TRANSPORTATION RESEARCH RECORD
522

Formerly issued as Highway Research Record

New Transportation Systems

7 reports prepared for the 53rd Annual Meeting of the Highway Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
Washington, D. C., 1974

Transportation Research Record 522
Price $3.40
Edited for TRB by Mildred Clark

subject area
84 urban transportation systems

Transportation Research Board publications are available by ordering directly from the Board. They are also obtainable on a regular basis through organizational or individual supporting membership in the Board; members or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

These papers report research work of the authors that was done at institutions named by the authors. The papers were offered to the Transportation Research Board of the National Research Council for publication and are published here in the interest of the dissemination of information from research, one of the major functions of the Transportation Research Board.

Before publication, each paper was reviewed by members of the TRB committee named as its sponsor and accepted as objective, useful, and suitable for publication by the National Research Council. The members of the review committee were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the subject concerned.

Responsibility for the publication of these reports rests with the sponsoring committee. However, the opinions and conclusions expressed in the reports are those of the individual authors and not necessarily those of the sponsoring committee, the Transportation Research Board, or the National Research Council.

Each report is reviewed and processed according to the procedures established and monitored by the Report Review Committee of the National Academy of Sciences. Distribution of the report is approved by the President of the Academy upon satisfactory completion of the review process.

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, serving government and other organizations. The Transportation Research Board evolved from the 54-year-old Highway Research Board. The TRB incorporates all former HRB activities but also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

LIBRARY OF CONGRESS CATALOGING IN PUBLICATION DATA

National Research Council. Highway Research Board.
New transportation systems.

(Transportation research record; 522)
1. Local transit–Congresses. 2. Personal rapid transit–Congresses. I. National Research Council. Transportation Research Board. II. Title III. Series.
TE7.H5 no. 522 [HE305] 380.5'08s [388.4]
ISBN 0-309-02367-X 75-6798

CONTENTS

FOREWORD

The papers in this RECORD report on an intermediate-capacity transit system, station and intersection for a personal rapid transit network, feasibility of an elevated STOLport test facility, application and development of demand-actuated transportation systems, and a moving walkway.

Harmelink describes a program for building and testing a demonstration transit system of intermediate capacity in Toronto. The demonstration system is considered a forerunner and test-bed for revenue systems that will be built in major Ontario cities in the next decade. The scope of the revenue system is described as are the plans to develop an industrial capability in Canada for developing improved transit systems.

Thangavelu, Berry, and Shaefer describe the development of geometric designs for high-capacity personal rapid transit links, stations, and intersections and the prediction and evaluation of their performance under quasi-synchronous control at different design and operating conditions.

Greenfield and Adams describe the results of a feasibility study and costs of building an elevated STOLport test facility. The major assumption in the study was that it is technically desirable to build an elevated STOLport in order to conduct a testing program to determine the feasibility of flight operations from such a space-limited structure. Engineering analyses were made of a full range of potential structural schemes from which 2 were chosen for more vigorous study to develop costs for STOLport test facilities to be situated at each of the 2 site options.

Lerman and Wilson present an analytic equilibrium model for use in designing demand-responsive transportation systems. The model requires minimal data and computational capability and is used to test the sensitivity of level of service and net operating cost to changes in demand and fares. The results demonstrate the important effects of decisions such as fleet size, service area, and fare levels on the economic prospects of a potential demand-responsive system.

Heathington, Davis, Middendorf, and Brogan describe research on 2 privately owned demand-responsive transportation systems to determine the economic feasibility and marketability of these systems and the roles that they play in small- to medium-sized urban areas. The 2 systems are taxicab companies that offer door-to-door service on a shared-ride basis in 6-passenger automobiles. Preliminary results reveal these systems to be economically viable and important components of the total public transportation system.

Shilling and Fielding describe the La Habra dial-a-ride project, which is operated by the Orange County Transit District and provides a high level of door-to-door service within a reasonable budget and fare structure. This service has proved to be efficient, extremely popular, and operationally feasible.

Todd discusses the need for a high-speed moving walkway to transport large numbers of passengers at speeds of 10 mph for a distance of 1 mile. The disadvantages of various systems that have been proposed are discussed. The principles of the Dunlop S-Type Speedaway and the ways in which this design overcomes the disadvantage of earlier proposals are described.

ONTARIO'S PROGRAM FOR INTERMEDIATE-CAPACITY TRANSIT

M. D. Harmelink, Ontario Ministry of Transportation and Communications

This paper describes the Ontario government's program for building and testing a demonstration transit system of intermediate capacity in Toronto. This demonstration system is considered a forerunner and test-bed for revenue systems, which, it is anticipated, will be built in major Ontario cities in the next decade. The scope of the revenue systems is also described as are the government's plans to develop an industrial capability in Canada for developing improved transit systems.

•IN November 1972, Ontario Premier William G. Davis announced a new urban transportation policy for Ontario (1). The policy, which is intended to shift emphasis from urban expressways to a variety of transportation facilities, will be implemented through a 6-point program administered by the Ministry of Transportation and Communications. The program includes

1. Subsidies of 75 percent for the purchase by municipalities of buses, streetcars, trolley buses, and related facilities;
2. Development, at provincial expense, of a prototype and operating demonstration of a new form of intermediate-capacity transit system together with a subsidy program of 75 percent to assist municipalities in applying the system to meet their needs (in Ontario, the highest priority candidates for such systems were identified as Toronto, Ottawa, and Hamilton);
3. Subsidies of 75 percent for studies and programs to alter demand for transportation at peak times such as the encouragement of staggered or flexible working hours to spread peak loads in major cities;
4. Subsidies of 50 percent to urban areas for upgrading and expanding computer-controlled traffic systems;
5. Subsidies of 75 percent for the continuation and expansion of transportation studies in cooperation with municipalities to maximize the use of existing roadways through the study of means such as 1-way streets and delivery and parking policies; and
6. Intensification of provincial efforts and resources to coordinate transportation planning among the municipalities in Ontario.

These new steps are in addition to the following previously introduced programs that will be continued:

1. Development, in partnership with municipal authorities, of new transit systems and upgraded existing ones;
2. Provision of aid to municipal transit systems in the form of deficit subsidies (50 percent of the deficits incurred up to a maximum amount limited by a formula); and
3. Financing of demonstration projects in the public transit field (e.g., demand-responsive buses and worker buses).

This brief description sets the framework of the province's urban transportation program. The rest of this paper deals with one of these program elements: the intermediate-capacity transit program.

BACKGROUND TO EVALUATION STUDY

The activity leading to the intermediate-capacity transit system program announced late in 1973 began in 1970 when the Ontario Ministry of Transportation and Communications convened a Transportation Technology Task Force with representatives from the provincial and federal governments, municipal planning boards, the Toronto Transit Commission, and private industry. The task force reviewed the status of development of new transit system concepts and technology. On the basis of extensive discussions, literature reviews, commissioned technical studies (including an inventory of more than 200 systems), and visits of inspection to a number of system developers in North America and Europe, the task force identified intermediate-capacity transit as a primary urban transportation need. Such systems could be used as a secondary or feeder system supplementing subways in large urban areas or as the primary system in cities of intermediate size. The capacity range to which these systems are most applicable was identified as approximately 6,000 to 20,000 passengers per hour per direction—the range in which low-capacity buses are inadequate, particularily on shared rights-of-way, and high-capacity subways are not usually economically feasible. The partial penetration of the new intermediate systems into traditional bus and subway capacity ranges was also considered a real and attractive possibility.

The Ministry of Transportation and Communications subsidizes transportation planning, construction, and operation in Ontario municipalities for both road and transit facilities and also acts in a technical advisory capacity to them. The ministry, therefore, has a strong interest in assessing the applicability and status of new transit systems across a broad spectrum of applications, including capacity, type of service, and urban environment. Following the activity of the Transportation Technology Task Force was the announcement by Premier Davis in October 1971 of a study for the evaluation and selection of intermediate-capacity transit modes for use in Toronto and other Ontario municipalities. The selected system would be tested at a demonstration track to be built in Toronto and thereafter installed in Ontario municipalities.

OBJECTIVES OF EVALUATION AND SELECTION STUDY

The objectives of the evaluation and selection study were as follows:

1. To evaluate intermediate-capacity transit systems relative to conventional transit systems across a broad range of capacity and network requirements (the optimum ranges of application of the feasible systems were expected to emerge from the study, permitting the best matching of systems to requirements in Ontario municipalities);
2. To evaluate in terms of engineering design and hard costs the most promising systems for application to a specific site in Toronto; and
3. To select one system for testing and demonstration on a track to be constructed at the selected Toronto site.

OBJECTIVES OF THE TRANSIT DEMONSTRATION SYSTEM

Since one objective of the evaluation study was the selection of one system for demonstration, it is appropriate to address the question, Why a demonstration system at all? When this question is asked, the usual related question is, Why not let the systems developers proceed until they have demonstrated a feasible, reliable system?

One of the strongest reasons for proceeding along the selected path was that of time. Left to themselves, various systems developers might eventually develop a system that would appear to match a "customer's" needs with greater or lesser degrees of success. However, left to themselves, or with the usual limited government funding distributed among them, the process of developing and proving the systems might also take many years. If the advanced systems do exhibit all, or even some, of the claimed advantages over conventional systems, the ministry considered that they should therefore be implemented soon rather than late to start reaping the benefits from their introduction. Furthermore, by defining its requirements early, rather than letting development proceed to a final product, the ministry felt that the chances would be enhanced of having a system that met the defined needs, rather than vice versa. Finally, a demonstration system is a normal stage in the development progression: design to prototype to demonstration system to revenue system. It was felt that the demonstration system cost, although substantial, represented only a small percentage of the cost of the ultimate revenue systems and was a worthwhile investment to ensure maximum benefits from the revenue systems.

The demonstration system is intended to test, insofar as possible, those features of the system related to typical transit characteristics and service. Demonstration system performance will be extrapolated to more extensive revenue applications in various Ontario municipalities. The objectives of the transit demonstration system are

1. To test technological feasibility (functional performance of the system and its various subsystems);
2. To test operational reliability in day-to-day service;
3. To test compatibility with climatic conditions in Ontario;
4. To provide real base data on costs (capital, operating, maintenance);
5. To test the passenger-carrying capability of the system;
6. To test the passenger-system interface and the passenger response to the system;
7. To test environmental impact (noise, visual intrusion); and
8. To provide a continuing test-bed for improvements in the system and subsystems.

SCOPE AND METHODOLOGY OF EVALUATION STUDY

Phase 1

On the basis of compiled information, 8 system developers were invited, in December 1971, to participate in the selection study. The developers were asked to provide detailed information on system and subsystem technology, performance, and capital and operating costs, as requested in a prospectus (2) accompanying the invitation to participate. General specifications only were given for parameters such as capacity, speed, safety, noise, ride comfort, and all-weather performance. The primary objective was to obtain information on the different systems to permit a comparative evaluation of them for a variety of applications. A developers conference was held in January 1972, and the developers were given 2 months to supply the information. The ministry felt that the developers should already have most of the requested information available, and, therefore, paid each developer only a nominal sum to cover costs of travel, reproduction, and mailing. The ministry team completed its evaluation and supporting analyses and the writing of more detailed specifications for phase 2 by August 1, 1972, as scheduled. The phase 1 evaluation resulted in the selection of 3 of the original 8 systems to proceed to phase 2. The 8 systems evaluated in phase 1 are given in Table 1.

Simultaneously with the evaluation, several other activities were initiated. The first was the selection and application for approval of the demonstration site. The second was the work on application studies: computer simulations applying the proposed systems to urban networks for real cities of varying size and tests of the sensitivity of cost and benefits to variations in parameters such as grid spacing (access time), head-

Table 1. Characteristics of systems evaluated in phase 1.

System	Design Concept	Automatic Command Control	Suspension	Propulsion
Alden StaRRcar (USA)	PRT	Yes	Rubber tires	Rotary ac motors, hydrostatic drive
Ford ACT	Line-haul or PRT	Yes	Rubber tires	Rotary dc motors
Transportation Technology, Inc. (USA)	PRT	Yes	Air cushion	Linear induction motors
Uniflo (USA)	PRT	Yes	Air cushion	Linear air turbine
Bertin Aerotrain (France)	Line-haul	Optional	Air cushion	Rotary or linear induction motors
Urba 30/100 (France)	Line-haul	Optional	Negative-pressure air cushion	Linear induction motors
Hawker-Siddeley Canada (Canada)	Line-haul with off-line stations	Optional	Rubber tires	Linear induction motors
Krauss-Maffei Transurban (Germany)	Line-haul or PRT	Yes	Electromagnetic	Linear induction motors

way, speed, and type of service. In addition, simulation studies of system performance and network dynamics were begun. These studies, and numerous discussions, seemed to indicate that feasible PRT systems were some years away for the following reasons:

1. Decision-makers would not likely approve, in the near future, areawide implementation of such a radical departure from conventional transit modes;
2. Feasible operation of PRT service appears to require extremely short headways, which, with the associated network dynamics, have not been demonstrated; and
3. The marginal benefits of PRT, compared with somewhat more widely spaced, frequent line-haul and express service, do not seem to justify the marginal costs (assumptions and claims made by PRT advocates in the past seem unduly optimistic).

The rationale was introduced into the phase 2 specifications (3) in these words:

> Preliminary assessments suggest that the first applications of advanced systems are likely to be of a "linear," line-haul nature. It is considered a good possibility, however, as transit systems and technology develop, that a transition to more extensive networks, smaller vehicles, shorter headways, and a more flexible and personal type of service will occur. It has been attempted in this specification for a demonstration system to keep a number of options open. The need for practical line capacities up to 20,000 passengers per hour per direction, with entrained vehicles, has been stressed, but at the same time intermediate size vehicles and short headways for single vehicle operation have been specified to permit, by testing, a start to be made on the transition to a more flexible and personal type of service.

<u>Phase 2</u>

The 3 system developers selected to proceed to phase 2 were Ford, Hawker-Siddeley, and Krauss-Maffei. The purpose of phase 2 was to generate a preliminary engineering design and a fixed-price bid on all elements of the demonstration system except the civil engineering (guideway and station structures) for which estimated costs are given. It was agreed that the prices established by a competitive tendering process with civil engineering contractors would be accepted at the time of implementation.

Partway through phase 2, the Ford Motor Company withdrew from the competition, having decided that to redesign its system to meet our specifications for speed and entraining capability was not in its corporate interest. The remaining 2 developers were each paid $50,000 to defray costs, and they submitted their technical design proposals and bids on February 1, 1973, as scheduled. The technical evaluation process took 3 months, and during that time mutually acceptable contracts were negotiated with both submitters. The major evaluation criteria were as follows:

Item	Criteria
Company	Long-term contractual conditions (licensing, data rights, royalties, competitive bidding, Canadian content) Ability to deliver the system with the required performance on time and at contracted cost (project management capability, level of commitment, status of hardware development)
Cost	Itemized capital costs of demonstration system Itemized capital cost estimates of future application and revenue system
System	Technology assessment, by subsystem and total system, in terms of feasibility, quality of design, and integration of subsystems Flexibility of application, including type of application (capacity range, geometric criteria), type of operation (operating strategies, transitions in service level), and expandability (network expansion, higher speed potential, potential for goods movement)

Item	Criteria
System	Safety for users, nonusers, and maintenance and operating personnel Reliability, by subsystem and total system Environmental effects (aesthetics, pollution, noise and vibration, space consumption) User attributes (time and convenience factors, ride comfort)

The evaluation process resulted in the selection of Krauss-Maffei AG of Munich, West Germany, and a contract for the transit demonstration system was awarded May 1, 1973.

DESCRIPTION OF TRANSIT DEMONSTRATION SYSTEM

The site of the transit demonstration system (TDS) is located within the Canadian National Exhibition Park and adjacent to Ontario Place in Toronto (Fig. 1). The TDS will be built as a 1-way loop about 2.5 miles in length and have 4 off-line stations. Station 1 is at Princess' Gate, the main entrance to Exhibition Park; station 2 interfaces with the York Station of the provincially operated GO-Transit commuter rail line; station 3, at the Dufferin Gate, connects with a nearby parking lot; and station 4 serves the main entrance to Ontario Place. A maintenance building and storage track will also be connected to the guideway loop.

The guideway is almost entirely elevated. The alignment has been laid out to permit testing on short sections at speeds as high as 80 km/h on both straight and curved alignments. Fifteen vehicles (Fig. 2) will be acquired for testing. These will be capable of operating either singly or in trains of 2 or 3 vehicles. Characteristics and system specifications are given in Table 2. The total cost of the demonstration system is approximately $16 million.

IMPLEMENTATION OF DEMONSTRATION SYSTEM

The TDS program is now in phase 2, which consists of detailed design, construction, commissioning, and acceptance testing. The major planned events in phase 3 are as follows:

Event	Date
Developer receives system specifications	May 1, 1973
Start of commissioning	
1 to 2 vehicles	January 1, 1975
3 to 6 vehicles	January 20, 1975
7 to 15 vehicles	May 30, 1975
Completion of acceptance testing on 15-vehicle system	July 31, 1975
Turnover to ministry (contingent on completion of acceptance testing)	August 10, 1975

Phase 4, the proving test phase, is not covered by the current contract. However, the plan is that a successful phase 3 will lead to the following sequence in phase 4:

Event	Date
Proving test program 1 begins	August 10, 1975
Public passenger-carrying at Canadian National Exhibition	August 15 to September 5, 1975
Winter testing	December to April 1976
Proving test program 1 completed	September 15, 1976

Figure 1. Route of transit demonstration track in Exhibition Park, Toronto.

Figure 2. TU-02 Transurban prototype at Krauss-Maffei Plant, Munich, Germany.

Table 2. Characteristics of transit demonstration systems.

Item	Description or Specification
Vehicle capacity	
Nominal	12 seated, 8 standing
Crush	12 seated, 15 standing
Vehicle dimensions, m	
Length	6.5
Width	2.25
Height	2.8
Minimum turn radius, m	35
Suspension and guidance	Electromagnets on vehicle base attracted to armature rails on guideway; current in magnets regulated to maintain constant air gap; no secondary suspension
Switching	Magnetic switching on the vehicle; no moving parts on track; on-board mechanical switch arm deployed as safety backup
Propulsion	Linear induction motor controlled by inverter, fed from 600-volt dc power distribution system
Command and control	Full automation, with a hierarchical, relatively centralized control system; triple computer configuration used to ensure safety and improve reliability
Guideway	Reinforced concrete box beam 0.75 m wide, depth varying with span, spans up to about 30 m; mounted atop the beam is a "console" made up of magnet armature rails and linear motor reaction rail
Braking	Regenerative motor braking and emergency caliper brakes
Headway, sec	
At 48 km/h	10
At 72 km/h	15
At 48 km/h, for testing, without carrying public passengers	6
Operating speed, km/h	
Nominal	72
Maximum normal	81
Maximum acceleration-deceleration, g	
Vertical	0.10
Lateral	0.10
Longitudinal	0.15
Maximum jerk, g/sec	
Vertical	0.05
Lateral	0.08
Longitudinal	0.08
Noise	
Interior	PNC 60
Exterior	PNC 50 at 7.6 m
Supervisory schemes	Scheduled line-haul Scheduled line-haul mixed with express service On-demand service (PRT model)
Maximum grade, percent	6.5

Table 3. Revenue system costs.

City	Number of Routes	Double-Track Miles	Projected Cost (millions of dollars)	Projected Cost per Mile (millions of dollars)
Toronto	5	56	756	13
Ottawa	1	11	195	17
Hamilton	3	17	283	16

IMPLEMENTATION OF REVENUE SYSTEMS

The November 1972 transportation policy statement described a number of revenue routes for intermediate-capacity transit systems in Toronto, Ottawa, and Hamilton. Although specific routes were examined and described in each city, the intention was to indicate that such routes were feasible rather than to define unilaterally where such routes should go. In keeping with its past practice, the ministry intends to consult fully with each municipality to arrive at the best transportation solution in terms of modes, routes, and service.

Nevertheless, it is of interest to describe briefly intermediate-capacity transit networks postulated for each city and to indicate the scope of the government's intentions and commitment to better transportation for Ontario cities. These routes are given in Table 3. Costs per mile, which include some tunnel sections, are still quite favorable compared with current subway costs of $25 to $30 million per mile. The target date for implementation of the first lines was set as 1977; the majority of the lines are to be constructed within the next 10 years.

THE ONTARIO TRANSPORTATION DEVELOPMENT CORPORATION

The Ontario government has also taken steps to develop a Canadian industrial capability in advanced transportation systems. In June 1973, it set up the Ontario Transportation Development Corporation (OTDC), a Special Act Company, to hold and exercise the license rights acquired by the government from Krauss-Maffei during the contract negotiations. These rights and arrangements are

1. Exclusive license rights on all present and future technology, including all patents and industrial property associated with the Krauss-Maffei system, for any application in Canada (these license rights include a training and know-how transfer provision to ensure capability of application);
2. Nonexclusive license rights in Central and South America to ensure an export market for Canadian industry and a "most favored nation" provision for sales to the balance of the world, except the European Common Market (special provisions apply to the United States market where the OTDC receives a percentage of all royalty income from that market);
3. The right to sublicense companies in Canada for the manufacture and sale of complete transit systems, subsystems, and components;
4. A contractual commitment that prior to May 1, 1974, Krauss-Maffei will establish a Canadian controlled company in Canada to hold 1 such sublicense; and
5. A contractual commitment for the provision of future technological development by Krauss-Maffei.

The role of the OTDC will be

1. To coordinate and promote the development of advanced technology of all types relating to public transit and to integrate this development with the design and production of conventional transit facilities;
2. To fund research in transit innovations in intermediate-capacity systems and others; and
3. To market systems through the private sector in Ontario and in Canada.

The Canadian government and other provincial governments in Canada have been invited to participate in the transit and industrial program. Many detailed aspects of the program have yet to be worked out, but the estimated Canadian market for intermediate-capacity systems of $3 billion and the employment of approximately 15,000 workers for a 10-year construction period indicate that a cooperative arrangement among the governments of Canada and the private sector will lead to the best achievement of the defined goals.

REFERENCES

1. Davis, W. G. An Urban Transportation Policy for Ontario. A Statement given at the Ontario Science Centre, Nov. 22, 1972.

2. A Study for the Selection of an Intermediate Capacity Public Transit System. Research and Development Division, Ontario Ministry of Transportation and Communications, Jan. 1972, Rev.
3. Schedule A—Specifications for Transit Demonstration System. Research and Development Division, Ontario Ministry of Transportation and Communications, April 30, 1973.

DESIGN ANALYSIS OF STATIONS AND INTERSECTIONS OF A HIGH-CAPACITY PERSONAL RAPID TRANSIT NETWORK

K. Thangavelu, D. S. Berry, and B. M. Shaefer, Northwestern University

This paper describes an effort to develop geometric designs for high-capacity personal rapid transit links, stations, and intersections and to predict and evaluate their performance under quasi-synchronous control at different design and operating conditions. The system assumed 1-way routes and vehicle accelerations and decelerations only on the off-lines. The geometric design of off-lines at stations and intersections considers recommended normal and centripetal acceleration and jerk rates, allowable radius of curvature, required maneuver zone length, and required capacity of the off-line and the line spacing chosen. Typical conditions for a large urban area are considered. In the PRT system, vehicle queues are formed on the upstream and downstream sides of station platforms and intersection turns. The modeling, analysis, and simulation of these queues are described. The excess capacities and the sizes of queuing zones needed can be obtained from simulation results for stations and intersections of different capacities. The resulting average waiting time, the probability of vehicle rejection on the upstream side, the probability of forced switching to prevent the stopping of vehicles on the downstream side, and the achievable guideway density are given as functions of design and operating parameters. The possible trade-offs among design capacity, traffic density, length of queuing zone, and user costs involved at stations and intersections are discussed.

•THE CONCEPTS of people movers, personal rapid transit systems, and dual-mode vehicle systems originated in the last decade as solutions to urban transportation problems. The personal rapid transit (PRT) system is proposed as an alternative to automobile use on urban arterial streets. These systems use automobile-sized vehicles on grade-separated guideways and are operated by electronic controls and computers. Complete network traffic control enables efficient routing, scheduling, empty-car dispatching, and balanced loading of the network.

During the past few years various strategies for network traffic control have been proposed: synchronous cycle concept, synchronous slot concept, quasi-synchronous concept, and multizone zone-synchronous concept. The selected network control philosophy affects the system performance—station and intersection use, waiting times and delays in the system, average speed of travel, average trip length, possible guideway density—and also the control, communication, and computer requirements for the vehicle and the Network subsystems.

The ongoing research work at Northwestern University consists of designing a hypothetical PRT network for possible application in a large metropolitan area and simulating its operation under various network control strategies to study the effect of control strategy on system performance. This paper deals with the design of stations and intersections for a PRT network under quasi-synchronous control.

ASSUMPTIONS

1. Vehicles operate at uniform speeds over 1-way guideways. The speed selected results in an average speed of travel higher than that possible with automobiles.
2. The stations and intersections are located on off-line guideways, which are designed with consideration to system effectiveness and geometric limitations.

3. The vehicles accelerate and decelerate only in the off-lines.
4. The network spacing and station distribution permit easy accessibility of the system in the CBD and inner-city areas and accessibility from the developed portion of land in the outer rings.
5. The vehicles are automobile-sized and can carry 4 to 6 persons. The average occupancy is 1.5 persons.
6. The vehicle spacing and control systems provide for acceptable levels of safety.
7. The network meets the personal travel demand for automobiles and bus transit expected within a typical large metropolis in 1990.

ABBREVIATIONS AND NOTATION

The abbreviations and notation used in this paper are given below.

a_m = maximum centripetal acceleration;
C = guideway capacity, in vehicles/hour;
C_S = station capacity, in vehicles/hour;
C_r = capacity ratio between main line and HIS;
C_θ = C/C_r, theoretical capacity of HIS;
C_v = velocity ratio between main line and HIS;
f = tire friction factor;
H_D = vehicle interarrival time or headway, in s-cycles;
HIS = high impedance section;
J = smallest integer such that (when C_r involves a fraction) JC_r is an integer;
K = spacing factor;
L_{tr} = trigger zone length, in feet;
LCC = local control computer;
L_S = station spacing, in miles;
LVS = local vehicle sensors;
m = $T_M/[(C_r - 1)J]$, maximum number of vehicles accommodated in the upstream and downstream queues after Markovian renewal process;
n_B = average number of vehicles block circling;
N_{cc} = time to communicate, compute, and command vehicle switching, in s-cycles;
N_{CMS} = travel time from switch to merge node on main line, in s-cycles;
N_{Cr} = minimum travel time on downstream side from HIS exit to merge node, in s-cycles;
N_{CSN} = maximum number of slots from switch to slot sensor;
N_θ = number of stations/square mile;
$N\Delta$ = number of slots to be checked to ensure forced switching with given probability;
p_B = probability of vehicle being observed block circling;
p_f = probability of forced switching;
p_r = probability of vehicle rejection at switch;
p_{SL} = $(1 - U_f) + p_v$, probability of an empty slot being observed on the main line;
p_v = probability of vehicle being observed seeking switching from main line to HIS or merging from HIS to main line during an s-cycle;
q_r = $(1 - P_r)$, probability of a vehicle being switched at the switch;
R = allowable radius of curvature;
R_a = p_r/q_r, average number of block-circling rounds;
S = spacing between vehicles;
S_L = $S + L_V$, length of slot, in feet;
S_L/V = s-cycle, the time for slot to cross any point on main line;
S_r = slot ratio, the reciprocal of ρ_D;
S_t = slot time, in seconds;
t_a = average interarrival time between vehicles on HIS;
t_b = average block-circling time;
t_{wq} = average waiting time in queue;
t_{wt} = average total waiting time;
T_A = trigger advance;

T_M = maximum number of triggers provided;
T_{MN} = maximum number of triggers required to allow waiting vehicle to occupy slot vacated by forced switching;
T_{MX} = maximum allowable number of triggers on the downstream side;
T_N = trigger used by the vehicle—vehicle waiting time in s-cycles;
TR = turn ratio, the ratio between smaller number of vehicles turning off a line and larger number of vehicles turning off cross line;
U_f = guideway density;
U_{fs} = guideway density downstream of switch;
U_{fx} = guideway density upstream of switch and on line off which smaller number of vehicles turn;
V = main-line velocity;
V_s = HIS velocity;
ρ_D = p_v/p_{SL}, density for downstream queue; and
ρ_s = HIS density.

