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Simulation and Demonstration of Innovative Transit Services

by

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THE DECLINE of urban public transportation in the middle third of this century has been the subject of much concern. Few would deny the necessity for an effective system of public transportation to provide an adequate level of mobility to the young, the aged, the poor, and the handicapped who may not have access to automobiles, or who may choose not to drive. And few doubt the value of rapid transit, of one type or another, in reducing traffic congestion and providing better access to major activity centers.

To help restore the vitality of urban public transportation, National and local governments, industry, universities, and professional societies have been investigating both technological innovations for improved efficiency and performance and also service innovations for greater convenience and amenities in travel. Research by General Motors has included three major categories of travel: local area travel within neighborhoods, communities, suburbs, central cities, and new towns; longer distance urban travel via roadways and rapid transit facilities which constitute metropolitan arterial networks; and circulation within major public places such as central business districts, and large airports.

Candidate systems which may meet these various needs have been identified and classified as a function of the character and scale of metropolitan units (Canty, 1969). Several of the more promising new system candidates included Demand-Responsive Jitney (or Dial-A-Bus) service in local areas (Table 1); Bus Rapid Transit, for arterial travel in lower density metropolitan areas (Table 2); and automated guideway systems within central business districts and airports (Table 3). Dual Mode Transit facilities would provide for integration of the collection, arterial and downtown distribution functions. That is, a Dual Mode Transit Vehicle could be operated as a Demand-Responsive Jitney in local areas, on a guideway to provide bus rapid transit, and staying on the guideway as a circulation system in downtown areas. These were among the modes investigated by General Motors in its New Systems Implementation Study for the U.S. Department of Housing and Urban Development (Canty, et al., 1968), and have been the subject of much subsequent research, analysis, and simulation by General Motors and other organizations.

It is one of the purposes of this paper to illustrate how the process of technological innovation and service improvement in urban transportation may be aided by the application of modern digital computers and operations research methods in comprehensive simulations of proposed new systems at an early point in the development cycle; and by the use of consumer attitudinal surveys and multivariate statistical methods to estimate potential user acceptance prior to the commitment of major technical and financial resources to product development. From the experience of General Motors Research Laboratories in the study of a wide range of new transportation systems, examples are given of innovative bus services.

DEMAND-RESPONSIVE JITNEY STUDIES

Demand-responsive transportation using small motor coaches has variously been called Demand-Responsive Jitney, Dial-A-Bus, Dial-A-Ride, Computer-Aided Routing System, DART, and other names. The concept, which involves flexible routing and scheduling of vehicles in response to individual traveler's needs, with highly methodized and sometimes computer-aided dispatching procedures (Figure 1), is only a decade old, having first been reported and discussed in a 1964 symposium at Stanford Research Institute (Jones, 1964). Since that time, the concept has been extensively studied and a number of operational system demonstrations are now in progress in various cities, principally within the United States and Canada.

The General Motors Research Laboratories efforts with regard to Demand-Responsive Jitney service include attitudinal surveys, system design, digital computer simulations of the system matched to the needs of a real city, market research and economic analysis.

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Table 1. MODES FOR LOCAL AREA TRAVEL

URBAN SCALE	INTRA-NEIGHBORHOOD TRAVEL	INTRA-COMMUNITY TRAVEL	INTRA-TOWN TRAVEL
HIGHER DENSITY (5,000 to 10,000 inhabitants per square mile)	•Pedestrian movement •Bicycles, motorcycles	•Pedestrian movement •Bicycles, motorcycles •Automobiles •Fixed-Route Public Transit (e.g., surface bus route)	•Automobiles •Bicycles, motorcycles •Fixed-Route Surface Transit •Demand Jitney Service •Fixed Guideway Transit Service •Rapid Transit Bus (collection/distribution)
LOWER DENSITY (1,500 to 2,500 inhabitants per square mile)	•Pedestrian movement •Bicycles, motorcycles •Automobiles •Elementary School Buses	•Bicycles, motorcycles •Automobiles •Secondary School Buses •Demand Jitney Service	•Bicycles, motorcycles •Automobiles •Demand Jitney Service •Rapid Transit Bus (collection/distribution, demand routed)

Table 2. MODES FOR ARTERIAL NETWORKS

	METROPOLITAN SCALE			
	SMALL		LARGE	
	COMMUNITY SCALE			
	HIGH DENSITY	LOW DENSITY	HIGH DENSITY	LOW DENSITY
PUBLIC TRANSIT	•Rail Rapid Transit •Guideway Bus	•Bus Rapid Transit (Metro-Mode)	•Rail Rapid Transit	•Bus Rapid Transit •Dual Mode Transit
PRIVATE VEHICLES	•Improved Freeways		•Improved Freeways •Dual Mode Systems	
INTEGRATED MODES (PUBLIC & PRIVATE)	(Integrated Mode Not Required)	•Bus Rapid Transit Via Freeway Lanes and Median Strips	•Dual Mode Systems (with captive transit and freight vehicles)	•Dual Mode Systems (with captive and dual mode transit and freight vehicles)

Table 3. MODES FOR CIRCULATION WITHIN MAJOR PUBLIC PLACES

PLACE SCALE	TOWN CENTERS AND SMALL CBDs	CBDs OF MAJOR METROPOLITAN AREAS	MAJOR AIRPORTS	LARGE CAMPUSES
SMALL (High Density)	None	•Continuous Systems; •People Mover Shuttles	•Continuous Systems	•Continuous Systems
LARGE (Low Density)	•Improved Pedestrian Ways	•Shuttle Buses; •Personal Rapid Transit; •Interlaced People Mover Shuttles	•People Movers; •Shuttle Systems	•Buses; •"Elephant Trains"

Source: Canty [1969]

Since the basic philosophy underlying the Demand-Responsive concept is to provide service which meets user needs and wishes, our work began with an investigation into the relative importances that various people place upon thirty-two selected attributes of transit service. These attributes ranged from the usual fare level and travel time factors, through various comfort and convenience attributes, and included a number of sociological and psychological aspects relevant to such service.

