A STRATEGIC VISION OF AVCS MAGLEV
AND ITS SOCIOECONOMIC IMPLICATIONS

by

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(ABSTRACT)

The purpose of this research is to develop a conception of a transportation system called AVCS maglev which is the synergistic combination of two promising concepts, AVCS and Maglev, and to assess its potential as a transportation strategy to cope with the forthcoming challenge of the mobility, safety, environmental protection, and economic growth of the United States. The emphases are put on investigating suitable technological aspects, selecting suitable operational control concepts, assessing economic viability, and determining socioeconomic impacts of the system. Also, the National Development Model (NDM) is developed and analyzed to obtain a deeper understanding of the rational policy formation about the U.S. socioeconomic development of the next century, based on the premise that development means improving both quantity of life and quality of life. NDM is organized into six sectors: (1) Industrial Sector, (2) Environmental Sector, (3) Infrastructure Sector, (4) Social Development Sector, (5) Demographic Sector, and (6) Employment Sector. Four policy alternatives are identified, based on the key issues relevant to the future development patterns, and analyzed by computer simulation: (1) Social Development Policy, (2) Industrial Development Policy, (3) Infrastructure Development Policy, and (4) Environmental Protection Policy.
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1. Introduction

1.1 The Problem

President Dwight D. Eisenhower [1] said, "Our unity as a nation is sustained by free communication of thought and by easy transportation of people and goods... Together, the uniting forces of our communication and transportation systems are dynamic elements in the very name we bear -- United States. Without them, we would be a mere alliance of many separate parts." Likewise, a nation's unity and vitality depend on the efficiency of its transportation system because it is a crucial means of socioeconomic activities.

However, in the United States, traffic delay due to congestion has reached alarming levels and is projected to keep on growing. For example, 21 congested airports cost American business and the aviation industry $5 billion annually and by 1997, 34 airports are projected to experience congestion at an estimated cost of $8 billion, even with planned capacity increases in place. On the other hand, jam-packed roads in 29 cities cost drivers $24.25 billion in 1986 through traffic delays, wasted fuel and higher insurance premiums. By the year 2000, 70 percent of peak-hour travelers will experience delays due to highway congestion, which will cost them over $100 billion annually. This urban congestion will continue to spread to intercity corridors. Also, there continues to be too many transportation accidents and fatalities. The problem is greatest on highways, where 41,000 people died and more than 5 million were injured. The figure could rise dramatically as highway traffic doubles by the early part of the next century [2, 3].
In addition, vehicles with internal combustion engines are major contributors to air pollution, accounting for 70 percent of carbon monoxide (CO), 33 percent of ozone-producing hydrocarbons, about 50 percent of nitrogen oxides (NO\textsubscript{x}), and 21 percent of suspended particulates. Despite the dramatic reductions in motor vehicle emissions rates over the past two decades, transportation-related air quality problems are likely to persist due to the growing demand for travel by a privately-owned automobile [4].

1.2 The Need

Put simply, traffic congestion means there are more people trying to use a given transportation facility during a specific period of time than the facility can handle with what are considered to be acceptable levels of delay or inconvenience. The consequences of congestion are serious to a community, a region and a nation. These consequences include impacts on the local traffic situation, economic growth, community access, quality of life, environmental quality, and safety. In the United States, traffic congestion will continue to increase, and the conventional approach of the past -- building more roads -- will not work in many areas of the country, for financial, land-take and environmental reasons. Public transportation systems, chronically short of funds, are not seen as an attractive alternative to personal driving.

There is a need to usher in a new era in transportation decision-making. In an ideal society, the transportation system would carry everyone from where they lived to where they wanted to go -- rapidly, economically and without unscheduled delays. It would require optimizing our technological advances to build the transportation system that will consume minimal nonrenewable resources, and that will minimize air pollution, not contributing to potential global warming.
Recognition of this need led to the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), signed by President Bush in 1991. The purpose of ISTEA is to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, that provides the foundation for the Nation to compete in the global economy, and that moves people and goods in an energy-efficient manner.

1.3 The Approach

The challenges posed by current surface transportation problems cannot be solved by the application of a few isolated independent actions. A broad, comprehensive solution is needed to restore and build the future mobility our society will demand. The concept for such a solution is embodied in the term, "AVCS maglev." AVCS maglev is the synergistic combination of Advanced Vehicle Control Systems (AVCS), which is the most comprehensive functional area of Intelligent Vehicle-Highway Systems (IVHS), and the high-speed magnetic levitation technology.
2. Intelligent Vehicle-Highway Systems

2.1 A New Era on Transportation

The six-year, $155 billion Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 reorganizes the highway program, enlarges the area of federal fund expenditure, augments the flexibility in the use of the fund, increases direct funding for transit, and sets up a new category of funding for congestion and air pollution reduction measures. Also, to help the United States compete in advanced transportation technologies, ISTEA significantly boosts funding for the IVHS program and maglev research and development, authorizing $660 million for the former and $775 million for the latter.

Despite the new emphasis on alternative modes, highways still get the lion's share of funding. Authorizations under Title I, which mainly relates to highways, total $121 billion for 1992-1997. That includes $21 billion for the new National Highway System (NHS), which is composed of about 155,000 miles of interstate and other primary routes, and $23.9 billion for a new block grant program called the Surface Transportation Program (STP). The latter program is where the new flexibility comes in. States can use STP funds for work on any federal-aided road, any bridge, transit capital projects, transport planning, research and development, wetlands mitigation, and improvements to accommodate other transportation modes. Also, states can transfer 50% of NHS funds to STP, or 100% with DOT approval. Along with increased direct funding for transit totaling $32 billion, most of it for capital projects, the flexibility in use of funds included in ISTEA restores the balance to the system.

The centerpiece of the ISTEA-funded program is the Congested Corridors Program,
which will receive $501 million, with the remainder going to other research and development activities, including electronic toll collection. DOT will select the corridors based on traffic density of at least 1.5 times as high as the national average and other factors. Half of the money will go to three to ten urban corridors, the remainder to rural or urban systems. The law also mandates the development and implementation of a prototype fully-automated highway system by the end of 1997, and establishment of five new transportation research centers [5].

2.2 Mobility 2000

The focus of ISTEA on new technologies is no accident. Mobility 2000 formally evolved in 1988 from earlier activities and provided an informal, flexible and singularly focused forum for developing what has become known as IVHS. Mobility 2000 rapidly emerged, nationally and internationally, as a unique and vital entity which provided the networking and common direction supportive of national IVHS program development efforts.

The IVHS National Workshop held in Dallas on March 19-21, 1990 was sponsored by government, university and industry, and hosted by the Texas Transportation Institute of Texas A&M University. The Workshop signaled the nation's move from the enormously successful Interstate Highway Program to the IVHS Program [6].

2.3 Elements of IVHS

IVHS include a range of technologies and ideas which can reduce congestion, enhance mobility, improve safety, maximize the efficiency of existing transportation facilities and energy resources, minimize the environmental impact, and promote economic
productivity in the transportation system. IVHS are based on modern communications, computer and control technologies. The program contains five broad, interrelated areas:

- Advanced Traffic Management Systems (ATMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Vehicle Control Systems (AVCS)
- Commercial Vehicle Operations (CVO)
- Advanced Public Transportation Systems (APTS)

Each element will be discussed briefly in the following sections.

2.4 Advanced Traffic Management Systems (ATMS)

A traffic management system (TMS) provides the means to improve the operating efficiency of a roadway network by monitoring traffic conditions, adjusting traffic operations, managing travel demand, and responding to accidents. One example which uses current technology is the use of vehicle detectors, communications, computers and ramp signals to meter the traffic entering a freeway. In order to better manage traffic congestion and maximize the usefulness of the IVHS concept, there is a need to advance the state-of-the-art of traffic management systems by integrating innovative technology and control strategies. The term Advanced Traffic Management Systems (ATMS) refers to systems in which these advances in the state-of-the-art have been included [7].

Simply speaking, ATMS will collect, use and disseminate real-time congestion data on
expressways and arterial streets, and will respond to changing conditions by routing drivers around delays and accidents, effectively reducing costs associated with traffic congestion. ATMS is the basic building block of IVHS. All other functional areas will use information provided by ATMS. ATMS will integrate the management of various roadway functions, such as freeway ramp monitoring and arterial signal control. In more sophisticated applications, ATMS will predict traffic congestion and provide alternative routing instructions to vehicle drivers over wide areas [8].

A great deal of effort is being made to advance the state-of-the-art around the world. In Europe, traffic signal control systems are in place which respond in real-time to network traffic conditions to optimize traffic flow. In addition, the European Community (EC) is sponsoring a collaborative research and development program, called DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe), to improve road safety, promote transport efficiency and reduce environmental pollution. DRIVE is being jointly funded by European governments and industry at a level of almost $150 million over a three-year period, of which half is from the public sector and half is from the private sector [9].

Japan has two major programs — Advanced Mobile Traffic Information and Communication System (AMTICS) and Road Automotive Communication System (RACS). Both programs emphasize communications and traffic control, combining ATMS elements and ATIS elements to provide real-time route guidance to drivers. Using a different communication technology, RACS is a parallel research project. Both systems have already been tested extensively, but the major obstacle to wide-scale implementation of one of these systems is a political decision on which one to implement [10]. In the United States, several programs, such as the Smart Corridor

2. Intelligent Vehicle-Highway Systems
project in Los Angeles and PATHFINDER project co-sponsored by the FHWA, the California DOT and General Motors, are already underway to advance the state-of-the-art, but the funding needed to develop a nationwide program which can compete with the progress made in Europe and Japan is not yet in place.

Advanced Traffic Management Systems have six primary characteristics which differentiate them from the current traffic management systems. First, an ATMS collects real-time traffic data, so that a control center can devise and implement an effective response quickly.

An ATMS responds to changes in traffic flow with timely traffic management strategies. In other words, ATMS detects the changes in traffic flow patterns and in fact, one step ahead, predicts when and where congestion will occur based on real-time information, informing motorists in advance of alternate routes, advising them to delay trips, and making appropriate adjustments to control devices. By doing this, many incidents will be avoided.

An ATMS includes area-wide surveillance and detection systems so that strategies can be devised which are truly optimal from an overall system perspective. The data collected by these systems, particularly origin-destination information, will also be very valuable for transportation planning purposes. Over and above this, an ATMS integrates the management of various functions, including travel demand management, freeway ramp metering, electronic toll collection, and arterial signal control.

An ATMS implies collaborative action on the part of transportation management agencies and jurisdictions so that the user perceives a seamless transportation system.
Finally, an ATMS includes rapid response incident management strategies. It is composed of rapid detection, verification and appropriate response plans. The response plan integrates incident site tactics such as site clean-up and site traffic control, and diversion strategies.

Other components of IVHS will provide better information to ATMS so that it can do the following: (1) better manage normal traffic flow, (2) better cope with incidents, and (3) interact with the intelligent vehicles that will be part of the Advanced Traveler Information Systems [11].

2.5 Advanced Traveler Information Systems (ATIS)

Advanced Traveler Information Systems (ATIS) are those vehicle features which provide a variety of information to assist travelers in reaching a desired destination via private vehicle or public transportation. On-board navigation systems are the essential ATIS building block. Advances in electronic technology have spurred development of a broad assortment of communication systems and media, through which a wide variety of information can be provided either to a driver in a vehicle or to a traveler at home, in the office, or at kiosks, for example, using a personal computer. Fixed information such as electronic route maps, tourist guides and service directories can be accessed in a vehicle through media such as a compact disk or magnetic tape. Vehicle status indications can also be provided through on-board sensors.

While these systems add convenience and security to the traveling experience, they cannot provide the dynamic, or real-time, traffic and roadway condition information which is necessary to reduce travel time, minimize traffic congestion and improve travel
safety. To obtain this information, it is necessary to establish communication links with ATMS described in the previous section. A one-way communication link to the vehicle from ATMS can provide up-to-date information on traffic congestion, locations of accidents, alternate routes, weather and road conditions, parking lot status, optimal routes, recommended speeds, lane restrictions (such as high occupancy vehicle lanes). With a two-way communication link, the vehicle can serve as a dynamic traffic sensor and provide feedback to the traffic management system, allowing the system to predict congestion and provide relief measures beforehand.

ATIS is expected to evolve in three stages -- an Information Stage, an Advisory Stage and a Coordination Stage -- in the 20-year period from 1990 to 2010, according to a Mobility 2000 study [12].

During the information stage, each traveler will be provided with information to improve his or her trip planning and decision making. Most capabilities rely on resources contained within a vehicle or a traveler information unit (such as a personal computer) and are not dependent on any infrastructure. The advisory stage will supplement static information with up-to-date traffic information. In the last stage, each vehicle and the infrastructure will exchange information to optimize the flow and safety of traffic over the entire network.

For several decades, efforts have been made to develop ATIS technologies. The United States led the world in developing the technologies in the late 1960's and early 1970's, but now lags behind both Europe and Japan. Recent competitive efforts in Europe and Japan are spurring the United States to pursue the development of ATIS technologies. Several ATIS operational tests, including Pathfinder in the Smart
Corridor of Los Angeles, TravTek in Orlando, and ADVANCE in Chicago, are already planned or under way [8].

Specific types of ATIS technologies include:

- On-board replication of maps and signs;
- Pre-trip electronic route planning;
- Traffic information broadcasting systems;
- Safety warning systems;
- On-board navigation systems;
- Electronic route guidance systems.

2.6 Advanced Vehicle Control Systems (AVCS)

Advanced Vehicle Control Systems (AVCS) incorporate sensors, computers and control systems in vehicles and on the roadway to enhance drivers’ control of vehicles, to intervene in the driving tasks, or ultimately to relieve the drivers of most driving tasks for greater safety and capacity. For example, collision warning systems will help the driver avoid accidents by alerting him or her to an imminent collision. Advanced systems will enable the vehicle to automatically brake or steer away from a collision. These systems are autonomous to the vehicle. In the future, it might be possible to integrate infrastructure information and control to increase roadway traffic throughput by as much as two or three times. One example of this concept is limited-access, automated lanes where vehicle movements are automatically controlled [8].

Generally speaking, AVCS includes individual vehicle controls, cooperative driver-
vehicle-highway systems, and eventually full automation on certain roadways. Such systems are possible today because of the tremendous advancements in vehicle and roadway sensors, servo systems, image processors, computers, and communication systems. While ATMS and ATIS make driving more efficient by providing the driver with better information about the macro-level conditions which affect his or her decision-making, AVCS can significantly enhance the roadway productivity (capacity, speed) and travel safety by providing information about highly localized and rapidly changing conditions in his or her immediate vicinity and initiating actions based on these conditions. Three levels of AVCS technology are anticipated and planned [13].

- **Level I. Autonomous Driver-Vehicle Systems.** Early AVCS technologies include vehicle-based radar-type systems which detect the presence of obstacles or other vehicles, providing the split second of warning that could prevent most rear-end collisions and intersection accidents.

- **Level II. Cooperative Driver-Vehicle-Highway Systems.** Intermediate AVCS technologies will initially implement lateral and longitudinal vehicle control functions in specific applications such as high occupancy vehicle (HOV) lanes. Vehicles would enter the lanes voluntarily under manual control, but once in the lane, would be under full or partial control, leading to the realization of higher speeds, increased throughput, and reduced collisions.

- **Level III. Automated Highway Systems.** The most comprehensive AVCS application would completely take over driving tasks on dedicated roadways, providing "automatic chauffeuring" of vehicles from on-ramp arrival to off-ramp departure. This application will increase the throughput in both urban freeway and intercity traffic corridors, and realize a new level of safety and mobility through high-speed operation.
Although AVCS is generally regarded as the most futuristic of the IVHS functional areas, the area has received significant attention over several decades and presently, driver warning, perception enhancement and assistance/control systems are under extensive research, development and testing in the United States, Europe and Japan by major automobile manufacturers and component suppliers. The European PROMETHEUS (Programme for European Traffic with Highest Efficiency and Unprecedented Safety) program includes various "Common European Demonstrator" projects on autonomous adaptive cruise control, vision enhancement, proper vehicle operation, collision avoidance, cooperative driving, and emergency warning and calling. In the United States, ISTEAM calls for the development of a completely automated highway and vehicle system. The goal is to have the first fully automated roadway or test track in operation by 1997 [8].

While no major technological breakthroughs will be needed to achieve the goals of AVCS, major non-technological barriers to the deployment of the technologies need to be overcome. These include social, safety, legal, political, and environmental considerations. As for social consideration, public acceptance of AVCS will be a principal concern. In other words, there is concern as to who will benefit from the technology and how the costs will be allocated between direct users and the general public. The question about the effect of AVCS technology on contemporary lifestyles has been raised.

Easily the greatest barrier to deployment is the safety issue because risks will increase if systems do not work as intended. Substantial research and development efforts will be required to minimize failures. Much attention will have to be paid to the public's emotional response to the travel utilizing AVCS and its perception of AVCS safety,
since it is difficult to anticipate human responses to the sensations of utilizing an AVCS, particularly for the more advanced versions in which vehicles may be operating much closer together than they do today. AVCS will significantly reduce traffic accidents overall, but inevitably some accidents will occur due to device malfunction or faulty system design. In addition, the driver has less responsibility for control of the vehicle. Ways are needed to limit the liability risk of AVCS developers, both public and private.

As a political consideration, regional transportation authorities which transcend jurisdictional boundaries will be needed since the automated highway systems will require a much higher level of coordination across jurisdictions than the current highway systems do. Lastly, reduced traffic congestion and fuel-efficient driving will produce less pollutant, but the great increase in traffic throughput will result in net increase in air pollution. The dilemma "more vehicles equal more pollution" must be overcome [13].

2.7 Commercial Vehicle Operations (CVO)

Commercial Vehicle Operations (CVO) systems employ various IVHS technologies to enhance the safety, and productivity of commercial vehicle and fleet operations. Commercial vehicles include trucks, delivery vans, buses, taxis and emergency vehicles.

The safety goal of CVO is to significantly reduce fatalities, injuries, property damage and accident-caused congestion involving commercial vehicles. Technologies involved are driver/vehicle real-time safety monitoring systems including vehicle diagnostic/monitoring and driver status monitoring, driver warning systems including
out-of-lane and obstacle detection/warning and automatic braking, hazardous material information systems including electronic HAZMAT tracking, and site-specific highway warning systems for trucks.

The productivity goal is to significantly reduce the expense and effort required for carrier compliance with government regulations. Technologies involved are automated vehicle identification, automated vehicle location, weigh-in-motion, dynamic network routing and scheduling, and automated toll collection [8, 14].

2.8 Advanced Public Transportation Systems (APTS)

Just as CVO is the application of ATMS, ATIS and AVCS to commercial vehicle operations, Advanced Public Transportation Systems (APTS) is the application of constituent technologies of these IVHS elements to mass transit and ride-sharing options. For example, ATMS and ATIS will be used to inform travelers of the alternative schedules and costs available for a trip, and AVCS to provide fully automated operations. In addition, APTS can also automatically handle trip fees.

The goals of APTS are as follows [8]:

- To decrease traffic congestion by using new high occupancy vehicle concepts to encourage increased use of HOV's;
- To improve traveler safety and security;
- To assist transit systems in reducing unit operating costs and increasing system revenues;
- To support legislative mandates such as Clean Air and Energy Acts.
2.9 Integration of IVHS Technologies

Viewing IVHS as five individual functional areas helps to understand the key elements of IVHS. However, the whole of IVHS is far more than the simple sum of the five areas and thus it should be regarded from the beginning as a set of integrated capabilities. Successful integration of the separate IVHS technologies requires that a number of cross-cutting issues and technologies be addressed at an early stage of the program. These include system architecture, standards and protocols, system safety and human factors, communications, and operational tests.

Initially, IVHS will progress as advanced technology and information integrated with conventional infrastructure to provide an expanding set of services over wider geographic areas. As IVHS progresses, greater integration among the functional areas of ATMS, ATIS and AVCS will occur. In fact, the synergy represented by IVHS can only be tapped if its constituent technologies are integrated to the fullest extent [8].

2.10 IVHS Strategic Plan

To guide the development and implementation of IVHS technology in keeping with the goals of improved safety, enhanced mobility and increased national productivity, Congress requested the U.S. Department of Transportation (DOT) to prepare a strategic plan. DOT, in turn, asked IVHS AMERICA, which is a non-profit educational and scientific association incorporated in August 1990, to plan, promote and coordinate the development and deployment of IVHS in the United States, and to prepare its own strategic plan to serve as a foundation for the Congressional report. On May 20, 1992, the IVHS Strategic Plan was published by IVHS America. The Plan includes goals and
Objectives for a national IVHS program, challenges to deployment and ways to resolve them, suggested roles for public, private and academic participants, a course of action, and cost estimates [8].

The Strategic Plan's principal goals -- recognizing IVHS technologies are dynamic and advancing rapidly -- are to:

- Establish the objectives of a national IVHS program and predict its benefits and costs;
- Identify key challenges to IVHS deployment and seek ways to resolve real and potential problems;
- Suggest appropriate roles for public, private and academic participants and help to build mutual cooperation;
- Outline a course of action to develop, test and deploy IVHS technology;
- Estimate the magnitude and sources of funding required.

These goals reflect the consensus of the IVHS community who were guided by the following important assumptions and principles:

- Government spending on infrastructure, particularly on advanced traffic management systems, is essential.
- Private spending (businesses and consumers) will pay for the bulk of IVHS development, products, systems and services, particularly for in-vehicle products.
- Large-scale operational tests under real conditions must be conducted using both public and private sector resources to make the transition between R&D
and commercial acceptance of IVHS technologies.

- Deployment of proven technologies will be emphasized initially.
- R&D will be conducted on promising technologies and in areas (human factors, for example) where standards must be established.
- Existing standards should be adopted where appropriate and new standards should be developed as needed to ensure that different systems work together throughout North America.
- The benefits of IVHS, although potentially enormous, will be difficult to quantify and communicate to the public and organizations who can benefit from IVHS unless a conscious effort is made to compile and disseminate the information.

A principal challenge to the national IVHS program is the need for new relationships among the traditional interest groups involved in surface transportation in America. The first step will require agreement on roles and responsibilities of participants. Many institutions must change to meet challenges posed by IVHS. Highway agencies, for example, may have to acquire or build stronger expertise in disciplines other than those traditionally employed. Government and industry, often adversaries, will be challenged to cooperate in making IVHS work. Government procurement practices, often cumbersome and inflexible, make joint efforts difficult. They may have to be reexamined to make it easier for suppliers and government agencies to work together on IVHS efforts.

Even more difficult to resolve may be a number of legal issues which could directly affect IVHS research, development and implementation. Foremost among these issues are product liability, antitrust, privacy and intellectual property. Product liability doctrines and practices alone may be a significant deterrent to development and
introduction of IVHS technologies. Attempts to reform the nation's product liability laws have consistently failed for more than a decade.

With respect to costs, the plan estimates $210 billion will be spent by the public and private sectors for IVHS infrastructure, products and services over the next 20 years, with the public sector accounting for 20 percent of the spending. IVHS will be paid for in large part by its users: individual consumers, commercial users (such as the trucking industry), toll authorities, and transit operators. Development costs -- estimated at $6 billion over the next 20 years -- will, for the most part, be paid by private industry. Federal government investment will be required for long-range research and development, academic research and essential activities which cannot be self-sufficient, such as resolution of legal and institutional issues. The projected costs, while sizable, are well within the means of our national economy and initial outlays are expected to be modest as IVHS programs get underway. To ensure that momentum is maintained, the Plan calls for a series of near-term actions. Foremost among these is a dependable source of public funding to help stimulate larger private investment in IVHS technologies and services. The Plan assigns the role of devising, testing and marketing IVHS technologies to the private sector and calls for government participation in testing promising vehicle fleet operation systems.

The Strategic Plan envisions over the next two decades a national IVHS program, larger in scope than the interstate Highway System program, as a program which depends on an unprecedented public/private/academic partnerships for its success. The United States is at the dawn of a new era when changes in transportation are within our reach. The IVHS America will play an integral role in ensuring that our new transportation era becomes a reality [6].

2. Intelligent Vehicle-Highway Systems
2.11 Points of View on IVHS

Even if, as supporters often claim, IVHS technology is the next revolution in transportation, with mobility impacts comparable to the interstate highway system, initially most people probably won't notice, says E. Dean Carlson, executive director of the Federal Highway Administration (FHWA). In many cases, the "I" in IVHS might as well stand for "invisible," too. While IVHS may lack the dramatic appeal of interstate highway construction, in an era when the ability to add new road capacity is limited -- especially around major urban areas, where traffic is thickest -- transportation planners are increasingly looking to IVHS to improve system efficiency by steering drivers away from bottlenecks (and perhaps to transportation alternatives like HOV lanes and public transit systems), as well as reducing air pollution caused by congestion [15].

The ISTEA of 1991 authorizes $660 million over the next six years for a national research initiative to develop and test IVHS technology. Although many transportation professionals are enthusiastic about the prospects of reaping large benefits from this enterprise, others are concerned about the high costs, the uncertainty of the technology, and the institutional barriers to successful implementation of IVHS [16].

Although it is difficult to argue about the potential for IVHS to increase the efficiency with which a given trip is made, IVHS does raise legitimate concerns. Some see it as one more way to make personal travel easier by automobile and thus promote the adverse effects of using private vehicles. Jane H. Kay [17], a prominent architectural critic and author of the forthcoming book *Carbound: Ending the Auto Age*, stated that pollution will increase because we continue to drive our way out of every advance with more cars and more miles traveled and thus we must "learn to control the way we live --
to better the mass transit we take and the walkable places we create, to settle and repair our centers, to rehabilitate old structures and infrastructures... Computerized roads or cars cannot alter a lifestyle and landscape that are economically costly, environmentally unsound, socially inequitable, culturally disastrous, and aesthetically ruinous."

The contrary view is espoused by David Schulz, Manager of Milwaukee County, who believes that those concerned with transportation in urban America can no longer wait for people to behave as we would like them to — living in compact, high-density residential neighborhoods, working in compact business districts, using public transit in large numbers because they want to and not because they have to, plan nonwork travel in orderly and efficient ways, become socially conscious in the selection and limited personal use of automobiles, and so forth. People are unlikely to accept, and are, in fact, likely to strongly resist such significant changes, especially if they perceive that such changes limit personal freedom [18].

These two views indicate that behavior can either be changed through some form of control, or that information and incentives can be provided to influence travel decisions without restricting personal freedom of choice. Most people would favor the latter. However, the social and environmental cost of the added travel that may accompany these improvements should be minimized.

Then, the following question must be asked: Is making travel easier through IVHS more benign than other transportation improvements? In other words, does IVHS cause less air pollution, urban sprawl and other social costs of travel than other transportation improvements? If so, we would not be confronted with either/or choices. Because
transportation improvements of all kinds are still very much on the U.S. agenda, positive responses to this question should increase the priority for IVHS [19].

The United States is trapped in a vicious cycle of public policy. Government does not promote a balanced transportation policy because of pressure from the highway lobby, and the public does not raise the issue because it is hooked on the automobile and unaware of other possibilities. Mass transit, bicycling and walking are widely considered impractical, and rightly so, due to 50 years of building cities designed for access by automobile only.

To get out of this vicious cycle will demand the commitment to land use change and transportation planning and to make the investments necessary to ensure that facilities are accessible not just to automobiles, but to people -- on foot, on bicycles and in mass transit vehicles. It will not be easy, but what are the alternatives? When the limits of what IVHS technology can do for traffic capacity are reached, we will still be in the same boat, but further up the creek [20].

Although IVHS may be beneficial, it should not be viewed as a panacea. The program must be based on a realistic assessment of actual benefits and total costs, and it must be combined with an aggressive national program to promote transportation alternatives and transportation demand reduction measures.

"It's a mistake to look at IVHS only in terms of added highway capacity," counters Daniel Brand, vice president with Charles River Associates Inc., Boston. In fact, the greatest benefit will come from user interaction with the system. "People can now make travel decisions to maximize their own individual benefits based on real-time
information. These decisions include not making a trip, or traveling by a different mode or at a different time, as well as what route to take," he says. "IVHS is not a highway improvement program but an improvement in the conditions of travel. To look only at aggregate volumes of travel and levels of congestion dramatically understates the potential benefits" [15].

To some, there is a feeling of deja vu regarding IVHS. Many of the issues are the same as in the era of the Interstate Highway System planning. Traffic congestion is still with us. However, this time there are differences which are the result of four principal factors: (1) powerful technological advances, (2) recognition that operation and maintenance are important, (3) recognition of global interdependence and (4) broad-based involvement [21].
3. Maglev and High-Speed Rail

3.1 Introduction

Although most major economic powers around the world have been actively engaged in a race for leadership in high-speed ground transportation technology, the United States has been conspicuous by its absence from this race. However, the ISTEA of 1991 authorizes $725 million for the development of a maglev prototype and $50 million for new technology demonstration projects on any type of high-speed rail and other provisions on rights-of-way and grade improvements to ease construction of high-speed systems. The rail association estimates that industry investments will boost ISTEA's authorization of $725 million to $1 billion. Robert Casey, president of the High Speed Rail Association, called the ISTEA's provisions "historic," adding that they'll help researchers designing maglev trains and contractors ready to build existing high-speed train technologies [5].

3.2 Motivation for High-Speed Rail

Present road and air traffic growth rates are such that congestion is an increasing threat, especially in peak periods. The trend is likely to worsen. In the road sector whole corridors are either permanently or periodically saturated by traffic flows. Time and energy are wasted as a result of traffic jams.

Where air traffic is concerned, deregulation in this sector and the weight of demand have led to a sharp upswing in the number of services offered, with each company out to strengthen its foothold in an increasingly open market. In recent years the number of
flights has risen significantly despite the advent of "jumbo" jets. Airports and air corridors are as a result completely congested and the consequences are beginning to be felt. Planes are obliged to queue, turnaround times are longer, and passenger dissatisfaction is growing. There are infringements of night flying restrictions and financial losses.

One notable consequence is the growing disquiet following the large number of near-misses admitted by the authorities. Yet, air traffic could, if trends persist, double by the year 2000. Improvement of navigational equipment and communications systems and the training of new air traffic controllers may give a little breathing space, but will not provide a proper long-term solution. It will be increasingly difficult to build new airports or motorways to meet heavier demand because of environmental and land-take considerations. Unless a new answer to the problem is found, we will be faced with a serious dilemma: either to opt to protect the environment, putting a brake on mobility or to favor mobility, at the expense of irreparable damage to the environment.

In this context the rail mode, which takes little space and is relatively less harmful to the environment, constitutes a third option to meet growing travel needs while still protecting the environment. This mode opens up the possibility of high-speed services which will be competitive in terms of journey times, comfort standards, frequency of service, direct connections, reliability, and safety. High-speed trains are fully able to provide a viable alternative, even in the face of fierce price competition.

3.3 HSR in Europe

In the context of the single European Market, the progressive dismantling of frontiers --
economic, administrative and cultural -- will inevitably trigger a surge in demand for travel. To meet this challenge the Community of European Railways is developing a high-speed rail (HSR) network, which is energy-efficient, environment-friendly, economical, and technically advanced. This HSR system will bring fast, reasonably-priced, and comfortable travel to the people of Europe, and thus boost the competitiveness and profitability of the railways while strengthening their position in the passenger transport market. It will help to resolve the worsening congestion problems in air and road travel and also provide a unique opportunity for regional, social, and economic development within the Community. It represents a powerful catalyst for European integration. At the turn of the 21st century the railways are preparing to share the goals and challenges of the new Europe.

In most Community countries, as well as in Switzerland and Austria, recent decisions and studies have provided practical proof of the considerable interest in high-speed trains. Indeed, the following projects are completed or in hand:

- Development of a fully interconnecting TGV network in France, following the success of the TGV Sud-Est line from Paris to Lyon;
- Progressive implementation of the rail part of the 1985 Federal infrastructure plan (BVWP'85) and establishment of a new version (BVWP'90) in the Federal Republic of Germany;
- The "Alta Velocità" project in Italy;
- The Rail Transport Plan (RTF) in Spain, and in addition, the historic decision made on December 9, 1988 to adopt standard gauge for all new high-speed lines;
- Further work on upgrading the British network for high-speed rails and plans for
a new line between London and the English Channel Tunnel;

- The prospectus "Rail 21 or lines for the future: looking ahead to the 21st century" in the Netherlands;
- Long-term development program (1983-1997) in Greece;
- Plans for higher speeds in Denmark, Ireland and Portugal, where, as in Spain, standard gauge is to be adopted for new lines;
- The "Rail 2000" project in Switzerland and the "Neue Bahn" project in Austria.

In addition to these national developments, some projects with a European dimension have been completed, launched or are reaching a very active stage of preparation. Particular mention should be made of the following:

- The Channel rail tunnel which was completed recently;
- The Paris/London - Brussels - Amsterdam/Cologne - Frankfurt project for which Ministers reiterated their joint support in October 1988;
- New Alpine crossings between the north of Europe and Italy.

The high-speed notion has therefore developed its own momentum in Europe. The number and detail of these projects form a solid basis for evaluating the work involved [22].

### 3.4 HSR Technologies

In 1972, the turbotrain reached a top speed of 162 mph and turbotrains now in service, fitted with the new TURBO XII turbines, are capable of being operated at 120 mph, provided that track and signaling are suitable. For higher speeds, the turbotrain is the
only rail system not requiring a considerable investment in network electrification [23].

On October 23, 1988, Amtrak tested the Turboliner on its run from New York to Boston. An American-built, French-designed train raced at speeds of up to 110 mph. The high-speed run concluded a year of testing performed by Amtrak and the Coalition of Northeast Governors, which have been experimenting with French, Spanish, Canadian and American trains. Although the governors' task force will not present its findings until early next year, it said that by using new technologies, such as turbine engines, and making minor track improvements, it should be possible to reduce the travel time between Boston and New York to three hours. Amtrak trains now take 4 hours and 30 minutes to make the 208-mile trip. Commercial jetliners take 40 minutes, not counting time spent traveling to and from airports or waiting for departures. The airlines attract 90 percent of the roughly four million passengers who travel between the two cities by plane or train each year, according to Massachusetts transit officials. Amtrak has projected that if the train trip were cut to three hours, ridership would triple from 400,000 to 1.2 million passengers a year [24].

The three most famous HSR Systems are the Japanese Bullet Trains, the German ICE (Intercity Express) and the French TGV (Train à Grande Vitesse). The Bullet Trains impressed the world with their comfort, punctuality and 125-mph speed. They have been in operation almost 30 years now. The new model, known as the Super Hikari, is quieter than other bullet trains and is expected to connect Tokyo and Osaka (320 miles) in about 2 hours and 30 minutes, while hitting a top speed of 167.8 mph. In February 1991, the Super Hikari set a Bullet Train speed record of 202 mph.

The ICE is electrically powered and its aerodynamic design reduces wind resistance,
allowing greater energy efficiency at high speeds. The trains have an on-board diagnostic system to allow fast corrections of malfunctions. The Hamburg-Munich line experienced the first ICE service on June 2, 1991. In May 1988 a prototype ICE train set a speed record of 252 mph with passengers aboard, the fastest steel wheel train in the world until the title was reclaimed by the TGV.

The TGV went into the first passenger service between Paris and Lyon at a top speed of 168 mph in 1981 and all the new sections were opened by September 1983. Advances in solid state technology and motors have resulted in the reduction of the size and weight of the TGV’s propulsion equipment. Equipped with a brushless synchronous motor generating twice the horsepower, yet weighing 10 percent less than the old TGV, the newer, lighter TGV Atlantique cuts power costs per passenger more than 15 percent and at 12,000 hp, can handle a 5-percent gradient without losing speed. The Atlantique, connecting points on the Atlantic coast with Paris at a top speed of 186.4 mph, is the world’s fastest regularly scheduled rail system. In a special run performed in 1990, the Atlantique set a speed record of 320.2 mph. It is electrically powered and 10 times more energy-efficient than airliners. The TGV is the core of the world’s most extensive HSR System [25, 26].

3.5 U.S. High-Speed Rail Initiatives

In the U.S., high-speed rail is progressing slowly because it has largely been left to the individual states, outside of the Northeast Corridor. Some states are now collaborating on HSR plans.

