PASSENGER BEHAVIOR STUDIES FOR AUTOMATIC TRANSIT SYSTEMS

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This paper reports on part of the coordinated Minitram research program in the United Kingdom being carried out by various groups under the direction of the Transport and Road Research Laboratory. The section of work discussed relates to tests carried out in full-scale simulations of passenger behavior on vehicles and stations to determine the effects on dwell and clearance times of changes in station and vehicle configuration, door sizes and opening times, and directional barriers. The tests were carried out with passengers stratified into commuters, noncommuters, and handicapped populations.

•OVER the last few years, the U.K. Transport and Road Research Laboratory of the Department of the Environment has carried out in-depth assessment of new forms of transport. Following earlier studies of the small-capacity personal rapid transit system known as Cabtrack, interest has centered on a development program for an intermediate-capacity, automatic light transit system known as Minitram. Similar in general concept to several other novel urban transport systems, Minitram is designed to run on its own segregated track with automatic operation, guidance, and control. Eventual designs are envisaged to have medium-density networks and system capacities that will make the system suitable for British provincial towns with populations between 250,000 and 750,000. The system will provide reliable urban transport similar in service level to that of the bus but requiring less operating staff.

In its initial concept, the Minitram system would have a theoretical line capacity of 5,000 to 10,000 passengers/h, depending on the final selection of headways and vehicle capacity. These theoretical capacities would be a significant improvement on observed bus-line capacities in large provincial towns; these are in the region of 3,000 passengers/h. The level of service would be further improved by the provision of small comfortable vehicles with a nominal capacity of between 12 and 30 persons; under automatic control on a segregated right-of-way flexible service with a high frequency of arrivals could be guaranteed. Such a service on a citywide basis could provide a suitable basic public transport alternative capable of offering a service level competitive to that enjoyed by the user of the private car.

Basic research being carried out under the auspices of the Transport and Road Research Laboratory examines the implications of the development of this type of automatic system through the following linked and coordinated programs:

1. Feasibility and project definition studies;
2. A civil engineering and architectural study for a scheduled public demonstration program; and

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3. Supporting studies on traffic simulation, passenger behavior, and parametric costs and benefits.

This paper describes the conduct and findings of the passenger behavior study.

PURPOSE OF PASSENGER BEHAVIOR STUDY

The Minitram will be an automatic system with no driver in the vehicle and no attendants in the stations. If the system is to run efficiently, the human factors requirements must be considered as an important part of the total system requirements. When comparing travel on an automatic system with that on a manned system, one observes that automation does not allow the same tolerances. Employees on a manual system can, within certain limits, adapt the operation of a system to the idiosyncracies of passenger behavior. An automatic system, on the other hand, must be designed in such a manner that it is acceptable and attractive to the public at large. It is possible that in time Minitram will both compete with and replace, to some degree, other forms of transport, both public and private. To do so there must be public acceptance; this acceptance entails the tailoring of the system in a manner that reflects observed behavior preferences.

The general public, for whom the Minitram system is designed, includes many sections of the population who currently find it difficult to travel on public transport systems. The provisions of the United Kingdom's Chronically Sick and Disabled Persons Act of 1970 have been considered in the early stages of project development.

> Any person undertaking the provision of any building or premises to which the public are to be admitted... shall, in the means of access both to and within the building premises... make provision, so far as it is in the circumstances both practical and reasonable, for the needs of the public visiting the building or premises who are disabled.

By studying passenger performance on a simulated Minitram system, we have been able to examine observed performance in relation to proposed vehicle and system requirements in the following areas:

1. Space requirement of passengers while traveling and its effect on vehicle dimensions for vehicle designers,
2. Passenger behavior at stations and its effect on station dimensions, and
3. Behavior of passengers entering and leaving the vehicle and its effect on door design and operation.

On the basis of the work carried out, the system is being developed by the engineer and designer to reflect human factors requirements in the prototype designs for the public demonstration program. This demonstration program, currently scheduled for the early 1980s, will provide an ideal situation for further human factors evaluation because it will be in a development stage even though it will be running as a regular transit service. Therefore, modifications could be incorporated.

