EVALUATION TOOL FOR DESIGNING PEDESTRIAN FACILITIES IN TRANSIT STATIONS

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This paper describes the Urban Mass Transportation Administration station simulation package—a model for evaluating transit station designs to determine whether a given layout achieves the design objectives of providing enough space for pedestrian movement, providing enough service facilities, and connecting these areas and facilities in the most efficient manner. To determine this, the package provides pedestrian occupancy data in all movement and queue areas; walk times, time in queue, and total times for specific areas, partitions, or the entire length of the station; and distribution of the previous variables for comparison with level-of-service standards. The model user converts a station building layout into nodes, links, and areas that represent queue devices or decision points, pedestrian paths between these devices or points, and the area associated with these devices and paths. The model simulates the flow of pedestrians along the links that represent the station and accumulates appropriate data.

•TRANSPORTATION system analysts have developed and applied sophisticated computer-based system techniques to design transportation systems, but similar techniques have generally not been available for the planning associated with pedestrian flow through station facilities. Station designers have had to rely on individual judgments or basic pedestrian flow-space relationships gathered from stations where problems already have been identified. At present, there are a few analytical design tools for analyzing pedestrian needs at stations on a systematic basis.

USS is a model that was developed for the Urban Mass Transportation Administration (UMTA) to simulate pedestrian flow through the various areas of a transit station. The general purpose of USS is to allow transit planners to study the station system before it is constructed to predict how it will function. When the final testing, documentation, and operation demonstration is completed, USS will become an integral part of the UMTA Transportation Planning Systems (UTPS). UTPS is a set of 13 computer programs with documentation to aid transportation planners in planning for urban multimodal transportation.

USS was developed in 4 phases—a general system model, detailed technical specifications for the simulation technique, an actual computer code, and acceptance testing. This paper is based on the results of the first 3 phases of the project (19, 20).

ROLE OF USS IN STATION DESIGN

Design Process

The physical design problem is a question of how much space or how many facilities are needed to meet satisfactorily pedestrian design objectives. The problem is solved in a repetitive fashion where a design is proposed and then evaluated against a set of objectives to select the optimum design as follows:

1. Define site constraints; basic architectural standards; and station origin-destination (O-D) statistics including mode, line, headway, and loadings;
2. Develop design objectives for the station (e.g., level-of-service standards for pedestrian occupancy in sq ft per person and waiting time);

3. Develop a station layout that appears to meet basic site constraints and design objectives;
4. Evaluate the layout by design objectives;
5. Refine the layout;
6. Reevaluate the layout;
7. Evaluate further and refine as required; and
8. Select the optimum design.

USS is an evaluation model that creates a machine-designer interaction—the designer makes the basic proposal and the machine provides the evaluation. Future activities may be directed toward developing a true design model that would fully automate station design.

Design Objectives

An early phase in developing USS was to define the station design problem by specific design objectives. A review of the literature revealed that, although there were many standards and design procedures, there were no universally accepted objectives for transit station design. Representatives of the professional planning community observed at a station simulation symposium that walking time, waiting time, total time in station, space standards per person, and delay times were important variables that should be considered to determine design objectives. Fruin further suggested that the overall objectives in planning for pedestrians were safety, security, convenience, continuity, comfort, system coherence, and attractiveness (8).

Based on the results of the symposium and on available literature, the station design problem was converted into the following 3 principal objectives for a safe, convenient, and comfortable pedestrian environment:

1. Provide enough space in basic queuing and movement areas;
2. Provide enough service facilities (e.g., doors, gates, and stairs); and
3. Connect these areas and facilities.

Achieving Design Objectives

The role of USS in the design process is to generate design data by measuring the extent to which design objectives are achieved. USS produces 3 basic types of design data for a layout submitted for evaluation.

1. Walking times, time in queue, total in-system times for individuals and an individual's paths in specific movement areas or the entire station;
2. Pedestrian occupancy (sq ft per person) in specific areas of the station; and
3. Distribution of these variables to compare them against design standards or level of service standards.

