Second-Generation UMTA Transit Station Simulation Model

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The Transportation Systems Center, under the sponsorship of the Urban Mass Transportation Administration, is developing a second-generation transit station simulation model called USS II. This new discrete-event simulation program will offer significant improvements over its predecessor, USS I, in terms of ease of use, station modeling capabilities, and simulation accuracy. The major features of the current USS II design with respect to its modeling capabilities, outputs, and operational environment are described.

During the latter half of the 1970s, the Urban Mass Transportation Administration (UMTA) developed a transit station simulation model called USS (1). USS is a discrete-event, Monte Carlo type of computer simulation program designed as a tool to aid transit planners, engineers, and architects in the evaluation of alternative transit station designs. The model permits a user to define the structure of a station (e.g., entrance and exit points, processing devices, and loading platforms) and operational attributes (e.g., distributions of pedestrian and vehicle arrivals at the station), simulates the operation of the station, and produces output statistics that describe the performance of the station (e.g., queuing and congestion levels).

Using the USS program, a designer may test a broad range of potential station configurations in a relatively short period of time, thereby assisting in the development of a cost-effective station design that meets or surpasses user-established station performance standards. Thus, use of the USS model can potentially result in major cost savings for transit system construction by more accurately predicting space and equipment requirements for transit stations and reducing "overdesign" of station components. Moreover, use of the model can result in safer and more convenient station designs by highlighting sources of pedestrian delay and flow conflicts and by measuring performance under emergency evacuation conditions.

Experience with USS has shown that, although it is a basically useful station design and evaluation tool, the program has some serious deficiencies (2-4). These include the inability of the program to adequately model some existing stations, excessive requirements for user sophistication and effort, and several conceptual inadequacies in the modeling of pedestrian movements. In addition, the program has proved to be very difficult to upgrade. Because of these shortcomings, the USS program has been distributed to only a handful of users, primarily for testing purposes.

Work is now under way on a replacement for USS. This new station simulation program, USS II, is intended to be a major improvement over its predecessor (now called USS I), particularly in terms of easier model operation (i.e., greater user orientation), increased modeling flexibility and accuracy, and improved program maintainability.

It should be understood that USS II does not yet exist in executable form; only the fundamental design work has been completed. This paper describes the major features of that fundamental design. By publicizing USS II at this time, before actual programming begins, it is hoped that interest among potential future users will be stimulated and that the discussions resulting from this paper will ultimately improve the quality of the final software product.

In comparison with USS I, USS II incorporates major technical improvements that make it a more powerful analysis tool as well as a number of environmental improvements that make it easier to use and maintain. The remainder of this paper describes the major technical and environmental features of USS II as currently designed.

MODELING CAPABILITIES

Pedestrians

Pedestrians using the station are stratified by pedestrian type. Each modeled pedestrian is described by a crush area (the area occupied by the pedestrian under extremely congested conditions) and a free walking speed (the velocity at which the pedestrian will move if unimpeded by congestion). Each pedestrian also has an origin and a destination.

The set of pedestrian types is constructed by taking all possible combinations of values of a user-defined set of discrete stratification variables. For example, if the possession of a prepaid pass and a pedestrian's handicapped status are the two determinants of the pedestrian's behavior in the station, then the user would define two discrete stratification variables, each having two possible values.

These two stratification variables imply the existence of four pedestrian types:

1. No handicap, no pass;
2. No handicap, pass;
3. Handicapped, no pass; and
4. Handicapped, pass.

USS allows the user to define any number of stratification variables and as many as 99 values in each variable. Consequently, the number of different pedestrian types that can be defined in USS II is theoretically unlimited.

The pedestrian's crush area is modeled as a function of the pedestrian's type and is fixed for all pedestrians of the same type.

The free walking speed is a function of the pedestrian's type and is randomly drawn at the time the pedestrian enters the station from a user-defined distribution of walking speeds for pedestrians of that type.

The pedestrian's origin and destination are also determined at the time the pedestrian enters the station and depend on the structure of the station and the transit service associated with the station. Origins and destinations are discussed further later in this paper.

The set of pedestrian types is fixed for the duration of the simulation, but the attributes of each pedestrian type--the crush area and the distribution of free walking speeds--can be changed by the user as the simulation proceeds.

Transit Service

The transit service associated with a station is represented as a set of routes, where each route simply represents a distinct set of unspecified external origins and/or destinations. This definition is sufficiently general to permit routes to represent both scheduled and unscheduled transit service.

Each route has a mean service frequency (i.e., the expected number of arrivals per hour), a train size (i.e., the number of vehicles per arrival), and a vehicle type. These route attributes can change as the simulation proceeds, but at any point in time are fixed for each route.

Each vehicle has, for each of its two sides, a doorway capacity (i.e., the number of pedestrians that can simultaneously enter or leave the vehicle) and a distribution of doorway service times. In addition, the vehicle has an area or capacity. All of these vehicle attributes are fixed for the duration of the simulation.