Currently, few passenger behavior data appear to be relevant to urban transport systems; those data available are not adapted easily to specialized new systems such as Minitram. Human factors data are available on environmental characteristics, such as noise and vibration (1, 2), lighting (3) and thermal environment (4), all of which are important in the design of vehicle interiors. The information gathered in this research, even though it is specifically relevant to Minitram design, is of general application to automatic vehicle systems. Equally, the full-scale experimental simulation indicates a general method of data gathering to provide reliable guidelines on the ergonomic considerations required for a safe and acceptable design.

EQUIPMENT

The experimental site at Loughborough University of Technology consisted of a 13 by 9-m purpose-built structure flanked by portable cabins that served as waiting rooms and offices. Within the structure, 2 platforms (a minimum of 13 by 3 m in size) were constructed on either side of a central well that accommodated the rubber-tired, tracked vehicle. The vehicle was able to move in and out of the platform area on a track approximately 50 m long with maximum velocities of 10 mph (16 km/h). The vehicle itself was mounted on a trailer drawn by a preprogrammed electric tractor that gave accelerations of up to 1.25 m/s^2 and had a cruising speed of 4.6 m/s. Longitudinal jerks also were controlled by the preprogrammed control unit to ensure that no values higher than 1.25 m/s^2 were obtained. By the use of preprogrammed traction, the experiments were carried out under conditions of controlled velocity, acceleration, and jerk with maximum values at levels found tolerable in previous research. Although vehicle loadings changed throughout experimental runs, the stopping position relative to the platforms was found to be repeatable to an accuracy of ±0.7 m, a distance that did not materially affect the test results.

The experimental vehicle was mounted on the flat trailer carriage and was constructed of 4 wooden partitions with windows. In design, the compartment was adjustable in both length and width so that basic tests could be carried out for a variety of vehicle sizes before in-depth testing of a final vehicle size in the second phase of the project. Both sides of the vehicle had double electrically actuated sliding doors; the variable opening times of the doors were monitored by an electronic digital clock. Flashing lights and an intermittent buzzer were used as a warning signal to passengers that the doors were about to open or close.

TEST VEHICLE SELECTION

In the original concept stage, a vehicle capacity between 12 and 30 passengers was considered for the Minitram vehicle. At an early stage, the 30-passenger vehicle was rejected as being too large chiefly because of the civil engineering and architectural problems that would arise from trying to obtain satisfactory horizontal alignments for such large vehicles in the typical provincial British town.

The design of the vehicle evolved from considerations that for small-capacity vehicles the "seats-facing" arrangement shown in Figure 1 allows the maximum maneuverability in the central standing space. Vehicle width must permit 3 seats side by side with adequate individual seat width. Ergonomics literature has set minimum seat widths of 0.48 m (5). McFarland has suggested that urban transport should provide elbow to elbow width of 0.56 m to allow for street clothing (6). Tests that we carried out indicated that a minimum seat width of 0.5 m would suffice. Later, this was increased slightly to allow better maneuverability in the central open space, giving an overall inside width of 1.7 m.

Seat depth was set at 0.85 m to give seat and knee room and adequate protection of feet. Standing space of 0.255 m^2 (0.46 m by 0.56 m) has been recommended by McCormick (5); the experimental vehicle was designed to provide minimum space of 0.25 m^2 for standees. Determination of final test-vehicle size was made from the 11 experimental vehicles, the specifications of which are given in Table 1. Vehicle dimensions for the dynamic stage of testing were selected from the results observed in the static tests involving all types of populations.

TRAVEL SUBJECTS

It was our intention throughout the experimental sessions to reproduce typical travel situations on an urban transport system designed to accommodate a broad range of travel purposes. Therefore, we decided that individuals traveling on the system could be designated into the following principal categories:

Figure 1. Final test-vehicle dimensions.

