HIGH SPEED GROUND TRANSPORTATION

by
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SUMMARY

The planning for and the initiation of the research and development program for high speed ground transport carried out under contracts to the Department of Commerce is described.

Several potential systems and subsystems for a high speed rail-like system for the Northeast Corridor are described which conceivably could be built if economic, political, and social factors all favor such action.

INTRODUCTION

In 1962 the late President Kennedy initiated the Northeast Corridor Project, assigning it to the Department of Commerce. Much of the impetus for the program came from Senator Claiborne Pell of Rhode Island who had long recognized the importance of public ground transportation between the cities of the Northeast Corridor.**

The project had as its objective the determination of need for transportation between the cities of the Northeast Corridor and possible improvements in the public ground transportation mode, specifically rail transportation, which would make such a system attractive to the users.

In May and June, 1963, the Department of Commerce awarded six study contracts to several firms which submitted reports which were programmed to:

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**The Northeast Corridor is roughly defined as that portion of the eastern seaboard stretching from Norfolk, Virginia to Portland, Maine, and inland as far as Albany, New York, and Harrisburg, Pa.

1. Forecast the passenger travel demand and its division among transportation modes in the Corridor to 1980.
2. Appraise the feasibility of rail transportation to handle anticipated travel demand in the Corridor for this period.
3. Appraise the feasibility of conventional air transportation to handle anticipated travel demand in the Corridor during the same period.
4. Quantify the demands which will be placed on the highway system of the Corridor to 1980.
5. Explore the problem of passage of a high-speed rail passenger system through the New York metropolitan area.
6. Forecast the demands which freight shippers will place on the Corridor transportation system to 1980.

As a result of these and other in-house studies, the Department of Commerce was able to report to President Johnson in July of 1964 with the following predictions:

1. The corridor population is 21% of the nation in 1960, standing at 38,000,000. By 1980 the percentage will increase slightly and the total amount will rise to 51,000,000.
2. The demand for travel between the cities of the Northeast Corridor will increase from 150 to 250 percent by 1980.

Commerce also made the following very general recommendations:

1. Engineering studies be undertaken on high speed rail facilities.
2. A basic research and development effort leading to higher speed systems be undertaken.
3. That there be field tests of high speed trains.
4. That general economic models be developed which would predict the economic performance of existing and new transportation systems.
5. That more precise estimates be made of demand for travel in the future.
6. That there be technical and economic evaluations made of work of others in the field of transportation.

The White House accepted these recommendations and further directed the Department of Commerce to report back to the White House with a program by October 15, 1964.

Since any major program affecting the civilian economy undertaken by our Federal Government must in fact have significant political support, and since the intercity transportation problems involve the major cities, an effort was made to secure the reactions of the mayors of the major cities in the corridor. The general reaction was, I believe, that the present rail system needed to be upgraded to provide better service, better schedules, clean stations and trains. This effort would be the easiest to undertake and the quickest to have any effect, if any.

An alternate group of advisors to the Department of Commerce recommended that it would be feasible to operate trains on the existing right of ways (with improvements) at speeds upwards of 150 mph, but that operating at such speeds on a day to day basis required technical improvements which could be brought about by a two to three year R and D effort.

MIT INITIAL PLANNING EFFORT

At this stage in early September, 1964, MIT was asked to assist in the basic planning for the intercity transportation system. The major problems were: should the relatively short range program of upgrading the existing system instituting better service be undertaken; should the system be upgraded to 150 mph involving major expenditures on the roadbed and some R and D effort or should something else be done.

To respond to this challenge we assembled on very short notice some 30 professors drawn from aeronautical, civil, electrical and mechanical engineering, and the departments of city planning and political science. With this group a major report was written and submitted to the Department of Commerce on October 12, 1964. This report presented conclusions which in essence were as follows:

a. Only by bold technological innovation, involving extensive research and development which exploits fully the nation's advanced technical resources, can the United States achieve a new, efficient and competitive system for transporting people and goods at very high speeds in densely populated regions such as the Northeast Corridor.

b. A new high speed ground transport (HSGT) system could be achieved technologically. It would differ radically from passenger trains and railways as we know them today. It would be, in fact, a new mode of inter-city transport designed to serve urban and suburban areas efficiently.

c. Main line vehicle speeds exceeding 300 m.p.h. and averaging 200 or more m.p.h. are needed to provide the character of service to which the public is entitled in the technological era ahead.

d. Wholly new kinds of vehicles, guideways, operational and control systems are required. It is realistic to expect that technical and system cost problems could be brought within reasonable limits by proper design and support of a program of research, development, and advanced engineering.

e. To bring about the advances in HSGT technology and design, expenditures of the order of $120 million may be required for the applied research and engineering development. A total project cost cannot be estimated until an overall system design is selected.

f. The research, development, engineering, and construction phases could be overlapped, and a range of possible schedules with frequent checkpoints for commitment decisions could be established. For example, if detailed studies were initiated in 1965, specific research and development tasks could be started in 1966, prototype construction could begin in 1968, and a complete system for the Northeast Corridor achieved by 1976.

g. The HSGT program would have benefits far beyond the Northeast Corridor. The technology of transportation for both intercity and urban area application would be advanced for utilization throughout the nation and the world.

h. For our nation to be underdeveloped in such an important area as high speed ground transportation is neither necessary nor consistent with our position of technological leadership. HSGT deserves careful consideration, both on its own merits and as an incentive to which both the public and private sectors of the economy might respond.

It was further recommended that:

a. The Federal government should initiate action to develop a new system of high speed ground transport.

b. Financial support of the order of $8,000,000 should be provided during the 1966 fiscal year for detailed technical studies of HSGT in order to implement a program of action.

Following the submission of the October, 1964, report, which was also submitted by Commerce to the Bureau of the Budget and the White House, a somewhat more normally paced though intensive study was undertaken by the interdisciplinary team at MIT on the general state of technology in high speed ground transportation. Out of this study there was developed a basic plan of high priority research tasks. To date the following reports have been published and all are available or will be shortly from the Clearing House for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virgina.

Part I Survey of Technology for High Speed Ground Transport, June 15, 1965.

Part II High Priority Research Tasks for High Speed Ground Transport

Part III A Systems Analysis of Short-Haul Air Transportation

Part IV Cost Methodology and Cost Models for High Speed Ground Transport

Still to be published is:

Part IA Bibliography for High Speed Ground Transport.

