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ANALYSIS OF DUAL MODE SYSTEMS IN AN URBAN AREA

Volume I: Summary

Peter Benjamin, et al.

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FINAL REPORT

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16. Abstract

Various forms of Dual Mode transportation were analyzed in order to determine the economic viability of the Dual Mode concept. Specially designed new small Dual Mode vehicles, modifications of existing automobiles, and pallet systems, all operating in conjunction with Dual Mode buses, were examined. The study was conducted in a Boston 1990 scenario, in which an extensive Dual Mode system providing service for the entire urban region was presumed to exist. This study was not intended to be a proposal for Dual Mode in Boston. The following conclusions are considered to be generally applicable to other large urban areas as well: (a) Dual Mode systems appear to be sufficiently attractive to warrant further technological development; (b) for urban-wide applications, a Dual Mode system which includes both buses and personal vehicles is more effective than one consisting of either fleet of vehicles alone; (c) a Dual Mode transportation system benefits from the use of various Dual Mode concepts throughout its development. An effective first step would be to install a limited network Dual Mode minibus system, with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.

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PREFACE

This coordinated Department of Transportation program for the analysis of Dual Mode systems was initiated by Dr. Robert H. Cannon, Jr., Assistant Secretary for Systems Development and Technology, in the Spring of 1971. It was undertaken to provide sufficient insight into the benefits, impacts and costs of Dual Mode concepts so that the Department of Transportation could determine (1) the potential of Dual Mode as an urban transportation alternative; and (2) whether further research and development was warranted, and if so, in which areas.

The analysis was conducted using a 1990 Boston scenario in which an extensive Dual Mode system was presumed to exist. The scenario in a specific city was chosen to provide meaningful base data for this analysis. The study is not a proposal for a Dual Mode system for Boston, nor is it a transportation planning analysis for that city. The study was intended to evaluate the Dual Mode concepts in an urban-wide application to assess the relative merits of the various general design types, to determine the economic viability, and to conduct an assessment of technology required.

This report is made up of four volumes having the following general content:

- Volume I - Summary
- Volume II - Study results
- Volume III - Description of the analysis techniques and data sources
- Volume IV - Program documentation of the Transportation Economic Analysis Model which was developed and used for the cost/benefit portion of this study

The study was performed by the Transportation Systems Center under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology in conjunction with, and including participation by, the Federal Highway Administration, the Federal Railroad Administration and the Urban Mass Transportation Administration. Close coordination was also maintained with the Office of the Assistant Secretary for Policy, Plans and International Affairs, and the Office of the Assistant Secretary for Environment, Safety and Consumer Affairs.

The Office of Systems Engineering in the Office of the Assistant Secretary for Systems Development and Technology was responsible for the management of the study. Overall program direction was provided by R.L. Maxwell; the Program Manager was R.L. Krick. Program coordination was achieved by the Dual Mode Transportation Working Group which reported to the Program Manager. The following Department of Transportation personnel served on the working group: R. Bruton, V. DeMarco, R. Fisher, S. Jackson, N. Kamalian, J. Leep, M. Miller, K. Okano and R. Reymond.

The cost/benefit, economic, and systems analysis portions of this study were conducted by the Systems Analysis Division of TSC, under the direction of C.H. Perrine. The primary contributors to the analysis were: P. Benjamin - task manager, analysis-team leader; J. Barber - performance, system characteristics, network analysis, final report; R. Favout - cost/benefit model; D. Goeddel - cost/benefit model; C. Heaton - impacts, network analysis, final report; R. Kangas - performance; G. Paules - ridership estimation; E. Roberts - network synthesis, scenario definition, ridership estimation; L. Vance - costs, fares, system comparisons.

TSC direction of the Dual Mode Program and the technology assessment portions of the study were conducted under the guidance of G. Pastor, Chief of the Ground Systems Programs Division. The following persons contributed: J. Marino - task manager; A. Malliaris - technology assessment; S. Pasternack - command and control; C. Toye - command and control.

In addition, D. Glater was responsible for the section on legal and administrative issues, and J. Wesler for the noise analysis. The firm of Peat, Marwick, Mitchell and Co. assisted in the analysis of potential system demand.

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EXECUTIVE SUMMARY

STUDY OBJECTIVE

The objective of the analysis was to obtain sufficient insight into the costs, impacts, and benefits of Dual Mode systems to enable the Department of Transportation to determine the potential of the Dual Mode concept as an urban transportation system.

SYSTEM DEFINITION

The Dual Mode concept refers to vehicles which are operated by manual control on existing streets during part of a trip and are automatically controlled on an exclusive guideway for another part of the trip.

BACKGROUND

For many years Dual Mode advocates have described the potential benefits of several different types of Dual Mode vehicles as urban transportation systems. In more recent years, the increasing public dissatisfaction with current urban transportation forms has reinforced the desire to understand more completely the attributes of Dual Mode as a potential improvement in urban transportation.

Although individual specific Dual Mode vehicles have been analyzed previously by various organizations, a comprehensive, consistent analysis considering multiple forms of Dual Mode has not been conducted. The Department of Transportation established a coordinated program to conduct such an analysis at the Transportation Systems Center.

SCOPE

The analysis was conducted in a 1990 Boston scenario, with an extensive Dual Mode system providing service for the entire urban region. The study was not intended to be a detailed transportation planning analysis or an analysis to recommend a transportation system for Boston. It was designed to permit a comparison of the attributes of the various generic Dual Mode concepts using a realistic urban setting as a data base. The study established the costs and benefits for a region-wide urban Dual Mode transportation system relative to the highway and transit systems proposed in 1968 by the Eastern Massachusetts Regional Planning Project for the 1990 time period.

For the purposes of the analysis, performance levels were specified with the assumption that appropriate technologies (such as command and control) would be developed sufficiently to permit their attainment.

DUAL MODE SYSTEM DESCRIPTIONS

Three generic baselines were defined from the large number of designs that had been suggested:

Pallet System Baseline

This concept includes electrically propelled pallets which carry conventional privately owned automobiles on the guideway in conjunction with electrically propelled Dual Mode 20-passenger buses operating directly on the guideway. Bus collection/distribution off the guideway is by fixed routes and schedules.

Automated Highway Vehicle System Baseline

This concept includes conventionally propelled privately owned automobiles modified or specially designed for operation directly on the guideway in conjunction with conventionally propelled 20-passenger Dual Mode buses. As in the case of the pallet system baseline, bus collection/distribution off the guideway is by fixed routes and schedules.

New Small Vehicle System Baseline

This concept includes specially designed electrically propelled, system owned 4-passenger small personal vehicles operating directly on the guideway in conjunction with a 12-passenger elec-rically propelled minibus fleet, which incorporates a dial-a-ride function for off-guideway collection and distribution.

RESULTS

The analysis of Dual Mode systems in the Boston scenario indicated:

(a) Relative to the Boston area 1990 Plan, Dual Mode baselines achieved increased accessibility to desired locations and reductions in

- average travel time
- highway congestion
- households impacted by noise
- households displaced
- accidents

(b) The introduction of Dual Mode systems caused increased regional transportation energy consumption relative to the 1990 Plan, due in part to the increased speeds attained.

(c) The total transportation contribution to regional pollutants was lower for the New Small Vehicle System Baseline than for the 1990 Plan due to its small size and electric propulsion. The other baselines increased pollution, compared to the 1990 Plan.

(d) Revenues equaled or exceeded the system operating costs for all the Dual Mode baselines but were not sufficient to cover the total system capital costs. Substantial capital subsidies were required to cover the initial installation and recurring capital costs.

(e) The regional benefits from every Dual Mode baseline studied relative to the 1990 Plan were more than twice the magnitude of the costs, and these benefits accrued to both system users and non-users.

(f) Each of the Dual Mode systems studied had specific attributes which could be more beneficial in some applications than the attributes of the other systems.