HYPOTHETICAL PRT NETWORK DESIGN

Main Lines

The hypothetical PRT network was designed to meet the traffic demand for the Chicago metropolitan area in 1990 as forecast by the Chicago Area Transportation Study (CATS) for the finger plan of the Northeastern Illinois Planning Commission (1). The CATS area in the 1956 study consisted of 8 rings. Each ring was treated as a uniform area and the internal trips, external trips, and through trips made in each ring by automobiles and bus transit were obtained. Based on trip lengths, peak-hour factors, and vehicle occupancy, the loaded vehicle flow rates per mile width of corridor per direction were obtained.

The maximum possible flow is less than the theoretical capacity of the main guideway because of the gaps left between vehicles to enable other vehicles to enter from stations and intersections. Hence, the main-line traffic density or the volume-capacity ratio is 0.6 to 0.85 at peak times. Several of the vehicles on the guideway will be empty, proceeding to stations to pick up passengers or returning from stations after dropping passengers. Thus, the effective use of the guideway is 0.6 or less at peak times.

The first PRT system should have a theoretical guideway capacity of 3 to 4 times the capacity of a freeway lane to justify the efforts, time, and funds required for research and development. This requires vehicle headways of about 0.5 sec and results in an actual loaded-vehicle flow rate of about twice the freeway lane volume. With this capacity, line spacings of ¼ mile in the CBD, ½ mile in the inner city, and 1 mile in outer rings meet the traffic demands in the Chicago area. Speeds of 20, 40, and 60 mph respectively may be considered for the above areas, based on average speeds of travel desired and the off-line lengths needed at stations and intersections.

Stations

If 1 station is placed on each link, 100 percent of the area in the CBD and inner-city areas and 39 percent of the area in the outer rings will be within ¼-mile walking distance from stations. If 2 stations are placed on each link, the accessible area can be increased to 64 percent, but the guideway speed will have to be decreased to 40 to 50 mph in the outer rings.

The peak-hour passenger load per station can be estimated from the traffic demand data. Excess empty vehicles must be provided to stations to serve stochastic passenger arrivals. Stations must be designed with excess vehicle-handling capacity to accommodate stochastic vehicle arrivals. Thus, effective use depends on station and vehicle use and is of the order of 0.6 or less. The station theoretical capacity is based on proper vehicle occupancy and effective use.

The ratio of theoretical guideway capacity to the station capacity affects queue characteristics and station performance. This ratio varies in the range of 8 to 18 for the

CATS area PRT network. Table 1 gives the guideway and station capacities and the capacity ratio for CATS area rings (2).

GEOMETRIC DESIGN OF STATIONS AND INTERSECTIONS

The geometry of the off-lines at stations and intersections has been considered by Dais (3, 4). These consist of a switch, a maneuver zone, a high-impedance section (HIS), a rear maneuver zone, and a merge (Figs. 1 and 2).

Switch and Merge

Vehicles exit the main line through the switch and enter the main line through the merge. These consist of 2 Euler spiral pairs. A lateral displacement of 12 ft between center lines of the main line and the off-line is reasonable for a vehicle width of 7 ft. The lateral displacement produced depends on allowable maximum centripetal acceleration and jerk rates. Since superelevation would be difficult to provide for the switch and the merge, all of the lateral acceleration must be balanced by the tire friction and will be experienced by passengers. For a maximum centripetal jerk of 0.125 g/sec, as observed by the Japanese National Railway (5), the a_m will be 0.14 g. The switches and the merges are designed with a_m varying from 0.14 g at 20 to 40 mph to 0.11 g at 60 mph, as recommended by Moyer and Berry (6). At higher speeds, 2 small circular arc segments are used in between the wind-unwind segments of the Euler spirals to obtain the necessary lateral displacement.

Maneuver Zone

The maneuver zones consist of 3 overlapping regions: trigger zone, speed-change zone, and queuing zone.

Speed-Change Zone—The speed-change zones (ramps) provide for vehicle deceleration from V to V_s on the upstream side of the HIS and vehicle acceleration from V_s to V on the downstream side of the HIS. These use trapezoidal deceleration and acceleration profiles. Normal acceleration and jerk rates of 0.25 g and 0.25 g/sec respectively are used for the ramps.

Queuing Zone—The capacity of the HIS off-line is much less than that of the main line. The stochastic vehicle arrival results in queue formation in front of the HIS. The station and turn performances can be measured in terms of probability of vehicle rejection at the switch, the average waiting time in queue, the number of vehicles block circling from a given station, and the total delays on the upstream side. All these depend on C_r, ρ_s for the queuing process, and the queue size provided.

Vehicles move at the speed of the HIS on the queuing zone. On the downstream side, the queuing zone is provided immediately after the HIS. The larger the relative velocity is between the main line and the HIS, the smaller the queuing zone length will be.

Trigger Zone—The trigger zone is provided at the switch end of the maneuver zone on the upstream side and the HIS end of the maneuver zone on the downstream side. Triggers, typically electrical loops, are provided at equal spacings on the trigger zone. The trigger spacing depends on the velocity ratio between the main line and the HIS and the length of slot on the main line. Triggers actuate vehicle deceleration circuits and initiate deceleration at proper points on the upstream side and acceleration at proper points on the downstream side. The triggers are operated by the local control computer, which receives communication from local vehicle sensors located on the main line (Fig. 1).

HIS

A platform is the HIS at stations, and the turn is the HIS at intersections. The platforms are linear and use moving belts. People use the belt to deboard and board the vehicle as it moves slowly along the platform. Belt speed is synchronized with that of the vehicles at the platform. Belt stations result in high capacity with small platform size and queue-zone length.

Table 1. PRT system guideway and station design factors.

Ring	Peak-Hour Person Trips/Direction/Mile Width of Corridor (persons/hour)	Lines/Mile Width of Corridor	Speed (mph)	S_L	$S_{L'}$	C	K	N_s	L_s	C_s	C_r
CBD	13,350	2	20	15	1/2	7,200	0.116	32	1/4	720	10
1	9,200	1	40	25	5/12	8,640	0.106	8	1/2	960	9
2	9,270	1	40	25	5/12	8,640	0.106	8	1/2	864	10
3	9,690	1	40	25	5/12	8,640	0.106	8	1/2	720	12
4	9,435	1	40	25	5/12	8,640	0.106	8	1/2	720	12
5	5,040	1	40	30	1/2	7,200	0.141	8	1/2	480	15
6	3,300	1/2	40	30	1/2	7,200	0.141	4	1/2	480	15
7	2,580	1/2	60	45	1/2	7,200	0.118	2 to 4	1 to 1/2	480	15

Figure 1. PRT off-line station.

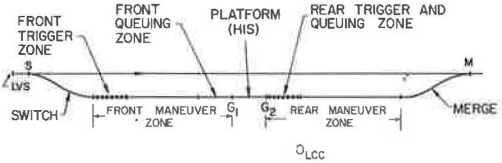


Figure 2. Plan view of PRT intersection.

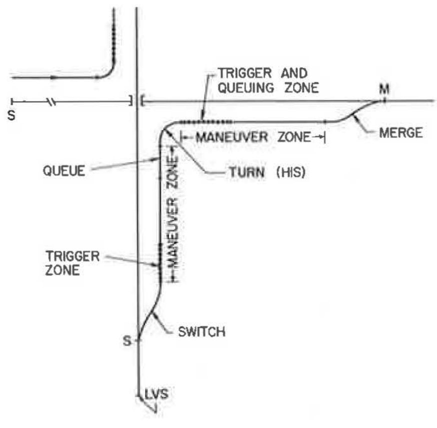


Figure 3. Triggering on upstream and downstream sides.

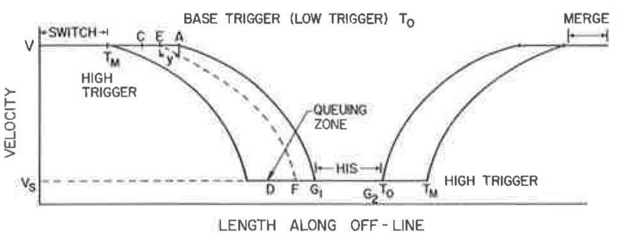
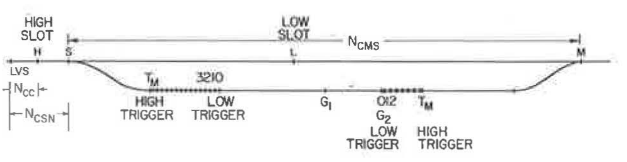


Figure 4. Numbering triggers on upstream and downstream sides.



Given the proper spacing between vehicles on the platform, the required vehicle and belt velocity can be obtained for the given station capacity. The platform length is chosen so that it provides for a platform time of 15 to 25 sec and is an integral multiple of slot length at the platform.

The turn consists of an arc with Euler spiral transitions at either end. In high-capacity PRT systems, the turns cannot be designed with the same capacity as that of the main line, for this requires a high turn velocity and hence a large radius of curvature and superelevation, which is unacceptable to the urban situation. The allowable radius of curvature in the urban areas is less than 40 ft for the turns. A tire friction factor of 0.2 g was considered realistic to allow for wet guideway conditions and rubber-tired wheels. If R = 35 ft and f = 0.2 g, the allowable maximum turn velocity is 15 ft/sec, which results in a theoretical turn capacity of 4,500 vehicles/hour and slot lengths of 12 ft at the turn. This capacity is considered sufficient in all rings, for only a fraction of main-line vehicles seek to turn at any intersection.

Lower speeds of turning can be used with lower turn capacities and will result in decreased acceleration and jerk during turns. C_r is the ratio of theoretical main-line capacity to the theoretical turn capacity, in vehicles/hour. For CATS area intersections, capacity ratios of 1.6, 2, and 3 were considered.

QUEUING PROCESS ON UPSTREAM SIDE OF HIS

Vehicle Arrival on Main Line

In PRT systems using synchronous and quasi-synchronous control, the vehicles move in discrete slots of length $S_L = S + L_V$. The time taken for a slot to cross any point on the main line is S_L/V and is called an s-cycle.

Vehicle observation by the LVS is a Bernoulli process. The probability of a vehicle being observed at LVS seeking switching from the main line to HIS is $p_v = \rho_s/C_r$. The number of vehicles seeking switching during n s-cycles is given by a binomial distribution of parameters n and p_v. C_s is a measure of the service rate, while C_r is a measure of service time in s-cycles.

For the Bernoulli vehicle arrival process, the vehicle interarrival time n has a geometric distribution. The probability of n, $p(n) = p_v q_v^{n-1}$, where $q_v = (1 - p_v)$.

Vehicle Maneuver on Upstream Side

A vehicle switched to the off-line moves at main-line speed on the switch. If it need not wait in queue, it traverses the trigger zone at the same speed and decelerates from A to HIS gate G_1, as shown in Figure 3.

Suppose another vehicle on the main line with vehicle 1 is switched. If H_D is less than C_r, the vehicle has to wait in queue. If vehicle 2 starts deceleration at the same point as vehicle 1, it will collide with vehicle 1 before reaching G_1. If vehicle 2 starts deceleration at the same instant as vehicle 1, it will reach G_1, $H_D C_v$ s-cycles after vehicle 1. This will result in low use of the HIS capacity, for the HIS can admit 1 vehicle every C_r s-cycles. By properly choosing the point where vehicle 2 starts deceleration, one can make the vehicles enter the HIS at intervals of C_r s-cycles without collision.

The distance of the point of initiation of deceleration from A is given by

$$y = \frac{S_L}{(C_v - 1)} (C_r - H_D) \tag{1}$$

C_r may be integer or noninteger. Choose a small integer J such that JC_r is an integer. The triggers are located at spacings of $S_L/[(C_v - 1)J]$. The value of y can then be given in terms of number of triggers counted.

The trigger spacing and the time taken to traverse a trigger spacing at normal speed before triggering are both called a trigger. Therefore,

$$1 \text{ trigger} = \frac{S_L}{(C_v - 1)J} \text{ ft} = \frac{S_t}{(C_v - 1)J} \text{ sec} \tag{2}$$

The triggers are numbered as shown in Figure 4. The lowest trigger is called the base trigger.

When the vehicle advance, $C_r - H_D$, is positive, triggering has to be advanced: $T_A = (C_r - H_D)J$. Given the trigger used by the Nth vehicle, that used by the (N + 1) vehicle is given by

$$T_{N+1} = T_N + T_A = T_N + J(C_r - H_D) \quad \text{if } T_N \neq 0$$
$$T_{N+1} = T_N + T_A = J(C_r - H_D) \quad \text{if } T_N = 0$$
$$T_{N+1} = T_N + T_A = 0 \quad \text{if } JH_D > (T_N + JC_r) \qquad (3)$$

When JH_D is greater than $(T_N + JC_r)$, the vehicle interarrival time on HIS is greater than C_r s-cycles. T_M, the maximum number of triggers provided, is finite because of the cost of triggers and the trigger zone. If the trigger required by the vehicle is greater than T_M, the vehicle will be rejected at the switch.

Queuing Process on Upstream Side and Its Simulation

In Eq. 3, C_r is the service time and H_D is the vehicle interarrival time in s-cycles. Hence, T_N and T_{N+1} are the vehicle waiting time in terms of 1/J s-cycles for the queuing process involved. 1/J s-cycle may be called a cyclet. A cyclet may be used as a unit of time for the off-lines. The queue can be represented by the model M/D/1-F, FIFO, for the vehicle arrival is a Markovian process (the vehicle arrival is an independent process, being a Bernoulli process), the service time is constant, and the queue size is finite.

The main HIS characteristics of interest are p_r and t_{wt}, both of which should be minimized. The vehicle is rejected when the required waiting time exceeds T_M or when the queue is full. If M is the maximum line length provided for, then $p_r = P_M$, the probability that there are M vehicles in the line. At stations the rejected vehicles go around the block, increasing the travel time and the trip length and unnecessarily loading the guideway.

The probability of rejection and the average waiting time in queue depend on C_r, ρ_s for the queuing process, and T_M. The maximum length of queue increases linearly with T_M. Vehicles having a minimum headway of 1 s-cycle require $(C_r - 1)J$ triggers. Hence, T_M may be provided as integral multiples of $J(C_r - 1)$ so that an integral number of successive vehicles may be accommodated in the queue after the renewal process.

The queuing process was simulated to determine the probability of vehicle rejection, the average waiting time in queue, and the vehicle interarrival time on the HIS. Experiments were conducted with C_r values of 8, 12, and 15 for stations and 1.6, 2, and 3 for intersections. ρ_s for the queuing process was varied from 0.6 to 0.9, and the value of m was selected in the range of 2 to 8.

Figure 5 shows the flow diagram for the simulation model used. The program is written in FORTRAN IV for execution on the CDC 6400 computer. Each experiment was repeated for 10 independent runs. As a fixed number of 600 vehicles were switched to the off-line, the total number of vehicles received, the total number of vehicles rejected, the trigger used by each vehicle (and hence vehicle waiting time), the vehicle interarrival time at HIS gate G_1, and the number of rounds made by the vehicle before switching were noted. Also the number of vehicles block circling was noted at regular intervals of 60 s-cycles at stations. Hence, p_r, t_{wq}, t_a, and n_B were all calculated for each run. From the 10 independent observations made during the 10 runs, the mean values of p_r, t_{wq}, t_a, and n_B were obtained for each experiment. The total waiting time at stations was the sum of waiting time in queue and average block-circling time. The probability and cumulative probability distributions were also obtained.

Characteristics of Queuing Process

Probability of Rejection—Figure 6 shows the variation of p_r with m, C_r, and ρ_s at the station upstream side. p_r decreases at a decreasing rate as m and, hence, queuing zone lengths are increased. The law of decreasing return applies here. As ρ_s decreases,

Figure 5. Upstream operation simulation.

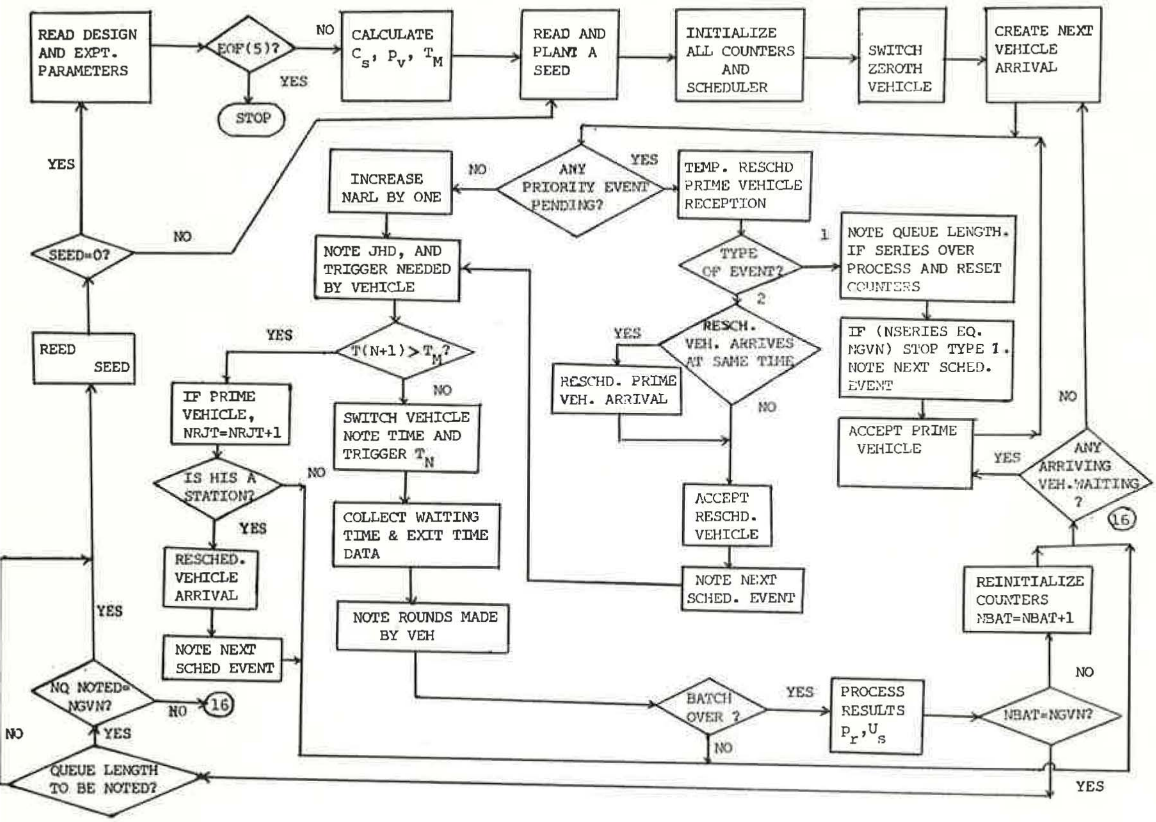


Figure 6. Variation of p_r at station on upstream side.

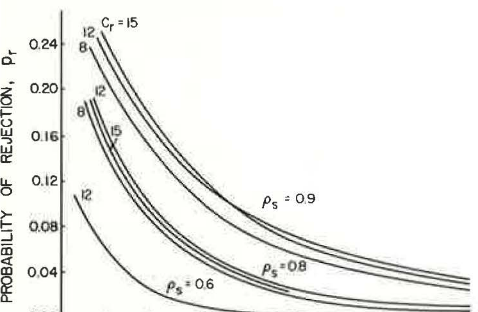
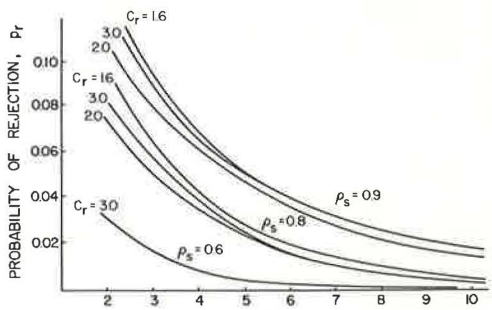


Figure 7. Variation of p_r at intersection.



the average queue length and waiting time in queue decrease, and, hence, p_r decreases. At stations, p_r decreases as C_r decreases at $\rho_s = 0.9$ because of the increased service rate. At $\rho_s = 0.8$, p_r first increases and then decreases as C_r decreases.

The relations given by Saaty (7) were used to calculate p_r values for different values of m and ρ_s. These p_r values do not depend on C_r. The calculated p_r values lie within the range of p_r values observed at different capacity ratios during simulation.

A probability of rejection of 1 to 2 percent is acceptable at stations at peak time. A p_r value of 2 percent is obtained for $\rho_s = 0.8$ at m = 6 and for $\rho_s = 0.9$ at m = 12. Thus, higher values of ρ_s require large trigger zone lengths. A ρ_s value of 0.8 is feasible for station operation at peak time. During the peak hour, the average ρ_s will be only 0.64 and, hence, p_r will be about 0.2 percent. m = 6 at $\rho_s = 0.8$ results in 6 vehicles being rejected during the peak 20 min in a busy high-capacity station. If m = 4 were used, $p_r = 0.055$ at $\rho_s = 0.8$, resulting in 14 vehicles being rejected during the peak 20 min at the busy station. The m values of 4 to 6 are reasonable for the stations. Higher values of m are not recommended because of decreasing benefits.

Figure 7 shows the variation of p_r at intersections. Use of noninteger capacity ratios results in increased probability of rejection. A p_r value of 1/40 is reasonable for intersections. This is achieved with m = 8 at $\rho_s = 0.9$ and m = 5 at $\rho_s = 0.8$. Since the intersection downstream requires more triggers, a ρ_s value of 0.8 and m = 5 are recommended for all intersections. The selected value of p_r results in a rejection of 20 vehicles during the peak 20 min in the inner city with $C_r = 3.0$. During the other 40 min of the peak hour, ρ_s is less than p_r is of the order of 0.006 to 0.008.

Number of Vehicles Block Circling From Station and Average Number of Rounds Made—At stations, the rejected vehicles block circle and return to the station. The observation of block-circling vehicles on the main line is a Bernoulli process. The number of vehicles block circling has a binomial distribution of parameters n and p_B, where n is the number of slots around the block and $p_B = p_v[p_r/(1 - p_r)]$.

A p_B value of 0.5 percent is allowable; i.e., the average number of vehicles block circling from a station may be 1/200 of the number of slots available around the block. Figures 8 and 9 show the variation of p_B with m, C_r, and ρ_s. At $\rho_s = 0.8$, $p_B = 0.35$ to 0.5 percent at m = 4 and $p_B = 0.1$ to 0.2 percent at m = 6. Thus, m = 4 to 6 is acceptable at stations. R_a values were both measured and computed from p_r; they vary with m, C_r, and ρ_s exactly as p_r. Average block-circling times were calculated from the R_a values measured. These are given in Table 2 for m = 4 to 6 and $\rho_s = 0.8$.

Average Waiting Time in Queue and Total Waiting Time—The variation of t_{wq} is shown in Figure 10. The queuing time increases as C_r, m, and ρ_s increase. It increases at a decreasing rate as m increases. The average queuing time is maximum for the infinite queue and is given by

$$W_q^* = (\rho_s/2)[C_r/(1 - \rho_s)] \quad (4)$$

t_{wt} at stations is the sum of average block-circling time and average queuing time. The variation of upstream total waiting time at stations is shown in Figure 11 for $\rho_s = 0.8$. The decreasing utility of additional triggers is evident above m = 6.

At stations, m = 4 results in total waiting time of 20 to 23 sec in the CBD and inner city and 30 sec in the outer rings. Assuming that acceptable t_{wt} is less than or equal to 30 sec, m = 4 is acceptable. At m = 6 and $\rho_s = 0.8$, t_{wt} is 13 to 17 sec in the CBD and inner city and 20 sec in the outer rings. Thus, m = 6 is sufficient for $\rho_s = 0.8$.

At intersections, m = 5 and $\rho_s = 0.8$ result in average queuing time of 0.87 s-cycles at $C_r = 1.6$, 1.46 s-cycles at $C_r = 2.0$, and 2.9 s-cycles at $C_r = 3$.

Possible Trade-Offs in Design of HIS

Stations and intersections can be designed with less excess capacity (higher capacity ratio) and a higher number of triggers or more excess capacity and a smaller number of triggers and hence smaller queue size. A third dimension is added by user costs, such as the average total waiting time and the inconvenience caused by the vehicle rejection at a switch. Thus, a trade-off is possible among HIS design and operating costs, trigger costs, and user costs involved.

Figure 8. Variation of p_B with m.

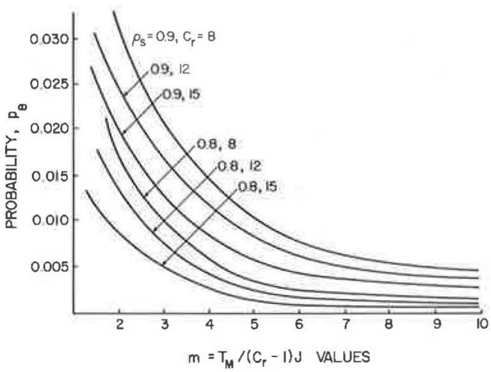


Figure 9. Variation of p_B with C_r.

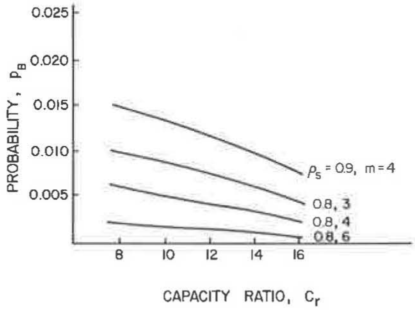


Table 2. Block-circling time on PRT network in CATS area.