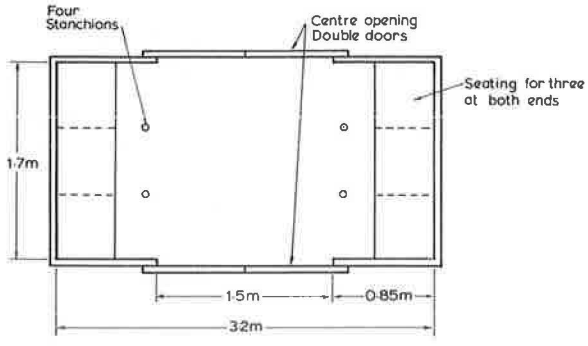
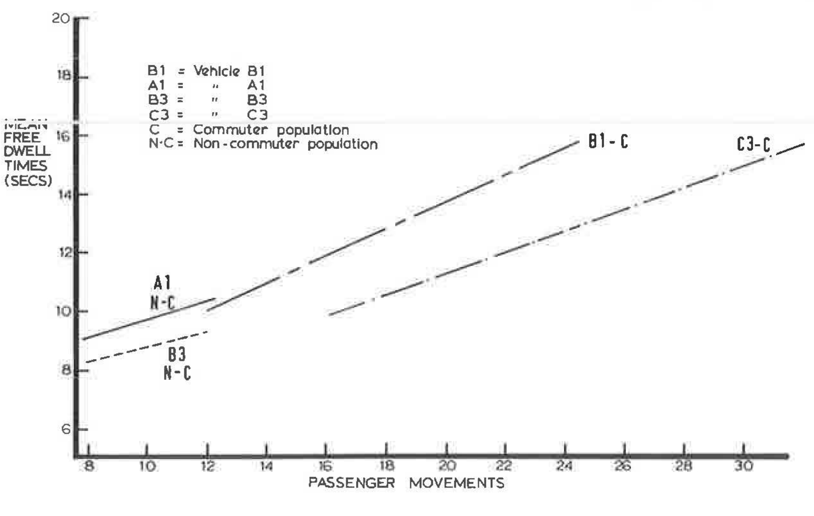


Table 1. Initial experimental and selected vehicle dimensions.

Length (m)	Width (m)	Nominal Capacity (persons)	Vehicle	Door Widths (m)
2.8	1.6	12	A1	1.2
			A2	1.4
3.2	1.8	12	B1	1.2
			B3	1.6
3.2	2.2	16	C1	1.2
			C3	1.6
3.6	2.2	20	D1	1.2
			D3	1.6
3.0	1.7	12	E2	1.4
3.2	1.7	12	F2	1.4
			F3	1.6
3.2	1.7	12	Selected	1.5

Figure 2. Variation of dwell time with passenger movement and vehicle size.



1. Passengers who travel to and from work or shopping during the peak travel hours (for the purposes of this research these were known as commuters) and
2. Passengers who travel during off-peak hours for various trips, such as shopping, sociorecreational, and other nonwork purposes (these were designated as noncommuters).

To suppose that commuters largely are between 18 and 60 years of age and carry little luggage on their journeys appeared reasonable; for the purposes of this study we also assumed that commuters are active and have no major physical handicaps. The noncommuters, on the other hand, were assumed typically to be constituted of mothers with children, shoppers, and elderly people. Noncommuters were considered to consist of a large range of types of persons who have different attributes; travel for a variety of purposes; and often are encumbered with luggage, infant children, and strollers. Handicapped and disabled people make up a major subset of this population; they also are more likely to travel in off-peak periods. The subjects used in the study covered the full range of travelers, from the active commuter to disabled people in wheelchairs.

Subjects taking part in the experimental sessions were encouraged to act as passengers would in a real travel situation. Commuters were asked to carry briefcases, and noncommuters were asked to carry shopping bags and hand luggage. Mothers with young children were asked to put their children in strollers if that was their normal manner of traveling. At least 1 stroller usually was in each noncommuter session.

STATIC AND DYNAMIC SIMULATION MODES

Experimental sessions were set up to provide a realistic simulation of passenger interchanges at stations during the journey through an urban on-line station transit system. The studies were executed in 2 modes.