(g) An assessment of the Dual Mode system capital costs and service characteristics as compared to proposed rapid rail systems showed that Dual Mode systems are capable of generating many times the passenger mileage of rapid rail transit systems at the same or lower capital costs per route mile.

(h) An assessment of the technology requirements for Dual Mode resulted in identification of the need for further development in the areas related to automation and short headway system operation. There were no areas which were considered to be technically unfeasible.

CONCLUSIONS

Although this analysis was conducted using the Boston area as a data base, the following conclusions are considered to be generally applicable to other large urban areas as well.

(a) Dual Mode systems appear to be sufficiently attractive to warrant further technological development.

(b) For urban-wide applications, a Dual Mode system which includes both buses and personal vehicles is more effective than one consisting of either type exclusively.

(c) A Dual Mode transportation system benefits from the use of various Dual Mode concepts throughout its development. An effective first step would be to install a limited network Dual Mode minibus system, with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.

1. INTRODUCTION

The automobile provides convenient, flexible, relatively low-cost transportation, and is thus the mode of transport overwhelmingly preferred by urban travelers. Currently, however, increasing concern is being voiced over the relatively uncontrolled growth of automobile travel. Noise and air pollution effects due to the concentration of autombiles in urban areas are receiving increasing attention and criticism. The divisive effect of ribbons of concrete cutting through neighborhoods is being recognized and the public has become more sensitive to the plight of those traditionally displaced by new urban freeways--minority groups and the poor. Environmentalists have generated an awareness of the destructive effect of new suburban highways upon the few remaining natural open spaces. Consequently, public pressure has come to bear opposing new highway construction. In fact, in a number of urban areas, new roadway construction has come to a virtual standstill.

Yet the demand for transportation continues to grow, and as ever more automobiles clog the existing roads, the spectre of hopelessly tangled traffic and totally jammed streets haunts those responsible for urban transportation. In general, conventional transit systems recently have been unable to attract significant ridership or to provide the service desired by travelers. What is needed is a transportation system with the apparent advantages of the automobile but without the associated congestion, pollution effects or large right-of-way requirements.

Dual Mode transportation systems have been suggested as candidate innovative transportation forms with the potential to meet this need. A Dual Mode vehicle is one which travels under manual control on the street network for some portion of its trip, and operates under automatic control on an exclusive guideway for some other portion. Thus low density collection/distribution functions could be accommodated at low capital cost using existing street facilities, while high density routes with common origins and destinations for many travelers could be automated. Automation provides the potential for achieving increased capacity through close headway operation while minimizing right-of-way requirements, allowing high speed travel with no congestion, relieving the driver of his duties and thereby providing increased free or productive time and eliminating accidents due to human driving errors, poor visibility and driver incapacitation. Electrically powered Dual Mode vehicles may help to reduce air pollution, and guideway design may permit minimization of noise transmission to adjoining areas. Dual Mode transportation systems have the potential to provide door-to-door transportation equivalent to the automobile in convenience, and thereby may attract ridership from highways and reduce the problems of congestion.

The U.S. Department of Transportation, through the Systems Analysis Division of the Transportation Systems Center, has conducted an economic feasibility analysis of Dual Mode transportation systems. Specifically, it was to be determined whether Dual Mode might be, in itself, an attractive urban transportation system, and given the multitude of ways in which Dual Mode could be designed, an evaluation was made of various alternatives in order to distinguish their relative advantages and disadvantages. The objective of the analysis was to obtain sufficient insight into costs, impacts, and benefits of Dual Mode systems to enable the Department of Transportation to evaluate the potential of Dual Mode as an urban transportation alternative and to determine whether further research and development was warranted.

The analysis was conducted in a 1990 Boston scenario, in which an extensive Dual Mode system was presumed to exist. The scenario was chosen to provide meaningful base data for this study; this report is neither a proposal for a Dual Mode system in Boston nor a transportation plan for that area. As a basis for comparison, the 1990 transportation plan for Boston as projected by the Eastern Massachusetts Regional Planning Project in 1968 was also analyzed. The analysis was oriented toward examining urban-wide applications of the Dual Mode concept, as opposed to limited service systems for specific purposes.

For the purposes of the analysis, performance levels were specified with the assumption that the appropriate technologies (such as command and control) would be sufficiently developed to permit their attainment. Continued technological development is required to achieve these capabilities.

2. BASELINE DESCRIPTIONS

The proposals for Dual Mode systems that have been made by various institutions, companies, and developers were examined for their basic technological and application elements. These basic elements were categorized and grouped according to common characteristics, from which evolved baselines which represent classes of proposals. Each of the baselines discussed herein consists of a combination of personal vehicles and buses, thereby providing the user with alternative choices in using the system. The three baselines examined in detail in this report are described in Table 1.

The pallet system baseline, illustrated in Figure 1, consists of conventional private automobiles which are driven onto system owned pallets that operate automatically on the guideway, and of 20-passenger buses which do not use pallets but interface directly with the guideway. The autos are powered by internal combustion engines, while the pallets and buses are electrically powered. Storage batteries provide the bus with a 30-mile range off the guideway.

A typical trip on the system is depicted in Figure 2. A standard automobile is driven manually on the street network to the guideway entrance. The car is then driven onto the pallet, which operates under automatic control on the guideway. If the destination is outside of the urban core, the car is driven off the pallet at the appropriate exit and then manually operated on the streets to the destination. A different procedure is used for destinations in the central business district. The already extremely congested downtown area of Boston does not rationally invite discharging large numbers of Dual Mode vehicles onto the streets. Consequently, vehicles are not permitted to leave the system in this area. Upon arriving at an urban core station, the automobiles are unloaded from the pallets and are parked in garages provided by the system, with no street access permitted. The riders then walk to their destinations or transfer at the

TABLE 1. DUAL MODE BASELINES

SYSTEM CHARACTERISTICS		PALLET SYSTEM		AUTOMATED HIGHWAY VEHICLE SYSTEM		NEW SMALL VEHICLE SYSTEM	
		AUTO/PALLET	BUS	AUTO	BUS	SMALL PERS. VEHICLE	MINIBUS
VEHICLES	Passenger Capacity	6	20	6	20	4	12
	Ownership	Private Auto	System	Private	System	System	System
	Propulsion on guideway	Electric Pallet	Electric	Internal Combustion	Internal Combustion	Electric	Electric
	Propulsion off guideway	Internal Combustion Auto	Electric	Internal Combustion	Internal Combustion	Electric	Electric
OPERATION	Suburban Collection and Distribution	Drive to/from Guideway on Streets	Fixed Routes and Schedules	Drive to/from Guideway on Streets	Fixed Routes and Schedules	Drive to/from Guideway on Streets	Dial-a-Ride
	Guideway Line Haul	Autos Ride on Pallets	(1) (No Driver)	(1)	(1) (No Driver)	(1)	(1) (No Driver)
	Urban Core Collection and Distribution (No Vehicle Exit or Entry)	(2)	(2)	(2)	(2)	<½Mile Walk	<½Mile Walk

(1) Vehicles operate directly on the guideway.

(2) Local transit interface is provided at Dual Mode stations.