Ring	Average Turn Time (s-cycles)	Main-Line Link (s-cycles)	Total Block-Circling Time (s-cycles)	R_A: ρ_s = 0.8, m = 4	R_A: ρ_s = 0.8, m = 6	t_b (sec): ρ_s = 0.8, m = 4	t_b (sec): ρ_s = 0.8, m = 6	C_r
CBD	56	54	440	0.062	0.025	13.65	5.5	10
1	75	72	588	0.059	0.024	14.45	5.87	9
2	75	72	588	0.062	0.025	15.2	6.13	10
3, 4	75	72	588	0.065	0.025	15.9	6.13	12
5	75	72	588	0.055	0.0225	13.5	5.5	18
6, 7	73	100	692	0.061	0.0225	21.1	7.8	15

Note: ρ_s = 0.9 at m = 7 has almost the same block-circling time as ρ_s = 0.8 at m = 4.

Figure 10. Variation of t_{wq} with C_r, m, and p_s.

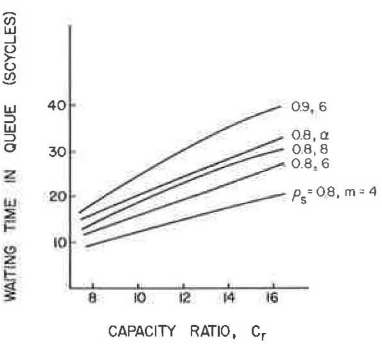
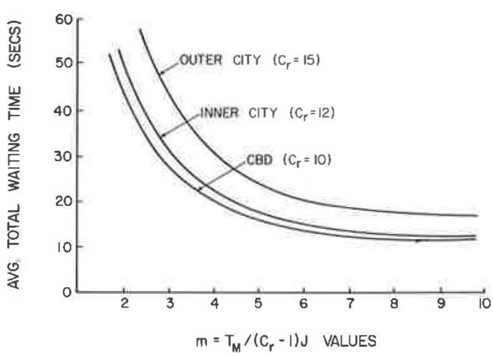


Figure 11. Variation of t_{wt} at station on upstream side.



Figures 12, 13, and 14 show for the stations typical probability and cumulative probability distributions of the number of vehicles block circling, the waiting time in queue, and the vehicle interarrival time at the HIS. Similar curves were obtained for intersections. A fraction of the vehicles have constant interarrival time at the HIS, but others have geometrically distributed interarrival time with a minimum of $(JC_r + 1)$ cyclets.

QUEUING PROCESS ON DOWNSTREAM SIDE OF HIS

The vehicles in queue on the downstream side of the HIS are waiting for empty slots on the main line. The queuing is accomplished by the relative velocity between the main line and the off-line. The vehicle waiting and merging are exactly similar to vehicle merging on freeways.

Triggers are provided to initiate vehicle acceleration at different points on the queuing zone so that the vehicle catches its assigned slot on the main line. The triggers are numbered as shown in Figures 3 and 4.

Suppose a vehicle is triggered by the base trigger at HIS gate G_2. If the next vehicle arrives after H_{DS} s-cycles at the HIS exit and the available empty slot has a headway of H_D s-cycles on the main line with the slot used by the previous vehicle, then the position y of the point for initiation of vehicle acceleration from G_2 is given by

$$y = \frac{S_L}{(C_v - 1)} (H_D - H_{DS}) \qquad (5)$$

If triggers are placed at spacings of $S_L/[(C_v - 1)J]$ ft, y is given in terms of number of triggers counted, as on the upstream side. If T_N is the trigger used for the Nth vehicle, then

$$\begin{aligned} T_{N+1} &= T_N + J(H_D - H_{DS}) && \text{if } T_N \neq 0 \\ T_{N+1} &= J(H_D - H_{DS}) && \text{if } T_N = 0 \\ T_{N+1} &= 0 && \text{if } JH_{DS} > (T_N + JH_D) \end{aligned} \qquad (6)$$

Equation 6 is the recursive equation for waiting time in queue for the queuing process involved. The trigger used by the vehicle gives its waiting time in cyclets. The queue has a general distribution for vehicle interarrival times. The slot arrival on the main line is a Markovian process (Bernoulli process). The queue size is finite. Hence, the queue can be represented by the Model G/M/1-F, FIFO.

Vehicle Merging From Downstream Side

At intersections, let p_v be the probability of vehicle arrival at the exit of a high-density turn. The ratio between a smaller number of vehicles turning off a line and a larger number of vehicles turning off the cross line is the turn ratio. The probability of slots being observed for merging the larger number of vehicles is

$$p_{SL} = (1 - U_{fx}) + p_v \, TR \qquad (7)$$

Hence, the traffic density ρ_D for the downstream queue is given by p_v/p_{SL}.

Because of the stochastic nature of vehicle and slot arrival, excess empty slots should be provided on the main line to enable easy vehicle merging. Hence, the ρ_D to be used is less than 1.0 at stations and intersections.

At intersections, C_r is small and a large number of vehicles seek to merge. TR will often be less than 1, and p_{SL} will be less on the line from which the smaller number of vehicles turn off. p_{SL} and s_r can be varied by varying U_{fx}. Thus, merging requirements at intersections determine the feasible guideway density.

The number of triggers provided on the downstream side is finite. Hence, the allowable vehicle waiting time is limited. If a vehicle does not get a slot within this time, it will have to be stopped on the downstream side. This may adversely affect

Figure 12. Probability of number of vehicles block circling.

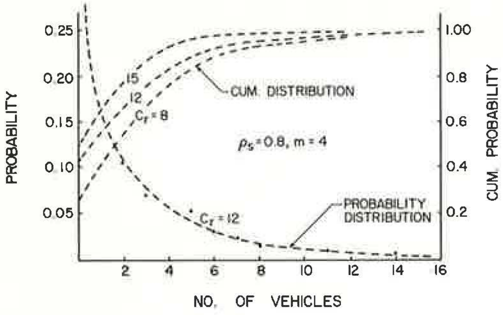


Figure 13. Probability of queuing time.

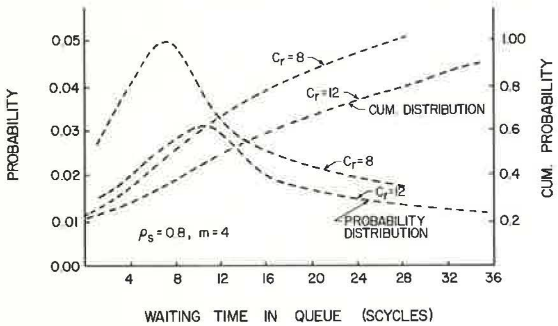
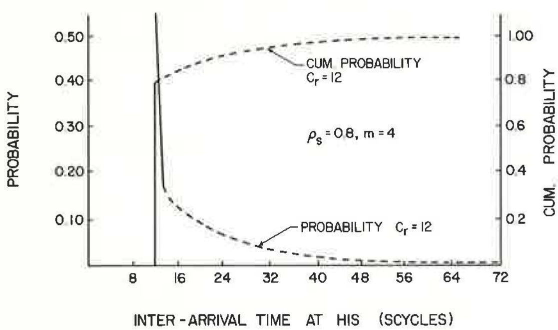


Figure 14. Probability of interarrival time in HIS.



the HIS operation and result in undesirable vehicle rejection on the upstream side. A low-priority vehicle on the main line can be forced to switch to the off-line and its slot used to merge a vehicle stopped on the downstream side. If the LVS is located several slots before the switch, the LCC can be provided with information regarding the status of vehicles on several slots so that an empty vehicle may be selected for forced switching without any cost to the users.

Simulation of Downstream Queuing Process

Since the queuing process involved on the downstream side is difficult for analytical study, the required excess slots on the main line, the number of triggers to be provided on the downstream side, the probability of forced switching, and the feasible guideway traffic density were all determined by the simulation method. Experiments were conducted at different vehicle arrival rates by varying C_r and keeping ρ_B constant at 0.8. The vehicle interarrival times at HIS gate G_1 measured during upstream simulation were used to create vehicle arrival. Different numbers of triggers were chosen for the downstream side.

At intersections, ρ_D was varied from 0.7 to 0.9. The slot arrival was created, and the resulting p_f was measured during the merging process. Hence the acceptable combination of T_M and ρ_D for the downstream side was obtained. At intersections, choosing ρ_D determines the p_{SL} required. If TR is known, the required U_{fx} can be obtained. A p_f value of 1/80 is considered acceptable at intersections. This results in forced switching of about 10 vehicles during peak time at a busy intersection with a capacity ratio of 3.0.

At stations, the number of vehicles seeking to merge is small. However, the vehicle interarrival time is large, and hence, for the same values of ρ_D as used at intersections, the service time is large. This results in a long waiting time and hence a large number of triggers. Thus, stations require smaller values of ρ_D and larger slot ratios. The experiments were conducted by varying U_f on the upstream side of the station switch from 0.7 to 0.9. For different capacity ratios and constant ρ_B of 0.8, the resulting p_{SL} and ρ_D were measured as well as the p_f and average queuing time at different values of number of triggers provided. Based on an acceptable p_f value of 1/200 at stations, the required T_M was selected.

When forced switching is adopted, the downstream side should have a certain minimum number of triggers provided to allow time for the vehicle waiting to catch the slot emptied by forced switching. The minimum number of triggers is given by

$$T_{MN} = N_{CMS} + (N\Delta - 1) - N_{Cr} \tag{8}$$

The number of triggers used and the location of the slot sensor are also related. The maximum allowable number of triggers is given by

$$T_{MX} = N_{CMS} + N_{CSN} - N_{cc} - N_{Cr} \tag{9}$$

At stations and intersections, for different numbers of triggers, T_M for the upstream and downstream sides, N_{CMS}, N_{Cr}, and T_{MN} were calculated for all rings in the CATS area. The maximum available sensing space before stations and intersections was determined, and T_{MX} was obtained. These values are given in Table 3 for stations. The selected values of T_M lie in the range of T_{MN} to T_{MX}.

Let N_{CSL1} be the position of the slot from the merge node when vehicle 1 reaches the HIS exit. Therefore,

$$T_1 = N_{CSL1} - N_{Cr} \tag{10}$$

If H_{DS} is the headway between vehicles at HIS and H_D is the headway of the next available slot, then

$$N_{CSL2} = N_{CSL1} - H_{DS} + H_D$$

$$T_2 = N_{CSL2} - N_{Cr} \tag{11}$$

Table 3. Values of N_{Cr}, N_{CMS}, T_{MN}, and T_{MX} at station.

Region	Speed (mph)	N_{Cr}		N_{CMS}			T_{MN}			T_{MX}
		m	Value	m_1	m_2	Value	m_1	m_2	Value	
CBD	20.0	2	20	4	2	36	4	2	16	24
		3	21	4	3	37	4	3	16	
		4	22	6	3	39	6	3	16	
		6	23							
Inner city	35.8	2	30	4	2	46	4	2	16	26
		3	31	4	3	47	4	3	16	
		4	31	6	3	48	6	3	16	
		6	32							
Outer rings	50.0	2	30	4	2	42	4	2	12	24
		3	31	4	3	43	4	3	12	
		4	31	6	3	43	6	3	12	
		6	32							

Figure 15. Variation of p_f at stations.

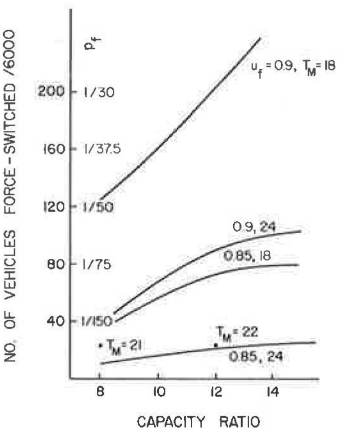


Figure 16. Variation of t_{wq} at stations on downstream side.

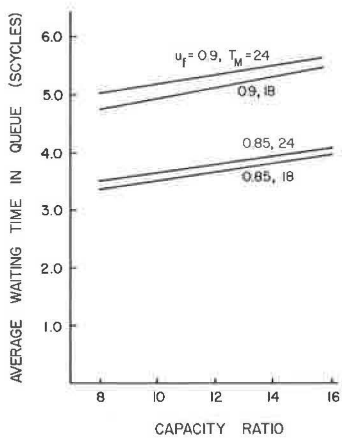


Figure 17. Number of vehicles forced to switch at intersections.

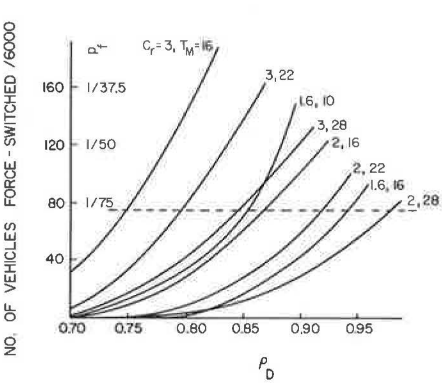
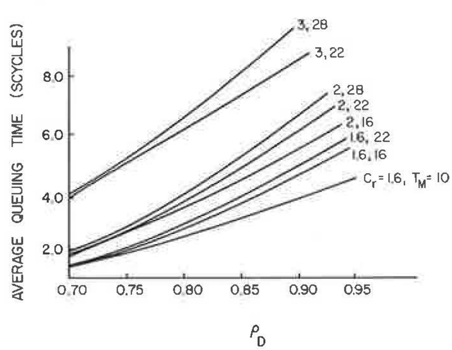


Figure 18. Average queuing time at intersections on downstream side.



When $T_2 > T_M$, forced switching is adopted. The position of the first vehicle to be checked is given by

$$N_{CSLf} = \text{maximum of } (N_{CSL1} - H_{DS} + 1,\ N_{CMS} + 1) \qquad (12)$$

Successive vehicles are checked to select a vehicle for forced switching.

Results of Simulation on Downstream Side

Figures 15 and 16 show the simulation results for the station downstream side. At stations, T_{MN} is 18 and T_{MX} is 24 when LVS is placed on the first slot on the intersection merge. A value of 20 to 24 triggers with $U_f = 0.85$ results in p_f of 0.004. Hence, at peak time only, 1 vehicle in 250 will require forced switching. About 2 to 3 vehicles will be accommodated in the downstream queue. The average vehicle waiting time is less than 2.0 sec.

At stations, values of m = 4 for upstream and m = 2 to 3 for downstream resulting in total trigger zone length of 70 to 80 ft are acceptable; m = 6 for upstream resulting in total trigger zone length of 104 ft is sufficient. On the upstream side, the length of the trigger zone is constant at all values of C_r, but the number of triggers varies. On the downstream side, the number of triggers increases slightly with C_r, but the trigger zone length decreases with an increase of C_r.

At intersections, T_{MN} varies from 17 to 25 and T_{MX} varies from 29 to 42. However, if the vehicles are allotted slots while they are on the turn, T_{MN} and T_{MX} can be decreased. T_M can then be low to decrease the downstream trigger zone length.

Experiments were conducted in which T_M was varied from 10 to 28 at different values of C_r and ρ_D. Figures 17 and 18 show the simulation results for the intersection downstream side.

p_f increases at an increasing rate as ρ_D is increased at all values of C_r and T_M. p_f is large at higher values of C_r because of higher interarrival time of vehicles and hence higher service time at the same ρ_D. p_f decreases as T_M is increased. A p_f value of 1/80 was selected as acceptable. The same value of p_f is obtained at higher values of ρ_D when the T_M used is large at a given C_r. At lower values of C_r, lower T_M and yet higher values of ρ_D can be used.

Table 4 gives the ρ_D values feasible and, hence, U_{fs} and U_{fx} values feasible at different values of T_M and C_r for p_f of 1/80. Higher values of ρ_D require more triggers and trigger zone length. A trade-off is possible between a higher value of T_M and a smaller value of U_{fx}.

U_{fx} values of 0.85 at TR = 0.75 and about 0.75 at TR = 0.5 were considered acceptable from guideway and intersection operation considerations. This requires a T_M value of 18 at all values of C_r. The resulting trigger zone length varies from 80 ft in the outer rings to 100 ft in the CBD at $C_r = 3.0$. At lower values of C_r, because of smaller relative velocity and velocity ratio, L_{tr} is higher. At $C_r = 1.6$, L_{tr} is 270 ft in the outer rings and 168 ft in the CBD.

Thus, use of larger capacity ratios and hence smaller capacities are preferred wherever possible. Also the variation of U_{fx} with TR is small at larger capacity ratios; hence, U_{fx} can be kept in the range of 0.70 to 0.85 for most intersections.

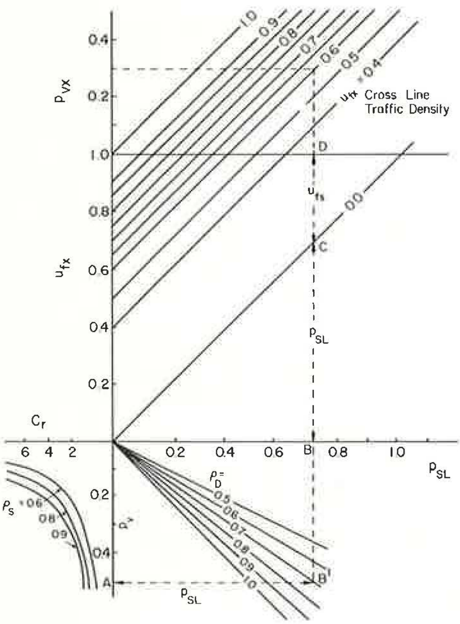
t_{wq} increases with ρ_D, almost linearly, and increases with T_M and C_r, as is expected. At the selected value of T_M, t_{wt} varies from 4.8 s-cycles at $C_r = 3.0$ to 5.5 s-cycles at $C_r = 1.6$. t_{wt} at an intersection varies from 7.7 s-cycles at $C_r = 3.0$ to 6.4 s-cycles at $C_r = 1.6$. At higher values of C_r, the time spent at the intersection off-line is slightly more. However, because of lower L_{tr} and hence the resulting higher feasible speeds of the main line, the travel time will be less at $C_r = 3.0$ than at $C_r = 1.6$.

Figure 19 shows the operating chart for intersections and stations. Suppose p_v for an intersection leg is given. It is shown as point A in Figure 19. ρ_D can be selected based on allowable p_f, available T_M on the downstream side, and C_r. Point B gives the required p_{SL}, and CD gives U_{fs}. If TR is known, U_{fx} can be obtained. If U_{fx} is given, the required TR and p_v for the cross leg can be obtained. If higher values of TR are used, U_{fx} can be large, as Figure 19 shows.

Table 4. Operating values at intersections for $p_f = 1/80$.

			U_{fx}				L_{tr}	
C_r	T_M	ρ_D	TR = 0.5	TR = 0.75	TR = 1.0	t_{wq}	CBD	Outer Rings
3.0	16	0.7475	0.7766	0.8433	0.9099	4.20	87.2	71.6
	22	0.795	0.7979	0.8646	0.9312	6.10	119.9	98.5
2.0	16	0.870	0.7402	0.8402	0.9402	4.70	213	114
	22	0.921	0.7657	0.8657	0.9657	6.60	293	157
	28	0.980	0.7919	0.8919	0.9919	9.30	373	187
1.6	16	0.945	0.7209	0.8459	0.9701	5.40	240	150
	22	1.00	0.7500	0.875	1.000	5.80	330	206

Figure 19. Intersection operating chart.



CONCLUSIONS

A PRT network has been designed to carry all internal automobile trips occurring in 1990 in a high-density large metropolis. The theoretical guideway capacities required are about 4 times those of freeway lanes. With line spacings of 1/4, 1/2, and 1 mile in the CBD, inner city, and outer rings respectively for the network of 1-way routes, respective speeds of 20, 40, and 40 to 50 mph are feasible.

Stations using moving belts are recommended for high-capacity PRT systems having station capacities of 480 to 960 vehicles/hour. Such belt stations result in shorter platform lengths and smaller vehicle queues at stations. The geometric design of stations and intersections has assumed acceptable and conservative normal and centripetal acceleration and jerk rates.

The stations should be designed with 25 percent excess capacity, for only 80 percent use is possible. The stations should provide for accommodating a maximum of 4 to 6 vehicles on the upstream queuing zone and 2 to 3 vehicles on the downstream queuing zone. The average waiting time will be 20 to 30 sec on the upstream side and less than 2.0 sec on the downstream side, and probability of rejection on the upstream side at peak time is 2 percent. At a guideway density of 0.85, the probability of forced switching at stations will be 1/250 at peak time.

For intersections, capacity ratios of 1.6, 2.0, and 3.0 were considered. The turns in a high-capacity PRT network cannot be designed for the same capacity as the guideways, for this will result in unacceptably large radii of curvature and superelevation. The intersection should accommodate a maximum of 5 vehicles on the upstream side of the turn and provide for a maximum waiting time of 18 s-cycles on the downstream side. A probability of rejection of 1/40 and probability of forced switching of 1/80 are feasible at peak time. To keep the feasible guideway density at 0.75 to 0.85, the turn ratio should be larger than 0.5 and as high as 0.75. The average waiting time at an intersection is less than 2.0 sec on the upstream side and 3.0 sec on the downstream side.

The trigger theory can also be used for vehicle merging with synchronous control strategy and will result in less maneuver zone length, less power required, and less inconvenience to passengers.

At present a 60-station PRT network operating under quasi-synchronous control is being modeled for simulation to determine possible average guideway density, average speed of travel, vehicle use, total waiting times and delays, and other operating data. The proposed simulation of the 60-station network will provide an opportunity to test various new ideas introduced in this project.

COMPARISON WITH PREVIOUS WORK

York (8) simulated a PRT network under quasi-synchronous control. The guideway capacity was 3,600 vehicles/hour. In the present paper theoretical guideway capacities of 7,000 to 8,000 vehicles/hour were considered realistic for the PRT to be an efficient alternative to the automobile.

Dais (4) used large centripetal acceleration and jerk rates, superelevation for switches, and small separation between the main line and the off-line in the geometric design of off-lines at stations and intersections. These are unacceptable to some transportation engineers. Lower rates are used in this paper.

A high-capacity PRT system requires station capacities of 480 to 960 vehicles/hour. Since use of taxi stations results in large vehicle queues, belt stations are preferred. Munson (9) simulated belt stations by using gates on the upstream and downstream sides. However, the relations between main-line and off-line capacities and velocities and gate spacing were not given. Munson did not treat the station problem as a queuing process, and the trade-offs possible among service rate, traffic density, queue zone length, and user costs were not considered.

In contrast with the approach used by Munson, the approach in this project involved detailed mathematical analysis and queues modeled as M/D/1-FIFO and G/M/1-FIFO. The influence of HIS capacity, traffic density, and number of triggers on excess capacity and queue zone length required, average block-circling time, and total waiting time has been considered, and the possible trade-offs have been analyzed. The probability and cumulative probability distributions of waiting time in queue and interarrival time on HIS have also been obtained.

Brill (10) modeled vehicle motion ahead of a bottleneck as a queuing model and obtained the distribution of slow-down points for a freeway system.

Munson (9) simulated an intersection with off-line capacity and speed the same as those for the main line, as used in a low-capacity, low-speed PRT system, and slot shifting that used repeated combined acceleration-deceleration maneuvers on the main line to reduce the probability of rejection. Such maneuvers require large excess power and result in much brake wear and passenger inconvenience. Dais (4) simulated intersections of the same capacity as the main line and assumed vehicle stopping on the off-line.

For the high-capacity PRT network in this project, intersection capacity is less than main-line capacity and slot slipping maneuvers are only on the off-lines. To prevent rejection of high-priority vehicles at the switch, forced switching is adopted at stations and intersections. It constrains the number of downstream triggers, depending on sensing space available and the length of main line between switch and merge.

REFERENCES

1. An Evaluation of Alternative Land Use and Transportation Systems in the Chicago Area. Chicago Area Transportation Study, Oct. 1968.
2. Thangavelu, K. Analysis, Simulation, and Design of Stations and Intersections for a Quasi-Synchronous Personal Rapid Transit Network. Urban Systems Engineering Center, Northwestern Univ., Aug. 1973.
3. Dais, J. Minichanges, Stations and Geometry in PRT. National Conference on Personal Rapid Transit, Univ. of Minnesota, Minneapolis, Nov. 1971.
4. Dais, J. Geometric Design of PRT Network Elements. PRT Conference, Minneapolis, May 1973.
5. McFarland, R. A. Human Factors in High-Speed Ground Transportation With Special Reference to Passenger Comfort and Safety. Carnegie-Mellon Univ., Transportation Res. Rept. 3, Nov. 1969.
6. A Policy on Geometric Design of Rural Highways. AASHO, 1965.
7. Saaty, T. L. Elements of Queuing Theory. McGraw-Hill, New York, 1961, pp. 154-155.
8. York, H. Simulation of Vehicle Management Strategies. In New Concepts in Urban Transportation, Univ. of Minnesota, Vol. 2, No. 11 and No. 12.
9. Munson, A. V. Quasi-Synchronous Control of High Capacity PRT Networks. National Conference on Personal Rapid Transit, Univ. of Minnesota, Minneapolis, Nov. 1971.
10. Brill, E. A. A Model of Traffic Jam Behind a Bottleneck. Operations Research, Vol. 4, No. 4, July-Aug. 1972.

FEASIBILITY AND COSTS OF AN ELEVATED STOLPORT TEST FACILITY AND ITS POTENTIAL FOR METROPOLITAN USE

S. S. Greenfield and R. B. Adams, Parsons, Brinckerhoff, Quade and Douglas, Inc.

This paper describes the results of a study of the feasibility and costs of building an elevated STOLport test facility that would eventually be expanded for revenue service. Engineering analyses were made of many structural schemes. Two were chosen for more rigorous study to develop costs for STOLport test facilities at 2 sites. The estimated construction costs of a metropolitan area site test structure are $22 million. The costs of the containment and arrestment systems and the land acquisition could add $2 to $10 million. The expansion of a test facility into a passenger-carrying facility with commercial joint use of the space below the flight deck was conceptualized to aid the Federal Aviation Agency in developing a policy for determining proportional participation in capital funding between the federal government and local authorities or private developers. The study concluded that there would be marginal savings in construction cost to those locating in the STOLport as compared to an alternative location. The potential for reducing or recovering the cost of an elevated STOLport through joint use is primarily in the dual use of the land area. The cost of the STOLport flight-deck support system would not change significantly if it were constructed as a free-standing structure, e.g., over a transportation corridor, or combined with a joint-use building.

•RECOGNIZING a particular confluence of different transportation modes and facilities on New York City's North River Chelsea waterfront, Bakke (1) proposed in 1969, "[If] we were to take a major section of real estate and build on it one mammoth structure tailored to serve the kinds of businesses that are suffocating in the city today, and locate this structure at a key transportation hub for easy accessibility by rail, wheel, and air... [and] then... were to ask the occupants of this superbuilding to share a common roof..., we would have a new tailor-made vertical- or short-takeoff and landing (V/STOL) airport capability." Bakke also detailed the potential for such an intermodal STOL facility to maximize access to concentrated downtown areas and the role such a facility could play in their continued economic vitality. Subsequently, however, efforts to develop STOL service have been frustrated by the lack of accepted definitions regarding facility design and aircraft performance. To overcome part of this lack, the Federal Aviation Agency sponsored an industrywide hearing in 1970 that led to the publication of design criteria (4). A nominal 2,000-ft (609.6-m) runway length and a combined runway and safety area width of 300 ft (91.4 m) were established.