The Michigan-Illinois program seeks to improve rail passenger services in the Detroit-
Chicago corridor by 1994. It involves a package of capital and operation improvements which will build on projects recently completed by Amtrak and Conrail. For example, Amtrak has completely rebuilt its portion of the corridor in the last few years with welded rail and signal enhancements. Conrail will finish a project to install new rail and signals by the end of this year permitting a modest 80 mph railroad to work.

Since 1974 New York State has invested approximately $125 million in improvements in track, signals and station facilities in the Empire Corridor between New York City and Buffalo/Niagara Falls. This investment was the State's part in a joint effort undertaken with Amtrak. Amtrak, for its part, supplied equipment capable of operating up to 110 mph and suitable for building the ridership envisioned by the State as a result of this investment.

A major feasibility study was commissioned in Texas in 1985 and was updated in 1987. These studies present strong evidence that the use of existing high-speed rail technology to interconnect the Texas metropolitan centers of Houston, Dallas and Fort Worth is technically and financially feasible and that the use of this technology will have significant positive economic benefits for the state. The proposed Texas HSR Project will employ existing technology to move people safely at speeds of 200 mph and above. The concept of high-speed rail service between the major cities of Texas is strongly supported by the large volume of intercity travel and the present competitive nature of travel, especially in the Houston-Dallas-Fort Worth corridor which was evaluated in this study. The majority of travelers in this corridor are very conscious of travel time and trip cost, and the high-speed rail alternative will enjoy significant advantages over existing automobile and air travel modes.
The proposed service will use electrically-powered trains with up to ten passenger cars, completing the 273-mile trip in the corridor within 130 minutes (80-110 minutes for the Houston-Dallas segment). Trains initially will depart in each direction every 30 minutes and could operate in regular revenue service every ten minutes as required by passenger demand. Passenger cars in the system will provide accommodations equivalent to those of first class air travel, expecting that special services such as dining, business facilities and meeting space, noise reduction, and all-weather reliability will exceed airline standards significantly.

Florida has an omnibus high-speed rail act that provides for eminent domain, the power to acquire real estate and a tax-exempt building authority. It also provides a one-step process for obtaining various state regulatory permits and allows for creating new residential areas or "new towns" as a means of directing residential growth. The approximately 300 mile system will link Miami, Orlando and Tampa.

The Ohio High Speed Rail Authority wants updated travel demand information and refined ridership and fare-based revenues forecasts for the proposed high speed train system on Ohio's 3-C (Cleveland-Columbus-Cincinnati) Corridor. This new information is needed to complete financing plans, the authority says.

Proposals to build high-speed systems in California should gain momentum as increasing number of people see the trains as providing relief from growing environmental and congestion problems. The Environmental Protection Agency in November presented Southern California with a grim view of its air pollution problems, including the possibility of a future ban on gasoline-fueled autos and a shutdown of aerospace plants. The proposed Los Angeles-Las Vegas super-speed train service
can help ameliorate the situation. The environmental benefits of operating advanced-technology trains on that route will benefit the very region that makes up the South Coast Air Basin [27].

In Pennsylvania, the high-speed rail commission has been studying a rail corridor across the width of the state. Here are a few of the positive results this study anticipates:

- Creation of up to 25,000 jobs during construction and thousands more operating jobs;
- Planting of a new industry;
- Dramatic enhancement of business and real estate opportunities;
- Drastic reduction in travel time.

High-speed rail is best suited in corridors of 200 to 500 miles. The Pennsylvania study is examining the corridor between Philadelphia and Pittsburgh. Currently, this trip (352 miles) takes about seven hours for a conventional passenger train and over six hours for a motorist using the Pennsylvania Turnpike. The commission is examining a 307-mile, high-speed route over which the trains could race in as little as 1 hour and 54 minutes at a top speed of 250 mph, or 2 hours and 30 minutes at a top speed of 180 mph [28].

The economic climate is ripening for high-speed trains to emerge in America. Today, feasibility studies - some private, most public - are advancing in about a dozen states, investigating this mode's opportunities and obstacles. A glance at the roster of corridors where studies now are underway shows the widespread interest: Florida
(Miami-Orlando-Tampa), Michigan-Indiana-Illinois (Detroit-Chicago), Nevada-California (Las Vegas-Los Angeles), New York-Vermont-Quebec (New York-Montreal), Ohio (Cleveland-Columbus-Cincinnati), Pennsylvania (Philadelphia-Harrisburg-Pittsburgh), and Texas (Dallas-Houston-San Antonio-Austin-Dallas). It is believed that, by the dawn of the 21st century, one or more of these lines should already be in operation, with others under construction.

3.6 Magnetic Levitation High-Speed Transportation Systems

Many of the major problems with conventional high-speed electric rail systems attribute to the contact required between the vehicle and the guideway (i.e., rail and catenary). Such contact is difficult to maintain and the failure in maintaining the contact results in intermittent electric power supply to the vehicle and unreliable tractive force applied to the rail. Meanwhile, a maglev vehicle is levitated, guided and propelled on magnetic fields so that there is no "physical" contact between the vehicle and its guideway even at high speeds. The vehicle cruises a few inches above the guideways at any convenient speed of up to 320 mph. Yet, it produces less noise than a well-muffled automobile, no vibration and no pollution.

Although maglev transportation systems may still be considered by some to be in the context of futuristic scientific fiction, as early as in 1912 French engineer Emile Bachelet, working in the U.S., levitated and propelled a model vehicle using magnetic forces. Since the 1960s, considerable maglev development effort has been made in several industrialized countries around the world [29].

In the United States James Powell and Gordon Danby of the Brookhaven National
Laboratory in New York invented the concept of levitating a vehicle above a guideway with superconducting magnets and then propelling it at high speeds with magnetic force, patenting a superconducting maglev vehicle in 1968. Research continued for the next seven years at the Stanford Research Institute, Ford Motor Company, Massachusetts Institute of Technology, Rohr Industries, Boeing Aerospace Company, and so forth. But the U.S. maglev development effort came to an abrupt halt in 1975 when the Ford administration cut all Federal Railroad Administration subsidies for this effort from the federal budget. This linking of maglev to railroad transportation has compromised its future in this country.

Now ironically, on October 1, 1994 -- if the promise of a consortium of German, Japanese and U.S. backers can be believed -- Americans will become the first fare-paying passengers on a magnetically levitated train, which will zoom at up to 300 mph in a friction-free ride suspended less than an inch above a guideway by nothing more than magnetic forces. The train would travel from the Orlando International Airport to Disney’s EPCOT Center and is supposed to take 7 minutes for the 20-mile trip [30].

Since 1984 more than 2.5 million people have ridden on the low-speed maglev traveling from the airport to the National Exhibition Center in Birmingham, England. In addition, hundreds of thousands have ridden test and demonstration high-speed maglev systems in Tsukuba, Japan; Vancouver, Canada; and Emsland, West Germany [31].

3.7 The Opportunity of Superconductivity

A vast share of the world’s electricity is lost to resistance in transmission lines. If an
everyday superconductor could be manufactured on a large scale, those losses could be eliminated, and new nuclear power plants or arrays of solar cells could be placed far from where people use the energy.

If a superconductor can be found that requires no cooling, and if it can be readily made into wires or films, physicists see few limits on its potential for improving the technologies of scientific research and everyday life. The breakthrough came in an unexpected kind of material -- a small, dark chunk of ceramic, an oxide instead of a metal alloy. Ordinarily, oxides are insulators, especially poor conductors of electricity, and most researchers in superconductivity were looking elsewhere [32]. In this material superconductivity can be achieved at the temperature above 77 K (-321.1 °F) -- previously, it was possible in the vicinity of 4 K (-452.5 °F) -- and it is expected that superconducting materials which operate at higher temperatures will be developed in the near future [33].

3.8 The Magneplane Concept

Not long after Powell and Danby invented superconducting maglev, Richard Thomton, Professor of Electrical Engineering, and Henry Kolm, one of the founders of MIT Francis Bitter National Magnet Laboratory, invented a dramatically different magnetic levitation concept known as "magneplane". Provided with superconducting magnets and suspended by eddy current repulsion about one foot above a semicircular trough, the magneplane is propelled by a synchronized wave of electromagnetic field that travels hundreds of miles per hour down an aluminum guideway. Unlike other maglev systems, the magneplane is free to roll so that, when negotiating curves, it can assume a coordinated bank angle, allowing it to turn on a much smaller radius than competing
systems. The work on the magneplane led to international patents on a linear motor which is similar to motors now in use on all high-speed maglev vehicles, but in spite of the impressive progress made in those few years, the government killed all federal maglev support in 1975. The world, or at least the United States, was simply not ready yet [34].

In the ensuing years, the German and Japanese governments have each spent over a billion dollars on further developing maglev technology, with some rather impressive results. In 1989, the German Transrapid carried passengers at speeds in excess of 250 mph at the Emsland test facility, while the same year Japanese demonstrated MLU002, which traveled at similar speeds. It now appears that with Japanese funds, the German Transrapid may in fact be implemented in Florida by the middle of the 1990s, for a 20-mile, 7-minute airport connector in Orlando. Another U.S. route which may get built, also using the Transrapid system, is a 75-minute zap from LA across the desert to Las Vegas. Meanwhile, funding for U.S. research has lain essentially dormant.
4. Purpose and Objectives of the Research

4.1 Background

Basic approaches to solving highway traffic congestion involve either reducing traffic demand or increasing highway capacity. Demand-oriented approaches include increasing the use of public transit, ridesharing, ramp metering, staggering of work hours, telecommuting and rational trip planning. Supply-oriented approaches include building more highways, introducing innovative vehicles that take less space, and implementing IVHS concepts.

The techniques of ATMS and ATIS have received a great deal of attention as a way of solving present highway transportation problems. However, their appeal lies in their relatively easy implementation, low costs and low risks and correspondingly, the benefits may be relatively modest.

An alternative approach is to apply automation techniques to vehicles and roadways under an evolutionary plan to dramatically increase the capacity of existing freeway facilities while retaining the advantages of personal transportation mobility. This is the concept of Advanced Vehicle Control Systems (AVCS).

Under this concept, a system of vehicles would operate both on conventional roadways under manual control and on specially instrumented guideways under automatic control. Previous investigations have confirmed its general feasibility, provided that the transition can be made cost-effective and practical in terms of impact on existing roadways and infrastructure.
4.2 IVHS for Intercity Highways

While gridlock is a term reserved for urban networks, congestion is a generic term independent of jurisdictional boundaries. Congestion occurs when traffic demand exceeds capacity and/or when the level of service is being reduced by the interactions between vehicles rather than roadway geometrics. Deterioration of the level of service is not just occurring in urban areas, but also on intercity highways located in less populated areas. For example, 90 percent of our aging interstate highway system serves intercity traffic and a significant number of sections of this system is exhibiting lower levels of service during most of the day. Therefore, while most of the interest of applications of IVHS has been centered on urban corridors, the need for intercity consideration is evident. There is a growing and painful awareness that we, in the United States, have permitted the growth of a serious transportation gap, namely, for the distances of 200 to 1,500 miles. The automobile is too slow and laborious for this spectrum, and the airplane leads to a false sense of speed when ground connections are considered.

4.3 Smart Cars and Smart Highways

IVHS proponents suffer a degree of schizophrenia in trying to prioritize driver-vehicle oriented research and guideway oriented research, and in reconciling the two within a strategic vision of the future.

Today's cars have very little built-in intelligence for receiving information on the surrounding traffic environment, and most highway systems have little capability for sensing traffic conditions quantitatively. At the risk of oversimplifying, we have
moderately dumb cars on dumb highways and the long-range goal of IVHS is smart cars interacting with smart highways.

In thinking about how we get there from here, experts foresee two extremes: one might be called the "smart car-dumb highway" approach, and the other the "dumb car-smart highway" approach. The question is, what balance is appropriate between these two extremes as the system evolves? We believe that the answer lies, in part, in recognizing that our highway transportation system is not monolithic, and therefore the intercity solution may be quite different from the urban solution. While the demand-oriented approaches including ATMS and ATIS may afford relief in urban areas, intercity level of service can only be improved through significant increases in supply (capacity) such as AVCS.

4.4 AVCS and Maglev

AVCS is one of the five IVHS functional areas. Maglev (magnetic levitation) represents a family of guided high-speed ground transportation modes which use magnetic forces for the three primary functions -- suspension, guidance and propulsion. Under AVCS maglev, cars, buses and trucks, instead of maglev trains, would operate on automated guideways.

It is believed that AVCS and Maglev would combine synergistically to provide a safe, high-speed, high-capacity, energy-efficient, environment-friendly intercity and intracity transportation system. Most importantly the new system would be compatible with and, indeed, an extension of the existing highway transportation system. The guideways would be constructed basically in the medians of existing freeways. While the vehicles
using the "magway" (maglev guideway) would be evolutionary, like present day automobiles, they would be privately owned and could operate on ordinary highways and streets as well as the AVCS magways.

4.5 Research Objectives

The purpose of this research is to assess the potential for AVCS maglev implementation and its socioeconomic implications. The emphases are put on investigating suitable technological aspects, selecting suitable operational control concepts, assessing economic viability, determining socioeconomic impacts, and investigating national development strategies. Specific objectives are to include, but not necessarily limited to, the following:

1. To arrive at longitudinal, lateral, merging and diverging control strategies consistent with suitable suspension, guidance and propulsion systems.
2. To develop peak period optimization strategies.
3. To envisage the shaping of urbanization.
4. To investigate the implications of various design speeds and guideway alignments on capacity and cost.
5. To determine the economic viability of implementation.
6. To investigate national development strategies.

The significance of this research lies in salvaging and capitalizing on two promising concepts, AVCS and maglev, both of which were invented in the United States, and melding them into a transportation strategy to cope with the forthcoming challenge of the mobility, safety, environmental protection, and economic growth of the North
American Continent. AVCS maglev overcomes the obstacles to AVCS and the legacies of maglev which will be discussed in the next two sections.

4.6 Obstacles to AVCS

AVCS enhances vehicle control by facilitating and augmenting driver performance. Ultimately, it is envisaged that AVCS will relieve the driver of most driving tasks in heavy traffic corridors, or on long-distance, high-speed trips. Three levels of AVCS technology were identified in Section 2.6 -- Level I, II and III.

AVCS is the most comprehensive of IVHS technologies. As such it will require the largest investment over the longest period of time to reach fruition. Mobility 2000 places the resources for AVCS I at $270 million, for AVCS II at $815 million and for AVCS III at $1,390 million, reflecting the increasing complexity of the higher levels of functionality. These estimates do not include costs required to construct and operate the needed specialized facilities, such as test tracks and demonstration facilities, or development costs, which are expected to be considerable. The annual funding is projected as peaking at $270 million in the year 2000.

Thus, the first obstacle for implementation of AVCS is the tremendous R&D costs. The second obstacle is the development and implementation time period which is estimated to range from 20 to 40 years. The third obstacle is institutional. The ultimate success of AVCS hinges upon such major factors as social acceptance, national commitment, and successful system integration and standardization. Legal obstacles are a significant concern primarily because of the level of automatic control. A major part of the research and development funds must be dedicated to achieving a fault-tolerant,
reliable system at reasonable costs. Also, efforts need to be devoted to developing cleaner propulsion systems; otherwise, AVCS technology may never be implemented. The "more vehicles equal more pollution" obstacle must be overcome.

As if these roadblocks were not enough, there is a fourth obstacle -- technical inertia. AVCS will never be realized with internal combustion engine powered vehicles. The three key elements of AVCS operation, automatic lateral control, automatic longitudinal control, and the manual/automatic control interface, require the transfer of energy as well as information from the roadway to the vehicle. The California PATH program is taking a small step toward addressing this problem using the electric powertrain. But the low performance, low-speed vehicles envisaged offer no hope as solutions to our intercity transportation problems. Maglev eliminates the need for Levels I and II, reducing research and development times and costs by two-thirds.

4.7 Maglev's High-Speed Rail Legacy

We have gridlock on our highways and winglock at our airports which threaten future mobility. The High Speed Rail Association holds out urban mass transit and intercity high-speed ground transportation (HSGT) as the answer to the coming crisis in personal mobility. Maglev is a relatively new transportation technology, which offers great promise particularly in high-density corridors. The problem, however, is that HSGT systems have always been conceptualized as "trains." As a result, maglev's feasibility is continually evaluated in comparison to such high-speed rail technologies as the turbotrain based on gas turbine propulsion and the French TGV. While there is little doubt that high-speed trains will play a limited role in the nation's transportation future just as Amtrak plays a limited role presently, Americans demand, and are willing to pay
for a high-speed, high-capacity transportation system designed for the privately-owned vehicle.

Maglev train transportation systems would cost more, provide not as great capacity, and generate much lower revenues than maglev personal vehicle transportation systems. For example, in determining passenger carrying capacity it is assumed that the trains are spaced far enough apart so that if one is involved in an accident which catastrophically damages a guideway, the following train would be able to stop. As a result, the high speed does not translate into high capacity in terms of passengers per hour moved. AVCS maglev, in contrast, realizes a corresponding increase in capacity with the increased speed due to the short headways between vehicles.

4.8 AVCS Maglev

Since the powertrain in a maglev train is not concentrated in a locomotive, which is different from the typical railroad system, and a maglev train must be articulated (broken up into cars) in order to negotiate turns, why combine the individual maglev vehicles into trains in the first place? AVCS maglev vehicles would be designed with dual capabilities permitting them to run on magways as well as conventional roadways (see Fig. 4-1).

The structural and geometric design requirements for AVCS maglev guideways would be much less demanding than for maglev trains. These maglev vehicles, operating on guideways constructed in freeway medians, would have to negotiate almost the same turns and grades as lower-speed freeway traffic. Continually accelerating and decelerating to negotiate turns would be compromising to speed, capacity and comfort.

4. Purpose and Objectives of the Research
Figure 4-1. AVCS Maglev Vehicle and Guideway
(Source: Ref. 35)
Since centrifugal force increases as the square of velocity, the guideway must allow the vehicle to bank with substantial angles.

It is believed that an interstate magway system could be built on the interstate highway rights-of-way with interchanges spaced at about 30-mile intervals for transferring traffic between the two facilities and that AVCS maglev could become a major new mode of travel in the early 21st century, carrying a significant portion of the passengers and freight now transported over airways and conventional highways.

4.9 Features of AVCS Maglev

AVCS maglev would be an electrodynamic suspension system. The repulsive force between the vehicle-borne superconducting magnets and the guideway electromagnets would keep the levitation height at a level of over 4 inches. The linear synchronous motor would propel the vehicle at speeds of up to 300 mph.

Features of AVCS maglev would include: (1) advanced technology, (2) ultra-high speed, (3) unmatched capacity, (4) improved safety, (5) innovative form, (6) energy benefit, (7) environmental protection, and (8) economic development. Each will be discussed briefly.

Superconductivity is a phenomenon in which electric resistance of a specific material approaches zero at low temperatures. A superconducting magnet is an electric magnet made of a superconductive material. Without electric resistance, once the electric current is circulated, it flows continuously. Very strong magnetic forces can be obtained from relatively small magnets.
The three primary functions basic to an AVCS maglev transportation system are levitation (or suspension), guidance and propulsion. It is believed that magnetic forces would be used to perform all three functions.

The vehicle is levitated by the repulsive force between magnets. When the high-speed vehicle with superconducting magnets on-board approaches and passes over the ground coils, the ground coils turn into electromagnets by the induced current.

The vehicle with superconducting magnets on-board is propelled by the attractive and repulsive force between the magnets. The ground coils for propulsion and guidance on both sides of the guideway are controlled so as to be the S pole or N pole electromagnets alternatively by the electric current supplied from the substations. The interaction between the superconducting magnets in the vehicle and the electromagnets on the ground is the driving force of the ultra-high speed.

The guidance system provides the sideward forces that are required to make the vehicle follow the curves and straightaways of the guideway. The necessary forces are supplied in an exactly analogous fashion to the suspension forces, either attractive or repulsive. The same magnets on-board the vehicle which supply levitation forces can be used concurrently for guidance, or separate guidance magnets can be used (see Fig. 4-2).

With an automatic longitudinal control system, vehicles can be operated with very small headways and the travel speeds would not be affected by the increase in traffic volume. This feature, combined with ultra-high speed operation, would achieve ultra-high capacities without compromising mobility.
Figure 4-2. Principles of AVCS Maglev Levitation, Guidance and Propulsion
(Source: Ref. 35)
As for safety, the vehicle/roadway interface is not affected by small stones, rain, snow and ice because the vehicles "float" above the roadway surface. Collisions between vehicles are impossible because headways are automatically maintained by control centers. Also, vehicles cannot escape laterally because both sides on the guideway are controlled magnetically. Magnetic flux leakage from the vehicle-borne superconducting magnets can be reduced to safe levels through shielding.

The AVCS maglev guideway requires about the same space as a normal highway lane and many existing freeway medians could accommodate two guideway lanes, one in each direction. Many of the geometric design constraints imposed by the tire/pavement interface can be eliminated.

AVCS maglev would be energy efficient since the power is produced in the main power stations, while the internal combustion engine automobile carries its own power station whose power generation efficiency is much lower. Furthermore, this power is provided in the form of electricity which is increasingly less dependent on petroleum for production.

AVCS maglev is a powerful means of limiting damage to the environment without curtailing mobility. Where atmospheric pollution is concerned, exhaust gases from automobiles and aircraft engines combine to produce five of the main noxious substances including toxic nitrous oxide and lead, corrosive sulfur dioxide, carcinogenic hydrocarbons, and carbon monoxide which affects oxygen supply and climate. AVCS maglev would reduce the generation of these harmful substances substantially.

As the last feature, AVCS maglev will enhance mobility and reduce traffic congestion
substantially, cutting down the transportation cost of production significantly. At the same time, AVCS maglev industry itself will become a huge industry and also will stimulate other related industries.
5. Status of Maglev Technologies

5.1 Introduction

Since the High Speed Ground Transportation (HSGT) studies authorized by the Congressional HSGT Act of 1965 were ended in 1976, there has been a growing public realization that the current airline industry hub system and personal automobile expressway system are approaching capacity. Transportation congestion and its adverse impact on personal mobility, air quality, and commerce are being felt across the nation. Delays caused by congestion alone are costing consumers and industries billions of dollars annually. Projections by the U.S. Department of Transportation (U.S. DOT) indicate steadily worsening conditions in the future. The National Transportation Policy, announced by President Bush and Secretary Skinner in early 1990, supports federal research to advance the implementation of promising transportation technologies such as maglev [3].

Maglev and associated linear motor drive technology, utilizing convenient and readily available electric energy, offer the potential for truly high-speed, economical movement of people between major urban centers with minimal environmental impact. When fully developed and implemented, such systems could offer a freedom of movement which is unknown today. Fast, efficient maglev travel would enrich the quality of human life and contribute to enhanced economic and social interchange between different cities or neighboring countries.

The goal of developing advanced ground transportation systems of the future is worthwhile and thus it should be pursued with enthusiasm and dedication. This chapter
addresses major technical and economic issues associated with this promising transportation technology. The ever-growing base of maglev knowledge and experience is producing benefits today and holds great promise for the future.

5.2 U.S. Maglev Efforts

Pioneering U.S. work on maglev transportation technology was conducted at Brookhaven National Laboratory in the early 1960s. Powell and Danby [36] of the Laboratory proposed the use of superconducting magnets on a moving vehicle to induce repelling currents in closed aluminum wire loops located on the guideway. They continued to refine their ideas, inventing the low-drag, null flux concept [37], later adopted by the Japanese and Canadians for their guidance systems. In 1970, a 500-ft-long test track containing 400 ft of continuous sheet aluminum guideway was built by the Stanford Research Institute (SRI) and later used to evaluate an 1,100-lb test vehicle levitated by superconducting magnets. In 1971, the Federal Railroad Administration (FRA) awarded contracts to SRI [38] and the Ford Motor Company [39] for parallel analytical and experimental studies of both electromagnetic suspension (levitation by attractive magnetic force) and electrodynamic suspension (levitation by repulsive magnetic force) systems.

Research sponsored by FRA led to the development of the linear electric motor. In 1974, a prototype LIM (linear induction motor) research vehicle set a world speed record of 255.4 mph at DOT's Transportation Test Center in Pueblo, Colorado. Sponsored by the National Science Foundation, AVCO and Raytheon, MIT researchers developed a 1/25th-scale model using superconducting magnets on a 400-ft-long guideway. This magneplane was the first maglev concept that incorporated a self-
banking feature as described in Section 3.8. The magneplane approach is currently being revived under the patronage of agneplane International, Inc. Other maglev concepts including new designs for the suspension and guidance/stabilization magnets have been proposed for consideration as high-speed ground transportation systems [3].

The Ford Motor Company was awarded a contract by DOT to develop a baseline vehicle and to build and evaluate a 300-mph test vehicle, but the Federal Government's funding for high-speed maglev research was suspended in 1975 and the vehicle was never built [29]. This administrative decision was justified by the belief that the United States could develop air transportation and highway infrastructure to accommodate the anticipated growth in intricate travel at least for the next decade.

Limited research on maglev technology is underway at this time. Although new interest in maglev systems have been generated due to recent advances in superconducting technology, it is believed that high temperature superconductivity is not a prerequisite for maglev feasibility. Industry representatives recognize that if the U.S. companies were to develop and manufacture advanced maglev systems for world markets, the benefits to this country could be substantial [3]. Fortunately, the ISTEA of 1991 authorized $725 million for the development of a maglev prototype and this seed money is expected to significantly encourage industry's involvement in this development.

5.3 Suspension Systems

The three primary functions basic to maglev transportation technology are: (1) levitation
or suspension; (2) guidance; and (3) propulsion. Although a non-magnetic force could be used for propulsion, in most current designs all three functions are achieved with computer-controlled magnetic forces.

A vehicle may be levitated by means of the attractive force between iron-core, copper-wire-wound electromagnets on the vehicle and ferromagnetic rails on the guideway, or by means of the repulsive force between superconducting air-core magnets on the vehicle and eddy currents induced in conductive sheets or a series of discrete short-circuited coils. The former mode is referred to as electromagnetic suspension (EMS), while the latter mode is referred to as electrodynamic suspension (EDS).

In the current application of the EMS concept, as shown in Fig. 5-1, the electromagnets used for suspension are generally fixed to the vehicle undercarriage that wraps around the guideway. These electromagnets draw the vehicle up to approximately 3/8 inch from the rails. Electromagnets located along the sides of the vehicle provide guidance. Some types of skids must be provided to protect the vehicle, magnets and guideway if the vertical suspension and lateral guidance systems fail and thus the air gap between the magnets and rails diminishes to zero while the vehicle is in motion. The wraparound design of the undercarriage is an important safety feature, preventing the vehicle from derailling.

The EMS system is inherently unstable since there exists no natural restoring force that can bring the vehicle back to its equilibrium position if it is disturbed. Therefore, this system must be stabilized by active feedback control of the suspension magnet excitation. Because of the relatively low field strength achievable with iron-core magnets and the high power required to maintain large air gaps, all practical systems
Figure 5-1. Electromagnetic Suspension System
(Source: Ref. 3)
are designed with air gaps limited to 0.3-0.4 in., providing very little tolerance for variations in payload weight, dynamic loads and guideway irregularities. However, the air gap is nearly speed-independent and vehicles can levitate at zero speed. EMS was made practical by advances in electronic control systems, which measure and adjust the air gap rapidly, and make higher speeds possible. The current EMS design also includes a secondary suspension to provide good ride quality.

The EMS system is being developed by the Konsortium Magnetbahn Transrapid and by the Japanese HSST Corporation, and has been implemented for the low-speed Birmingham Airport People Mover. The German and Japanese EMS systems are now nearing commercial application. However, only the German system, Transrapid, is a high-speed system, capable of speeds of more than 250 mph [3, 29, 40].

In the simplest form of EDS, superconducting magnets are fixed to the vehicle so that eddy currents are induced in conductive sheets or closed-loop coils on the guideway as the vehicle moves over them. This resulting repulsion produces inherently stable vehicle suspension and guidance because the magnetic repulsion increases as the vehicle/guideway gap decreases. However, the vehicle must be equipped with retracting wheels for "takeoff" and "landing" because the EDS system will not generate enough repulsive force at speeds below 25 mph (see Fig. 5-2).

Initially, as vehicle speed increases, the repulsion and electrodynamic drag (magnetic drag) increase. The levitating force remains constant after takeoff, although the levitation height increases slightly. The electrodynamic drag reaches a peak value at a relatively low speed and diminishes thereafter. One method of reducing this electrodynamic drag (suggested by Powell and Danby [36] and currently used by
Figure 5.2. Electrodynamis Suspension System
(Source: Ref. 3)
Japanese EDS system design [41]) is the use of discrete closed-loop coils in lieu of conductive metal sheets. With EDS test vehicles, air gaps of 3.9-7.9 inches have been achieved. Such large air gaps provide substantially great tolerance for guideway misalignments and accumulations of ice and snow or debris on the guideway. EDS technique has progressed with advances in superconducting magnet technology along with cryogenic technology.

The air-core superconducting magnets produce much stronger external magnetic fields than iron-core electromagnets, generally requiring shielding of the passenger compartment and careful selection of guideway structural materials to avoid excessive electrodynamic drag. The prospects of superconducting magnets will be discussed in the next section [3, 29].

Since the initial development of EDS system in the U.S., the Japanese Railway Technical Research Institute has been actively involved in its refinement and implementation. At the Miyazaki Test Track, test runs of the MLU002 test vehicle are continuing, while the Ministry of Transport has authorized a new test track about 27 miles long. The funding was approved in June 1990 as a government subsidy [41].

The third magnetic levitation mode is referred to as permanent magnet suspension (PMS). PMS may be configured as either attractive or repulsive suspension. In this system, permanent magnets on the vehicle interact with either guideway permanent magnets, guideway ferromagnetic rails, or eddy current induced in guideway conductive slips or coils. Recent improvements in permanent magnet materials and progress in developing superconducting permanent magnets have increased the potential for their use. A low-speed revenue service PMS system has been developed by Germany's
Magnetbahn Gmb H (M-Bahn). In M-Bahn, vehicle-borne permanent magnets are attracted to a ferromagnetic core. The air gap varies depending on load (approximately 1 inch when empty and 0.6 inch at maximum load) and is regulated mechanically by the support wheels. At present, the PMS mode is generally not favored for high-speed applications because the suspension heights are small and weights and costs are high [3, 29].

5.4 Superconducting Magnets

Superconductors are materials whose resistance to the flow of electric current approaches zero when cooled below a critical transition temperature, thus permitting minimal loss of electric energy in the form of heat. A superconducting magnet is an electromagnet made of superconductive coil. Due to the lack of electric resistance, once the electric current is circulated, it flows persistently. Very strong electromagnetic forces can be obtained from small magnets.

Superconducting magnets require a cooling system to keep the superconductive coil at extremely low temperatures. Conventional superconducting magnets using niobium-titanium or niobium-tin conductors must be cooled to the vicinity of absolute zero (4 K) to achieve superconductivity, requiring the use of liquid helium as the coolant. The costly and complex liquid helium refrigeration system has been great obstacles to their broad applications. These conventional superconductors are called low temperature superconductors (LTSC).

The LTSC magnet system for the Japanese MLU002, as shown in Fig. 5-3, consists of aluminum outer vessels and stainless steel inner vessels. The vacuum space formed
Figure 5-3. Superconducting Magnet for MLU002
(Source: Ref. 41)
between these two vessels serves as an intermediate thermal insulator. Superconducting magnet coils are placed in the stainless steel inner vessels and cooled down to 4 K (-452.5 °F) with liquid helium. Even though the inner vessels are thermally insulated, heat will intrude into the inner vessel and gasify the liquid helium. The on-board refrigeration system liquefies this helium gas for reuse [3, 29, 41, 42].

The application of the LTSC magnet system to the maglev technology achieved impressive performance records, but the use of costly liquid helium and heavy compressors on-board the vehicle to reliquify the evaporating helium has required improvements.

The recent discovery of ceramic materials in which superconductivity can be achieved at a temperature above the boiling point (77 K or -321.1 °F) of liquid nitrogen, which is far cheaper and easier to handle, gives the possibility of wide applications of superconductivity. It is expected that the intense worldwide research effort on high temperature superconductivity (HTSC) will be able to develop HTSC materials operating at higher temperatures, even though no one knows yet whether room temperature superconducting materials will ever be developed.

Frequently mentioned as potential HTSC applications are maglev vehicles, generators, magnetic separators, transmission lines, ship propulsion motors, and magnetic energy storage coils [33].

Using HTSC magnets instead of LTSC magnets for the maglev system could provide the following advantages:
• Much cheaper and more abundant coolants
• Reduced energy consumption by coolant system
• Much more reliable and less costly coolant system
• Reduced maintenance costs and propulsion energy requirement due to replacing the liquid helium cryostat, reservoir, and liquefier with a simplified liquid nitrogen system [29].

The availability of commercialized high temperature superconductors would enhance the performance and economics of the EDS type maglev system and may find applications in EMS type maglev systems as well.

5.5 Guidance and Propulsion Systems

Although EMS and EDS systems ensure stable vertical suspension, they cannot prevent the vehicle from hitting the sides of the guideway in the presence of side thrusts caused by winds, cornering and guideway irregularities. A guidance system provides the sideward forces that are required to make the vehicle follow the curves and straightaways of the guideway. The necessary forces are supplied in an exactly analogous fashion to the levitation forces, either attractive or repulsive. The same vehicle-borne magnets which supply levitation forces can be used concurrently for guidance, or separate guidance magnets can be used [3].

In EMS systems, guidance forces may be provided by separate vehicle-borne electromagnets interacting with ferromagnetic rails on the sides of the guideway (as in the Transrapid system), or these forces may be provided by locating the levitation
magnets to generate both suspension and guidance and by laterally offsetting them with respect to the guideway ferromagnetic rails (as in the HSST system).

In EDS systems, "null-flux" guidance -- developed by Powell and Danby [37] -- is provided by "8-figure" conductive coils fixed to the guideway, interacting with the vehicle-borne superconducting magnets. When the vehicle is centered, the passive coil configuration intercepts zero net magnetic flux from the vehicle-borne superconducting magnets and no current is induced. However, when the vehicle departs from its centered position, a net flux linkage induces currents in the coil, generating a restoring force. With this scheme, an additional electrodynamic drag caused by the guidance system can be minimized. This concept has been incorporated into the design of the Japanese high-speed MLU system [40].

A maglev transportation system requires a non-contact means of propulsion and braking that is compatible with the vertical suspension gap. Thus, EDS system requires a linear electric motor that can operate efficiently at a gap of 3.9-7.9 in. The smaller gap (0.3-0.4 in.) of EMS system allows greater design flexibility.

The long-stator linear synchronous motor (LSM) appears to be the most favored option for high-speed maglev. It is the most expensive because of its high guideway construction costs. However, it has the advantage of reduced vehicle weight and increased vehicle payload efficiency. Stator windings in the guideway are electrically powered with three-phase AC and are energized sequentially, causing a magnetic wave to travel along the guideway. This traveling magnetic wave interacts with the vehicle-borne electromagnets or superconducting magnets to propel the vehicle. The speed of the magnetic wave is determined by the frequency of the input AC line.

5. Status of Maglev Technologies
voltage, providing precise speed control of the vehicle with high power-factor-efficiency operation. Speed can be adjusted with cycle converters varying the power and frequency of the three-phase input current. By reversing the poles of the magnetic field, the driving force turns into braking power.

To minimize energy losses, the long-stator in the guideway is divided into individual segments. As the vehicle moves along the guideway, successive guideway segments are powered-up and the vacated segments are shut-down. The power of long-stator LSM in the guideway is designed to meet various local requirements such as ascending and descending gradients [3, 29].

Major advantages of the long-stator LSM propulsion are that it requires no on-board power supply for propulsion and it can operate efficiently with a air gap of 5.9-7.9 in., whereas the short-stator linear induction motor must usually have an air gap smaller than 1.2 in. [43]. Energy required for the subsystems on-board the vehicle such as communication and control, lighting, air conditioning/ventilation, levitation and guidance magnets, is supplied through battery buffered inductive linear generators integrated in the levitation magnets [44].