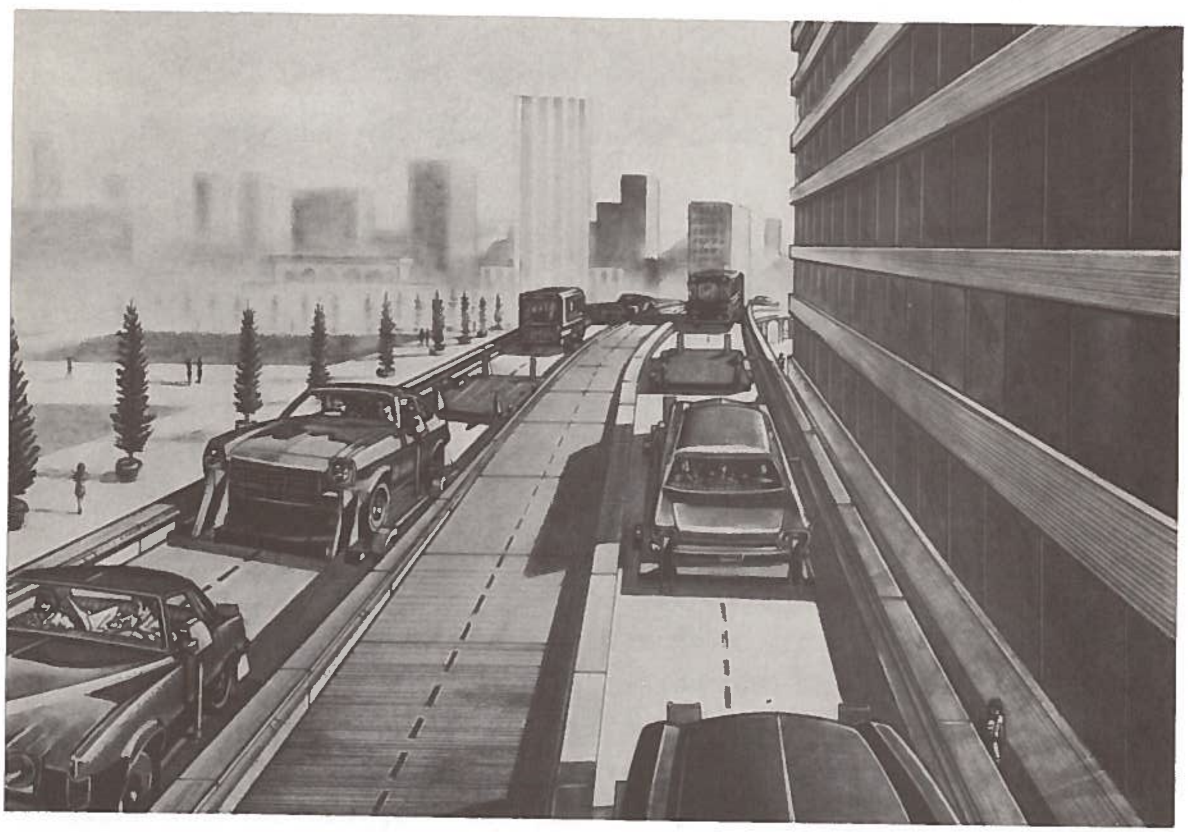


Figure 1. Pallet System

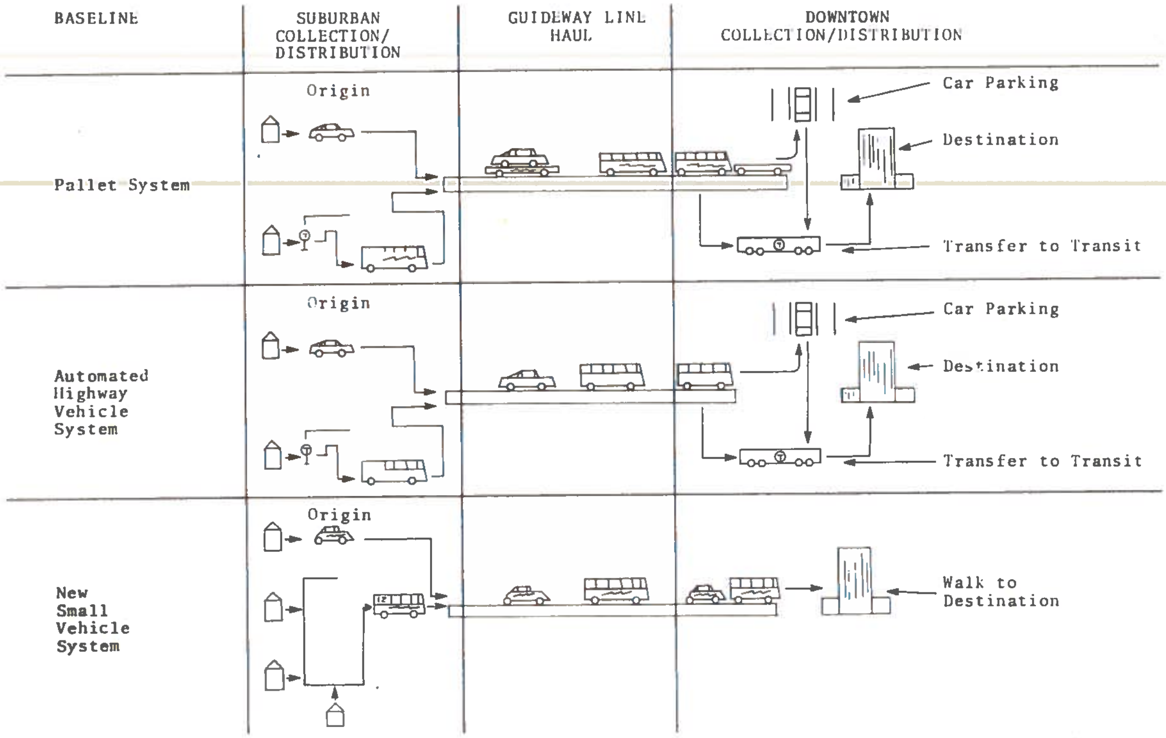


Figure 2. Dual Mode System Operation

garage to the existing local transit system for downtown collection and distribution.

On local streets outside the downtown area, the buses operate on fixed routes and schedules in the normal way. Upon entry to the guideway the driver leaves the vehicle and it operates automatically. In the downtown area, transfer to conventional transit is required. For the bus portions of all baselines examined, single vehicle, no-transfer service is provided between origin and destination for all trips except those to the urban core.

The automated highway vehicle baseline, depicted in Figure 3, consists of privately owned automobiles which, in their automated mode, interface directly with the guideway and buses which operate in the same fashion as the pallet system buses. Off the guidway, the autos perform in the conventional manual mode. Both vehicles utilize internal combustion engines and a comparison with the pallet system characteristics provides the opportunity for analyzing the relative effects of electrical and internal combustion

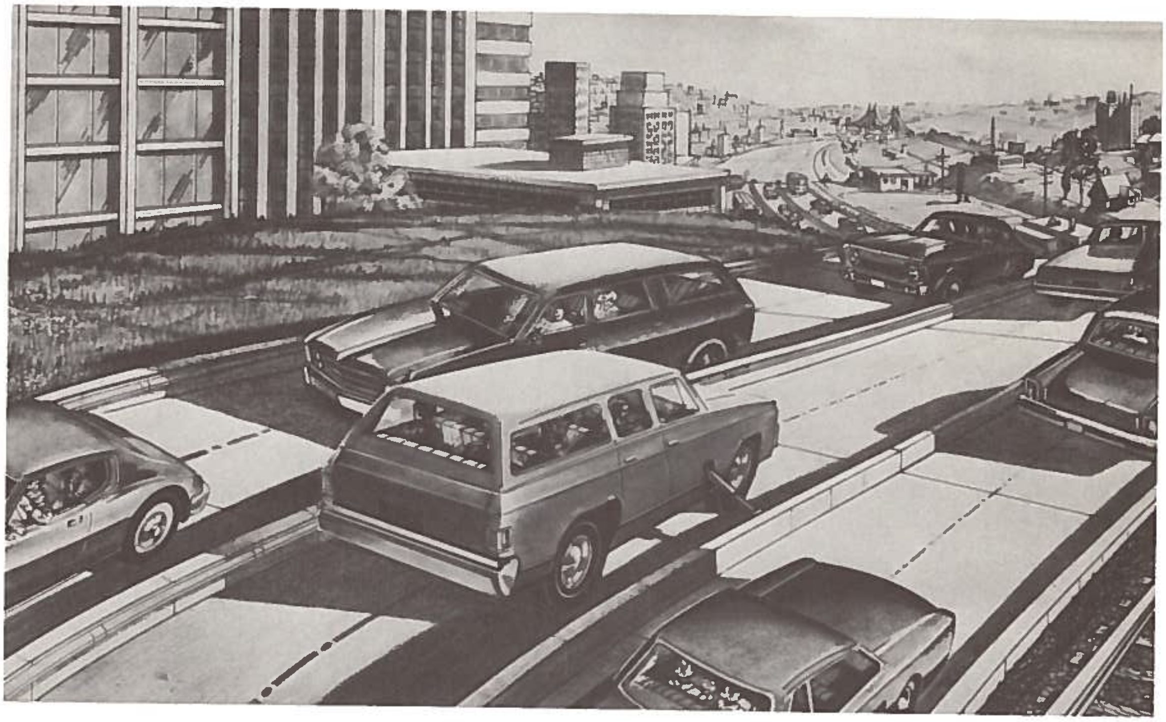


Figure 3. Automated Highway Vehicle System

propulsion.