In the meantime, while we were carrying on our basic planning studies leading to the program for research and development of the technology of high speed ground transport, corrolary studies on demand for travel and on the development of a general economic model were being undertaken by the Department of Commerce or other contractors to that agency. The economic model was, and is, being developed by a group in the Department of Commerce. This model will hopefully predict the response of passengers to travel between cities by the different modes, air, bus, car, train, as they evolve and improve with time. Hopefully the model would provide one mechanism for evaluating what improvements in transportation systems would be economic in the very general sense.

MIT's effort was, and is, restricted to the technology of high speed ground transport, although it has always been our desire to work on all aspects of transportation including the economic, social and political considerations so necessary for effective transportation planning. Too frequently transportation studies which are made include only limited considerations of all aspects of the problem.

NATIONAL LEGISLATION

In January, 1965, President Johnson in his State of the Union message said, "To encourage long overdue improvements in surface transportation in our densely populated regions, I will propose legislation to authorize a comprehensive program of technical research and development on high speed intercity surface transport." Later, in March, 1965, he sent a message to Congress requesting specific funds for the High Speed Ground Transportation Study. Both recommendations were in accord with MIT's basic recommendation of October 1964.

In late spring and summer of 1965 hearings were held by both House and Senate Committees on Interstate and Foreign Commerce, and the legislation was acted on favorably and signed by President Johnson on September 30, 1965. This was a historic occasion in that for the first time major funds were to be committed by the federal government on research and development for transportation by rail or a rail-like mode.

Transportation now absorbs about 20 percent of our gross national product, yet very little research is done. A modest program has been underway in connection with our federally supported highway program, and much of this program has been effective in bringing modern computational techniques and input-output devices to the problem of highway and bridge design. However, little effort has been devoted to evolving new concepts of vehicles and highways. The railroad industry likewise spends little on research, a miniscule 1/5% of operating revenue. Albeit major progress has been made in the freight handling field and many railroads, notably the New York Central, have been progressive in the field of data processing and associated activities which will tend to make freight movement more economical. But with few exceptions, the business of moving passengers by rail has been a dying business.

On the other hand, the whole air passenger business has reaped major benefits from the substantial research and development program of the Department of Defense. The jet engine and the 707 outgrowth from the KC 135 are but two examples of many.

The rail passenger industry had not benefited from parallel research and development programs. September 30, 1965, was thus a historic date.

PRESENT FEDERAL PROGRAM

The High Speed Ground Transportation bill signed by President Johnson provided basically for a bifurcated program: (1) demonstration projects of moderately high speed trains (125 mph) which will soon operate on the Pennsylvania and New Haven railroads, and (2) a longer range research and development program from which a new much higher speed ground transport system could be designed.

The demonstration projects have as their purpose the determination of passenger response to improved services. Specifically, there will be introduced on the New York—Washington run some 50 new electrically powered MU cars which will operate at higher speeds than the existing trains, with a top speed of 125 mph. This will permit the reduction in running time of New York to Washington from approximately 4 hours to 3 hours. Similarly, a gas turbine powered lightweight three-car train will be operated on the Boston to Providence run. In each case the effect of faster service and other improvements in passenger service will be measured by a careful data collection program.

To date a contract has been let to the United Aircraft Corporation to produce two three-car gas turbine powered trains which appear to be well designed according to the best of current technology. In addition, a contract has been let to the Budd Company to produce four test vehicles which will be instrumented to obtain vehicle performance at high speed on a test track near Trenton, New Jersey.

The second portion of the program, that is, the long range research and development effort, has also been initiated with two research contracts under way, one with MIT on 15 technological research tasks, and the other with Rensselaer Polytechnic Institute to investigate the potential of a specific transportation system proposal. The MIT tasks will be described later in this paper.

Other research contracts will be initiated in the near future by the Department of Commerce in this first year of a programmed three year effort. As originally planned, the

TABLE I

High-Speed ground transportation research, demonstrations, and national statistics program, fiscal years 1966-68

	Fiscal Year 1966	Fiscal Year 1967	Fiscal Year 1968
I. Research and Development Program			
Administration	$ 310,000	$ 310,000	$ 310,000
Test Track	4,000,000	2,000,000	2,000,000
Gas Turbine	500,000	--------	--------
Rail technology	2,400,000	8,890,000	9,190,000
Research in high-speed ground trans.	2,400,000	12,400,000	17,400,000
Cost methodology	390,000	400,000	100,000
Total	10,000,000	25,000,000	29,000,000
II. Demonstration Projects			
Administration	$ 100,000	$ 100,000	$ 100,000
Equipment and operation:			
Pennsylvania Railroad. .	5,400,000	4,200,000	--------
New Haven	2,000,000	1,500,000	1,500,000
Data collection	200,000	300,000	300,000
Accounting	100,000	100,000	100,000
Experiment design	100,000	--------	--------
Improvement experiments .	100,000	800,000	100,000
Total	8,000,000	7,000,000	3,000,000
III. National Transportation Statistics Program			
Information system, development and operation . .	$ 500,000	$ 800,000	$ 500,000
Standardization and adjustment of information system to collection procedures of other agencies	500,000	750,000	600,000
Data collection	1,000,000	1,450,000	1,900,000
Total	$2,000,000	$3,000,000	$3,000,000

expenditure of funds under the high speed ground transportation bill was as given in Table I. Whether this planned expenditure will be carried out is of course uncertain, since funds must be appropriated yearly by Congress. Already the effect of the Vietnam war is evident since the present Administration budget message which has been sent to Congress has increased in funds for the second year to $24,000,000 from a first year effort to $18,250,000, although a larger increase was originally programmed.

INTERCITY TRANSPORTATION

In 1960 intercity travel in the Northeast Corridor was divided between the various modes as follows: 20.6 percent by rail; 11.9 percent by bus; 7.5 percent by air and 60.0 percent by automobile. With increased travel demand by the 1980's, additions to capacity and improvements in each mode seem appropriate. Looming as very significant on the horizon is the possibility of short range aircraft operating either as VTOL, jet lift planes, STOL or helicopters. The potential for such aircraft operating from minimal size pads and terminal facilities essentially as air buses, obtaining near all weather operational capability by the use of inertial navigation, has been studied at MIT by Professors R. Miller and Simpson with others under Project Transport.