CHARACTERISTICS OF THE USS MODEL

System Concept

The station system was envisioned as the activities and facilities within the station building plus adjacent transit vehicle loading facilities (Fig. 1). USS can be used to evaluate any pedestrian-oriented station facility. The facility could be a small portion of a station, such as the fare collection area, or the entire station. USS is not restricted to any form of vehicular arrival or departure mode associated with the station.

System Modeling

A station system is subdivided into a series of subsystems. In general, each of the subsystems is modeled by using links, nodes, and areas that represent the basic functional areas of a station as shown in Figure 2. Pedestrian flow areas generally are represented by a link that connects the ends of the area. The ends of the area are represented by nodes that can represent queue devices, decision points, and points where arrivals or departures are created or destroyed.

Figure 1. Transit station concept.

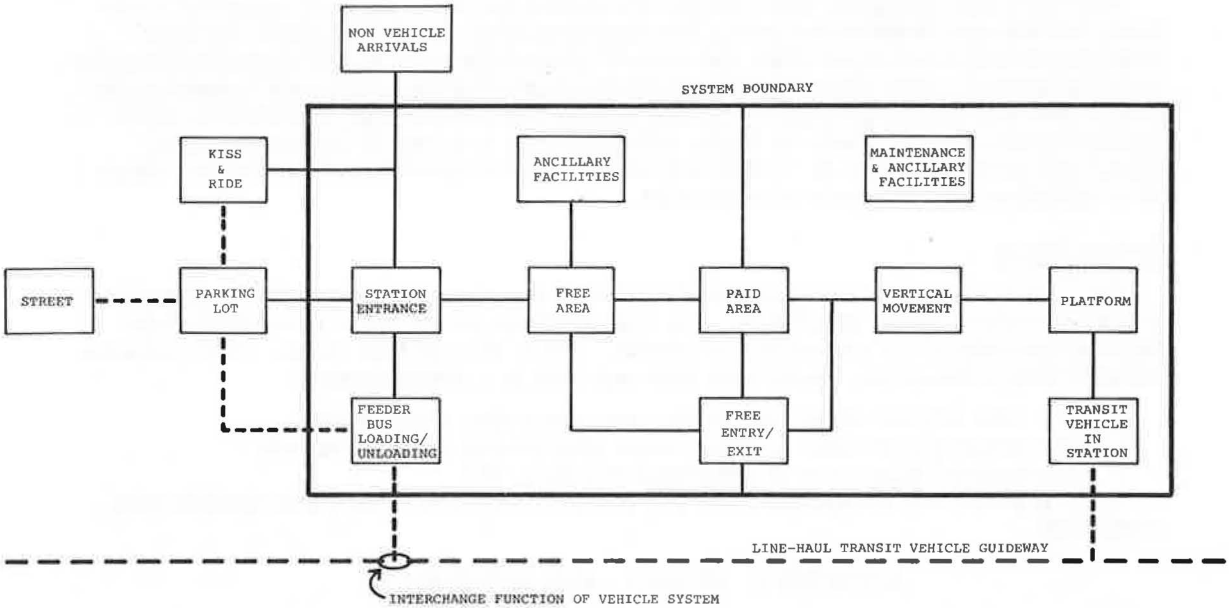


Figure 2. Link, node, and area modeling convention.