The new small vehicle baseline, shown in Figure 4, consists of innovative small personal vehicles specifically designed for Dual Mode operation and owned by the system, and Dual Mode 12-passenger minibuses. In this case a dense guideway network with stations easily accessible by walking is provided in the central business district, eliminating the downtown transfer to transit. The small personal vehicle is designed for individual use, but is owned by and rented from the system. As shown in Figure 2, for suburban collection the vehicle is driven manually to the closest station, and if the destination is in the downtown area the user leaves the vehicle upon arrival at the station closest to the intended destination. The vehicle is available for further use by someone else or routed to a remote storage area for later use. For the user's return trip, a vehicle (but not necessarily the same one driven in) is provided at whichever downtown station is chosen. Thus a vehicle is always guaranteed at a downtown station,

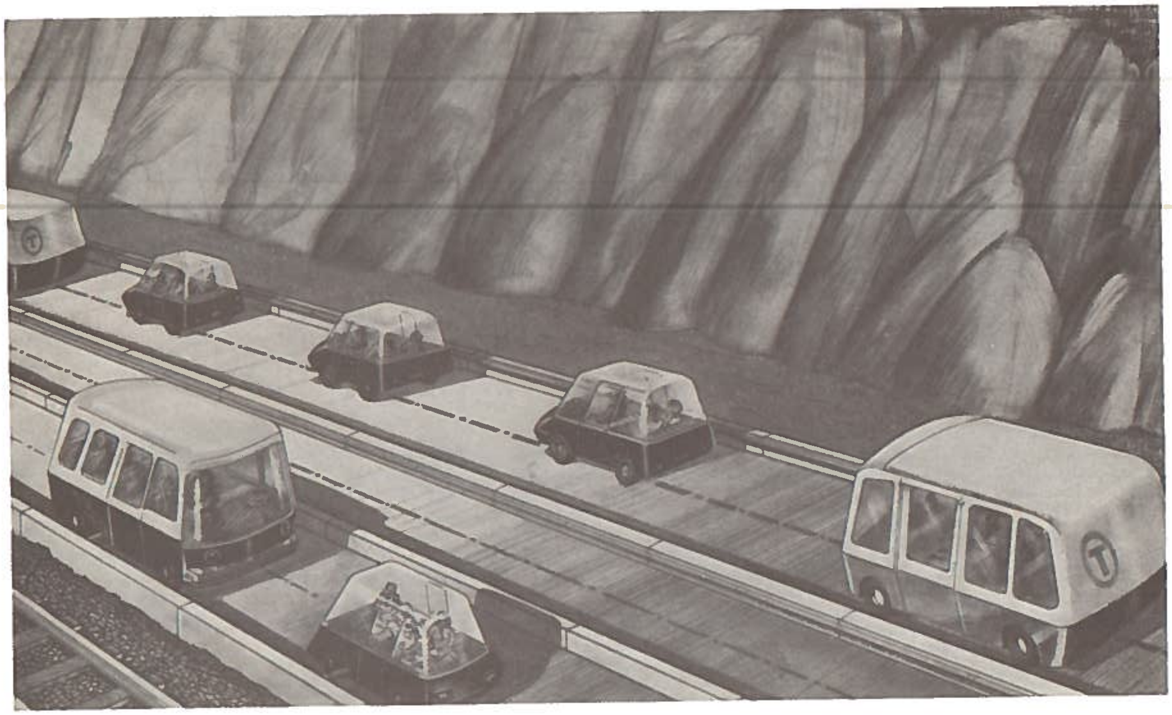


Figure 4. New Small Vehicle System

but no permanent correlation between particular individuals and vehicles exists. The minibus operates as a dial-a-ride vehicle in the suburbs. This permits a comparison of the benefits of this type of bus service with the fixed route and schedule service of the Dual Mode buses in the other baselines.

3. NETWORK DESCRIPTION

A single Dual Mode guideway network was designed for all baselines, with some adjustments required to meet the peculiarities of specific systems, particularly in the downtown area. In keeping with the objective of minimizing community disruption, existing rights-of-way were used whenever possible.

The Dual Mode guideway network designed for Boston is depicted in Figure 5. Most of the stations, shown as circles, provide entry to and exit from the system. Stations in and near the central core are indicated as three different types. At stations designated by diamonds or triangles, vehicle exit from and entry to the street network is forbidden. At stations indicated by squares, vehicles are permitted access to the street network, but automobile parking there is encouraged by means of reduced parking fees. Dual Mode users can transfer to the existing rapid transit system at the stations designated by squares and diamonds. However, the one station shown with a triangle has no transit interface since it is within walking distance of the main financial district.

Approximately 70 percent of the proposed 1990 highway construction was eliminated or replaced by the Dual Mode system. A majority of the Dual Mode network was laid out on existing rail rights-of-way, and consequently little new land was required. The network was structured to attempt to meet the projected 1990 origin/destination demand pattern. Stations were located to permit maximum access to the guideway from major sources of demand through the available arterial and freeway network. The dense downtown collection/distribution guideway network for the new small vehicle system is shown in Figure 6. All points within this area are within a one-quarter mile walk of a station.