Meanwhile, short-stator propulsion uses a linear induction motor (LIM) winding on board and a passive guideway. When the vehicle-borne windings are powered up, the electromagnetic field sweeps the passive stationary conductive element, generating the relative thrust directly against the guideway rail. While short-stator propulsion reduces guideway construction costs, the vehicle-borne heavy LIM reduces payload capacity, resulting in higher operating costs and lower revenue potential compared to long-stator propulsion [3]. Another disadvantage is the need for wayside power pickup for the
propulsion function, because at high speeds it is quite difficult to keep sliding contacts from bouncing off the trackside conductors [43].

EDS systems such as Japanese MLU use an air-cored LSM. There are two options for EMS systems: the iron-cored LSM and LIM. The German Transrapid uses the former, while the Japanese HSST and the Birmingham People Mover use the latter [40].

5.6 Guideway Considerations

A high-speed ground transportation system, based on maglev vehicles propelled by a linear electric motor, has been proposed to meet future intercity transportation requirements. One possible and attractive approach is in replacing air travel for selected intercity trips of 100 to 600 miles. The maglev system will offer the advantages of lower noise, less emissions and better ride quality, as well as potential energy savings and economic benefits.

While some design concepts have been developed nearly to commercial application, the attractiveness of maglev systems is expected to be enhanced even further over the next several years by new or improved concepts, improved design and construction methods, and new material (including high-temperature superconductors, high-energy permanent magnets, and advanced material for guideways). It is therefore reasonable to expect that maglev systems may indeed be a key transportation mode in the 21st century. For several decades, research and development have been performed in the areas of magnetic levitation, response of maglev vehicles to rough guideways, interaction of variously suspended vehicles with flexible guideways, and optimization of
vehicle suspensions. The results of these efforts are useful in providing appropriate criteria for the design of maglev systems [45].

As we move towards extensive implementation, we must choose between various maglev systems not only from the point of view of vehicle innovation, but also with respect to available geometrics, design options of the guideway, its constructibility and anticipated maintenance. While the development of maglev vehicles has claimed the majority of research and development so far, the role of the vehicles in the commercial system based on maglev trains will be relatively small. The guideway structure itself will reportedly take up 60 to 75 percent of the overall initial capital investment cost. The proper choice of a maglev system with respect to optimizing the guideway is the area where potential capital savings may most likely exist.

Maglev systems can be divided into two groups. The first group includes systems which do not involve mechanical contact. These systems are designated as "high speed" maglevs. The maglev systems of the second group rely on mechanical contact. This contact involves either power transfer to the vehicles, using contact rails or trolleys; or levitation control and lateral guidance provided by rollers. These systems are meant for urban rapid transit, for connections between airports and city centers, and for people movers. Because of their limitation to intermediate and low speeds, they are referred to as "low speed" maglevs.

Zicha [46] states that maglev route choice is quite flexible due to its safety against derailment and its independence from adhesion for climbing grades. This flexibility is a common advantage of all maglev systems. Indeed, the limiting factor in specifying line geometry comes from the established level of passenger comfort. However,
specifications established for wheel-on-rail systems may be unnecessarily conservative for a maglev, since a high-speed maglev can easily utilize gradients of up to 3.5 percent and a low-speed maglev can afford up to 10 percent.

Chen et al. [47] discuss the structural aspects of guideways as centering around design considerations involving the substructure, superstructure and materials employed. To reduce construction cost, a narrow guideway with widely spaced supports is desirable, while to achieve an acceptable ride quality level and/or to meet constraints on guideway stress, a wide guideway with narrowly spaced supports would be better. To meet ride comfort specifications, guideway stiffness usually becomes the controlling factor. Furthermore, the amount of guideway flexibility and irregularity that can be tolerated depends on the vehicle suspension and other motion controlling systems.

To match the expected low maintenance and great durability of maglev systems, the guideway should be constructed of materials having longer life than conventional structures used for wheel-on-rail tracks. Moreover, prefabricated support columns and guideway spans should be considered to make construction faster and less expensive. Indeed, elevated maglev superstructures built in Germany and Japan have been usually prefabricated. In EMS systems, any of the common construction materials can be used for the guideways; steel and concrete girders have been developed. However, in EDS systems, standard steel girders will generate strong magnetic drag and thus the reinforcement steel of concrete structures must be insulated or made of non-magnetic materials to reduce the concrete reinforcement eddy current induced magnetic drag.

The guideway superstructure supports the maglev vehicles and the guidance, propulsion, and control equipment. Since the spans of aerial structures represent
about 40 percent of initial capital cost, much can be saved by providing a structurally-efficient guideway. Therefore, the structural arrangements, static and dynamic design, materials employed, constructibility and construction timing of maglev guideway should receive adequate theoretical attention early in the development stage. This begins with the choice between active and passive guideway.

From the civil engineering point of view the use of a passive guideway with short stator is the preferred option, since it does not require placement of windings on the guideway. The nature of high-speed maglev systems, however, necessitates the use of an active guideway with long stator. If the short stator alternative was used, a huge amount of power (1 to 10 MW) would have to be transferred without contact on the vehicle, since power transfer through mechanical contact does not work at high speeds. Linear power generators are not capable of supplying more than 0.4 MW at speeds around 250 mph [46].

The dynamic response of maglev systems has important consequences for safety and ride quality, guideway design, and system costs. The dynamic response of the vehicles is the key element in determining ride quality, and vehicle stability is an important safety-related element. Thus, to design a proper guideway that provides acceptable ride quality in the stable region, vehicle dynamics must be understood. Furthermore, the trade-off between guideway smoothness and the levitation and control systems must be considered if maglev systems are to be economically feasible. The link between the guideway and the other maglev components is vehicle dynamics. For a commercial maglev system, vehicle dynamics must be analyzed and tested in detail. Pursuing this end, Chen et al. [47] developed a dynamic interaction model of a maglev system with a multicar, multioad vehicle traveling along a flexible guideway.

5. Status of Maglev Technologies
Still, a series of research needs can be identified. It is necessary to determine the trade-offs between large gap (EDS) and small gap (EMS) systems with respect to guideway costs in terms of initial construction and maintenance. However, no data are available for comparison and identification of the critical parameters for EDS and EMS in terms of guideway tolerances and stiffness requirements to meet appropriate ride quality. The critical system parameters for EDS and EMS relative to guideway costs should be identified and studied and the relationships should be quantified. The sensitivity of guideway costs to the use of single versus trained vehicle sets is an important issue that requires quantification [48].

5.7 German Maglev Technologies

In the next two sections, comparative assessments of the three high speed maglev mass transportation systems, which are under extensive development in Germany and Japan, will be made. One approach, which is promoted by Transrapid International (TRI) in Germany, is based on the EMS concept; a second approach, which is promoted by the High Speed Surface Transport (HSST) Corporation, is based on the EMS concept developed by and licensed from Japan Airlines (JAL); a third approach, which is promoted by the Railway Technical Research Institute (RTRI), the developer of the Shinkansen train, is based on the EDS concept. Also included is an outline of a new High Speed Transportation Strategy for North America (HSTSNNA), which is needed to supplement the existing airline hub concept and personal automobile expressway systems currently in place, and to insure prosperity into the 21st century.

For the past 25 years intensive research and development has been carried out in Germany to make super speed maglev trains ready for revenue service. In June 1977,
Transrapid-05 was demonstrated at the International Traffic and Transportation Exhibition in Hamburg, and was the first maglev vehicle to be licensed for passenger-carrying purposes. In 1978 the decision was made to test the maglev vehicle under practical operating conditions on a full-scale test track. The companies which had been working on the development formed the industrial consortium Transrapid International (TRI) to plan and build the Emsland test facility and the Transrapid-06 train. In early 1988 Transrapid-06 set a speed record of 257 mph and participated in a month-long high-speed public demonstration at the test facility with 8 to 10 minute transits of the 25 mile circuit at speeds up to 250 mph. Transrapid-07, the prototype revenue service vehicle, began testing in 1989.

Transrapid vehicles are magnetically levitated and guided, being propelled by linear synchronous motor windings on the guideway. When the levitation magnets, which are mounted on the vehicle undercarriage, are energized, the vehicle is levitated and a fixed gap of about 3/8 in. is maintained between the magnets and the linear synchronous motor windings on the underside of the guideway. The lateral guidance magnets are oriented at a right angle to the levitation magnets and controlled separately to accommodate crosswind velocities up to 56 mph. Linear generators charge vehicle-borne batteries and provide power for magnets, emergency brakes and hotel services. The long-stator motor provides propulsion and braking. Only small sections of the guideway are powered as the vehicle passes.

The guideway structures are steel or concrete beams mounted on piers elevated about 16 feet. Switches are curved steel beams which are aligned by actuators. The vehicle wraps around the guideway and is automatically controlled so derailment is virtually eliminated.
Transrapid-07 set a speed record of 271 mph. Measurements taken during high speed runs confirmed that Transrapid system emits the lowest noise level compared to other transportation systems, with a peak level of about 93 db(A) at 250 mph at 25 meters. There is no rolling noise, gear noise or wayside vibration, which is quite different from conventional rail systems. Measurements of magnetic flux density of the passenger compartment confirmed that the levels are low and impose no threat to health, with 0.1 to 1 gauss at the floor and 0.01 to 0.03 gauss at the seat level. As a comparison, the earth has a natural magnetic field background level of about 0.5 gauss [49, 50].

5.8 Japanese Maglev Technologies

In Japan almost every high-speed surface transport configuration option has been investigated. Out of this dedicated effort, the HSST EMS and RTRI EDS concepts were selected, developed and carried to the prototype stages. In 1974, Japan Airlines (JAL) began to research and plan the development of High Speed Surface Transport (HSST) with the aim of improving airport/city-center access. None of the levitation concepts under study abroad at that time met all of the criteria believed to be necessary for commercialization. Therefore, JAL launched their own R&D program, whose acronym was HSST, to define system requirements. This research led to the conclusion that an EMS system, using transverse flux electromagnets offset with respect to the ferromagnetic rail center line to integrate suspension and guidance, and linear induction motor propulsion, offered the best performance/cost tradeoff for the proposed HSST system. Two test vehicles, HSST-01 and HSST-02, were assembled and tested on a 1-mile track near Tokyo. HSST-02 had seats for six passengers and was demonstrated at speeds up to 63 mph. Fifty-seat HSST-03 was operated for demonstration at EXPO 85 in Tsukuba, Japan [40].
HSST Corporation, established in 1985, has licensed all the maglev technology accumulated by JAL and demonstrated 70-seat HSST-04 at the '88 Saitama Expo held near Tokyo in 1988. HSST-05, a 158-seat 2-car train, was operated at the '89 Yokohama Expo on a 1870 ft long elevated guideway between two stations. It was the first magnetic levitation public transit system in Japan to obtain a railway business license from the Ministry of Transport.

The HSST utilizes an EMS concept. "Module," one of the HSST's most essential parts, is a unit performing the levitation and propulsion. Eight modules on each car, which are arranged in a line along both sides of the vehicle to distribute the weight evenly, equalizing and minimizing the load throughout the entire car length, are connected to main body with secondary suspension system. Each module is equipped with four magnets, a linear induction motor coil, a mechanical brake, two skids, two gap sensors and four accelerometers.

The HSST vehicle is propelled by a short-stator linear induction motor mounted on the vehicle and the tractive force is induced in the stationary aluminum rotor by a traveling magnetic field generated by the 3-phase AC short-stator traction coils on the vehicle. Propulsion or braking is achieved by controlling the phasing of the traction coils. Power is picked up through contact with two hot DC conductors under the track [51, 52].

The development of EDS maglev in the Japanese National Railways (JNR) has been taken over by the Railway Technical Research Institute (RTRI) since April 1987 when the JNR was privatized and divided into several railway companies and organizations including the RTRI.

5. Status of Maglev Technologies
In July 1977, a series of test runs using the ML-500 test vehicle began on the Miyazaki test track and in December 1979, a speed record of 322 mph was established, demonstrating the possibility of super speed running. Thereafter, the guideway has been changed from an inverted T-type to a U-type, and the test vehicles have been upgraded and designated MLU001 and MLU002. Three vehicles of the MLU001 type were manufactured and series of test runs was performed using not only a one-car unit but also a two-car unit or a three-car unit. A speed of 250 mph was attained by a manned vehicle of this type in February 1987. Since April 1987, test runs have been carried out using an MLU002 type vehicle with 44 seats. Demonstration runs carrying invited passengers have continued in parallel with test runs. The number of passengers on demonstration runs registered 4,000 during a short summer period in 1988 [41].

When vehicle-borne superconducting magnets move horizontally over ground coils located on the guideway, eddy currents are induced in the ground coils, thus generating a repulsion force between the superconducting magnets and the ground coils, which in turn causes the vehicle to float more than 3.9 in. above the ground coils.

The ground coils for propulsion mounted on the sidewalls of guideway and the vehicle-borne superconducting magnets for propulsion/suspension constitute a long-stator linear synchronous motor. Electricity with commercial frequency supplied by power companies goes through a transformer and a cycloconverter. The latter changes the frequency of the alternating current into the frequency harmonized with the running speed of the vehicle and the current is supplied via a feeder and feeding section circuit-breaker to the ground coils for propulsion.
Each pair of linear synchronous motor coils, on opposite sides of the guideway, are cross-coupled and when the vehicle deviates to one side, an eddy current circulates. The interaction between these induced currents and the vehicle-borne magnets forces the vehicle back to center by null-flux guidance. Hence, the arrays of superconducting magnets along each side of the vehicle provide electrodynamic suspension and guidance, together with the excitation for linear synchronous propulsion [53].

A regenerative brake based on the linear synchronous motor and other electric brakes are used as service brakes and, in addition, a friction brake based on sliding shoes and an aerodynamic brake are provided as emergency brakes.

The superconducting magnet system for the MLU002 type maglev vehicle consists of aluminum outer vessels and stainless steel inner vessels, between which a vacuum space serving as an intermediate adiabatic layer is formed. Superconducting coils are placed in inner vessels and cooled down to -452.5 °F with liquid helium. Although the inner vessel is thermally insulated to a high degree, a small amount of heat will intrude into the inner vessel and gasify liquid helium. This helium gas is re-liquefied for reuse by a vehicle-borne refrigerator [54]. Measurements of magnetic flux density of the passenger compartment shows about 200 gauss at the floor and a gradient diminishing to about 30 gauss at the head rest [55].

A contactless linear generator, using the space harmonic component of the flux produced by track levitation coils to induce voltage in coils mounted between the vehicle-borne superconducting magnets, has been tested. The result shows that this linear generator, in association with vehicle-borne batteries, can provide sufficient
power for superconducting magnet refrigeration and for hotel services in a revenue system [40].

5.9 Euro-Japanese Experience and American Choice

Both Japanese maglev concepts have been carried to the prototype stages. The MLU is scheduled to begin passenger service in the densely populated 320 mile long Tokyo-Nagoya-Osaka corridor by the end of this decade. This has caused the world to pay attention to the Japanese transportation policy that is based on four principles: (1) new technology is the basis of prosperity; (2) a strongly linked research, development and manufacturing chain is essential; (3) the role of the academic community is to provide technical personnel not research results; (4) the role of the government is to identify visions for the nation and catalyze cooperation between the national, industrial and academic groups. As a result of the combination of clear goals, organization, planning, and strongly linked R&D and manufacturing chain, Japanese maglev public transit concepts have made a dominant contribution to high speed surface transportation technology and reduced to commercial practice high speed surface transport concepts from many sources.

In addition to this, there is also a national commitment to the rapid development of technology in general due to a vision for the 21st century that is driven by national and societal interests. For instance, the long term goal for the nation is centered on an all electric, high-technology, computer-controlled, information-based society in the first quarter of the next century. This vision also includes turbine engine vehicles, electric cars, and high-speed maglev vehicles connecting the major domestic and international transportation, industrial and technology zones [56].
Although North American contributions to the advancement of maglev technology have been very modest over the past decade, interest in the implementation of high-speed intercity transportation systems has remained high. This interest was born with the energy crises of the mid-70s, when the world realized that it could no longer rely upon low-cost, readily-available petroleum fuels for automobiles, diesel-electric trains and aircraft.

While these concerns have receded temporarily, gridlock and winglock are becoming emergent threats to mobility in North America. Traffic continues to grow at a faster rate than new transportation infrastructure can be provided, and many airports will reach capacity over the next decade. According to the air travel demand projection made by the Federal Aviation Administration, air traffic will nearly double by the year 2000 over 1985 level.

There will be a need for electrically-powered high-speed intercity ground transportation in North America to offload short-haul flights from major airports, and to provide both business and social travelers with a safe, reliable and fast means of transportation over the intermediate distance range (150 to 650 mi.). Although not yet in revenue service as high-speed mode, maglev is a maturing technology and it is increasingly being considered in parallel with proven high-speed rail technology in techno-economic assessment studies of many high-density corridors [57].

In North America, the conditions for high speed ground transport may be quite different than in Europe since (i) the urban structure is more dispersed and more reliant on the automobile; (ii) the distance between major urban centers is greater and the airline industry is more competitive; (iii) the decision making powers are more decentralized
and procedural; and (iv) the climate for investment by the government in railroad infrastructure is much frostier. Blumstein and Brand [58] discuss how these differences affect the relative chances of a maglev or TGV high speed rail corridor.

The dispersal of urban living in many North American cities was caused by the automobile, and the increased emphasis on rational planning in the last two decades has resulted in many large new suburban areas completely planned for the automobile. This style of city obviously affects whether a high speed rail service is attractive for making trips under several hundred miles, but it does not appear fundamentally to affect the choice between TGV or maglev. The cost and environmental advantages of TGV's sharing of right-of-way and tracks with existing rail system remain strong; as a result, the larger expanse of urban area may make the TGV's compatibility somewhat more important.

A dozen or so candidate corridors for high speed ground transportation in North America have been identified. The two most active in terms of assessment, development potential and implementation plans are in Miami-Orlando-Tampa and Las Vegas-Los Angeles. The other corridors are Pittsburgh-Philadelphia, Cleveland-Columbus-Cincinnati, Dallas-San Antonio-Houston, San Francisco-Los Angeles-San Diego, Milwaukee-Chicago-Detroit, Detroit-Toronto-Ottawa-Montreal-Quebec, Portland-Seattle-Vancouver, Boston-New York-Philadelphia-Washington, New York-Montreal and Edmonton-Calgary [57].

In corridors where urban centers are more than two or three hundred miles apart, the higher speed of the maglev can reduce travel times. Taking a simple example of cities two hundred miles apart, a TGV at 185 mph cruising speed and 150 mph average
speed makes the trip in an hour and twenty minutes; a maglev at 250 mph cruising speed and an average speed of the same percentage below cruising speed of 203 mph, could make the trip in just an hour. Assuming that getting to and from the station takes about an hour, the twenty minute difference is about 15% of total travel time. For cities four hundred miles apart, though, the TGV time is two hours and forty minutes, with the maglev time some forty minutes faster. Making the same calculation produces a 20% difference. Purely on the marketing side, then, the greater the distance, the greater the maglev advantage over TGV [58].

However, the additional distance adds some disadvantages for the maglev as well, primarily in the area of capital costs. Since building the maglev costs roughly 50 to 100 percent more per mile than the TGV, the greater distance imposes greater capital costs. To whom the economic advantage goes as a result of a longer corridor will depend on the sensitivity of the market to travel time decreases. With respect to this, the Paris-Cologne study reports operating costs of five to six cents per seat mile for maglev, without any allowance for capital cost financing. Barton-Aschman, in "The Florida High Speed Rail Study" prepared for the Florida DOT in September 1984, reports an annualized cost including capital charges amounting to 36 cents per seat mile with similar operating cost levels. Airline costs are reported at somewhat over twelve cents per seat mile, including interest and depreciation charges.

5.10 Technical Feasibility of AVCS Maglev

Many have come to the conclusion that American infrastructure must be rebuilt and redesigned in contrast to the practices that have been followed over the past few decades with disastrous results. Air traffic deregulations have led to the bankruptcy of
some major U.S. airlines, a deterioration in service and in safety standards. Since 1980, railroads have been cut back by at least 25%, as measured by track length. Railroad employment has been cut by half, which is an indication that fewer trains are running on these tracks. With the shift back to coal production, much of the existing rail capacity is used up in transporting coal. Half of total freight moved is accounted for by shipments of coal, crude oil and refined petroleum products (some of the latter by pipeline).

Bridges are collapsing and highways are in disrepair. Many U.S. ports have been turned into tourist areas, and none of those remaining can handle a vessel in excess of 100,000 tons, which is standard for world shipping. Trucking now accounts for over 40% of the freight moved in the United States, and rail for only about 18%.

While the United States has lagged behind, Germans and Japanese have maglev train systems ready for commercial development, with Germany presently in the lead. The German Transrapid system has received government approval for commercial operations, and in the first phase it will be used to connect the airports of Cologne/Bonn and Dusseldorf.

The Japanese presently have two different maglev system designs that are running experimentally. The HSST system has been developed by Japan Airlines, with the drive provided in the vehicle, not in the guideway. It runs at lower speeds than the mainline Japanese Linear Motor Car (MLU) which uses an EDS system based on the principle of repulsion. The MLU is scheduled to begin passenger services in the densely populated 320-mile-long Tokyo-Nagoya-Osaka corridor by the end of this decade. The MLU uses superconducting coils which are cooled by liquid helium.
These are located on the vehicle, interacting with a magnetic field that is generated by induction in the guideway coils. However, up to speeds of 62 mph, it operates on wheels.

Maglev technology developed in Germany operates by a different principle. It operates with ordinary magnets, and does not use wheels. Its suspension and guidance system operates according to the principle of EMS, based on the attraction between electromagnets mounted on the undercarriage of the vehicle and the ferromagnetic reaction rails installed under the guideway.

Preliminary analyses by countless universities, research laboratories and consulting firms support the proposition that the use of maglev in the United States is technically feasible. Both EMS and EDS systems appear suitable for U.S. deployment. EMS advantages include a high-speed prototype demonstrating good ride quality, off-line switching capability, and very low ambient magnetic field levels. The EDS is lighter and requires less power per seat-mile. Also, its bigger allowable gap between vehicle and guideway requires less precise guideway construction and vehicle control. Current designs of both systems use the long-stator, requiring an actively powered guideway which accounts for a large percentage of system capital costs.

The Federal Railroad Administration identifies the following research and development opportunities that could result in significant increases in technical effectiveness [3]:

- Guideway structure -- Fixed facilities account for about 90 percent of overall maglev capital costs. Seventy percent of these costs stems from the guideway
structure. Any technological improvements in this area could have a substantial impact on system economics.

- Right-of-way -- Interstate highways and railroad rights-of-way represent potentially valuable resources for accommodating maglev routes. Use of these resources needs further investigation because highways and railroads were originally designed for speeds well below 100 mph. Many routes have curves and clearances that may constrain higher maglev speeds.

- Propulsion system innovation -- Long-stator windings, which run the length of the guideway, are a major element of capital costs. Breakthroughs in design or in the use of alternative propulsion concepts could reduce capital costs and hasten implementation.

- Operational Considerations -- High-speed switching is a major operating challenge for a U.S. maglev system, because switches are among the least developed components. Another important operating consideration that needs further study is whether to use multicar trains with a limited number of intermediate stops or single-car trains serving individual parts of stations, some of which are located on branch lines.

- Other development opportunities -- High-temperature superconducting magnets, limiting exposure to magnetic fields, improved stabilization, and better cryogenic systems are also areas for which development opportunities exist.

Based on the criteria of suspension, guidance, propulsion, guideway structure, right-of-way, and operational considerations discussed above, high-speed maglev trains are deemed to be technically feasible and will be in commercial operation in Germany and Japan before the end of this decade. The requirements with respect to the same criteria would be less for the automobile-size personal maglev vehicles envisaged for
the proposed AVCS Maglev System described in this dissertation. For the purposes of
this research, it suffices to treat the system as a "black box" fully describable in terms of
decision and policy variables. By assigning the variables ranges of values, scenarios
can be generated that help establish solution spaces for user benefits, financial
viability, economic feasibility, resource conservation, and environmental impact.

5.11 Maglev Tunnel Concept

The idea of operating vehicles in reduced atmosphere tunnels is not particularly new.
When the concept of ballistic passenger travel was studied in the United States in the
mid 1950s, it was decided that evacuated tubes located in straight underground tunnels
would be needed and the vehicles would be both magnetically levitated and propelled.
The Japanese and Swiss are now independently searching for systems whereby
maglev vehicles will travel in evacuated tubes as one way of resolving the space
problem and greatly reducing the aerodynamic problem. Swiss Metro, a government-
sponsored project for connecting all Swiss cities, calls for an entirely underground,
reduced atmosphere maglev system.

It is envisioned that much of the maglev guideway system will be built under the ground
to minimize geometric constraints hindering high-speed operation. An underground,
reduced atmosphere maglev tunnel system would therefore be more practical
especially in urban and mountainous areas for the following reasons [59]:

- In urban and mountainous areas where the land acquisition and/or the straight
  line construction are difficult, it offers the best alternative.
- Reduced geometric constraints enable high-speed operation.
The environmental impact can be substantially reduced.

An unacceptable environmental (noise) and aesthetic element can be avoided.

The conflict between guideway traffic and conventional roadway traffic can be avoided.

The vulnerability to weather condition can be minimized.

Reduction of aerodynamic drag can achieve the substantial increase in operation speed and energy efficiency.

There are two high-speed maglev tunnel concepts. One is the evacuated tube concept and the other is the evacuated tunnel concept (see Fig. 5-4). In the former concept, a single tunnel of 35-ft inside diameter will accommodate 4 evacuated tubes of 12-ft diameter and the vehicles will travel inside these tubes. In the latter, the entire tunnel will be evacuated with an internal seal. Trade-off studies will be required to determine the preferred method. The tunnel cross-section will provide ample space for communication lines, power lines and water, oil, gas pipelines.
Figure 5-4. High-Speed Maglev Tunnel Concepts
(Source: Ref. 59)

5. Status of Maglev Technologies
6. Automated Highway Systems

6.1 Background

The past two years have seen a whirlwind of activity within the Federal Highway Administration (FHWA) and other U.S. DOT agencies responsible for fulfilling the federal role in the national IVHS program. Most of these efforts have concentrated on implementing the provisions of the IVHS Act of 1991, which is an integral part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. While ISTEA provided several new wrinkles, mostly the IVHS provisions directly supported and endorsed the full range of efforts that had been initiated by DOT agencies, IVHS America, and its predecessor organization, Mobility 2000.

The major area of support from ISTEA is the provision of a total of $660 million for fiscal years 1992-1997 to help carry out the goals of the program. Some of the funding is to support the requirement that DOT develop an automated highway and vehicle system, having a demonstration in place by 1997 [60]. Although it is questionable if such a goal could be met, this is an exciting opportunity to significantly advance the vehicle control aspects of IVHS.

The vision for the Automated Highway Systems (AHS) program is to create a fully automated system that evolves from today's roads, beginning in selected routes or corridors; provides fully automated, "hands off" vehicle operation at better levels of performance than today in terms of safety, efficiency and comfort, while retaining the advantages of personal mobility; and allows equipped vehicles to operate both on
instrumented roads under automatic control and on conventional roads under manual control [61].

Although complete deployment of an AHS is certainly a long-term goal, pursuit of this goal is very important since a new level of benefits could be realized with the full automation of certain facilities. By eliminating human error, an automated highway could provide a nearly accident-free driving environment and the automatic control of vehicles could result in an increase of several times the capacity of today’s facilities, while encouraging use of more environment-friendly propulsion methods.

6.2 Overview of AHS Studies

A great deal of early research in the area of the automatic control of individual rubber-tired vehicles was conducted on both a theoretical and an experimental basis, and prototype experimental equipment was developed and operationally tested by General Motors Corporation [62], Ohio State University [63], the Japan Governmental Mechanical Laboratory [64], the U.K. Road Research Laboratory [65], Ford Motor Company [66], and the Japan Automobile Research Institute [67]. This testing was mainly concerned with the automatic control of the longitudinal and lateral movements of the vehicle, and little effort was expended on automated network control.

In 1986, the Federal Railroad Administration initiated the Northeast Corridor Study, one part of which was focused on the automated highway [68] as a means of relieving congestion in this corridor. Here, TRW Systems Group considered intercity travel as part of this study and examined a representative AHS that would accommodate rubber-tired passenger vehicles. The application of dual-mode vehicles for intracity and
intercity travel has been studied, and several system concepts have been developed [69, 70]. The use of automated pallets has also been frequently suggested [71].

Most of the studies on AHS have been conducted using computer simulations of theoretical network configurations; however, some of the network analyses have been site specific. For example, Howson [72] developed a simulation model of an automated roadway network for the metropolitan Detroit area. The simulation studies were conducted to determine the performance of systems as a function of the various design parameters, to develop operation software, and to evaluate the computer hardware needs of a real-world system.

The California Program on Advanced Technology for the Highway (PATH) has emphasized work on automatic vehicle control technology for highway automation to a greater extent than any of the other current IVHS programs. The primary reason for this emphasis is that automatic vehicle control offers the most dramatic potential for solving both traffic congestion and safety problems, and the secondary reason is that it is most appropriate for a university research program to be emphasizing more advanced technologies than those currently being developed as products by private industry, rather than finding itself in potential competition with industry [73].

The AHS concept is receiving renewed consideration as a means of alleviating some serious highway problems. Some potential advantages include:

- a substantial increase in lane capacity;
- a significant improvement in highway safety;
• a substantial decrease in both the economic and psychological costs associated with accidents;
• an enhancement in highway level of service
• an improvement in energy efficiency and a reduced consumption of petroleum-based energy;
• a lessening of environmental and community impacts.

6.3 AHS Concepts

Potential AHS concepts are being identified in order to determine the most promising concepts for detailed system implementation, analysis and trade-off evaluation. These concepts include system structural, system operational, and vehicle subsystem technological aspects of an automated transportation system. The structural aspects of a system concept are concerned with the decision-making capability allocation between a vehicle and the guideway, and the characteristics of the control and data equipment contained within the guideway subsystem, as well as the traveling unit configuration and certain structural and equipment considerations of the vehicle. The operational aspects of a system concept are concerned with vehicle entrainment policy, system fleet mixture, network type and control functions, and guideway lane separation requirements. The vehicle subsystem consists of the body and chassis subsystem, the propulsion and brake subsystem, and vehicle control subsystem.

To describe potential AHS concepts, Bender [74] identifies two different types of traveling units, two different distributions of control intelligence, and two different types of power sources. The detachable electronics package (DEP) is a system-owned electronic unit that can be quickly installed on a modified vehicle at an AHS entry point,
as well as at remote locations. The DEP contains the equipment necessary for the measurement, command, control, and communication functions and interfaces with the vehicle subsystems and computers. The two distributions of control intelligence are termed "average" and "smart" vehicle concepts. The former concept requires that the control intelligence be approximately equally divided among the vehicle, guideway, and wayside locations. The latter requires that the control intelligence be located on the vehicle to the greatest possible extent. The electric vehicle concept has electric power pickup from the guideway by either contact or inductive power coupling technology, and a small battery pack for propulsion off the guideway.

The advantages of battery-powered electric vehicles have been known for a long time: no mobile-source pollution; quiet, low-vibration powertrain; fast response, with high torque at low speeds; long component life; and relatively low maintenance costs. However, these have been outweighed by the limitations of the batteries, principally their very limited range, heavy weight, low ratio of power to weight, and limited lifetime. Efforts are continuing at many research centers to improve the performance of batteries so that the aforementioned limitations can be overcome. An alternative approach is to provide a source of recharging power along the roadway to enable the batteries to be recharged while the vehicle is in operation, either moving or stationary. This approach can work even with the batteries available today, though it will be even more effective when higher-performance batteries become available. This technology is known as the roadway-powered electric vehicle (RPEV), or more simply, roadway electrification.

The RPEV technology works by inductively transferring power from a primary inductor mounted immediately beneath the road surface to a secondary inductor mounted on the underside of the vehicle. Because this power transfer is inductive (i.e., magnetic),
there is no physical contact between the primary and secondary inductors, no exposed conductors to represent a potential shock hazard, and no arcing. Burying the primary unit beneath the road surface enables it to be used by any road vehicle, regardless of its sizes or geometry. The geometric constraints that would be imposed by the use of an overhead trolley wire system are avoided, as are the aesthetic impact and the adverse-reliability implications. The electrified roadway can be shared with conventional, nonelectrified vehicles and pedestrians, without adverse impact on them or on the system.

In the PREV system, the vehicles can be designed to run extended distances entirely on their own battery power, so that the roadway inductor needs to be located only at limited, carefully selected spots where the maximum system benefits can be generated. The availability of in-vehicle battery power makes the system relatively immune to failures caused by roadway-power loss or the disabling of individual vehicles, in stark contrast to conventional trolley systems [75].

6.4 The Promise of the Electric Vehicle

Guideway electrification is recognized as being suited for AHS. However, the AHS is a desirable concept both with and without electrification. At this time, the economics of an electrified AHS look desirable only in comparison to a battery electric vehicle and not in comparison to an internal combustion engine vehicle. Thus, an electrification of the AHS is recommended only if it is done simultaneously with a general switch to battery electric vehicles.

Despite huge reductions of noxious emissions from factories and cars, Southern
California's air is still terrible. It's so bad that the state is requiring that two percent of new cars sold in 1998 be zero polluters and ten percent by 2003. Many researchers here have become preoccupied with the foul air, and so are searching for ways of making cars less obnoxious and hence better servants. In a remarkable shift toward a national industrialization policy, the White House recently proposed deferring anti-trust regulations to permit a consortium among the big-three automakers and the federal government. The aim is to design a better car -- safer, with improved fuel economy and reduced emissions.

General Motors and Nissan are front-runners in developing a practical electric car which can be on the market by 1998. A key element in the competitive sweepstakes is finding a battery which can be rapidly recharged, and which will allow the car to travel for more than 100 miles (at normal highway speeds) without the need for recharging. Since these batteries are heavy, one pathway for higher performance from the batteries is to reduce the weight of the car itself below that of today's compact car. This, however, creates a safety problem in the event of collision, and it also limits the carrying capacity of the car.

Electric vehicles are nothing new. General Motors had lead-acid battery-powered trucks running around as early as 1916. And while the basic physics of electric motors hasn't changed -- spin a rotor inside a stator -- the motors and their controllers have changed [76]. In 1990 General Motors unveiled a new battery-powered electric vehicle, called the Impact -- the flashiest, best-engineered electric vehicle ever. Thanks to an advanced electric drivetrain and a light-weight, aerodynamic, energy-conserving body, the Impact accelerates faster than comparable gasoline-powered cars. However, even under the best conditions, despite its advanced technology and state-of-the-art lead-
acid battery, it will go not more than 120 miles and, as with all battery-powered vehicles, it requires hours to recharge.

The challenge facing electric car builders today is to squeeze the most performance from the limited amount of on-board power. While some manufacturers are looking at powering conventional vehicles with exotic battery technology that packs three times the power of conventional lead-acid units, the problem is that those batteries cost more than the total price of the Impact. Virtually no one believes that zero emission vehicles (ZEVs) will dominate the automobile market unless they can accelerate as fast, drive as far, and be refueled as quickly as today's gasoline cars. The only ZEV that potentially can satisfy these requirements is a fuel cell vehicle (FCV). An FCV combines the best features of a battery-powered car -- zero emissions, high efficiency, quiet operation, and long life -- with the long range and fast refueling of a gasoline car. This combination makes FCVs one of the most attractive transportation technologies for the 21st century.

An FCV is an electric vehicle that uses a fuel cell and fuel-storage system in place of, or perhaps in parallel with, a rechargeable battery. A fuel cell generates electricity electrochemically using hydrogen and oxygen as the reactants, the by-product of the reaction being water. Hydrogen can be stored and used directly, or be reformed from a hydrogen-rich fuel such as methanol. Air provides the necessary oxygen. A complete fuel-cell and fuel-storage system consists of several components [77]:

- the fuel-cell stack which produces the electricity
- a storage container for the fuel (hydrogen or a hydrogen-rich compound such as methanol)
• auxiliary subsystems, which, depending on the type of fuel cell, compress and supply air, cool the stack, keep the membranes saturated with moisture and dispose of excess water

If the problems of low power density and high cost can be overcome, FCVs could become an important component of a strategy for reducing dependence on imported oil, mitigating global warming, and improving urban air quality, and all at an acceptable cost.