Any number of routes and vehicles may be defined in USS II. The set of routes serving the station is fixed for the duration of the simulation, but the route attributes may vary. In short, USS II, through the route and vehicle entities, affords the user considerable flexibility in the specification of transit service.

Station Structure

A station model should be capable of representing virtually all physical station attributes that influence pedestrian movement through a station. This is accomplished in USS II through the use of two basic modeling entities: sectors and nodes.

Station sectors are used to represent discrete pedestrian flow areas such as lobbies, corridors, stairs, escalators, elevators, ramps, and platforms (i.e., passenger boarding and deboarding areas). A station consists of one or more contiguous sectors. Sectors usually (but not always) represent areas separated by physical barriers and/or service devices or doorways. Besides a type and a shape, each sector also has an area or capacity and either a speed (if the sector is an escalator or elevator) or a volume-delay function that governs the speed at which pedestrians move through it. The list of pedestrian exclusions and the speed and volume-delay functions may vary as the simulation proceeds, but the type, shape, and area of each sector are fixed.

Nodes are used primarily to represent passenger processing entities such as service devices (e.g., turnstiles and pass gates), doorways (including entrances and exits), diversion points (e.g., newsstands, rest areas, and ticket vendors), and transit boarding and deboarding points. Each node may have delays associated with it (i.e., service times, opposing flow delays, etc.), and thus queues may form at the node. In addition, each node may be assigned restrictions pertaining to directionality (i.e., one-way or two-way flow), capacity (i.e., the number of pedestrians that can be processed simultaneously), and allowable pedestrian types (e.g., modeled wheelchair patrons may be prevented from using escalators). With the exception of directionality, all node attributes can vary during the course of the simulation.

Each node must appear on the boundary of two and only two sectors (since the "outside" is regarded as a sector, nodes may be positioned on the exterior boundary of the station and still meet this condition). USS II automatically connects each pair of nodes on the boundary of each sector in each allowable direction with a link. This node-link network represents all possible pedestrian-movement paths within the station.

The important element to note is that links are not specified by the user; they are automatically generated by USS II from user-supplied node and sector information. This feature greatly reduces the user input requirements for USS II in comparison with USS I.

Pedestrian-Transit Interface

Accurate modeling of pedestrian behavior with respect to the transit service in the station was one of the highest USS II design priorities. It is accomplished through the use of waiting rooms, platforms, dock nodes, docks, and tracks.

A waiting room is a sector in which transit-bound pedestrians may wait for the arrival of trains. Each waiting room may serve as few as one or as many as all transit routes, the set of routes served being defined by the user.

A platform is a waiting room at which vehicles can dock. Part of each platform's perimeter must be on the station perimeter, and that part of the perimeter must have at least one node, called a dock node. A dock is an ordered set of dock nodes located on the perimeter of a common platform. A track is an ordered set of docks that may or may not be on the same platform. Figure 1 illustrates these concepts.

The user must provide, for each route, a prioritized list of docks that identifies the set of docking locations available to trains on that route. Every list must contain at least one dock, and each dock in a route's list must contain at least as many nodes as there are cars in a train on that route.

The waiting room-route and platform-dock relations are fixed for the duration of the simulation, but a route's list of prioritized docks may change as the simulation proceeds.

Demand

Demand for the use of the station is modeled in USS II as a set of origin-destination demand tables, one table per pedestrian type. Each demand-table cell contains the arrival rate (pedestrians per hour) for a particular pedestrian type from a particular origin to a particular destination. The demand tables can be changed during the course of the simulation, thus permitting the user to model varying demand levels and mixes of pedestrian types over the duration of the simulation.

The set of origins is composed of the set of entrance nodes plus the set of routes serving the station. The set of destinations is composed of the set of exit nodes plus the set of routes serving the station plus the set of route groups, if any. A route group is a set of two or more routes that provides joint service to some external destinations; all routes in a route group are regarded jointly as a station destination by any pedestrians headed for one of those external destinations. The structure of the demand tables is shown in Figure 2.

Pedestrian arrivals at entrance nodes are generated randomly by using a user-specified distribution around the average; the average arrival rates are provided by the demand tables. Arrivals are generated independently for each cell in the demand tables, so at generation time the pedestrian type, origin, and destination of each generated pedestrian are known.

Pedestrian arrivals by transit are generated similarly but appear as a group when a train arrives on a route. The number of persons on board a train is derived from the pedestrian arrival rate for the route (i.e., the sum of the arrival rates for all demand cells that have that route as an origin), the expected train frequency on the route, and a user-specified distribution of variations from the mean. The number of arrivals that do not deboard is known

Figure 1. Basic modeling concepts.