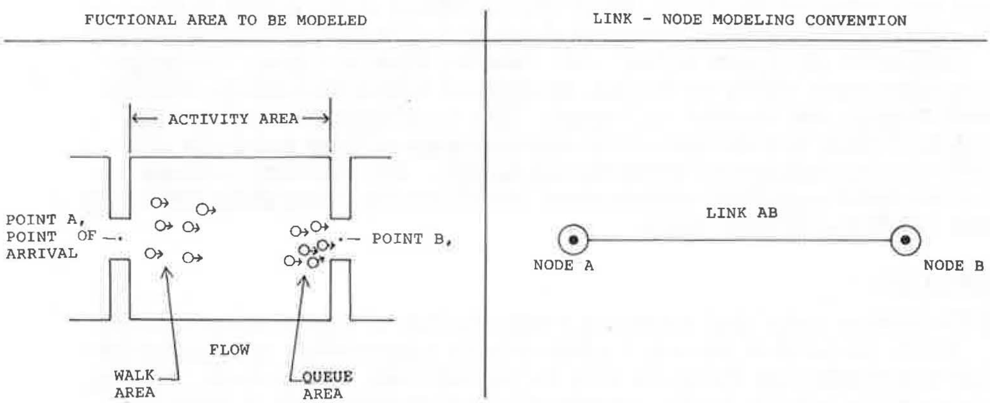
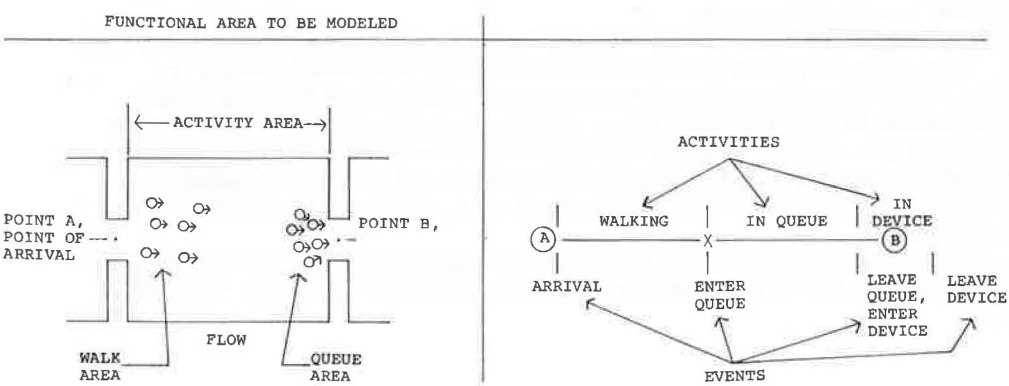


Figure 3. Relation of events, activities, and system model.



The link-node convention provides the framework for describing all important activities, events, and interactions within any station system. It also provides the user flexibility to add or combine links and thereby control the level of detail used to describe a station system. The link-node convention also provides the framework to develop efficient data processing techniques because it uses methods already developed in other transportation models. And, by laying out the station in terms of functional areas, links, and nodes, the user is forced to think through the operation of the station, which is an effective and rigorous evaluation tool.

System Image

The link-node convention provides the physical description of the station system from which the system image is created. The system image is the set of numbers that describes the state of the system at any instant. There is a system image, which includes the following information, associated with each link in a station system:

1. The total number of persons in the area associated with the link;
2. The number of persons in queue at the downstream node of the link;
3. The number of persons in movement on a link; and
4. The pedestrian occupancy (area per person) associated with the movement area of the link.

ACTIVITIES, EVENTS, AND ATTRIBUTES

The mathematical operations of the simulation model the activities of people and vehicles within the station. The simulation is event oriented; that is, the beginning of an event may stop or start an activity (Fig. 3). An event usually triggers a change in the system image or a modification of the changeable attributes of the people in the system or both. There are 2 types of attributes of people in the station—changeable and unchangeable. Changeable attributes include walk time and time on a link. Unchangeable attributes include origin within the station, destination within the station, whether the person is handicapped, and desired walk speed. The accumulation of information on the changes of individuals and changes in the system image of links and nodes provides the required data to evaluate any given station design. The following sections describe some of the more important mathematical operations and processing steps that generate data and create the system image.

Determining Walk Time

Determining the time an individual spends on a specific link of a system has 2 major complications. First, the node at the end of a link usually represents a queuing device so there is a high probability that the speed near the end of a link breaks down. Second, there is a high probability that the person's speed will be modified by other individuals moving in the same direction, people moving in the opposing direction, or people crossing the flow. Thus, the actual time on a link is a function of link length, desired walk speed, concentration of people in the area of movement, amount of conflicting flows, length of the queue, and time in queue.