1. Under static simulation, the test vehicle did not move.
2. Under dynamic simulation, the test vehicle moved out of the station to the end of the 50-m track and returned.

Because the dynamic simulations were time consuming, the majority of the test sessions consisted of static tests after it had been verified that a simple conversion relationship existed between the results for static and dynamic simulations.

EXPERIMENTAL PROGRAM

The experimental program was carried out in 2 parts: the introductory program and the main program.

Introductory Program

The first part of the study was carried out to determine the effect of various design and population factors on dwell time. In an on-line transit system such as Minitram, minimum safe headways are related strongly to the time that the vehicles spend stationary in the station when discharging and taking on passengers. Variation in this critical dwell time was studied in relation to the following factors:

1. Number of passenger movements in and out of the vehicle,
2. Door width,
3. Type of traveling population (commuter or noncommuter), and

4. Presence of a time stress on the passenger movement (from free or fixed dwell times).

In item 4, a free dwell time was the dwell time required for a certain number of passenger movements to take place with no time constraint placed on the travelers. A fixed dwell time was the minimum time during which the passengers could make the required number of passenger movements when they knew that the doors would be open for a stated time.

The introductory program was carried out by using static simulations with a number of different vehicle and door dimensions. The results from the introductory program provided suitable dimensions for a nominal 12-passenger vehicle; further cognizance was taken of the requirements of handicapped passengers from supplementary tests carried out.

Main Program

The main program of experimentation carried out on the selected 3.2 by 1.7-m vehicle over a period of 9 months consisted of 5 areas of investigation.

1. Dynamic validation tests examined the effect of vehicle movement by comparing the results of similar test procedures carried out with static and moving vehicles.
2. Overcrowding tests studied the effect on station dwell time of operation with greater occupancy than the nominal 12-passenger capacity.
3. Through-flow sessions investigated the effect on dwell time of using separate doorways on the opposite sides of the vehicle for segregated entry and exit under conditions of simultaneous and staggered door operating times.
4. Flow-barrier studies were carried out to determine whether dwell-time improvements could be achieved by separating passenger flows with platform barriers. These were conducted for both commuters and noncommuters with handicapped subjects.
5. Platform layout studies investigated the effect of changes in platform characteristics such as platform area and positions of exit and entry.

The experiments of the main program were carried out by using a mixture of static and dynamic tests.

Summary of Results

The overall findings of the passenger behavior study have been reported in depth to the Transport and Road Research Laboratory (7); only the principal results are summarized here.

The relationship between the required free dwell time and the number of passenger movements through the doors was found to be described reasonably by linear relationships for the range of passenger movements investigated. Eleven different configurations of vehicle and door size were tried as indicated in Table 1.

Figure 2 shows the variation of required free dwell time for both commuters and noncommuters. Graphs in the form of regression lines show the best and worst time performances for each population grouping; all of the other 9 vehicles gave performances within these limiting lines. It was further found that, when passengers moved under conditions of time constraint with audible and visible warning, the best noncommuter time improved by approximately 1.5 s and commuter times improved by approximately 2 s.

Because the system was being designed to fulfill the travel needs of all sections of the population, it was necessary to determine the ability of handicapped individuals on crutches or in wheelchairs to negotiate automatic doors. A series of tests were carried out with vehicles A2, B3, E2, F2, and F3. The effect on free dwell times was substantial, and the best results varied from 10 s for 8 passenger movements to

11 s for 12 passenger movements with vehicle F3. However, under the constraint of fixed dwell times it was found that, provided the dimensions of the vehicle were sufficiently large to allow sufficient room for handicapped persons to maneuver, their unhindered progress in and out of the vehicle was no slower than that of other passengers as indicated by the following data:

Vehicle	Passenger Movements	Mean Fixed Dwell Time (s)
F3	8	8.4
	9	7.9
	12	8.9
A2	8	9.9
	9	10.0
	12	10.9

Based on the observations of the constraining effect of standing area and door size on clearance times, we selected a vehicle size of 3.2 by 1.7 m and a door size of 1.5 m. This vehicle was found to operate without noticeable deterioration of dwell time with handicapped passengers.