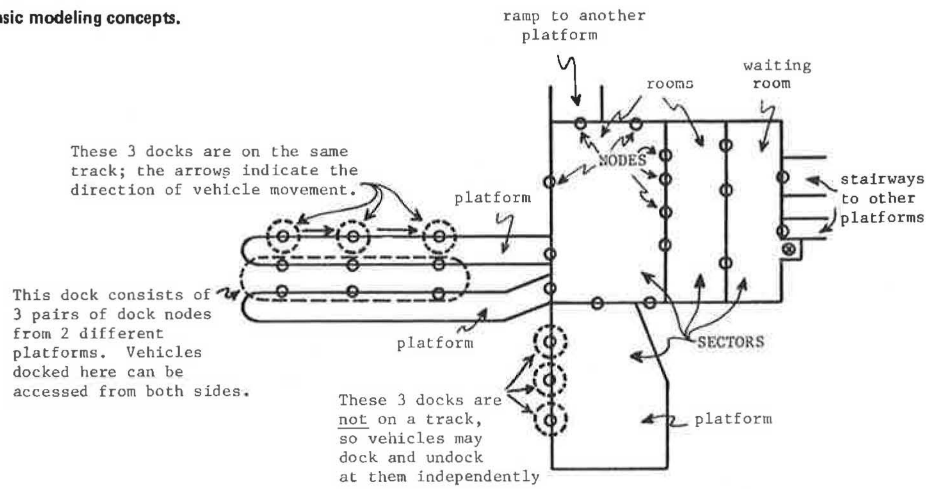
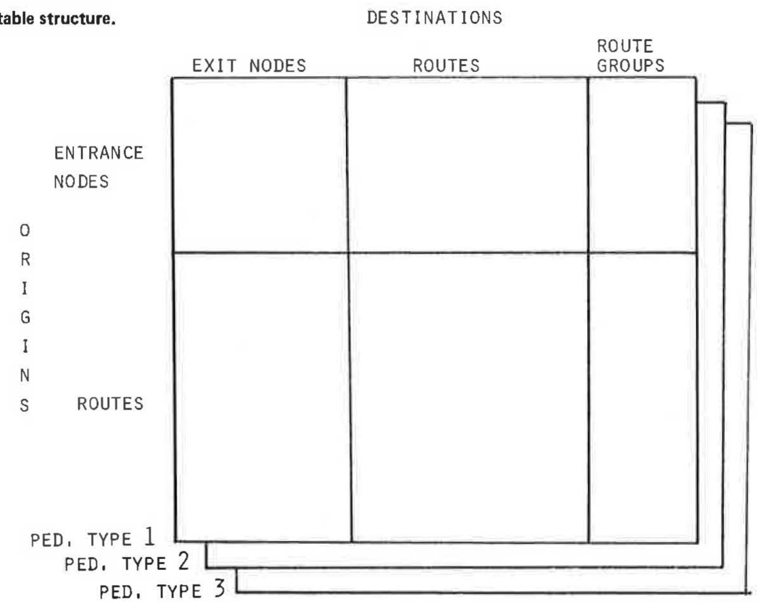


Figure 2. Demand-table structure.



from the demand cells that have that route as both an origin and a destination. The remaining pedestrians deboard when the train docks and thereafter move through the station in the same way as pedestrians who arrive on foot.

Pedestrian and Train Movements

The movement of pedestrians through the station can be modeled at a potentially high level of detail in USS II. Pedestrian routing from arrival to departure through the station's link-node network is accomplished by using a dynamic multipath assignment procedure. According to this procedure, each pedestrian probabilistically "chooses" a path from present location to destination (i.e., his or her transit route or station exit) based on the relative travel times by those paths. The total travel time is a composite of walking and conveyance time, service time, time in queues (waiting for service), and, if the destination is a transit route, time spent waiting for a vehicle. A pedestrian updates his or her path choice each time he or she enters a new sector.

Numerous options are provided for controlling pedestrian movements. One important feature allows the user to define horizons (or groups of station sectors) within which pedestrians possess "current" information on travel conditions. Beyond the bounds of his or her horizon, a pedestrian knows only the "expected" travel conditions. This feature is important when the user wishes to accurately model situations in which pedestrians have clear lines of sight (or can otherwise perceive operations) over a large area of the station. Both expected and current times can be generated automatically by USS II without input from the user.

Another important pedestrian-movement feature provided by USS II is the ability to model the use of intermediate destinations, or diversions. The use of a diversion--a newsstand, a change booth, or a ticket vending machine, for example--is modeled as a Markov process in which the probabilities of use are supplied in diversion tables stratified by pedestrian type, much like the demand tables. Like demand tables, the diversion tables may change during the course of the simulation.

Capacity constraints are incorporated into the USS II movement algorithms in two ways:

1. A sector may become full (i.e., the sum of the areas of the pedestrians in the sector may ex-

ceed the sector area). If this occurs, pedestrians are prevented from entering the sector until space becomes available; pedestrians waiting to enter the sector queue up at the nodes on the sector boundary.