Walk time is calculated by determining the length of the queue when an individual first enters a link. Then, this length is subtracted from the total link length, and it is assumed that the individual moves along the remaining portion of the link at a speed based on the congestion in the movement area. On reaching the end of the queues, the individual is inserted into a queued events list to wait to be served. The length of the queue is determined by multiplying the length of the designated queue area (supplied by the user) by a queue link factor—the ratio of the number in queue to the capacity of the designated queue area.

The difference between an individual's desired walk speed in the free flowing area of a link and actual speed is due to other persons sharing the same area. The walk time in a corridor is

$$(t_{AB})_i = \frac{60\ x}{(u_i)\text{actual}}$$

where

$(t_{AB})_i$ = actual walk time over AB for individual, i, in sec, and
(u_i) actual = walk speed of individual, i, in congestion, in ft/min (m/min).

The actual walk time of an individual in a specific area of a station is a function of the desired walk speed and the ability to maintain this speed. The determination of actual travel time for an individual is thus related to the macroflow characteristics of the area being analyzed. The effect of competing flows on the travel times on a specific link is based on the absolute number of people in the area associated with the link and the desired walk speeds of individuals on the link.

Service Time

The most critical operation in the station system, for effect on the system image, is determining service times at a queue device. The congestion created by doors, fare collection gates, escalators, corridor constructions, and vehicle doors is of prime importance to the station designer. In USS, the service time is described by a service time distribution that defines the times between passengers served (interservice times). Variation between the interservice times of the service channel and the interarrival times creates the queuing environment.

In the simulation model, specifying service time distribution is a user option. The negative exponential distribution defines the time relationship between individuals if none is supplied by the user. And, in most cases, this assumption will be the best estimate of service time distributions.

Deriving Numerical Values From Distribution Functions

Numerical values are determined in USS by obtaining a sample from a distribution specified by the user or a list of default values in the program. The distributions are used by a table lookup procedure or by the inverse form of the theoretical distribution. The theoretical distributions to be included initially as user options are the negative exponent, Erlang, where K = 1, and the normal distribution. The derivation of these functions can be found in several texts. In addition, the algorithm to derive random deviates from these distributions is described by Alan et al. (16).

Generation of Arrivals

Associated with every station system to be simulated is a series of loading bays, sidewalks, doorways, or similar devices where people come into and leave the system. At the arrival and departure point, a node representing a zone of origin or destination will indicate the location of the arrival and departure device. Each of these nodes (also called zones) will be connected to a link that will tie the arrival point to the remaining portions of the system (Fig. 4). The type of arrival mode will determine the types of statistics to be generated. Two major types of nodes are possible—vehicle loading bays and walkways-doorways.

Path Choice

One of the critical and sophisticated simulation algorithms in USS is the procedure for simulating individual path choices. The following items are considered in the path choice algorithms:

1. Station arrival-departure mode and line;
2. Passenger attributes such as handicaps;
3. Activities that can be reached on alternate paths; and
4. Length of queues where equal alternate paths are available.

The actual procedure can be thought of as a modified, continuous-parameter, dynamic Markov chain (3) where the transition probabilities from node to node within the station are updated dynamically as a function of congestion within the station. The sequential computational steps in the path choice model are as follows before simulation begins:

1. Determine preliminary t(i, j) values for the network where t(i, j) is the anticipated hindrance time link;
2. Calculate shortest time path from a destination in the network to all other nodes in the network;
3. Calculate preliminary link likelihoods (e.g., link resistances as opposed to path resistances); and
4. Calculate preliminary link weights.

The sequential computational steps are as follows during simulation:

1. When a passenger reaches a node in the station, determine the reasonable links emanating from this node by applying a closer-to-destination criterion;
2. Check for user-specified input percentages applying to either reasonable or unreasonable links;
3. Screen the efficient and inefficient links by relevant passenger attributes;
4. Determine t(i, j) for the next link based on walking times over the next link and relative queue lengths;
5. Calculate link likelihoods over the reasonable links;
6. Calculate dynamic link weights;
7. Calculate transition probabilities by using link weights and, if applicable, user-specified input percentages; and
8. Repeat steps 2 through 8 for each node traversed by each passenger in the network.