The results of a total random sample of 786 home-interview survey respondents are shown in Figure 2, together with the results for the subsample of elderly residents. Other subsamples investigated included teenagers, working wives, the poor, and the affluent. For detailed data, see Gustafson, et al. [1971] and Golob, et al. [1972].

An additional survey involving 817 home interviews was concerned with preferences with regard to a variety of subsystem design features, for example:

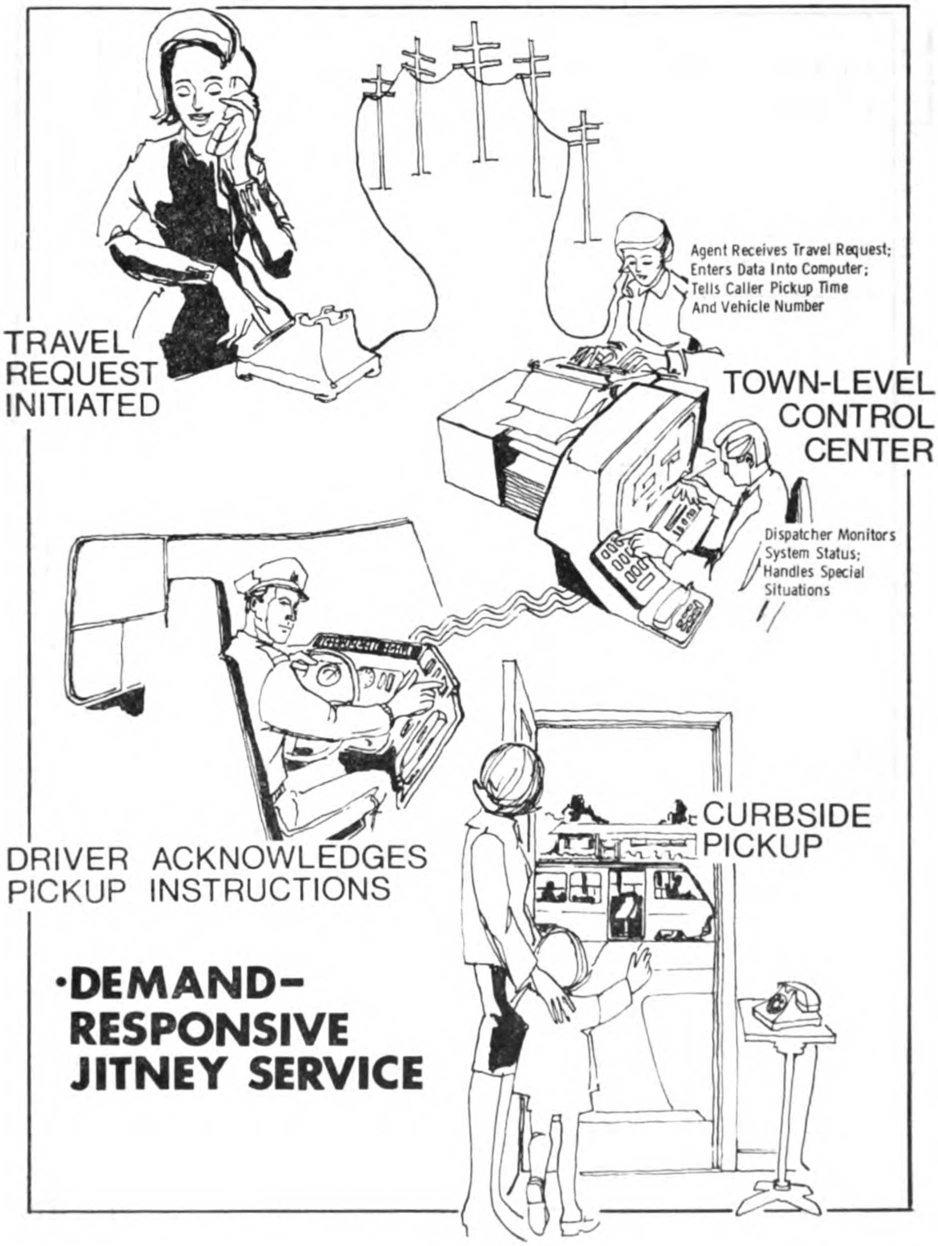


Figure 1.

seating arrangements and fare collection methods. The various survey results were very instructive. We found, for example, that the public's attitudes as to what was important and what not important in regard to demand-responsive transit was somewhat at variance with what earlier system designers thought was important. The knowledge gained about the traveler's value system and his design preferences, from the approximately 1600 home interviews, was applied to our design for the Demand-Responsive Jitney System and used as