The key to intercity STOL service is the downtown site, particularly one such as lower Manhattan. High land costs and development pressures in town centers tend to support Bakke's contention that a STOLport should be elevated, most likely atop a multilevel, multiuse structure. There is, however, little experience for developing a satisfactory design or assessing the costs of such a structure. Research on STOLports will also apply to off-shore jet ports, for they too require elevated structural decks. Indeed conducting flight operations from space-limited, elevated-deck facilities is one of the major challenges facing aviation in serving urbanized areas.

Flight operations from an elevated flight deck essentially have only one useful precedent: aircraft carrier operations. But the operations are different in 3 fundamental ways: Carrier operations are assisted takeoff and landing and involve a complement of complex expensive equipment; the carrier will steam into the wind to produce optimal aerodynamic conditions for takeoff and landing operations; and the mission-oriented military nature of carrier operations is such that the costs and risks accepted are higher than those that could be accepted in market-oriented, civilian STOL operations. The attention that the problem of an elevated flight deck for civil STOL operations has received indicates the need for a flight test program to develop experience with such a facility.

STOL DEVELOPMENT PROGRAM

Among the key concerns in the Federal Aviation Administration program for the development of quiet short-haul intercity air service is that of the operational feasibility of an elevated STOLport. Three main questions were addressed in this study.

1. What is an appropriate design for an elevated structure that could be used at the National Aviation Facilities Experimental Center (NAFEC) for a program of flight testing off an elevated deck? What would such a structure cost?
2. What is an appropriate design for a comparable structure for a flight test program in a downtown metropolitan site? What would be its cost?
3. What are the land requirements and urban development and environmental impacts of a downtown elevated STOLport for passenger service and with joint commercial uses in the lower portions of the structure?

An elevated flight operations test program is needed to provide the necessary data for certification criteria, operational criteria, aerodynamic effects and crosswind control, pilot visual cues, visual and electronic landing aids, noise level measurements and abatement procedures, STOLport layout criteria, aircraft containment and arrestment operational criteria, initial and recurrent pilot training, facility requirements, passenger acceptance, structural considerations, and aircraft certification and systems testing.

ELEVATED STOLPORT STUDY

A study was performed on the structural feasibility and cost of an elevated flight-deck structure to facilitate a test program to aid the FAA in formulating standards and criteria for aircraft, facility, and appurtenances; to aid manufacturers in the development of aircraft and facility hardware; and to aid operators in the development of suitable sites.

Design Analysis for Facility at NAFEC

The first consideration in the study was the design analysis for a low-cost structure at the NAFEC site at Atlantic City, New Jersey. Removed from metropolitan pressures and supported by extensive testing resources, such a facility would provide an ideal environment in which to gain the necessary knowledge to establish standards and criteria. The estimated construction cost of a test structure that would be 300 ft (91.4 m) wide by 2,000 ft (609.6 m) long by 100 ft (30.4 m) high and that would accommodate a 100,000-lb (45 400-kg) gross weight STOLcraft was $18 million, which is less than a structure at a metropolitan site where heavier aircraft would have to be accommodated.

Design Analysis for Facility at a Metropolitan Site

The second consideration involved a STOLport test facility to be located in a typical large metropolitan downtown area. The advantage of such a concept is that the test facility costs could be subsequently amortized by future expansion to a passenger facility. The difficulties, however, must be recognized:

1. The vast test support resources of NAFEC could not be used;
2. Greater costs of the test structure are necessitated by STOLcraft in the 150,000-lb class;

3. A test program in such a locale, even if permitted, would be constrained by considerations of public reaction and safety;
4. The duration of testing would be limited, and there would be no facility for recurrent or advance testing; and
5. Land would have to be acquired.

Some of these considerations are reflected in the higher development costs of a prototype metropolitan STOLport test facility. Because the metropolitan site is believed to be of interest to a wider audience, this paper emphasizes it rather than the one at NAFEC.

Implications of Urban Site and Joint Development

An analysis was made of the space requirements below the flight deck for passenger terminal and other ancillary functions within a structure 100 ft high. The results were used in determining the proportional use of the area below for the aviation facility and the joint commercial uses that would share space in the structure. Analysis was also made of its impact on the urban environment.

ELEVATED STOLPORT AT METROPOLITAN SITE

Site Choice

A hypothetical metropolitan site was evaluated for its potential as an interim use test facility that, after a successful test phase, could be expanded to serve as a passenger operational STOLport. The reasons for evaluating this approach were that the cost of building a test facility is a substantial part of the cost of an operational facility and that, in addition to the aeronautical problems, a greater measure of the problems of operation in an actual metropolitan environment could be experienced and evaluated. Some disadvantages of this strategy have been noted above. The value of such an approach is in determining the type of problems that an authority or municipality might anticipate in planning such a facility and developing a preliminary means of assigning areas to joint users that might share the costs of construction. Further, the FAA could use such an analysis to develop a policy for proportional participation in funding such facilities.

Facility

The hypothetical metropolis has a population of 2 million and is located in a large urbanized region that has heavy intercity traffic. Other assumptions are that 50 percent of the air traffic is short-haul, the STOLport is the primary airport serving the city, and the facility attracts about half of the short-haul market. This was computed to involve ½ million passengers initially, 2 million by 1984, and 5½ million by 1990.

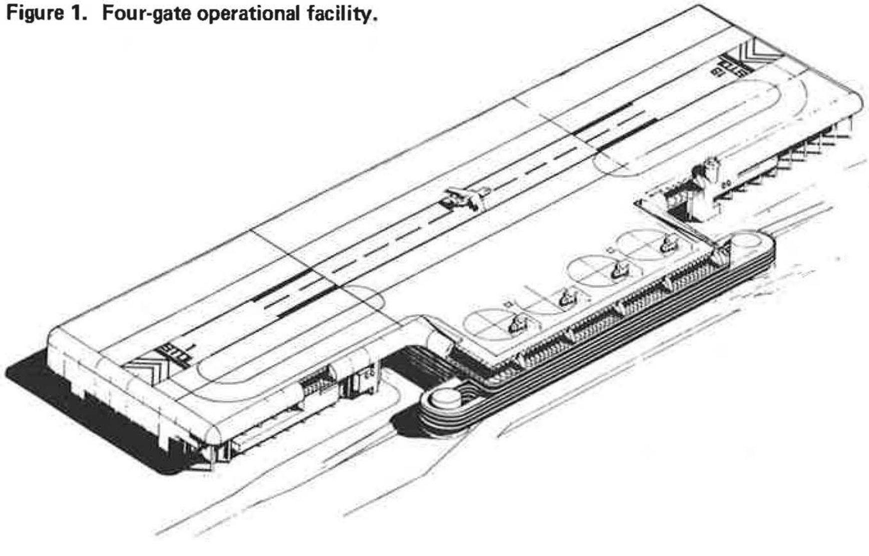
The test facility is essentially that developed for the NAFEC site, with the following 3 differences:

1. In the absence of the NAFEC capabilities, adequate capability is required at the metropolitan site to carry out the test program;
2. Requirements are more stringent for aircraft containment to protect the adjacent urban environment; and
3. Since the passenger-operational structure will eventually be required to accept 150-passenger, 150,000-lb (68 000-kg) aircraft, the test structure must meet the same loading requirements because to modify the structure later to carry higher loads would be expensive.

The metropolitan test facility was evaluated for a height of 100 ft (30.5 m), a width of 300 ft (91.4 m), and a length of 2,000 ft (609.6 m). The construction cost is $22 million, exclusive of the costs of land acquisition and arrestment equipment.

An operational facility for STOLcraft operation at the hypothetical metropolitan site expanded to a width of 500 ft (152.4 m) was conceptualized to serve a projected daily demand of 2,300 passengers in 1973, 10,000 in 1984, and 18,000 in 1990. Daily aircraft movements were assumed to be 100 in 1973, 200 in 1984, and 300 in 1990. An

Figure 1. Four-gate operational facility.



isometric view of the operational facility with a flight-deck height of 100 ft is shown in Figure 1.

The single bidirectional runway, expanded from the test phase to a width of 500 ft (152.4 m), is capable in the operational phase of handling 50 operations per peak hour, although the maximum peak-hour demand expected is only 20 operations per hour by 1990. Airside facility requirements are the same as those for the NAFEC site except that in the operational phase an ATC control post is located on top of a 30-ft (9.1-m) tower or at an appropriate height in an adjacent building.

Airside Requirements

Analysis of the passenger demand indicated that a total of 4 gates are required for 1978 and 1984 and 6 or more gates for 1990. The 4 gate areas represent nearly minimum building-size requirements based on operational needs, parked aircraft obstruction criteria, and lateral arrestment requirements. The total area of flight deck and 4 gates is 1,180,000 ft^2 (109 500 m^2). The 1978-84 facility can be expanded either by adding gates on the same side or by developing an apron area and parallel taxiway on the opposite side.

Passenger Facilities

The 4 gates were developed into separate terminal modules each providing ticketing, passenger-holding, baggage-handling, and airline operations. Passenger amenities and other terminal functions are provided in or adjacent to the passageway connecting the gates. Access to STOLcraft is by escalator from the terminal level to the flight deck (to loading bridges in later stages). Access to the terminal area from street and STOLport parking levels is by two 20-passenger elevators in 1978 and 4 in 1984.

At street level, passengers are not separated by arrivals or departures but by mode of transportation. A central island with lobby for elevators, information counters, and baggage checking separates private cars from bus and taxi traffic. STOLport parking for 1984 is on 5 levels between street level and passenger terminal level; 600 cars can park on each level. The passenger terminal requirements including parking are confined as nearly as possible to the area under the STOLcraft apron area.

JOINT-USE POSSIBILITIES

Locating the STOLport in or near the central business district would entail high real estate and construction costs, but the possibilities of joint use and resulting revenues would be high. Joint uses listed in order of their attractiveness for and compatibility with a STOLport are parking, warehousing, light industry, and offices and retail stores. In addition, the STOLport could be placed over a transportation facility such as a highway or railroad.

Probably the most important factor for attracting joint users is the assembly of land into a parcel of sufficient size to accommodate the STOLport. The most promising location for assembling a suitable site is probably in older, central portions of urban areas, which in most cases would also be more attractive to travelers and site users. Moreover, when tracts of this size are assembled, their total area value is often more than the sum of the value of the individual parcels. Thus, one might recover part of the cost of the land and at the same time offer sites at reasonable costs to potential joint users. A methodology was developed to determine available commercial rental space so that a municipality planning for a STOLport can develop cost and revenue based on anticipated demand.

ENVIRONMENTAL IMPACT

Possible beneficial effects are in terms of the total regional transport capability.

1. Additional airport capacity for the metropolitan region can be attained at reduced real estate costs because of the joint uses of an elevated or multilevel facility. In addition, if the facility were combined with an industrial building, the host municipality would lose no tax base.
2. The STOLport can be located close to the urban center and thus significantly reduce access requirements.
3. Noise impact would be minimized because the elevated flight deck would act as a sound reflector when STOLcraft are above the building.
4. A large structure offers opportunities to combine uses and could provide the stimulus for commercial, industrial, or transportation center development.
5. The limited and high-cost expansionability of such a structure will allay fears of future airport expansion.
6. The building height places the operational area above structures and natural barriers that would be obstructions at an at-grade STOLport. This allows more flexibility in site selection.

Potential adverse effects are as follows:

1. The fears of aircraft landing short, veering off the building, or otherwise endangering the surrounding area could cause community apprehension and opposition;
2. Such a large facility will tend to be incompatible with the scale and character of existing nearby development and could cause adverse visual and aesthetic impacts;
3. Noise and vibration transmission through the STOLport building could be a problem to certain joint uses;
4. Aircraft approaching over highways could distract motorists, and pilots could mistake the lighted highway for a runway unless there is proper identification such as colored lights;
5. If the STOLport is located in an urban area, the approach-departure clearance requirements would restrict adjacent building heights; and
6. The elevated STOLport will experience a high percentage of conditions requiring Instrument Flight Rules [e.g., a 200-ft (60.8-m) ceiling at-grade would be a 100-ft (30.4-m) ceiling on a 100-ft-high STOLport].

In the evaluation of a site for an operational STOLport in an urban area, a community would also need information on the extent of noise and types of land use affected, type of land use under approach and departure flight paths, contribution of STOLport operations to air pollution in the area, impact on street congestion and public transportation of vehicles and passengers coming to the site, and impact of construction and operations on the environment.

DESIGN-DEVELOPMENT OF ELEVATED STOLPORT TEST FACILITY

The elevated flight deck, whose dimensions determine generally those of the structure, is essentially flat with slight lateral gradients for drainage. The structure, however, was designed in such a way that superelevation or gradient may be introduced during the course of the test program to determine its efficacy in improving STOL operations. For example, axial gradient might reduce fuel requirements.

Facility Safety

Safety is fundamental to the operational and design requirements of a facility of this type. Facility safety programs have historically focused on postcrash equipment and procedures, the aim of which is damage and injury reduction. Current safety activities distinguish between postcrash procedures and a precrash or accident-avoidance strategy. Design that is aimed at "normal, smooth, and safe" operations falls into this latter strategy. Air traffic control, aids to flight, aerodynamics, and aircraft containment-arrestment fall into the postcrash strategy. Containment-arrestment is a critical element of the elevated STOLport.

Containment-Arrestment

The chief concerns in the development of satisfactory flight-deck containment systems are the terminal activities and populations in the flight-deck area and the modes of containment systems and their effect on equipment and passengers (e.g., brick walls would provide excellent containment but at too high a price). The containment system must have a reasonable cost and operate with minimal damage to equipment and minimal injuries to people. Containment systems, although a fundamental necessity in crash damage reduction, may result in reduced deck-area requirements.

The 2 main elements of containment on the flight deck are longitudinal or end arrestment and lateral or side arrestment. The current state of the art of end arrestment is satisfactory. The FAA requires end-arrestment systems capable of arresting aircraft of 80,000 lb (36 320 kg) gross weight (with growth to 150,000 lb, 68 000 kg) at a maximum landing speed of 65 knots, not to exceed 1.5 g (1.4 m/s^2) within 300 ft (91.4 m), and to operate with a reliability of 3 sigma (2). Longitudinal arrestment devices are satisfactory because the aircraft engages symmetrically: The leading edge of the wings offers an appropriate surface, and the wings act as girders loaded in plane.

The state of the art of lateral arrestment is at present far from satisfactory. The problem of lateral containment is more difficult, for the aircraft is moving away from the centerline at a low angle of incidence, advancing the wing tip and outboard main bogie away from the centerline toward the containment-arrestment assembly first. The engagement of either wing tip or outboard bogie may be expected to aggravate the swerve, requiring a massive arrestment effort and great lateral stopping distance and probably causing both damage and injuries.

In the course of the study, it became clear that inadequate information exists to formulate meaningful criteria concerning containment-arrestment requirements, particularly those concerning lateral arrestment. Some innovative solutions were conceptualized involving curved curbs and rails and bilateral superelevation to redirect aircraft back toward the centerline, but a fuller investigation of this critical area is required. The structure design-development was nonetheless carried out to ensure the structure's integrity to survive arrestment loads on the order of those indicated above.

Aerodynamics

A conventional runway is situated at-grade in the open, and the wind moves across it in a relatively undisturbed mass. The bulk of an elevated deck structure creates a major local perturbation, referred to as a building-induced flow field. In such a flow field, the flow is vertical on the windward building faces, creating large pockets of nonlaminar, turbulent flow along roughly a fourth to a third of the windward portion of the deck, reattaching to the surface, and flowing more or less smoothly downwind from that point (3). Such a situation would be clearly hazardous to takeoff and landing operations. Further, the costs of elevated flight decks tend to limit wind coverage to a single runway; and the constraints of site selection and the problems of parcel assembly in downtown areas tend to indicate not only that there will be only 1 runway but that it will probably not be optimally oriented in relation to the wind rose. Thus, the prevailing wind at a given site may well be a crosswind.

The test structure will initially be open so that the test program can be facilitated and these problems explored. That is, the structure will have no external walls except for some vertical end-corner panels that will be marked to serve as visual cues in landing. The structure is designed so that the entire building can be enclosed for subsequent joint uses. When fully enclosed by paneling, the building can withstand winds as high as 88 mph. The open structure will have less aerodynamic complexity and will provide a better basis for initial study than would an enclosed structure. As experience is developed in taking off from an open elevated facility, wall screen elements can be added selectively and their effects on aerodynamic turbulence evaluated. The structure is also designed to accept various crosswind and turbulence control devices as may be developed from other studies.

Flight Deck

Landing gear loadings were considered paramount among the flight-deck design criteria because, as developed during the course of the study, the deck scheme designs were influenced more by the live loads of the landing gear than by the dead load of the deck. At a 13-ft/sec (3.9 m/s) rate of descent, an impact factor of 200 percent of the gear-imposed loadings was calculated for the runway. The aircraft types assumed were a first-generation 40,000-lb (18 000-kg), 50-passenger aircraft; a near-future 100,000-lb (45 000 kg), 100-passenger aircraft; and a 150,000-lb (68 000-kg), 150-passenger aircraft anticipated for the mature phase of STOL aviation in the 1980s. Building heights of 40, 70, and 100 ft (12.2, 21.3, and 30.4 m) were considered.

EVALUATION OF ALTERNATIVE STRUCTURAL SCHEMES

Preliminary Screening

A preliminary screening of structural schemes appropriate to this application was conducted; novel schemes were also introduced. Twelve potential schemes were developed. An evaluation procedure was used to compare the schemes in terms of the analytically derived unit costs and other factors whose values were based on engineering judgment. Factors, other than direct construction costs, that were taken into consideration included ease of construction, maintainability, life or durability, space use, fire rating, and aesthetics. The 12 preliminary schemes developed were as follows:

1. Orthotropic steel deck with trumpet tower and truss support (has minimum weight deck, shop fabrication, and ease of erection);
2. Orthotropic posttensioned deck with steel tower column support (has considerable weight savings in structural steel);
3. Composite concrete and steel deck with steel column support (uses steel and concrete to best advantage);
4. Lift slab (waffle) deck with steel pipe columns (has lift slab construction);
5. In situ posttensioned concrete deck with concrete columns (has prefabricated formwork and erection from moving platform, better concrete finish, and reusable forms);
6. Prestressed concrete box girders with prestressed concrete columns (has standard, precast, prestressed members and on-site assembly);
7. Waffle slab with trumpet tower and truss support [has precast 20-ft (6.1-m) square units and on-site assembly];
8. Wood panel deck with steel tower columns (has short-span built-up wood deck);
9. Nail-laminated wood and concrete composite deck with steel columns (uses materials for least loading conditions);
10. Glue-laminated wood deck with steel tower columns (is factory glue-laminated and has on-site modular unit assembly);

11. Earth fill (uses readily available and cheap fill materials and standard construction methods); and
12. Cable-suspended structure (is unconventional, exotic scheme and was not examined for that reason).

Recommended Schemes

Two schemes were selected as the most suitable for final analysis and evaluation. Scheme 3, composite concrete and steel deck, and scheme 5, in situ posttensioned concrete deck, were estimated and evaluated for height and aircraft loading variations. Figure 2 shows that if the selection were made on the basis of project cost then the selection process would lead to the lowest height and lightest aircraft. If, however, a 100-ft (30.4-m) height and 100,000-lb (45 000-kg) aircraft weight were used, the difference between schemes 3 and 5 would be $0.75 million, or 4 percent, a nominal difference.

Since both schemes 3 and 5 were adequate in all respects to the requirements of an elevated test facility and their construction costs were essentially the same, the selection had to be based on other considerations. If used at NAFEC, scheme 3 would involve somewhat higher maintenance cost (because of exposed structural steel, which would require periodic painting) than scheme 5, which is an all concrete structure. Scheme 5 was, therefore, recommended for use at NAFEC.

Scheme 3 was selected for the test facility at the metropolitan site because of the expected use of the space below the flight deck. Spans could be designed for 250 ft, thus creating a column-free area. This flexibility in span and column spacing makes scheme 3 particularly appropriate for the varying commerical joint uses below the flight deck of a STOLport.

Scheme 3

Scheme 3 (Fig. 3) has corrugated structural metal plate as formwork for the concrete slab and sheet metal as formwork for concrete joist (or rib) construction. The formwork, prefabricated into panels of modular size for ease of installation, is designed to function as part of the completed structure and therefore would not be removed. The formwork is supported by structural steel trusses that span 50 ft (15.2 m) and are supported by 15-ft (4.5-m) structural steel trusses spanning 100 ft (30.4 m) between columns. The top flange of the smaller truss and the top flange of the large truss are designed as composite concrete and steel members, thus using both materials to their best advantage, i.e., concrete in compression and steel in tension.

Scheme 5

Scheme 5 (Fig. 4), cast-in-place posttensioned concrete, provides the best solution of all the schemes investigated. High-strength concrete of 5,000 $lb/in.^2$ (352 kg/cm^2) in compression, reinforced with strands of high-strength steel 270,000 $lb/in.^2$ (19 000 kg/cm^2), reduces the quantity of concrete from that required in the usual reinforced concrete construction. Tensioning in 2 directions makes the construction watertight and virtually crack free. The deck and all members remain in compression under all loadings, and the tension cracks that are commonplace in concrete construction do not develop. Large areas can be built without requiring expansion joints, which often create maintenance problems. The structure is designed to be continuous over its supports so that the material savings inherent in this type of load-distribution design can be obtained.

This scheme minimizes the high cost of formwork because the steel formwork can be used repetitively. The formwork, fabricated from steel plates, is supported by steel girders resting on hydraulic jacks. A crane assembly of structural steel moves on rails on wooden tie cribbing. When the tensioning of strands is completed, the deck formwork is removed by lowering by the hydraulic jacks. Then the crane assembly is moved, and the hydraulic jacks lift the deck form to the required position. After the strands are placed in their proper positions, the new area is ready for the placing of

Figure 2. Costs of recommended schemes.

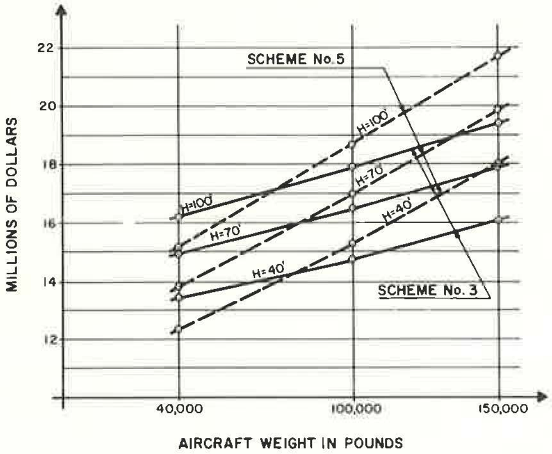


Figure 3. Scheme 3.

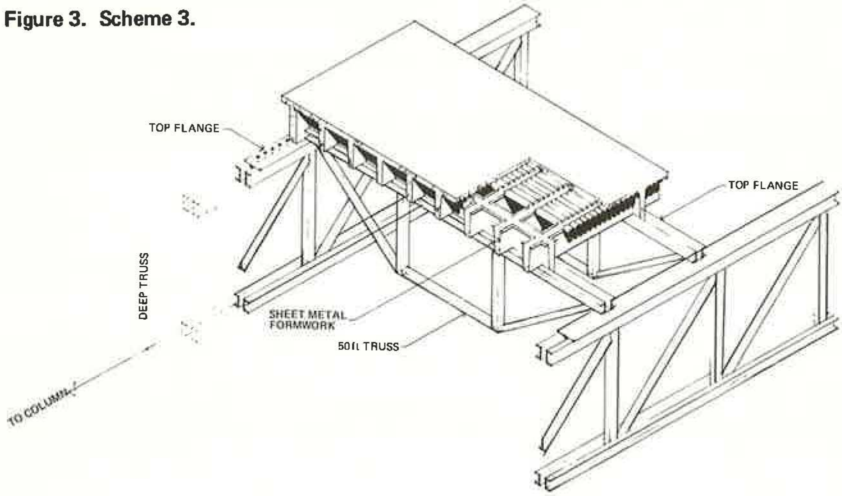
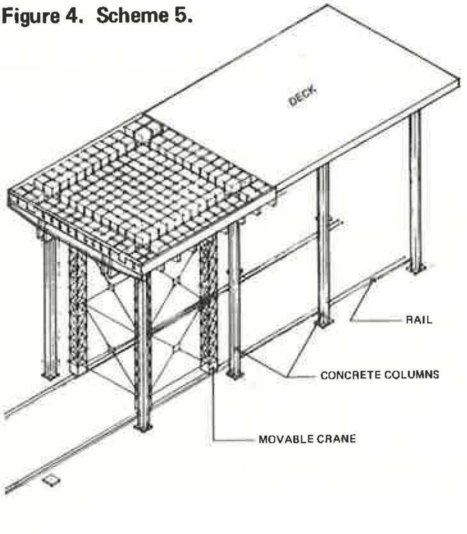


Figure 4. Scheme 5.



concrete. Cast-in-place posttensioning has all of the advantages of precast, prestressed shop production but eliminates transportation, handling, and erection. In addition, the problems of connections between members and smoothing the surface with concrete fill required by precast prestressed construction are eliminated. With cast-in-place post-tensioned concrete construction, the structure is monolithic, which is important because of the large horizontal forces involved in aircraft braking.

REFERENCES

1. Bakke, O. New York Transportation: Revolution Within a Revolution. Trans., New York Academy of Sciences, May 1969.
2. D'Aulerio, H., et al. Feasibility of Applying Existing Aircraft Arresting Systems to STOLports. FAA Memorandum Rept., Aug. 1969.
3. Parker, H. M., Blanton, J. N., and Grunwald, K. J. Some Aspects of the Aerodynamics of STOLports. University of Virginia and Langley Research Center, May 1971.
4. Planning and Design Criteria for Metropolitan STOLports—AC150/5300-8. Federal Aviation Agency, 1971.

ANALYTIC EQUILIBRIUM MODEL FOR DIAL-A-RIDE DESIGN

Steven R. Lerman and Nigel H. M. Wilson, Department of Civil Engineering, Massachusetts Institute of Technology

Dial-a-ride is a demand-responsive transportation system in the experimental stages of development. Previous analyses of the system have been dominated by relatively expensive, supply-oriented simulation models and crude, insensitive demand predictions. This paper presents an analytic equilibrium model that has minimal data and computational requirements and is suitable for use in designing future dial-a-ride systems. The model is used to test the sensitivity of level of service and net operating cost to changes in demand model parameters and fares. The results demonstrate the important effects of decisions such as fleet size, service area, and fare levels on the economic and noneconomic prospects of a potential dial-a-ride system. In dial-a-ride as in many other transportation systems, the interrelations between design parameters and demand response are so complex that only an equilibrium model can predict the impacts of a specific design.