The path-choice algorithm just given models the nonoptimal behavior of passengers within the station. (For example, all passengers do not choose the shortest path from their origins to their destinations within the station.) It also models the probability of their selecting alternate paths at a decision point within the station. It minimizes the user-specified input needed and allows the user the flexibility to specify input percentages at nodes in the station network to divert passengers on efficient or inefficient paths to auxiliary facilities such as phone booths, concessions, rest areas, restaurants, and newsstands.

The path-choice model satisfies 3 functional specifications. First, the model gives a nonzero probability of use to all reasonable paths between a given origin and destination, whereas all unreasonable paths have a zero probability use. Second, all reasonable paths of equal time have an equal probability of use. Third, when there are 2 or more reasonable paths of unequal time, the shorter path has the higher probability of use.

OUTPUT

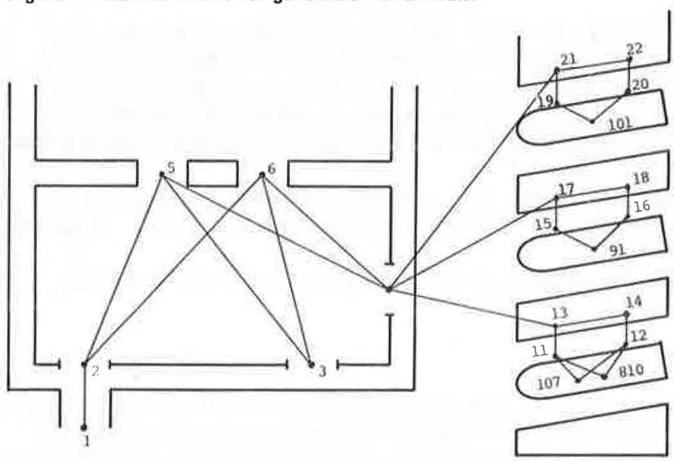
The development of output reports is the end product of the transit station simulation model. Output reports can be put into 2 general groups—stationwide statistics and link-node statistics.

Station Statistics

Four types of output reports present overall station statistics for various types of information.

1. The output for overall station statistics is a presentation in numerical order of basic system operating characteristics by link and node. For a link, the basic output is the maximum number of persons that were in the area associated with the specific link at any instant, the lowest pedestrian occupancy in the movement area (in sq ft per person) at any instant, and the total number of persons that were assigned to the link (e.g., the hourly volume) during the simulation period. For a node, the basic output is the maximum number of persons in queue at the node at any instant during the simulation period, the maximum density of people in the queue area expressed as a percentage of the capacity of the queue area, and the total volume through the node. The data for the node are presented for both the inbound and the outbound sides of the node.

Figure 4. Nomenclature for generation of arrivals.



NODES 1 AND 3 ARE NODES OF PEDESTRIAN ARRIVAL GENERATION AND DEPARTURE, NODES 107, 810, 91 AND 101 ARE NODES OF VEHICLE ARRIVAL GENERATION AND DEPARTURE WITH NUMBERS CORRESPONDING TO LINES WHICH LOAD AND UNLOAD AT THIS BAY, LINES 107 AND 810 USE THE SAME BAY.

Figure 5. Station time summary.

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PAGE XXX     10JUL73    SAMPLE TRANSIT STUDY - STATION XX   RUN XX
   0    4    8   12   16   20   24   28   32   36   40
   +----+----+----+----+----+----+----+----+----+----+   P.C.   CUM  COUNT
  0.                                                      0.0    0.0     0
  5.........................                             21.0   21.0    21
 10...........................................           35.0   56.0    35
 15................................                      26.0   82.0    26
 20.................                                     13.0   95.0    13
 25.......                                                5.0  100.0     5