6.5 AVCS Maglev System Architecture

A system architecture can be characterized as a description of how the many elements, or subsystems, of a system work together to perform the system's actual functions. In the case of AVCS Maglev, an architecture would lay out the specific functions performed by vehicle-borne equipment, by wayside devices, by traffic management facilities or information distribution centers, and so forth. The architecture also describes how these subsystems interact by defining the types and formats of information exchanged between and among them.

The development of AVCS maglev system architecture is based on a hierarchical approach that relies on goals, objectives, scenarios and modeling to guide the architecture design [78]. Goals state the broad requirements of the customers, user, and service provider communities. These goals contain more general statements than objectives and can be regarded as somewhat philosophical, such as "dramatically increase the capability to move vehicular traffic." Objectives reflect quantitative and measurable criteria that can be used to evaluate the performance and cost of the
proposed architecture solutions. In the context of this research, objectives takes the form of "synthesizing an AHS - Maglev vehicle system that will move 30,000 vehicles per hour by the year 2020." Scenario description supports the definition of potential and proposed economic, political, and social conditions under which the architectures will operate. A sufficient number of scenarios should be developed to properly identify the constraints that govern architecture evaluation. As the architectures are assessed, major and minor adjustments in component selection and interaction are generally identified to make the architectures less expensive, more effective, more politically and socially acceptable, and more robust. Architecture refinement continues, over the broad range of scenarios, until the best solutions are reached consistent with the architecture development schedule and budget. Architecture evaluation is supported by using measures of effectiveness that express the quantitative and qualitative performance and life-cycle costs of the proposed architecture solutions. For the purpose of this research, the architecture development process will only be iterated once for obvious reasons. It begins with a refinement of the recommended system concept first advanced in Section 4.9.

6.6 Recommended System Concept

The most exciting, integrated conception for the electric car of the future, first described by Drew [30, 35], refined by Drew and Trani [79] and advanced in this dissertation, is the idea of designing an electric car of today which could become the magnetically levitated car of tomorrow. Such a car would effectively function as a magnetically levitated automobile under highway conditions of driving, where it could travel at extremely high speeds in complete safety, and yet offer the driver the option of door-to-door travel in one vehicle.
One is reminded of an America now unfortunately receding in memory, when men such as Henry Ford led the U.S. automobile industry, and the model T brought rural America into the modern age. Along with other towering engineers, such as Thomas Alva Edison and the Wright brothers, Ford was the kind of far-sighted company president who put America on the map as an industrial giant, while today, American corporate presidents like Lee Iacocca pride themselves on being financial managers.

The recommended system concept for AVCS maglev is based on applying the idea of maglev trains to an entirely new design of automobile. In Japan, Aisin and Equos Research [80] are involved in planning new maglev train systems in which the train's cars could also function independently as trucks, so as to have an integrated train-and-truck freight system. These two concepts, for trains which become trucks and automobiles which become trolleys, are in a sense complementary, although the technologies involved are quite different.

The maglev car would take an individual from his own door to his final destination, but during the bulk of its trip, it would travel on a special highway on which it would be guided. Since it could travel at speeds as high as over 300 mph, it would not be driver-controlled. It would have to be carefully guided because of these high speeds, following the concept of AHS. The maglev car would also operate under its own power, entering and leaving the special highway at the will of the driver.

On the guideway, vehicle-borne superconducting magnets would provide levitation. It is proposed, in this system, that current-carrying superconducting loops arranged in the vehicle (like very strong permanent magnets but requiring to be permanently supercooled) would induce currents in discrete loops or conducting sheets on the track as a
result of the motion of the vehicle. At a certain velocity (depending on the design) the repulsive forces would be sufficient to support the vehicle. Lateral stability would be achieved in one arrangement by means of vertical loops at each side of track, producing restoring forces when the vehicle moved out of alignment. As for its propulsion, one obvious way would be to use a long-stator linear synchronous motor.

An intriguing alternative would necessitate redesign of the fundamental concept of all maglev trains -- because the magnets would be located in the rotating wheels of the car, rather than attached to the fixed underbody. The advantage is the reduction of weight which comes from locating the propulsion device within the wheels. As is the case with Japanese maglev trains, the design calls for the use of super-cooled magnets. Therefore, the maglev cars would require miniature refrigerators in order to maintain the temperature of the superconducting magnets.

Locating magnets in each of the four wheels of the car coincides with the Equos design, which places motors in each of the four wheels of the automobile, rather than using a central battery and a heavy transmission system. The batteries are operated by a computer located under the hood, and there is an optical communications system between the computer and the motors. There are also American-designed cars which place motors in the wheels of the cars, either in two or four of the wheels. Thus, in itself, this feature is not unique to the Equos.

Two approaches are recommended for modifying vehicles for AHS operation. An individual vehicle with fully built-in AHS equipment is one approach. This is seen as the ultimate mature system approach. However, before AHS becomes a pervasive system throughout entire regions of the country, the fully modified vehicle is expected to be

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attractive only to a high-use fleet operator and possibly as a top-of-the-line luxury vehicle option. The majority of the AHS fleet is recommended to be modified through the use of detachable electronics packages (DEPs). The preparation of a vehicle to accept a DEP can be made with a factory option or an after-market conversion. The vehicle owner would obtain a DEP for his vehicle either from a DEP rental company or the AHS authority some time before arriving at the AHS entrance. The DEP would be mounted, all functional connections made, and a diagnostic test run similar to that required at the AHS access facility in a matter of minutes. Eventually, bar code sensing could reduce this to seconds [74].

6.7 Longitudinal Control Alternatives

Two fundamental AHS technologies are automatic lateral control and automatic longitudinal control. Lateral control (automatic steering) serves to let vehicles follow the center of a lane with better accuracy and reliability than when vehicles are steered by human drivers, so that safety is improved. Longitudinal control (automatic headway control) serves to substantially enhance capacity, safety and ride comfort, in unison with automatic lateral control. It is implemented by automatic accelerating and braking. These automatic control systems are characterized by dramatically enhanced perception/reaction time and accuracy, enabling them to operate vehicles safely with high cruise speed and small headways. Based on the conventional highway capacity formula (Capacity = Velocity / Headway Spacing), it is apparent that small headway operation will increase lane capacity.

The choice of a minimum safe headway is not so much dependent on normal operations of an AHS as it is on the question of passenger safety at the time of the
system failure. An unforeseen stop by one vehicle should not involve following vehicles in a dangerous pileup collision. In addition, space may have to be reserved to permit safe merging and exiting of vehicles. Thus the minimum headway will depend on the safety policy, the type and frequency of prospective failures, human tolerances (deceleration and jerk limits), hardware realities (response time, the levels of emergency braking available), and in-vehicle safety equipment (compressible bumpers, air bags, seat belts).

No consensus has been reached yet among experts about what constitute a prudent headway strategy for optimizing the conflicting claims of capacity and safety. Safety criteria should be based on a realistic analysis of failure modes and other hazardous conditions, and of their consequences on passenger safety, since the adoption of criteria based on an unreasoned standing tradition may rule out the possibility of a short headway and therefore make AHS infeasible. Here, it may be useful to mention briefly some of the minimum safe headway strategies either now in use or being proposed.

One traditional strategy which seems to have evolved historically from the railroad industry is the so-called "brick wall" approach in which vehicles must be separated by a distance sufficient to allow the following vehicle to apply brakes and come to a stop without collision, assuming that a failing vehicle stops instantaneously. However, a vehicle does not stop instantaneously when it malfunctions. Even in the extreme case where all wheels lock, a vehicle will slide quite a distance until it comes to a stop. Thus this strategy tends to be conservative from a safety viewpoint and accordingly, provides relatively low guideway capacity. The safety of the actual system is measured by the minimum number of safe stopping distances -- the distance required to stop without collision -- permitted between following vehicles [81].
The non-brick-wall approach is based on the assumption that a failed vehicle does not stop instantaneously. In reality, it decelerates at a finite rate. A number of researchers have proposed designing to this reality. However, there is some controversy over what deceleration rates it is safe to assume. Usual practice for a typical PRT (Personal Rapid Transit) system which uses traction brakes would be a maximum deceleration rate of 0.5 g. Depending on the cause of failure, the deceleration rates of 1 to 1.5 g for the failed vehicle might be considered. The braking systems such as linear motor braking and eddy current braking do not rely on traction and thus can achieve higher values. The Japanese CVS (Computer-Controlled Vehicle System) design uses traction brakes for normal braking and clamps the guideway for high-level 2 g emergency braking and thus the safe headway can be reduced dramatically. As would be expected, this approach will always achieve higher capacities than the brick wall approach, but not without a cost of a less conservative safety criterion.

The least conservative safe headway strategy permits collision of following vehicles but uses impact-absorbing bumpers and passenger restraint devices to assure that impact levels are tolerable. This approach is based on the argument that velocity differential at impact becomes smaller with smaller headway. Obviously, if two vehicles are in physical contact, which means zero spacing, there is no impact velocity differential when the lead vehicle decelerates unexpectedly. Such is the situation with railroad cars coupled into a train. Accordingly, this strategy can achieve the highest capacity. To achieve this fantastic promise, however, the operational problems of safe merging and exiting of vehicles and the design problems in the area of collision absorption, passenger restraint, switching, and command and control must be addressed and solved [82].
Shladover [83] proposes that in order to increase the capacity of the automated guideway it will be necessary to operate the vehicles at significantly closer average spacings, although it would not be possible to completely avoid rear-end collisions from these close longitudinal spacings even with the use of a high-performance vehicle-follower control system. The safety implications of this are quite unfavorable unless the vehicles are operated in close-formation platoons or trains.

Close-formation in this case refers to longitudinal spacings between vehicles of less than one meter within a platoon, while the spacings between platoons would be significantly larger than the spacings between present-day automobiles on freeways. The very close intra-platoon spacings provide improved safety compared to intermediate spacings because in the event of failure that produces an abrupt but finite deceleration of a vehicle, the vehicles behind it would collide with it at a modest relative speed. For this close-formation platoon operation, it is necessary that the spacing between consecutive vehicles be controlled extremely accurately, so that the dynamic variations are no more than a fraction of the nominal spacing. The second issue is ensuring that the platoon remains asymptotically stable, so that the disturbances are damped out as they proceeds down the line of vehicles [84].

In summary, the choice of a minimum safe headway has a significant impact on a system capacity and it depends on the question of passenger safety at the time of the system failure. As a better understanding develops of the safety issues and as better operation and safety features develops for both AVCS maglev guideways and vehicles, small headway operation of AVCS maglev will become more realistic. This issue will not be pursued in detail in this study and will be left for future research.
Longitudinal control is necessary to regulate the velocity and spacing of individual vehicles within an automated highway system. In normal situations, the longitudinal control system maintains proper velocity and spacing between vehicles during:

1. constant speed operations
2. transitions between different speed operation regions
3. merges and diverges at ramp sections and intersections.

Longitudinal control in normal situations must be accomplished without subjecting passengers to acceleration and/or jerk levels which may cause discomfort. In emergency situations, the longitudinal control system is required to avoid or control collisions. Careful consideration must be given to the selection or design of the longitudinal controller and its operational policies to assure good performance over the entire range of operating speeds.

Traditionally, block control has been used in rail transit systems. In this control system, the guideway is divided into blocks and when a vehicle or a train of vehicles enters a block, its presence is sensed and speed control commands are issued to vehicles or trains of vehicles in upstream blocks so that a spacing equal to at least one emergency stopping distance is always maintained between vehicles or trains of vehicles. Block control can be easily automated and is currently used in many automated transit systems [85]. However, for short headway operations this control system becomes somewhat unwieldy and other control concepts have been proposed. These are the vehicle-follower and point-follower control concepts.
In the usual vehicle-follower systems, the vehicles communicate directly with one another in order to maintain proper velocity and spacing. Here, the velocity difference and spacing between each vehicle and its immediate predecessor are used as stimuli to the control logic [86, 87, 88]. In other words, if the preceding vehicle is distant, the control system maintains the vehicle's velocity at the nominal value for the section of the guideway which the vehicle is traversing. If the preceding vehicle is nearby, the control system maintains predetermined spacing between the vehicles. If the spacing between vehicles decreases too rapidly, the control system applies emergency braking.

This system minimizes burden of wayside communication facilities and it is very flexible in accommodating platoons of vehicles of diverse length. Also, speeds can be adjusted easily to adapt to demand shifts or incidents, and some operations are possible even when a vehicle or a wayside system fails. However, since a vehicle has no knowledge of the sudden stopping of a downstream vehicle until the immediate predecessor has started to brake, the braking response propagates down the line of vehicles in a wavelike manner. Moreover, since the usual measurements are of spacing and relative velocity, detection of an inadvertent deceleration of the vehicle ahead may be delayed. The latter type of delay can be avoided if each vehicle reported its anomalous deceleration to the vehicle behind it, and if this information were relayed back along the line.

Up to this point the term "vehicle-follower" has been discussed in its usual context of indicating a system where on-board equipment measures the distance to the vehicle ahead and then the following vehicle's speed is adjusted to maintain safe spacing. However, there might be a second meaning of the term "vehicle-follower," where the motion of a vehicle is adjusted to maintain the spacing from the vehicle ahead,
regardless of how the spacing is measured. For example, if there were continuous or very frequent wayside measurements of the positions of all vehicles, then it might be possible to use control algorithms that adjust a vehicle’s speed, not to keep it in a prescribed slot or to follow a designated point, but rather to adjust its distance from the vehicle ahead [81].

In point-follower systems, vehicles do not communicate directly with one another, but rather communicate with wayside censors and/or computers in order to maintain proper velocity and spacing. The actual velocity and/or position of each vehicle are compared with the corresponding velocity and/or position of a reference point within an assigned moving slot, the length of which is equal to the length of the vehicle plus the minimum allowable nose-to-tail spacing between vehicles [89, 90, 91]. The difference between the measured information and the commanded information are used as error signals. Typically, overall system operations are performed by a central computer, intersections are controlled by wayside decentralized computers, and vehicle control functions are assigned both to wayside computers and to the vehicles themselves. Wayside computers command the vehicles to perform various maneuvers and the vehicle-borne control system regulates accelerating and braking so as to accomplish the commanded maneuvers. In the absence of maneuver commands, the vehicle-borne system maintains each vehicle at a predetermined position within an assigned slot which moves along the guideway. These slots may be hypothetical or may be electronically generated by creating waves traveling at the predetermined vehicle velocity in transmission lines buried in the guideway. The control system forces the vehicle to follow the null points in the amplitude of the traveling wave [85].
The point-follower system may be very simple to design because each vehicle operates according to a well-defined target and only one communication path is needed. Also, merging and routing are simplified by fixed, discrete spacing increments. However, it is not easily adaptable to sudden demand shifts and the whole system must be shut down when a vehicle or a wayside system fails to function properly [84].

Various operational philosophies for AHS networks have evolved. A careful consideration should be given in the selection of an appropriate network control policy, since this selection can influence not only the capacity and operational effectiveness of the system, but also the complexity of its hardware and software elements. Preferred network control approaches must facilitate efficient handling of the close-headway, high-speed traffic on the various lines of the network and also be capable of responding rapidly to emergency situations [81].

Two classes of AHS network control approaches can be identified based on the degree to which the trajectory (state, as a function of time) of each vehicle should be specified. The synchronous control approach was first suggested by Gluck [92] and has subsequently been studied in detail by many others including Godfrey [93], Wilkie [89], Howson [72], and Boyd and Lucas [94]. In this approach, a vehicle's entire trajectory (i.e., its schedule over a selected route) is computed prior to its entry into the system. Here, a sequence of slot assignments, which would allow an uninterrupted trip from origin to destination, would be specified for each vehicle. A high-speed, high-capacity central computer would calculate optimum trajectories (based on fuel economy, travel time variance, percent of loading, or any other desired performance criterion) for every vehicle. While this highly centralized approach might be the best from a system's point of view for the system is completely observable and controllable, in practice, this
approach has several serious shortcomings. These include [95]:

- Requirement for a large computer to process and store reservations and two or more for redundancy, because failure of the computer would be catastrophic;
- Vulnerability of communication due to long communication distances;
- Deficiencies in system utilization (e.g., vehicles might be delayed excessively or denied entry since a conflict-free trajectory was not immediately available when, in fact, a trajectory could have been created by the maneuvering of online vehicles); and
- An inability to respond effectively to vehicle or system failures (i.e., a failure could necessitate the rescheduling and/or rerouting of many vehicles).

A less rigid and more adaptive approach is to remove the requirement for a priori slot assignments. Instead, a vehicle would be merged into the first available vacant slot, and then moved in synchronization with other traffic. This quasi-synchronous control approach was first introduced by Munson [90], and has subsequently been studied in detail by numerous researchers including Whitney [96], Rule [97], Roesler et al. [98], Komhauser and McEvaddy [99], and Sarachik and Chu [100]. This network control policy is characterized by minimal waiting time at an entry point, some decentralizing of the control functions (e.g., the use of some local or wayside decision-making), and an enhanced ability to handle system anomalies.

The evidence for the superiority of one policy over another is not conclusive. However, it appears that quasi-synchronous network control policy offers greater operating flexibility, less delays, and a simpler implementation. Typically, vehicle-follower and point-follower control are used in quasi-synchronous systems, whereas only point-
follower control is applicable to synchronous systems. Block control can be used for collision avoidance in both systems when spacings are sufficiently long. In practice, the same automated highway system may use both the vehicle-following and point-following control and operate both synchronously and quasi-synchronously [85].

6.8 AHS Longitudinal Control Concept

It is envisaged that the AHS guideway consists of three types of sections: (1) unrestricted capacity sections (UCSs), (2) restricted capacity sections (RCSs), and (3) speed transition sections (STSs). UCS and RCS are never adjacent, but rather are always separated by STS. The volumes over all sections are the same, but the velocities differ. RCS exists because of compromising geometrics that call for reduced design and operating speeds. UCS operate at the maximum speed that can be achieved by the AHS technology. The function of STS is to adjust the speeds between these two types of sections. Interchanges are always located in UCS (see Fig. 6-1).

The practical capacity of the guideway \( Q \) is determined by the RCS design speed \( V(RCS) \), the average length of vehicle \( L \) and the safe following distance \( \varepsilon \) that can be achieved by the AHS technology:

\[
Q = V(RCS) \times 5280 / S_L
\]  \hspace{1cm} (6.1)

where \( S_L = L + \varepsilon \). The average headway in the UCS, \( S(UCS)_{av} \), to achieve a volume equivalent to \( Q \) is

\[
S(UCS)_{av} = S_L \times V(UCS) / V(RCS)
\]  \hspace{1cm} (6.2)
Figure 6-1. Time-Space Diagram Illustrating AHS Longitudinal Control
As traffic volumes increase, "platoons" of vehicles are naturally formed. Since AHS will permit much shorter headways than on conventional highways, "platooning" takes on added significance. The criteria for determining when a vehicle is part of a platoon is arbitrary but, for our purpose, it will be assumed to be part of a platoon if its headway \( x \) is less than \( S \) feet, where \( S \) varies according to the type of section. Since merging occurs in UCS, this part of our analysis applies to that type of section and follows a "moving queues" development [101].

The formulation of our platooning model is based on performing a Bernoulli test with probabilities \( p \) and \( 1 - p \) on each headway. If headways between successive vehicles are assumed to be independent, then the probability of having a platoon of exactly one vehicle is

\[
P_1 = 1 - p
\]  

(6.3)

where \( 1 - p \) is the probability that the headway of vehicle 2 is greater than or equal to the arbitrary platooning headway \( S \). Similarly the probability of a platoon of exactly two vehicles is obtained by a combination of one "success" followed by a "failure," or

\[
P_2 = p(1 - p)
\]  

(6.4)

where \( p \) is the probability that the headway of vehicle 2 is smaller than the arbitrary platooning headway \( S \). By induction, the individual platoon sizes form a geometric distribution:

\[
P_n = p^{n-1}(1 - p) \quad n = 1, 2, \ldots
\]  

(6.5)
The expected platoon size \( E(n) \) is given by

\[
E(n) = \sum_{n=1}^{\infty} nP_n
\]

which yields

\[
E(n) = (1 - p)^{-1}
\]  \hspace{1cm} (6.6)

The probability \( 1 - p \) of any vehicle headway \( x \) being greater than or equal to the arbitrary platooning headway \( S \) is, of course, dependent on the distribution of vehicles in space on the guideway lane:

\[
1 - p = P(x \geq S) = \int_{S}^{\infty} f(x; k, a)dx
\]  \hspace{1cm} (6.7)

The two-parameter probability distribution implied in (6.7) is the Erlang distribution.

Substituting in (6.7),

\[
P(x \geq S) = \int_{S}^{\infty} \frac{(ka)^a}{(a - 1)!} x^{a-1}e^{-akx}dx
\]  \hspace{1cm} (6.8)

where \( k = \) average concentration of vehicles
\( x = \) distance
\( a = 1, 2, 3, 4, \ldots \)

Substituting (6.8) and (6.7) in (6.6) yields
\[ E(n) = \left[ \int_0^\infty \frac{(ka)^a}{s(a - 1)!} x^{a-1}e^{-akx}dx \right]^{-1} \]  

(6.9)

which is the fundamental relationship between the platoon size \( E(n) \), concentration \( k \), the arbitrary platooning headway \( S \), and the distribution of concentration \( a \).

Integration of (6.9) for \( a = 1, 2, 3 \) and 4 yields.

\[ E(n)_{a=1} = e^{ks} \]  

(6.10)

\[ E(n)_{a=2} = \frac{e^{2ks}}{2ks + 1} \]  

(6.11)

\[ E(n)_{a=3} = \frac{e^{3ks}}{4.5(kS)^2 + 3kS + 1} \]  

(6.12)

\[ E(n)_{a=4} = \frac{e^{4ks}}{10.67(kS)^3 + 8(kS)^2 + 4kS + 1} \]  

(6.13)

It should also be noted that the platoon size parameter \( E(n) \) was formulated in such a way that it is the reciprocal of the probability of receiving a headway larger than or equal to the platooning criteria. Thus, since

\[ P(x \geq S) = \frac{1}{E(n)} \]  

(6.14)

\( E(n) \) is actually a measure of gap availability. This property makes it extremely important as a tool in AHS entrance ramp control.
6.9 Entrance Ramp Capacity

The average delay of a ramp vehicle $\bar{t}$ in position to be merged onto the AHS guideway is the next step in rational analysis of AHS control:

$$\bar{t} = E(n) \cdot (\bar{x} / v)$$  \hspace{1cm} (6.15)

where $\bar{x}$ is the average length of a headway smaller than $S$ and $v$ is the speed of the platoon in fps. For $a = 1, 2, 3$ and $4$,

$$\bar{x}_{a=1} = \int_0^S x f(x) dx = k^{-1}[1 - e^{-ks} - kSe^{-ks}]$$  \hspace{1cm} (6.16)

$$\bar{x}_{a=2} = k^{-1}[1 - e^{-2ks} - 2kSe^{-2ks} - 2(kS)^2 e^{-2ks}]$$  \hspace{1cm} (6.17)

$$\bar{x}_{a=3} = k^{-1}[1 - e^{-3ks} - 3kSe^{-3ks} - 4.5(kS)^2 e^{-3ks} - 4.5(kS)^3 e^{-3ks}]$$  \hspace{1cm} (6.18)

$$\bar{x}_{a=4} = k^{-1}[1 - e^{-4ks} - 4kSe^{-4ks} - 8(kS)^2 e^{-4ks} - 10.67(kS)^3 e^{-4ks} - 10.67(kS)^4 e^{-4ks}]$$  \hspace{1cm} (6.19)

Substituting in (6.15)

$$\bar{t}_{a=1} = k^{-1}(e^{ks} - 1 - ks) / [V(UCS) \times 1.47]$$  \hspace{1cm} (6.20)

$$\bar{t}_{a=2} = k^{-1} \left[ \frac{e^{2ks} - 1 - 2kS - 2(kS)^2}{1 + 2kS} \right] / [V(UCS) \times 1.47]$$  \hspace{1cm} (6.21)
\[ \dot{i}_{a=3} = k^{-1} \left[ \frac{e^{3kS} - 1 - 3kS - 4.5(kS)^2 - 4.5(kS)^3}{1 + 3kS + 4.5(kS)^2} \right] / \left[ V(UCS) \times 1.47 \right] \] (6.22)

\[ \dot{i}_{a=4} = k^{-1} \left[ \frac{e^{4kS} - 1 - 4kS - 8(kS)^2 - 10.67(kS)^3 - 10.67(kS)^4}{1 + 4kS + 8(kS)^2 + 10.67(kS)^3} \right] / \left[ V(UCS) \times 1.47 \right] \] (6.23)

Now the ramp capacity \( Q_r \) can be determined in two ways: First \( Q_r \) is the reciprocal of the average service time, so

\[ Q_r = (\bar{t} + T')^{-1} \] (6.24)

where \( T' \) (as described in the next paragraph) is defined mathematically as

\[ T' = S' / \left[ V(UCS) \times 1.47 \right] \] (6.25)

The second approach to the determination of \( Q_r \) is direct \([102]\). Consider a single inexhaustible queue waiting on the entrance ramp of a guideway. If the headway \( x \) on the guideway is less than the critical headway \( S \) required by computer control for a safe merge, no ramp vehicle is merged; if \( x \) is between \( S \) and \( S + S' \), one vehicle enters; if \( x \) is between \( S + S' \) and \( S + 2S' \), two vehicles enter, etc. The ability of the guideway to absorb ramp vehicles becomes

\[ Q_r = q \sum_{i=0}^{\infty} (i + 1) P[T + iT' \leq t \leq T + (i + 1)T'] \] (6.26)
where \( q \) is the guideway flow rate and \( T = S / v \), etc.

If the distribution of gaps on the guideway \( f(t) \) is given by the negative exponential distribution

\[
f(t) = qe^{-qt}
\]

then it follows from (6.26) that

\[
Q_r = \frac{qe^{-qT}}{1 - e^{-qT}}.
\] (6.27)

The similarity of the two approaches can be seen by comparing (6.24) and (6.27) for the case in which \( T = T' \) and noting that \( kS = qT \).

\[
Q_r = [q^{-1}(e^{qT} - 1 - qT) + T']^{-1} = qe^{-qT} / [1 - e^{-qT}] 
\] (6.28)

Equation 6.28 shows that both approaches yield the same values for \( T = T' \).

It follows that Drew's expressions [102] for average delay for various distributions of guideway gaps (\( a = 1, 2, 3 \) & 4 of the Erlang distribution) can be converted to ramp capacities using (6.24)

\[
Q_r^{(a=1)} = [q^{-1}(e^{qT} - 1 - qT) + T']^{-1}
\] (6.29)
\[ Q_{r}^{(a=2)} = \left[ \frac{e^{2qT} - 1 - 2qT - 2(qT)^2}{q(1 + 2qT)} + T' \right]^{-1} \] (6.30)

\[ Q_{r}^{(a=3)} = \left[ \frac{e^{3qT} - 1 - 3qT - 4.5(qT)^2 - 4.5(qT)^3}{q[1 + 3qT + 4.5(qT)^2]} + T' \right]^{-1} \] (6.31)

\[ Q_{r}^{(a=4)} = \left[ \frac{e^{4qT} - 1 - 4qT - 8(qT)^2 - 10.67(qT)^3 - 10.67(qT)^4}{q[1 + 4qT + 8(qT)^2 + 10.67(qT)^3]} + T' \right]^{-1} \] (6.32)

### 6.10 Ramp Queue Length

The concept of the delay to a ramp vehicle in position to merge, discussed above, becomes important as an input in a queueing model. Consider vehicles on an entrance ramp arriving at the merging area at a rate described by \( f(q_r) \) where \( q_r \) is the average rate of arrival. These vehicles are obliged to yield to the guideway traffic, forming a single line and waiting for successive vehicles at the head of the line to be merged by computer control. If the distribution of service for vehicles at the head of the queue is \( f(Q_r) \), it is apparent that an entrance-ramp merging operation is within the realm of a classical queueing system.

Using the approach of Kendall [103], let \( n_0 \) and \( n_1 \) be the ramp queue lengths immediately after two successive ramp vehicles \( C_0 \) and \( C_1 \) have merged, \( t \) be the service time of \( C_1 \) and \( r \) be the number of ramp vehicles arriving while \( C_1 \) is being served. If a random variable \( \delta \) is introduced such that \( \delta = 1 \) if \( n_0 = 0 \) and \( \delta = 0 \) if \( n_0 \neq 0 \), then it follows that

6. Automated Highway Systems
\[ n_1 = n_0 + r - 1 + \delta \quad (6.33) \]

It is to be noted from the definition of \( \delta \) that

\[ \delta^2 = \delta \]

and

\[ n_0\delta = 0 \]

and hence, from (6.33), on taking expected values, we obtain

\[ E(n_1) = E(n_0) + E(r) - 1 + E(\delta) \quad (6.34) \]

If the system is assumed to be in a state of statistical equilibrium, \( E(n_1) = E(n_0) \) and

\[ E(r) = \frac{Q_r}{Q_t} = \rho \]

Thus substituting in (6.34)

\[ E(\delta) = 1 - \rho \]

Squaring both sides of (6.33) and taking expected values as before,

\[ E(r - 1)^2 + E(\delta^2) + 2E[n_0(r - 1)] + 2E[\delta(r - 1)] = 0 \]
which reduces to

\[ E(n) = \rho + \frac{E(r^2) - \rho}{2(1 - \rho)} \]  \hspace{1cm} (6.35)

It is now necessary to calculate \( E(r^2) \), the second moment of the number of arrivals in the service time \( t \), making use of its relationship to the mean and variance in arrivals. Assuming that ramp arrivals are Poisson and remembering that "averaging" here must be carried out with respect to both \( r \) and the service time \( t \), we have

\[ E(r^2) = q_r E(t) + q_r^2 E(t^2) \]

Since \( E(t) = Q_r^{-1} \) and

\[ E(t^2) = \sigma^2 + [E(t)]^2 \]

then,

\[ E(r^2) = \rho + \rho^2 + q_r^2 \sigma^2 \]  \hspace{1cm} (6.36)

Substituting (6.36) in (6.35) gives the expected queue length on the ramp as

\[ L = \frac{q_r}{Q_r} + \frac{Q_r q_r^2 (Q_r^{-2} + \sigma^2)}{2(Q_r - q_r)} \]  \hspace{1cm} (6.37)
If \( w \) is the waiting time (before merging) of \( C_1 \), then \( n_r \) ramp vehicles arrive in time \( t + w \). Thus since the mean arrival rate is \( q_r \),

\[ L = q_r E(t + w) \]

It follows that the average waiting time for a ramp vehicle before merging is

\[ E(w)_r = \frac{L}{q_r} - Q_r^{-1} \quad (6.38) \]

and the mean wait in the system for a ramp vehicle is

\[ E(v)_r = \frac{L}{q_r} \quad (6.39) \]

Major and Buckley [104] have interpreted the service time for the queue \( Q_r^{-1} \) as identical to the summation of the rejected gaps for a ramp vehicle in position to merge (what we have referred to as the merging delay). Based on the assumptions that the average service time is equal to the average merging delay and the distribution of service times is of the form of the Pearson type III distribution, we obtain from (6.37),

\[ L = Q_r^{-1}q_r + \frac{(Q_r^{-1}q_r)^2(1 + a^{-1})}{2(1 - Q_r^{-1}q_r)} \quad (6.40) \]

where \( Q_r \) is given by Eqs. (6.29) to (6.32), and \( a \) is the parameter describing the distribution of service times.
Figure 6-2 illustrates the AHS design-operational methodology that has been developed here. The inputs are: (1) the restricted capacity section velocity, \( V(RCS) \); the controlled headway in the RCS, \( S_L \); the ramp demand, \( q_r \), and the critical gap for a controlled merge, \( T \). Starting at the bottom right, we enter the table with \( V(RCS) \), move horizontally to the left to \( S_L \), then up to the scale for the value of the guideway capacity, \( Q \). From \( Q \), continue upward vertically to the horizontal line corresponding to the ramp demand, \( q_r \). From this intersection point, move diagonally up and to the left to find the guideway volume, \( q \). From \( q \), move vertically upward to find the value of \( T \) and then horizontally to obtain the ramp capacity, \( Q_r \). Using the table in the upper left with the abscissa \( q_r \) and ordinate \( Q_r \), find the ramp queue length, \( L \).

In order to complete the graph for \( L \), the case in which the ramp demand, \( q_r \), exceeds the ramp capacity, \( Q_r \) (the upper triangle of the graph), is considered using deterministic queueing. We know that for uninterrupted and uniform flow situations no delay results if \( q_r / Q_r \) is less than 1.0. However, there are many other uniform flow situations of considerable interest and of relevance to a variety of traffic problems. Among these is the temporary overloading of a traffic-flow facility, such as during peak periods. If the duration of the overload is \( T_s \) and the ratio of the flow during the overload period to the normal flow is \( p \), then the duration of congestion is given by

\[
T_c = T_s + \left[ L - \frac{\left( Q_r - q_r \right)}{T_s} \right]
\]  

(6.41)

where

\[
L = (pq - Q_r)T_s
\]  

(6.42)
Figure 6-2. AHS Operational Nomograph (a = 1)

Notation:
- RCS velocity = $V_{RCS}$
- guideway capacity = $Q$
- bus space headway = $S_b$
- guideway volume = $q$
- ramp capacity = $Q_r$
- ramp demand = $q_i$
- critical gap = $g$
- ramp queue length = $L$
- gap dist parameter = $d(-1)$
The total delay to all ramp vehicles affected by this temporary overload is

\[ D = L \frac{T_s}{T_c} / 2 \quad (6.43) \]

The average numbers of ramp vehicles in the queueing system during the period of congestion is found to be

\[ L = \frac{D}{T_c} = \frac{[(pq - Q_r)T_s]}{2} \quad (6.44) \]

The curves for \( L \) in Fig. 6-2 have been plotted for \( T_s = 30 \) min giving the curves for \( L = 125 \) through \( L = 1000 \) on the graph.

Figure 6-2 was prepared assuming the Erlang parameter, \( a \), describing the distribution of gaps on the guideway conforms to a negative exponential distribution (\( a = 1 \)). On conventional highway facilities, we know that this Erlang parameter is affected by the volume level, alignment, grade and environmental conditions. As volumes build up, the parameter has been found to increase from \( a = 1 \) for low volumes to \( a = 4 \) for high volumes. In Figs. 6-3, 6-4, and 6-5, nomographs have been prepared for \( a = 2, 3 \) and 4 using the same format as for Fig. 6-2.

**6.11 STS Operation**

As mentioned in Section 6.8, the speed transition section (STS) is always located between UCS and RCS to adjust the speeds between these two types of sections. During the speed transition operation average spacing between vehicles will change, but at any moment the capacity of STS should not be smaller than the traffic volume of
Figure 6-3. AHS Operational Nomograph (a = 2)
Figure 6-4. AHS Operational Nomograph (a = 3)
Figure 6-5. AHS Operational Nomograph (a = 4)

Notation

\[ \text{RCS velocity} = V(\text{RCS}) \]
\[ \text{guideway capacity} = Q \]
\[ \text{min space headway} = S_t \]
\[ \text{guideway volume} = q \]
\[ \text{ramp capacity} = Q_r \]
\[ \text{ramp demand} = q_r \]
\[ \text{critical gap} = g \]
\[ \text{ramp queue length} = L \]
\[ \text{gap dist parameter} = a(\cdot 4) \]
the upstream section to ensure smooth flow (i.e., no congestion). Also, the safe following distances between vehicles should be maintained. Vehicle-following models offer these features since the velocity difference and headway spacing between each vehicle and its immediate predecessor are used as inputs to the control logic. However, this system is intrinsically unstable since each vehicle's operation is based mostly on stimuli from its predecessor [105]. Thus, in order to operate vehicles with small spacings as in AHS, it is crucial to ensure that each controlled vehicle must be stable relative to the position of its immediate predecessor (local stability) and the disturbances in the velocity of the lead vehicle should not propagate in an amplified fashion along the line of vehicles within the platoon (asymptotic stability). Therefore, the vehicle-following model that can ensure the intra-platoon stability is essential to the development of an automatic longitudinal control scheme of STS.