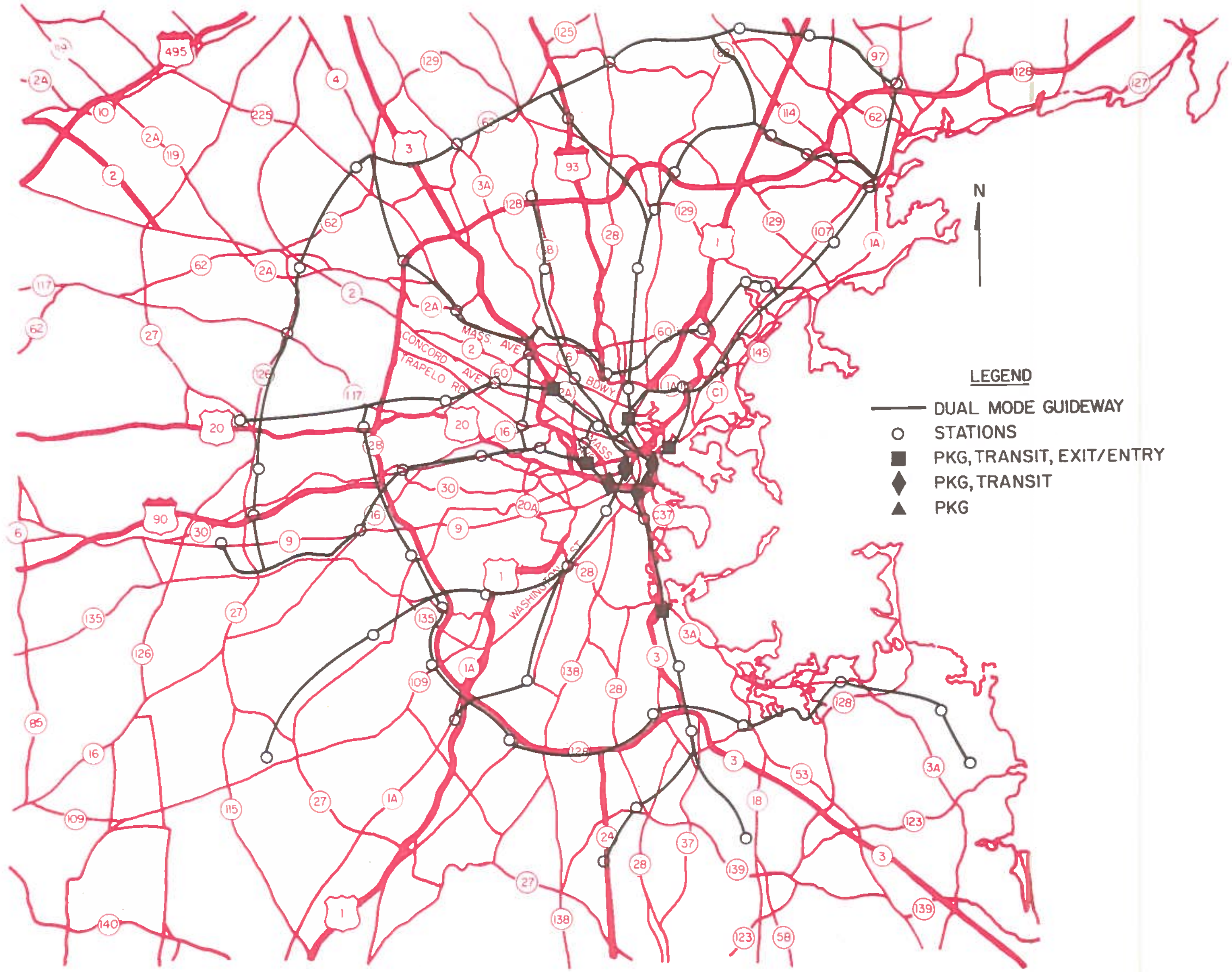


Figure 5. Boston Dual Mode System Guideway

Figure 6. Downtown Network for the New Small Vehicle System Baseline

4. RESULTS

Preliminary analyses of the various baselines indicated that, for urban-wide applications, mixed vehicle fleets are more attractive than systems composed exclusively of either personal Dual Mode vehicles or of Dual Mode bus systems. In all cases examined, mixed fleets provided greater ridership and higher revenues as well as lower cost per passenger trip than single vehicle type systems. The bus portions provide service for the "transportation poor" while the personal vehicle portions maximize diversion of travelers from the highway onto the guideway. The mixed fleet provides a logical implementation sequence, starting with the bus and then adding the more complex personal vehicles operation; furthermore, it provides the flexibility to meet changing patterns of transportation demand.

4.1 SERVICE

The service level achieved by the three Dual Mode baselines and by the 1990 plan are compared in Table 2. The pallet and automated highway vehicle systems used the 249-mile basic network. The new small vehicle system baseline included an extra 12 miles of network for the dense downtown collection/distribution system.

All of the Dual Mode systems attained more than a 10 percent daily modal split -- more than the transit split in the 1990 case. Since less than half of the trips in the region are of sufficient length or are located so as to be candidate Dual Mode trips, the 16 percent daily split attained by the new small vehicle baseline actually represents the attraction of more than 30 percent of the potential Dual Mode users. Dual Mode attracted as much as 53 percent of the peak hour downtown-bound travelers.

This relatively high ridership level was attained in spite of the competitive effects of Boston's extensive transit system, which continued to exist in parallel with the Dual Mode system. Although the transit and Dual Mode systems were designed to be complementary, considerable competitive characteristics remained. Therefore, the Dual Mode systems might be expected to fare even better in other scenarios without the large existing investment in transit.

The diversion of riders from the highways onto the Dual Mode guideway reduced highway traffic congestion, as evidenced by an increased peak period surface arterial speed of as much as 18 percent. The Dual Mode systems themselves achieved as much as a 57 percent increase in door-to-door travel speed compared to a similar trip under the 1990 plan. For a typical Dual Mode trip (which for personal vehicles averaged nearly 15 miles in length) the average user saved in the vicinity of 15 to 20 minutes compared to the trip he would have taken if the 1990 plan had been adopted. The combination of reduced highway congestion and generally higher average speed of Dual Mode travel resulted in the saving of as much as 36 years of travel time every day.

4.2 COSTS

The total capital cost of the urban-wide systems studied in the Boston scenario ranged from 1.6 billion dollars to more than 4 billion dollars, as shown in Table 3. These represent multi-year investments in an extensive transportation system. Smaller systems could be constructed at proportionately lower costs. Just over 1 billion dollars (in the form of 114 miles of highway and 29 miles of rapid transit extension) of proposed construction in the 1990 plan would not be built if Dual Mode were installed. This, in effect, represents a capital cost savings incurred by the adoption of a Dual Mode system. The rest of the 1990 plan was assumed to be built and operate in conjunction with the Dual Mode systems.

The vehicle capital costs represent nearly half of the total capital cost of the new small vehicle system. This includes the purchase price of 420,000 small personal vehicles, since these are system-owned and rented to users. The magnitude of the total capital investment is very sensitive to the unit cost of the small

TABLE 2. COMPARATIVE SERVICE

	1990 PLAN	PALLET SYSTEM	AUTOMATED HIGHWAY VEHICLE SYSTEM	NEW SMALL VEHICLE SYSTEM
Route Miles	114 Highway(1) 29 Transit	249	249	261
Dual Mode Daily Modal Split(%)		12	11	16
Transit Daily Modal Split(%)	10	6(2)	6(2)	6
Peak CBD Modal Split (Dual Mode/Transit) (%)	46	22/35	21/36	53/21
Peak Period Surface Arterial Speed (mph)	15.8	17.7	17.5	18.6
Average Dual Mode Trip Speed (mph)		24.0	23.8	25.3
Typical Dual Mode Trip Time Savings (min.)		17	16	19
Daily Regional Time Savings (years)		19.4	19.3	36.0

(1) Highway and transit miles not built when Dual Mode is constructed.

(2) Does not include the Dual Mode users transferring to transit at parking garages.

TABLE 3. COMPARATIVE COSTS

	1990 PLAN	PALLET SYSTEM	AUTOMATED HIGHWAY VEHICLE SYSTEM	NEW SMALL VEHICLE SYSTEM
Total Capital Cost ($ x 10^6)	1,020(1)	2,630(2)	1,620(2)	4,200(2)
Dual Mode Vehicle Capital Cost ($ x 10^6)		682(3)	83(4)	1,970(5)
Annual Door-to-Door Dual Mode Capital and Operating Cost ($ x 10^6)		724	625	972
System Operator Annual Capital Cost ($ x 10^6)		308	180	681
System Operator Annual Operating Cost ($ x 10^6)		254	46	291
Dual Mode Private Vehicle User Annual Cost (In Addition to Fare) ($ x 10^6)		162	399	0
Dual Mode Door-to-Door Cost per Passenger Trip ($)		1.83	1.81	1.90
Regional Door-to-Door Cost per Passenger Mile (¢)	12.6	13.4	13.3	14.0

NOTES:

(1) Highway and transit extensions that are not built if Dual Mode is put in.

(2) Dual Mode system only.

(3) Pallet and bus portion of the total capital cost.

(4) Bus portion of the total capital cost.