REMAINING VALUES ARE ALL ZERO
XXXXXX OBSERVATIONS       XXXXXX OBSERVATIONS TRUNCATED TO ELIMINATE BIAS
XXXXXXX. = SUM    XXX.XXX = MEAN    XX.XXX = VAR    XX.XXX = SD
XXX.XXX TO XXX.XXX = CONFIDENCE INTERVAL FOR MEAN
```

Figure 6. Overall station statistics.

PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

ORIG NODE	DEST NODE	-----ARRIVALS----- MODE/LINE		PEOPLE	----DEPARTURES---- MODE/LINE		PEOPLE
1001	1316	BUS	11	475	WALK		469
1005	1211	TRANS	42	1021	BUS	17	1001
1010	1316	BUS	13	242	TRANS	12	242
.	.	.	.	.	.	.	.
1201	1412	WALK		47	TRANS	7	46

PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

ORIG NODE	DEST NODE	----WALK TIME----- MEAN	MIN	MAX	--TIME IN QUEUE--- MEAN	MIN	MAX	--TIME IN SYSTEM-- MEAN	MIN	MAX
1001	1316	12.3	7.1	17.3	7.1	3.1	14.1	20.2	11.1	30.2
1005	1211	15.6	7.9	23.1	9.7	4.9	19.1	25.9	11.7	43.1
1010	1316	10.1	6.6	14.2	11.2	6.2	16.3	22.3	13.9	35.7
.	.	.	.	.	.	.	.	.	.	.
1201	1412	8.1	3.1	12.8	2.1	0.8	4.1	10.6	2.1	18.2

2. To allow the user to easily identify the most critical areas of system use, the output reports could be reformatted to print in descending order the density of people for both links and nodes. To minimize core storage and computer running time, the user will need to limit the number of links and nodes on which statistics will be saved. This output report will allow the user to identify those links and nodes where saving detailed statistics will have some value.

3. To evaluate the overall station operation, the user may request summaries of overall station walk time, time in queue, and total time in the station system. A sample of this type of output is shown in Figure 5.

4. To evaluate station hindrance times by arrival-departure mode, the user can specify output as shown in Figure 6.

Link and Node Statistics

For selected links and nodes in the system, the user will want specific occupancy and hindrance time characteristics. Based on a preliminary evaluation of critical station areas, or experience on previous runs, the user will select specific link and node output reports for these purposes. The following are types of link and node output reports.

1. Figure 7 shows an occupancy report for a link in a station. This report summarizes the system image at each simulation interval. Activity in the link is frozen every 10 seconds to show area requirements and the number of persons arriving, departing, in movement, competing with the movement, and in queue. The user may find the number of persons in queue exceeds that designated for the queue area. Then, the station planner may increase the queue area. Average values of the statistics during the simulation period are also shown.

2. For each of the output statistics in the occupancy report, the user may request a more detailed summary of the characteristics similar to that in Figure 5.

3. Hindrance time statistics are also available for selected links or nodes. There are 3 types of link and node hindrance summaries. First, the user may request a summary for a walk time between 2 nodes. Second, the user may request time-in-queue statistics at a particular node. Finally, the user may request statistics for total in-system time from 1 node through another node. The user could specify statistics for 1 link or a number of links. The format of these reports also would be similar to Figure 5.

Application of Statistical Analyses

Most of the output reports summarize output values by mean, variance, and confidence intervals. Because the values used to calculate the output statistics are generated by a stochastic, time-dependent process, the values in the time series will be correlated with each other. So, a finite autoregressive technique to represent the autocorrelated behavior in the time series must be used. The station simulation model uses the autoregressive statistical package to generate the following statistics for any series of user-specified output values:

1. The sample mean;
2. The sample population variance;
3. The lower confidence point of the confidence interval for the mean;
4. The sample size used to calculate the mean and variance; and