It seems, however, that conventional aircraft involving traditionally long runways will be limited in numbers due to the difficulty and cost of building additional airports near major centers. New York City has for several years been unable to select its fourth major airport and there are some that doubt that it will be built.

Obviously intercity travel by automobile which now has a major share of the traffic will continue in importance, although the problem of land taking for highways is becoming increasingly difficult from economic, political and social considerations. Proposed automated highway systems, although not yet really evaluated, appear to offer such limited increase in capacity that they may not be a realistic solution.

The problem of planning additional facilities for intercity travel is complex, for a variety of reasons:

1. There are already extensive facilities constructed, such as the rail system, the highway network and the major airports, which tend to force new solutions as mere expansions of older systems.

2. Demand for travel is increasing at a burgeoning rate due to increase in population, the affluence of our society, and changes in our modes of work. A factor which might tend to decrease travel is that of more effective communication such as closed circuit television, an obvious example for communication between groups of people.
3. Additions to existing systems to permit capacity increases lead to major economic and political problems as "no one wants the new highway near his door unless such a location will prove to be of direct economic benefit to him."
4. The present highway automobile system is grossly inefficient in terms of space requirements for passengers moved. This arises in part because of inefficient scheduling (averages of 1.4-1.7 passengers per car) plus relatively inefficient packaging as used in most conventional automobiles.
5. Present systems are inefficient in terms of intermodal transfers. As an example, travel time to the airport in such cities as New York, Chicago, Los Angeles, is frequently a major part of the total travel time, door to door.
6. Many public agencies now are involved in planning or regulatory activities over transportation systems. Further these agencies are modally oriented, i.e., the FAA, the CC, the BPR, etc. (Plans for a new Department of Transportation may overcome these difficulties.)
7. Many restrictions on efficient transportation now exist, as witnessed by restrictive legislation on size of crew required to man railroad trains in certain states.

DESIRABLE TRANSPORTATION CHARACTERISTICS

Considering only the case of passenger transportation, certain characteristics appear to be desirable at least to a major portion of the travelling public.

1. Minimum Travel Time from Door of Origin to Door of Destination: This desire is particularly important for business travel, and specifically for commuting.

2. High Predictability of Arrival Time: The present efficient air travel system between major cities is degraded by the variance in arrival times due to weather and traffic conditions. Thus, to be certain to be at City X for a specified meeting time frequently we are forced to be conservative in establishing a departure time.
3. Departure Directly from Door of Origin: One of the obvious major advantages of the automobile is its inherent mobility. It can go directly from one door to another, albeit deterred by traffic jams, required space for parking, etc. This, plus the concomitant advantage of providing convenient baggage space, has contributed in major part to its popularity.
4. Minimum Number and Delay Time of Interchanges: These are obvious criteria.
5. Attractiveness of the Travel Function: While there are those of us who delight in the driving function, particularly if on a back road or at Limerock, there are others who treasure the ability to read in comfort or to work while travelling. There is also an occasional one who delights in sightseeing despite the blandishments of the movie or stereo music. What is important, however, is the ability to perform functions other than the operation of the vehicle.
6. Minimum Undesirable Effects on Surroundings: The obvious detrimental side effects of transportation systems are their noise, air pollution products, vibration or pressure wave effects, and undesirable visual or aesthetic effects on people, houses, buildings and countryside. These should be minimized in a desirable transportation system.

SOME POSSIBLE SYSTEM CONCEPTS

Many possible systems could be chosen but to date none have been selected, nor is it likely that any specific system will be chosen until a number of the technological and economic studies are completed. The purpose of this presentation is, however, to give some idea of a range of concepts which have been suggested.

A system consists of many components, some of which are not compatible with others. Thus there is the network, the guideway, the vehicles, the propulsion system, and the control systems.

Network

Since one of the desirable objectives of a transportation system is to minimize travel time from door of origin to door of destination, the system selected should provide easy exchange with other modes of travel. Further travel on any sector of the network itself should be accomplished with minimal lost time, if any, at the nodes. Further, access to the network from any place in the corridor must be rapid. Obviously the extent and character of the network must be a function of potential demand for travel plus a consideration of the effect of other modes of travel which will interface with the new system. A number of potential network configurations is shown in Figure 1.

At this stage of our research we* are studying the general problem of flow in a network and are looking specifically at the problem of dispatching policies and vehicle size and groupings to optimize availability and passenger delay. No work is being done at this stage to locate and select a network for the Northeast Corridor.

Switching and Capsule Concepts

Since a major objective of any new system might be to minimize time of travel, several vehicle concepts should be considered. An obvious technique involves the use of express and local trains,** but to make such a system effective either these vehicles must be capable of being switched at high speed, or high speed capsule exchange between adjacent vehicles on parallel guideways must be provided for. Possible concepts are shown in Figures 2 and 3. For the case of vehicles which have a fluid suspension (that is, air cushion or air bearing) switching vehicles at speed may require special techniques, some of which are illustrated in Figure 4.

*By Professor Bisbee and supporting staff in Civil Engineering.