Vehicle-following models are essentially a form of a stimulus-response equation, in which the response (accelerating or braking) is made in proportion to the magnitude of the stimuli after a time lag "TL." This time lag is comprised of perception lag, information-processing lag, and powertrain response lag. In other words, no on-board or wayside equipments (sensor, computer, powertrain, etc.) can respond instantaneously. Thus, the basic equation can be expressed as the following:

\[ \text{Response}(t + TL) = \text{Sensitivity} \times \text{Stimulus}(t) \]

The simple linear vehicle-following model suggested by Pipes [106] implies that a driver's response is directly proportional to the velocity difference between his car and the car ahead of him, but independent of the spacing between those two cars. In 1961, Gazis et al. [107] proposed a general (or non-linear vehicle-following) model which...
involves the reciprocal of spacing and the velocity of the follower in the sensitivity factor. The model is of the following form:

\[ a_{n+1}(t + TL) = \alpha \frac{v_{n+1}^m(t)}{[x_n(t) - x_{n+1}(t)]} [v_n(t) - v_{n+1}(t)] \]  

(6.45)

where  
\[ x_n(t) = \text{position of the } n\text{-th vehicle} \]  
\[ v_n(t) = \text{velocity of the } n\text{-th vehicle} \]  
\[ a_{n+1}(t + TL) = \text{acceleration of the } (n+1)\text{-th vehicle} \]  
\[ TL = \text{time lag} \]  
\[ \alpha = \text{proportionality constant} \]  
\[ l, m = \text{exponents} \]

It can be seen that when \( m = 0 \) and \( l = 0 \), the general equation becomes the simple linear vehicle-following model. The previous study by Lee and Drew [108] reports that the parameter values \( m = 0.7 \) and \( l = 2.7 \) achieves the stability of the model based on the following assumptions:

- Every car has the same length and weight.
- It has the same accelerating/braking capabilities, and maximum speed.
- It has the same perception and reaction lags.
- It has the same initial spacing and velocity.
- A platoon consists of 6 cars.

Here, we use the same assumptions and parameter values as the above. The RCS operating speed is assumed to be 200 mph and the UCS operating speed 300 mph.
The platoon leader starts from 200 mph in RCS and achieves the UCS operating speed with a uniform acceleration rate of 0.3 g (9.66 ft/sec²). During this speed transition operation the acceleration/deceleration rates of the following cars are constrained not to exceed this speed change rate. The initial headways are assumed to be 28 ft and time lags 0.08 second. The whole simulation process is shown in Fig. 6-6 (For the interpretation of the causal diagram, refer to Section 9.3.1.). The results are summarized in Table 6-1. We can see that with the above nonlinear vehicle-following model the STS operation is completed with a good system stability after about 18 seconds. The average headway in UCS is 40.7 ft, which guarantees the smooth flow and the minimum length of STS required for this particular operation, in which \( V(\text{RCS}) = 200 \text{ mph} \), \( V(\text{UCS}) = 300 \text{ mph} \) and the max. acceleration/deceleration = 0.3 g, is about 7,000 ft.

6.12 Peak Period Optimization

A location at which the capacity is lower than the possible upstream traffic flow rate is called a bottleneck. In an AHS guideway system bottlenecks occur due to the existence of the restricted capacity sections (RCSs) where vehicles should operate at reduced design speeds because of compromised geometric features. Based on the AHS longitudinal control concept defined in the previous sections, the traffic volumes over all the sections within an interval between two adjacent ramp facilities are the same, but the traffic volumes which can be accommodated in the intervals along the guideway system may differ, since RCSs may have different geometric restrictions. Nevertheless, if we try to achieve constant traffic volumes along the entire guideway route, the maximum affordable capacity will be the capacity of the lowest design speed section along the route, which will bring about the worst operating efficiency.
Figure 6.6. Causal Diagram for STS Operation
Table 6-1. Simulation Results for STS Operation

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Note: $v_n$ = velocity of the n-th vehicle
      $x_n$ = position of the n-th vehicle
      $d_{s mn}$ = space headway between the m-th and n-th vehicles ($= x_m \cdot x_n$)
Therefore, to achieve the best utilization of the guideway facility the capacity in each interval between two adjacent ramp facilities must be based on the lowest design speed in the same interval. And as for the safe following distance, up to certain operating speeds the same safe following distances will be achievable through modern and future AHS technologies. Thus, the relationship between the safe following distance and operating speed will not be a form of a one-to-one function, but of some step function.

The difference in traffic volumes between two adjacent ramp facility sections must be managed by monitoring entrance and exit ramp operation. While the main purpose of entrance and exit ramps on conventional freeways is loading and unloading traffic, ramp metering is utilized as a key to smoothing traffic flow rates, thus avoiding any possible traffic congestion and utilizing freeway facilities more efficiently. The utilization of this ramp metering concept becomes essential in order to achieve the best AHS guideway operating economy. In addition, this concept will be much better and more easily applicable to AHS guideway facilities than to conventional freeway facilities, since the AHS control center will have the real time information about each vehicle's trip origin/destination, the aggregate travel demand, and the bottleneck capacities.

Now, a linear programming (LP) model of the operation of an automated highway system is developed to illustrate its peak-period optimization scheme. The guideway system considered here is shown schematically in Fig. 6-7. The model has as its objective the maximization of the output of the system of interest in the time period considered. The output is considered to be the traffic volume leaving the system through the guideway mainline and all of the exit ramps. For steady state conditions, the input of the system must be equal to its output [109], so input can be substituted for
$X_j =$ input traffic volume (vph)
$C_j =$ section length (mi.)
$D_j =$ max. hourly demand (vph)
$Q_i =$ section capacity (vph)

$i = 1,\ldots,4$ and $j = 1,\ldots,5$

Figure 6-7. Schematic of an AHS Guideway System for Peak-Period Optimization
output in the criterion function. Then, the objective of the model is to maximize the input to the system.

Based on Fig. 6-7 and the above argument, our example problem can be stated as follows: Find \( X_i \), the input traffic volumes, that will maximize \( Z \), the AHS guideway throughput, subject to the section capacities \( Q_i \), assuming that the peak-period ramp metering rates are proportional to the demands. For computing the ramp capacities \( Q_{ii} \), assume that \( T = 0.2 \) sec, \( T' = 0.08 \) sec and the distribution of gaps on the guideway is given by \( a=3 \) of the Erlang distribution. A summary of the trip origin-destination information and other parameter values for a peak-period are given in Table 6-2.

Since the objective is to maximize the input to the guideway system, the variables of the LP problem are the traffic volumes entering through the mainline (\( X_5 \)) and the entrance ramps (\( X_1, X_2, X_3 \) and \( X_4 \)) from each of the input sources. Thus, the objective function is expressed as follows:

\[
\text{Maximize } Z = X_1 + X_2 + X_3 + X_4 + X_5
\]  

(6.46)

However, these variables or the combination of them are constrained by certain factors. As shown in Table 6-3, the first set of constraints indicates that the traffic volumes going through the guideway sections cannot exceed the section capacities. Also, it is obvious that the merging traffic volumes cannot be greater than the travel demand (the third set) and that these volumes are limited by the entrance ramp capacities (the second set). The travel demand indicated by \( D_5 \) is not controlled, which means that \( X_5 = D_5 \) should always be satisfied. As for solving the LP problem, since the entrance ramp capacities depend on the upstream traffic volumes as shown in Eq. 6.31 and
Table 6-2. Trip O-D Information and Parameter Values for a Peak-Period

Trip Origin-Destination Information:

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<td>-</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>15</td>
<td>50</td>
</tr>
</tbody>
</table>

Parameter Values:

Max. Hourly Demands, $D_i$

$D_1 = 5000$ vph
$D_2 = 4000$ vph
$D_3 = 5500$ vph
$D_4 = 6000$ vph
$D_5 = 35000$ vph

Section Capacities, $Q_i$

$Q_i = V(RCS)_i \times 5280 / S_L$
$S_L = 28'$

$V(RCS)_1 = 150$ mph
$V(RCS)_2 = 130$ mph
$V(RCS)_3 = 160$ mph
$V(RCS)_4 = 170$ mph
Table 6-3. LP Model for an AHS Peak-Period Optimal Control

Maximize \( Z = X_1 + X_2 + X_3 + X_4 + X_5 \)

subject to

\[
X_1 + 0.95X_2 + 0.90X_3 + 0.80X_4 + 0.50X_5 \leq Q_1 \\
X_2 + 0.97X_3 + 0.83X_4 + 0.57X_5 \leq Q_2 \\
X_3 + 0.95X_4 + 0.72X_5 \leq Q_3 \\
X_4 + 0.82X_5 \leq Q_4 \\
X_1 \leq Q_{r1} \\
X_2 \leq Q_{r2} \\
X_3 \leq Q_{r3} \\
X_4 \leq Q_{r4} \\
X_1 \leq D_1 \\
X_2 \leq D_2 \\
X_3 \leq D_3 \\
X_4 \leq D_4 \\
X_5 = D_5 \\
D_2X_1 - D_1X_2 = 0 \\
D_3X_2 - D_2X_3 = 0 \\
D_4X_3 - D_3X_4 = 0
\]
these upstream volumes are decided by the input traffic volumes, we assume some values for the input volumes to compute the upstream volumes and then the ramp capacities. If the computed $X_j$ values are equal to the assumed values, we end the process. If not, we should repeat the whole process by assuming different sets of values for $X_i$ until we reach the equilibrium. The solution for our example problem is $(X_1, X_2, X_3, X_4, X_5) = (1594, 1275, 1754, 1913, 35000)$.

Up to this point we have considered how to maximize the throughput of an AHS guideway system, but another interesting approach from the point of view of the AHS guideway authority, public and/or private, will be how to maximize the revenue, since it is envisaged that the AHS guideway users will be charged for their own use. As one of the basic pricing methods the toll will be charged based on the distance a vehicle traveled on the guideway. Then, the total revenue will be proportional to the total travel length and the objective function will be expressed as follows (see Fig. 6-7):

$$\text{Maximize} \quad \text{Total Travel Length} = C_1V_1 + C_2V_2 + C_3V_3 + C_4V_4 + C_5V_5 \quad (6.47)$$

where $C_j =$ guideway section length and $V_j =$ guideway section volume. The constraints will be the same as in the first example problem.
7. Shaping Human Activity with AVCS Maglev

7.1 Introduction

Transportation has always been a major force in determining the pattern of human settlements and activity. From the beginning of civilization some six thousand years ago, when our ancestors settled in fertile valleys in half-a-dozen locations spread across the face of the earth to live by growing food rather than hunting for it, to the present century, in which the rural poor migrate to urban areas in search of jobs, man has continually sought a place where life was easier.

Just as, historically, canals, railroads, and freeways have shaped our human settlements and activity, so shall AVCS maglev guideways (AVCS magways). The most insistent man-made order in the regional landscape is the pattern of streets and roads. One of the problems alleviated by transportation systems over the ages is the inefficient distribution of population at all levels from the world scale to a region within a country. We know that populations respond to changing economic and social circumstances through migration in free societies and through relocation in autocratic countries.

7.2 Background

One of the principal goals of any development plan is to provide for the rational distribution of population and economic activities. The goal is to achieve balanced development among regions in order to reduce their per capita income differentials. The knowledge of exactly what patterns are likely to evolve naturally or in response to
certain policies is uncertain because population moves partly in response to changes in geographic opportunities, and firms are started, or move, partly in response to population and market shifts.

Once reliable estimates of the future state of these geographical patterns are available, we can begin to ask ourselves how the patterns might be altered to conform more closely with social objectives, and what programs can be applied to achieve the objectives. But this presupposes a clear notion of what these objectives are -- something that is painfully lacking. Most contemporary planners abhor the notion that we are drifting more and more towards megalopolitan growth. Yet this opposition is a subjective one, based more upon esthetic myths than upon any clear notion of the economies, diseconomies, and social effects of increases in urban scale. Similarly, we are unable to compare the political and social benefits between less centralized and concentrated human settlements. Lacking a systematic understanding of these issues, it is impossible to clarify the social objectives concerning the distribution of population and economic activity [110].

Two approaches that contribute to this understanding are the "location" approach and the "land use" approach. The first is based on finding locations for given activities; the second is based on deciding what activities should be carried on at given locations. One of the first schemes explaining urban patterns was central-place theory. It was formulated by Christaller in 1933 and published in German. Christaller considered that his theory could also be designated as the theory of location of urban trades and institutions to be placed beside von Thunen's theory regarding the location of agricultural production and Weber's theory regarding the location of industries. A good portion of August Losch's works are given to the evaluation of and extension of central
place theory [111]. He found that the theoretical shape of a trading area is a hexagon.

In applying von Thunen's theory to urban residential areas, we are merely replacing an agricultural commodity with an urban "product" -- the housing of people. The products are high-rise apartments, multistory-row houses, single-unit dwellings, etc. Given equal neighborhood amenities, the value per unit area of land decreases with the distance from the city center. However, in urban areas unit transport costs are not only a decreasing function of distance traveled, but are also an increasing function of population density. These two factors -- "production" and transport costs -- explain why the type of residential housing in cities are arranged in order of decreasing density per acre as one moves away from the city-center [112].

The principal determinant of land use is economy of location. Three conceptual systems have been suggested to explain the distribution of land uses in urban areas and their changes over time: (1) the concentric zone concept, (2) the sector concept, and (3) the multiple nuclei concept. Referring to the first, the concentric zones are bounded by von Thunen's rings. As growth occurs, each inner zone tends to invade the next outer zone in what sociologists call the "invasion-succession" phenomenon. The sector concept is based on the theoretical explanation of residential land uses in terms of wedge-shaped sectors radial to the city's center along established lines of transportation. The remaining area is filled in with concentric zones. The multiple nuclei hypothesis is built on the observation that there are often, not one but, a series of cores in the patterning of urban land uses [113].

Land use is intimately related to transportation. The different activities associated with particular types of land use generate travel. Transportation facilities represent the most
expensive single infrastructural investment and the intelligent planning of these facilities
depends on an understanding of the interaction between land use and transportation.
The point here is that it is possible that the contemporary application of land-use in
urban areas by function may be an outmoded form of classification if it does not enable
us to answer the proper questions. Perhaps, in a form analogous to the use of
productivity in agricultural land-use classifications, "intensity" and "accessibility" would
be better bases for urban land-use classifications.

7.3 Planning Based Methodologies

The art and science of planning is in the throes of a complex evolution. One of the
most serious problems facing planning at the present time is the difficulty of relating
anticipated needs to past experience due to rampaging technologies and social
change. Some implications of this problem are the need to place more emphasis on
the understanding of social change and the need to look beyond the mere projective
aspects of planning to more scientific approaches such as systems analysis. In the
past two decades many aspects of planning have been transformed by the systems
approach. It started with the urban area transportation studies in the United States and
with the regional science movement. This approach has led to a systematic
examination of the whole process of planning [114, 115, 116].

Contrary to what some of the more enthusiastic advocates of quantitative analysis
think, many authors feel that systems analysis can only play a somewhat modest,
perhaps significant, role in overall planning and the decision-making process [117]. No
attempt will be made to resolve this difference of opinion here since it is the purpose of
this study to advance arguments on both sides. Recognizing the interdependency and
intersensitivity of all mankind’s serious problems, the author feels the need for dealing
with some transdisciplinary and transnational problems using systems analysis. Still
the experience of many developing countries indicates that national plans based on
narrowly constructed econometric models for development, for example, have proved
to be misleading. The need in planning is for a new conceptualization of the meaning
of development based on a relevant -- whether mathematical or intuitive -- planning
methodology.

"Ekistics" is the science of human settlements. It is not a general theory of planning per
perse but more of a general framework for organizing the whole field of knowledge related
to human settlements. Although the ekistics concept goes back to the time of the
ancient Greek civilization, this concept was popularized with the founding of the journal
of the same name in 1955. The "Ekistic Grid" was conceived by Constantinos Doxiadis
[118] in the early sixties as a device for ordering conceptualization of settlements.

Human population growth has become the focus of attention of demographers,
biologists, anthropologists, sociologists, economists, agriculturists, medical scientists,
and many others. The mobility of human populations is of particular concern to
geographers and planners. To some, population geography is a distinctive field of
geographical inquiry, examining and interpreting the spatial patterns of population
distribution, composition, migrations and growth in relation to human activities and the
nature of places [119].

Whereas demographers concentrate on the processes of numerical population change
mainly for countries as units rather than for their component areas, the contribution of
geographers to the study of population has been principally in spatial analysis.
Geographers no longer regard population merely as a response to economic processes which, themselves, are conditioned by the physical environment; they, the geographers, examine population as a causal element.

7.4 Land Use Conversion

Changes in the rural environment come about as a result of shifting patterns of primary production. These changes, in turn, are the outcome of other forces and increasing pressure from the urban and industrial sectors. They are also caused by the demand for houses and better housing standards, the demand for natural resources in the form of minerals and water, the demand for transport facilities and the need for outdoor recreation. The increasing use of motor vehicles also creates additional pressures on land resource, not only in terms of road requirements and parking space, but simply by virtue of the added mobility people have as a result, allowing them access to previously unvisited areas.

The steady conversion of agricultural land to urban uses is of concern to many [120]. This conversion could be especially critical in developing countries where agriculture is already at the subsistence level and increases in production are only being achieved by bringing more land under cultivation. Efforts must be made to steer urban development away from potentially valuable agricultural land.

Some insight into the pattern of urban expansion can be gained by this simple model proposed by Medvedkov [121]. The basic relationship is as follows:

\[ E_j = 1 + 2j(j + 1) \]  

(7.1)
where $E_j$ is the total size in terms of equal square blocks of a city in the time state $j$ (see Fig. 7-1). If the original block is neglected, then

$$\Delta E_j = 2j(j + 1) \quad (7.2)$$

and, accordingly,

$$\Delta Y_{j+1} = 4(2j + 1) \quad (7.3)$$

where $Y_{j+1}$ is the number of new streets stretching corner-to-corner along the sides of square blocks. This analysis is repeated for hexagonal areas, as shown in Fig. 7-1.

$$E_j = 1 + 3j(j + 1) \quad (7.4)$$

or, neglecting the original area,

$$\Delta E_j = 3j(j + 1) \quad (7.5)$$

and

$$\Delta Y_{j+1} = 6(3j + 1) \quad (7.6)$$

Obviously, the time variable as related to the conversion of land use is important. Some feel for its effect can be gained by assuming that population grows exponentially at a rate $k$ and that the conversion of land from agricultural to urban land uses is a function of the growth of the economy $r$. Hence
\[ E_t = E_0 e^{k(1+r)t} \]  

(7.7)

and through its application one can obtain the time needed to expand to any stage as a function of the time in each state \( T_{j+1} \) as follows:

\[ E_{j+1} = E_j e^{k(1+r)T_{j+1}} \]  

(7.8)

We know that land is being relentlessly converted from rural to urban uses. The scale of stage consumption for the theoretical model given in Eq. 7.4 forms a sequence with \( E_0 = 1, E_1 = 7, E_2 = 19, E_3 = 37, E_4 = 61, E_5 = 91, E_6 = 127 \), etc. Since each stage covers the same period of time, the sequence thus formed reveals that while the rate of urban expansion decelerates, the absolute increases are tremendous.

7.5 Growth and Spatial Organization

The first settlers in a new, and virtually undeveloped region have to exist in a self-sufficient manner. Within the constraints of their necessarily limited knowledge, judgments concerning the choice of sites for their settlements must be made. Important considerations would be a close supply of potable water, availability of arable land, and the proximity of building material and fuel. Such a settlement would draw upon a tributary area for its support and the size of the population would be determined by the quantities of resources available.

In the absence of technological change, we know that a central city cannot grow indefinitely. Even before its entire population is engaged in transportation activities it must reach a limit where just enough labor remains to produce the industrial products
needed to meet the increased demand by the receivers of rent in the rural areas, according to von Thunen's theory. As the maximal size of the city is reached, central-place theory dictates that another central place must be founded to become the nucleus of another market area and other central places must rise in the functional hierarchy.

The idea of a maximal size city is still a vague concept. Isard [122] illustrates economies of scale with urban size, hypothetically, in a diagram reproduced in Fig. 7-2. The Figure shows economies rising as city size increases to a certain point, beyond which diseconomies of scale began to operate. Still, as Isard points out, for each firm there are attracting and repelling forces for a location in cities of different sizes.

Of critical importance to economic and social development is the planning of human settlements -- their location, function, size, structure and interaction. Analytical models that have been developed with respect to four crucial areas of urban and regional planning: (1) population activity, (2) economic activity, and (3) land use/transportation activity. The synthesis of these activities, if performed properly, should lead to a rational spatial organization of human settlements and human activities.

7.6 The Meaning of Metropolis

America has built, in this century, a new kind of city. It bears little resemblance to the traditional European cities, which developed as the concentrated and self-contained centers of economic and political life. Instead, the lines of commerce and communication in this new kind of city extend to the fringes of metropolitan areas -- of metropolis. This city, metropolis, has many centers rather than one, even though one
Figure 7-1. Space Consumption by Square Expansion and Hexagonal Expansion

Figure 7-2. Urban Economies of Scale
may predominate. The major center, the urban core, and its diverse suburbs are thoroughly interdependent [123].

The process of spontaneous urbanization by which metropolis has been formed is both wasteful and destructive of natural resources. The most precious of them -- land -- has been treated not as a resource at all, but as a commodity to be bought, sold, and speculated upon just like any other. Land prices have risen sharply with the spread of metropolis and land speculation has become a major industry [124].

If we are to accommodate America's urban growth in the first half of the 21st century, we must have a three-pronged attack. First, we must allow existing cities to rebuild and reorganize, sustaining and enhancing their values, and making them livable for centuries to come. Second, we must rationalize suburban growth through community design. Third, we must build new cities, not new towns, beyond commuting distance of existing cities. They can be located in the open countryside, on virgin lands, or they can grow up around existing small towns, all in conjunction with AVCS magway construction.

If we allocate one half of the coming 100 million people to peripheral growth around existing cities and 10 percent to small towns and farms, the remaining 40 million would require the building of 20 cities of one million people each and 200 new towns of 100,000 each.

The most important aspect of building new cities is the opportunity for a fresh start, a chance to put to work what we know of how to build better places to live, to work, to invest. to be educated, and to grow old; places of safety, convenience, excitement, and
beauty; places free of all the conditions that make Americans anti-city. The most affluent nation in the world has the capacity to create the most wonderful urban places on earth through public power, public financial leadership, and wise use of private enterprise. All it needs is a reason to act; that reason is a new ubiquitous transportation system that will revolutionize the way people live their lives.

7.7 The Fringe and the Form

Twin symbols of our vehicular age are the cloverleaf interchange and the signalized intersection. The significance of the cloverleaf is that traffic merges tangentially, eliminating both danger and delay. In the case of an intersection, conflicting traffic closes at a right angle and a signal is required to allocate right of way. Of course, cloverleaf interchanges utilize grade separation structures whereas the signalized intersection employs no vertical separation. Some of the advantages in efficiency and safety can be achieved with the old-fashioned traffic circle. The problem is that few cities can afford the space required for wholesale use of traffic circles and rather than being built, they are being replaced with intersections in many cities [125].

It comes as no surprise to students of central place theory based on hexagonal shapes, that a hexagonal honeycomb city plan can receive traffic loads from all directions and divert them to other directions most economically and efficiently. A maximum acreage of each hexagonal block is made available for a minimum length of surrounding roads, which of course, is shared by other contiguous hexagonal city blocks (see Fig. 7-3).

All transportation modes have two major components -- the fixed facilities and the vehicles. The route factor is a useful measure of effectiveness of the geometrical
Figure 7-3. Hexagonal Grid
characteristics of the road network. It can also be used as a measure of comparative performance for different designs and operational schemes. The route factor for a transport link is the actual distance from end to end divided by the direct distance. The route factor of a network may be defined as the ratio of the total distance traveled between any pair of nodes to the sum of direct distance between them. Blunden [126] illustrates the calculation of the theoretical forms for the square grid network and the ring radial network.

Hsu [127] has evaluated four road network systems (parallel, rectangular, hexagonal and triangular) assuming that trips were generated with equal frequency at all points in an infinite plane, and that the direction of these trips were uniformly distributed. Based on average travel time, the hexagonal network pattern was found to be the most efficient.

7.8 A New Urban Structure

There is now scarcely a city in the world which is not in more or less serious trouble in its central area, from which there seems to be no escape except by drastic and extremely costly measures. In the United States, in similar circumstances except that car ownership levels are much higher, a 'natural' remedy has applied itself in the form of a departure of activities to suburban sites with a corresponding "run down" of the central areas. Vast spreads of development have taken place. The United States often provides housing conditions which many people in the world would be only too ready to grasp, but even so it has gradually accumulated the most formidable problems of traffic. The old highways, even though on a much more generous scale than in most of the world, have been unable to meet the demands made on them, and it has been
necessary to interlace the development with new highways inserted at great expense and difficulty.

All these considerations point to the need for a new kind of city structure which can cope with a greatly increased scale of accessibility and which is capable of adapting to future growth and unexpected trends. This is of special importance in areas where new urbanization on a large scale is expected to take place. We could see that the requirement in broad principle would be for a structure of low overall density, ordered by a movement pattern, adjustable and extendable, with a dispersal of "facilities" -- both for convenience and in order to avoid heavy concentrated movement loads.

Buchanan et al. [128], in considering how urban systems and subsystems might be "structured" in order to accommodate growth and change, studied three patterns and judged the hexagonal to be the best based on the following criteria:

1. There should be maximum freedom of choice, communications, and association for people throughout the area.
2. As the structure grows, it should be possible for each phase to function efficiently and not to be dependent upon further growth taking place.
3. The structure should lend itself to change and renewal in its elements, once they have been brought into existence.
4. The versatility of the structures should not be limited by rigid standards in such matters as transport modes or housing groupings.
5. The structure should be capable of growth without the risk of deformation or distortion.
Thus, a hexagonal arrangement has been adopted for urban form in this research. Moreover, a modular structure is proposed in which self-contained urban units could be combined and added to over time. The basic urban module is shown in Fig. 7-4. The size of a module would range from 1 to 3 miles on a side so as to accommodate a population of from 50,000 to 500,000 persons depending on the intensity of land use. The new cities would consist of various modules combined according to topographic and demographic conditions and would be located at guideway interchanges. Figures 7-5 to 7-13 illustrate ways in which modules would be combined to form new cities and how they might be served by AVCS magway interchange configurations. Figures 7-14 and 7-15 provide geometric design details for the guideway interchanges.

7.9 The Urgent Future

Many people seem to be frightened by the prospect of continuous low-density urban belts stretching from Maine to Florida, from Toronto to Mexico City, and from New York to Los Angeles. Planners suggest establishing barriers to prevent their cities from growing together and many American planners would like to do so, if they could. However, there seems to be no reason why, properly organized and interlaced with greenbelts, guideways, natural reservations and sites of historical interest, and accented vertically by occasional high-rise elements, these low-density urban regions of tomorrow should not be more livable and effective in satisfying the totality of human values than the transitional urban forms of today.

To achieve this form, of course, the urban regions must be shaped consciously with an end in view, rather than evolving, as they do now, from the haphazard results of thousands of uncoordinated private, corporate, municipal, and higher governmental
decisions. Not only is comprehensive planning needed on this new scale so that the decisions can follow a more cooperative pattern, but regional planning must be given a visual, esthetic dimension; otherwise no one will be aware of its presence, no matter how successful the decision may be within an administrative or economic framework.

We are in the midst of an endemic -- urban crisis. It has been accumulating over many decades. But it has only recently begun to be fully recognized. It is likewise now evident that we have had only rather feeble action over the fifty years since we began taking measures.

One awakening is particularly necessary on our urban scene. We have long equated modern technology with positive human gain, but in fact, as has been emphasized, technology is neutral. It can accomplish good or ill. It may be just possible that technology can make megalopolis work after a fashion, at very great cost in resources and in human tensions. But equally, it now makes fluently possible the accomplishment of the great new adventures: the New Town, the new region, the re-created city. It can endow the smaller city with competitive equality, greater humanity, and ecological superiority. These things we must demand of technology [130].

7. Shaping Human Activity with AVCS Maglev
Figure 7-4. New City Module for a Planned Megalopolis
(Source: Ref. 129)
Figure 7-5. AVCS Maglev-Serving Large Linear Metropolitan Area
Figure 7-6. AVCS Maglev-Serving Large Double Linear Metropolitan Area
Figure 7-7. AVCS Maglev-Serving Large Compact Circular Metropolitan Area
Figure 7-8. AVCS Maglev-Serving Large Dispersed Circular Metropolitan Area
Figure 7-9. AVCS Maglev-Serving Large Double Linear Dispersed Metropolitan Area
Figure 7-10. AVCS Maglev-Serving Medium Linear Metropolitan Area
Figure 7-11. AVCS Maglev-Serving Medium Radial Metropolitan Area
Figure 7-12. AVCS Maglev-Serving Medium Radial Dispersed Metropolitan Area
Figure 7-13. AVCS Maglev-Serving Large Circumferential Metropolitan Area
Figure 7-14. AVCS Magway Interchanges (Cloverleaf Type)
Figure 7-15. AVCS Magway Interchanges (Directional Type)
8. Economic Appraisal of AVCS Maglev

8.1 Introduction

The basic purpose of the economic appraisal of a transportation project is to help select an efficient transportation investment plan from the socioeconomic viewpoint of a country as a whole. Here, efficiency means achieving the best transportation service from a given investment and the generated net benefits at least as great as the costs of the investment. Therefore, the evaluation of a transportation project requires to identify the consequences of its investment.

Benefits generated from a transportation investment can be categorized into user benefits and nonuser benefits. The former imply the advantage, privileges and cost reductions accruing to the users of a particular transportation facility; and the latter imply beneficial social, economic and environmental effects enjoyed by the affected communities.

Important user benefits include reduced vehicle operating costs; savings in travel time; fewer traffic accidents and reduced damage; and increased comfort and convenience. Since most of these costs can readily be valued in dollars, it is a general practice that user benefits are measured in terms of a decrease in the user costs and compared with the costs of the project in order to appraise its economic desirability. This economic appraisal methodology is referred to as the benefit-cost analysis. Since the basic objective of public investments such as a transportation project is to advance the social welfare, and the benefit-cost analysis aims to secure the optimum resource allocation from the viewpoint of a country as a whole, this analysis method is frequently employed.
in public investment decisions [131, 132].

In the following sections, three future transportation investment alternatives are compared using the benefit/cost ratio method to illustrate the economic desirability of the AVCS maglev alternative. In Section 8.8, for the completeness of the economic appraisal, the effects of implementing AVCS maglev on the U.S. socioeconomic system are evaluated based on the National Development Model (NDM) to provide a guide to performing nonuser benefit analysis for the promising IVHS technology. NDM will be discussed in detail in the next chapter. In the last section, the AVCS Maglev Vehicle Development Model will be discussed.

8.2 Transportation Investment Alternatives

Highway traffic volumes are forecast to double on the highway network of the United States from 1.9 trillion vehicle miles of travel (VMT) in 1988 to 3.8 trillion VMT in 2020 and this growth in traffic volumes will increase congestion and reduce the urban and rural mobility [133]. Therefore, unless the United States develops an AVCS alternative, it is estimated that 20,000 miles of the Interstate Highway System will have to be widened from 4-lane (2 lanes in each direction) to 10-lane (5 lanes in each direction).

Based on the above argument, the following three alternatives are proposed and their economic desirability is compared using the benefit/cost ratio method:

1. Do-nothing Alternative: 4-lane (2 lanes in each direction)
2. Expansion Alternative: 10-lane (5 lanes in each direction)
3. AVCS Maglev Alternative: 2-lane guideway (1 lane in each direction)
8.3 Benefit/Cost Ratio Method

Benefit/cost ratio (B/C ratio) is expressed by the ratio of net annual benefits to net annual capital costs, and thus any project alternative the B/C ratio of which is above 1.0 is economically feasible and the alternative having the highest B/C ratio is indicated as the preference. In a transportation project evaluation, usually, the B/C ratio method is applied in pairs of alternatives. In this study, the null alternative (do-nothing alternative) serve as the base for comparison. In other words, the B/C ratio of Alternative 1 is taken to be 1.0. The following equation is used for the computation of B/C ratio:

$$\frac{R - E}{C r} (1 - e^{-rt})$$  \hspace{1cm} (8.1)

where

- \( BCR = B/C \) ratio
- \( R \) = annual revenues
- \( E \) = annual expenses
- \( C \) = capital costs
- \( r \) = annual interest rate
- \( t \) = life span of the project

8.4 Annual Revenues

Since the purpose of utilizing the B/C ratio method for the comparison of the aforementioned alternatives is to select the best one that can bring the most benefits to the U.S. socioeconomic system as a whole, user benefits, which are more correctly termed incremental perceived user travel benefits, reflecting the reduction of perceived
user travel costs, will substitute for R.

One approach to the user benefit computation adopted by AASHTO [134] is based on the consumers' surplus theory, which argues that benefits of a roadway improvement include both savings in travel costs that accrue to current users and the "surplus" willingness-to-pay that remains with the new users. These new users are now able to make trips and participate in benefit-yielding activities elsewhere in the economy that they had foregone before the roadway improvement. There is no better estimate of these benefits than the users' willingness-to-pay for the transportation services that enabled them to engage in these activities. If there were no real benefits to be gained, there would be no willingness-to-pay for the necessary transportation services. Therefore, in the simplest case, the estimate of the net user benefits of a roadway improvement on a single link of a finite length in one period will be represented by the area $P_oKLP_n$, where the improvement will reduce the measurable prices or costs of travel from $P_o$ to $P_n$ and increase the traffic volume from $V_o$ to $V_n$ (see Fig. 8-1). This improvement will yield measurable cost savings to current users of $P_oKMP_n$ and benefits to new users of $KLM$, which can be referred to as the surplus willingness-to-pay. The total area $P_oKLP_n$ is the change in consumers' surplus, or simply consumers' surplus for short. The formula for consumers' surplus or net user benefits is:

$$UB = \frac{(P_o - P_n)(V_o + V_n)}{2}$$ (8.2)

where

$UB = user\ benefits$

$P_o = original\ price\ of\ travel$

$V_o = original\ travel\ demand\ (original\ annual\ volume)$
Figure 8-1. Consumers' Surplus

$S_0$ = original supply curve  
$S_n$ = new supply curve  
$P_o$ = original price of travel  
$P_n$ = new price of travel  
$V_o$ = original travel demand  
$V_n$ = new travel demand
\( P_n = \text{new price of travel} \)
\( V_n = \text{new travel demand (new annual volume)} \)

In this approach an important assumption is that the demand for travel depends only upon travelers' perceived costs. However, it has been argued that an improvement on a roadway will not only yield measurable travel cost savings, but it will also shift the demand curve due to changes in noncostable qualities such as comfort, view and convenience. For our user benefit computation this shift in the demand curve will not be considered.

For the computation of UB in our analysis, only savings in travel time will be considered among the user benefits, since the proposed alternatives will remarkably differ from each other in travel speed and the supply-price-demand concept can be well applied. The value of travel time is assumed to be 10.80 $/veh-hr in the year 2000 dollars. According to NDM, per capita income (PCI) will be $28,100 in 2000. AASHTO [134] adopted 3.00 $/veh-hr in 1975, when PCI was $7,400. Therefore, the user price (or cost) of travel is computed by the following equation:

\[ P = v \times T \]  \hspace{1cm} (8.3)

where
\( P = \text{price of travel ($/veh-mi)} \)
\( v = \text{value of travel time} \)
\( = 0.18 $/veh-min \)
\( T = \text{travel time per unit length of road (min/mi)} \)

As for a supply curve, it illustrates how the unit price or cost of travel will change as
more trips are made and as the roadway system design and operation is changed. For this relationship, Drew's formula [135] is used:

\[ T = T_f \frac{1 - (1 - j) q/Q}{1 - q/Q} \]  \hspace{1cm} (8.4)

where  \( T \) = total travel time per unit length of road (min/\text{mi})
\( T_f \) = free flow travel time (min/\text{mi})
\( q \) = traffic volume (vph)
\( Q \) = capacity (vph)
\( j \) = level of service factor \( (0 \leq j \leq 1) \)

The above equation was formed based on the fact that for a finite length of a roadway, as traffic increases, delay arises from the disturbance to the speed distribution resulting from faster vehicles catching up with slower ones and being required to wait until passing or lane changing is possible or in the case of single lane or crowded lane conditions, being prevented from passing at all.