(5) Minibus and small personal vehicle portion of the total capital cost.

personal vehicles. In this baseline a significant benefit accrues to the large number of users who rent a Dual Mode vehicle and forego the purchase of a second family car. For the automated highway, the system vehicle capital costs include only the purchase of buses, since the personal vehicles are privately owned and operated. Both pallets and buses are included in the vehicle cost for the pallet system: the personal vehicle costs are borne by the private owner.

Capital costs were annualized by depreciating each individual element of each system over its lifetime using a 10 percent interest rate. For example, buses were depreciated over 12 years, guideway structures over 50 years, etc. Total annual Dual Mode capital and operating cost as shown in Table 3 reflects total door-to-door transportation costs to society, including such items as the operating and depreciation costs of private vehicles during the off-guideway portions of pallet or automated highway Dual Mode trips. They range from a low of just over 600 million dollars to almost 1 billion dollars, with the variation largely representing differences in service levels and ridership. The annual costs per passenger trip for all systems were approximately the same.

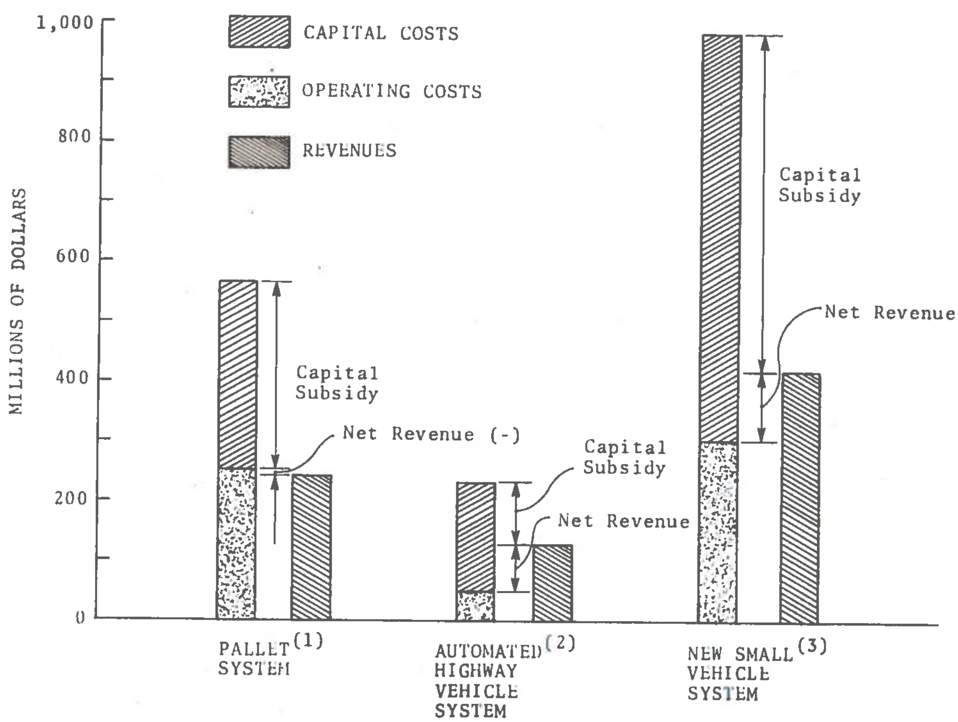
In all cases, regional costs per passenger mile (reflecting highway and transit costs and ridership) were higher for Dual Mode systems than for the 1990 plan. The benefits of Dual Mode transportation are the compensation for these increased costs.

As shown in Figure 7, at the nominal assumed fare levels, revenues exceeded operating costs for the new small vehicle and automated highway vehicle, and nearly equalled it for the pallet system. In all cases, however, capital subsidies would be required to meet total system costs. Parametric analyses of fare effects indicated, as depicted in Figure 8, that the revenues of all systems can equal or exceed operating costs. This figure shows the effects of up to 25 percent variation from the base fare. None of the increases in fares, however, provided a sufficient net revenue to cover capital costs.

4.3 IMPACTS

Table 4 is a comparison of some of the regional impacts of the various Dual Mode alternatives and of the 1990 plan.

Pollution level determinations assumed that appropriate Environmental Protection Agency standards for motor vehicles or power generating plants were in effect. The pollution output associated with the generation of electrical power for the pallet and new small vehicle baselines was calculated. The figures shown are for all transportation modes in the region. The high power



(1) Does not include capital and operating costs borne by private vehicle owners for the off-guideway portion of Dual Mode trips.
(2) Does not include capital and operating costs borne by private vehicle owners for Dual Mode trips.
(3) Total door-to-door transportation costs.

Figure 7. Annual Costs and Revenues Accrued to the Dual Mode System Operator

TABLE 4. COMPARATIVE IMPACTS

	1990 PLAN	PALLET SYSTEM	AUTOMATED HIGHWAY VEHICLE SYSTEM	NEW SMALL VEHICLE SYSTEM
Regional Annual Trans. Pollutants (10^6 lb.)	309	343	321	292
Daytime Noise Impacts (Households) (1)	41,000	431	1,032	336
Household Displacements (1)	58,000	6,100	6,100	5,400
Peak Period CBD Access (10^3 Persons) (2)	2,288	2,898	2,898	3,148

NOTES:

(1) Associated with new transportation facilities.

(2) Within 40 minutes of travel.

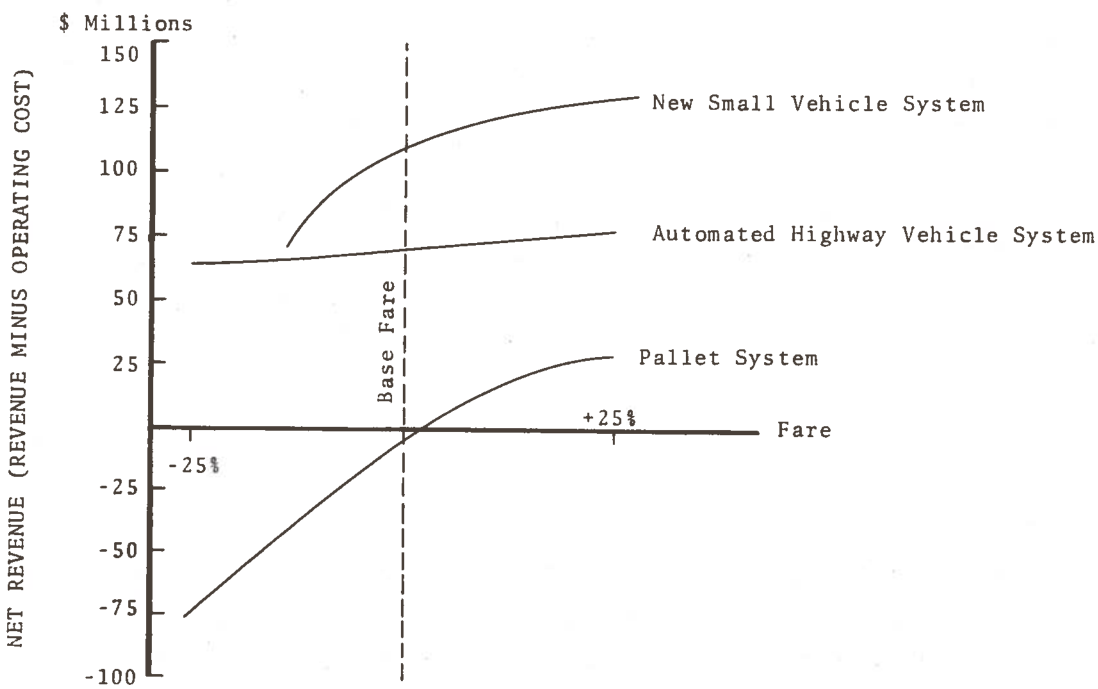


Figure 8. Effect of Fare Variation on Net Revenue

requirements of the pallet alternative caused by the necessity to move heavy pallets and the vehicles on them, as well as empty pallets, resulted in pollution levels of this baseline exceeding the 1990 plan. Longer trip lengths, high speed operation, and diversion from transit caused the internal combusion powered automated highway vehicles to contribute to a greater total pollution level than the 1990 plan. The only significant reductions in pollution levels were achieved by the new small vehicles.