Tests were carried out to compare the dwell times obtained for a vehicle moving in and out of the station. It was found that, for commuters, movement of the vehicle appeared to cause an increase of approximately 2 s above the values observed in static tests. For noncommuters, which included both elderly and very young people, the increase varied from 3 to 5 s. These results are shown in Figure 3, and they indicate that static simulations can be converted readily into results for moving tests with reasonable certainty and accuracy, and considerable testing time can be saved.

The vehicle layout tested had seating accommodation at each end of the vehicle and a central standing area. It is possible that during peak travel times urban travelers would attempt to board the vehicle even though it already carried its nominal passenger capacity. This possibility must be seriously considered where vehicles have been designed on an ergonomic basis to allow comfortable standing room for standees and sufficient maneuvering space for wheelchairs. When overloading is allowed to occur, not only are the vehicle propulsion units seriously overloaded but also station dwell time can be increased further by the additional passenger movements through the doors. The implications of overloading on the component of station dwell time are shown in Figure 4. It can be seen that the mean values, as might be expected, are higher than for the normal loading case and are linear in behavior over the range of values investigated. At the highest levels of passenger movements, the variation in observed dwell times was noted to be very high, which indicates that, if overloading is permitted, a strong probability of long station dwell times that will affect overall system headways and system reliability exists for the system.

The information shown in Figure 5 indicates the effect of through-flow operation with either simultaneous or staggered door opening times. It can be seen that significant time savings can be achieved by the adoption of through flow, in which one door would operate for exiting passengers only and the opposite door would operate for entering passengers only. The superior vehicle performance must be balanced against the added cost and environmental intrusion of the larger platform requirements for this sort of operation. It is interesting to note that staggered door opening did not improve overall dwell times. The difference in time between the 2 types of door openings was 1.7 s. It is apparent, however, that the space vacated by alighting passengers is large enough to allow free access for the boarding passengers when doors are opened simultaneously in a vehicle of this size. The extra space provided by staggered door opening is unnecessary, and dwell times increase.

The final part of the study investigated the implications of platform design from the

Figure 3. Comparison of dwell times under dynamic conditions with times for static tests.

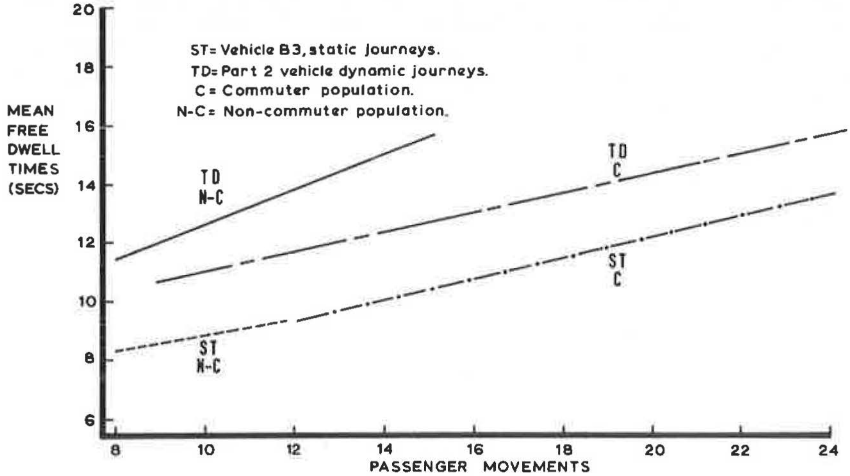


Figure 4. Effect of vehicle overloading.