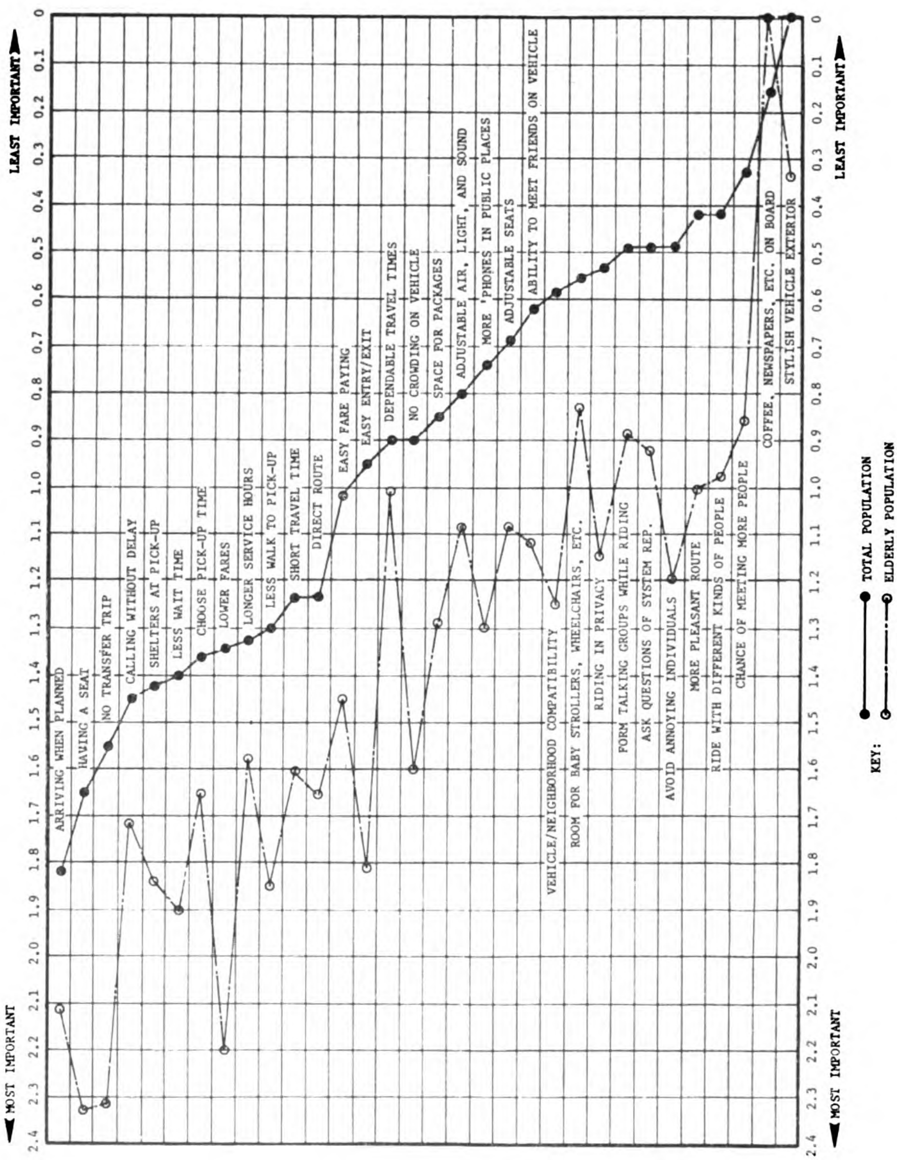


Figure 2. Relative Importance Ratings of Demand-Responsive Jitney System Attributes

the basis for computer simulation of system operations and for the economic and market analyses (Bauer, 1970).

System operation was then simulated on a large scale digital computer (IBM 360/67). Detailed origin and destination data for a real city of about 200,000 population was used, so as to simulate telephone calls from individual addresses. Time and motion studies, involving vehicle operations (without passengers) on local streets and at various times of day, yielded travel time and dwell time data for use in the modeling. The simulation was monitored and controlled by Reactive Graphic methods utilizing an IBM 2250 console. A photograph of a cathode ray tube display, which provides a plan view of the projected itineraries of several Demand-Responsive Jitney vehicles, is provided as Figure 3. The simulation is described in Howson, et al. [1970] and Highway Research Record No. 318 [1971].

It is felt that the detailed event-ordered computer simulation was suf-

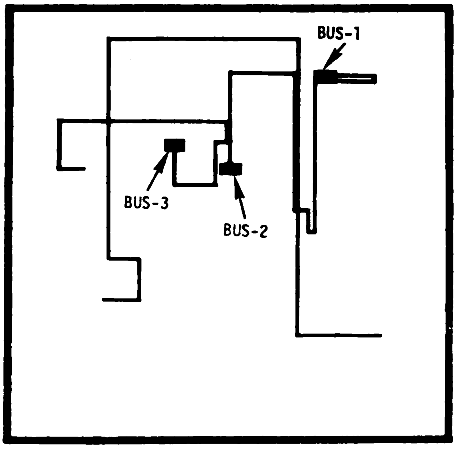


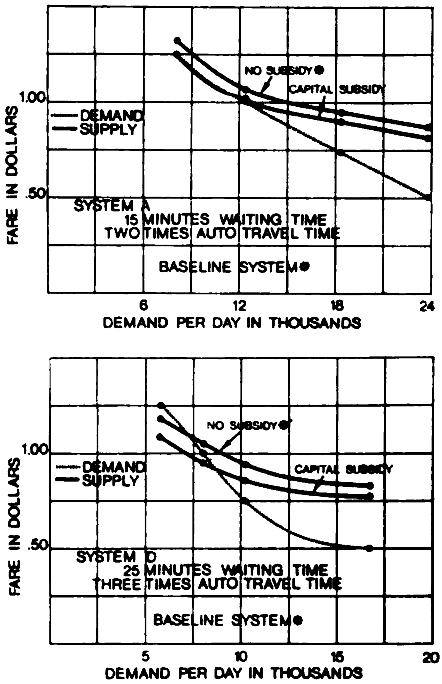
Figure 3. Reactive Graphic Display, Vehicle Tours, Demand-Responsive Jitney Simulation

ficiently detailed and realistic to yield valid estimates of system performance, and to provide a basis for sizing and cost estimation (i.e., supply functions for economic analysis). The performance and cost estimates were combined with the results of a market research study (which yielded demand functions) in a general economic feasibility study of the Demand-Responsive Jitney System. Example results are given in Figure 4; more detailed results are provided in Golob and Gustafson (1972), including the effects of alternative driver wage rates, bond interest rates, etc.

The ability to perform the detailed computer simulation of the Demand-Responsive Jitney service is clear evidence of the system's technical feasibility. While the economic study results are directly applicable only to the case study community, the pattern of interplay between levels of service, fare levels, ridership, and possible operating cost subsidies is clear.

Several demand-responsive systems are now in operation or being demonstrated, primarily in North America. Technical descriptions and operational results have been reported in a series of technical conferences under the auspices of the New Transportation Systems and Technology Committee of the Highway Research Board, U.S. National Academy of Sciences, and/or by Professor D. Roos of the Massachusetts Institute of Technology. See HRB Special Report 124 (1971), Roos (1972), and HRB Special Report 136 (1973).