**The trains may be individual vehicles, or groups of vehicles coupled mechanically, or by electronic control systems.

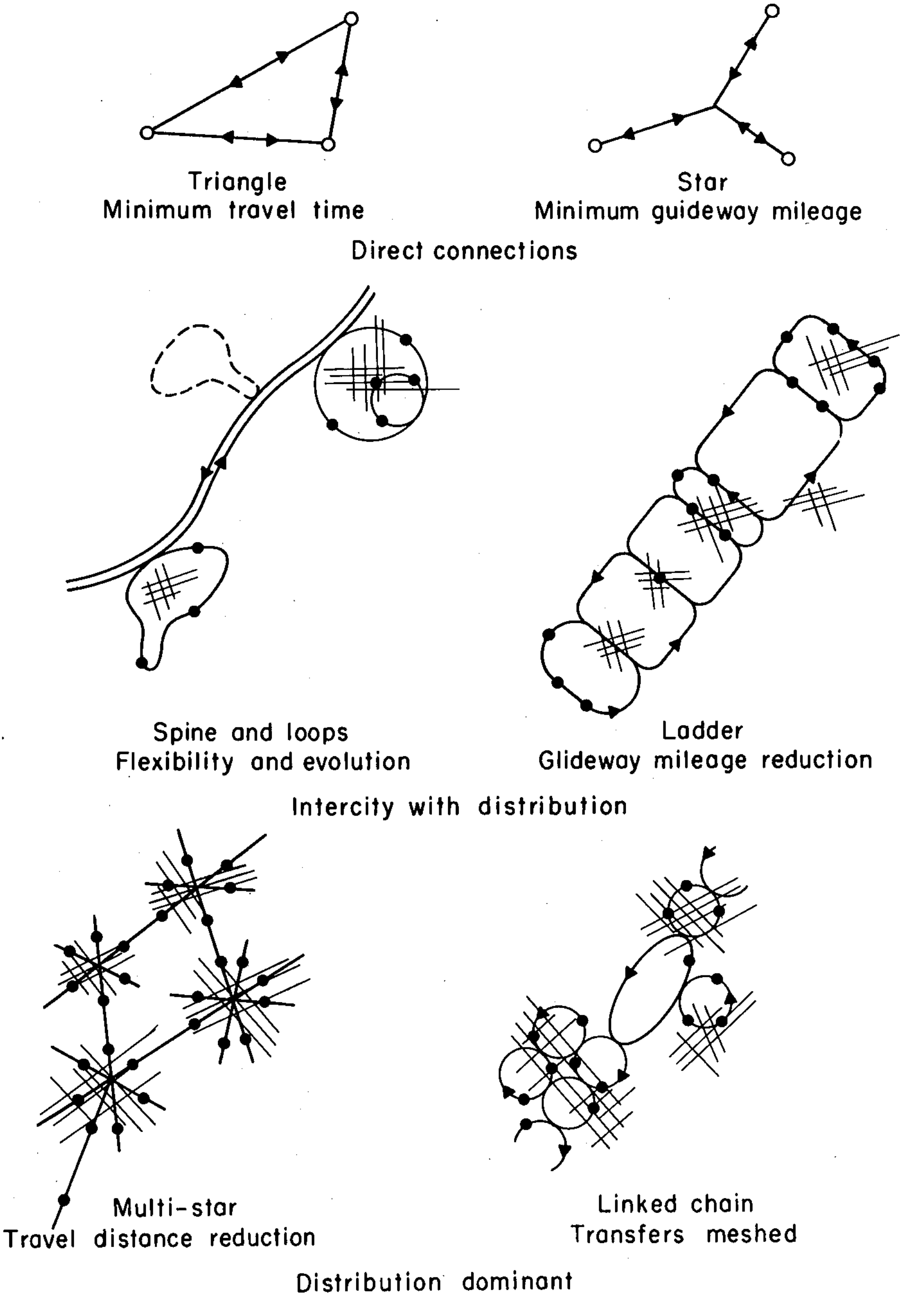

Fig. 1. Some Examples of Network Configuration

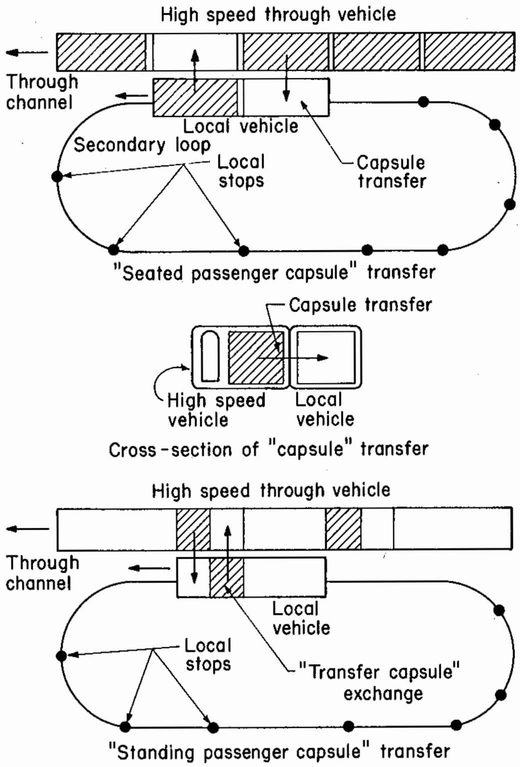

Fig. 2. Alternate Capsule Transfer Configuration

Propulsion Systems

A variety of propulsion schemes are under study. Energy sources available are chemical, electrical or nuclear. Force generators may be ducted fans, ejectors, linear electric motors, linear turbines, propellors, ramjets, rockets, traction wheels or turbojets. Energy converters may be electro-magnetic, reciprocating engines or turbines. The force may be applied to the vehicle by use of gravity or a force field which is electromagnetic; by use of impact reaction in which the vehicle accelerates a portion of the environment with respect of itself, or in which the vehicle carries reaction mass. In addition the force may be applied by mechanical or fluid traction or it may be applied by impact. This very general listing may be illustrated by some practical systems which are now in use or under consideration.

An obvious technique is the use of electric traction motors in which the energy is supplied from a central source and the force is applied by mechanical traction.