The level of service factor \( j \) denotes that for well designed and operated roadways the total travel time is not affected so much by the increase in traffic volume. Therefore, \( j = 0 \) indicates the perfect roadway such as AVCS maglev on which the total travel time is always equal to the free flow travel time. The parameter values of the supply curves corresponding to the three alternatives aforementioned are shown in Table 8-1.

It should be noted that in the case of the AVCS maglev alternative, the governing controlled headway \( S_L \) is taken to be 24 ft and the governing design speed \( V_M \) is taken...
Table 8-1. Parameter Values of Supply Curves

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Free flow speed (mph)</th>
<th>Capacity (vph/lane)</th>
<th>No. of lanes in each dir.</th>
<th>Level of service factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>2,000</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>2,000</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>100 - 300</td>
<td>22,000 - 66,000</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 8-2. Supply and Demand Curves for User Benefit-Cost Analysis
to be in the range of 100 to 300 mph. Supply curves for the three alternatives are shown in Fig. 8-2. In this figure, the supply curve for Alternative 3 is based on the parameter values $S_L = 24$ ft and $V_M = 200$ mph.

As for a demand curve, it illustrates what price different volumes of tripmakers will be willing to pay for the trip in question. Different people wanting to make trips between a given set of origin and destination points will value the trips differently due to differences in income and ability to pay for the trip, differences in the urgency of the trips, differences in the value of getting to their destination, and so forth. In general, as the price (or cost) of travel increases, less trips will be made, everything else being equal. In other words, the demand curve will be downward sloping.

In this study, three travel demand curves are assumed as shown in Fig. 8-2. The first demand curve intersects the supply curve of Alternative 3 at the point where the demanded travel volume is smaller than the capacity; the second one at the point where the demand is equal to the capacity; and the last one at the point where the demand exceeds capacity, resulting in longer waiting time and thus the increase in the total travel time. The demand curves for the 20-mile link are expressed as follows:

\[
\begin{align*}
\text{Demand Curve 1:} & \quad T_{kl} = \frac{198000}{q_{kl}} \\
\text{Demand Curve 2:} & \quad T_{kl} = \frac{264000}{q_{kl}} \\
\text{Demand Curve 3:} & \quad T_{kl} = \frac{396000}{q_{kl}} \\
\end{align*}
\]

where $T_{kl} =$ link travel time (min/trip)

$q_{kl} =$ peak hour volume (vph)
So far, the supply and demand curves which will be used in our analysis have been introduced. The interplay between these two relationships will determine the level of actual use which a roadway facility will experience and the price which tripmakers should pay. In other words, at the equilibrium point \((q_{kl}, T_{kl})\) which is the intersection between the supply and demand curves, the peak hour volume \(q_{kl}\) and the link travel time \(T_{kl}\) will be determined, so that the system user cost and further, the user benefit in annual terms can be computed. For this purpose, the peak hour volume is converted into the annual volume \(V\) by the following equation:

\[
V = 2000 \times q_{kl}
\]  

(8.6)

where \(V =\) annual volume (veh/yr)

\(q_{kl} =\) peak hour volume (vph)

The link travel time is converted into the unit length travel time by dividing by the average length of a link, and then the user price of travel \(P\) is found by Eq. 8.3. The converted equilibrium point \((V, P)\) is substituted into Eq. 8.2 to find the unit user benefit for an 1-mile section and the result is multiplied by 20,000 to find the user benefit based on the assumption that 20,000 miles of the Interstate Highway System will need improvements.

The user benefit for Alternative 2 is $54.50 billion per year for Demand Curve 1, $80.48 billion per year for Demand Curve 2, and $132.06 billion per year for Demand Curve 3. For the AVCS maglev alternative, the user benefit \(UB_3\) -- here, the subscript 3 indicates Alternative 3 -- can be expressed in terms of the governing design speed \(V_M\) as follows:
\[ UB_3 = 1 \times 10^{-9} \frac{L_M}{2} [(P_1 - P_3)(V_1 + V_3)] \quad (8.7) \]
\[ UB_3 = 10 [0.495 - \frac{10.8}{V_M}][7.19 + 0.33V_M] \quad \text{for Demand Curve 1} \quad (8.8) \]
\[ UB_3 = 10 [0.641 - \frac{10.8}{V_M}][7.41 + 0.44V_M] \quad \text{for Demand Curve 2} \quad (8.9) \]
\[ UB_3 = 10 [0.936 - \frac{16.2}{V_M}][7.61 + 0.44V_M] \quad \text{for Demand Curve 3} \quad (8.10) \]

where \( UB_3 \) = user benefit for Alternative 3 (billion \$/yr)

\( L_M \) = total length of magway network (mi)

\( = 20000 \text{ mi} \)

\( V_M \) = governing design speed (mph)

For \( V_M = 200 \text{ mph} \), \( UB_3 = 322.77 \text{ billion per year for Demand Curve 1} \). The equilibrium values \( (q_{ki}, T_{ki}) \), the converted equilibrium values \( (V, P) \), and the user benefits for the three alternatives are summarized in Table 8-2. For the AVCS maglev alternative, the results are shown for the governing design speed of 200 mph.

### 8.5 Capital Costs

#### 8.5.1 Introduction

Capital costs include costs of advance planning, preliminary engineering, final design, rights-of-way acquisition and preparation, and construction. For Alternative 2, the capital costs are assumed to be $200 billion ($10 million per mile), based on Route 460 Corridor Study performed by the Virginia Department of Transportation and the
Table 8-2. Results of User Benefit-Cost Analysis

<table>
<thead>
<tr>
<th>Demand Curve</th>
<th>Project Alt.</th>
<th>Peak Hour Volume $q_m$ (vph)</th>
<th>Travel Time $T_{kl}$ (min/trip)</th>
<th>Annual Volume $V$ (veh/yr)</th>
<th>User Price $P$ ($/veh-mi$)</th>
<th>User Benefit UB ($/yr$)</th>
<th>B/C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3,596</td>
<td>55.0</td>
<td>7.19 M</td>
<td>0.495</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>7,296</td>
<td>27.2</td>
<td>14.59 M</td>
<td>0.245</td>
<td>54.50 B</td>
<td>1.7</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>33,000</td>
<td>6.0</td>
<td>66.00 M</td>
<td>0.054</td>
<td>322.77 B</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3,704</td>
<td>71.2</td>
<td>7.41 M</td>
<td>0.641</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>8,000</td>
<td>33.0</td>
<td>16.00 M</td>
<td>0.297</td>
<td>80.48 B</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>44,000</td>
<td>6.0</td>
<td>88.00 M</td>
<td>0.054</td>
<td>560.06 B</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3,807</td>
<td>104.0</td>
<td>7.61 M</td>
<td>0.936</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>8,713</td>
<td>45.4</td>
<td>17.43 M</td>
<td>0.409</td>
<td>132.06 B</td>
<td>5.6</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>44,000</td>
<td>9.0</td>
<td>88.00 M</td>
<td>0.081</td>
<td>817.47 B</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Note: M = million and B = billion
Results of Alternative 3 are based on the governing design speed of 200 mph.
consultant team [136]. For the estimation of capital costs of the AVCS maglev alternative, the capital costs are divided into the fixed facilities cost (FC) and the land cost (LC), and thus can be expressed as follows:

\[ C = FC + LC \]  

**(8.11)**

### 8.5.2 Fixed Facilities Cost

The fixed facilities cost is assumed to be $30 million per mile (in the year 2000) for the governing design speed of 100 mph and to increase as the governing design speed increases. The U.S. Federal Railroad Administration [3] used a fixed facilities cost of $16.5 million per mile for most potential maglev corridor studies, assuming a single-track guideway. Also, Maglev Transit, Inc. [44] estimated that the total cost of Florida Magnetic Levitation Demonstration Project, including the system cost for the 20-mile elevated guideway, vehicles, stations and other facilities, together with all soft costs, contingencies and financial costs incurred in the pre-construction and construction periods, would be in the range of $450 million to $650 million. Thus, the fixed facilities cost for AVCS maglev is expressed in terms of the governing design speed as follows:

\[ FC = 30 \times 10^{-3} L_M [1 + \frac{V_M - 100}{300 - 100}] \]  

**(8.12)**

where \( FC = \) fixed facilities cost (billion $)

For example, when the governing design speed is 200 mph, the fixed facilities cost amounts to $900 billion for the entire AVCS maglev guideway network.
8.5.3 Land Cost

Using the rights-of-way of the Interstate Highway System for the construction of the AVCS magway system is advocated as a way to minimize the cost of purchasing new rights-of-way and at the same time, to avoid the additional environmental disruption. However, Interstate Highways, which are designed for the maximum speeds of 70 to 80 mph, have curve sections that are not suitable for the super-speed operation of AVCS maglev. To overcome the resulting speed penalties, it will be necessary to purchase new rights-of-way along the existing Interstate Highway routes.

To find the amount of additional rights-of-way required, we will begin with the analysis of turning movements of an AVCS maglev vehicle. Figure 8-3 illustrates the conditions for an AVCS maglev vehicle traveling around a curve. The forces on the vehicle include the vehicular weight (W), levitation force (N), guidance force (S), and centrifugal force. For the vehicle to stay on the centerline of a guideway lane, the forces in the direction parallel to the guideway surface should be in equilibrium. By equating the x-direction components of vehicular weight, guidance force, and centrifugal force, we obtain

\[
\frac{W (1.47 V_M)^2}{g R_M} \cos \theta = W \sin \theta + S
\]

Solving for \( R_M \),

\[
R_M = \frac{(1.47 V_M)^2}{g (\tan \theta + S/W \cos \theta)}
\]  

(8.13)
Figure 8-3. Conditions for a Vehicle Traveling around a Curve
The guidance force $S$ can be expressed in terms of $W$. The maximum available guidance force depends on the system design. Slemon [43] reports that the electrodynamically-suspended, LSM-propelled system can provide the guidance force which is equivalent to the total weight of the vehicle. For the purpose of our analysis, $S$ is taken to be one-tenth of $W$. Then, (8.13) can be expressed as

$$R_M = \frac{(1.47 V_M)^2}{g(\tan \theta + 1/(10 \cos \theta))} \quad (8.14)$$

where $R_M =$ radius of curvature for magway (ft)

$\theta =$ angle of incline (degrees)

When the design speed is 200 mph and the bank angle is 20°, the minimum required radius of the guideway is about 5,750 ft. The vehicle will experience a centrifugal acceleration of 0.47 g.

Using (8.14), we can derive, in terms of the governing design speed, the expression for the amount of additional rights-of-way required to enable the AVCS maglev vehicles to operate with high speeds throughout the entire guideway routes. Figure 8-4 illustrates the centerline of a freeway (arc CDE) and the centerline of a magway (arc CBE). Although there can be any size of a turning angle, it is assumed that the typical turning angle is 90°. In other words, angle CAE is taken to be 90°. It should be noted that angles are in degrees, lengths and radii are in feet, and areas are in square feet. Area BCDE illustrates the additional right-of-way required for the high speed operation of AVCS maglev vehicles. Applying the Law of Sines to triangle OAC, we obtain
$R_F = \text{radius of curvature for freeway}$

$R_M = \text{radius of curvature for magway}$

Figure 8-4. Diagram for Additional ROW Acquisition Analysis
\[ \frac{R_F}{\sin \alpha} = \frac{R_M}{\sin 135^\circ} \] (8.15)

Solving for \( \alpha \),

\[ \alpha = \sin^{-1}[0.7071/\left(\frac{R_M}{R_F}\right)] \] (8.16)

For \( L_2 \),

\[ L_2 = R_M \sin(45^\circ - \alpha) \] (8.17)

Since

\[ \text{area OAC} = \frac{1}{2} R_F L_2 \]

and

\[ \text{area GBC} = \frac{\alpha}{360} \pi R_M^2 \]

then, area \( ABC \) can be expressed as

\[ \text{area ABC} = \frac{\alpha}{360} \pi R_M^2 - \frac{1}{2} R_F R_M \sin(45^\circ - \alpha) \] (8.18)
Also, we know that

\[ \text{area ACD} = \frac{45}{360} \pi R_F^2 \quad (8.19) \]

and

\[ \text{area BCDE} = 2 \times \text{area BCD} = 2 (\text{area ACD} - \text{area ABC}) \quad (8.20) \]

Area BCDE in Eq. 8.20 indicates the amount of an additional right-of-way required for the section CDE. It can be converted into the amount required for an 1-mile section. For this purpose, we find

\[ \text{length CDE} = \frac{90}{360} 2\pi R_F \quad (8.21) \]

Then, the amount of an additional right-of-way required for an unit-length (here, 1-mile) section (ROWUL) can be expressed as

\[ \text{ROWUL} = \frac{\text{area BCDE}}{\text{length CDE}} \quad (8.22) \]

Substituting (8.18), (8.19), (8.20) and (8.21) into (8.22), we find

\[ \text{ROWUL} = 2640 R_F \left[ 1 + \frac{4}{\pi} \sin(45^\circ - \alpha) \frac{R_M}{R_F} - \frac{\alpha}{45} \left( \frac{R_M}{R_F} \right)^2 \right] \quad \text{in ft}^2 \quad (8.23) \]
\[ \text{ROWUL} = 0.0606 \, R_F \left[ 1 + \frac{4}{\pi} \sin(45^\circ - \alpha) \frac{R_M}{R_F} - \frac{\alpha}{45} \left( \frac{R_M}{R_F} \right)^2 \right] \text{ in acres} \quad (8.24) \]

Using (8.24), the cost of rights-of-way acquisition for the entire guideway network can be expressed as

\[ \text{LCWO} = (1 \times 10^{-9}) \, \text{ULC} \times \text{PRI} \times L_M \times \text{ROWUL} \quad (8.25) \]

Substituting (8.24) into (8.25),

\[ \text{LCWO} = (0.0606 \times 10^{-9}) \, \text{ULC} \times \text{PRI} \times L_M \]
\[ \times R_F \left[ 1 + \frac{4}{\pi} \sin(45^\circ - \alpha) \frac{R_M}{R_F} - \frac{\alpha}{45} \left( \frac{R_M}{R_F} \right)^2 \right] \quad (8.26) \]

where

- \( \text{LCWO} = \) land cost without interchanges (billion $)
- \( \text{ULC} = \) unit land cost ($/acre)
- \( \text{PRI} = \) proportion of network requiring improvements (dim.)
- \( R_F = \) radius of curvature for freeway (ft)

It should be noted that Eq. 8.26 is effective when \( R_M \) is greater than or equal to \( R_F \). \( R_F \) is taken to be 2,000 ft according to AASHTO [137]. When Eq. 8.26 was derived, the cost of acquiring interchange rights-of-way was not explicitly mentioned. The amount of interchange rights-of-way required will depend upon the number of interchanges, interchange type, design speed, bank angle, utilization rate of the existing freeway interchange rights-of-way. In this dissertation, this subject will not be pursued in detail, being left for future research. However, not to disregard the impact of the interchange
rights-of-way acquisition on the land cost estimation, the following expression is added to Eq. 8.26:

\[
ROWIC = NIC \times 100 \times \max\left(\frac{R_M}{R_F}, 1\right)
\]  

(8.27)

where  \( ROWIC = \text{rights-of-way for interchanges (acres)} \)

\( NIC = \text{number of interchanges} \)

Eq. 8.27 implies that up to the governing design speed of 120 mph (i.e., \( R_M = 2,000 \text{ ft} \)) the right-of-way required for a guideway interchange is 100 acres. Beyond that speed the requirements are proportional to the ratio of \( R_M \) to \( R_F \). Illinois DOT [138] is suggesting about 100 acres for a full cloverleaf interchange. Also, we assume that there will be an interchange (including both cloverleaf and directional types) for every 100 miles, which means \( NIC = 200 \). Then, the total land cost \( LC \) (billion $) is

\[
LC = (0.0606 \times 10^{-9}) ULC \times PRI \times L_M \times R_F \left[ 1 + \frac{4}{\pi} \sin(45^\circ - \alpha) \frac{R_M}{R_F} - \frac{\alpha}{45} \left( \frac{R_M}{R_F} \right)^2 \right]
\]

\[
+ (100 \times 10^{-9}) ULC \times NIC \times \max\left(\frac{R_M}{R_F}, 1\right)
\]

(8.28)

The unit land cost is assumed to be $120,000 per acre in the year 2000. FRA [3] is using $10,000 per acre for rural areas and $100,000 per acre for exurban/suburban areas. PRI is assumed to be 20 percent.

In summary, capital costs of the AVCS maglev alternative is assumed to mainly consist
of the fixed facilities cost and land cost. And both FC and LC are expressed as a function of the governing design speed. For the estimation of the capital costs, Eqs. 8.11, 8.12, 8.14, 8.16 and 8.28 are used.

As for an annual interest rate, \( r \), Hirshleifer et al. [139] suggest that 4 to 5 percent would be an appropriate riskless discount rate for government investments in the United States, but 10 percent would be more appropriate for public water resources' investments if the discount rate is to reflect the risks of incorrectly estimating the project benefits and costs. Again, to avoid the risk of overestimating the benefits generated by the AVCS maglev alternative, the annual interest rate is taken to be 10 percent. The life span of each project is assumed to be 50 years.

8.6 Annual Expenses

In general, annual expenses include maintenance and operation costs. In the case of AVCS maglev, the contact-free propulsion and guidance systems require less maintenance and do not wear in the conventional sense. Maglev Transit, Inc. [44] estimated that the annual operation cost would be about 8 percent of the total project cost. In this study, the annual expenses are assumed to be 10 percent of the capital costs. The system of equations needed for the estimation of the user B/C ratios for the AVCS maglev alternative is summarized in Table 8-3.

8.7 Results of User Benefit-Cost Analysis

The results of the user benefit-cost analysis are summarized in Tables 8-2 and 8-4. Table 8-2 shows that both Alternative 2 and Alternative 3 are economically feasible and
Table 8-3. System of Equations for User Benefit-Cost Analysis of AVCS Maglev

BCR = \frac{R - E}{Cr} (1 - e^{-rt}) \quad (8.1)

where
BCR = \text{benefit/cost ratio}
R = \text{annual revenues}
E = \text{annual expenses}
C = \text{capital costs}
r = \text{annual interest rate} (= 10\%)
t = \text{life span of the project} (= 50 \text{ yr})

UB_3 = 10 [0.495 - \frac{10.8}{V_M}][7.19 + 0.33V_M] \quad \text{for Demand Curve 1} \quad (8.8)

UB_3 = 10 [0.641 - \frac{10.8}{V_M}][7.41 + 0.44V_M] \quad \text{for Demand Curve 2} \quad (8.9)

UB_3 = 10 [0.936 - \frac{16.2}{V_M}][7.61 + 0.44V_M] \quad \text{for Demand Curve 3} \quad (8.10)

where
UB_3 = \text{user benefit for Alternative 3 (billion \$/yr)}
V_M = \text{governing design speed (mph)}

C = FC + LC \quad (8.11)

FC = 30 \times 10^{-3} L_M \left[1 + \frac{V_M - 100}{300 - 100}\right] \quad (8.12)
Table 8-3. (Continued)

\[
R_M = \frac{(1.47 \ V_M)^2}{g(\tan \theta + 1/(10 \ \cos \theta))} \tag{8.14}
\]

\[
\alpha = \sin^{-1}[0.7071/(\frac{R_M}{R_F})] \tag{8.16}
\]

\[
LC = (0.0606 \times 10^{-9}) \ ULC \times PRI \times L_M \times R_F \left[1 + \frac{4}{\pi} \ \sin(45^\circ - \alpha) \ \frac{R_M}{R_F} - \frac{\alpha}{45} \ \left(\frac{R_M}{R_F}\right)^2 \right]
+ (100 \times 10^{-9}) \ ULC \times NIC \times \max(\frac{R_M}{R_F}, 1) \tag{8.28}
\]

where
- \(C\) = capital costs (billion $)
- \(FC\) = fixed facilities cost (billion $)
- \(LC\) = land cost (billion $)
- \(L_M\) = total length of magway network (mi)
  - = 20,000 mi
- \(R_M\) = radius of curvature for magway (ft)
- \(R_F\) = radius of curvature for freeway (ft)
  - = 2,000 ft
- \(\theta\) = bank angle (degrees)
  - = 20 degrees
- \(LC\) = land cost (billion $)
- \(ULC\) = unit land cost ($/acre)
  - = 120,000 $/acre
- \(PRI\) = proportion of network requiring improvements ( = 0.2)
- \(NIC\) = no. of interchanges ( = 200)
Table 8-4. Results of User Benefit-Cost Analysis for AVCS Maglev

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>155.54 B</td>
<td>600.00 B</td>
<td>1427</td>
<td>2.40 B</td>
<td>602.40 B</td>
<td>1.6</td>
</tr>
<tr>
<td>200</td>
<td>322.77 B</td>
<td>900.00 B</td>
<td>5707</td>
<td>21.72 B</td>
<td>921.72 B</td>
<td>2.5</td>
</tr>
<tr>
<td>300</td>
<td>487.41 B</td>
<td>1200.00 B</td>
<td>12840</td>
<td>34.03 B</td>
<td>1234.03 B</td>
<td>2.9</td>
</tr>
</tbody>
</table>

*Note: B = billion
Results are based on Demand Curve 1.*
further, the latter will be much more beneficial, since B/C ratios for both alternatives are over 1.0 and the AVCS maglev has much higher B/C ratio values for all three demand curves. It should be noted that the results of Alternative 3 is based on the governing design speed of 200 mph. The results of Table 8-4 are based on Demand Curve 1.

Table 8-4 shows that as the governing design speed of the AVCS maglev system increases, so does the B/C ratio. The cost of rights-of-way acquisition amounts to only 2 to 3 percent of the capital costs. Therefore, we can conclude that to get the most benefit out of the AVCS maglev system, the curve sections which can put speed penalties should be avoided, if possible, so that the technologically-feasible highest speed operation can be achieved. It should be mentioned that the results in Tables 8-2 and 8-4 do not reflect such benefits of AVCS maglev as reduced accident costs, increased comfort and convenience, and so forth.

Up to this point, the user benefit has been analyzed to illustrate the economic desirability of AVCS maglev. In the next section, however, the nonuser benefit will be analyzed for the completeness of the economic appraisal of AVCS maglev and then, the total benefit/cost ratio -- here, the total benefit include the user and nonuser benefits -- of AVCS maglev will be estimated.

8.8 Nonuser Benefit Analysis

Information about nonuser social, economic and environmental consequences -- community impacts for short -- of transportation investments is frequently of crucial importance, due to the existence of the desire to achieve the highest possible state of economic efficiency, the trend to impose the cost of highways upon the beneficiaries
thereof and the concern about the effect of highway location upon land use pattern, land value, population location, business activity, social disruptions and environmental disruptions. Therefore, a need exists to develop a community impact assessment methodology which can provide an indication of all significant impacts in order to choose transportation investment plans which can enhance community benefits and mitigate or avoid community costs.

However, the above general nonuser consequences involve the complex factors of general economics. It is quite difficult to isolate the beneficial and adverse consequences, and the transfers, to get to the net change because of the far-reaching character of economic forces and their tendency to overlap and to offset. In addition, the important factor of from whose viewpoint has to be considered. For example, a community local to the highway improvement gains business volume and employment, but other communities may have lost that business and employment [140]. Because of the above difficulties in treating in detail the subject of general nonuser consequences of transportation investments, our discussion will be limited to the effect of the AVCS maglev investment on the nation's economy as a whole.

Economically speaking, transportation investments positively affect a nation as a whole and its gross national product (GNP). Indeed, it requires the most imaginative mind to describe our economic society as it would be now without the motor vehicle. The main contribution of transportation investments to the economy of a nation comes from lowering the transportation cost of materials, supplies and products, reducing the cost of doing business, enhancing employment opportunity, increasing business activities, and making it possible to reach new land and obtain new natural resources.
Based on the above argument, it is obvious that the implementation of the most promising IVHS technology, the original objective of which is to meet the challenge in the future mobility of the United States, will make a substantial contribution to the nation's gross national product. In other words, the dramatically improved mobility will reduce the proportion of industrial output allocated to the transportation service of raw materials, supplies and products, resulting in the increase of GNP since GNP is computed by subtracting a certain portion of the industrial output used to pay for raw materials, transportation service, energy supply, etc. from the output.

To evaluate the savings in the transportation service cost, which are called the nonuser benefit of the AVCS maglev investment, the following statements are added to NDM-2 (for NDM-2, refer to Chapter 10 and Appendix B):

\[ L \quad \text{CNUB.K} = \text{CNUB.J} + \{\text{DT}\} \times (\text{NUB.JK}) \]

\[ N \quad \text{CNUB} = \text{CNUBN} \]

\[ C \quad \text{CNUBN} = 0 \]

\[ R \quad \text{NUB.KL} = \text{IO.K} \times (\text{FIOMWN} - \text{FIOMW.K}) \]

\[ A \quad \text{FIOMW.K} = \text{FIOMWN} \times \text{FIOMWM.K} \]

\[ N \quad \text{FIOMWN} = \text{MWIFR} \times \text{FIOIFN} \]

\[ C \quad \text{MWIFR} = .35 \]

\[ A \quad \text{FIOMWM.K} = \text{FIOIFM.K} \]

**CNUB** - CUMULATIVE NONUSER BENEFIT ($)

**CNUBN** - CUMULATIVE NONUSER BENEFIT INITIAL ($)

**NUB** - NONUSER BENEFIT ($/YR)

**IO** - INDUSTRIAL OUTPUT ($/YR)
FIOIFN - FRACT INDUSTRIAL OUTPUT TO INFRA NORMAL (DIM)
FIOIFM - FRACT INDUST OUTPUT TO INFRA MULTIPLIER (DIM)
FIOMW - FRACT INDUSTRIAL OUTPUT TO MAGWAY (DIM)
FIOMWN - FRACT INDUS OUTPUT TO MAGWAY NORMAL (DIM)
MWIFR - FIOMWN FIOIFN RATIO (DIM)
FIOMWM - FRACT INDUS OUTPUT TO MAGWAY MULTIPLIER (DIM)

In the above statements, FIOMW indicates the fraction of industrial output used to pay for the AVCS maglev transportation service, and FIOMWN the fraction of industrial output used to pay for the service before AVCS maglev is implemented. Therefore, the nonuser benefit (NUB) can be expressed as the difference between the amounts of industrial output used to pay for the transportation service before and after the implementation of AVCS maglev. CNUB indicates the accumulation of the nonuser benefit over time and is represented by the area between the two curves (see Fig. 8-5).

In Sections 8.5 and 8.6, it was estimated that the capital costs of the AVCS maglev system would be $602 billion for the governing design speed of 100 mph, $922 billion for 200 mph, and $1,234 billion for 300 mph. The annual expenses for the maintenance and operation of the system were assumed to amount to 10% of the capital costs, and the annual interest rate was assumed to be 10%. So, the total annual expenditure will be $120 billion for 100 mph, $184 billion for 200 mph, and $247 billion for 300 mph.

In the case of the infrastructure development policy of NDM, $570 billion (7.5% of GNP) will be invested to the infrastructure sector in the year 2000, when GNP is $7.6 trillion. Thus, we can say that about 21%, 32%, and 43% of the infrastructure investments are allocated to the AVCS maglev system of the governing design speeds of 100, 200, and
Figure 8-5. Nonuser Benefit
300 mph each. Based on this argument, FLOMW is assumed to be 20%, 35%, and 45% of FLOIF (fraction of industrial output to infrastructure) depending upon the above design speeds. So, the nonuser benefit will be computed using MWIFR = 0.2 for 100 mph, 0.35 for 200 mph, and 0.45 for 300 mph. FLOMW reflects the effects of the AVCS maglev investment on the industrial production efficiency.

The results of the nonuser benefit analysis are summarized in Table 8-5. The results are based on the governing design speed of 200 mph. Figures 8-6 and 8-7 illustrate NUB and CNUB over the 50-year period. In the figures, 1, 2 and 3 indicate NUB or CNUB for the governing design speeds of 100, 200, and 300 mph, respectively.

Using Table 8-4 and the results of the nonuser benefit analysis, we can compute the total benefit/cost ratio (TBCR). For the calculation of TBCR, we need to substitute the total benefit (TB = user benefit + nonuser benefit) for R in Eq. 8.1. However, NUB changes over time and it is not expressed in terms of the year 2000 values. So, first, NUB is converted into the year 2000 values by assuming the annual inflation rate of 2.5% (In NDM, the annual inflation rate was assumed to be 2.5%), and then, the average NUB over the 50-year period is calculated.

The results of the total benefit-cost analysis for AVCS maglev is summarized in Table 8-6, and graphically shown in Fig. 8-8. For the governing design speed of 200 mph, the user benefit is $323 billion, and the nonuser benefit is $293 billion, all in the year 2000 constant dollars. The total benefit/cost ratio is 5.6.

In this study the nonuser benefit analysis has been focused on the savings in transportation service costs. However, it should be mentioned that since AVCS maglev
generates much less air pollution, compared with conventional internal combustion powered vehicles, the governmental regulation for environmental protection toward the industrial activities would be eased a great deal and thus the industries would be able to reduce spendings for the environmental protection facilities. The savings in production cost will increase the industrial output produced with a unit capital. The quantification of these benefits is left for future research.

8.9 Maglev Vehicle Development Model

In this section, the AVCS Maglev Vehicle Development Model is developed to outline the important factors in reducing the weight and the price of the vehicle. Reducing the weight of the vehicle will help increase the operating efficiency and reducing the price will help increase the accessibility to this highly beneficial transportation system. The whole simulation process is illustrated in Fig. 8-9. The simulation results are presented in terms of the vehicle price, demand, sales revenue, and vehicular weight.

The number of maglev vehicles (MV) increases by the production of vehicles and decreases by the disposal of them. The vehicle production rate (VPR) depends on their demand. The demand for the vehicles (VD) increases as the price of the vehicle (VP) decreases and decreases as the price increases. The initial price of the vehicle is assumed to be $260,000 in the year 2000 which is taken as the base year of the analysis. However, this price will go down as more vehicles are produced and as the weight of the vehicle reduces. The reduction of the vehicular weight will result mainly from the advances in the high-temperature superconducting technology. The sales revenue from the vehicles (REV) is decided by the price and the demand.
Table 8-5. Results of Nonuser Benefit Analysis for AVCS Maglev

<table>
<thead>
<tr>
<th>Year</th>
<th>Industrial output ($/yr)</th>
<th>FIOMWN</th>
<th>FIOMW</th>
<th>Nonuser Benefit ($/yr)</th>
<th>Nonuser NUB ($)</th>
<th>Cumulative NUB ($)</th>
<th>GNP ($/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>19.0 R</td>
<td>0.14</td>
<td>0.1400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7.60 R</td>
</tr>
<tr>
<td>2010</td>
<td>27.9 R</td>
<td>0.14</td>
<td>0.1330</td>
<td>195 B</td>
<td>0.94 R</td>
<td>11.70 R</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>41.7 R</td>
<td>0.14</td>
<td>0.1299</td>
<td>423 B</td>
<td>3.96 R</td>
<td>17.91 R</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td>62.9 R</td>
<td>0.14</td>
<td>0.1283</td>
<td>734 B</td>
<td>9.62 R</td>
<td>27.25 R</td>
<td></td>
</tr>
<tr>
<td>2040</td>
<td>94.3 R</td>
<td>0.14</td>
<td>0.1275</td>
<td>1177 B</td>
<td>18.98 R</td>
<td>41.07 R</td>
<td></td>
</tr>
<tr>
<td>2050</td>
<td>139.6 R</td>
<td>0.14</td>
<td>0.1270</td>
<td>1813 B</td>
<td>33.66 R</td>
<td>61.03 R</td>
<td></td>
</tr>
</tbody>
</table>

Note: B = billion and R = trillion
FIOMWN = fraction of industrial output to magway transportation input normal
FIOMW  = fraction of industrial output to magway transportation input
Results are based on the governing design speed of 200 mph.
Figure 8-6. Nonuser Benefit for AVCS Maglev
Figure 8-7. Cumulative Nonuser Benefit for AVCS Maglev
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>155.54 B</td>
<td>167.35 B</td>
<td>322.89 B</td>
<td>602.40 B</td>
<td>1.6</td>
<td>4.3</td>
</tr>
<tr>
<td>200</td>
<td>322.77 B</td>
<td>292.85 B</td>
<td>615.62 B</td>
<td>921.72 B</td>
<td>2.5</td>
<td>5.6</td>
</tr>
<tr>
<td>300</td>
<td>487.41 B</td>
<td>376.53 B</td>
<td>863.94 B</td>
<td>1234.03 B</td>
<td>2.9</td>
<td>6.0</td>
</tr>
</tbody>
</table>

*Note: B = billion
Results of the user benefit computation are based on Demand Curve 1.*
Figure 8-8. User B/C Ratio and Total B/C Ratio for AVCS Maglev
L MV.K=MV.J+(DT)(VPR.JK-VDR.JK)
R VPR.KL=VD.K
A VD.K=VDN*VDM.K
A VDM.K=TABHL(VDMT,VPN/VP.K,1,10,.6)
T VDMT=.8/1.2/1.4/1.8/2.8/5.2/13.6/15.8/22/32/38/43/46.5/48.2/49.3/50
A VP.K=VPN*VUM.K*VPCM.K
C VPN=260000
S REV.K=VPCD.K*VD.K

MV - MAGLEV VEHICLES (VEH)
VPR - VEHICLE PRODUCTION RATE (VEH/YR)
VDR - VEHICLE DISCARD RATE (VEH/YR)
VD - VEHICLE DEMAND (VEH/YR)
VDN - VEHICLE DEMAND NORMAL (VEH/YR)
VDM - VEHICLE DEMAND MULTIPLIER (DIM)
VP - VEHICLE PRICE ($/VEH)
VPN - VEHICLE PRICE NORMAL ($/VEH)
VUM - VEHICLE UNAVAILABILITY MULTIPLIER (DIM)
VPCM - VEHICLE PRODUCTION COST MULTIPLIER (DIM)
REV - REVENUE ($/YR)

The vehicle discard rate (VDR) is inversely proportional to the average life-span of the vehicle (ALV). Also, it is assumed that for ten years after the AVCS maglev system is implemented, no vehicles are discarded. For this period, the vehicle will be quite expensive, and thus the owners will try to keep it as long as possible. The initial average life-span of the vehicle is assumed to be 15 years. As more vehicles are
produced, the price will become lower and the consumers will buy new vehicles more often.

\[ R \quad VDR.KL = CLIP(MV.K/ALV.K,0,(TIME.K-2000),10) \]

\[ A \quad ALV.K = ALVN*ALVM.K \]

\[ C \quad ALVN = 15 \]

\[ A \quad ALVM.K = CLIP(ALVM2.K,ALVM1.K,(MV.K/MVN)/1E4,11) \]

\[ A \quad ALVM1.K = TABHL(ALVM1T,(MV.K/MVN)/1E4,1,11,2) \]

\[ T \quad ALVM1T = 1/.98/.97/.95/.93/.92 \]

\[ A \quad ALVM2.K = TABHL(ALVM2T,(MV.K/MVN)/1E4,11,211,50) \]

\[ T \quad ALVM2T = .92/.90/.85/.80/.75 \]

**VDR - VEHICLE DISCARD RATE (VEH/YR)**

**ALV - AVE LIFETIME VEHICLE (YR)**

**ALVN - AVERAGE LIFETIME VEHICLE NORMAL (YR)**

**ALVM - AVE LIFETIME VEHICLE MULTIPLIER (DIM)**

The weight of the maglev vehicle is assumed to be 6,000 pounds initially. The vehicular weight reduces as the weight of the superconductor-cryostat assemblies (WMSCA) decreases. The weight of the superconductor-cryostat prototype (WMSCP), which is assumed to be 1,200 pounds initially, reduces as the high-temperature superconducting technology develops. The development of the technology is assumed to depend on the amount of R&D budget (HTSB) allocated. HTSB will increase as the demand for maglev vehicles increases.

\[ A \quad WMV.K = MAX(WMSCA.K/FATVW.K,3000) \]
A  FATVW.K=FATVWN*FATVWM.K
A  FATVWM.K=TABHL(FAVWM, WMSCA.K/WMSCAN, 0, 1, 1)
T  FAVWM= .25/1
L  WMSCA.K=WMSCA,J-(DT)(WRR, JK)
R  WRR.KL=CLIP((WMSCA.K-WMSCP.K)/ADT, 0, WMSCA.K.WMSCP.K)
A  WMSCP.K=WMSCPN*WMSCPM.K
A  WMSCPM.K=TABHL(WMSCPMT, HTSB.K/HTSBN, 0, 2, 1)
T  WMSCPMT=2/.5/.25
A  HTSB.K=HTSBN*HTSBM.K
A  HTSBM.K=TABHL(HTSBMT, (VD.K/VDN), 1, 31, 10)
T  HTSBMT=0/1/1.5/2

WMV - WGT MAGLEV VEHICLE (LB)
FATVW - FRACT ASSEMBLY TO VEHICLE WEIGHT (DIM)
FATVWN - FRACT ASSEMBLY TO VEHICLE WEIGHT NORMAL (DIM)
FATVWM - FRACT ASSEMBLY TO VEHICLE WEIGHT MULTIPLIER (DIM)
WMSCA - WGT MAGLEV SC-CRYOSTAT ASSEMBLIES (LB)
WRR - WEIGHT REDUCTION RATE (LB/yr)
ADT - ASSEMBLY DEVELOPMENT TIME (YR)
WMSCP - WGT MAGLEV SC-CRYOSTAT PROTOTYPE (LB)
WMSCPN - WGT MAGLEV SC-CRYOSTAT PROTOTYPE NORMAL (LB)
WMSCPM - WGT MAGLEV SC-CRYOSTAT PROTOTYPE MULT (DIM)
HTSBN - HIGH TEMPERATURE SC BUDGET NORMAL ($/yr)
HTSB - HIGH TEMPERATURE SUPERCONDUCTING BUDGET ($/yr)
HTSBM - HIGH TEMPERATURE SC BUDGET MULT (DIM)
The simulation results are summarized in Table 8-7. The number of maglev vehicles reaches over 210 million in 2040, when the U.S. population is 379.6 million persons according to NDM. There were 143 million automobiles in 1991, when the population was about 250 million persons [144, 145]. The demand for maglev vehicles reaches 20 million veh/yr in 2040. The price of the vehicle will be very high initially, but it will go down as more vehicles are produced. in 2040, the price will be $26,000 in the year 2000 constant dollars and $70,500 in the year 2040 current dollars. In the same year, PCI will be $108,200 according to NDM. The revenue from the sales of maglev vehicles amounts to $1,411 billion, which corresponds to 3.4% of GNP. People in the United States spent $184.1 billion for motor vehicles and parts in 1991, when GNP was $5,673 billion [145]. The weight of the vehicle is projected to decrease down to 3,000 pounds from 6,000 pounds, provided that the high-temperature superconducting technology develops to the full extent. These results are illustrated in Figs. 8-10 to 8-12.
<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Vehicles</th>
<th>Demand for Vehicles</th>
<th>Vehicle Price Current Dollars</th>
<th>Revenue ($/yr)</th>
<th>Vehicle Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MV (veh)</td>
<td>VD (veh/yr)</td>
<td>VP ($/veh)</td>
<td>VPCD ($/veh)</td>
<td>REV</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
<td>0.32 M</td>
<td>260.0 T</td>
<td>260.0 T</td>
<td>83</td>
</tr>
<tr>
<td>2010</td>
<td>44.5 M</td>
<td>9.29 M</td>
<td>44.3 T</td>
<td>56.8 T</td>
<td>528</td>
</tr>
<tr>
<td>2020</td>
<td>122.5 M</td>
<td>17.83 M</td>
<td>33.0 T</td>
<td>54.4 T</td>
<td>970</td>
</tr>
<tr>
<td>2030</td>
<td>185.3 M</td>
<td>20.00 M</td>
<td>26.0 T</td>
<td>55.0 T</td>
<td>1,099</td>
</tr>
<tr>
<td>2040</td>
<td>210.2 M</td>
<td>20.00 M</td>
<td>26.0 T</td>
<td>70.5 T</td>
<td>1,411</td>
</tr>
<tr>
<td>2050</td>
<td>218.9 M</td>
<td>20.00 M</td>
<td>26.0 T</td>
<td>90.5 T</td>
<td>1,811</td>
</tr>
</tbody>
</table>

*Note:* T = thousand, M = million and B = billion.
Figure 8-10. No. of Maglev Vehicles and Demand

8. Economic Appraisal of AVCS Maglev
Figure 8-11. Vehicle Price (in Constant and Current Dollars) and Vehicle Weight
Figure 8-12. Revenue from Sales of Vehicles
9. National Development Model

9.1 Introduction

Development is a comprehensive process by which a region or a nation strives to gain a greater control over its environment and the destiny of its people through the efficient use of its limited resources and thus, it has inevitably been linked to the concepts of "quantity of life" and "quality of life" [141]. In the early phase of development, however, the former concept is given a higher priority than the latter. As a result, development has often been interpreted as synonymous with industrialization.