While the operating experience from these various service demonstrations varies from city to city, Roos [1972] has provided a comparison of the various systems. His findings are generally con-



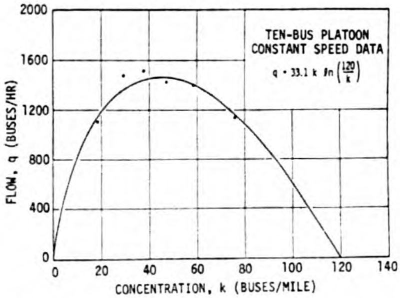
Source: Golob and Gustafson [1972]

Figure 4. Supply and Demand Functions, Two Examples, Demand-Responsive Jitney Economic Analysis

sistent with the results of the General Motors Demand-Responsive Jitney Case Study with regard to: vehicle design requirements and customer preferences; levels of fare and allowable service delays which are acceptable to the public; system productivity with regard to utilization of drivers and vehicles; and operating costs. We are looking forward to further results from these service demonstrations and from the computerized dispatching service which is under test in Haddonfield, New Jersey, under the sponsorship of the U.S. Urban Mass Transportation Administration. This data will be used to further validate the effectiveness and value of computer simulations and public attitudinal surveys in the early evaluation of proposed new systems of urban transportation.

BUS RAPID TRANSIT STUDIES

Larger metropolitan areas require rapid transit facilities for arterial travel: i.e., conventional commuting from outlying suburban areas to major activity centers and other locations in the central city, so-called reverse commuting between central city homes and suburban job opportunities and, to a lesser extent, transportation in crosstown corridors.



Source: Rothery, et al, [1964]

Figure 5.

While rapid transit is thought of by many people as synonomous with Rail Rapid Transit, in fact the principal attribute of rapid transit: speed, derives from the provision of an exclusive grade-separated right-of-way rather from specific propulsion, guidance, or suspension technology. Thus, there are other viable forms of rapid transit with their own unique characteristics including Bus Rapid Transit, wherein motor coaches have either an exclusive or preferred access to a separated roadway or a designated lane on a shared roadway (GMC, 1964).

The first experimental and analytical work on Bus Rapid Transit was accomplished in the early 1960's, by Robert Herman and his colleagues, and was an outgrowth of related work on the theory of traffic flow. As shown in Figure 5, optimum flow (i.e., yielding maximum capacity) was approximately 1450 buses per hour, and occurred at a speed of 53 kilometers per hour (km/h) (or, 33 miles per hour) in exclusive use of a single lane of an expressway type facility.

For motor coaches with 50 or more passenger seats, the equivalent maximum capacity of an exclusive bus lane is thus in excess of 72,000 seated passengers per hour. At a speed in the order of 90 km/h, maximum capacities were in the order of 1100 vehicles per lane per hour and thus 55,000 seated passengers per hour. Such capacities are in excess of the maximum peak hour flows forecasted by transportation planners in most urban transit corridors.

For example, in a cooperative study with the Southeastern Wisconsin Regional Planning Commission, it was shown that the potential of Bus Rapid Transit exceeded the projected capacity requirements for the most heavily traveled transit corridor in the Milwaukee area, and that the Bus Rapid Transit system would offer a number of service advantages relative to rail rapid transit as well as requiring only about one-half the capital investment (GMC, 1967). A subsequent case study was made of Bus Rapid Transit in the most prominent transit corridor of the Detroit metropolitan area, further defining the design and performance characteristics of this new system concept (Canty et al., 1968). Application to a wider range of cities was investigated by Wilbur Smith and Associates under commission from the Automobile Manufacturers Association (AMA, 1970).

The concept of Bus Rapid Transit has been slowly coming into favor. Although a large number of express bus operations in mixed traffic on freeways have been in operation for several years, it is only over the last couple of years that exclusive bus lanes have been used (Morin, 1972).

One service demonstration sponsored by the U.S. Department of Transportation is the so-called Shirley Highway project on the outskirts of the city of Washington [Echols, 1971]. As shown in Figure 6, this involves the use of two center lanes of a freeway that were originally designed as reversible lanes for conventional freeway traffic. The freeway construction is not yet complete and the resultant detours and partly temporary pavement have resulted in a limitation on bus speed to about 65 km/h. Nevertheless, the time saving in peak traffic periods is approximately 13 minutes. This has made the service very popular with commuters and as a result, there has been an increase of 350% in ridership on the bus lines using the exclusive busway (Figure 7). In fact, the number of passengers carried on the exclusive bus lane during the peak hour already exceeds the total number of occupants of the automobiles using the three conventional freeway lanes in that direction (NVTC, 1973).

Another very important experiment sponsored by the U.S. Department of Transportation has been that conducted on an exclusive lane on the New Jersey

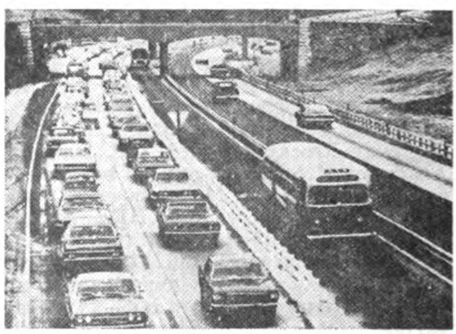
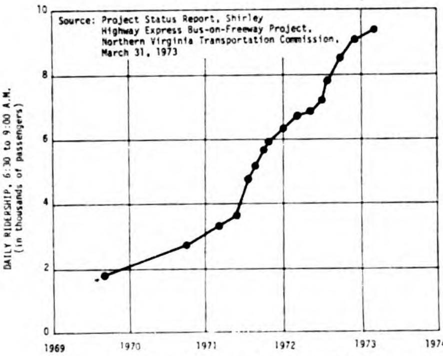


FIGURE 6

Shirley Highway Express Bus Project



RIDERSHIP TREND, SHIRLEY HIGHWAY EXPRESS BUS

Figure 7.

approach to the Lincoln Tunnel [PONYA, 1967]. As shown in Figure 8, this involves the expropriation of one outbound lane for use by inbound buses in the morning peak period. A summary of the impact of the exclusive bus lane is given in Exhibit 1 (UMTA, 1972). Note that the capacity of the bus lane is expected to be substantially above 800 vehicles per hour, as was predicted by the Proving Ground experiments.