2. A node may become full (i.e., the number of pedestrians being served may equal the node capacity). If this occurs, pedestrians are prevented from entering the node until a pedestrian leaves the node. These two types of capacity may be viewed as "volume capacity" and "flow capacity".

Additional pedestrian-movement features of USS II include the ability to model different types of pedestrian queues (first in/first out and random) and the ability to model different policies for resolving directional conflicts at a node. USS II also provides an "evacuation" mode of operation that automatically changes the station's operating characteristics to simulate a crisis. In this mode, pedestrian and train arrivals are terminated, trains in the station are unloaded, pedestrians are rerouted to exits, and their walk speeds are increased.

With respect to the movement of trains, USS II stops short of explicitly tracking their movement within the station; only when a train is docked is the exact position of the train known. However, the user can model most of those aspects of train movement that affect the operation of the station. For example, a dock may be allocated to a train for a period longer than the actual docking period; this feature may be used to simulate the effect of control signal blocks, for example. Similarly, serial dependence of one dock on another (as when two docks are on the same track) can be modeled.

When a train enters the station, its route's list of docks is searched for an available dock and, if any are available, the train is allocated to ("docked at") the dock that has the highest priority. If no dock in the list is available, the train waits until one becomes available. This mechanism allows the user to model dynamic dock-allocation policies.

When a train docks, all pedestrians waiting for it (i.e., waiting for an arrival on this route or on a route group that contains this route) on all platforms and in all waiting rooms associated with the route are released and move toward the train. Those pedestrians waiting for the train on the platform at which it docks instantaneously queue up at the individual vehicles of the train--i.e., at the dock nodes corresponding to the vehicles (there is a one-to-one correspondence between dock nodes and docked vehicles). As pedestrians arrive at this platform from other locations, they are subjected to a fixed delay (representing the minimum platform traversal time) and then are instantaneously transported to the docked vehicle doorways.

When the doors of the vehicles open, all deboarding passengers leave and boarding passengers enter. If the train reaches capacity before all queued pedestrians have boarded, or if the doors close before all have boarded, then all remaining pedestrians wait on the platform for the next arrival. If one car becomes full before the others, pedestrians queued at the full car automatically requeue at the other cars.

Once its doors are closed, the train attempts to leave the station. However, it may be prevented from doing so by another train in front of it on the track (if the dock is on a track). If so, the train waits until its way is clear and then departs. The dock is unavailable for use by a second train until the first one leaves the station.

MAJOR ENVIRONMENTAL FEATURES

Providing adequate station modeling capabilities was an important USS II design goal. Equally important, however, was the goal to make USS II directly usable by architects, planners, and others who have little or no computer expertise. Meeting this goal required the development of a "friendly" user environment. This section describes the major environmental features of USS II that make it a very friendly program.

User-Control Interface

The USS II user-control interface is designed to operate primarily in "interactive" mode, which means that the user can input control information as the program is executing. However, USS II can also operate in the cheaper "batch" mode to reduce the cost of operation.

The current design of the USS II user-control interface requires the use of a Tektronix 4014 storage-type cathode ray tube (CRT) display terminal. The bulk of the user inputs are designed to be provided graphically--which means that a CRT terminal is required--and the Tektronix was selected because it is one of the most widely available. However, a goal of the detailed design effort is the elimination of this Tektronix dependence.

The USS II user-control interface is completely passive; that is, all of the USS II control information is provided in response to prompts and menus and the user does not have to learn a USS II "command language". Moreover, the USS II user has access to "on-line" assistance in responding to any prompt or menu. In short, the USS II user-control interface is interactive, passive, and self-documenting.

Data Base Management System

The information needed to adequately simulate the operation of a transit station is necessarily complex and voluminous. Moreover, the information produced by such a simulation is also of necessity complex and even more voluminous. The organization, management, and manipulation of these vast quantities of input and output data are difficult tasks that, left to the user, would overwhelm him or her and make USS II unusable. It was imperative that, as part of USS II, comprehensive automatic data storage and retrieval capabilities be provided. In short, one of the USS II design goals was to provide a data base management system (DBMS).

The basic structure of the data to be stored in the DBMS is shown in Figure 3. The core of the data base--the data relating to stations--is hierarchical in structure. Each station can have several versions (i.e., several structural variations), each version can be simulated several times by using different control parameters and transit services, and each simulation consists of one or more time segments (i.e., one or more periods in which all operating parameters are fixed). Demand tables (i.e., pedestrian origins and destinations) are associated with a station at the simulation level but are used at the time-segment level, as is all information related to transit service. Pedestrian characteristics are related to the station at the simulation level, but pedestrian restrictions (e.g., the exclusion of cash-paying customers from prepaid pass gates) are established at the time-segment level.