The industrialization has brought material affluence as expected, but also such unexpected byproducts as unequal distribution of wealth, overcrowding in cities, depletion of certain natural resources, and environmental pollution. The efforts to control these unwanted byproducts are often neglected when people are preoccupied with the achievement of material well-being.

Only after the economy has reached a certain level of maturity do people recognize that these unexpected byproducts of industrialization are preventing them from fully enjoying the fruit of their development effort and that their quality of life is not as good as it should be. This process of initial negligence and later recognition has been repeated by many development-dedicated countries [142].

In 1970, Ehrlich and Holdren [143] said, emphasizing the need to control the unexpected byproducts of economic development, "Quality of life means breathable air, drinkable water, and the hope of a future for one's children, none of which are
measured by GNP. At a time of great technological advancement, dramatic growth in material wealth, and emphasis on high GNP growth rate, it is significant that in the United States, the world's leading economic power, the question of its quality of life, as distinguished from the quantity of life, has been becoming an increasing concern. Trying to develop a systematic methodology to assess the overall "health" of the nation and its citizen's well-being, the Midwest Research Institute chose, as indicators for assessing the quality of life, the following factors: individual status, equality, living conditions, agriculture, technology, economic status, education, health, welfare, and governments.

As for the outline of the U.S. socioeconomic status, the population doubled since the Second World War, reaching over 250 million people in 1992. It is projected to grow up to more than 380 million people in 2050. Its economy has enjoyed a fairly persistent growth and its real GNP quadrupled for the same period, reaching over $6 trillion in 1992. The interaction between the labor force growth and the economic growth has kept the unemployment rate in the range of 5 to 7 percent [144, 145].

As for environmental conditions, even though air quality is better in most U.S. cities compared to conditions in 1960s, over 100 urban areas have yet to meet the national health standard for man-made air pollutants. The annual spending to improve air quality amounts to approximately $32 billion. Likewise, public and private efforts have improved water quality in the majority of U.S. lakes and rivers, but rapid growth in coastal areas has led to localized water quality degradation. Some major coastal cities still do not have adequate sewage treatment facilities. Runoff from farms and cities are a stubborn, continuing problem. Americans produced 88 million tons of trash in 1960, and 180 million tons in 1988. Meanwhile, the number of landfills open to receive these
wastes declined from 20,000 sites in 1978 to fewer than 6,000 in 1991. Due to increasing regulations, new waste management facilities are difficult to site. The United States has tried to reduce the amount and toxicity of wastes through such approaches as pollution prevention and recycling, but still, improperly handled, hazardous, and/or solid wastes are contaminating drinking water sources and releasing toxic vapors into the air [146].

In summary, the nationwide efforts to prevent environmental degradation has brought about substantial improvement. However, projected population growth and the necessary economic development will present challenges in the years to come.

Over the past three decades, the growth of infrastructure capital stock fell from an average annual rate of 4.9 percent in the 1960s to 0.9 percent in the 1980s. The inadequate public infrastructure investment resulted in insufficient capacity to deal with waste water and solid waste, poor conditions of roads and bridges, and increased urban freeway congestion and air traffic delays [147, 148]. To meet the challenges of the next century, the issues related to rebuilding the deteriorating infrastructure and constructing new facilities to meet future demands need to be identified and resolved.

Improvements in the education of the U.S. labor force were an important factor for a rapid economic growth. The median years of schooling acquired by young adults rose to 12.9 years in 1976. However, there has been no increase since then, while the demand for skilled labor continues to grow. Raising the quality of education is at least as important as increasing years of schooling, but the National Assessment of Educational Progress indicates that nearly 60 percent of all 17-year-olds cannot read well enough to understand, summarize, and explain relatively complicated information.
Science and Mathematics is the basic foundation for developing technology. However, the international comparisons of Science and Mathematics competency show that the performance of U.S. students is lower than that of students from other developed countries. To better prepare tomorrow's workers for productive employment major improvements in the education system are badly needed [147].

In summary, the national development strategy for the next century must be considered based on the premise that development means improving both quantity of life and quality of life.

### 9.2 Purpose and Approach

The purpose of this study is to obtain a deeper understanding of the rational policy formation about the future socioeconomic development of the United States. It is not the intent of this study to provide a blueprint for the development of the nation.

The approaches to national socioeconomic development will be dealt with by a computer simulation model to analyze possible future development patterns based on scenario analysis. A scenario is a forecast of the future states of a system based on the likely interactions between system variables and the external forces for change. Scenario analysis helps to understand at once the interaction of biological, technological, socioeconomic, cultural and political dimensions, thus making it the best tool for policy research [149]. The product of scenario analysis is a description of future states, in this case the U.S. national development patterns over the 50-year period beginning the year 2000. This study is composed of the description of the model, scenario analysis and conclusions.
9.3 Description of the Model

9.3.1 Overview

The National Development Model (NDM) is described in two complementary forms of the system dynamics modeling, causal diagrams and DYNAMO equations. The causal diagram in Fig. 9-1 not only portrays the cause and effect relationships between the goal and policy variables of NDM, being used as a communication and reasoning media, but also facilitates writing DYNAMO equations which permit one to perform the computer simulation.

In a causal diagram, arrows describe the direction of causality between each pair of variables, where the arrow can be interpreted as 'affects' and the sign, plus or minus, indicates the type of relationship between the independent variable and the dependent variable. Two types of arrow lines are used. Solid lines indicate physical flows between the rate variables and the level variable, and dashed lines indicate information flows between any other pairs of variables. Level variables (L) represent the accumulation of resources such as population, capital and output. Rate variables (R) represent the activities in the system such as population movement, birth, death, capital investment and capital depreciation [141].

NDM consists of six sectors which can accommodate three development orientations: (1) resource development, (2) regional development, and (3) sectoral development. Resource development is based on components such as natural resources, land resources and human resources. Regional development is based on the interaction between AVCS maglev corridor and non-corridor subsectors. Economic elements in
Figure 9-1. Causal Diagram for National Development Model
the model include manufacturing, service, agriculture, physical and social infrastructure. The three orientations overlap and are tied together by two elements which are most responsible for economic growth -- population and capital [149].

For the purpose of this study, NDM is organized into six sectors: (1) industrial sector, (2) environmental sector, (3) infrastructure sector, (4) social development sector, (5) demographic sector, and (6) employment sector. Many of the sectors in NDM can be considered as elements in the national accounts.

The national accounts are concerned with the measure of aggregate output produced within the geographical boundary of a nation to gain a picture of the nation's economic performance. The most comprehensive measure of national output is the gross national product (GNP). GNP is the value of all goods and services produced annually in the nation. In NDM, the "value-added" approach is used to avoid double-counting, i.e., to include only final goods and not the intermediate goods which are used to make the final goods. Expenditure components of GNP, which means a final use of GNP, include private consumption, private investment, government consumption, and net export. For the purpose of national accounts analysis, GNP statistics are subdivided into nine major categories, which are mutually exclusive and collectively exhaustive, based on the International Standard Industrial Classification (ISIC) (see Table 9-1).

In NDM, the industrial sector is comprised of six subsectors such as mining, manufacturing, construction, service, agriculture, and maglev industry. Outputs for ISIC divisions 1, 2, 3 and 5 are produced through agriculture, mining, manufacturing, and construction subsectors. The service subsector includes the economic activities listed under ISIC divisions 6 and 8. The maglev industry (vehicles, guideways, etc.) could be
Table 9-1. International Standard Industrial Classification

<table>
<thead>
<tr>
<th>Code</th>
<th>Classification and Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture, hunting, forestry, and fishing</td>
</tr>
<tr>
<td>2</td>
<td>Mining and quarrying</td>
</tr>
<tr>
<td>3</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>4</td>
<td>Electricity, gas, and water</td>
</tr>
<tr>
<td>5</td>
<td>Construction</td>
</tr>
<tr>
<td>6</td>
<td>Wholesale and retail trade, restaurants, and hotels</td>
</tr>
<tr>
<td>7</td>
<td>Transport, storage, and communication</td>
</tr>
<tr>
<td>8</td>
<td>Financing, insurance, real estate, and business services</td>
</tr>
<tr>
<td>9</td>
<td>Community, social, and personal services</td>
</tr>
</tbody>
</table>
categorized into ISIC divisions 3 and 6. However, it is separated into its own category because its share of GNP accounts and socioeconomic impact will be tremendous. The infrastructure sector of NDM is comprised of ISIC divisions 4 and 7, and the social development sector corresponds to ISIC division 9.

The aforementioned sectors are associated with particular capital stocks, and thus ISIC economic output divisions. While the aggregated version of the model is called NDM-2 (see Appendix B), the disaggregated version written in DYNAMO III is called NDM (see Appendix C).

9.3.2 Development Indicators

Simply speaking, the development indicators can be defined as the elements necessary to describe a nation's future development profile. Based on the ideas presented in Section 9.3.1, some development indicators are selected to aid scenario analysis (see Table 9-2).

Indicators in the human resources category include P (population) and LF (labor force). People are the center of all socioeconomic activities, because they are both producers and consumers of those activities. If there are no people, goods or services cannot be produced. On the other hand, if there is no one to consume those goods and services, no incentive exists to produce them. Therefore, it is crucial for the socioeconomic development of a nation to maintain a certain size of population, especially a good number of productive workers.

The wealth indicators include GNP and PCI (per capita income). Traditionally, GNP is
<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Resources</td>
<td>Population</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Labor Force</td>
<td>LF</td>
</tr>
<tr>
<td>Wealth</td>
<td>Gross National Product</td>
<td>GNP</td>
</tr>
<tr>
<td></td>
<td>Per Capita Income</td>
<td>PCI</td>
</tr>
<tr>
<td>Distribution of Wealth</td>
<td>Unemployment</td>
<td>UNEM</td>
</tr>
<tr>
<td>Environment</td>
<td>Infrastructure Capital per Capita Ratio</td>
<td>IFCPCR</td>
</tr>
<tr>
<td></td>
<td>Social Devel. Capital per Capita Ratio</td>
<td>SDCPCR</td>
</tr>
<tr>
<td></td>
<td>Pollution Ratio</td>
<td>POLR</td>
</tr>
</tbody>
</table>
used as a measure of total wealth or resources produced over a specified period of
time by the residents of a country. Currently, the trend is that GDP (gross domestic
product) is replacing GNP. GDP indicates the market value of all goods and services
produced domestically over a specified period of time. The difference between these
two concepts is that while GNP does not include the contribution by the foreign capital
and labor, GDP does not include the goods and services produced abroad by its
residents [150]. However, in this study no distinction will be made between GNP
statistics and GDP figures, because the difference in these two amounts is not
significant. The second indicator of the wealth category, PCI, is a better measure of the
well-being of its people than GNP.

These two wealth indicators are quite useful to describe the future development profile
of the United States, because without significant economic growth, it would be
impossible to improve its quantity as well as quality of life, expecting that its population
will increase by about 50 percent by the year 2050.

However, the above two indicators, GNP and PCI, do not guarantee the material well-
being of its people in general, unless the produced wealth and resources are
distributed fairly equally through good employment opportunity. This is the reason
UNEM (unemployment rate) is chosen as a development indicator.

The aforementioned development indicators are mostly concerned with the quantity of
life. The environmental indicators, which are the measures of the quality of life, include
IFCPCR (infrastructure capital per capita ratio), SDCPCR (social development capital
per capita ratio), and POLR (pollution ratio). The first two indicators have a unit value in
the base year, the year 2000, and change over time according to the capital to
population growth ratio. The last indicator, PCLR, provides a measure of ecosystem
destruction and thus our living condition degradation. Expected population growth and
required economic growth will inevitably release materials which will pollute the natural
environment. However, for the well-being of this generation and the generations to
come, our wisdom needs to be gathered together to keep the balance between growth
and conservation.

All the development indicators are not independent, but interconnected. Fig. 9-1
illustrates the interwound cause-effect relationships among these parameters. In the
next six subsections the DYNAMO equation version of NDM, which was developed
based on Fig. 9-1, will be analyzed sector by sector.

9.3.3 Industrial Sector

The industrial sector of NDM is divided into mining, manufacturing, construction,
service, agriculture, and maglev industry subsectors based on ISIC which is used for
the breakdown of GNP statistics by sector. The industrial capital (IC) is the monetary
value of the total means of industrial activities and it increases by the industrial capital
investment and decreases by its depreciation. ICN denotes the industrial capital of the
base year (here, the year 2000), and is divided among the six subsectors. The annual
inflation rate is assumed to be 2.5 percent.

FOR A=1,6=MINING, MANUFA, CONSTR, SERVIC, AGRICL, MAGLEV
  L IC.K(A)=IC.J(A)+(DT)(CF.JK(A)*((1+AROI*DT)-CD.JK(A))
  N IC(A)=ICN(A)
  T ICN(*)=.23E12/5.61E12/.9E12/11E12/56E12/.7E12

9. National Development Model
C  AROI=.025

A  -  SUBSCRIPT FOR EACH SUBSECTOR
IC  -  INDUSTRIAL CAPITAL ($)
ICN  -  INDUSTRIAL CAPITAL INITIAL ($)
AROI  -  ANNUAL RATE OF INFLATION (1/YR)

The value of industrial capital, the buildings and equipment used for industrial activities, declines as a result of use and aging. The worn-out portion should be replaced to maintain the same level of productivity. Also, new investment should be made to increase the productivity. For these purposes a certain amount of GNP will be allocated. Here, it is assumed that 20 percent of GNP is used for the capital formation. In 1990, the gross fixed capital formation amounted to 16.1 percent of GNP [148]. The industrial capital for each subsector is assumed to last 25 years.

R  CD.KL(A)=IC.K(A)/LIC(A)
T  LIC(*)=25/25/25/25/25
R  CF.KL(A)=FGNPCF(A)*GNP.K

CD  -  CAPITAL DEPRECIATION ($/YR)
LIC  -  LIFETIME INDUSTRIAL CAPITAL (YR)
CF  -  CAPITAL FORMATION ($/YR)
FGNPCF  -  FRACT GNP TO CAPITAL FORMATION (DIM)

The industrial capital yields the industrial output (IO). However, a certain portion of the
output is used to pay for raw materials, transportation, energy, etc., and thus should be excluded from the national income calculation. FIOIFM (fraction industrial output to infrastructure multiplier) reflects the effect of infrastructure improvements on production efficiency. In other words, improved infrastructure system reduces the industrial production cost and thus increases the industrial product.

\[
\begin{align*}
A \quad \text{GNP.K} &= \text{SUM(IP.K)} \\
A \quad \text{IP.K(A)} &= \text{IO.K(A)} \times (1 - \text{FIOI.K(A)}) \\
A \quad \text{IO.K(A)} &= \text{IC.K(A)} \times \text{CUF.K(A)}/\text{COR.K(A)} \\
A \quad \text{FIOI.K(A)} &= \text{FIFORM(A)} + \text{FIOIF.K(A)} \\
T \quad \text{FIFORM(*)} &= .2/2/2/2/2/2 \\
A \quad \text{FIOIF.K(A)} &= \text{FIOIFN(A)} \times \text{FIOIFM.K(A)} \\
T \quad \text{FIOIFN(*)} &= .4/4/4/4/4/4 \\
A \quad \text{FIOIFM.K(A)} &= \text{TABXT(FIOIFT, (TICCI.K/TIFCI.K)/(TICN.K/TIFN.K), 0, 2, .5)} \\
T \quad \text{FIOIFT} &= .6/75/1/1.1/1.2
\end{align*}
\]

GNP - GROSS NATIONAL PRODUCT ($/YR)
IP - INDUSTRIAL PRODUCT ($)
IO - INDUSTRIAL OUTPUT ($/YR)
FIOI - FRACT INDUSTRIAL OUTPUT TO INPUT (DIM)
FIFORM - FRACT INDUSTRIAL OUTPUT TO RAW MATERIALS (DIM)
FIOIF - FRACT INDUSTRIAL OUTPUT TO INFRASTRUCTURE (DIM)
FIOIFN - FRACT INDUSTRIAL OUTPUT TO INFRA NORMAL (DIM)
FIOIFM - FRACT INDUST OUTPUT TO INFRA MULTIPLIER (DIM)
FIOIFT - FIOIFM TABLE VAULES
The industrial output depends upon IC, COR (capital output ratio), and CUF (capital utilization factor). COR is the parameter indicating the capital required for a unit output and it is assumed that as the pollution level increases, the industrial output produced with a unit capital decreases. CUF indicates the relationship between a capital-intensive production and a labor-intensive scheme. For example, adoption of unmanned machines for production will lower the demand for labor.

\[
\begin{align*}
A \quad & IO.K(A)=IC.K(A)^*CUF.K(A)/COR.K(A) \\
A \quad & COR.K(A)=CORN.K(A)^*CORM.K(A) \\
A \quad & CORN.K(A)=CLIP(CORNCV(A),1,TIME.K,2000.01) \\
T \quad & CORNCV(*)=1/1/1/1/1 \\
A \quad & CORM.K(A)=TABXT(CORT(*,A),POLR.K/5.,2,7,2,7) \\
T \quad & CORT(*,MINING)=1/1.35 \\
T \quad & CORT(*,MANUFA)=1/1.35 \\
T \quad & CORT(*,CONSTR)=1/1.35 \\
T \quad & CORT(*,SERVIC)=1/1.35 \\
T \quad & CORT(*,AGRICL)=1/1.35 \\
T \quad & CORT(*,MAGLEV)=1/1.35 \\
A \quad & CUFT.K(A)=TABXT(CUFT(*,A),(1-UNEM.K),.5,.5,.5) \\
T \quad & CUFT(*,MINING)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1 \\
T \quad & CUFT(*,MANUFA)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1 \\
T \quad & CUFT(*,CONSTR)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1 \\
T \quad & CUFT(*,SERVIC)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1 \\
T \quad & CUFT(*,AGRICL)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1 \\
T \quad & CUFT(*,MAGLEV)=1/1/.9/.8/.7/55/.4/.3/.2/.1/1
\end{align*}
\]
IO - INDUSTRIAL OUTPUT ($/YR)
COR - CAPITAL OUTPUT RATIO (1/YR)
CORN - CAPITAL OUTPUT RATIO NORMAL (1/YR)
CORNCV - CORN CLIP VALUE (1/YR)
CORM - CAPITAL OUTPUT RATIO MULTIPLIER (DIM)
CORT - CORM TABLE VALUES
CUF - CAPITAL UTILIZATION FACTOR (DIM)
CUFT - CUF TABLE VALUES

PCI denotes the average share of GNP per person and is calculated by dividing GNP by the population.

\[ A \quad PCI.K = GNP.K/P.K \]

PCI - PER CAPITA INCOME ($/PERSON-YR)
P - POPULATION (PERSONS)

9.3.4 Environmental Sector

Industrial activities will inevitably generate pollution and the pollution generated will be absorbed and decayed by the ecosystems as time passes. The rate of pollution generation (POLG) depends upon IO and UPG (pollution generated per unit IO).

\[ L \quad POL.K(A) = POL.J(A) + (DT)((POLG.JK(A)/(1+AROI*DT)) - POLA.JK(A)) \]

\[ N \quad POL(A) = POLN(A) \]

\[ N \quad POLN(A) = 3*ICN(A) \]
R POLG.KL(A)=10.K(A)*UPG(A)
T UPG(*)=.2/.2/.2/.2/.2/.2

POL - POLLUTION (UNITS)
POLN - POLLUTION INITIAL (UNITS)
POLG - POLLUTION GENERATION (UNITS/YR)
UPG - UNIT POLLUTION GENERATION (UNITS/$-YR)

The rate of pollution absorption (POLA) increases as the level of pollution (POL) increases and decreases as the pollution absorption time (POLAT) increases. The change of pollution absorption time is based on the fact that the capacity of ecosystems to absorb pollution is not unlimited, but decreases as the level of pollution increases.

R POLA.KL(A)=POLAN(A)*POL.K(A)/POLAT.K(A)
T POLAN(*)=.5/.5/.5/.5/.5/.5
A POLAT.K(A)=POLATN(A)*TABXT(POLATM(*.A),POLR.K,0,10,1)
T POLATN(*)=7.5/7.5/7.5/7.5/7.5/7.5
T POLATM(*.MINING)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM(*.MANUFA)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM(*.CONSTR)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM(*.SERVIC)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM(*.AGRICL)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM(*.MAGLEY)=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16

POLA - POLLUTION ABSORPTION (UNITS/YR)
POLAN - POLLUTION ABSORPTION NORMAL (DIM)
POLAT - POLLUTION ABSORPTION TIME (YR)
POLATN - POLLUTION ABSORPTION TIME NORMAL (YR)
POLATM - POL ABSORPTION TIME MULTIPLIER TABLE VALUES (DIM)

The pollution should be controlled below a certain limit not to totally destroy ecosystems in the end, but the pollution control will cause extra expenses in the industrial activities and lower the production efficiency denoted by COR. POLR, which indicates the change in the pollution level as compared to its initial value, is computed to help evaluate the impact of industrial policy.

\[ \text{POLR} = \frac{\text{SUM(POL.K)}}{\text{SUM(POLN)}} \]

POLR - POLLUTION RATIO (DIM)

9.3.5 Infrastructure Sector

The well-planned investments in physical infrastructure will raise the industrial productivity, lower the pollution level, and increase the employment opportunities. The infrastructure sector of NDM is divided into highways, railways, ports, airports, power, water, telecommunications, and sewerage subsectors.

The infrastructure (IF) deteriorates due to its use and aging. Investments need to be made to maintain and/or improve its serviceability. Therefore, a certain portion of GNP should be allocated for this purpose and it is denoted by FGNPIF (fraction GNP to infrastructure). The lifetime of infrastructure is assumed to be 50 years and its total capital stock in the base year (the year 2000) to be $8 trillion.
FOR \( b = 1, B = \text{HIGHWAY}, RAIL, PORTS, AIRPRT, POWER, WATER, TELCOM, SEWER \)

\[ L = \text{IF}(\text{K}(b)) = \text{IF}(\text{J}(b) + (DT)(\text{IF}.J\text{K}(b) - \text{IFD.K}(b))) \]

\[ N = \text{IF}(b) = \text{IFN}(b) \]

\[ T = \text{IFN}^*(b) = 2.4E12 \times 10^3 / 16E12 \times 10^3 / 16E12 / 4E12 / 1.2E12 / 1.2E12 / 1.2E12 / 1.6E12 \]

\[ R = \text{IFD.KL}(b) = \text{IF}.K(b) / \text{LIF}(b) \]

\[ T = \text{LIF}^*(b) = 50 / 50 / 50 / 50 / 50 / 50 / 50 \]

\[ R = \text{IF}.K.L(b) = \text{GNP}.K^* \text{FGNPIF}(b) \]

\[ T = \text{FGNPIF}^*(b) = 0.18 / 0.0012 / 0.0012 / 0.003 / 0.009 / 0.0072 / 0.0084 / 0.012 \]

B - SUBSCRIPT FOR EACH SUBSECTOR

IF - INFRASTRUCTURE ($)

IFN - INFRASTRUCTURE INITIAL ($)

IFD - INFRASTRUCTURE DEPRECIATION ($/YR)

LIF - LIFETIME INFRASTRUCTURE (YR)

IFI - INFRASTRUCTURE INVESTMENT ($/YR)

FGNPIF - FRACTION GNP TO INFRASTRUCTURE (DIM)

To portray the impact of infrastructure investment on the quality of life, IFCPCR (infrastructure capital per capita ratio) is computed by dividing the infrastructure growth rate by the population growth rate.

\[ S = \text{IFCPCR.K} = (\text{TIFCL.K/P.K}) / (\text{TIFN.K/PN}) \]

IFCPCR - INFRA CAPITAL PER CAPITA RATIO (DIM)

TIFCL - INFRASTRUCTURE CORRECTED FOR INFLATION ($)

TIFN - TOTAL INFRASTRUCTURE INITIAL ($)
9.3.6 Social Development Sector

While the industrial and infrastructure sectors deal with non-human capital investments, the social development sector deals with human capital investments. These investments are made to and for the people and have a significant impact on the national development. For example, without good education and health, people cannot become productive workers. Also, without good housing, people cannot keep good health. Therefore, the social development sector can be called the social infrastructure, as compared to the physical infrastructure.

The social development sector of NDM is divided into health, education, housing, and welfare subsectors. The social development capital (SDC) is increased by the social development capital investment and decreased by its depreciation. The social development capital investment (SCI) depends on GNP and the social development policy which decides what fraction of GNP should be invested for this program. The social development capital depreciates at a rate in inverse proportion to its lifetime as other capitals do, and its lifetime is assumed to be 50 years. The initial capital of $6 trillion is allocated to the four subsectors.

FOR C=1,4=HEALTH,EDUCAT,HOUSE,WELFRE
L SDC.K(C)=SDC.J(C)+(DT)(SCI.JK(C)-SDC.JK(C))
N SDC(C)=SDCN(C)
T SDCN(*)=1.4E12/2.9E12/.3E12/1.4E12
R SCD.KL(C)=SDC.K(C)/LSDC(C)
T LSDC(*)=50/50/50/50
R SCI.KL(C)=GNP.K*FGNPSD(C)
T FGNPSD(*)=.013/.026/.003/.013

C - SUBSCRIPT FOR EACH SUBSECTOR
SDC - SOCIAL DEVELOPMENT CAPITAL ($)
SDCN - SOCIAL DEVELOPMENT CAPITAL INITIAL ($)
SCD - SOCIAL CAPITAL DEPRECIATION ($/YR)
LSDC - LIFETIME SOCIAL DEVELOPMENT CAPITAL (YR)
SCI - SOCIAL CAPITAL INVESTMENT ($/YR)
FGNPSD - FRACT GNP TO SOCIAL DEVELOPMENT (DIM)

To see the impact of social development policy on the quality of life, SDCPCR (social development capital per capita ratio) is computed by dividing the social development capital growth rate by the population growth rate.

\[ S \quad SDCPCR.K = \frac{(TSDCCI.K/P.K)}{(TSDCN.K/PN)} \]

SDCPCR - SOCIAL DEVELOPMENT CAPITAL PER CAPITA RATIO (DIM)
TSDCCI - TOTAL SOCIAL DEV CAPITAL CORRECTED FOR INFLATION ($)
TSDCN - TOTAL SOCIAL DEVELOPMENT CAPITAL INITIAL ($)

9.3.7 Demographic Sector

It is a common practice that the demographic sector is divided into the urban and rural subsectors. In case of NDM, however, it is divided into the corridor and non-corridor subsectors, because the implementation of a high-speed automated personal transportation system, such as AVCS maglev, will give a tremendous incentive for the
migration from the non-corridor to the corridor area which will give much easier access
to the extremely beneficial transportation system. Therefore, the demographic sector of
NDM is formed by the combination of a demographic model and a corridor development
model.

The population of the United States is composed of the corridor population and the
non-corridor population. It is assumed that in the base year (the year 2000) the
population is 270 million persons, based on the population projection made by the U.S.
Bureau of the Census [144], and all of them are located in the non-corridor area.

\[
\begin{align*}
A & \quad P.K=CP.K+NCP.K \\
N & \quad PN=CPN+NCPN \\
C & \quad CPN=0 \\
C & \quad NCPN=270E6
\end{align*}
\]

\(P\) - \text{POPULATION (PERSONS)}

\(PN\) - \text{POPULATION INITIAL (PERSONS)}

\(CP\) - \text{CORRIDOR POPULATION (PERSONS)}

\(CPN\) - \text{CORRIDOR POPULATION INITIAL (PERSONS)}

\(NCP\) - \text{NON CORRIDOR POPULATION (PERSONS)}

\(NCPN\) - \text{NON CORRIDOR POPULATION INITIAL (PERSONS)}

The corridor population (CP) is increased by corridor births and migration from non-
corridor, and decreased by corridor deaths. The increase in corridor population will
stop when it reaches the capacity of the corridor area which is expressed by the
minimum share of land per person (LPP) and the projected corridor area (PCA).
CP.K = MIN(CP.J+(DT)(CBR.JK-CDR.JK+RR.JK),PCA/LPP)

CP - CORRIDOR POPULATION (PERSONS)
CBR - CORRIDOR BIRTH RATE (PERSONS/YR)
CDR - CORRIDOR DEATH RATE (PERSONS/YR)
RR - RELOCATION RATE (PERSONS/YR)
LPP - LAND PER PERSON (SQ MI/PERSON)
PCA - PROJECTED CORRIDOR AREA (SQ MI)

CBR (corridor birth rate) depends on CP and F (fertility). The fertility decreases as population increases. To take the immigration effect, which will not be an insignificant size in the 21st century, into consideration, a little higher fertility normal value is taken. Mortality is the reciprocal of the life expectancy which is assumed to be 76.9 years. In 1990, the life expectancy was approximately 75.4 years, and it has been continuously increasing for the last 25 years [145].

CBR.KL = CP.K*F.K
A F.K = FN*FM.K
C FN = .026
A FM.K = PN/P.K
R CDR.KL = CP.K*M
C M = .013

CBR - CORRIDOR BIRTH RATE (PERSONS/YR)
F - FERTILITY (1/YR)
FN - FERTILITY NORMAL (1/YR)
FM - FERTILITY MULTIPLIER (DIM)

CDR - CORRIDOR DEATH RATE (PERSONS/YR)

M - MORTALITY (1/YR)

The relocation rate, or the migration rate from the non-corridor to the corridor area, will decrease as the higher fraction of the corridor area is occupied. The maximum holding capacity of the corridor area is 1,250 persons per square mile.

R  RR.KL=NCP.K*RF.K*RM.K
A  RF.K=TABHL(RFT,TIME.K,2000,2100,25)
T  RFT=.01/.06/.04/.02/.005
A  RM.K=CLIP(0,1-LFO.K,CP.K/PCA.1/LPP)
A  LFO.K=CLIP(1,CP.K*LPP/CA.K,CP.K/CA.K,1/LPP)
C  LPP=.0008

RR  - RELOCATION RATE (PERSONS/YR)
RF  - RELOCATION FRACTION (1/YR)
RFT  - RF TABLE VALUES
RM  - RELOCATION MULTIPLIER (DIM)
LFO  - LAND FRACTION OCCUPIED (DIM)
LPP  - LAND PER PERSON (SQ MI/PERSON)

The non-corridor population (NCP) is increased by non-corridor births and decreased by both deaths and outmigration. The non-corridor birth rate and death rate are controlled by the same mechanism as in the corridor area.
L  NCP.K=NCP.J+(DT)(NCBR.JK-NCDR.JK-RR.JK)
R  NCBR.KL=NCP.K*F.K
R  NCDR.KL=NCP.K*M

NCP - NON CORRIDOR POPULATION (PERSONS)
NCBR - NON CORRIDOR BIRTH RATE (PERSONS/YR)
NCDR - NON CORRIDOR DEATH RATE (PERSONS/YR)

The easy access to the extremely beneficial transportation system in the corridor area will attract lots of people and industries, requiring a huge amount of investment for its development. The corridor area will be developed at a faster rate by the increase of the development budget and the decrease of the development cost. The corridor area is projected to be 100,000 square miles when fully developed, and FCD indicates the ratio of the corridor development to its projected development.

L  CA.K=CA.J+(DT)(CDV.JK)
N  CA=CAN
C  CAN=1000
R  CDV.KL=CDB/CDC.K
C  CDB=10E9
A  CDC.K=CLIP((CN/(1-FCD.K)**.05),10E15,(1-FCD.K),.01)
C  CN=10E6
A  FCD.K=CA.K/PCA
C  PCA=100000

CA - CORRIDOR AREA (SQ MI)
CAN - CORRIDOR AREA INITIAL (SQ MI)
CDV - CORRIDOR DEVELOPMENT (SQ MI/YR)
CDB - CORRIDOR DEVELOPMENT BUDGET ($/YR)
CDC - CORRIDOR DEVELOPMENT COSTS ($/SQ MI)
CN - CORRIDOR DEVELOPMENT COSTS NORMAL ($/SQ MI)
FCD - FRACTION CORRIDOR DEVELOPMENT (DIM)
PCA - PROJECTED CORRIDOR AREA (SQ MI)

9.3.8 Employment Sector

The three sectors of NDM -- industrial, infrastructure and social development -- not only produce goods and services, but also generate jobs. The demographic sector generates labor force. The interaction between these two components are described in the employment sector.