Most of the route miles (80 percent) of the systems analyzed in the scenario were accommodated on existing rights-of-way or were tunneled. Dual Mode systems, with twice the route mileage of planned highway and transit additions, displaced only 10 percent of the number of families which the 1990 plan construction would have moved. Although the pallet and the automated highway vehicle system baselines had fewer route miles than the new small vehicle system baseline, the former required large parking garages for the storage of private vehicles, thereby causing somewhat greater displacements. Largely because of guideway structure design and location, Dual Mode systems caused only 1 percent of the noise impacts associated with the 1990 plan. Thus, at a time when community pressures are making acquisition of new right-of-way for transportation systems increasingly difficult, Dual Mode systems can significantly reduce neighborhood disruption and division as well as avoid the displacement of minority groups and low-income families--the traditional victims of new transportation system construction.

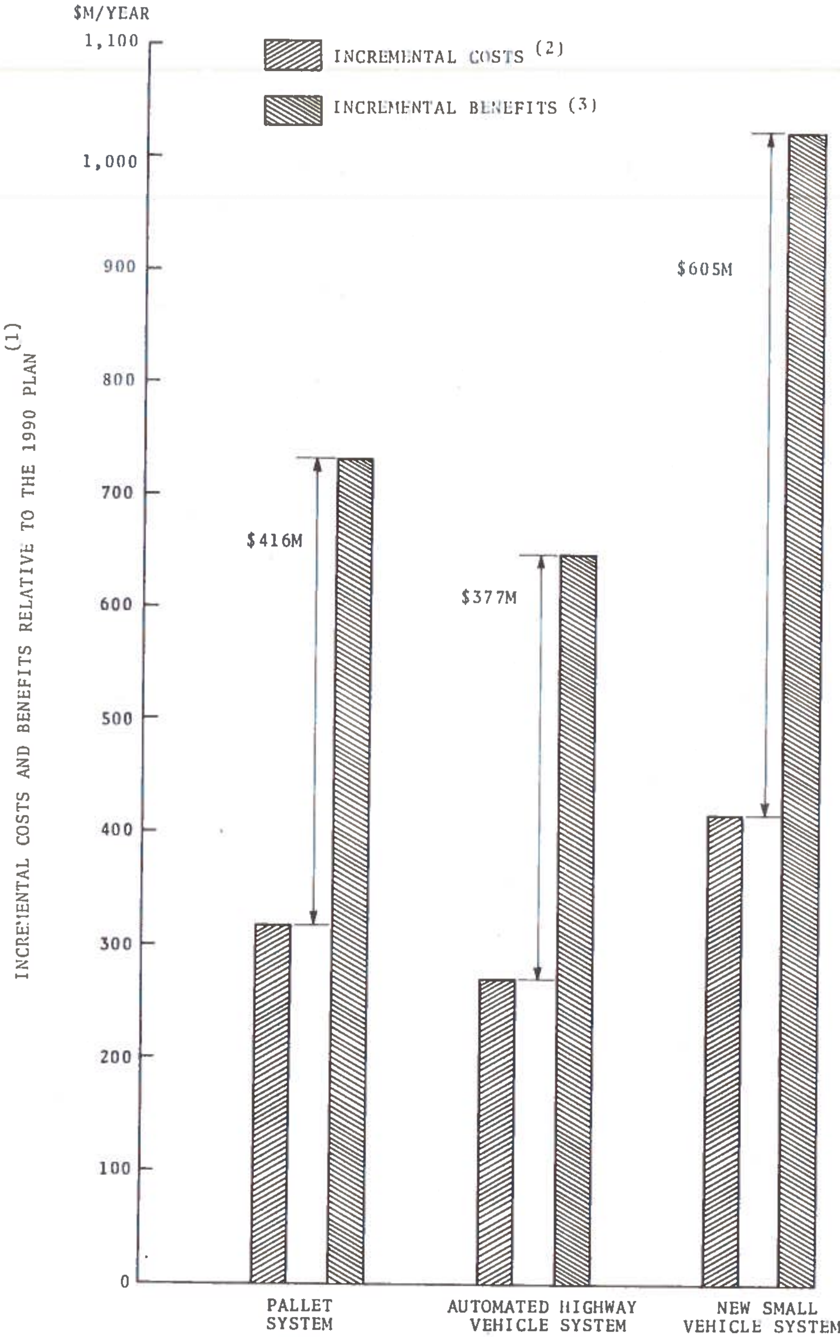
During the peak period, up to 25 percent more people could reach the city center within 40 minutes using Dual Mode than the 1990 plan permitted. Again, the new small vehicle baseline was most effective due to its shorter travel time for the same trip length. Similar results were obtained for other origins and destinations, with increased access to public facilities and new job opportunities by low-income users also being a benefit.

4.4 COSTS AND BENEFITS

The relative costs and benefits of the Dual Mode alternatives relative to the 1990 plan are summarized in Figure 9. Costs and benefits were calculated on a regional basis for all transportation modes. The incremental costs were found by subtracting from the Dual Mode operating costs and annual capital debt service, savings due to reduced highway and transit construction and maintenance, and changes in the costs incurred by individual motorists operating their vehicles. The benefits costed include travel time savings, relocation savings, accident savings, changes in pollution costs, changes in land values and tax revenues, and driver relief. They do not include benefits from such items as decreased neighborhood intrusion, additional job accessibility, or regional economic stimulation.

A large portion of the benefits were directly or indirectly attributable to travel time savings achieved by both Dual Mode and highway users. The 1990 plan was used as a base, and all costs incurred beyond that level and all benefits obtained above that base were included.

Figure 9 shows that the regional benefits of the mixed vehicle Dual Mode systems, for urban-wide applications, are more than twice the costs. Of the systems analyzed, the new small vehicle system has the greatest total benefits, the largest net benefits, and the highest ratio of benefits to costs. Moveover, this baseline attracts the highest level of ridership, and revenues exceed the operating costs by the greatest increment. It obtains this, however, at the highest capital cost of any baseline and thus requires the biggest capital subsidy. In spite of the fact that benefits are on the order of two and a half times the costs, the requirement still exists to invest about 4 billion dollars over a period of years into building an urban network of this extent and populating it with vehicles. These capitals costs, although quite large, are not inconsistent with the costs of any large urban transportation system, and on a route mile basis are lower than those of the New York Second Avenue Subway and the projected unit costs of the Washington, D.C. (METRO), Baltimore, and Atlanta rapid transit systems.



(1) Includes costs and benefits to all users of highway, transit and Dual Mode systems relative to those associated with the 1990 plans.
(2) Includes total Dual Mode capital costs plus operating costs, minus 1990 Plan capital and operating cost savings.
(3) Includes dollar valuation of time savings, relocation savings, accident savings, changes in pollution costs, changes in land values and tax revenues relative to the 1990 Plan.

Figure 9. Regional Annual Incremental Costs and Benefits Relative to the 1990 Plan.

Induced demand (increased total regional trips generated due to the attractiveness of Dual Mode systems) was not predicted because of the inadequate state-of-the-art in this area. However, parametric analyses examined the effects of up to 20 percent induced demand for all baselines. Factors such as congestion increased somewhat in all cases, but in no case did the peak period surface arterial speed drop to the 1990 plan level. In all cases net incremental benefits and benefit-to-cost ratios increased.

Because of the generally conservative assumptions used in this analysis the results presented tend, except where noted, to project a conservative case for the Dual Mode systems. More optimistic projections would, as parametric analyses indicated, improve the general picture, although the relative results (differences between alternatives) would not be expected to change significantly.