In this data structure, the transit service information is largely independent of the station information. This arrangement permits the modeling of transit service independent of station design. An important implication of this independence is that a network of transit service, once modeled, may be used with little or no additional effort in the

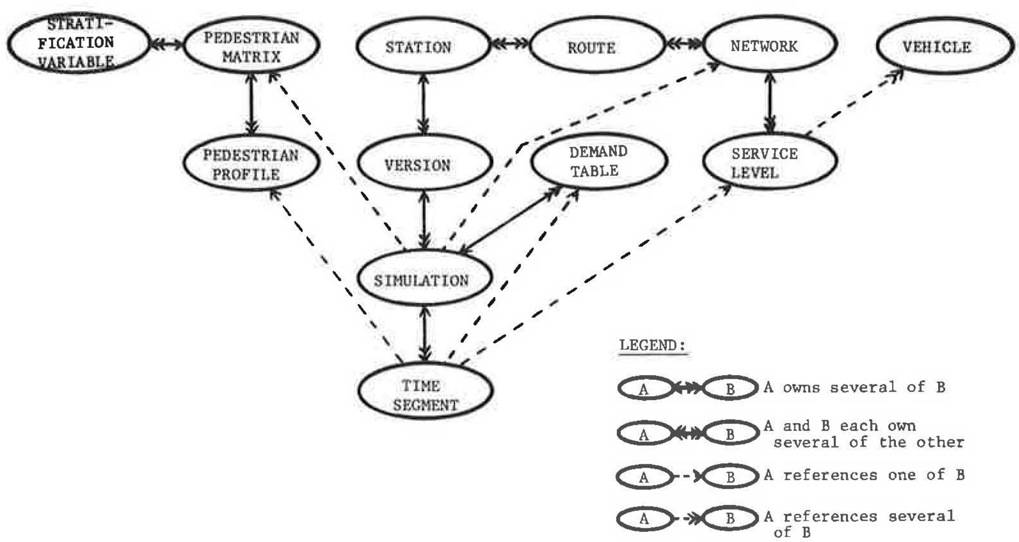


Figure 3. Basic USS II data structure.

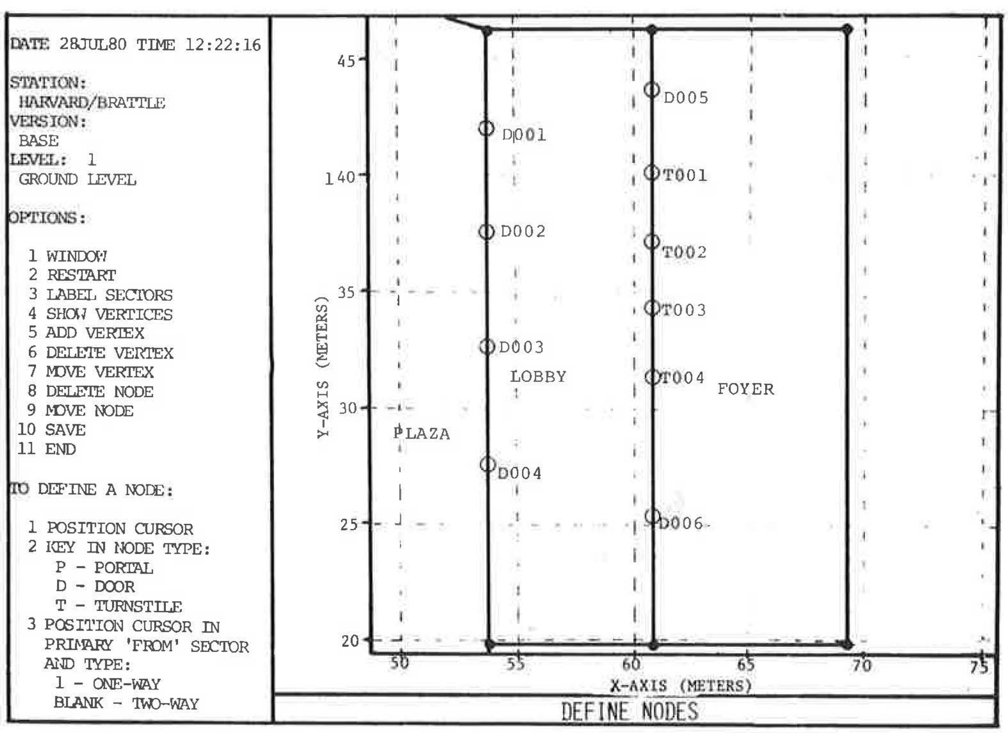


Figure 4. Interactive graphical input display.

modeling of any station in the network. However, this does not imply that a transit network must exist before a station can be modeled: The network modeling capabilities are optional.

The DBMS is responsible for storing data as input, for retrieving it as necessary for use in simulating a station, and for display purposes. It serves as a single file replacing the numerous files that would be required in its absence. As a central repository for information describing multiple stations and other entities, it greatly relieves the file-handling burden of the user, promotes the efficient use of data (e.g., one station can be defined in terms of differences from another), and facilitates the comparison of corresponding bodies of information. The existence of the DBMS enables the USS II user to view, for example, time-series displays in which the outputs of several time segments appear together. In short, the DBMS greatly increases the analytic capabilities of USS II while greatly simplifying its use.