The first facility to be designed and constructed from the start as an exclusive busway is on a former railroad right-of-way in the median strip of or paralleling the San Bernardino Freeway east of the city of Los Angeles. Operations began this year, and while initial results appear to be favorable, little technical information is yet available. Similar busways are planned for Atlanta, Pittsburgh, and other cities. These projects should be a valuable source of information on Bus Rapid Transit system performance, cost, and passenger acceptance.

Summary of Results:
Lincoln Tunnel (I-495)
Experimental Bus Lane

Bus time on I-495 was reduced an average of 44 percent. Savings average eight minutes for the entire peak period, ten minutes during the hour of greatest congestion and a half hour or more during abnormal conditions.

The traffic carrying capacity of the six lanes of I-495 has increased. Inbound vehicle flow increased by 40 percent during the a.m. peak with no adverse affect on the outbound flow. Eastbound truck and automobile speeds on I-495 increased.

The bus lane handles ten times the number of people carried in any of the three regular eastbound lanes and at a much higher level of service.

Data collected between January and May, 1971 indicate a variation in bus volumes from a low of 724 per peak period to a high of 852. The highest five minute count was 68 buses which translates into an **hourly rate** of 817 buses. Analytical studies based on surveys indicate that the capacity of the lane is substantially higher than 800 buses per hour.

Auto occupancy in the eastbound Lincoln Tunnel declined from 1.60 to 1.54 percent between January and May, 1971.

Use of the Lincoln Tunnel park-ride lot before 9 a.m. increased ten percent in 1971.

The time **all vehicles** spent on I-495 decreased by 23 percent.

The bus lane did not adversely affect unloading operations at the Port Authority Bus Terminal.

Seventy-five percent of the bus drivers felt safer on the exclusive lane. Operating police felt bus lane safety was adequate and observed little major change in accidents on I-495.

Bus ridership was not expected to increase greatly since about 85 percent of the person trips on I-495 during the a.m. peak period were by bus before the exclusive lane was opened. However surveys indicate that about 2,300 new riders (six percent increase) were attracted to buses by May, 1971.

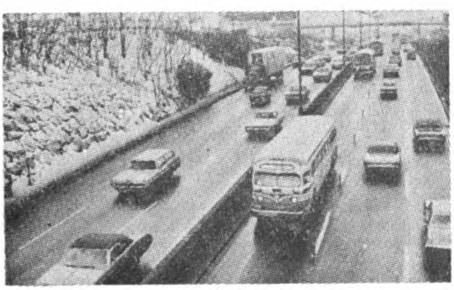


FIGURE 8
Lincoln Tunnel Exclusive Bus Lane

EXHIBIT I

[Source: U.S. Department of Transportation, Urban Mass Transportation Administration Notice No. 4, September 11, 1972]

DOWNTOWN DISTRIBUTION

It is desirable to complement the high speed and high capacity arterial performance capabilities of Bus Rapid Transit with suitable provisions for passenger service within central business districts and other major activity centers. Two approaches are possible: (1) to route the buses into a high capacity central terminal such as the Port Authority West Side Bus Terminal adjacent

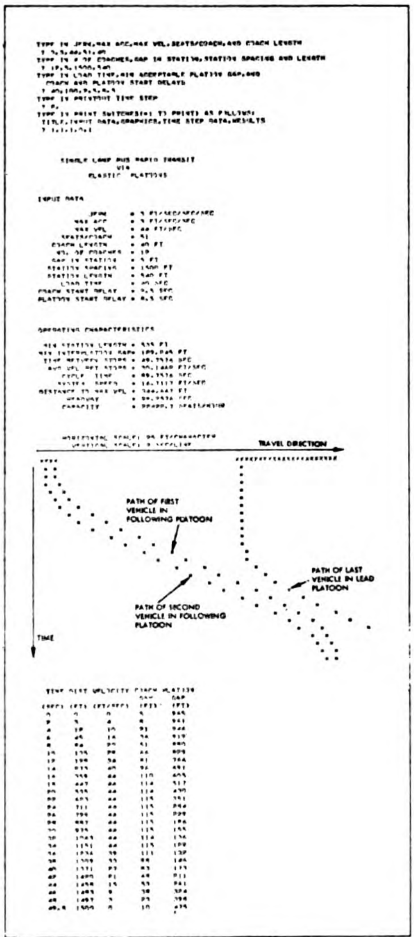


Figure 9. Single Lane Bus Platoon - Linear Station Computer Program Printout

Source: Scheel and Foote [1968]

to the Lincoln Tunnel, from which point passengers use other means of transit or walk to their destinations; or (2) to provide for distribution of passengers by routing of buses through the downtown area, making a number of stops therein. For the latter situation, the buses may remain on a separated busway (either elevated or in a subway) or may use dedicated lanes on surface streets.

The second cycle of Bus Rapid Transit experiments was concerned with the dynamics of vehicles traveling on an exclusive busway and making on-line station stops. Per the conventional wisdom, the maximum capacity under such conditions was assumed to be in the order of 120 buses per lane per hour (essentially, the reciprocal of the vehicle dwell time at a stop, if assumed to be 30 seconds). However, a platooning concept was developed by General Motors Research Laboratories wherein several vehicles, each under [illegible] driver control, would proceed from station to station as a group, in single file. It was felt that significant increases in capacity would result.

Theoretical analyses were made from which it was concluded that for nominal values of platoon length, vehicle acceleration, cruise speed, station dwell time, driver reaction time, etc., capacities in the order of 435 vehicles per hour, or 22,400 seats per hour were realizable. These results were sufficiently encouraging to warrant computerizations of the analysis process to facilitate simulation studies of system speed and capacity as a function of design variations. An example "BUSRAP" computer simulation program print-out is shown in Figure 9. The BUSRAP program was used to generate parametric analyses, including capacity functions as shown in Figure 10. Similar plots were developed for system speed; further details are given in Scheel and Foote (1968).

In order to validate these analytical models, experiments were conducted at the General Motors Proving Ground. Six buses were driven in platoon fashion through a series of simulated passenger stations, stopping at each station to simulate the dwell time associated with stopping for passenger pick-up and discharge. A seventh bus was used to simulate the phasing relationship between platoons (Figure 11).