•BY THE END OF 1973, about 20 demand-responsive urban bus systems were operating in North America (1, 2). These systems are designed to provide high-quality service at a premium fare. Dial-a-ride systems have been implemented in widely dissimilar locations, ranging from small independent cities (Batavia, New York) to commuter suburbs (Haddonfield, New Jersey; Bay Ridges, Ontario) to sectors of large cities (Regina, Saskatchewan; Ann Arbor, Michigan; and Rochester, New York) to new communities (Columbia, Maryland). As awareness of the potential of this new system increases, many other localities will likely consider the implementation of demand-responsive services. In this type of planning environment it is important that modeling tools be available to help answer questions such as, What service area is best? What are the implications of a given fare on ridership, profit, and service? How many vehicles should be operated to provide a desired quality of service?

To date, the most frequently used analysis tool for aiding in the design of dial-a-ride systems is the detailed computer simulation model (3). Although simulation can be very effective, it suffers from 2 major deficiencies in this application. First, it is generally an expensive tool, requiring extensive software development and involving large amounts of computational resources in the application. More important, however, is the fact that dial-a-ride simulation models have been supply oriented. In these models demand must be exogenously determined; traditionally it has not been considered an explicit function of the quality and cost of service provided by dial-a-ride or competing modes. These models may be accurately described as defining a supply surface rather than determining an actual operating point.

This paper describes an analytic model that builds from the existing models to overcome their weaknesses so that it is suitable for assisting in the design of future dial-a-ride systems. This model uses an equilibrium framework in which dial-a-ride ridership is assumed to be a function of the average fare, wait time, and in-vehicle time of the dial-a-ride system and a function of automobile travel time. The model has minimal data and computational requirements and can therefore be used to test a broad range of policy options at extremely low cost. Since the model is discussed elsewhere in detail (4, 5), this paper summarizes the model system and presents some test results.

MODEL SYSTEM

The model system consists of 3 basic components: a supply model, a demand model, and a net cost model. The supply model determines the quality of service that can be provided in an area by a specified vehicle fleet at a given level of ridership. The demand model predicts the level of ridership that will result from a given quality of service and fare level. The net cost model determines the financial implications of the service. The supply and demand models are solved simultaneously and yield the equilibrium level of ridership and quality of service. By using the models repeatedly, one can determine the implications of selecting different numbers of vehicles, fares, or service areas. In this analysis, fare, number of vehicles, and service area are key policy variables. To use the models, the planner must specify the following inputs:

1. Average vehicle speed,
2. Average trip length,
3. Total number of minutes per day during which dial-a-ride operates,
4. Factor input prices such as labor wage rates and vehicle capital and operating costs,
5. Size of the service area,
6. Total number of vehicle trips made in the service area during the time the dial-a-ride system operates,
7. Time needed for a passenger to exit a vehicle, and
8. Time needed for a passenger to board a vehicle.

From these parameters, the model determines daily dial-a-ride ridership, revenues, costs, average travel time, and average wait time.

Supply Model

The supply model is formulated to predict average wait time and average travel time for a given system. The aim is to develop good structural relations that can then be calibrated with simulation model results. The model should be accurate over the reasonable operating range of dial-a-ride, but because of the objective of minimal computational requirements the full complexity of dial-a-ride operating decisions cannot be included. The travel time model is derived by treating each vehicle as a queue. The act of picking up a passenger corresponds to the arrival of a user at the end of the queue, and the act of dropping off a passenger is analogous to the user's being served and his leaving the queue.

The rate of arrivals per vehicle per minute is defined by λ, which is determined in the demand model. The rate at which passengers are serviced, μ, depends on the vehicle speed, the distance between drop-offs, and the time required to actually pick up and drop off a passenger.

The wait-time submodel was based on a simple assumption about the dispatching algorithm: The vehicle is routed to move toward a waiting passenger's origin as directly as it moves toward an in-vehicle passenger's destination. From the travel time submodel, the mean velocity toward any point, V_{EFF}, can be estimated as the ratio of the average trip length to the average travel time. Given the average distance between the vehicle that is assigned to the new demand and the demand origin L_W, the expected wait time is simply L_W/V_{EFF}.

This 2-component supply model was calibrated by the adaptation of a detailed simulation model and the testing of 27 hypothetical systems. These test results were then used to develop an expression for the mean vehicle interstop distance and L_W and to select the most appropriate queuing model form.

The interstop distance was modeled as a linear function of the average trip length and the demand arrival rate λ, which together measure the efficiency with which tours can be put together. L_W was modeled as a function of the vehicle density and the demand density in the service area. Both equations yielded reasonable fits for linear forms and had coefficients with the expected signs.

Both the single-server queuing models tested tended to underpredict travel and wait times for highly congested systems. However, the range of demand rates and vehicle densities over which the model was valid was quite well defined. All the results reported in this paper are within the range of model validity.

In general, the M/M/1 model, which assumes a Poisson process for the server, resulted in predictions that better matched the simulated data and so it was used in the supply model.

Demand Model

At present, there are few comprehensive data on the demand for dial-a-ride service. For this reason, a relatively simple incremental demand model form was selected (6).

Total daily travel within the service area is assumed to be fixed, and the dial-a-ride modal split is determined as a function of fare, wait time, and the ratio of dial-a-ride in-vehicle time to automobile travel time. The model assumes a known base-point modal split denoted as MS^0, which corresponds to a known base fare, wait time, and travel time ratio, denoted as f^0, tw^0, and TTR^0 respectively. The modal split at other fares, wait times, and travel ratios is expressed as follows:

$$MS = MS^0 \left[1 + e_w \left(\frac{tw - tw^0}{tw^0} \right) + e_{TTR} \left(\frac{TTR - TTR^0}{TTR^0} \right) + e_f \left(\frac{f - f^0}{f^0} \right) \right]$$

where e_w is the elasticity of demand for dial-a-ride with respect to wait time, e_{TTR} is the elasticity of demand for dial-a-ride with respect to the travel time ratio, and e_f is the elasticity of demand for dial-a-ride.

Simply stated, this model predicts changes in modal split from the base point as the weighted sum of 3 effects: the fraction deviation of wait time from the base point, the fraction deviation of the travel time ratio from the base point, and the fraction deviation of fare from the base point. The coefficients for these 3 variables are their respective elasticities.

The base point selected was a 2 percent modal split for a wait time of 15 minutes, a travel time ratio of 2.0, and a fare of $0.60. This is based on the records of the Batavia, New York, system for the early months of operation in the fall of 1971.

The elasticities used have a great deal of uncertainty associated with them. The figures chosen are based on the attitudinal survey of Golob and Gustafson (7). They derived a set of demand curves from these surveys; however, these models gave predicted modal splits that seem far too high when compared with the market shares observed in cities with dial-a-ride service. Rather than use these demand curves directly and seriously overestimate demand, we used only the elasticities implied by their work. These elasticities are rough averages over the range of levels of service and fare considered. The elasticities used are as follows:

$$e_{TTR} = -0.3$$

$$e_w = -0.3$$

$$e_f = -1.1$$

The service elasticities are lower than those often used, and the fare elasticity is quite high. This may reflect the tendency for the elderly, poor, and young to use the system. Such socioeconomic groups are likely to be more fare sensitive and less service sensitive.

The service elasticities for travel time and wait time were roughly equal in Golob and Gustafson's demand curves. This is somewhat unusual in that wait time is generally regarded as being more onerous than is vehicle time (8). However, dial-a-ride wait time is generally spent in the passenger's home rather than at a bus stop or transit station. Furthermore, the arrival of the dial-a-ride vehicle is likely to be quite reliable since the telephone operator at the control center can often give the passenger an expected vehicle arrival time. Because the service elasticities are well below other estimates, such as the -0.593 value found in a model calibrated by Domencich and Kraft, extensive sensitivity analysis was done to determine whether elasticities would greatly affect the predictions made (9).

The fare elasticity, although higher than those generally assumed for public transportation, seems reasonable since the dial-a-ride fare is generally substantially higher than fares for conventional public transit. Golob and Gustafson's survey work indicates that fare elasticity tends to increase with fare. Analysis of the results of a fare increase in the Peoria Premium Special subscription bus service also indicated a fare elasticity near unity (10).

For the dial-a-ride system to be in equilibrium, both the supply and demand relations must be satisfied concurrently. The simultaneous solution of these equations results in a third order polynomial expression in λ, the demand arrival rate. The coefficients of this polynomial are functions of the trip length, vehicle speed, and the coefficients of the equations for the mean interstop distance and L_w.

Net Cost Model

The cost for any given dial-a-ride system was divided into 4 major categories (11):

1. Customer communications, including handling and processing incoming calls;
2. Vehicles, including capital and operating costs and driver wages;
3. Dispatching, including computer rental, space, maintenance, and programming; and
4. Overhead.

Each of these categories was further disaggregated into space, labor by job type, phone rental, and other subcategories. Wage rates and other factor input prices were derived from a number of sources and represent reasonable values for the northeast United States where there is unionized labor.

In the cost analysis, true demand-responsive service operated only during off-peak hours; more efficient subscription bus service operated during peak hours. Thus, a portion of the cost was allocated to these peak-hour activities. The entire model system was developed for a typical weekday of operation. Thus, some fraction of fixed costs was allocated to weekend and holiday dial-a-ride service.

PARAMETRIC TEST CASE

The entire model system was used to test the effects of various dial-a-ride systems and the sensitivity of the model to a range of parameters. The sizes of the 3 hypothetical areas considered were 2 by 2, 2.8 by 2.8, and 3 by 4 miles. The average trip length, fare, fleet size, demand elasticities, and base modal split were all varied. Only increases in the magnitude of the travel time ratio and wait time elasticities were considered because of the unusually low value of these elasticities implied by attitudinal survey research. The following variations were examined for all systems.

1. Trips per day: 16,000, 2 by 2 miles; 32,000, 2.8 by 2.8 miles; and 48,000, 3 by 4 miles.
2. Trip lengths: $\frac{1}{6}(h_1 + h_2)$, $\frac{1}{3}(h_1 + h_2)$, and $\frac{1}{2}(h_1 + h_2)$, where h_1, h_2 are the dimensions of the service area.
3. Fare elasticities: -0.8, -1.1, and -1.3.
4. Base modal splits: 1, 2, and 3 percent.
5. Fares: \$0.25, \$0.50, \$0.75, \$1.00, and \$1.25.
6. Wait time and travel time ratio elasticities: -0.3, -0.3; -0.5, -0.5; and -0.7, -0.7.

The following parameters were held constant.

1. Total service time per day: 480 minutes.
2. Vehicle speed: 0.25 miles per minute.
3. Base fare: \$0.60.
4. Base travel ratio: 2.0.
5. Base wait time: 15 minutes.

For systems characterized by both high fares and high fare elasticities, no positive equilibrium solution could be found. This probably resulted from the inadequacy of the constant elasticity assumption used in developing the demand model. Occasionally, when the high-fare, high-elasticity system did yield a positive volume, the results were completely unreasonable in that the predicted dial-a-ride travel time was less than the automobile travel time. However, these systems were a small fraction of those tested and were characterized by input values far beyond the range of values for which the supply model was calibrated.

No system tested showed a profit. This appears reasonable in light of existing operational experience and when one considers that only the off-peak hours were considered. Efficient peak-hour subscription bus service could offset some or all of the off-peak loss.

Figures 1 through 6 show some of the results of the test runs for various representative systems. Two basic statistics were considered. First, the ratio of total dial-a-ride travel time and automobile travel time is termed the level of service. This measure reflects the overall quality of service provided by the system, and its value increases as the actual quality of service declines. Second, the daily deficit of the system is an economic performance measure. In general, there is a trade-off between improved service and reduced deficit.

Figures 1 and 2 show that the fare is a significant design variable. Higher fares imply lower demand, which results in improved service, which encourages more demand, which to some extent offsets the impact of increased fare. However, because the fare elasticity is high while the wait time and travel ratio elasticity is low, this offsetting effect is quite small. The deficit curves for various fare levels are U-shaped, and the minimum deficit lies between $0.75 and $1.00 per trip, depending on the fare elasticity. In general, this fare is somewhat higher than is currently being charged by most existing dial-a-ride systems.

Figures 3 through 6 show the effects of various demand parameters on the level of service and net daily deficit. The base modal split is a major determinant of service quality and economic performance. For example, the deficit for an 8-vehicle system is almost $100 per day less at the 2 percent base modal split than at the 1 percent (Fig. 3). The magnitude of this differential tends to increase with vehicle fleet size. In general, a 1 percent increase in modal split produced a 10 to 20 percent decrease in daily deficit. The significant effect that the base modal split also has on quality of service is shown in Figure 4.

Figures 5 and 6 show the effect of the travel time ratio and wait time elasticities for various fleet sizes. In general, because most of the system tested operated at wait times and travel time ratios considerably below the base points of 15 minutes and 2.0 respectively, higher service elasticities implied higher demand and resulted in a lower operating deficit.

Relatively small increases in the service elasticities had substantial effect on the size of the deficit. For example, Figure 5 shows that a shift in the elasticities from -0.3 to -0.5 resulted in a 12 to 15 percent decrease in deficit, depending on the size of the vehicle fleet. In general, the size of the deficit decrease was a constant proportion of the total deficit, independent of the vehicle fleet.

The effect of increases in service elasticity on the quality of service is shown in Figure 6 for the same system as was used in Figure 5. The increase in demand implied by higher elasticities resulted in poorer quality service. To maintain the same level of service when the service elasticities shifted from -0.3 to -0.5 would have required the addition of 2 to 3 vehicles. Shifts from -0.3 to -0.7 imply the addition of 3 to 5 vehicles to maintain an equivalent level of service.

CONCLUSIONS

In previous analyses of dial-a-ride systems, either simulation has been used to analyze supply characteristics or attitudinal or empirical analysis has been used to predict demand. This analysis shows that both supply and demand parameters are important and must be considered in an integrated framework in designing dial-a-ride systems.

Figure 1. Fare versus deficit for various elasticities.

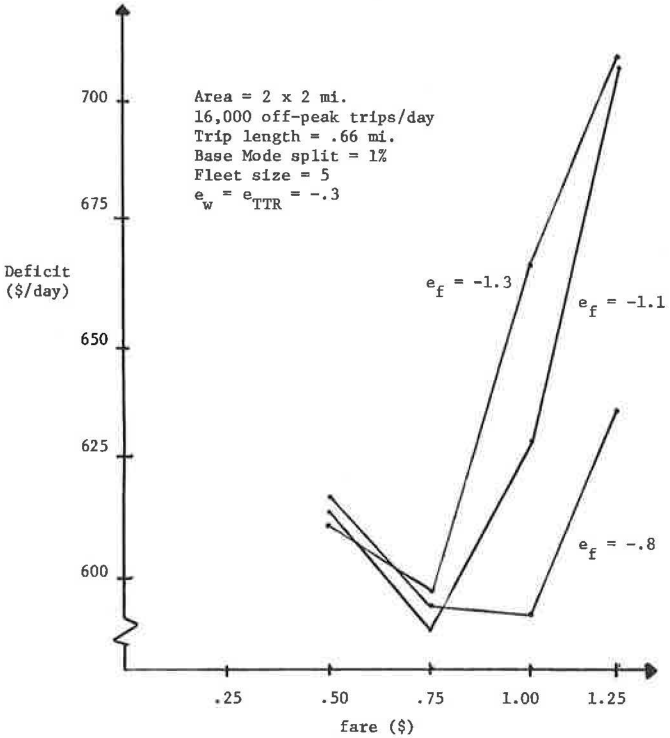


Figure 2. Fare versus level of service for various elasticities.

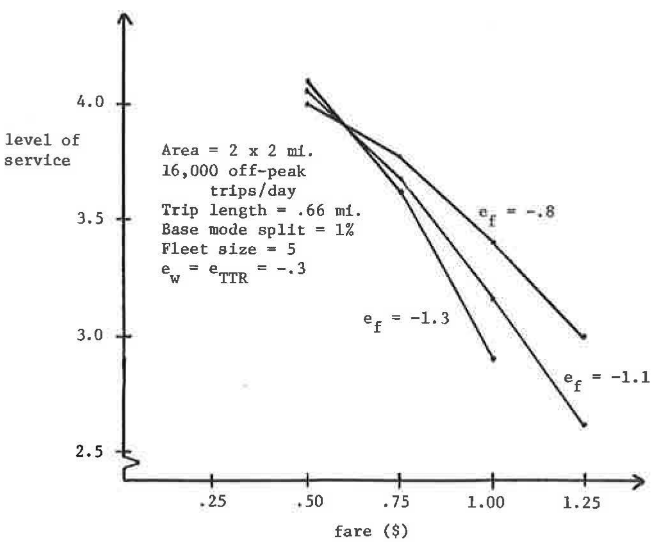


Figure 3. Fleet size versus deficit for various base modal splits.

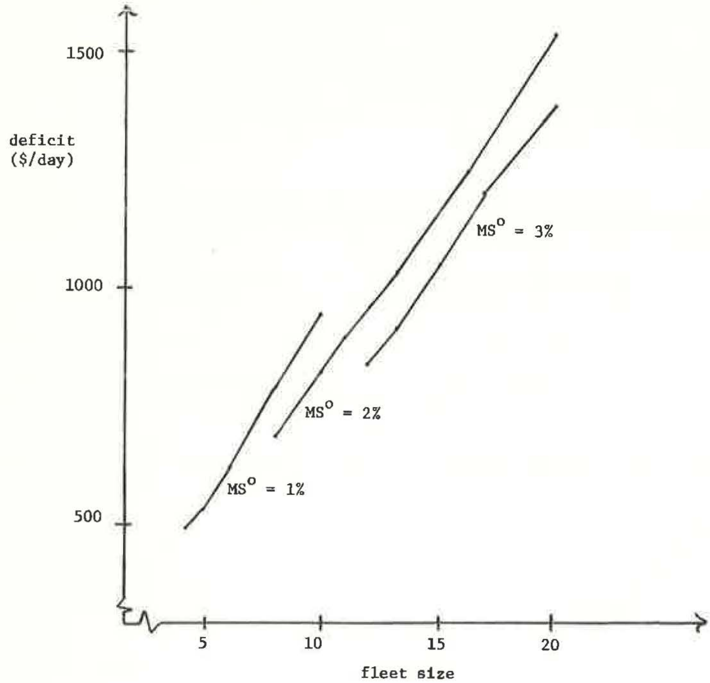


Figure 4. Fleet size versus level of service for various base modal splits.

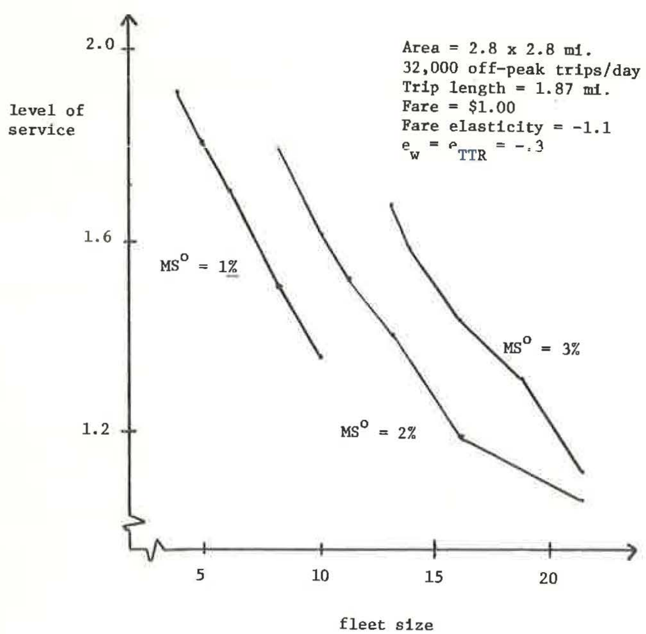


Figure 5. Fleet size versus deficit for various service elasticities.

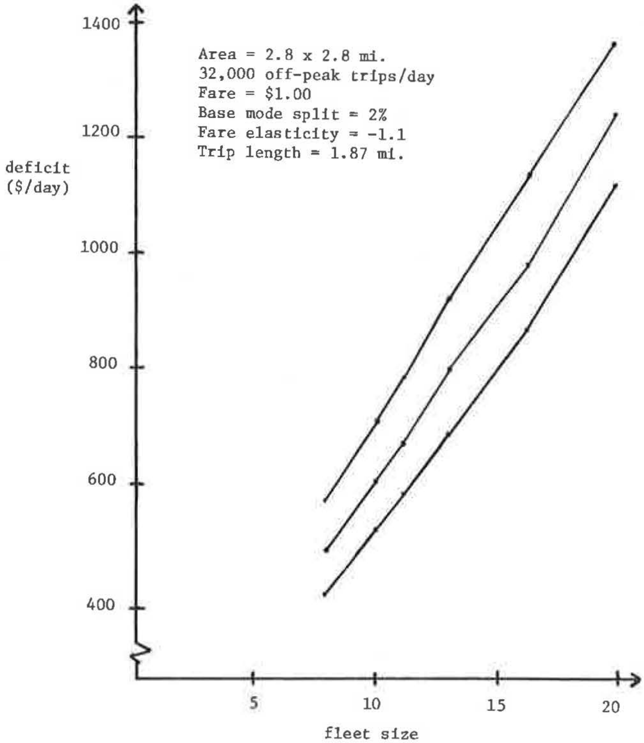
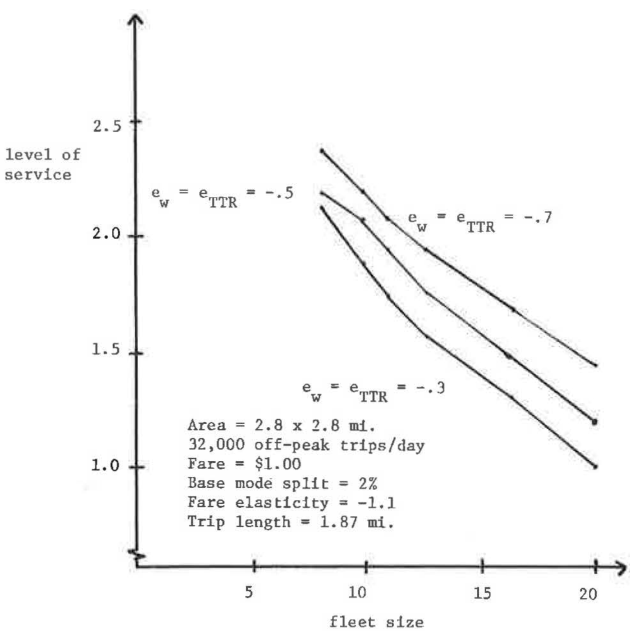


Figure 6. Fleet size versus level of service for various service elasticities.



This paper presents a model system based on an equilibrium framework that requires that both supply and demand be satisfied. Furthermore, the analytic form of all of the model components greatly reduces the computation required to evaluate a broad spectrum of design options.

The model system developed is of necessity somewhat crude, but it is sensitive to the types of system design options that are probably most relevant and is useful in analyzing changes in both short-run operating policy such as fare and long-run investment decisions such as fleet size and service area.

REFERENCES

1. Roos, D. Operational Experience With Demand-Responsive Transportation Systems. Department of Civil Engineering, M.I.T., Cambridge, Res. Rept. R-72-2, Jan. 1972.
2. Saltzman, A. Para-Transit: Taking the Mass out of Mass Transit. Technology Review, July-Aug. 1973.
3. Wilson, N., et al. Scheduling Algorithms for a Dial-A-Ride System. M.I.T., Cambridge, Rept. USL TR-70-13, March 1971.
4. Lerman, S., and Wilson, N. An Analytic Model for Predicting Dial-A-Ride System Performance. HRB Spec. Rept. 147, 1974, pp. 48-53.
5. Lerman, S. R. A Search Model for Dial-A-Ride System Design. M.I.T., Cambridge, MS thesis, Sept. 1973.
6. Wilson, N., et al. Service Modifications for Local Bus Operations of the Massachusetts Bay Transportation Authority. Boston Urban Observatory, Aug. 1972.
7. Golob, T., and Gustafson, R. L. Economic Analysis of a Demand-Responsive Public Transportation System. Highway Research Record 367, 1971, pp. 114-127.
8. Demand Actuated Road Transit: Performance and Demand Analysis. Institute of Public Administration and Teknekron, Inc., March 15, 1969.
9. Kraft, G., and Domencich, T. A. Free Transit. Paper presented at Conf. on Transportation and Poverty, American Academy of Arts and Sciences, June 1968.
10. Mass Transportation Demonstration Projects ILL-MTD 3, 4. Univ. of Illinois, 1968.
11. Urbanek, G. L. Cost Considerations for Dial-A-Ride. M.I.T., Cambridge, MS thesis, July 1971.

DEMAND-RESPONSIVE TRANSPORATION SYSTEMS IN THE PRIVATE SECTOR

Kenneth W. Heathington, Frank W. Davis, Jr., David P. Middendorf, and James D. Brogan, University of Tennessee

Two privately owned demand-responsive transportation systems were investigated to determine the economic feasibility and marketability of these systems and the roles that they play in small- to medium-sized urban areas. The 2 systems are operated by innovative taxicab companies that offer door-to-door service in 6-passenger automobiles on a shared-ride basis. This paper summarizes the results of preliminary analyses of some of the basic information collected on the daily operations of these systems. The 2 companies differ in terms of fleet size, service area, fare structure, types of service offered, market strategies, and goals. Those differences are reflected in ridership, level-of-service, and economic characteristics. Preliminary results reveal the systems to be economically viable, marketable, and important components of the total public transportation system.

•EFFORTS to increase ridership on public transit systems have centered on improvements to existing systems. Among the more common solutions are fare reductions, fare subsidies for certain socioeconomic and age groups, new rolling stock, route and schedule modifications including service extensions, construction of pedestrian shelters at access points to the system, and improved informational services. In addition, a number of advertising and motivational devices have been employed to influence automobile drivers to use the bus or subway for certain trips. These are positive inducements for increasing the use of the transit system, but many negative ones have recently come into prominence. The latter usually consist of methods of restricting the use of the automobile, augmenting the cost of automobile usage, or otherwise inconveniencing the automobile user. The positive approach usually results in a slight increase in ridership although never to the extent that the transit system becomes a profitable enterprise or that it significantly reduces traffic congestion, traffic accidents, air pollution, or other problems attributed to automobile usage. The negative approach has not been implemented to any large degree. Neither approach recognizes the diversity of individual needs relative to transportation or carefully considers the actual and potential markets for alternative public transportation services.

Some think that a consumer-oriented approach to the planning of public transportation systems is needed. This approach requires the planner to identify the transportation needs of population groups and then to design a system or several systems to satisfy those needs within the limits imposed by available resources. Some transportation planners and a few public officials are beginning to realize that, in many small- and medium-sized urban areas, fixed-route and fixed-schedule bus systems have been rendered obsolete by present-day, low-density development patterns and, therefore, no longer adequately meet the needs of the majority of the public. In fact, this mode of transportation may no longer adequately serve the needs of captive riders. As a result, a considerable amount of research effort has been expended lately in analyzing a rather old concept: demand-responsive transportation.