Use of Graphics

Since the intended users of USS II--architects and planners--are visually oriented, it was decided that USS II must use graphical displays whenever possible. Consequently, graphics have been incorporated into the USS II design to perform two major functions: to input station structure information and to display simulation results.

USS II does not produce any dynamic graphical displays while the simulation is proceeding, since that type of display would drastically slow the simulation. Within the bounds of static graphics, however, a wide variety of graphical input and output capabilities are available.

All "structural" station information--sector lay-

Figure 5. Mean queue length display.

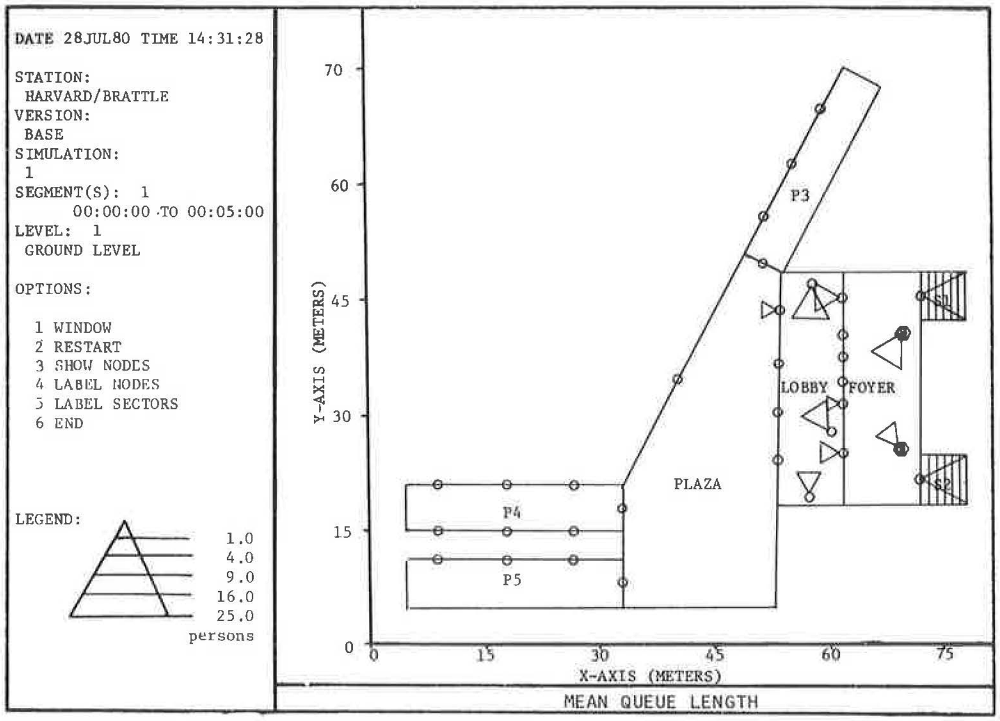
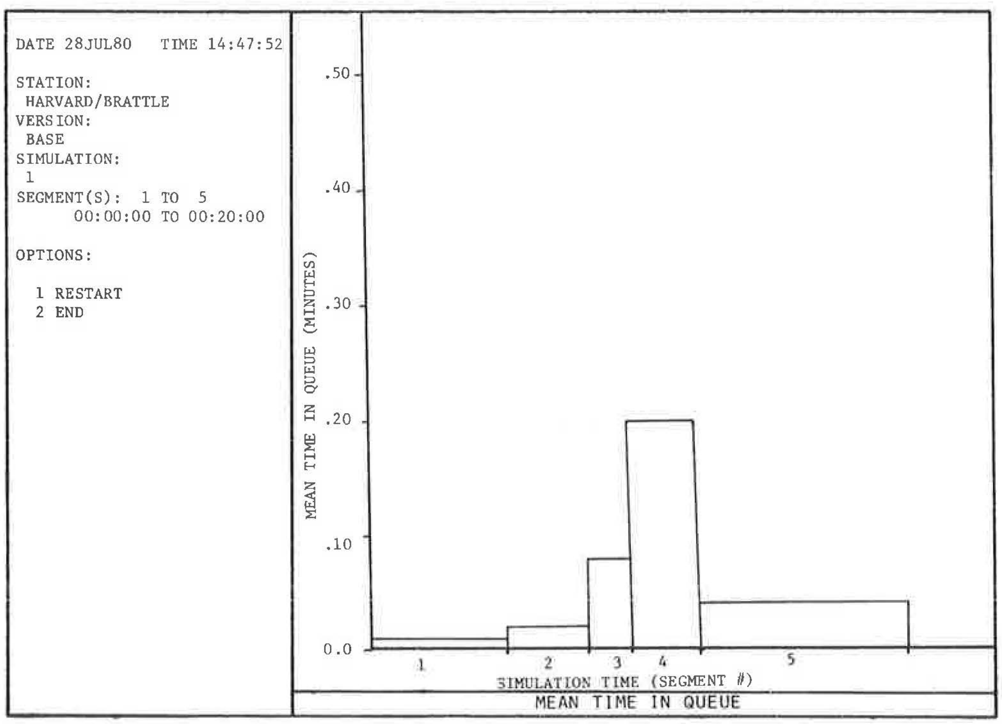


Figure 6. Mean time in queue display.



