyed. Each station was inspected, photographed, and evaluated for its restoration potential by criteria that were developed for the study. The Red Bank station was selected as a case study. The study included the development of community and local government participation, the renovation of the 100-year old depot, the redesign of the passenger facility as an intermodal terminal for bus, rail, and taxi, the redesign of the pedestrian facilities, and an economic analysis. The municipality has now taken possession of the station, which is used by 1500 daily commuters. Preliminary architectural plans have been drawn up, the station has been designated as an historic site, and the building restoration and sitework are nearly completed. This study is intended to be a prototype for other restoration projects that could modernize urban transportation facilities while preserving historically valuable structures. The emphasis is on maximizing the economic benefits of the project.

Each day, approximately 500 000 Americans travel to work on commuter railroads. In the Northeast, seven of these private carriers are bankrupt, are unable to make a profit even on freight traffic, and have been federally reorganized into a single entity, the Consolidated Rail Corporation (Conrail). Passenger service exists only because of heavy federal and state subsidies and is often run entirely by public authorities. Although intercity rail service is being steadily improved by the National Railroad Passenger Corporation (Amtrak), intraregional commuter service is barely adequate, and only on those routes where high concentrations of commuters bound for the central business district (CBD) create intolerable highway congestion. Off-peak, weekend, and non-CBD-bound travelers have little rail service. Over the past 40 years, service quality has steadily declined, breakdowns have become more frequent, cars have grown dirtier, and track and equipment have deteriorated. As conditions have worsened, more commuters have sought alternative means of going to work, primarily by automobile. As rail commuters have switched to automobiles, rail revenues have declined, which has caused even more cutbacks in service and less maintenance. Thus, today commuter railroads are in a continual downward spiral.

Because of decentralizing trends in metropolitan growth and the convenience of the automobile, it is unlikely that railroads will ever again have the major role in intraregional passenger transportation. But recent petroleum shortages and price increases have emphasized the need to conserve energy resources and, specifically, to reduce automobile travel. Railroads can be from 5 to 10 times more energy-efficient than can automobiles, depending on the number of seats occupied per vehicle. In addition, one railroad track has an hourly capacity approximately equal to that of 10 expressway lanes carrying automobiles. In certain applications, notably the journey to work, railroads can still provide an important service.

IMPROVEMENTS IN RAIL SERVICE

Where there are competing facilities, the commuter has a choice of travel modes. In selecting the preferred travel mode, he or she attempts to minimize travel time and cost and the discomfort of the trip. Trade-offs are made, since individuals value time differently, and since time spent in uncomfortable or unpleasant surroundings is more onerous than time spent in a pleasant environment. Travelers value time spent waiting for transit more highly than time spent riding in a vehicle (1). Transfers between modes also impose penalties beyond time and cost.

The relation between factors such as transfers, discomfort, inconvenience, and unpleasant surroundings and the decision to use rail transit is known to exist, although it is not easily quantified. Time and cost are not the only factors that influence modal choice.

Through subsidies from federal and state governments over the past decade, efforts have been made to improve service for rail commuters. Priority has been given to purchases of new cars and locomotives. In most metropolitan areas, electrified commuter service was established in the early 1900s, and cars built then can still be found in active service. These ancient vehicles have caused frequent breakdowns and delays, and their poor riding quality and environmental conditions have been major irritants to passengers. Newer