Demand-responsive transportation is usually associated with, but is by no means restricted to, the notion of small vehicles providing door-to-door service on a shared-ride basis. There is some agreement among transportation planners that this type of service is more marketable and could more adequately serve a wider segment of the population in low- and medium-density urban areas than the conventional fixed-route and fixed-schedule bus system. However, a lack of information regarding the actual public response to a demand-responsive system has been a major obstacle to a thorough evaluation of the potential of this concept despite the fact that several market surveys and research projects have indicated that such a response would be favorable. If both a conventional bus and a demand-responsive system were in operation in a given urban area, one could begin to answer some interesting and important questions concerning the ridership patterns and market characteristics of each. For example, what population groups are attracted to each type of service? Is each system used more frequently for certain trip purposes than for others? How frequently is each system used for specific trip purposes? To what extent is each type of transit service a primary or secondary mode of transportation? The urgent need to answer these and other related questions, the gradual shift toward a consumer-oriented approach to public transit planning, and some disenchantment with contemporary modal-choice models have served to magnify the need for more research on choices of, attitudes toward, and preferences for alternative modes of transportation.

A number of taxicab companies in small- and medium-sized cities and in suburbs of large metropolitan areas offer transportation on a shared-ride basis, seemingly unaware of the research having been conducted in this area. Many of these companies combine goods delivery with passenger service, and some are contemplating the implementation of computer-dispatching. The existence of these privately owned, shared-ride, and demand-responsive transportation systems seems to indicate that the concept of demand-responsive, for-hire transportation has been and is economically feasible.

In addition to the shared-ride transportation systems, conventional fixed-route and and fixed-schedule bus systems exist in many urban areas. As a result, researchers are now afforded an excellent opportunity to determine the roles of each of these systems, to study the various markets that each attracts, to identify the needs, attitudes, and preferences of these markets relative to public transportation, to determine the most important variables involved in the process of choosing among alternative modes of public transportation, and to formulate more reliable, behavior-oriented demand or modal-split models for alternative modes of public transportation.

This paper reports on a comprehensive investigation of the economic and service characteristics of 2 privately owned, demand-responsive transportation systems. These systems—one in Davenport, Iowa, and the other in Hicksville, New York—consist of innovative taxicab companies that offer door-to-door, shared-ride service at fares somewhat lower than those charged by conventional single-ride cab systems. In addition, each study area is served by one or more conventional fixed-route and fixed-schedule bus systems, and thus comparisons can be made of the demand characteristics of the 2 forms of public transportation.

STUDY AREAS

The 2 urban areas whose public transportation systems are being studied are representative of vastly different urbanized areas and are dissimilar in terms of population composition, economic base, travel patterns, land use patterns, and residential densities. This constitutes an important advantage in that it enables one to ascertain the applicability of the demand-responsive transportation concept to widely varied economic, cultural, and political environments. This section contains a brief profile of each study area and of the demand-responsive transportation systems that serve them. Table 1 gives some of the population characteristics.

Davenport, Iowa, is 1 of a cluster of 4 incorporated communities commonly known as the Quad Cities, which are located in the states of Iowa and Illinois and have a population of approximately 300,000 people. Situated along the Mississippi River, the area is a major midwestern trading and industrial center and is often referred to as the farm implement capital of the world. Davenport, which is the largest of the 4 communities in terms of population, experienced an approximate 11 percent growth in population between 1960 and 1970.

Table 1. Population characteristics.

Characteristic	Davenport	Hicksville
Area, miles^2	19.7	6.8
1970 population		
Total	98,500	48,100
Persons/mile^2	5,000	7,100
Nonwhite, percent	7	1
Over 64 years, percent	11	6
Under 19 years, percent	37	39
Labor force employed	96	96
Professional, managers, or technical workers, percent	23	
Sales, clerical, or skilled workers, percent	57	62
Service, farm, or unskilled workers, percent	20	38
Median family income, dollars	10,800	13,900
Median value of homes, dollars	17,800	27,500

Hicksville, New York, is an unincorporated community located on Long Island and within the New York City Standard Metropolitan Statistical Area. It was at one time the terminus of a branch of the Long Island commuter railroad system and is still noted as a major transportation hub. The local railroad station handles the largest number of riders of any station on the island. Although the county in which it is located has undergone a rapid and extensive transformation from open space to urban land use since World War II, Hicksville itself experienced a 4.6 percent decrease in population between 1960 and 1970 as a result of commercial expansion and population relocation.

Although both demand-responsive transportation systems under analysis use 6-passenger automobiles to provide on-call, door-to-door service on a shared-ride basis, in many respects they are as dissimilar to each other as the urban areas they serve. For example, both systems charge for services on a zonal fare basis, but each has developed its own rate structure. The 2 systems also differ in terms of service offered, market strategy, ridership levels, travel patterns, and other trip characteristics.

TAXI SYSTEMS

The present demand-responsive or shared-ride cab system in Davenport was established in 1967. The company operates 20 Checker cabs and employs more than 40 drivers. Drivers are encouraged to lease their vehicles on a weekly basis at a rate of $240 per week. The company provides insurance, vehicle maintenance and cleaning, licensing and dispatching services, and technical assistance; the driver pays the cost of fuel. The lease arrangement is designed to allow the lessee to retain the same vehicle during an extended period of time and to hire other individuals to operate the vehicle during second and third shifts on a commission basis. This arrangement fosters pride in equipment and provides the opportunity for drivers to increase their weekly income. The company's rate structure is based on a zonal system consisting of a central zone that encompasses the downtown business area and from which additional zones radiate. Consequently, fares are computed on the basis of distance from the central business district and, because of this geographical orientation, the fare for a short crosstown trip can be substantially higher than that for a much longer trip having its origin or destination in the downtown business area.

The system in Davenport employs the concept of shared riding in which a customer may have to share the vehicle with passengers with whom he has no affinity and who may have different origins or destinations. No specified maximum or minimun intervals of time for waiting or riding are guaranteed although the company strives to provide as high a level of service as is consistent with the prevailing conditions of the cab system and the street network. Users may request direct origin-to-destination service (no intermediate pickups or deliveries) for a somewhat higher fare. In addition, cruising is not permitted and is precluded by the present lease arrangement that requires the drivers to pay for their own gasoline. "Flagging" a vehicle is not common although drivers are permitted to serve such a form of request.

The privately owned demand-responsive transportation system in Hicksville has been in operation since 1961. The company's fleet consists of approximately 30 Dodge passenger cars driven by 100 full- and part-time drivers. Drivers lease their vehicles on a daily basis for a fee that is composed of a mileage and an hourly dispatching rate. Fuel costs are borne by drivers, and all other expenses including maintenance, cleaning, insurance, and licensing are borne by the cab company. The fare structure is based on a combination zone-mileage plan consisting of 6 overlapping zones, each of which has a cab stand serving as a focal point. Consequently, the determination of the fares for various interzonal and intrazonal movements can be quite complex, and, in a few instances, the actual fare charged is negotiable. The company, of course, uses the shared-ride concept although, as in Davenport, the customer can obtain non-stop or direct origin-to-destination service for a higher fare.

RIDERSHIP CHARACTERISTICS

Davenport

Table 2 gives a summary of daily passengers on both the demand-responsive and the bus transit systems in Davenport for those days on which system operations data were collected. The difference between the number of requests for shared-ride taxi service and the number of daily person trips handled by this system is an expression of the degree of group riding. This study makes a distinction between group riding and shared riding. If a request for service involves more than one individual, the resulting trip is defined as a group ride. Although this concept is perhaps not so important as that of shared riding in the analysis of demand-responsive transportation systems, it does have an advantage for patrons of the shared-ride taxi service in Davenport in that the fare depends not on the number of persons in the group but on a zone-based charge that is subdivided among the members of the group. Whether this advantage has indeed influenced the practice of group riding in Davenport cannot be accurately determined at this time. However, preliminary results indicate that on weekdays an average of only 11 percent of all requests for shared-ride taxi service involves 2 or more persons. A higher degree of group riding was observed on Saturday, May 12, and Sunday, May 20, when 18.5 percent and 22 percent respectively of all requests for service involved groups of 2 or more individuals.

The demand-responsive transportation system carried an average of 1,269 person trips on weekdays or approximately 48 percent of the average number of weekday trips handled by the local bus transit system. The demand for both forms of public transportation on Saturday (May 12, 1973) was remarkably consistent with weekday demands. Ridership decreased on the shared-ride taxi system on Sunday (May 20). Fixed-route and fixed-schedule bus service is completely curtailed on Sundays.

Figure 1 shows the absence of sharp morning and afternoon peaks corresponding to the morning and afternoon rush hours. Many intraurban bus systems and almost all urban streets and highways are characterized by heavy use during the morning and afternoon rush hours and light use during other periods. The demand-responsive transportation system in Davenport, however, experiences a reasonably constant level of use throughout much of the day and has the heaviest use during the noon hour. Relatively minor peaks occur during the morning and after the afternoon rush hours. One of the future tasks of this research effort is to fully establish the reasons underlying these observed hourly demand patterns.

A comparison of the percentages given in Table 3 for residence-oriented and motel- or hotel-oriented trips seems to imply that the demand-responsive transportation system is used primarily by residents. This is firmly supported by the percentages given in Table 4, which indicate that the most frequent unidirectional movement on the average weekday is between 2 residences. The shared-ride taxi service is apparently used quite extensively for social visiting. Even trips to and from business establishments are highly oriented toward residences.

Table 2. Daily ridership.

		Demand-Responsive System		
City	Date	Requests for Passenger Service	Person Trips	Bus Transit Person Trips
Davenport	Tuesday, 4-10-73	1,150	1,303	2,516
	Wednesday, 4-18-73	988	1,137	2,622
	Thursday, 4-26-73	964	1,108	2,587
	Friday, 5-4-73	1,271	1,528	2,826
	Weekday average	1,093	1,269	2,638
	Saturday, 5-12-73	988	1,278	2,422
	Sunday, 5-20-73	514	680	No service
Hicksville	Wednesday, 4-10-73	755	858	
	Thursday, 5-3-73	832	943	
	Friday, 5-18-73	856	971	
	Weekday average	814	924	
	Saturday, 6-2-73	471	528	

Figure 1. Hourly distribution of average weekday person trips.

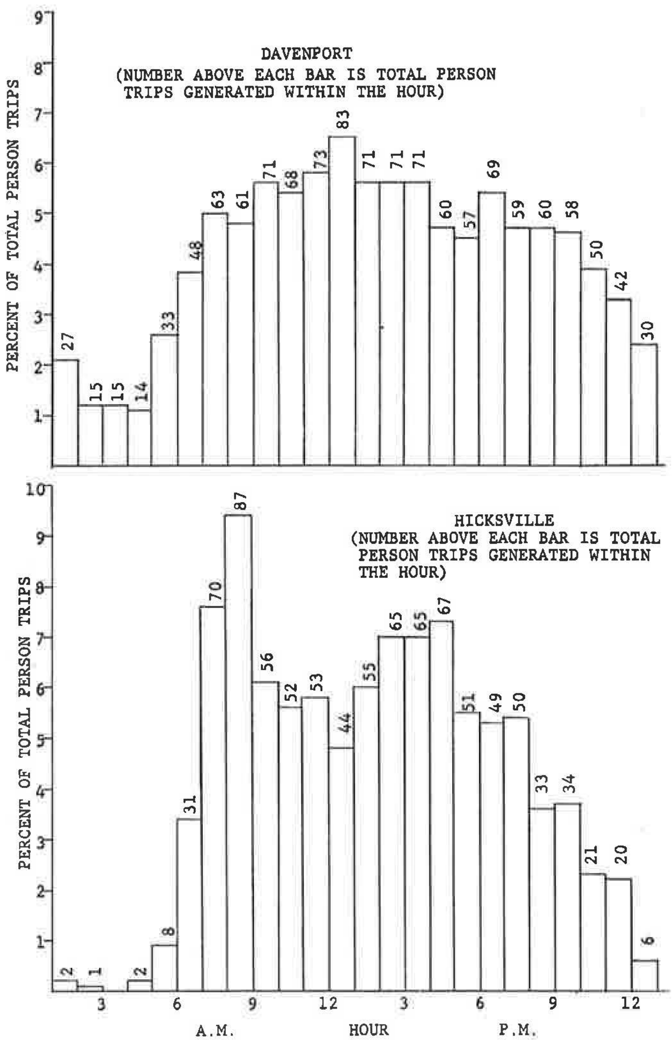


Table 3. Average weekday person trips by type of origin and destination.

City	Trip Generator	Origin		Destination	
		Number	Percent	Number	Percent
Davenport[a]	Residence	695	52.8	793	60.2
	Business	351	26.6	309	23.4
	Tavern	108	8.2	52	4.0
	Medical facility	72	5.5	87	6.6
	Motel or hotel	51	3.9	20	1.5
	Public facility	29	2.2	40	3.0
	School	12	0.9	17	1.3
Hicksville[b]	Residence	397	42.9	444	48.0
	Public facility	327	36.4	276	29.9
	Business	155	16.8	164	17.7
	Medical facility	22	2.4	25	2.7
	Tavern	12	1.3	8	0.9
	Motel	12	1.3	7	0.8
	School	0	0.0	0	0.0

[a]Based on data collected on 4-26-73 and 5-4-73.
[b]Based on data collected on 4-18-73, 5-3-73, 5-18-73.

Table 4. Dominant weekday origin-destination person trip flow on demand-responsive systems.

City	From	To	Number	Percent
Davenport[a]	Residence	Residence	348	26.4
	Business	Residence	265	20.1
	Residence	Business	211	16.0
	Tavern	Residence	69	5.3
	Residence	Medical Facility	68	5.2
	Medical Facility	Residence	56	4.2
	Business	Business	47	3.6
	Residence	Public Facility	26	2.0
Hicksville[b]	Public Facility	Residence	234	25.3
	Residence	Public Facility	200	21.6
	Business	Residence	120	12.9
	Residence	Business	109	11.8
	Residence	Residence	68	7.4
	Public Facility	Public Facility	43	4.6
	Public Facility	Business	37	4.0
	Business	Public Facility	22	2.4

[a]Based on data collected on 4-26-73 and 5-4-73.
[b]Based on data collected on 4-18-73, 5-3-73, 5-18-73.

Table 5. Average daily ride, wait, and deviation time in minutes.

City	Date	Wait Time[a]	Ride Time[b]	Deviation Time[c]
Davenport	Wednesday, April 18	16.7	10.3	2.2
	Thursday, April 26	16.1	10.3	3.1
	Friday, May 4	21.2	11.1	7.8
	Saturday, May 12	24.0	11.7	3.8
	Sunday, May 20	20.5	10.4	3.6
Hicksville	Wednesday, April 18	10.8	9.6	3.7
	Thursday, May 3	9.7	9.4	2.9
	Friday, May 18	9.9	8.8	4.4
	Saturday, June 2	8.7	9.6	5.6

[a]Includes radio-dispatched trips only.
[b]Includes all shared-ride taxi trips.
[c]Includes prearranged trips only.

Table 6. Income and mileage.

City	Day	Miles Operated	Miles/ Vehicle	Miles/ Vehicle/ Hour	Revenue/ Vehicle (dollars)	Revenue/ Vehicle/ Hour (dollars)	Revenue/ Vehicle/ Mile (dollars)
Davenport	Tuesday	2,988	175.8	8.55	84.23	4.10	0.47
	Wednesday	3,359	186.6	11.28	74.63	4.51	0.39
	Thursday	3,128	195.0	10.80	84.29	4.53	0.43
	Friday	3,729	219.4	10.93	97.07	4.84	0.44
	Saturday	3,162	243.2	12.07	101.78	5.05	0.41
	Sunday	1,460	146.0	11.15	63.92	4.85	0.43
	Weekday avg	3,301	194.2	10.38	85.05	4.49	0.43
	Weekend avg	2,311	194.6	11.61	82.85	4.95	0.42
Hicksville	Wednesday	3,740	155.8	12.39	69.02	5.49	0.44
	Thursday	3,083	154.2	9.80	80.55	5.12	0.52
	Friday	3,119	148.5	10.76	82.11	5.95	0.55
	Saturday	2,363	138.9	11.66	56.76	4.78	0.40
	Weekday avg	3,314	152.8	10.99	77.22	5.52	0.50

Of the 110 traffic zones in Davenport, an average of 83 zones generated at least 1 passenger trip on weekdays. The largest generator of demand-responsive transportation trips was the central business district, which produced an average of 219 daily person trips and attracted an additional 158 trips, 18 and 13 percent respectively of the total daily demand. The next most productive zones are the 4 zones clustered around the CBD; hence, the demand for shared-ride taxi service tends to be highly concentrated spatially.

Hicksville

The total demand for shared-ride taxi service on the average weekday in Hicksville is slightly less than three-fourths of the average weekday demand in Davenport (Table 2). However, the seemingly large disparity between ridership levels in the 2 study areas is not quite so striking when one considers that the population of Hicksville is approximately one-half that of Davenport. Consequently, based on population size, Hicksville appears to serve a larger proportion of its population. Saturday ridership in Davenport remained at weekday levels, but the demand in Hicksville fell to 57 percent of the weekday average.

The hourly distribution of shared-ride taxi trips in Hicksville (Fig. 1) exhibits a slightly different demand pattern from that in Davenport. The most notable dissimilarity is the peak system use between 7:00 and 9:00 a.m. The principal role of the cab service during this period is one of collecting and distributing commuters journeying to or from the area's 3 commuter rail stations. After the morning peak period, hourly ridership fluctuates, is lowest during the noon hour, and increases sharply during the early afternoon to an obtuse secondary peak that extends for a 3-hour period.

Residences were the most common type of origin and destination in Hicksville, but they produced and attracted less than half of all person trips (Table 3). The lesser importance of the residence as a trip generator in Hicksville can be explained by the public facility category, which includes the Long Island Railroad station. This single facility produces and attracts more than a third of the total demand for demand-responsive transportation. Even on Saturday, June 2, 38 percent of the cab system's business was oriented to this terminal.

Trips between public facilities (primarily the commuter rail station) and residences account for nearly half of all daily person trips made on the demand-responsive system (Table 4). The number of shared-ride taxi trips between residences is relatively small, indicating that the cab system is used more for commuting, personal business, and shopping than for social visiting.

The Hicksville zone that contains the commuter rail station and a large shopping area dominates all other zones in terms of trip generating potential, producing 41 percent and attracting 32 percent of all daily shared-ride taxi trips. In general, demand-responsive trip origins and destinations tend to be more highly concentrated spatially in Hicksville than in Davenport. Of the 87 zones within the cab system's service area, 50 generated at least 1 trip and 15 of those zones accounted for 75 percent of all person trips.

LEVEL-OF-SERVICE CHARACTERISTICS

In both Davenport and Hicksville, 3 mutually exclusive types of request for service are recognized: radio dispatched, "flagged," and prearranged. The most common is the radio-dispatched service in which the customer telephones a request for transportation but does not state a specific pickup time. By definition, then, radio-dispatched trips have associated with them a period of waiting. In flagged service, the customer hails a standing or moving cab and obviously has no wait time. In prearranged service, the user requests in advance to be picked up at a specific time. The difference between the requested and the actual vehicle arrival time is the deviation time. Average daily wait, ride, and deviation times for each date on which system operations were monitored are given in Table 5.

The user of the demand-responsive transportation system in Davenport must wait for a vehicle, on the average, between 16 and 24 minutes. Because of the number of cabs operating on the street network, the level of the demand for service, and traffic conditions in general, the wait varies considerably by hour or day. The average individual wait times for all radio-dispatched trips during a 1-hour period fluctuated between 6 and 31 minutes. In general, mean hourly wait times tend to be lower than the average daily wait time in the morning and higher in the afternoon.

Demand-responsive system users in Hicksville spend considerably less time waiting for cab service and are subjected to less uncertainty with regard to the expected arrival time of a vehicle. Mean hourly wait times typically vary between the extremes of 4 and 12 minutes. They tend to be lower than the average daily wait time during the morning and higher during the afternoon and early evening.

Both cab systems are usually punctual for prearranged trips. The vehicle can be expected to arrive at the customer's origin 5 minutes before or after the requested time of boarding in about two-thirds of the cases in Davenport and three-fourths of the cases in Hicksville.

The mean hourly ride time, which is the average travel time for all trips made within a 1-hour period, generally varies between 6 and 14 minutes in Davenport and between 5 and 13 minutes in Hicksville. These average hourly ride times tend to be at or above the average daily ride time between 7:00 a.m. and 5:00 p.m. in Davenport and between 3:00 p.m. and 9:00 p.m. in Hicksville. The highest ride times typically occur during periods of heavy traffic congestion.

On the average, use of the demand-responsive transportation system involves approximately 30 minutes in Davenport and 20 minutes in Hicksville between the time service is requested and the time the trip is completed (wait time plus ride time). The shared-ride taxi service thus appears to offer little advantage over a fixed-route and fixed-schedule bus system that operates on 30-minute headways. The extent to which the measured wait and ride times are considered to be unfavorable by users and nonusers remains to be determined.

ECONOMIC CONSIDERATIONS

The demand-responsive transportation systems in Hicksville and Davenport operate on 2 different market philosophies. The Hicksville operation seeks to maximize return on investment through higher fare levels and strict attention to cost control. Thus, it has followed a strategy of periodic fare increases and relatively stable ridership. The Davenport operation, on the other hand, seeks to provide a low-cost transportation service to a rapidly growing market segment. As a consequence, ridership on the Davenport system has increased from 174,000 in 1967 to 485,000 in 1972. (Public bus ridership decreased from 1,472,399 to 740,000 in this same period.)

The taxi fleet maintained in daily operation is approximately 76 percent in Davenport and 69 percent in Hicksville. A vehicle is driven approximately 13.5 hours a day in Hicksville and 18.4 hours a day in Davenport, but a driver operates a vehicle an average of 10.9 hours a day in Davenport and 9.5 hours a day in Hicksville. Hicksville increases vehicle use by leasing vehicles to second-shift drivers, while Davenport leases its cabs for a flat fee each week, thus encouraging the lessee to hire a driver for the second shift. This results in an average vehicle use of 1.43 shifts in Hicksville and 1.65 shifts in Davenport.

The Davenport passenger pays an average fare of $1.25 per trip but, in a group ride, the average fare per person is reduced to $1.03. The Hicksville passenger pays an average fare of $1.83 per trip or $1.79 per passenger. In Davenport, the fare is independent of each additional person in the group; the cost per person is equal to the zone fare divided by the number of people in the group. In Hicksville, an incremental charge is added for each additional person, resulting in a charge per person that is equal to the base fare plus the incremental charge for each additional person divided by the number of people in the group. Consequently, group riding does not have as significant an advantage in Hicksville as it does in Davenport.

Table 6 gives the effect of the 2 market strategies. On an average weekday in Davenport, each vehicle travels an average of 10.38 mph and produces $4.49 each hour or $0.43 each mile. Hicksville's system generates less revenue per vehicle but more revenue per vehicle-hour since it operates each vehicle only 13.5 hours per day. The higher profitability of the Hicksville system is explained by the high income per mile and per hour. In fact, the income per mile is 16 percent higher and the revenue per hour is 22.9 percent higher in Hicksville than in Davenport. Since these differences are on the basis of gross revenue, the profit margins in Hicksville are many times greater than in Davenport.

SUMMARY

This discussion has illustrated the applicability of the concept of demand-responsive transportation to different economic, cultural, and political environments. Not only do the 2 communities of Davenport and Hicksville differ in terms of geographic location, population composition, size, density of development, economic base, and political structure, but the 2 privately owned demand-responsive transportation systems differ in several important aspects. Although each system operates under the semblance of a taxicab company and provides on-call, door-to-door, shared-ride transportation, each is characterized by its own fleet size, fare structure, driver leasing arrangements, types of service offered, market strategy, and goals. These differences between study areas and between cab companies are reflected in dissimilarities in ridership, levels of service, and economic characteristics of the 2 demand-responsive transportation systems. These 2 companies are economically strong, have been in operation for a considerable period of time, and have never received capital or operating subsidies. Their ridership has consistently grown while that on fixed-route and fixed-scheduled buses has declined.

LA HABRA DIAL-A-RIDE PROJECT

David R. Shilling and G. J. Fielding, Orange County Transit District, California

The La Habra dial-a-ride project, operated by the Orange County Transit District, has provided a high level of door-to-door service within a reasonable budget and fare structure. The service has proved to be efficient, extremely popular, and operationally feasible.

•THE DIAL-A-RIDE transportation system in La Habra is made up of a fleet of small, radio-dispatched vehicles that respond to transportation requests received by a central dispatcher. The dispatcher-scheduler combines customer information regarding location, number of riders, and desired pickup time with information regarding vehicle positions, tentative routes, and trip characteristics of other passengers. Using preplanned scheduling and dispatching procedures and a radio communication link, the dispatcher assigns a vehicle to pick up and deliver each customer. The customer is advised of the expected pickup time and, perhaps, the fare.

A large metal-backed map and magnetic pieces are used in the control center. The magnetic pieces hold trip tickets containing customer trip data—one kind of piece denotes an origin and another kind, a destination. When a trip is assigned, colored markers corresponding to the vehicle are placed on both pieces. These markers also serve as pointers to the vehicle's next stop and effectively trace out a tentative route for each vehicle. When the bus arrives at a stop, the driver notifies the control center operator, who updates the driver's position on the map and in turn notifies him or her of the next stop. The map, therefore, represents quite accurately the true state of the system, i.e., vehicle position, customers onboard, and customers waiting. Given this full view of the system, the control staff can alter tentative routes as necessary to accommodate new trip requests.

As calls are received and relayed to the driver via 2-way radio, the vehicle moves through the city and passengers get on and off along the way. Passengers whose origins and destinations are in close proximity are batched to increase vehicle productivity (passengers delivered per vehicle-hour). In an efficiently operated system, service is orderly and predictable, fares are reasonable and commensurate with the level of service provided, and wait and travel time are minimized. This shared-limousine service is operating in some eastern cities, Canada, and Europe; La Habra had the first full-scale dial-a-ride service west of the Mississippi, and systems are now operating in the Los Angeles and San Francisco Bay areas, including La Mirada, El Cajon, and Watts, and are being planned for Richmond, Fremont, Ojai, Hemet, and Santa Clara County.

LA HABRA EXPERIMENT

The Orange County Transit District (OCTD) decided in the summer of 1972 to experiment with the dial-a-ride concept to discern its usefulness as the primary local transit service in Orange County and as a feeder system into the district's fixed-route, conventional line-haul bus network. The managerial advantages of the system have been discussed by the authors elsewhere (2); this paper emphasizes the operational details of the dial-a-ride experiment.

The OCTD entered into an agreement with a consultant to establish the system, operate it for 1 year, and aid in the evaluation. Consultant fees, insurance, and professional staff time amounted to approximately $300,000. The city of La Habra also contributed office space, a shared radio frequency, public works services, and $26,000 to support the project. Service began February 1, 1973.

SERVICE AREA

The city of La Habra has a population of 44,200 and covers 6.3 miles^2. In addition, unincorporated county areas within the city have a population of 2,800 and cover 0.7 miles^2. The socioeconomic characteristics of the population are mixed: old, young, rich, poor, black, white, and Mexican-American. The land area is 92 percent developed, and there are several distinct nodes of commercial, recreational, and residential activity.