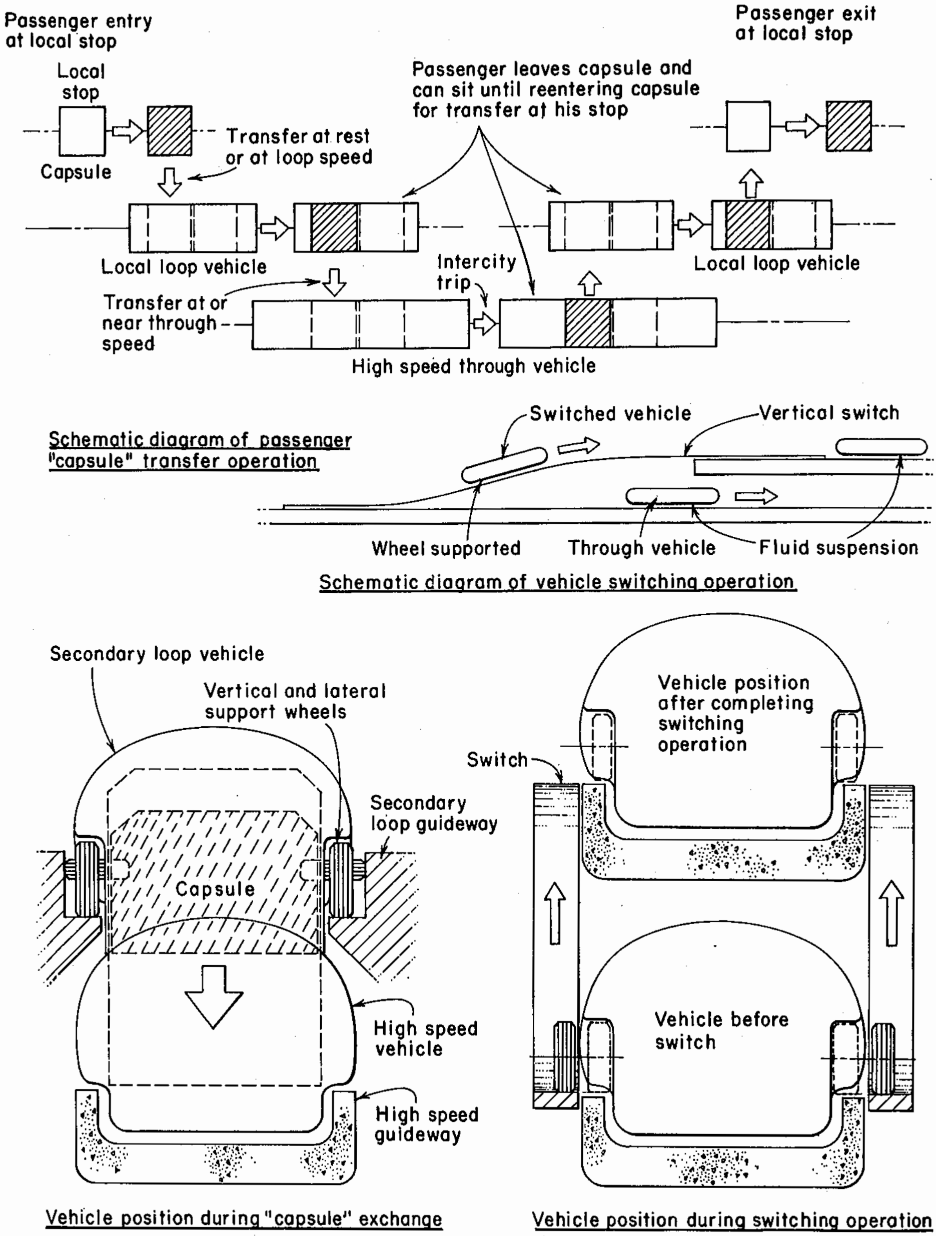

Fig. 3. High Speed "Capsule" Transfer and Switching

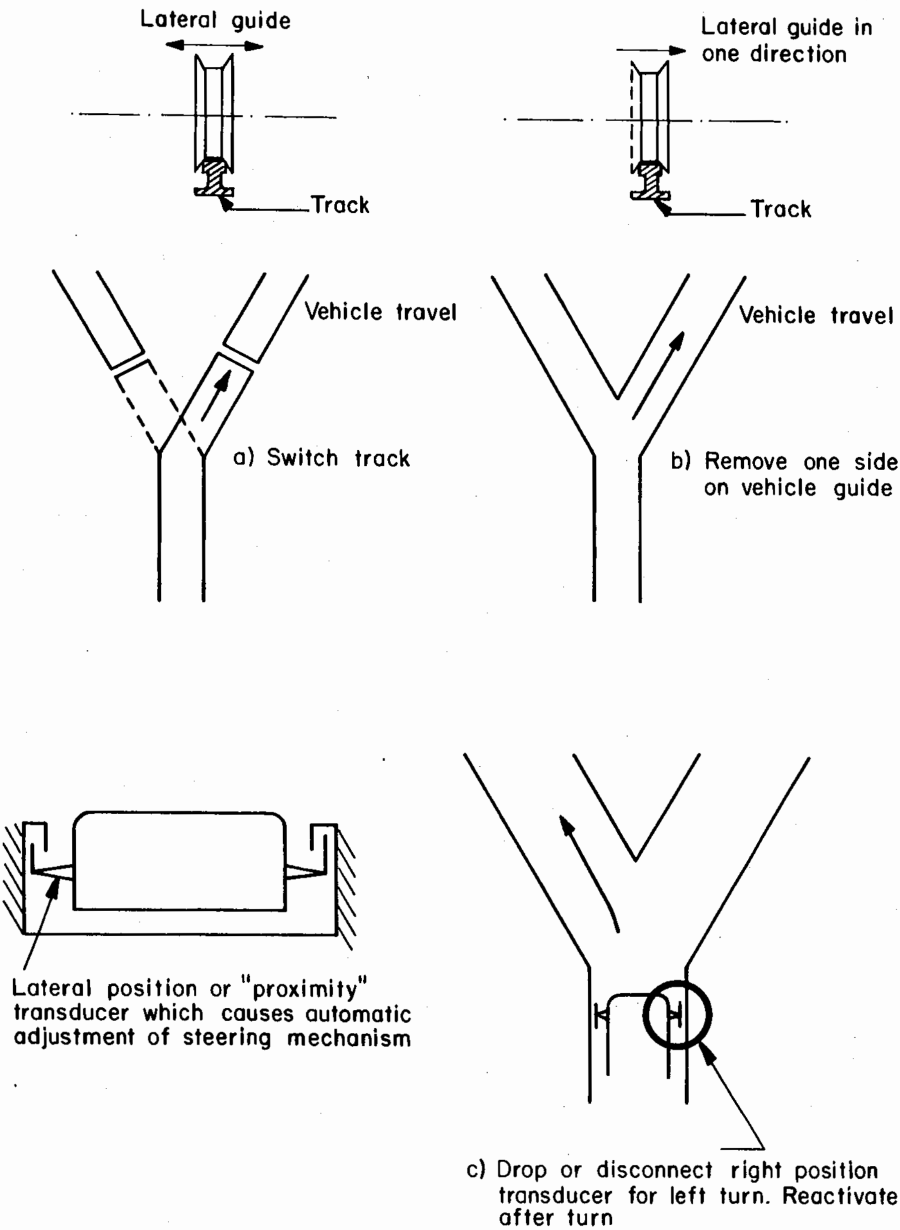

Fig. 4. Alternate Switching Modes

This is the basis of propulsion of many of our present systems, including the new Tokaido Line of Japan. A limitation to this system arises from the problem of getting power to the vehicles at high speed. The Japanese have solved this problem for sustained speeds of 125 mph but the technique must be revised for higher speeds. A second equally serious defect comes from the limitation on tractive effort that can be applied through the wheels. As the speed of the vehicle increases the required tractive effort increases non-linearly due to drag forces. Possible solutions involve enclosing the guideway and evacuating the system to reduce the drag forces, but the magnitude of reduction necessary to be effective is substantial.