5. The upper confidence point of the confidence interval for the mean.

The output statistics generated by the model when the station first starts do not represent stable operating characteristics. Because they depend on the initial condition, observations near the beginning of the simulation period do not represent the true process, and including them in calculating the mean biases the true mean value. But, as the number of observations used to calculate the mean becomes large, the bias goes to zero because the early observations have less influence on the average. Thus, the statistical package used in the model identifies the number of observations, x, that must be discarded from the total observations to ensure that the output statistics are not biased by the initial conditions.

Checkpointing

The simulation will terminate when 1 of the following conditions is met:

1. The simulation period ends;
2. The number of persons outside any queue area exceeds the user's specified limit (in percent); and
3. The occupancy in any movement area is less than the user's specified limit.

Termination is always considered a checkpoint and the user receives the output statistics specified plus the checkpoint file for preloading the network on a future run. The checkpoint file includes card images of user input plus the attribute records of all persons in the station at the time the checkpoint occurred. At restart after checkpoint, the user has the option of adding, deleting, or changing the input values used on the previous run and modifying station loadings for the next run. Checkpoint termination should be triggered by situations where simulation of output values exceeds a specified limit that reflects an out-of-control situtation rather than by an undesirable level of operation that should be allowed to occur to experience a full range of values. For example, the user might specify that the program be checkpointed if the number of persons in queue exceeds 200 percent of the queue space or if the occupancy values in the movement area exceed the level of service F.

Input

The bulk of the input data will be coded on 1 of 9 different types of input cards. In many cases, however, the user may use only 5 or 6 of these cards. The 9 types of input cards are as follows.

Distribution Input Card—When it is necessary or desirable to specify a distribution for use in generating numerical values in the program, the user will specify either the parameters of a theoretical distribution or the x and y points of an empirical distribution.

Device Input Card—The user may wish to specify input data for 1 form of device, such as an escalator, and use the same input data each time that device is specified. This card would be particularly valuable for minimizing the amount of input required where nodes representing queuing devices have the same characteristics.

Node Data Card—For each node in the station, the user must specify node characteristics including identification number, type of device, and queue characteristics.

Link Data Card—For each link in the station, the user will specify link identification, link length, movement area, capability to accept handicapped persons, and other pertinent data.

Shared Area Card—Where links and nodes share the same area (overlapping movement or queue areas), the user must specify these interrelationships. This would be used primarily in the platform area, and, because of the impact on computer running times, the user would limit the number of shared areas to an absolute minimum.

Arrival-Departure Node Data Card—For each node that represents a point where passengers are generated and removed from the systems, data describing the arrival process must be specified and include O-D zone number, type of distribution of arrivals, and characteristics of the door where the arrivals occur.

Elevator Input Card—Specific data is required for a link that describes an elevator. The user must specify headways, link lengths, and door opening times.

O-D Input Card—An O-D table by O-D zone is required.