The La Habra dial-a-ride system operates six 19-passenger Flxible Flxette minibuses and one 8-passenger Dodge van throughout the city from Monday through Saturday, 7 a.m. to 7 p.m. During the Christmas season, Friday service was extended to 10 p.m. Free transfers can be made to and from dial-a-ride buses on OCTD's Harbor, Beach, and State College Boulevard routes.

PUBLIC RESPONSE AND RIDERSHIP

The OCTD dial-a-ride service has received a strong, positive response. Few complaints about the fare structure have been received by OCTD. Requests for service now total 10,000 per month.

Trip requests are divided into 4 categories:

1. Immediate—a customer requests service by calling just before making trip;
2. Deferred—customer wants to begin the trip at some specified time in the future;
3. Periodic—through 1 telephone call, a customer requests service between the same origin and destination, at the same hour of the day, on specified days of the week; and
4. Extra-on—a customer boards an available vehicle without first calling the control center.

In the latter type of trip, the driver contacts the control center to determine whether the customer's trip fits into his or her route. If it does, the customer is permitted to board. If it does not, another bus is routed to provide service to the customer. Immediate requests for service account for about three-fourths of La Habra's total ridership; deferred, periodic, and extra-on requests account for the remaining 25 percent.

Ridership for the first 11-month period is as follows:

Month	Riders
February	5,931
March	7,960
April	8,345
May	8,816
June	8,439
July	9,722
August	8,783
September	7,332
October	9,085
November	9,905
December	10,011

More than 100,000 trips were made by dial-a-ride during the first year. On a number of days more than 500 riders were carried, and on July 18 an all-time high of 706 riders were carried. The system in La Habra can carry as many as 600 riders per day at its present capacity without diminishing the level of service.

Dial-a-ride is a favorite of the elderly and mothers of young children who appreciate the door-to-door security. Although senior citizens are only 5 percent of the population in La Habra, they account for 20 percent of the riders. The service is also used by school groups on field trips within the city and by a significant number of commuters. Dial-a-ride is connected to the intercommunity bus system, and more than 100 people transfer between these systems every day. (Periodic riders, those who subscribe by calling once to place a request for a pickup at a regular prearranged time, now number more than 150. Approximately 60 percent of these make work trips, 30 percent school trips, and 10 to 15 percent miscellaneous trips.)

The La Habra system can operate in any combination of 3 modes: (a) many-to-many—vehicles travel between any origin-destination pair in the service area; (b) many-to-one—customers are picked up at several origins and brought to a single destination, such as a shopping center; and (c) one-to-many—customers are picked up at a single origin, such as a shopping center, and delivered to several destinations. About 90 percent of the trips are dispatched in a many-to-many mode, and the remaining 10 percent are dispatched in a many-to-one or one-to-many mode.

FARES, COSTS, REVENUES, AND FUNDING

The basic fare for dial-a-ride is 50 cents, but books of coupons are available at 35 cents a ride. Children under 12 may ride free when accompanied by a cash-fare passenger. The fare on OCTD's fixed-route bus system is 25 cents. The additional fare on dial-a-ride is warranted by the additional expense of providing door-to-door transportation and the more personalized nature of the service. Negotiations have been completed with the city of La Habra for a city subsidy to OCTD to provide free fixed-route service to senior citizens and a 25-cent fare on dial-a-ride.

Dial-a-ride is more heavily subsidized than fixed-route services. Initial estimates indicate that revenues on dial-a-ride average 22 cents per mile, gross operating costs average $1.17 per mile, and net operating costs (subsidy) are about 81 cents per mile. (The remaining deficit of 14 cents per mile is absorbed by the city's contribution). The initial costs of the system, the additional expense of technical study and consulting fees, and the leased vehicles account for a large percentage of the expense. However, estimates are that, with an established system directly operated with vehicles purchased under a capital grant and with some economies, the operating deficit can be decreased to about 60 cents per mile. In fact, as the system "settles down" and as ridership increases, there are indications that the cost of operating dial-a-ride is decreasing.

Because of the present physical capacity of the system and the extraordinary added costs, the La Habra system will never break even. The goal, then, is to optimize the efficiency of the system and bring the subsidy down to approximately 70 cents per mile to be in line with the subsidy of OCTD's fixed-route operations. When compared to the deficit of approximately 60 cents per mile incurred on OCTD's fixed routes, the additional cost is warranted because of the personalized, door-to-door service. Moreover, in low-density areas, the operating deficit for dial-a-ride may be equal to or less than the costs of providing fixed-route services where low passenger volumes do not warrant line-haul service.

The Orange County Transit District believes that public transportation should be provided as a public service, much as police and fire protection are. Implicit in this opinion is the idea that providing superior service—not making a profit—is the primary criterion by which any system of public transportation should be evaluated. Nevertheless, the realities of economics require that the provision of the service be justified in terms of what it costs to provide that service.

At present, the cost of providing dial-a-ride service in La Habra is $11.87 per vehicle-hour. This figure includes the constraints imposed on a small fleet that operates 12 hours a day and 6 days a week and that has some extraordinary as well as ongoing operating expenses. The most expensive element of the system is the driver, accounting for a fourth of total costs. By comparison, the driver costs in the federal demonstration project in Haddonfield, New Jersey, represent more than half the cost of operation. The significant difference is a result of wages paid in the 2 projects. The labor-intensiveness of a small, manually controlled system is a key element in determining system costs—and possibly the critical element in analyses of the ultimate cost-effectiveness of the dial-a-ride concept.

OCTD has made an application to UMTA for a capital grant to assist in the purchase of 47 additional dial-a-ride vehicles and equipment. Between 10 and 15 dial-a-ride modules are contemplated for an ultimate system that will be implemented during a 4-

year period and will involve 180 to 200 vehicles. The first modules will be manually operated, but each will be developed so as to facilitate conversion to computer-assisted dial-a-ride modules as efficient computer programs are released.

ADVERTISING, PROMOTION, AND MARKETING

OCTD's Marketing Department has established a dynamic campaign to promote the district's services, including dial-a-ride. The dial-a-ride inauguration, attended by more than 250 people, received regional television coverage. An aggressive direct-mail campaign, door-to-door contact with the business community, advertisements in local newspapers, Dial-A-Ride Demonstration Days at local shopping centers, and cooperative promotional events between OCTD and local merchants have highlighted the advertising effort. Bilingual employees went into the Mexican-American community to inform Spanish-speaking residents of the service, and a bilingual brochure was developed. In fact, dial-a-ride drivers and dispatchers took a conversational Spanish course to better enable them to assist and stimulate minority use of the system. The Mexican-American community, 10 percent of the population, is using dial-a-ride at a steadily increasing rate, now representing 15 percent of ridership.

Sophisticated marketing techniques were used to determine the public's opinion and desires about public transportation. Attitudinal surveys were taken to determine what people want (and do not want) their public transit system to be. A stratified random sample of 300 households in La Habra was selected, and a longitudinal follow-up survey and on-board surveys are planned. The data will provide OCTD with valuable information useful in attracting more people to its services. But perhaps the most effective promotional tool is the service itself: The buses on the street are visible, the drivers and dispatchers are friendly and helpful, and word-of-mouth from customer to customer has largely resulted in the public's positive response to the dial-a-ride project.

PERSONNEL

At present dial-a-ride in La Habra operates with 12 employees: A site manager and a senior controller administer the service; 2 controllers handle the telephones, bus scheduling, and radio dispatching; and 4 drivers work part time and 4 work full time. This group is made up of 7 women and 5 men. The drivers are young, and usually single. Dial-a-ride offers a good opportunity for part-time work or a second job. Little turnover in staff has occurred; the employees like their work, and promotion is possible within the system. Wage rates are slightly below industry standards, but competitive salaries are planned for in the expanded dial-a-ride program. Dial-a-ride drivers currently receive an hourly rate varying between $2.50 and $4.00 per hour, plus an incentive payment reflecting total ridership carried.

Although wages of dial-a-ride bus drivers are low relative to those of bus drivers in general, in La Habra they are in line with wages, or earnings, of most taxicab drivers in the United States. Wages are also competitive with other part-time employment opportunities in the area. Driving for dial-a-ride is a good part-time or second job.

VEHICLES

Satisfied personnel is a key to an efficient operation, but a vehicle fleet, adequate in both reliability and size, is also a necessity. At present, the La Habra system operates 6 Flxible Flexette propane-powered buses that seat 19 riders and 1 Dodge 8-passenger Sportsman van. The buses use Ford components, and major maintenance work is performed by the local Ford dealer in La Habra. Each bus currently operates about 150 miles per day and about 15,000 miles per month. Routine maintenance is performed on a regular schedule by a mechanic retained on a part-time basis; other maintenance is done as needed.

Vehicle reliability has been only fair. The Flxette is one of the better American-built small buses but is more costly to maintain than the larger, standard bus. Brakes, the propane system, the hydraulic door system, and parts supply have been major trouble areas. Maintenance difficulties are being worked out, but having 1 or more of the 6 vehicles out of service for unforeseen repairs had a negative impact on the service during peak loading periods when the maximum number of vehicles in service was needed. In fact, the van was added to the dial-a-ride fleet as a seventh vehicle because of this problem. Recent hiring of a part-time mechanic has greatly reduced the vehicle downtime problem, and the high level of service has consequently been restored. At its present capacity, the La Habra dial-a-ride service will peak at about 600 riders per day because of vehicle limitations. Additional increases in ridership will necessitate additional vehicles if the same level of service is to be provided.

Dial-a-ride propane-powered vehicles exceed 1975 emission standards. Tests undertaken for the California Air Resources Board indicate that 93 percent of all hydrocarbons are emitted in the first 4 miles of a 20-minute automobile trip because of cold-start emission characteristics. This short trip is the kind that dial-a-ride accommodates, and, if it can be diverted to dial-a-ride vehicles, air pollution will thereby be reduced.

QUALITY OF SERVICE

In general, quality of service is a rather nebulous term encompassing factors such as comfort, convenience, reliability, and, perhaps the most important, time. For the purposes of dial-a-ride analysis, a more restrictive definition can be adopted—one that limits quality to time factors. Thus, the following 4 measures of service quality have been suggested (3).

1. Customer wait time is the elapsed time between the receipt of a customer's request for service and the boarding of the vehicle by the customer. In La Habra, this averages to 15 to 20 minutes during off-peak periods and 30 to 40 minutes during peak periods.
2. Customer ride time is the elapsed time between boarding and exiting of a vehicle by a customer. Average travel time in La Habra is 11 minutes.
3. Level of service is the ratio of customer wait plus ride time to the corresponding automobile travel time for the same trip. Level of service is discussed in more detail in a later section of this report.
4. Pickup time deviation is the difference between a vehicle's actual arrival time at a customer's origin and the expected arrival time quoted to the customer when the trip was requested. In La Habra, actual pickup time averages 2.2 minutes earlier than promised.

LEVEL OF SERVICE AND SYSTEM EFFICIENCY

One way of measuring level of service is to determine the ratio of wait time plus trip length on dial-a-ride to an estimate of the time the same trip would take in an automobile. Dial-a-ride systems normally operate at a ratio of about 3:1; in the La Habra system, for example, a 10-minute automobile trip takes 30 minutes on dial-a-ride. Because the La Habra dial-a-ride does not yet operate at capacity, many travel times (time on the bus) are nearly equal to automobile travel times. The La Habra system has a level of service of approximately 2.5:1 during off-peak periods and 3:1 during peak periods (7 to 9 a.m. and 2 to 4 p.m.).

Within the wait and ride times experienced in La Habra, a level of service of 3:1 may be considered acceptable. However, assessing the efficiency of a dial-a-ride system solely in terms of level of service can be misleading. Level of service is relatively insensitive to absolute differences between dial-a-ride and automobile trip times whereas potential users are not likely to be so insensitive. For example, if the dial-a-ride time were 5 minutes and the corresponding automobile time were 1 minute, the resulting level of service of 5 would be acceptable to many users since the absolute difference is only 4 minutes. If, however, the respective times were increased to 50 minutes and 10 minutes, the level of service would remain at 5, but the absolute time difference would be 40 minutes, which, as Zobrak and Medville (3) indicate, could be unacceptable to dial-a-ride users. Consequently, other variables must also be taken into consideration.

The key factor in La Habra is wait time, the elapsed time from phone call to actual pickup. Dial-a-ride wait time is normally 15 to 30 minutes and averages 22 minutes, while travel time averages 11 minutes. The parameters vary, depending on time of day, number of vehicles in service, and weather. Under unusual circumstances, wait time can range from 5 minutes (a bus happens to be on the same street when the request for service is received) to an hour (it is a rainy day, and 3 buses are in for maintenance during the morning commuter peak period). Riders who call well in advance of their desired pickup times are usually picked up 1 to 5 minutes prior to the time promised (the average is 4 minutes earlier). So, La Habra dial-a-ride provides a level of service commensurate with system capacities.

DIAL-A-RIDE THEORY

Previous analyses have yielded relations among quality of service, demand rate, vehicle supply, and area size (4, 5). For a dial-a-ride system operating in a contiguous service area, the expected effect on wait time plus ride time of changes in area, fleet size, and demand is expressed by

$$T = 2.2\sqrt{A}\left\{1 + \left[\frac{A(0.82 + 0.087D)}{N}\right]^2\right\} \tag{1}$$

where T is the dial-a-ride wait plus ride time, in minutes; A is the size of a service area, in square miles; D is the demand density rate in terms of trips per square mile per hour; and N is the number of vehicles in service. (Trips randomly arrive on time, and trip ends are uniformly distributed in a square area, A. The factor $2.2\sqrt{A}$ represents the automobile, or direct, travel time required to make a trip of average length in A at a speed of 15 mph.) Thus, for a given number of vehicles, wait plus ride time varies essentially as the square of demand density rate and the 2.5 power of area.

VEHICLE PRODUCTIVITY

An important measure in assessing the economic characteristics of a public transportation system is vehicle productivity, defined here in terms of passengers per vehicle-hour. In a dial-a-ride system, the upper limits on vehicle productivity are considerably lower than those in a fixed-route, fixed-schedule system. In the latter, any increase in demand that does not cause the vehicle capacity to be exceeded causes only a slight delay at a stop and a near linear increase in vehicle productivity. In a dial-a-ride system, however, each additional user typically generates not only additional vehicle stops but additional diversions to the stops as well. Thus, Zobrak and Medville (3) determined the effect on vehicle productivity to be considerably more severe.

Productivity varies greatly throughout the day. The La Habra dial-a-ride operates at 4 to 10 passengers per vehicle-hour and a daily average of 6.6. Productivity peaks are less discernible in the many-to-many mode than in the gather-and-scatter modes common to a commuter service, but are highest between 8 and 10 a.m. and especially from noon until 3 p.m., reflecting extensive school and shopping trip usage. When the actual is compared to the theoretical, Eq. 1 is used to solve for productivity, $V = DA/N$, and the average wait time, ride time, and density rates encountered in La Habra are inserted, the result is 6.30 passengers per vehicle-hour. This corresponds fairly well with the 6.6 passengers per vehicle-hour actually achieved.

In theory, 15 passengers per vehicle-hour is an optimal level of vehicle productivity. But this would represent 1 passenger entering and leaving the bus every 2 minutes. This is where theory breaks down and the realities of daily operation are evident. The movement of people at 15 riders per vehicle-hour is not a realistic goal; La Habra now peaks at 10 passengers per vehicle-hour when the system is operating quite efficiently and actively. As a means of comparison, the federal demonstration project in Haddonfield, New Jersey, operates at a vehicle productivity level of 6.5 passengers per vehicle-hour. On a recent no-fare day, the system reached 14 passengers per vehicle-hour—

an all-time high, but the system was certainly overstressed. Wait time, a key to customer perception of the level of service, increased greatly, and the demand on equipment and personnel was stretched to the limit. (The Haddonfield system, operating with 18 vehicles and carrying as many as 1,400 passengers per 24-hour day during the week, also has the advantage of some major traffic generators, including a large regional shopping center and a transit station on the Lindenwold Line to Philadelphia. The resultant demand for the scatter-and-gather mode is advantageous to high vehicle productivity. La Habra has no such major trip generators.)

POTENTIALS FOR DIAL-A-RIDE

The dial-a-ride concept is a proven one. The La Habra project has shown that public response to dial-a-ride is positive. Ridership in La Habra has been disproportionately high with regard to the relatively small service area and limited number of vehicles.

Dial-a-ride can serve local trips that cannot be accommodated with conventional fixed-route bus service. Further, it can serve as an efficient feeder system to these fixed routes and to line-haul rapid transit systems.

An established dial-a-ride system can be financially feasible. A large system can make use of automated dispatching equipment to efficiently and effectively handle a large fleet of vehicles and a high volume of riders. Fleet size and service areas can be expanded, federal support can aid in defraying costs, and cities can cooperate by providing facilities, public works services, and financial aid for the establishment of dial-a-ride.

Automation and a modified van (e.g., raised roof, driver-operated door) costing $9,000 and lasting 4 years instead of a bus costing $20,000 to $25,000 and lasting 6 to 8 years could reduce costs below the present levels. Based on current computerized control developments and costs, a computer system capable of controlling 100 vehicles would probably not cost more than $200,000. This includes equipment for automated customer communications on 5 lines, but excludes development costs. Monthly maintenance for such a system would be approximately $2,000. Furthermore, the system would require digital communications with the vehicle fleet at an estimated $2,000 per mobile unit instead of $1,175. These costs, the cost of a van, and changes in other costs appropriate to the increased system size decrease costs per vehicle-hour about one-fourth to one-half—$12.09 for Haddonfield and $6.99 for La Habra.

AN EXPANSION STUDY

The OCTD Board of Directors has directed the staff to undertake an expansion study to analyze other areas in Orange County where dial-a-ride would be feasible. That study, currently under way, will analyze costs and system utility and the use of dial-a-ride as an integral part of a hierarchy of transit services. The ultimate product of the study will be a complete and detailed report of a comprehensive program for the planning, implementation, and financing of an areawide dial-a-ride system.

That system would be developed incrementally to a fleet of 180 vehicles within 4 years and eventually be computer controlled. As an integrated system of public transportation in a suburban metropolitan area, it would visibly demonstrate the feasibility of a countywide transportation system of this type to other American communities. Key features of the system would include

1. Full integration of all transportation modes to maximize efficiency, provide a superior level of service, and demonstrate a fully integrated system of transit modes in a suburban area;
2. Door-to-door service anywhere in the developed area of the county for nearly a million people;
3. Innovative management by OCTD of both public and private organizations that would be an incentive to provide a high level of service, to keep costs down, to ensure responsiveness to public needs, and to develop new techniques;
4. New marketing strategies for increasing ridership of low-mobility groups and also for penetrating the automobile-commuter market;

5. More efficient use of existing rights-of-way and equipment to minimize costs and optimize present-day technologies;
6. Transfer-of-technology capabilities to develop dial-a-ride as a modular system that can be implemented in communities in need of transit services or new approaches to management and control; and
7. Mitigation of ecological and social problems, including pollution, energy consumption, transportation network encroachment on land use, and mobility of the carless.

The foundation of the system includes 4 basic elements:

1. Community dial-a-ride services provided by 180 vehicles operating from 12 to 15 dial-a-ride nodes and connecting with scheduled buses;
2. Intercommunity scheduled buses operating on both arterials and freeways, the latter as express buses;
3. Airport, heliport, commuter railroad, and other transportation modes integrated via the dial-a-ride; and
4. A computerized information and control system to provide real-time optimization, to automate dispatching so as to minimize passenger inconvenience, and to provide management information for operations analyses and decision making.

The detailed planning for system expansion is to be completed by spring of 1974, and the first dial-a-ride modules are to be operational in mid-1974. If adequate federal support is achieved, the complete system could be functional by mid-1976.

In the long range, dial-a-ride can evolve as need and technology increase. The possibility of the system evolving to dual-mode dial-a-ride should be considered. OCTD is studying alternative transit corridors, and sections of the southern California freeway system may be recommended as primary corridors. OCTD is aware of the potential of dual-mode transportation in this respect; it may be a feasible alternative to a conventional rail system.

CONCLUSION

The La Habra project has proved the technical and operational feasibility of the dial-a-ride concept. The site receives numerous visitors, and the experiment has been influential in stimulating dial-a-ride programs in at least 8 other California communities. Much has been copied from the federally funded demonstration project in Haddonfield, New Jersey. However, La Habra has provided a secondary center for the diffusion of information about the dial-a-ride mode.

The public has responded favorably to the system, operating techniques have been developed and refined, and the concept has great potential for continued development of new procedures that will optimize modal efficiency (e.g., automated dispatching). Dial-a-ride can tap a new market previously not reached by conventional public transit. Because of its door-to-door service, dial-a-ride has attracted a new type of transit patron. In fact, the cost-effectiveness of dial-a-ride can be greater than that of fixed-route transit in areas of marginal demand or during off-peak periods where cost per passenger carried is a critical factor.

Dial-a-ride has shown that the system can attract a significant number of serve-passenger trips such as those chauffering children, older people, and others who do not drive. This market is as large as current transit patronage and often 10 times as large in suburban areas (1).

Dial-a-ride can greatly increase the mobility of the transit dependent, including the elderly, the handicapped, and the young, to whom the convenience and the security of door-to-door transportation are important.

Still, with all its advantages, the dial-a-ride mode is not the ultimate answer to the country's transit problems. The dial-a-ride concept is limited by a number of operational and financial constraints. Effectiveness as a rapid transit feeder system is still uncertain.

Dial-a-ride will not reverse the need for deficit financing of public transit systems. The high costs of operation correspond to the high level of service provided. A break-even philosophy would only require fares so high that ridership would decline to a point where the system could no longer be financially justified.

An ideal dial-a-ride vehicle is not yet available. Most existing minibus vehicles are a conglomeration of parts, poorly thrown together, and usually unreliable. Until private enterprise recognizes a real market potential for such a small vehicle, vehicle design and reliability will remain a problem.

Labor rates are the main factor in high operating costs. Dial-a-ride is labor intensive in terms of passengers carried per vehicle-hour. Limitations on vehicle productivity and provision of an acceptable level of service make labor costs, which are continually rising, a factor more critical in the cost of operating a dial-a-ride system than in the cost of operating a fixed-route system.

These problems are common in one way or another, however, to virtually any kind of public transportation. Viewed as only one part of an overall integrated transit system of buses and fixed-route transit, dial-a-ride has its place. It provides the convenience and security of door-to-door service that both young and old appreciate.

REFERENCES

1. Crain, J. L. Status Report on the Dial-A-Bus Transit Mode. Paper presented at the Transportation and Public Works Conference, San Diego, March 22-24, 1973.
2. Fielding, G. J., and Shilling, D. R. Dial-A-Ride: An Opportunity for Managerial Control. TRB Spec. Rept. 147, pp. 69-77, 1974.
3. Zobrak, M. J., and Medville, D. The Haddonfield Dial-A-Ride Experiment: Interim Results. Paper presented at International Conference on Transportation Research, Bruges, Belgium, June 1973.
4. Wilson, N. H. M., et al. Scheduling Algorithms for a Dial-A-Ride System. M.I.T., Cambridge, 1971.
5. Demand Activated Road Transit (DART): Performance and Demand Estimation Analysis. Institute of Public Administration, Washington, D.C., 1969.

DUNLOP S-TYPE SPEEDAWAY: A HIGH-SPEED PASSENGER CONVEYOR

J. K. Todd, Dunlop-Angus Belting Group, Dunlop, Ltd.

This paper shows that there is an obvious need for a continuous system to transport large numbers of passengers at speeds as high as 10 mph for distances as great as 1 mile. The disadvantages of various systems that have been proposed are discussed, and the operation of the S-Type Speedaway and the ways in which this design overcomes the disadvantages of earlier proposals are described. The development of the system began in 1968, and a full-scale prototype has been operating since 1971. Aspects of the design and the particular attention paid to passenger acceptability and safety are discussed. The point-to-point S-Type Speedaway has a short constant-speed entry section after which the passenger is accelerated smoothly in a curved path until the main high-speed section is reached. The speed of this section is as much as 5 times the entry speed. At the end of the high-speed section, the passenger is decelerated to step off the system at low speed. Capacity of a single unit is 10,000 people per hour. Applications and installations for high-speed moving walkways are described, and the paper concludes with a look at possible future developments of the system.

•THE BASIC problems of moving people over relatively long distances by road, by rail, and by air have to some extent been solved, although undoubtedly future developments will reduce journey times and improve passenger comfort and safety. One of the major problems with most cities is the congestion caused by vehicles, and many suggestions for improved transportation systems are being considered throughout the world. The problem of moving large numbers of people over relatively short distances has, however, not been given so much attention, possibly because until recently no satisfactory system has been available.

Figure 1 shows that there are 2 important gaps left to be filled by new forms of transportation. The top line shows the total demand for transportation plotted against distance to be traveled. The heavy curves show the demand for the 3 main forms of existing transportation, and the distances for which each is most suitable. The curves are also a measure of the degree of satisfaction with the chosen form of transport; at the peak of each curve, virtually 100 percent of the passengers will be satisfied with that particular form of transport for the distances indicated at the peak. For distances much smaller or much greater than this, only a small percentage of passengers will be satisfied with that particular method of travel.

The total number of potential passengers for a new transport system in the first gap is, of course, much greater than that for a new transport system in the second gap. In addition the development of high-speed trains is now extending the middle curve to the right, and the development of helicopters and STOL aircraft could extend the right curve to the left so that the second gap is rapidly being bridged. The first gap, therefore, indicates that there is a large potential market for a high-speed moving walkway like the Dunlop S-Type Speedaway.

Although new forms of transportation may extend the middle curve slightly to the left, human nature is not likely to change much to extend the pedestrian curve to the right. Thus, not only do high-speed moving walkways have a great potential demand but, positioned as they are to the left of center of the first gap, they are unlikely to be challenged by other forms of transportation.

Figure 1. Transport gaps.

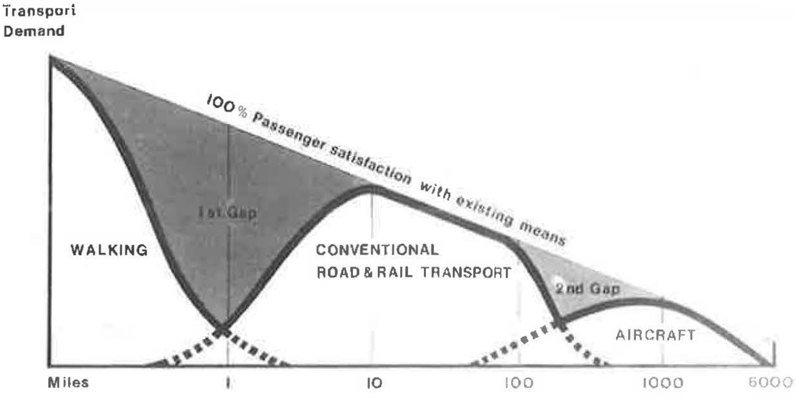
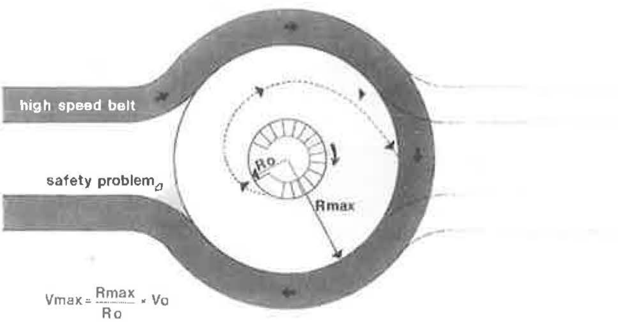


Figure 2. Moving sidewalks at Paris Exhibition.