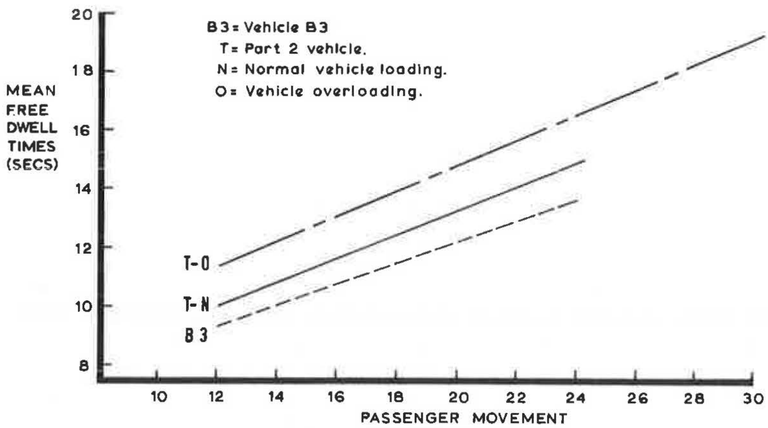


Figure 5. Dwell times under conditions of through flow.

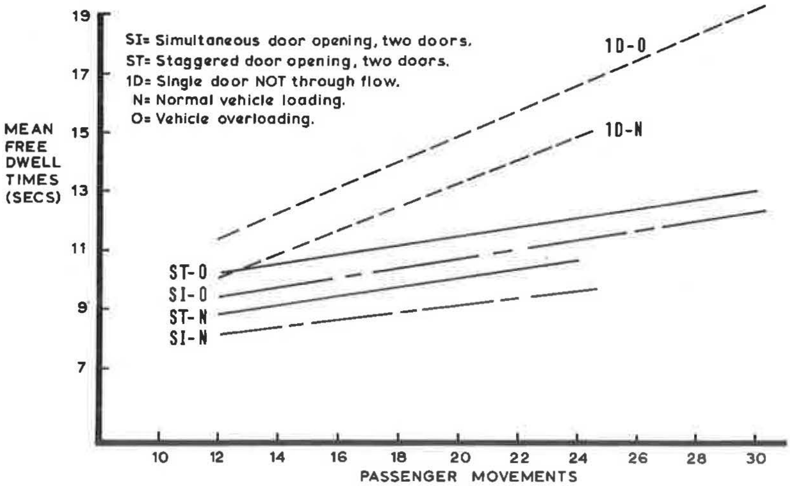


Figure 6. Platform layout, entry and exit at same end.

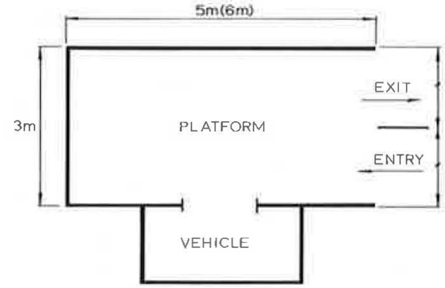


Figure 7. Platform layout, entry and exit at opposite ends.