This suggests a second propulsion technique, namely the pneumatic tube, which was used as early as 1870 in a pneumatic train in New York City and was constructed by Alfred Ely Beach, an early editor of Scientific American. More recently, this concept has been the basis of a serious proposal made by L. K. Edwards* (See Figures 5, 6, 7.) Edwards has also added the concept of using gravity to accelerate and decelerate the trains by using appropriate tunnel profits.

Another obvious scheme is the use of a linear induction or synchronous motor. Such a motor may be powered either from the guideway or from the vehicle. The choice depends on a number of trade-offs. If the motor is in the track, a large amount of metal (copper and steel) is required, but no on-board propulsion, except for environmental controls. If the motor is aboard the vehicle, less metal is required, unless vehicles are operated at very high densities. However, there remains the major problem of getting the power to the vehicles.

Another potential system involves the use of the "air gulper' in which the air in front of the vehicle is displaced by an on-board compresson system and expelled behind the vehicle. A significant application of this principle is being studied by Professor Joseph Foa and his colleagues at Rensselaer Polytechnic Institute, under contract to the Department of Commerce. Figures 8 and 9 present artists' versions of the concept in which the vehicle is supported on air

*L.K. Edwards, "High-Speed Tube Transportation", Scientific American, August 1965.

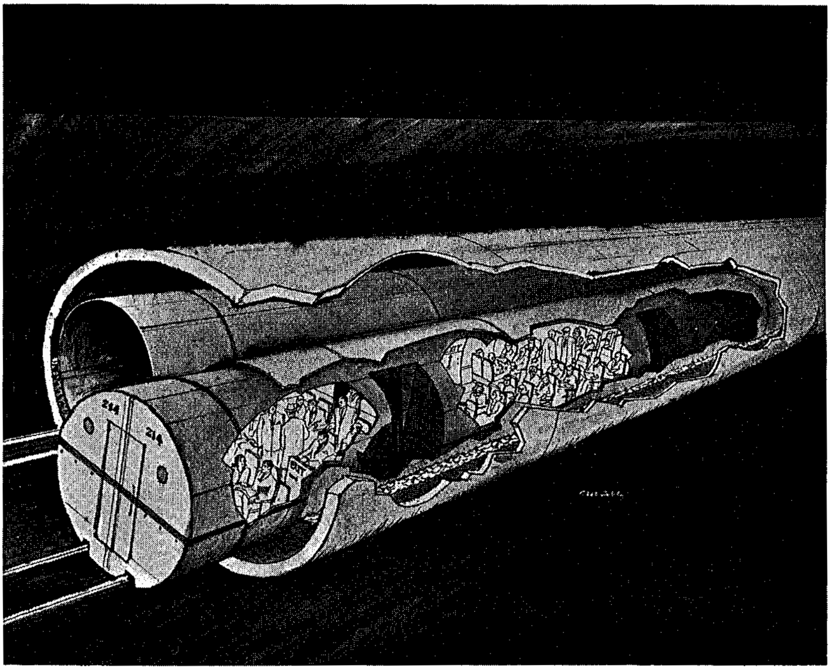

Fig. 5. Edwards Scheme - Sectional View

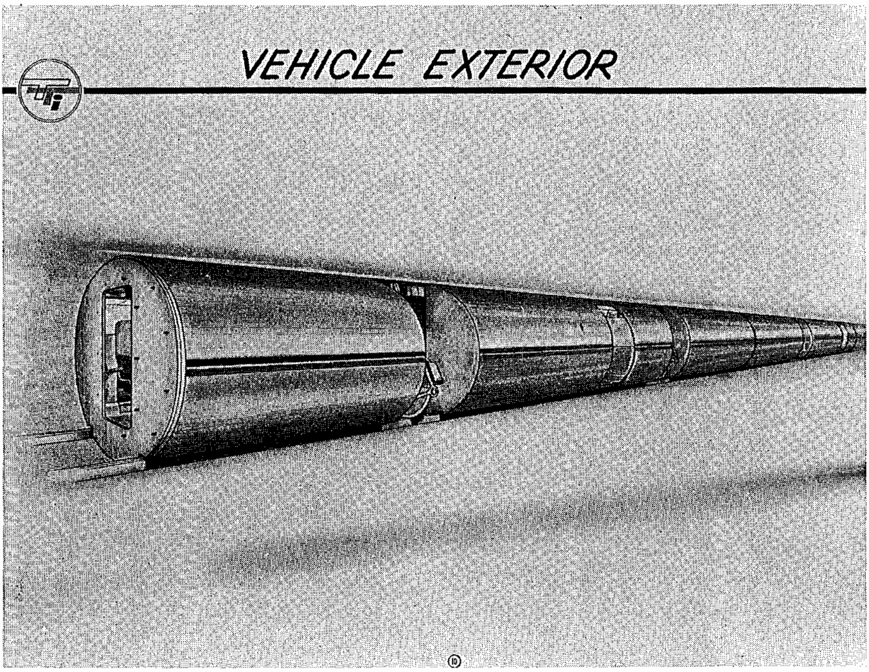

Fig. 6. Edwards Scheme - Vehicle Profile

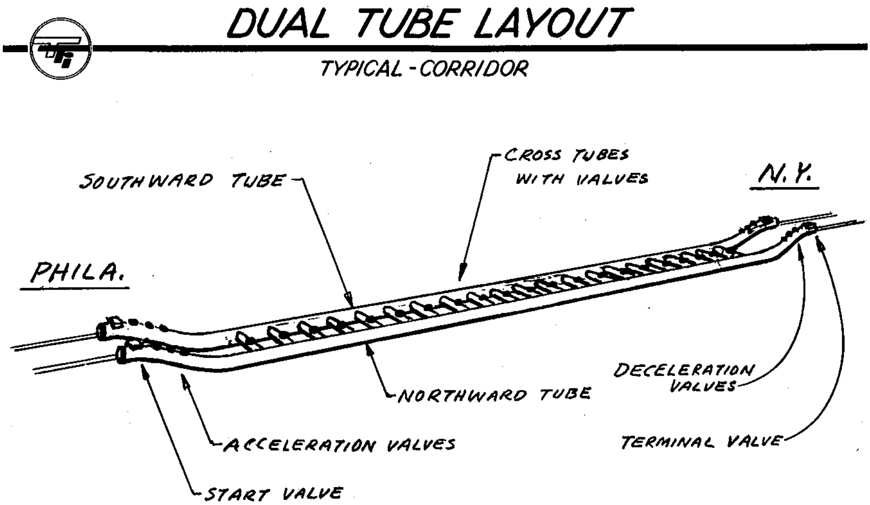

Fig. 7. Edwards Scheme - Tunnel Layout

pads in a tube. On-board propulsion is required. Gas turbines and electric motors are being considered. The latter application, however, implies getting power to the vehicle, a major technical task now under study.

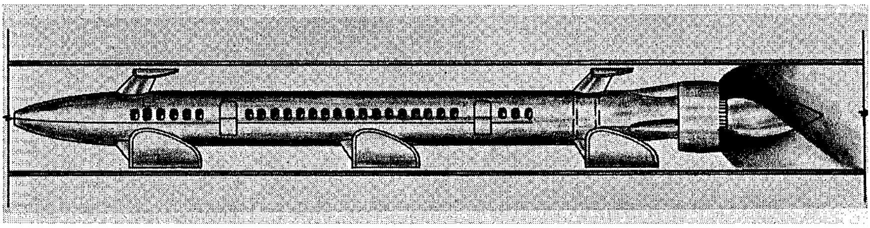

Fig. 8. Foa Scheme - 375 mph Cruise Speed

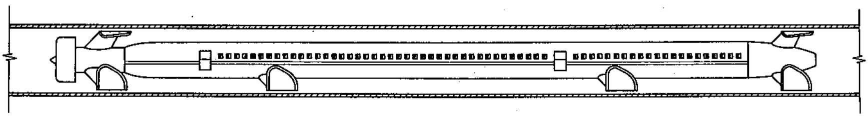

Fig. 9. Foa Scheme - 475 mph Cruise Speed

SUSPENSION SYSTEMS