The observed capacities in vehicles per hour slightly exceeded in every case

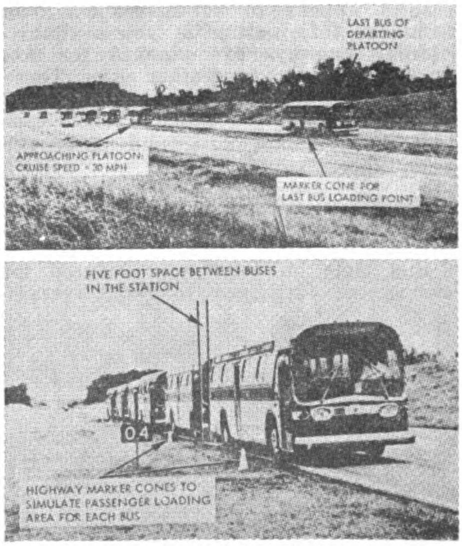
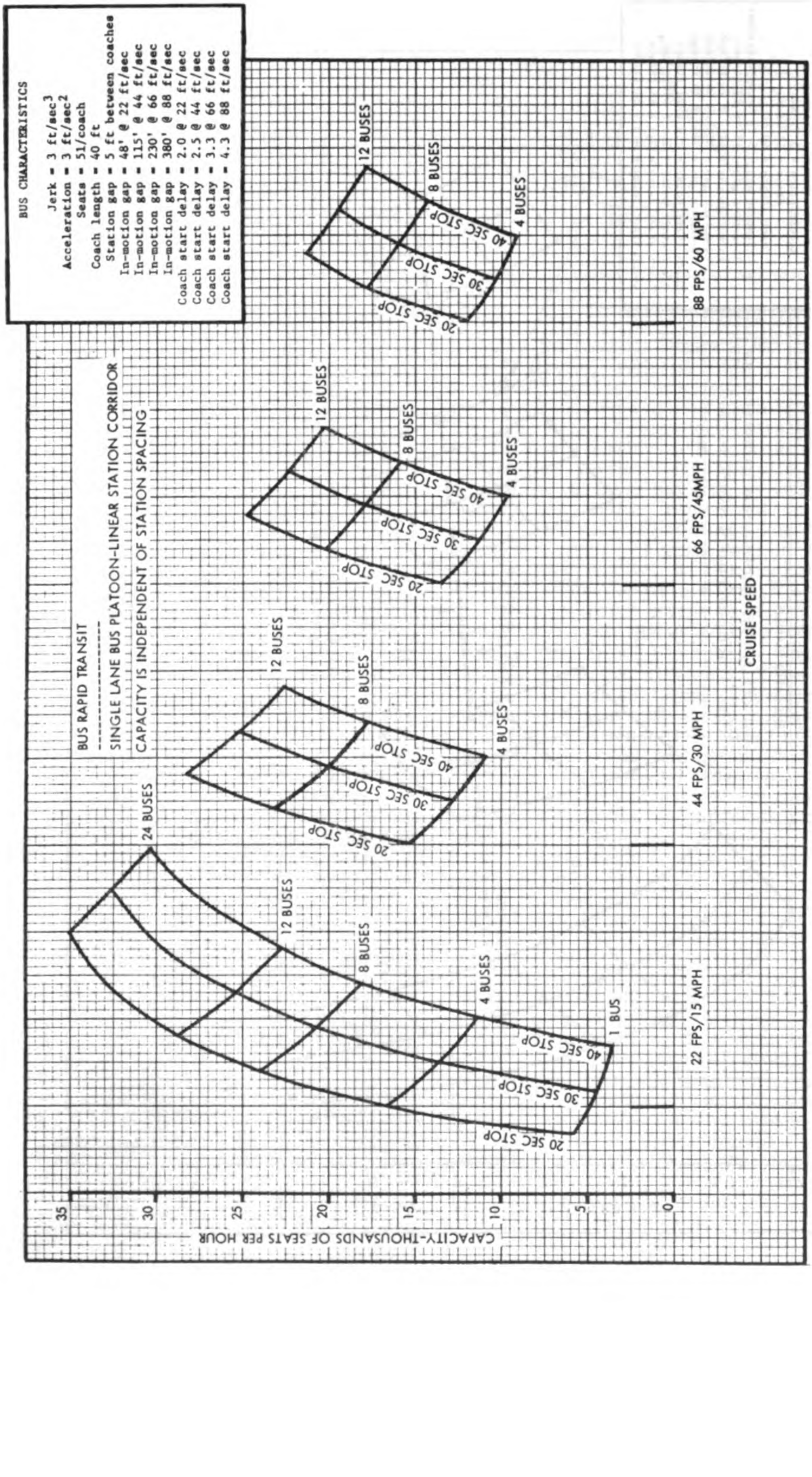


FIGURE 11

Single Lane Bus Platoon Experiment With Simulated Stations

Source: Scheel and Foote [1969]



Source: Scheel and Foote [1968]

Figure 10. System Capacity Ranges for Various Speeds, Stop Times and Platoon Sizes