Output Report Generator Card—For the user to generate data on selected links or nodes, the links or nodes on which reports are desired must be specified.

How USS Is Used

To start, the user would review the Program Write-Up and User's Guide supplied with the USS package, which will provide all the information that the user requires to use the program. After reviewing the guide, the user would run the sample problem that is part of the computer code. Although the sample problem includes only a small

Figure 7. Link occupancy report.

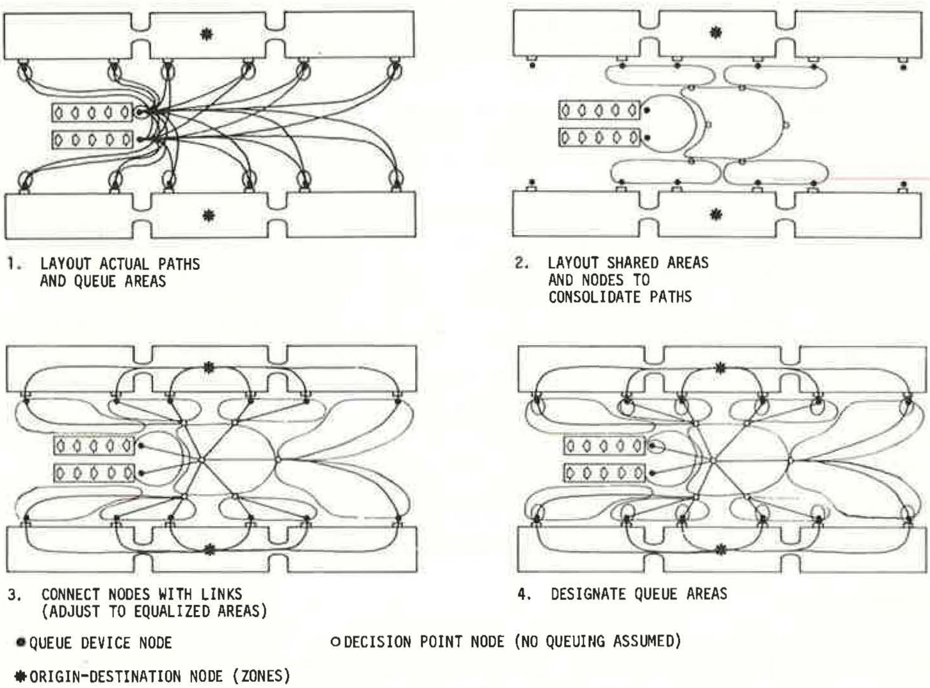
PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

TIME	PERSON ARRIVALS	PERSON DEPARTS	NUMBER ON LINK	NO. THAT COMPETE	TOTAL IN MOVEMENT	AREA/ PERSON
0010	53	15	47	3	50	10.1
0020	77	17	75	0	75	10.6
0030	62	43	87	6	93	9.2
⋮	⋮	⋮	⋮	⋮	⋮	⋮
3600	14	51	99	18	117	5.3
TOTAL	6143	6002	5800	407	6207	
MEAN	21	20	22	2	21	8.2
MIN	0	0	0	0	0	4.2
MAX	123	151	150	20	151	12.7
BIAS	12	14	14	50	12	15

PAGE XXX 10JUL73 SAMPLE TRANSIT STUDY - STATION XX RUN XX

	----'A' NODE QUEUE-----			----'B' NODE QUEUE-----		
TIME	NO. IN QUEUE	REQ'D AREA	OUTSIDE QUEUE	NO. IN QUEUE	REQ'D AREA	OUTSIDE QUEUE
0010	7	35	0	0	0	0
0020	12	60	2	1	5	0
0030	11	55	1	5	25	1
⋮	⋮	⋮	⋮	⋮	⋮	⋮
3600	14	70	3	7	35	11
TOTAL	8732		120	2670		175
MEAN	15	75	0	7	35	0
MIN	0	0	0	0	0	0
MAX	60	300	4	10	50	12
BIAS	15	15	50	32	20	70

Figure 8. Station layout process.



network, it would familarize the user with the basic capabilities and options of the program. The user then would be ready to select an actual station layout for evaluation. Initially he or she probably would select a simple layout or a portion of a layout for testing to become more familiar with the package.

The first step in evaluating the layout would be to convert the layout into links, nodes, and areas. This begins when the user lays out paths that people follow and queuing areas that they use in the station. The user would consolidate areas of conflicting movement into shared areas, locate nodes where paths intersect or areas come together, connect the nodes with links, determine movement areas and other link and node statistics, and designate queue areas. This process is shown in Figure 8.

The user then would prepare the input cards for the program. At first, the user would want to code only a minimum of data to keep running time short and the problem simple. The program includes default values for all but the basic network description. The minimum input includes the following:

1. A parameter card listing the number of links and nodes in the station network and the number of O-D zones;
2. An O-D table (number of persons from inbound node x to outbound node y);
3. A node card for each of the nodes in the network with the mean service time, (e.g., 2.5 seconds per person for a doorway) and the designated queue area (sq ft per person);
4. A link card for each of the links in the network with the link length and the movement area; and
5. An O-D node card for each O-D zone in the network with the node identification number, the O-D zone number that corresponds to this node in the O-D table, the minimum door-open and door-open-extension time, and, if the node represents a vehicle loading bay, the vehicle arrival pattern expressed as a mean headway (e.g., 15 min between vehicles) or a distribution of headways.

With this minimum input the user would run the program. At the termination of a typical run, a checkpoint file would be created for preloading the network on the next run. The user then would add, delete, or change input values to modify the network or its characteristics. As the user became more familiar with the package he or she could change distributions supplied by the program, use device input cards, create more shared areas, and select more detailed output.

SUMMARY

USS can be used in evaluating proposed transit station layouts. Although it will require additional testing and calibration to integrate USS into the transit station design process, it is clear that it will significantly increase the identifying of potential operational problems on the drawing board.

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