The guideway and suspension system for an HSGT vehicle must support and guide the vehicle safely and limit its vertical, lateral and angular motions to levels which are acceptable to the passengers. Since we are thinking of very high speeds, guideway imperfections which may be inherent due to construction limitations or to subsequent distortions due to wear, temperature variations, or settlements or heaves of the underlying foundation must be limited, or the suspension systems must be capable of accepting large variations.

We* are considering in depth at this stage mechanical and fluid suspension systems. At this moment we are developing a generalized model for suspension systems applied to any positions on an elastic vehicle. The model will be computerized so that the characteristics of suspension systems acted upon by any guideway irregularities can be evaluated.

Obviously mechanical suspension systems can be improved if they are made active, that is, powered. This area of technology has only been tentatively explored largely because the cost and complexity of such systems have not been justified for the relatively low speed ground transport vehicles in use. We have under way an investigation of the desirable characteristics of active suspension systems to determine the practicality of this device.

An alternative and extremely attractive suspension system is that of the air cushion. The unsprung mass of such a system is negligible, thus the coupling between vehicle and guideway can be very soft. Accordingly, larger deviations from flatness can be tolerated than would be possible with mechanical systems. Further, since the vehicle can be supported over areas which are large relative to wheels or tires, the contact pressure on the guideway can be small, leading to less serious problems for the guideway design.

Fluid suspensions may be of several types, as illustrated in Figure 10. The simplest air cushion is the plenum, which is essentially an inverted box. More advanced concepts include diffusing actions within the plenum which tend to improve the efficiency of the cushion. Fluid suspensions

*Professors Richardson and Paul and supporting staff in Mechanical Engineering.