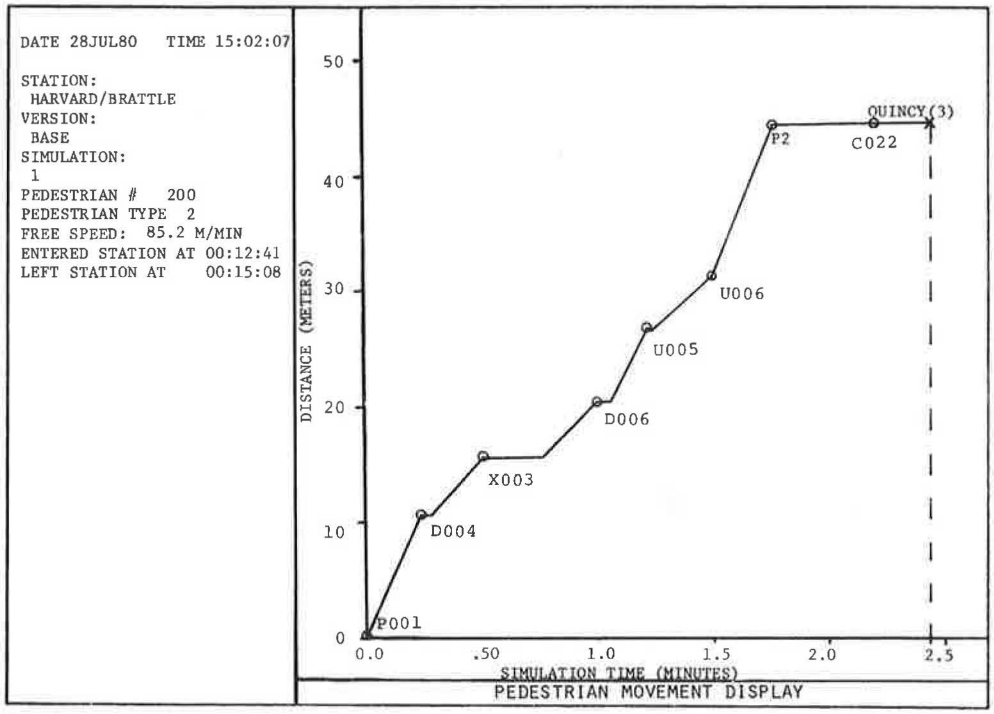
outs and node locations and types--is input graphically. Each level in the station is defined independently and then the levels are connected by the placement of elevators, stairways, ramps, and escalators. Figure 4 shows how the CRT screen may look during the graphical input process.

Many types of graphical outputs are also provided by USS II. Some of the major ones are described below.

A mean queue length display is shown in Figure 5. This display is available for each level within a station. Similar displays are available for cumulative mean queue length and current queue length. Windowing is available for this display (and all other station-based displays) to permit concentration on a portion of a level.

A mean time in queue display is shown in Figure 6. It shows how the mean time in queue has varied over several time segments for the station as a whole. Similar displays are available for time in motion, waiting time, service time, and on-board time. Each display is available for the entire sta-

Figure 7. Pedestrian movement display.



tion, for one level within the station, or for a particular category of components (e.g., queue time resulting from all turnstiles).

Figure 7 shows a pedestrian movement display. This display shows the entire trip of a selected pedestrian and all components of his or her total travel time. This display is extremely useful in verifying the modeling of the station.

USS II can also produce a variety of printed reports. Although it is not included in the current USS II design, consideration is being given to incorporating a general-purpose report generator that would allow the USS II user to design the format and content of all printed reports. In any case, reports would be produced only after the simulation had ended; outputs from the simulation would be limited to short messages.

CONCLUSIONS

This paper has described the major modeling features and environmental characteristics of USS II, the second-generation UMTA transit station simulation program. USS II will offer major improvements over its predecessor, USS I, in terms of expanded station modeling capabilities, more realistic pedestrian movement algorithms, and a more dynamic station-transit interface. Moreover, USS II should be significantly easier to use, since it requires fewer user inputs, operates interactively with on-line "help" facilities, uses a DBMS, and has a variety of graphical input and output capabilities.