5. POTENTIAL SYSTEM IMPLEMENTATION SEQUENCE

Urban-wide applications of Dual Mode transportation systems were considered in this analysis. Such systems will not, however, come into existence instantaneously; rather they will grow over a period of years. Because the system characteristics will change during this implementation period, various Dual Mode alternatives will provide the greatest effectiveness at each stage. This requires sufficient flexibility in Dual Mode system design to accommodate various forms during the implementation sequence. A potential implementation sequence for an urban area is depicted in Figure 10.

Initial implementation of Dual Mode will in all probability occur in a high demand density corridor. The limited guideway extent and restricted number of origins and destinations would tend to discourage the purchase or rental of personal Dual Mode vehicles. Thus, if personal vehicles are to be used in a limited

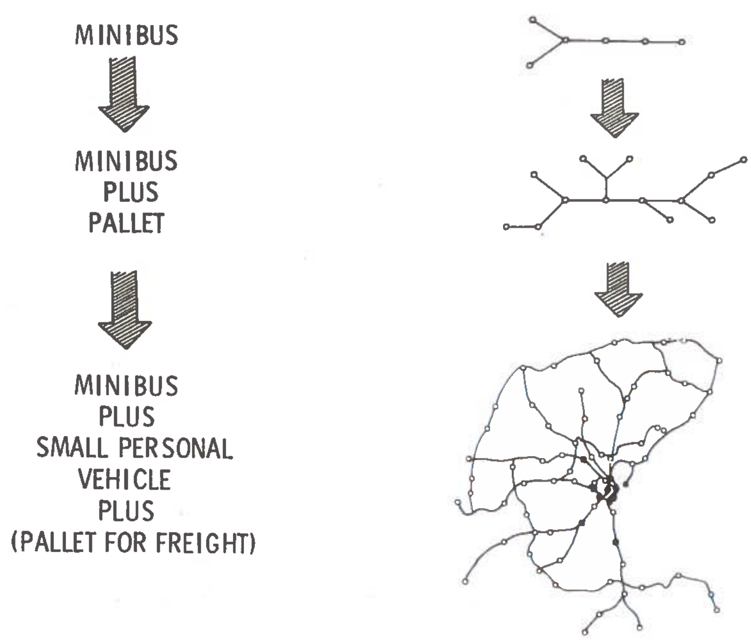


Figure 10. A Potential Implementation Sequence

scale system, the pallet, which does not require modification of automobiles, would appear to be the most appropriate alternative.

A limited corridor with relatively high demand occurring between common origins and destinations permits the attraction of sufficient ridership and the achievement of high enough load factors to make bus systems alone very effective. The low vehicle capital and operating costs per passenger mile of high load factor bus systems in such limited applications provide the opportunity to install a working Dual Mode system at minimal cost and still achieve acceptable ridership.

Because Dual Mode buses can be operated on guideways at relatively large headways compared to those required to move the same volume of people in personal vehicles, bus systems would appear ideal for the initial developmental stages of these systems, when command and control technology is in its early stages of maturity. Of the bus systems examined, the minibus with dial-a-ride service achieved the greatest ridership. This high ridership of the minibus would be desired to help defray the relatively large automation costs over the widest possible user base.

Thus, the dial-a-ride minibus would appear to be most suitable as an initial limited corridor application of the Dual Mode concept. Personal vehicles could be introduced at a later date to increase utilization of the guideway, with the pallet being the most attractive candidate so long as a limited diversity of origins and destinations is available.

This analysis suggests that as the network expands, the new small vehicle alternative, in scenarios similar to Boston, provides the greatest benefits for the costs incurred. If sufficient funds are not available for implementation of this alternative, continued expansion of the pallet or introduction of the personal automated highway vehicle may be preferred, despite their slightly lower benefit/cost relationship. Were the new small vehicle system to be implemented, however, continued use of pallets or pallet-like vehicles for freight would be desired to further diversify system usage. Utilization of the Dual Mode system for freight, particularly during off-peak periods, could contribute considerably to increasing the net benefits of the system. This factor was not included in the present analysis.

The introduction, at a later stage, of a coordinated off-guideway non-Dual Mode dial-a-ride bus feeder and on-guideway personal vehicle (PRT) system has the potential to further increase ridership while decreasing costs per passenger trip through increased bus load factors. The evolution of an urban-wide application of Dual Mode transportation, therefore, would utilize a number of the concepts examined during its various stages of growth.

6. TECHNOLOGY ASSESSMENT

An investigation into various aspects of Dual Mode technology was conducted in order to provide technical information for the cost/benefit analysis and to provide information for determining the direction for future Dual Mode development efforts. The approach taken was to assess automated guideway system technology and identify those areas critical to Dual Mode systems. The general area of command and control was further studied by reviewing the present state-of-the-art of automated control systems software for Dual Mode applicability, developing performance analysis models and methodology for studying large network systems, and conducting some limited performance tradeoffs.

The investigation was conducted on two levels. Areas such as guidance systems, vehicle diagnostics, propulsion, communications and high speed switching were surveyed to determine the present state-of-the-art. Traffic management and associated close headway operating strategies were considered to require special attention, so they were investigated in more depth.

As a result of the survey, it was concluded that the following critical areas of Dual Mode technology require further development. In order of development priority, they are:

(a) electromechanical lateral guidance

(b) longitudinal guidance

(c) manual/automatic control conversion

(d) loading/unloading of pallets

(e) electronic lateral guidance

(f) high speed (60 mph) switching of vehicles

(g) headway protection

(h) navigation and traffic control

(i) advanced propulsion

(j) communications

These priorities reflect not only the complexity of the task and current state of development, but also the level of effort already being applied in each case. Technical investigations at the Transportation Systems Center into several of these areas have resulted in the publication of the reports listed in the Appendix.

7. CONCLUSIONS

Although this analysis was conducted using the Boston area as a data base, these conclusions are considered to be generally applicable to other large urban areas as well:

(a) Dual Mode systems appear to be sufficiently attractive to warrant further technological development.

(b) For urban-wide applications, a Dual Mode system which includes both buses and personal vehicles is more effective than one consisting of either type exclusively.

(c) A Dual Mode transportation system benefits from the use of various Dual Mode concepts throughout its development. An effective first step would be to install a limited network Dual Mode minibus system, with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.

7.1 APPLICABILITY CONSIDERATIONS

The results presented here are for only one scenario and for urban-wide implementation of the concept. It is expected that different demand patterns, population densities, and urban forms would lead to some differences from the results obtained in this analysis. The rather extensive rail rapid transit system in existence in Boston, together with the extremely dense downtown district with poor surface arterial circulation, forced the network design and operating policies for the alternatives examined to be considerably different from those which would be expected in other scenarios. The prohibition of Dual Mode vehicles from the downtown streets would probably not be necessary in cities with a lower population density and better downtown arterial circulation. The differentially priced downtown and peripheral parking with transfer to transit might not be as desirable elsewhere, nor would the extensive tunneling for the downtown network necessarily be required. In Boston the analysis examined Dual Mode and transit both as complementary and as competing modes. This would not be the case in cities which do not have an existing investment in rapid transit.

If the bus portion of the Dual Mode system provided the entire transit service for a community, more extensive off-guideway local service and transfer service would be required, with a consequent increase in modal split.

APPENDIX

Technical investigations at the Transportation Systems Center into a number of critical areas of Dual Mode technology have resulted in the publication of the following reports:

"Modern Control Aspects of Automatically Steered Vehicles," DOT-TSC-OST-72-3 (December 1971)

"Automated Guideway Network Traffic Modeling," DOT-TSC-OST-72-7 (February 1972)

"Alternative Dual Mode Network Control Strategies," DOT-TSC-OST-72-10 (March 1972)

"Accumulative Probability Model for Automated Network Traffic Analyses," DOT-TSC-OST-72-30 (October 1972)