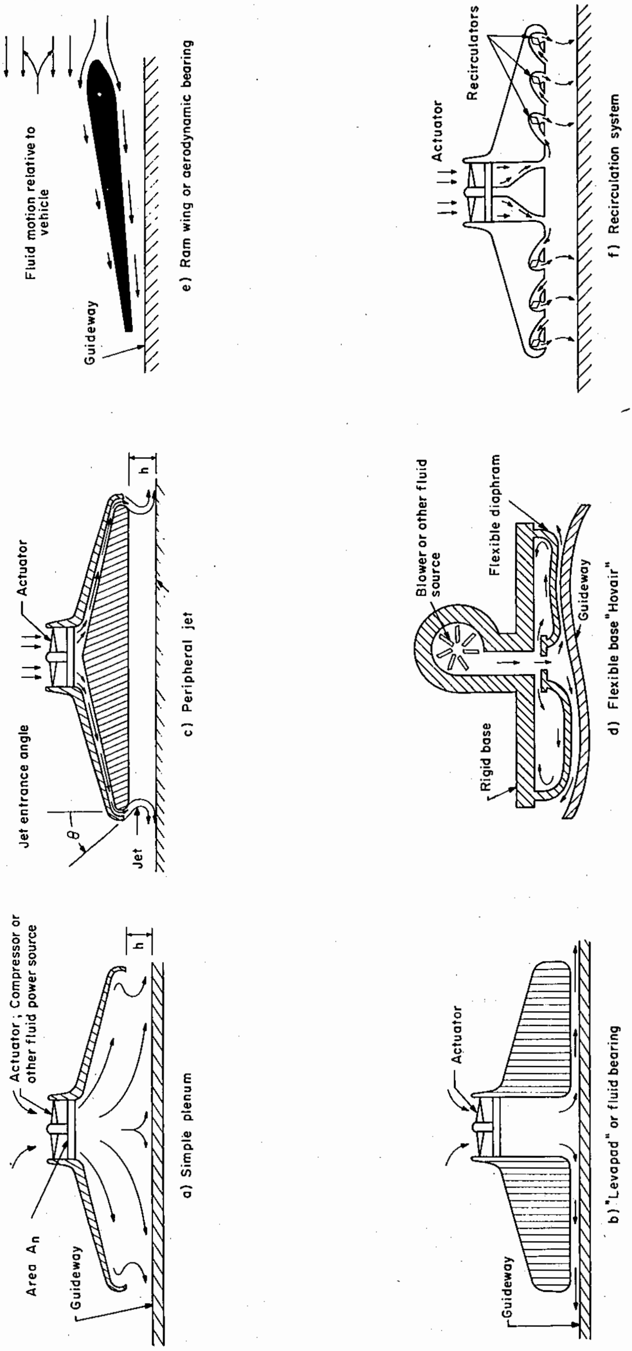

Fig. 10. Basic Types of Fluid Suspension

are currently used commercially in the British Hovercraft, the French Bertin systems and the flexible base plenum types developed and patented by the General Motors Corporation.

No application of these concepts has been made to the high speed vehicles we deem necessary for the HSGT system. Accordingly, basic studies of the dynamics and stability of fluid suspensions is currently underway.

Magnetic suspensions are theoretically possible and some applications have been made in instruments such as gyroscopes, galvanometers, etc. for vehicle support in conjunction with linear induction motors used for propulsion. A one-passenger vehicle has been built and tested at the Westinghouse Research Laboratories. The concept of using magnetic suspension has been evaluated by Project Transport personnel and is deemed worthy of further investigation for potential use in an HSGT system. No major research is being conducted on this subject under our research program this year, however.

GUIDEWAY

We call the roadbed a guideway in order to permit consideration of all types of suspensions, e.g., wheels on rails, fluid bearings, magnetic suspension, and to imply that we are not restricting our considerations to wheels on rails.

Obviously, the guideway may be located at grade on cuts and fills and through short tunnels, on elevated structures, or underground in soil or rock tunnels. Present long distance ground transportation systems are generally directly on the ground surface. Cuts and fills are used to smooth the existing topography. Use is also made of bridges and tunnels where appropriate. As vehicle speeds have increased it has been necessary to use straighter alignments, involving accordingly higher costs for cuts and fills.

Increasing urbanization has increased both the cost and the political difficulties of acquiring right of way. The political difficulties may well control many future route locations if they are in part surface or elevated routes. Another major constraint on the guideway is the necessity for gentle curves, both horizontal and vertical, brought on by the high speeds to be used in the system.

These factors have led us to seriously consider tunnels for portions of the proposed systems. Obviously, there will be trade-offs in location of the guideway as a function of the topography, geology, builtupness, and the system characteristics. Table II presents a comparison of infrastructures based on a number of considerations.

There are a number of research areas which must be pursued to effectively evaluate alternate guideway configurations and to permit design and construction. The prediction of settlement of fills and heaves in cuts is now not sufficiently accurate to permit the design of a high speed system. Accordingly, a portion of our research effort this year is directed to this end.* The other area of intense activity is that of increasing our capability of tunneling economically. There have been developed in recent years a variety of tunneling machines which have in some instances been used very effectively. Their continued and substantial development has been recommended in our research plan.

A supportive and hopefully very influential effort which has been undertaken this year at MIT relates to the possibility of weakening rock so that tunneling machines can be more effective. Our research** aims at reducing the surface energy and/or increasing inherent flaw size in rocks to reduce the tensile strength at failure.

CONCLUSIONS

While it is very early to forecast the ultimate developments under the Northeast Corridor Project, it is fair to state that a substantial research effort on the technology of high speed ground transportation has been initiated. While to date only two contractors*** have started, it is planned and expected that a number of other groups including industrial firms, educational and research institutions will be shortly brought under contract to the Department of Commerce to investigate in depth the various technologies involved and to engineer in a preliminary way possible but potentially competing systems which at some future date will be evaluated economically and politically for final selection

*By Professors Lambe and Hirschfeld of Civil Engineering, with supporting staff.

**By Professors McGarry, Moavenzadeh, Williamson and Wissa of Civil Engineering.

***MIT and RPI

TABLE II. COMPARISON OF INFRASTRUCTURES

Trade-Off Factor	Tunnel		Surface	Elevated
	Deep Tunnel	Shallow Tunnel		
Route Location	Great flexibility	Some constraints in metropolitan areas due to deep building foundations and underground utilities.	Very many constraints in metropolitan areas due to land use.	Some constraints in metropolitan areas due to land use and street location
Interference with existing activities	None	Interference with utilities, etc.	Very great, especially in urban areas. Roads, etc., must be bridged across guideway.	Interference with structures and air rights.
Isolation and safety to public	Very good. Complete isolation from public	Same as for hard rock.	Poor. Special structures (fences, etc.) must be provided for public safety and noise abatement.	Good. Moderate isolation from public
Vulnerability	Relatively invulnerable except to deliberate sabotage. Difficult to restore.	Same as for hard rock.	Moderately vulnerable, moderately difficult to restore	Extremely vulnerable; very difficult to restore
Aesthetic and psychological acceptability	Exterior appearance no problem. Passengers may suffer from enclosed effects and lack of visual experience	Same as for hard rock.	Similar to present systems (highways, railroads)	High visibility of structure will cause problems similar to elevated highways
Transient movements	Negligible	Probably negligible	Possibly on order of 0.1 inch	Possibly on order of inches; may be coupled with vehicle speed.
Long-term movements	Probably negligible except in earthquake areas	Possibly on order of inches	Possibly on order of inches or feet (if such motions are intolerable, poor soil areas would be bridged).	Possibly on order of inches.
Cost of right of way	Negligible	Negligible	Very expensive, especially in metropolitan areas	Expensive but reduced by utilizing air rights over existing roadways.
Cost of construction	Expensive but uncertain (development of tunneling machines; unexpected zones of defective rock encountered during construction).	Expensive but uncertain. High costs for tunneling, locating and moving utilities, and shoring foundations.	Least costly	Expensive due to structure costs, especially in urban areas.
Cost of operation	Costly due to requirements for access and ventilation	Similar to hard rock, but less costly.	Least costly	Slightly more costly than surface route.

and possible implementation by actual detailed design and construction.

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