Unfortunately, USS II is not yet available for use. The design, as discussed in this paper, is not yet complete, and implementation of the design has not yet begun. The intent of this paper is to stimulate discussion on the design at an early phase in the development.

Comments and criticisms are solicited. Additional details of the USS II design are available on request.

ACKNOWLEDGMENT

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Discussion

Gregory P. Benz

The most important improvement in the USS program, as described by Albright and Couture, will be its ability to be used interactively and its development of graphic input and output. Other improvements, such as the modeling of the dynamic docking of vehicles, should be particularly useful for applications involving bus depots and downtown people mover/automated guideway transit (DPM/AGT) stations. The ability to simulate DPM/AGT stations is particularly important because the close headways of the vehicles make simulation analysis of stations almost imperative.

Designating waiting areas as separate from loading areas should help to overcome a problem that was prevalent in the earlier version of the model. Pedestrian behavior, as handled by the USS program's path-choice model, was always one of finding the shortest path, which is true for most of the station network. However, on the platform a different type of behavior takes over, particularly if the vehicle is not waiting at the platform. USS should now be able to simulate this non-minimum-path type of behavior.

These improvements, as well as giving USS the ability to operate interactively, should result in a vastly improved and easier-to-use model. An improved USS program should be a valuable tool for station designers and planners. The model can help in the sizing of stations, particularly complex station areas that are difficult to analyze by manual techniques. It can assist in analyzing special situations, such as emergency evacuations. This ability is a significant improvement in the program. In this light, the program could aid in the evaluation of present fire and safety codes and regulations, which, in many cities, are not responsive to the needs of transit systems. The model could also help in developing operating strategies for stations, particularly during construction, maintenance activities, and special situations such as a vehicle breakdown. Simulation models offer a tool for use in sensitivity analysis of station concepts and layouts. This is particularly valuable, given the error that is inherent in patronage forecasts. The simulation model would impose a planning discipline on the user, a discipline that is often lacking. USS requires designers and users to analyze station plans in terms of pedestrian paths through the stations and not just as an arrangement of spaces.

UMTA should continue development of the USS computer program, including demonstration of its capabilities through case studies. If USS helps to reduce the capital cost of just one transit station, UMTA's investment in the computer program would probably be more than recouped.

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Functional Design Elements for Ferry Terminals

PHILIP A. HABIB AND ROGER P. ROESS

The functional design of ferry terminals requires the exercise of a variety of skills and knowledge from such diverse areas as traffic engineering, pedestrian design, transit planning, and vessel operation. Specific types of ferry services are defined, and research findings are presented on how the terminal should be selected and the facilities planned to accommodate these services. For passenger-only ferry operations, planning guidelines are presented for passenger storage and processing facilities, including parking areas, waiting rooms, gangways, and other terminal elements. For vehicle-ferry terminals, guidelines are presented for toll facilities, vehicle sorting and holding areas, discharge demand needs, and other elements of vehicle-ferry terminals.

In March of 1979, the Transportation Training and Research Center of the Polytechnic Institute of New York was awarded the first year of a proposed three-year study to prepare a manual on the planning and functional design of ferry systems. The study is being funded under the University Research Program of the U.S. Maritime Administration. The first year of the study (1) focused on issues of functional design of various system elements. This paper treats these aspects with respect to the complex interface between the vessel and land: the ferry terminal.

CLASSIFICATION OF FERRY SERVICES

There are distinct relations between various characteristics of the ferry service provided and the internal environment that the terminal will require. The project has resulted in the identification of the following list of such characteristics: mode and purpose of ferry service, range and number of stops, frequency of service, and ferry capacity and design.

Mode of Ferry Service

The planning and design of the terminal are controlled by the mode of service provided. The principal modes are (a) passenger only and (b) vehicles and passengers ("passenger" denotes a walk-on rider without a vehicle).

Terminals that service "passenger-only" ferries (i.e., those that carry no vehicles) generally require large park-and-ride facilities as well as efficient transit access. In terminals that serve vehicles as well as passengers, smaller park-and-ride facilities are needed. The major element of ferry terminals that serve vehicles is the extensive amount of holding space required for the sorting and queuing of waiting vehicles.

Purpose of Ferry Service

There is a general relation between the principal purpose of a ferry service and the mode as defined above. The principal purposes of ferry services are commuter journey to work, recreational, and maintenance.

The commuter ferry services generally have a downtown urban center as their base. These ferry services are inclined to have a higher percentage (up to 100 percent) of walk-on passengers who access the terminal by various means. The recreational service, on the other hand, is primarily vehicle oriented and may also carry a moderate number of bicycles. The maintenance service is a mixture of all purposes, including journey to work, delivery of essential services and freight, and recreational trip making. The maintenance purpose applies to routes that service relatively isolated (with respect to land access) locations and effectively "maintains" the principal connection to nearby population centers.

Range of Service

The range of the service describes the total one-way trip length (in terms of travel time) and the number of intermediate stops (destinations). The longer