Figure 3. Circular loading disk.



The Dunlop-Angus Belting Group has been involved for a number of years in the manufacture of conventional passenger conveyors and has more than 100 installations throughout the world. However, the speed of the conventional moving pavement is the same all along its length, and this speed is governed by the speed at the entry. This is normally kept to about half normal walking speed so that the elderly and the non-habitual users do not have any difficulty in stepping onto the moving belt. The low speed, however, can be frustrating to many people, particularly where installations of more than 100 m are involved. Therefore, Dunlop developed the S-Type Speed-away, which allows passengers to step onto the system with the same speed at entry as that of the conventional moving pavement, but then for the main part of their journey accelerates them safely and smoothly to speeds 5 times greater than the entry speed. They are decelerated automatically before stepping off in the normal manner.

HISTORY OF ALTERNATIVE SYSTEMS

Parallel Belts

Before the turn of this century, inventors saw the need for and have made attempts to design high-speed passenger conveyors. Among the earliest of these was a system exhibited at the Paris Exposition in 1900. This consisted of 2 rows of parallel platforms (Fig. 2) onto which the passengers side-stepped. The speed of the fastest pavement was limited, and the system had to be arranged in a closed loop to be endless and avoid the problem of a barrier at the ends. Posts were provided on the platform to aid the side-stepping maneuver.

The problem with a parallel-belt system is that the speed differential between the different rows of belts must be limited to about 1½ mph and certainly no more than 2 mph for it to be acceptable to most people. Therefore, to achieve a maximum speed of, say, 10 mph requires a minimum of 5 parallel belts. The cost of the system itself and of land acquisition for such a wide installation rules it out in present-day cities.

Loading Disk

A second system that has been proposed for loading passengers onto a high-speed belt is the circular loading disk. In this system (Fig. 3), the passengers enter at the center of the washer-shaped disk, where they board by side-stepping onto the inner diameter, which is moving at about 2 mph. They then walk out across the disk, which is rotating at constant velocity, to the outer diameter, where the peripheral speed has increased in proportion to the radius. At the periphery they transfer to the moving belt.

Passengers experience the unpleasant effects of the Coriolis force as they walk out across the revolving disk and, although the system has been used as a means of loading never-stop railways, the peripheral speed at the outside of the disk has been limited to about 4 mph. This is thought to be about the limit. An increase in speed from 2 to 10 mph is almost certainly quite unacceptable for the comfort and safety of the passengers. In addition, such a system requires unacceptably large stations and has a severe safety problem at the point where the high-speed belt leaves the disk. At this point there must be a gap, and this must be covered by a stationery post or surface of some kind. If a passenger has not completed a transfer before reaching this point, a serious accident could occur.

In-Line System

The third general category, and perhaps the one that has received most attention from inventors through the years, is the straight-line acceleration type of system. In theory, if not in practice, this can be achieved in 2 different ways. The first of these is shown in Figure 4 and is based on the well-known "lazy tongs" mechanism. The links are compressed in the slow-speed zone and stretched out in the high-speed zone. When the links are stretched out, large gaps make the mechanism unacceptable and it has therefore to be covered with some elastic material that will both support the weight of the passengers and extend sufficiently. To achieve a speed ratio of 1:5 (i.e.,

Figure 4. Lazy-tongs accelerator.

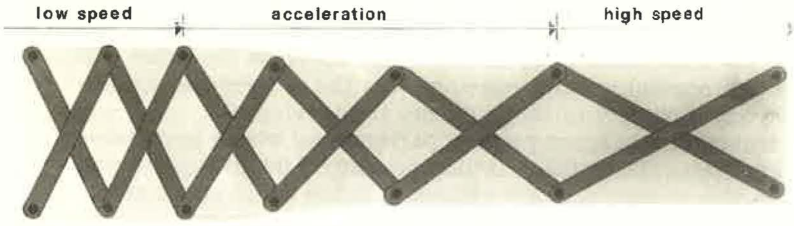


Figure 5. In-line accelerator.

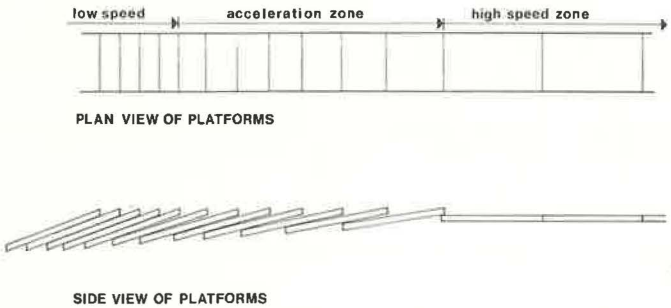
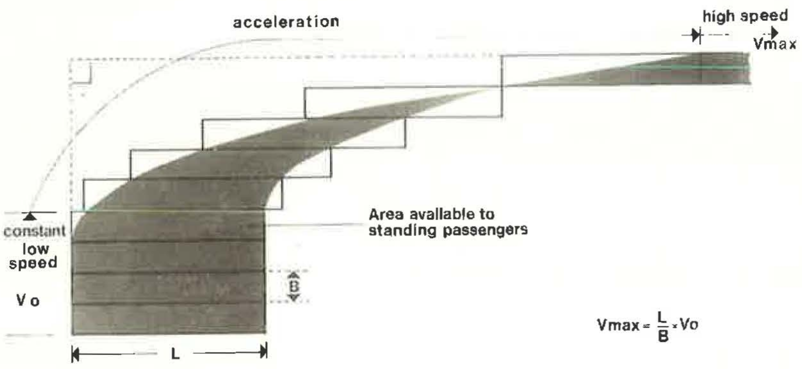


Figure 6. Original Battelle accelerator.



from 2 to 10 mph) requires a material with an extension ratio of 1:5, and this ratio is well beyond present-day materials. The second basic method of achieving in-line acceleration is to have a system of plates that slide over one another as shown in Figure 5. This presents a severe safety problem as the plates or "scales" slide over one another and, in addition, imparts a feeling of discomfort as the plates lift or tilt. Despite every possible safety precaution that is taken in the design of transportation systems, no system has proved to be 100 percent safe.

A high percentage of the few accidents that do occur on conventional moving pavements or escalators occur at the exit comb plate, which each passenger has to step over once in every journey. In an in-line accelerator with plates that are sliding into or over one another, the passenger is, in effect, continuously standing on a comb plate that moves with him for the duration of the deceleration, and the chances of an accident must be increased many times.

Another much less obvious but perhaps even more important safety problem with these in-line acceleration systems is that the surface area available to the passengers decreases in the deceleration zone in comparison to that available in the high-speed zone. As standing passengers are accelerated, the distance between them increases as more of each plate becomes uncovered; and in the high-speed zone there is nothing to prevent passengers from walking along the platforms and bunching together. In the deceleration zone the plates again slide over one another, drastically reducing the area available to the bunched-together passengers. On a crowded conveyor this could result in a serious accident.

Ideal System

From experience gained through the years, we should be able to set out the basic requirements for an ideal high-speed passenger conveyor to meet present-day needs.

1. The entry and exit speeds should be the same as those of conventional low-speed passenger conveyors and escalators, i.e., not greater than about 2 mph.
2. The high-speed section should travel at speeds of about 10 mph; i.e., the unit should have a speed ratio of 1:5, although anything with a speed ratio of 1:3.5 or higher would be useful.
3. The unit must be as safe as current low-speed passenger conveyors and must be acceptable to those who may use it.
4. Acceleration and deceleration levels must be acceptable.
5. The surface areas available to passengers should remain constant and, in particular, should not decrease in the deceleration zone.
6. The system should take up the minimum amount of room both at the ends and along its high-speed length.
7. A moving handrail should be provided.

DUNLOP S-TYPE SPEEDAWAY

The velocity of water flowing through a channel of constant depth is directly proportional to the width of the channel. If the beginning of the channel is wide, the velocity of the water is low; if the width is gradually reduced, the velocity has to increase to get the same quantity of water through. The surface of the water, therefore, represents the ideal acceleration zone for a high-speed passenger conveyor. The basis of most high-speed passenger conveyors is an attempt to produce a solid mechanical equivalent of the surface of the water.

To understand the operation of the Dunlop S-Type Speedaway, one should consider a series of rectangular platforms (Fig. 6) that start moving in a direction parallel to their short sides and then slide across one another so that their centers move around a curve, resulting in the platforms moving end to end at right angles to their original direction. The speed ratio of such a system is the ratio of the breadth to the length of the platforms. Figure 6 shows that the platforms reach an intermediate position where they are corner to corner before they can slide end to end and that unacceptable gaps appear in the surface of the system around this point. The patented Dunlop S-Type

Speedaway used a modification of this system. The platforms always remain parallel, but the change in angle between the initial direction and the final direction is restricted to less than 90 deg. This results in a system that presents to the passenger a continuous surface, without gaps, the speed ratio being determined by the angle of the platforms to the sides of the high-speed transportation zone (Fig. 7). The maximum speed ratio between entry and high-speed zone currently proposed is approximately 1:5, although the theoretical ratio that can be achieved with this arrangement is well beyond this.

Parallel sides are provided, and the width in the high-speed zone is reduced by the removal of a triangular portion from each end of the platforms. The complete S-Type Speedaway is shown in Figure 8. A single unit has a capacity of 10,000 people per hour.

Development of System

The original concept for the speedaway system was proposed by the Battelle Research Centre in Geneva. The Dunlop-Angus Belting Group sponsored a design feasibility study in November 1968 and jointly sponsored a detailed design study with the National Research Development Corporation, an agency of the U.K. Government. This was followed by the decision to build a full-scale prototype unit in Geneva and at the same time to build a number of rigs to test a number of the vital components before the prototype unit was completely assembled.

The prototype unit (Fig. 9) was commissioned in March 1971. It consists of a short constant-speed entry section, curved acceleration section, a relatively short high-speed section, and a corresponding curved deceleration zone and exit zone. The total length is approximately 33 m. The speed ratio between the entrance speed and the high-speed zone is 1:3.5 or, in other words, passengers travel $3\frac{1}{2}$ times faster than they do on a conventional passenger conveyor.

The unit proved the engineering feasibility of the design and has been run for many hundreds of hours. The engineering is entirely conventional, and no exotic materials are used. Tolerances are within normal engineering limits for escalators and moving pavements. Besides proving the basic engineering, the unit has been used to test passenger acceptability and safety. Although from the inception we considered that a moving handrail would eventually be necessary, all the initial testing of passenger reaction was conducted without one.

Many hundreds of people have now traveled on the Speedaway in this form and with few exceptions passenger reaction has been enthusiastic, and most passengers have found the Speedaway as easy to use as an escalator. Test passengers included families with young children, people with wheelchairs, and the disabled.

The prototype unit has, as one would expect, highlighted a number of simplifications and modifications in engineering and a number of improvements for the comfort and safety of passengers. All of these features have been incorporated in the design of the commercial unit.

During 1973 the patented moving handrail (Fig. 9) was developed, and one side of the prototype unit has now been fitted with a conventional balustrade, which is curved at entry and exit to follow the line of the edge of the platforms. A moving rubber handrail of conventional appearance is fitted on top of the balustrade. This handrail is divided into a series of constant-speed zones that approximately match the mean speed of the platforms in that zone. Passengers entering the system hold the handrail, which moves at exactly the same speed as the platform on which they stand. As they begin to accelerate they can continue to hold the handrail in the same position, but their hand begins to move back for they are then moving slightly faster than the handrail. Before a passenger's arm position has become uncomfortable, he or she has reached the next section of the handrail and can readily transfer to it. In the high-speed transport zone, the handrail moves at exactly the same speed as the platforms. Care has been taken with the design of the balustrading in the area where the handrails overlap to ensure that there is no safety problem irrespective of the direction of travel of the system.

Figure 7. Speedaway principle.

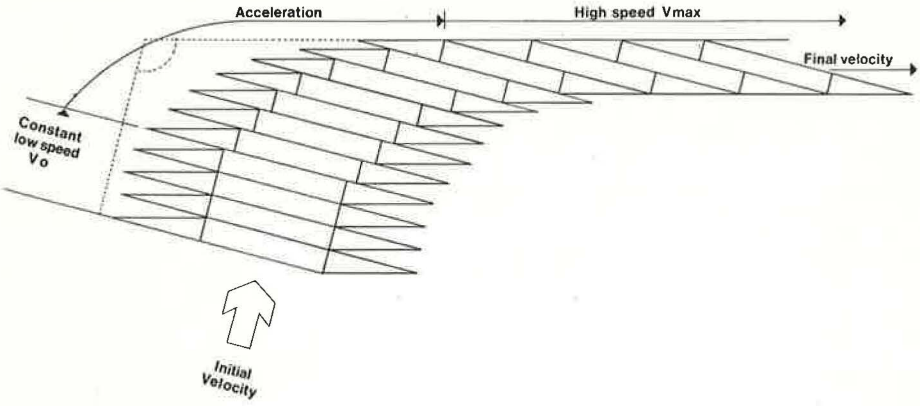


Figure 8. S-Type Speedaway.

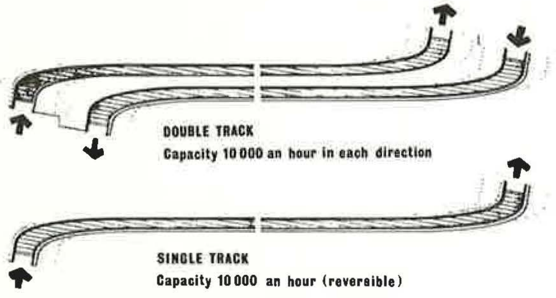


Figure 9. Full-scale prototype unit.

Engineering Details

The platforms themselves are made from aluminium extrusions, which require little machining, and are covered with grooved aluminium tread plates so that they pass through a conventional comb plate at each end of the system. Each platform is connected to its neighbor by 2 sliding members to keep it parallel to, but to allow it to slide relative to, the next platform as it passes through the curved acceleration and deceleration zones. In the relatively long high-speed zone, there is no relative sliding between platforms. The sliding members also allow the platforms to pivot relative to one another in the vertical plane so that they can recycle beneath the passenger surface after they have passed through the comb plate. Each platform is supported and guided by 2 bogies that are free to pivot and that run on circular section rails. The platforms are driven by a friction drive powered by variable-speed electric motors that are positioned along the length of the system and run on the undersides of the platforms. Disk brakes are provided on the driving wheels to provide for emergency stops. Linear electric motors can be used in the variable-speed zones. A simple control system synchronizes the various drives.

APPLICATIONS AND INSTALLATIONS

The Dunlop S-Type Speedaway can be used in any installation where a low-speed moving pavement is used at present. In practice, however, it will normally be used for the longer installations of more than 125 m. In those installations, the low speed of the conventional unit can become extremely frustrating, particularly to those passengers in a hurry. The advantages of the high-speed passenger conveyor are that the passenger never needs to wait for it to arrive because it is a continuous rather than an intermittent transport system and it can handle large numbers of passengers (as many as 10,000 per hour) when this is required.

S-Type Speedaways can be installed singly, in pairs, or 3 or more abreast. The units are reversible, and in multiple installations directions of travel can be altered or units shut down depending on passenger demand. The Speedaway can be installed in an overhead tube, at ground level, or underground. Ground level units are, however, not always acceptable because they prevent access from one side of the system to the other. The obvious application for the Speedaway system is in mass activity centers such as airports, railway and bus stations, shopping centers, pedestrianized streets, and other traffic-free areas.

In airports, Speedaway can be used as a link between terminal buildings, from main terminal buildings to satellite terminals on the apron, and from car parks and other transport facilities to the main terminal building. Passengers can deposit their luggage on the platforms while they ride beside it or they can park luggage trolleys on the Speedaway. Figure 10 shows how the Speedaway might be used as a link between an underground railway station and a nearby surface train or bus station. The applications to pedestrian areas are for transport along pedestrianized streets and as a means of linking those traffic-free areas with transport facilities and car parks. In many instances the cost of the Speedaway system can be largely offset by moving car parks to more remote areas where land is cheaper.

Specific Studies

The Dunlop-Angus Belting Group has carried out, in conjunction with its consultant architects and civil engineers, a number of detailed studies on the application of Speedaway in various parts of the world. These include studies relating to London Bridge and cross-town Manhattan.

During the rush hour each morning some 20,000 people per hour leave London Bridge Station and cross London Bridge for their offices in the city. A similar reverse flow occurs during the evening rush hour. The new London Bridge already has the foundations for a central overhead walkway, and studies have shown that this would be an ideal application for 2 S-Type Speedaways in parallel. In the morning, both units would travel in the same direction to give the required capacity and would be reversed in the

Figure 10. Speedaway underground.

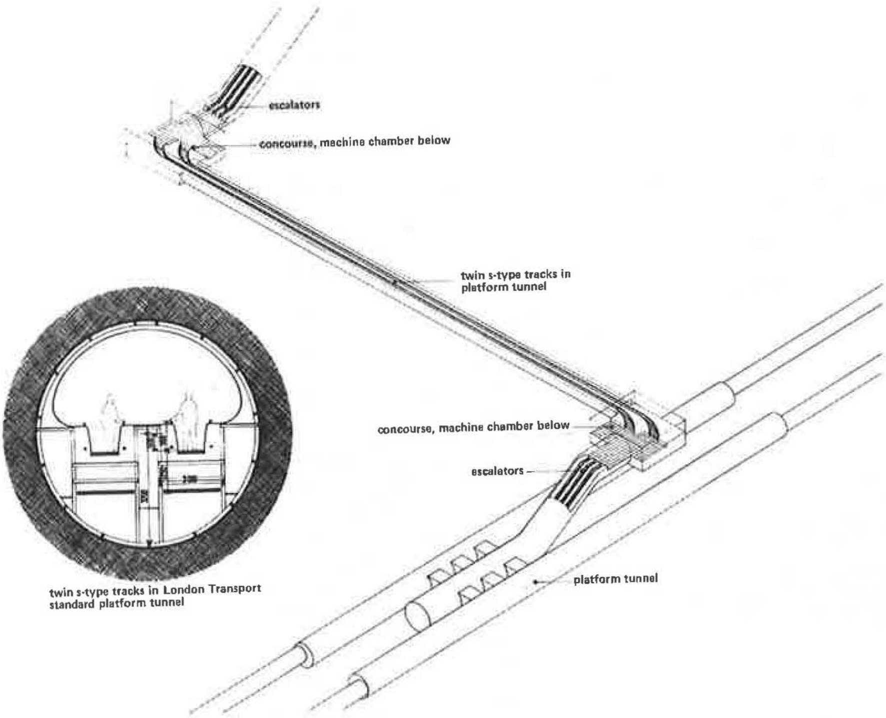


Figure 11. Speedaway overhead.

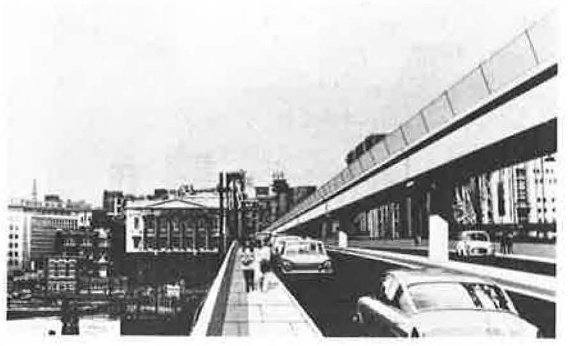


Figure 12. Speedaway at ground level.

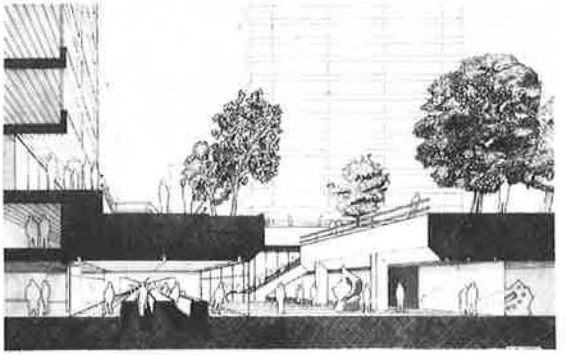


Figure 13. Speedaway below street level.

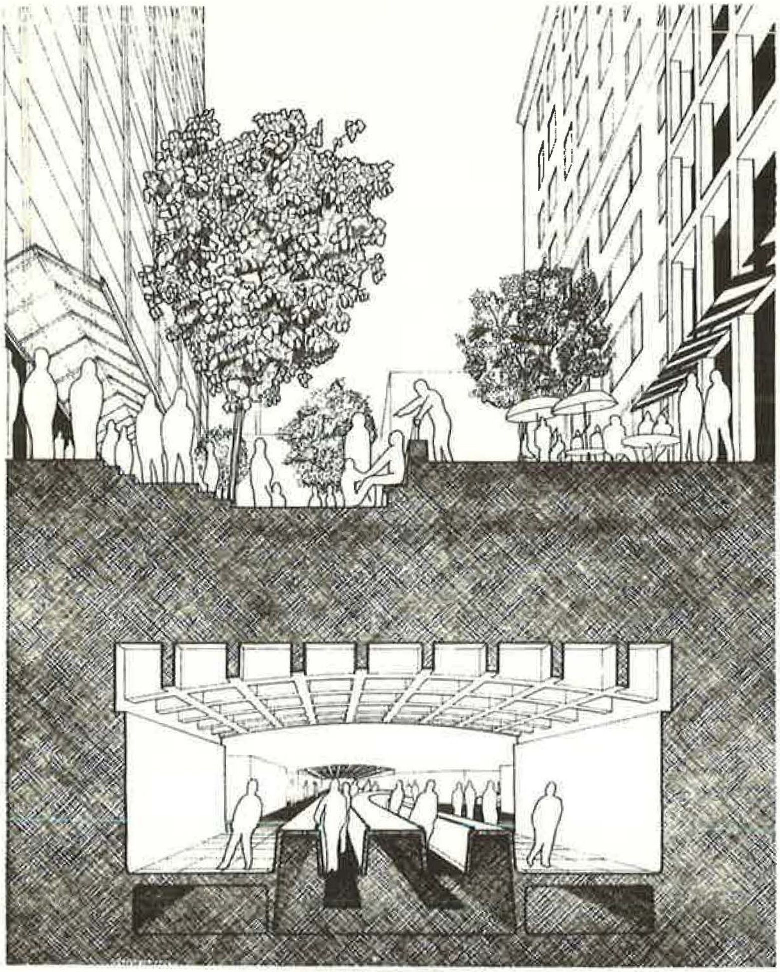
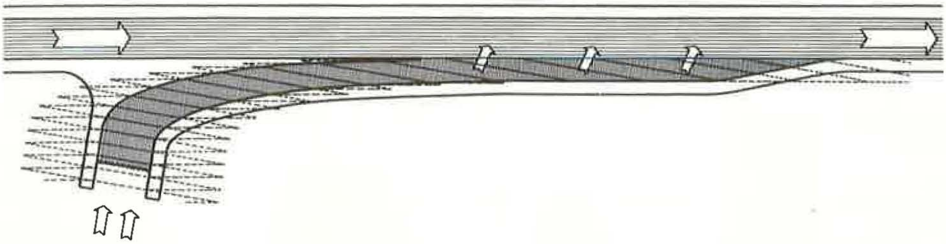


Figure 14. Possible future developments of Speedaway.



evening. During the rest of the day, the units would run in opposite directions. Figure 11 shows what the overhead air-conditioned tube could look like if it were installed on London Bridge.

In New York, Manhattan has good transport facilities from north to south, but east-west connecting links between the blocks are required. A study carried out in this area showed that the Speedaway system below street level could provide the missing links. Figure 12 shows a station below grade in a shopping plaza, and Figure 13 shows the system installed below a vehicular street.

First Public Installation

The first public installation of the Speedaway system might well be in a business area redevelopment in Paris. Dunlop, through its French licensees, has put forward a fully detailed scheme. The authority responsible for the redevelopment of the area has carried out detailed studies on the transportation requirements for the area, and our proposal is based on traffic flow estimates from those studies. When this development is completed it will have office accommodation for 100,000 people, homes for a further 20,000, and shops, restaurants, theatres, hotels, and cinemas. It is served by rail, express metro, and buses; these and the roads and car parks are underground. The main feature of the area is a central pedestrian deck about 1 km in length, and the proposed installation of the Speedaway is in an overhead tube along the center portion of this pedestrian deck.

An S-Type Speedaway has also been designed for a business redevelopment area in Paris. This installation has a length of just over 460 m and a speed ratio between entry and the main transportation zone of 1:4. If the contract specifies Speedaway, the system could be operational in 1976.

FUTURE DEVELOPMENT

The S-Type Speedaway is really a high-speed version of the existing low-speed moving pavements. It can be used for greater distances and with few additional problems for the designer or the passenger. In the future one can foresee further exciting developments in this field. The curved accelerating portion of the S-Type could be used as a means of loading passengers onto a high-speed belt. Figure 14 shows how an intermediate station on a belt system might be arranged. Such a system could be several miles long with intermediate stations at suitable intervals. Technically such a system could be designed almost immediately, but a number of safety problems will need to be overcome before it becomes operational. An ability to move around corners and to surmount inclines can also be developed.

CONCLUSION

For the first time, a high-speed passenger conveyor has been developed. The Dunlop S-Type Speedaway can be used to transport large numbers of passengers safely, efficiently, and without pollution over point-to-point distances of 450 m or greater in a single stage.

SPONSORSHIP OF THIS RECORD

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Charles V. Wootan, Texas A&M University, chairman

TRANSPORTATION SYSTEMS PLANNING AND INNOVATION SECTION
Siegfried M. Breuning, Wayland, Massachusetts, chairman

Committee on New Transportation Systems and Technology
Leon M. Cole, University of Texas at Austin, chairman
J. Edward Anderson, William H. Avery, Robert U. Ayres, George J. Bacalis, Joan B. Barriage, Robert A. Burco, Eugene T. Canty, Michael G. Ferreri, Donn Fichter, William Hamilton, M. D. Harmelink, Clark Henderson, Thomas Lisco, Roger L. Merrill, Harold W. Merritt, Theodore F. Morf, Robert A. Olmsted, C. Kenneth Orski, Daniel Roos, Richard Shackson, Albert J. Sobey, Charles E. Taylor, J. William Vigrass, M. Lucius Walker, Jr.

James A. Scott, Transportation Research Board staff

The organizational units and the chairmen and members are as of December 31, 1973.