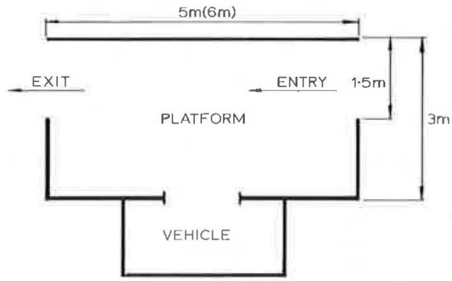
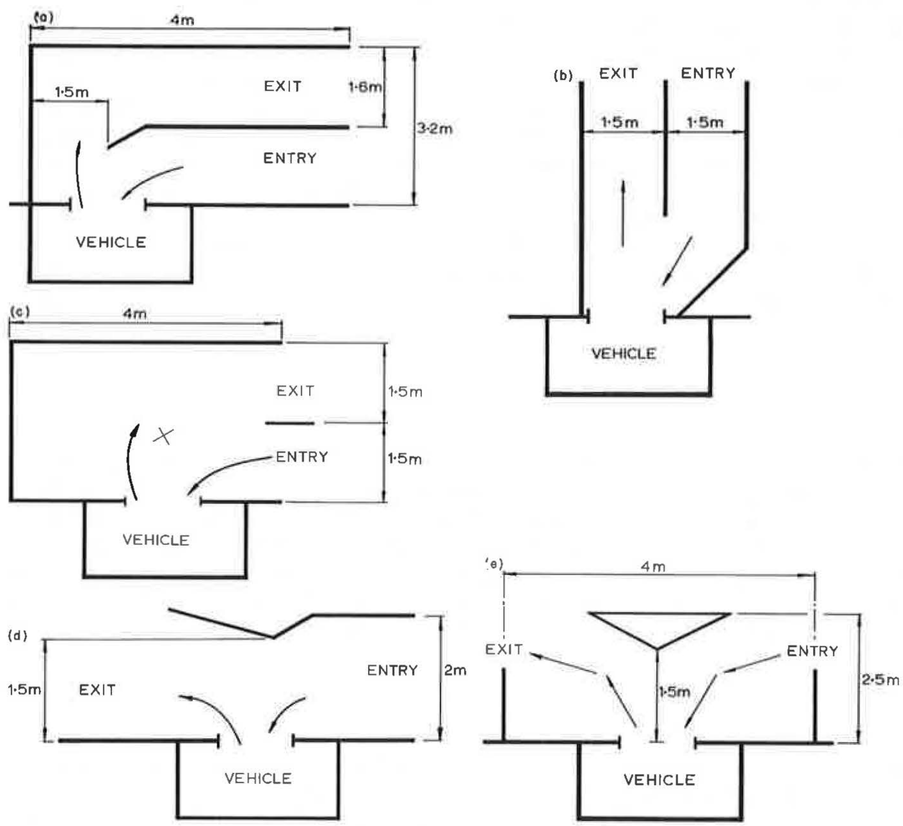


Figure 8. Barrier configurations.



viewpoints of size, location of exit and entry, and use of platform barriers to channel flow. Fruin's work gives standards for personal space for walkways and queues (8), but these are not entirely applicable. For testing purposes, space standards of 1.5 m^2 and 1.25 m^2/person were tested. In the nominal 12-passenger vehicle, these standards gave 6 by 3-m and 5 by 3-m platforms as shown in Figures 6 and 7 for 2 different types of exit-entry arrangements. The clearance times for the 4 different arrangements were very similar; a difference of only 2.5 s existed between the worst and best times for 24 passenger movements.

Because Minitrams possibly will operate in short trains during peak hours, experiments were conducted using an 8 by 3-m platform and 2 vehicles. It was found that the vehicle dwell time was only marginally affected by the position of platform entry and exit. A time saving of 0.5 s occurred when entry and exit were at opposite ends of the platform. The platform itself cleared 3 s faster under these conditions. There was no evidence that the 2 vehicles interfered with each other and vehicle dwell times were in fact noted to be shorter than when 1 vehicle was used.

Minitram stations are expected to be constructed in built-up areas; consequently, platform size will be restricted. The cost of land in such areas is high, and, if street space is to be used, visual intrusion will be high. If there is a single platform, it will be used by passengers boarding and alighting from both directions of travel. Cross flows and collisions occur as various groups of passengers attempt to walk in different directions in confined space. The experimental sessions investigated the possibility of passenger separation by a variety of barriers, as shown in Figure 8. It was found, however, that only 1 s of difference in vehicle dwell times occurred for the various configurations of barriers tested for both 24 commuter passenger movements and 12 noncommuter movements. No barrier appeared to have any distinct advantages in terms of dwell time or ease of passenger flow, and no clear evidence existed to show that a system of barriers would improve platform efficiency. In dealing with handicapped passengers some disadvantage appeared to be incorporated in installing fixed barriers.

CONCLUSIONS

The 1-year project has indicated that the simulation of operating conditions of automatic transit systems can be extended from mathematical modeling to full-scale trials of human factors relationships under controlled conditions. These full-scale trials have permitted design decisions on vehicle and platform configuration to be taken with some confidence that operational behavior will reflect the conditions found in the simulations, and they have provided a basic design for vehicle and platform configurations for the public demonstration program to be carried out in the coming years.

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