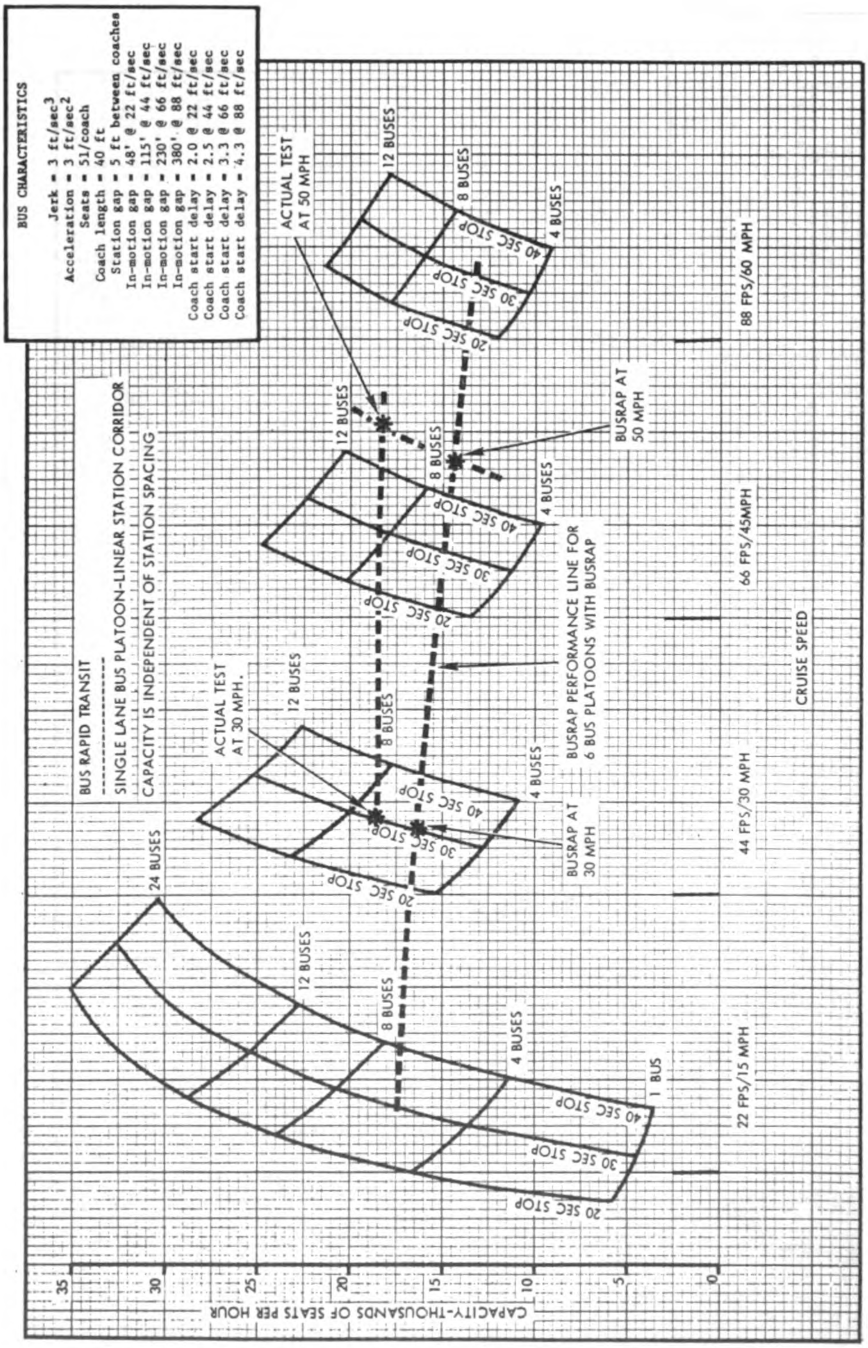


Figure 12. System Capacity Ranges for Various Speeds, Stop Times and Platoon Sizes
Comparison of Experimental Data with BUSRAP Simul: 'on Results

Source: Scheel and Foote [1969]

those predicted by the BUSRAP computer program as shown in the example of Figure 12.

Using buses in platoons of six, at a cruise speed of 48 km/h (30 miles per hour) between stations spaced 480 meters (0.3 mile) apart, and with a 30 second dwell time, capacities ranged from 350 to 400 buses per hour. This is approximately three times the capacity value previously ascribed to bus transit with station stops. Further details are given in Scheel and Foote (1969) and Herman, et al., (1971).

An experimental demonstration of platooning of buses along a reserved bus lane on a downtown street is now in progress in the city of Rochester, New York, as a cooperative project between the Regional Transit Service, Rochester-Genesee Regional Transportation Authority, and General Motors. The project is intended to test the effectiveness of bus platooning on vehicle average speed and lane capacity under actual transit service conditions. An important part of this experiment is the determination of the attitudes of the bus passengers. Figure 13 shows one of the new passenger information signs which was developed to inform passengers as to where their vehicle will be stopping, and thus to help form orderly queues. The results of the experiment will be reported when more data is available.

DUAL MODE TRANSIT STUDIES

Dual Mode Transit is a system whereby small buses are operated under driver control on ordinary streets (the first mode), and under automated control (the second mode) on specially instrumented guideways. The dual mode technology may be exploited so as to achieve significant improvements in passenger service by integration of the local area passenger collection-distribution, the arterial line haul, and the downtown circulation functions, as suggested in Figure 14.

The small vehicles under driver control on local streets would provide a

FIGURE 13
Rochester Demonstration Project—Passenger Information Sign

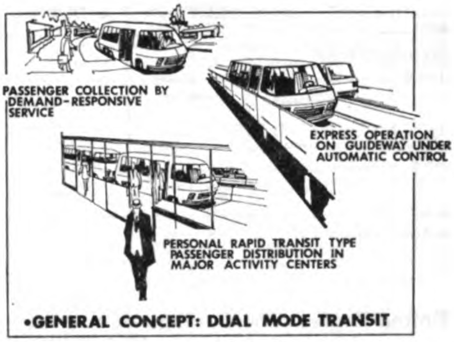


FIGURE 14

Demand-Responsive Jitney (Dial-A-Bus) feeder service, with curbside pickup in front of the traveler's home and with no transfer being required upon reaching the guideway. Automated operation on the guideway enables a Bus Rapid Transit express service with operating economics due to labor savings, as well as a faster and more convenient service through more direct routings and fewer stops. A network of guideways in downtown areas enables a Personal Rapid Transit (Demand-Responsive People Mover) service for access to and circulation within such major activity centers.

Since Dual Mode Transit includes and extends beyond the Demand-Responsive Jitney and personal Rapid Transit functions, it is inherently more complex in a technological sense than either of those systems. Moreover, the potential system user will be confronted with wholly new system service attributes, or combinations of attributes, not previously available in public transportation. It is necessary and desirable to evaluate both the technical and the socio-economic feasibility of Dual Mode Transit prior to the expenditure of large amounts of effort and money in system development, and such evaluations are significant challenges to the physical science and social science disciplines.

Dual mode research began at General Motors approximately fifteen years ago and resulted in analytical studies and experimental demonstrations of automobiles under automatic control with regard to steering, speed and safe separation (Bidwell, et al., 1960). The vehicle was automatically steered with reference to an electromagnetic field generated by low radio frequency current in a cable embedded in the roadway.

Work specifically on Dual Mode Transit systems began in 1967 and included a case study (Canty, et al., 1968) of an electrically propelled, mechanically guided bus on a network of guideways in a medium size metropolitan area in the

		SINGLE MODE VEHICLES (VEHICLES CAPTIVE TO GUIDEWAY NETWORK)	DUAL MODE VEHICLES (OPERATE ON STREETS AND GUIDEWAY)
PRIVATE PASSENGER TRANSPORTATION		———	DUAL-MODE AUTOMOBILES
PUBLIC RAPID TRANSIT	PERSONAL TRANSIT	PERSONAL RAPID TRANSIT	———
	GROUP TRANSIT	———	DUAL MODE DEMAND JITNEYS
	MASS TRANSIT	MEDIUM-SIZE TRANSIT CARS TRAIN OPERATED	———
FREIGHT TRANSPORTATION		TERMINAL/TERMINAL UNATTENDED CONTAINERS	DUAL MODE LIGHT VANS

Figure 15. Metro Guideway Functions

United States. The findings of this case study led to the conclusion that it would be more cost effective to include Dual Mode Transit as part of an integrated urban transportation concept called the Metro Guideway (Figure 15) which includes other forms of public transit and dual mode automobiles and small trucks on a common guideway network (Canty, 1972).

A wide range of analytical methods are being employed in the study of the Metro Guideway system. These include:

Computer simulations, at the individual vehicle level, of various methods of automatic acceleration, braking, and steering control;

Computer simulation of automatic routing, scheduling, and traffic control systems, sometimes involving several thousands of vehicles on complex guideway networks. Reactive graphic methods are employed to control and monitor the simulation. Figure 16 is a photograph of the console display, showing a close-up display of automated traffic at an intersection between two guideway facilities. Such displays are valuable in observing the effectiveness of various computer programs in scheduling traffic so as to make maximum use of guideway facilities while guaranteeing against conflicts at intersections, such as shown. (For descriptive matter, see Howson, 1972).

Attitudinal surveys are being conducted in about 500 households to help ascertain probable public attitudes toward the various modes of the Metro Guideway system including Dual Mode Transit. The questionnaire forms, households selection procedures, and other survey methods are carefully structured to obtain a meaningful data input to multivariate statistical models of traveller attitudes and behaviour. To our knowledge, this is the first public attitudinal survey on the Dual Mode Transit Concept, and

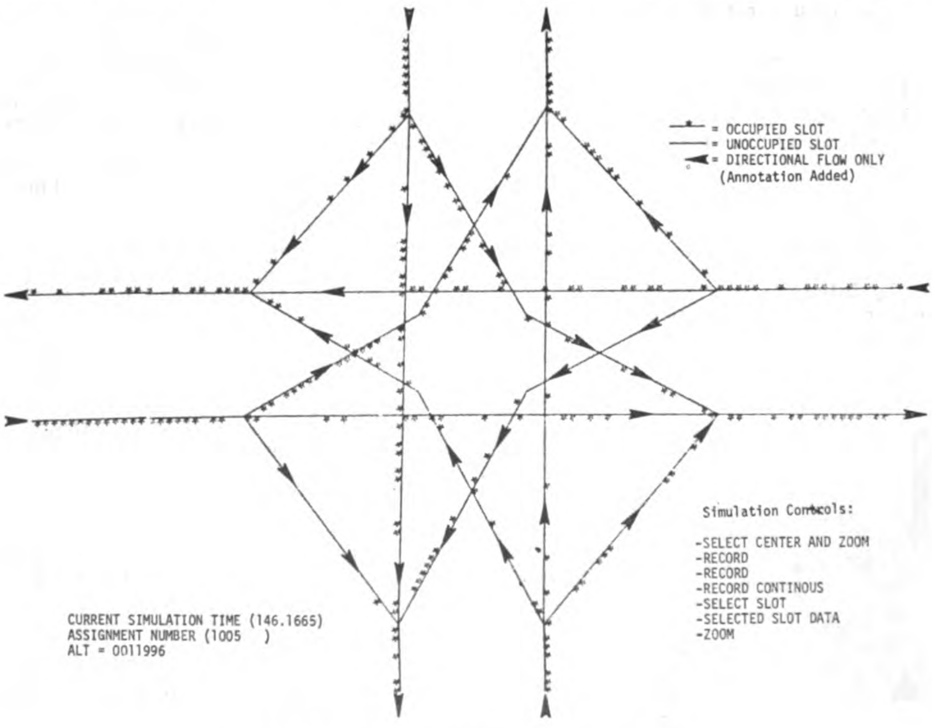


Figure 16. Metro Guideway Network Simulation, Example Display at Major Interchange

should be helpful in firming up the system design and in estimating potential ridership.

Mathematical models have been developed and calibrated for estimating various social and environmental impacts of urban freeway and guideway construction, including such impacts as the number of families who would have to be relocated (Ventura and Mehta, 1973). The resulting estimates are used in the evaluation of the overall costs and benefits of new system implementation.

SUMMARY AND CONCLUSIONS

Successive stages of system development, from concept formulation to design to development to experimental test to service demonstration to widespread implementation, involve successively larger investments of technical effort, time, and capital. It is desirable to optimize such investment and minimize technical and financial risk by testing, evaluating, and modifying or scrapping new system concepts as early as possible in the development cycle.

Examples have been given of General Motors use of analytical models, computer simulations, and attitudinal surveys in a program of research and development toward new systems of urban transportation. We feel that this analysis-simulation-survey approach is an effective way to predict the eventual performance of proposed new systems of public transportation, and we are hopeful that it will be an effective means of forecasting public attitudes toward and acceptance of such new systems.

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