The number of jobs in the industrial sector \((JII)\) increases as the level of industrial capital in real terms \((ICCI)\) increases, and it decreases as the industrial capital labor ratio \((ICLR)\) increases. ICLR, which indicates the amount of capital necessary to generate one job in the sector, tends to increase as the industrial capital stock in real terms increases. This trend is indicated by the industrial capital labor ratio multiplier \((ICLRM)\).

\[
\begin{align*}
A & \quad JII.K(A) = ICCI.K(A)/ICLR.K(A) \\
A & \quad ICLR.K(A) = ICLRN(A)^*ICLRM.K(A) \\
T & \quad ICLRN(*) = 19.03E4/19.03E4/19.03E4/19.03E4/19.03E4/19.03E4 \\
A & \quad ICLR.K(A) = TABXT(JII.A,ICCI.K(A)/ICN(A),1,8,1)
\end{align*}
\]
T  ICLRT(1,1)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T  ICLRT(1,2)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T  ICLRT(1,3)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T  ICLRT(1,4)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T  ICLRT(1,5)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T  ICLRT(1,6)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07

JII - JOBS IN INDUSTRY (PERSONS)
ICCI - INDUSTRIAL CAPITAL CORRECTED FOR INFLATION ($)
ICLR - INDUS CAPITAL LABOR RATIO ($/PERSON)
ICLRN - INDUS CAPITAL LABOR RATIO NORMAL ($/PERSON)
ICLRM - INDUS CAPITAL LABOR RATIO MULTIPLIER (DIM)
ICLRT - ICLRM TABLE VALUES

As in the case of the industrial sector, the number of jobs in the infrastructure sector (JIIF) increases as the level of infrastructure capital in real terms (IFCI) increases, and it decreases as the infrastructure capital labor ratio (IFCLR) increases. IFCLR, which indicates the amount of capital necessary to generate one job in the sector, tends to increase as the infrastructure capital stock in real terms increases. This trend is indicated by the infrastructure capital labor ratio multiplier (IFCLRM).

A  JIIF.K(B)=IFCI.K(B)/IFCLR.K(B)
A  IFCLR.K(B)=IFCLRN(B)*IFCLRM.K(B)
T  IFCLRN(*)=88.6E4/88.6E4/88.6E4/88.6E4/88.6E4/88.6E4/88.6E4
A  IFCLRM.K(B)=TABXT(IFCLRT(*,B),IFCI.K(B)/IFN(B),1,8,1)
T  IFCLRT(*,1)=1/1.58/2.16/2.74/3.32/3.90/4.48/5.06

9. National Development Model
Similarly, the number of jobs in the social development sector (JISD) increases as the level of social development capital in real terms (SDCCI) increases, and it decreases as the social development capital labor ratio (SDCLR) increases. SDCLR, which indicates the amount of capital necessary to generate one job in the sector, tends to increase as the social development capital stock in real terms increases. This trend is indicated by the social development capital labor ratio multiplier (SDCLRM).

\[
A \quad \text{JISD.K(C)} = \frac{\text{SDCCI.K(C)}}{\text{SDCLR.K(C)}}
\]

\[
A \quad \text{SDCLR.K(C)} = \text{SDCLRN(C)} \times \text{SDCLRM.K(C)}
\]

\[
T \quad \text{SDCLRN(\*)} = 33.2E4/33.2E4/33.2E4/33.2E4
\]

\[
A \quad \text{SDCLRM.K(C)} = \text{TABXT(SDCLRT(\*,C),SDCCI.K(C)/SDCN(C),1,8,1)}
\]
T  SDCLRT(*,1)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T  SDCLRT(*,2)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T  SDCLRT(*,3)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T  SDCLRT(*,4)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13

JISD - JOBS IN SOCIAL DEVELOPMENT (PERSONS)
SDCCI - SOCIAL DEVELOP CAPITAL CORRECTED FOR INFLATION ($)
SDCLR - SOCIAL DEVELOP CAPITAL LABOR RATIO ($/PERSON)
SDCLRN - SOCIAL DEVEL CAPITAL LABOR RATIO NORMAL ($/PERSON)
SDCLRM - SOCIAL DEVELOP CAPITAL LABOR RATIO MULTIPLIER (DIM)
SDCLRT - SDCLRM TABLE VALUES

The number of total jobs (JOBS) is the sum of jobs in the aforementioned three sectors.

A  JOBS.K=TJII.K+TJIIF.K+TJISD.K
A  TJII.K=SUM(JII.K)
A  TJIIF.K=SUM(JII.F.K)
A  TJISD.K=SUM(JISD.K)

JOBS - JOBS (PERSONS)
TJII - TOTAL JOBS IN INDUSTRY (PERSONS)
TJIIF - TOTAL JOBS IN INFRASTRUCTURE (PERSONS)
TJISD - TOTAL JOBS IN SOCIAL DEVELOPMENT (PERSONS)

The labor force, which is the second component of the employment sector, depends on the population (P) and the labor participation factor (LPF). LPF tends to increase
mostly due to an increasing female participation rate. This trend is indicated by the labor participation factor multiplier (LPFM).

\[
\begin{align*}
A \quad & \text{LF.K} = P.K \cdot \text{LPF.K} \\
A \quad & \text{LPF.K} = \text{LPFN} \cdot \text{LPFM.K} \\
A \quad & \text{LPFM.K} = \text{TABXT} (\text{LPFMT}, \text{TIME.K}, 2000, 2050, 10) \\
T \quad & \text{LPFMT} = 1/1.018/1.027/1.034/1.043/1.048 \\
C \quad & \text{LPFN} = .5
\end{align*}
\]

**LF** - LABOR FORCE (PERSONS)

**LPF** - LABOR PARTICIPATION FACTOR (DIM)

**LPFM** - LABOR PARTICIPATION FACTOR MULT (DIM)

**LPFMT** - LPFM TABLE VALUES

**LPFN** - LABOR PARTICIPATION FACTOR NORMAL (DIM)

The unemployment rate (UNEM) is computed by subtracting the number of total jobs (JOBS) from the size of labor force (LF) and dividing by LF.

\[
\begin{align*}
A \quad & \text{UNEM.K} = (\text{LF.K} - \text{JOBS.K}) / \text{LF.K}
\end{align*}
\]

**UNEM** - UNEMPLOYMENT (DIM)

In this section the DYNAMO version of NDM was analyzed sector by sector. In the next section, scenario analysis will be performed to illustrate the usefulness of NDM in evaluating the development policy alternatives.
9.4 Model Experiments

9.4.1 Policy Alternatives

NDM is structured so that it can perform some forecasting tasks of the future socioeconomic states of the United States based on the interactions between the system variables and the policy parameters. To provide a useful tool for the formation of the national development policy, several policy alternatives are investigated by assigning different values to the policy parameters and comparing the impacts on the aforementioned development indicators. Here, the policy alternatives are identified as the measures to tackle the recognized problems. Based on the key issues relevant to the future socioeconomic development of the United States, four policy alternatives are identified which will be referred to as follows:

1. Social development policy
2. Industrial development policy
3. Infrastructure development policy
4. Environmental protection policy

In Figs. 9-3 to 9-12, B indicates the base run, S the social development policy, I the industrial development policy, F the infrastructure development policy, and E the environmental protection policy.

9.4.2 Base Run

Simulation of the base model over the 50-year period (2000 to 2050) illustrates the
behavior of the socioeconomic system resulting from no change in the development policy, and thus it becomes the base line to evaluate the effectiveness of the aforementioned policy alternatives. Although NDM provides many outputs, the evaluation of the development policy alternatives shall be performed based on the following indicators:

1. Gross national product (GNP)
2. Per capita income (PCI)
3. Unemployment (UNEM)
4. Infrastructure capital per capita ratio (IFCPCR)
5. Social development capital per capita ratio (SDCPCR)
6. Pollution ratio (POLR)

Based on the model simulation, the population (P) increases from 270 million persons in 2000 to 379.6 million in 2040, registering an increase rate of over 40% for the same period. The resident population projections made by the U.S. Bureau of the Census [144] indicate that the population will reach about 275 million in 2000 and 364 million in 2040 according to the middle level assumptions in which the ultimate fertility rate is 21 per 1000 population, the life expectancy in 2050 is 82.1 years, and the annual net immigration is 880,000. In 2040, over 12% of the population will reside in the AVCS maglev corridor area. The labor force (LF) increases from 135 million persons in 2000 to 198 million in 2040, registering an increase rate of 47%, mainly due to an increased female participation rate and a net immigration (Fig. 9-2).

The gross national product (GNP) increases from $7.6 trillion in 2000 to $35.42 trillion in 2040, registering an average annual growth rate of over 3.9% (Fig. 9-3). However, it
must be noted that with an annual inflation rate of 2.5% as reflected in the model, this increase does not represent the real growth. The per capita income (PCI) increases from $28,100 to $93,300 for the same time period (Fig. 9-4). The real gross domestic product (GDP) has grown by 1.8% per year for the period 1959 to 1991 at diminishing rates and GDP was over $6 trillion in 1992. PCI was $23,300 in the same year [144].

The total employment (Fig. 9-5) indicated by the variable JOBS grows from 126.9 million jobs in 2000 to 186.0 million in 2040. It is composed of the employment in the industrial sector (Fig. 9-6), the infrastructure sector (Fig. 9-7), and the social development sectors (Fig. 9-8). However, for the same period the unemployment (UNEM) remains at the level of about 6% (Fig. 9-9). In 1990, the total employment was 119.5 million persons, with 5.4% of the labor force unemployed, and in 1991, the total employment was 126.9 million, with 6.6% unemployed [144].

As for the environmental indicators, the pollution ratio (POLR) changes from 1 in 2000 to 3.1 in 2040 (Fig. 9-10), the infrastructure capital per capita ratio (IFCPCR) from 1 to 3.2 (Fig. 9-11), and the social development capital per capita ratio (SDCPCR) from 1 to 3.9 (Fig. 9-12). The results of the base model simulation are summarized in Table 9-3.

9.4.3 Social Development Policy

In this policy experiment, the strategy to be investigated is increasing the government's allocation to the social service programs such as public health-care, education, housing, welfare and so forth. The policy variable for this effort is FGNPSD (fraction GNP to social development), which is increased by 18.2% for each subsector. In all, 6.5% of GNP is allocated to the social development sector, while 5.5% of GNP was
Table 9-3. Simulation Results of Base Run

<table>
<thead>
<tr>
<th>Indicator</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>270.0 M</td>
<td>303.0 M</td>
<td>331.9 M</td>
<td>357.3 M</td>
<td>379.8 M</td>
<td>399.2 M</td>
</tr>
<tr>
<td>P (persons)</td>
<td>270.0 M</td>
<td>303.0 M</td>
<td>331.9 M</td>
<td>357.3 M</td>
<td>379.8 M</td>
<td>399.2 M</td>
</tr>
<tr>
<td>Corridor Population</td>
<td>0</td>
<td>12.0 M</td>
<td>24.3 M</td>
<td>36.5 M</td>
<td>47.9 M</td>
<td>59.0 M</td>
</tr>
<tr>
<td>CP (persons)</td>
<td>0</td>
<td>12.0 M</td>
<td>24.3 M</td>
<td>36.5 M</td>
<td>47.9 M</td>
<td>59.0 M</td>
</tr>
<tr>
<td>Labor Force</td>
<td>135.0 M</td>
<td>154.2 M</td>
<td>170.4 M</td>
<td>184.7 M</td>
<td>198.0 M</td>
<td>209.2 M</td>
</tr>
<tr>
<td>LF (persons)</td>
<td>135.0 M</td>
<td>154.2 M</td>
<td>170.4 M</td>
<td>184.7 M</td>
<td>198.0 M</td>
<td>209.2 M</td>
</tr>
<tr>
<td>Gross National Prod.</td>
<td>7.60 R</td>
<td>11.27 R</td>
<td>16.64 R</td>
<td>24.39 R</td>
<td>35.42 R</td>
<td>50.79 R</td>
</tr>
<tr>
<td>GNP ($)</td>
<td>7.60 R</td>
<td>11.27 R</td>
<td>16.64 R</td>
<td>24.39 R</td>
<td>35.42 R</td>
<td>50.79 R</td>
</tr>
<tr>
<td>Per Capita Income</td>
<td>28,100</td>
<td>37,200</td>
<td>50,100</td>
<td>68,300</td>
<td>93,300</td>
<td>127,200</td>
</tr>
<tr>
<td>PCI ($)</td>
<td>28,100</td>
<td>37,200</td>
<td>50,100</td>
<td>68,300</td>
<td>93,300</td>
<td>127,200</td>
</tr>
<tr>
<td>Jobs</td>
<td>126.9 M</td>
<td>144.9 M</td>
<td>160.2 M</td>
<td>173.7 M</td>
<td>186.0 M</td>
<td>196.7 M</td>
</tr>
<tr>
<td>JOBS</td>
<td>126.9 M</td>
<td>144.9 M</td>
<td>160.2 M</td>
<td>173.7 M</td>
<td>186.0 M</td>
<td>196.7 M</td>
</tr>
<tr>
<td>Total Jobs in Ind.</td>
<td>99.8 M</td>
<td>113.5 M</td>
<td>125.2 M</td>
<td>135.8 M</td>
<td>145.9 M</td>
<td>154.5 M</td>
</tr>
<tr>
<td>TJII</td>
<td>99.8 M</td>
<td>113.5 M</td>
<td>125.2 M</td>
<td>135.8 M</td>
<td>145.9 M</td>
<td>154.5 M</td>
</tr>
<tr>
<td>Total Jobs in Infra.</td>
<td>9.0 M</td>
<td>10.4 M</td>
<td>11.6 M</td>
<td>12.6 M</td>
<td>13.4 M</td>
<td>14.0 M</td>
</tr>
<tr>
<td>TJIIF</td>
<td>9.0 M</td>
<td>10.4 M</td>
<td>11.6 M</td>
<td>12.6 M</td>
<td>13.4 M</td>
<td>14.0 M</td>
</tr>
<tr>
<td>Total Jobs in Soc. Dev.</td>
<td>18.1 M</td>
<td>21.0 M</td>
<td>23.4 M</td>
<td>25.2 M</td>
<td>26.8 M</td>
<td>28.2 M</td>
</tr>
<tr>
<td>TJISD</td>
<td>18.1 M</td>
<td>21.0 M</td>
<td>23.4 M</td>
<td>25.2 M</td>
<td>26.8 M</td>
<td>28.2 M</td>
</tr>
<tr>
<td>Unemployment</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>UNEM</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>Pollution Ratio</td>
<td>1.00</td>
<td>1.12</td>
<td>1.49</td>
<td>2.13</td>
<td>3.13</td>
<td>4.57</td>
</tr>
<tr>
<td>POLR</td>
<td>1.00</td>
<td>1.12</td>
<td>1.49</td>
<td>2.13</td>
<td>3.13</td>
<td>4.57</td>
</tr>
<tr>
<td>Infra. Capital. per Cap. Ratio</td>
<td>1.00</td>
<td>1.29</td>
<td>1.73</td>
<td>2.35</td>
<td>3.23</td>
<td>4.47</td>
</tr>
<tr>
<td>IFCPCR</td>
<td>1.00</td>
<td>1.29</td>
<td>1.73</td>
<td>2.35</td>
<td>3.23</td>
<td>4.47</td>
</tr>
<tr>
<td>Soc. Dev. C. per Cap. Ratio</td>
<td>1.00</td>
<td>1.42</td>
<td>2.0</td>
<td>2.78</td>
<td>3.88</td>
<td>5.41</td>
</tr>
<tr>
<td>SDCPCR</td>
<td>1.00</td>
<td>1.42</td>
<td>2.0</td>
<td>2.78</td>
<td>3.88</td>
<td>5.41</td>
</tr>
</tbody>
</table>

Note: M = million and R = trillion
allocated in the base run. However, increasing FGNPSD will inevitably reduce the allocations to other sectors, so that 19.5% of GNP is invested in the industrial sector (FGNPCF) and 5.5% in the infrastructure sector (FGNPIF).

For this policy experiment, the following statements are added to the base model:

\[ T \ FGNPCF^*(\text{)} = .0020475/.0517725/.010725/.11544/.00429/.010725 \]
\[ T \ FGNPIF^*(\text{)} = .0165/.0011/.0011/.00275/.00825/.0066/.0077/.011 \]
\[ T \ FGNPSD^*(\text{)} = .015362/.030731/.003545/.015362 \]

Investing more resources in the social service programs does not improve GNP. In fact, GNP declines as compared to the base run, and thus by the year 2040, GNP will be 9.9% less than that of the base run (Fig. 9-3). As a result, PCI declines from $93,300 to $84,100 in 2040 (Fig. 9-4). This decline ascribes to less investment in the industrial sector and the infrastructure sector.

As for the total employment, this policy creates more jobs in the social development sector, but the number of jobs in the other sectors decreases. As a result, the unemployment rate increases from 6% in the base run to 7.2% in 2040 (Figs. 9-5 to 9-9).

As for the environmental indicators, the pollution ratio (POLR) decreases mostly due to reduced industrial activities, while the infrastructure capital per capita ratio (IFCPCR) decreases due to less investment (Figs. 9-10 to 9-12). The results of the social development policy simulation as compared to those of the base run are summarized in Table 9-4.
9.4.4 *Industrial Development Policy*

In this policy experiment, the effects of increased industrial activities on the U.S. socioeconomic system are investigated by increasing the policy variable FGNPCF (fraction GNP to capital formation) by 7.5% for each subsector. In all, 21.5% of GNP is invested in the industrial sector instead of 20%, with 10% in the other two sectors.

For this policy experiment, the following statements are added to the base model:

\[
\begin{align*}
T & \quad \text{FGNPCF}^* = .0022575/.0570825/.011825/.12728/.00473/.011825 \\
T & \quad \text{FGNP1F}^* = .0165/.0011/.0011/.00275/.00825/.0066/.0077/.011 \\
T & \quad \text{FGNPSD}^* = .01063/.02129/.00245/.01063
\end{align*}
\]

Increased investment in the industrial sector improves GNP, which in 2040, increases from $35.42 trillion in the base run to $39.52 trillion in this development policy in 2040 (Fig. 9-3). The increase in industrial product is due to the increase in industrial capital. PCI reaches over $100,000 instead of $93,300 in 2040, registering the increase rate of 11.6% as compared to the base run (Fig. 9-4).

The increase in industrial capital creates more jobs in this sector, and thereby lowers the unemployment rate to 4.4% instead of 6% by the year 2040 (Figs. 9-5 to 9-9). However, reduced investment in the infrastructure, which is the base for the industrial activities, tends to hinder the progress in these activities by raising the cost of inputs such as transportation, power, water, telecommunications, and so on.

As for another drawback of this policy, the increased industrial activities inevitably
Table 9-4. Simulation Results of Social Development Policy

<table>
<thead>
<tr>
<th>Indicator</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNP ($)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>7.60 R</td>
<td>11.27 R</td>
<td>16.64 R</td>
<td>24.39 R</td>
<td>35.42 R</td>
<td>50.79 R</td>
</tr>
<tr>
<td>Social</td>
<td>7.60 R</td>
<td>10.98 R</td>
<td>15.79 R</td>
<td>22.55 R</td>
<td>31.93 R</td>
<td>44.74 R</td>
</tr>
<tr>
<td>PCI ($)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>28,100</td>
<td>37,200</td>
<td>50,100</td>
<td>68,300</td>
<td>93,300</td>
<td>127,200</td>
</tr>
<tr>
<td>Social</td>
<td>28,100</td>
<td>36,300</td>
<td>47,600</td>
<td>63,100</td>
<td>84,100</td>
<td>112,100</td>
</tr>
<tr>
<td>Unemployment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>Social</td>
<td>0.060</td>
<td>0.063</td>
<td>0.067</td>
<td>0.070</td>
<td>0.072</td>
<td>0.072</td>
</tr>
<tr>
<td>Pollution Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>1.00</td>
<td>1.12</td>
<td>1.49</td>
<td>2.13</td>
<td>3.13</td>
<td>4.57</td>
</tr>
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<td>Social</td>
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<td>1.45</td>
<td>2.03</td>
<td>2.91</td>
<td>4.15</td>
</tr>
<tr>
<td>IFCPCR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>1.00</td>
<td>1.29</td>
<td>1.73</td>
<td>2.35</td>
<td>3.23</td>
<td>4.47</td>
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<tr>
<td>Social</td>
<td>1.00</td>
<td>1.24</td>
<td>1.59</td>
<td>2.10</td>
<td>2.81</td>
<td>3.78</td>
</tr>
<tr>
<td>SDCPCR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>1.00</td>
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<td>2.78</td>
<td>3.88</td>
<td>5.41</td>
</tr>
<tr>
<td>Social</td>
<td>1.00</td>
<td>1.53</td>
<td>2.20</td>
<td>3.07</td>
<td>4.24</td>
<td>5.81</td>
</tr>
</tbody>
</table>

Note: R = trillion
generate more pollution (Fig. 9-10). This increase in the pollution ratio necessitates the cost for regulating the pollution generation, resulting in the lower industrial productivity indicated by COR. The effects on the other two environmental indicators are shown in Figs. 9-11 and 9-12. The results of the industrial development policy simulation as compared to the base run are summarized in Table 9-5.

9.4.5 **Infrastructure Development Policy**

This policy is aimed at inducing the socioeconomic development through the indirect approach. This means that improving GNP is achieved by investing in the infrastructure, which plays only a supporting role to that development, thus lowering the cost of infrastructure-related services, rather than investing directly in the industrial sector. This development strategy seems to achieve two favorable results: improving GNP and reducing pollution generation as well.

The policy variable for this purpose is FGNPIF (fraction GNP to infrastructure). The allocation to each subsector is increased by 25% as compared to the base run. As in the previous two experiments, the allocations to other sectors are decreased as a result. Therefore, in all, 7.5% of GNP is allocated to the infrastructure sector, while 19% is directed to the industrial sector and 5% to the social development sector. For this policy experiment, the following statements are added to the base model:

\[ T \ FGNPCF(*) = .001995/.050445/.01045/.11248/.00418/.01045 \]
\[ T \ FGNPIF(*) = .0225/.0015/.0015/.00375/.01125/.009/.0105/.015 \]
\[ T \ FGNPSD(*) = .0118/.0236/.0028/.0118 \]
Table 9-5. Simulation Results of Industrial Development Policy

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicato</td>
<td></td>
<td>R</td>
<td></td>
<td>R</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>GNP ($)</td>
<td>7.60</td>
<td></td>
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<td>17.71</td>
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</tr>
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<td>PCI ($)</td>
<td>28,100</td>
<td></td>
<td>37,200</td>
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<tr>
<td>Pollution Ratio</td>
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<td>1.49</td>
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</tr>
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</tr>
<tr>
<td>IFCPCR</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>Base</td>
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<td>1.42</td>
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<td>1.30</td>
<td></td>
<td>1.77</td>
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</tr>
</tbody>
</table>

*Note: R = trillion*
Based on the simulation results, by the year 2040, GNP and PCI are improved a little more than in the industrial development policy, achieving an annual growth rate of 4.3%, compared to the industrial development policy at 4.2% (Figs. 9-3 and 9-4). Although this policy creates less jobs than the industrial development policy since the infrastructure capital labor ratio (IFCLR) is much bigger than the industrial capital labor ratio (ICLR), by the year 2040, it achieves the unemployment rate of 5.1% as compared to 6% in the base run. This means that it creates 1.9 million more jobs than the base run (Figs. 9-5 to 9-9).

As for the quality of life, since this policy does not make an investment directly to the industrial activities, the dilemma that economic growth means pollution growth can be avoided to a substantial degree (Fig. 9-10). IFCPCR also improves substantially, while SDCPCR remains at the same level (Figs. 9-11 and 9-12). The results of the infrastructure development policy simulation are summarized in Table 9-6.

**9.4.6 Environmental Protection Policy**

The last policy experiment can be considered as evaluating trade-offs between environmental protection and economic development. This experiment is implemented by increasing the industrial capital output ratio (COR) and thereby reducing the pollution generation. In other words, in order to generate less pollution, some portion of the industrial capital, which otherwise, can be used to produce industrial output, should be allocated to facilitating environmentally-safer production processes and/or facilities.

For this policy experiment, the following statements are added to the base model:
Table 9-6. Simulation Results of Infrastructure Development Policy

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<tr>
<td><strong>Indicator</strong></td>
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</tr>
<tr>
<td><strong>GNP ($)</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>7.60 R</td>
<td>11.27 R</td>
<td>16.64 R</td>
<td>24.39 R</td>
<td>35.42 R</td>
<td>50.79 R</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>7.60 R</td>
<td>11.70 R</td>
<td>17.91 R</td>
<td>27.25 R</td>
<td>41.07 R</td>
<td>61.03 R</td>
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<td>50,100</td>
<td>68,300</td>
<td>93,300</td>
<td>127,200</td>
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<td>Infrastructure</td>
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<td>38,600</td>
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<td>76,300</td>
<td>108,200</td>
<td>152,900</td>
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<tr>
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</tr>
<tr>
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<td>0.060</td>
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<td>0.059</td>
<td>0.054</td>
<td>0.051</td>
<td>0.049</td>
</tr>
<tr>
<td><strong>Pollution Ratio</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>1.00</td>
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<td></td>
</tr>
<tr>
<td>Base</td>
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<td>1.73</td>
<td>2.35</td>
<td>3.23</td>
<td>4.47</td>
</tr>
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<td>2.09</td>
<td>3.01</td>
<td>4.35</td>
<td>6.27</td>
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<tr>
<td><strong>SDCPCR</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
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<td>1.42</td>
<td>1.99</td>
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<td>1.92</td>
<td>2.72</td>
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<td>5.60</td>
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</tbody>
</table>

*Note: R = trillion*
It should be noted that in the base run, the capital output ratio normal (CORN) equals 1.0 and the unit pollution generation (UPG) equals 0.2 for each industrial subsector. Under this policy, GNP and PCI decrease by about 16% by the year 2040 as compared to the base run (Figs. 9-3 and 9-4). The adoption of capital-intensive production schemes, which is indicated by the increased CORN, results inevitably in a decrease in the employment opportunity. In 2040, the unemployment rate reaches 8.1%, leaving 16 million people unemployed (Figs. 9-5 to 9-9).

As expected, the pollution ratio decreases significantly (Fig. 9-10), while both IFCPCR and SDCPCR deteriorate due to the reduced GNP growth (Figs. 9-11 and 9-12). Therefore, it cannot necessarily be said that the quality of life is improved at the significant sacrifice of the quantity of life under this policy. The results of the environmental protection policy as compared to the base run are summarized in Table 9-7.
### Table 9-7. Simulation Results of Environmental Protection Policy

<table>
<thead>
<tr>
<th>Year</th>
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<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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</tr>
<tr>
<td>GNP ($)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Base</td>
<td>7.60 R</td>
<td>11.27 R</td>
<td>16.64 R</td>
<td>24.39 R</td>
<td>35.42 R</td>
<td>50.79 R</td>
</tr>
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<td>14.86 R</td>
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<td>41.96 R</td>
</tr>
<tr>
<td>PCI ($)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>28,100</td>
<td>37,200</td>
<td>50,100</td>
<td>68,300</td>
<td>93,300</td>
<td>127,200</td>
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<tr>
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<td>59,200</td>
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<td>105,100</td>
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</tr>
<tr>
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<td>0.078</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
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<td>4.57</td>
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</tr>
<tr>
<td>Base</td>
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<td>1.73</td>
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<td></td>
</tr>
<tr>
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<td>5.41</td>
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</table>

*Note: R = trillion*
Figure 9-2. Population, Labor Force and Corridor Population
Figure 9-3. Gross National Product

9. National Development Model
Figure 9-4. Per Capita Income
Figure 9-5. Total Employment

9. National Development Model
Figure 9-6. Total Jobs in Industrial Sector
Figure 9-7. Total Jobs in infrastructure Sector
Figure 9-8. Total Jobs in Social Development Sector
Figure 9-9. Unemployment
Figure 9-10. Pollution Ratio

9. National Development Model
Figure 9-11. Infrastructure Capital per Capita Ratio
10. Conclusions and Recommendations

10.1 Conclusions

The consequences of traffic congestion are serious to a community, a region and a nation. These consequences include impacts on the local traffic situation, economic growth, community access, quality of life, environmental quality, and safety. In the United States, traffic delay due to congestion has reached alarming levels and is projected to keep on growing. However, the conventional approach of the past -- building more motorways or airports -- will not work in many areas of the country, for financial, land-take and environmental reasons. Public transportation systems, chronically short of funds, are not seen as an attractive alternative to personal driving. Also, there is a growing and painful awareness that we have permitted the growth of a serious transportation gap, namely, for the distances of 200 to 1,500 miles. The automobile is too slow and laborious for this spectrum, and the airplane leads to a false sense of speed when ground connections are considered.

There is a need to usher in a new era in transportation decision-making. In an ideal society, the transportation system would carry everyone from where they lived to where they wanted to go -- rapidly, economically and without unscheduled delays. It would require optimizing our technological advances to build the transportation system that will consume minimal nonrenewable resources, and that will minimize air pollution, not contributing to potential global warming. The challenges posed by current surface transportation problems cannot be solved by the application of a few isolated independent actions. A broad, comprehensive solution is needed to restore and build the future mobility our society will demand.
This research was implemented to develop a conception of a transportation system called AVCS maglev which is the synergistic combination of AVCS, which is the most comprehensive functional area of IVHS, and the high-speed maglev technology, and to assess its potential as the foundation for a strategic vision of the next revolution in transportation. Also, the National Development Model was developed and analyzed to obtain a deeper understanding of the rational policy formation about the future socioeconomic development of the United States.

The strategic vision is based on the following five fundamental premises. The first premise is that all of the elements of AVCS maglev is within the current technological state-of-the-art. For example, high-temperature superconductivity is an enhancing, not an enabling technology for AVCS maglev. The second premise is that the human being resents all interferences within a sphere of one meter around him, but greatly appreciates a freedom of behavior, of choice, and of interest in and from this sphere. AVCS maglev retains this personal sphere as current automobiles do. The third premise is that a transportation system should guide and control population distribution and land use. As an approach to accommodate America's urban growth in the first half of the 21st century, we must build new cities beyond commuting distance of existing cities. They can be located in the open countryside, on virgin lands, or they can grow up around existing small towns, all in conjunction with AVCS magway construction. The fourth premise is that since both concepts, AVCS and Maglev, were invented in the United States (unfortunately abandoned), we have a vested interest in this promising transportation system which can substantially help overcome the forthcoming challenge of the mobility, safety, environmental protection, and economic growth of the North American Continent. The fifth premise is that existing interstate highways are the only practical resource for meeting present and future travel needs in hubs and along
corridors, where the ground and air are already congested. The vision for the U.S. national development strategy is based on the premise that development means improving both quantity of life and quality of life.

In conjunction with these premises, the emphases of this research were put on investigating suitable technological aspects (Chapters 5 and 6), selecting suitable operational control concepts (Chapter 6), assessing economic viability (Chapter 8), determining socioeconomic impacts (Chapters 7 and 8), and investigating national development strategies (Chapter 9).

Based on the findings of this research, we believe that AVCS and Maglev would combine synergistically to provide a safe, privately-owned, high-speed, high-capacity, energy-efficient, environment-friendly intercity and intracity transportation system. Most importantly, the new system would be compatible with and, indeed, an extension of the existing highway transportation system.

Also, the implementation of AVCS maglev, whose original objective is to meet the challenge in the future mobility of the United States, would make a substantial contribution to the nation's gross national product. In other words, the dramatically improved mobility would reduce the proportion of industrial output allocated to the transportation service of raw materials, supplies and products, resulting in the increase of GNP. Additionally, it should be mentioned that since AVCS maglev generates much less air pollution, compared with conventional internal combustion powered vehicles, the governmental regulation for environmental protection toward the industrial activities would be eased a great deal and thus the industries would be able to reduce spendings for the environmental protection facilities. The savings in production cost will increase
the industrial output produced with a unit capital. As for another economic aspect of this highly beneficial transportation system, AVCS maglev would not only be a form of infrastructure which can make other industries more efficient, but would itself be a huge industry with a direct effect on economic development.

Therefore, it is envisaged that AVCS maglev could become a major new mode of travel in the early 21st century, carrying a significant portion of the passengers and freight now transported over airways and conventional highways, although substantial investments of time and effort will be required to bring the AVCS and Maglev technologies to the stage of large-scale public use, and highly challenging institutional problems will have to be solved.

10.2 Recommendations for Further Research

The purpose of this research was to assess the potential for AVCS maglev implementation and its socioeconomic implications with emphases on technological aspects, operational control concepts, economic viability and socioeconomic impacts. For extension of this study, the following recommendations are made:

1. To develop suitable configurations of automated and manual roadways.
2. To investigate appropriate interchange geometrics.
3. To make modal split projections for key corridors in the North America.
4. To develop suitable pricing methods.
5. To investigate appropriate safety criteria for small headway operation.
References


29. Johnson, L. R. et al., "Maglev Vehicles and Superconductor Technology: Integration of High-Speed Ground Transportation into the Air Travel System,"
Center for Transportation Research, Argonne National Laboratory, Argonne, IL, April 1989.


Appendix A. Maglev Vehicle Development Model

NOTE

MAGEV VEHICLE DEVELOPMENT MODEL

NOTE

MV=MVN

NOTE MV-MAGLEV VEHICLES (VEH)

C MVN=100

NOTE MVN-MAGLEV VEHICLES NORMAL (VEH)

R VPR, KL=VD.K

NOTE VPR-VEHICLE PRODUCTION RATE (VEH/YR)

A VD.K=VDN*VDM.K

NOTE VD-VEHICLE DEMAND (VEH/YR)

C VDN=400E3

NOTE VDN-VEHICLE DEMAND NORMAL (VEH/YR)

A VDM,K=TABHL(VDMT,VPN/VP.K,1,10,.6)

T VDMT=.8/1.2/1.4/2.8/5.2/13.6/15.8/22/32/38/43/46.5/48.2/49.3/50

NOTE VDM-VEHICLE DEMAND MULTIPLIER (DIM)

S REV,K=VPD.K*VD.K

NOTE REV-REVENUE ($/YR)

A VPCD,K=VP,K*(((1+AROI DT)**(TIME,K-2000)/DT))

NOTE VPCD-VEHICLE PRICE CURRENT DOLLARS ($/VEH)

C AROI=.025

NOTE AROI-ANNUAL RATE OF INFLATION (1/YR)

A VPN=VPN*VUM,K*VPCM.K

NOTE VP-VEHICLE PRICE ($/VEH)

C VPN=260000

NOTE VPN-VEHICLE PRICE NORMAL ($/VEH)

A VUM.K=CLIP(VUM2.K,VUM1.K,(MV,K/MVN)/1E4,1)

NOTE VUM-VEHICLE UNAVAILABILITY MULTIPLIER (DIM)

A VUM1,K=TABHL(VUM1T,((MV,K/MVN)/1E4),0,1,1)

T VUM1T=1.6/5.4/35.3/31.3/28.2/27.26

A VUM2,K=TABHL(VUM2T,((MV,K/MVN)/1E4),1,101,20)
T  VUM2T=.26/.23/.22/.21/.205/.2
A  VPCM.K=TABLE(VPCM.T,WMV.K,WMVN,.5,1,1)
T  VPCM.T=.5/.6/.7/.75/.8/1

NOTE VPCM-VEHICLE PRODUCTION COST MULTIPLIER (DIM)
R  VDR.KL=CLIP(MV.K/ALV.K,0,(TIME,K-2000),10)

NOTE VDR-VEHICLE DISCARD RATE (VEH/yr)
A  ALV.K=ALVN*ALVM.K

NOTE ALV-AVE LIFETIME VEHICLE (yr)
C  ALVN=15

NOTE ALVN-AVERAGE LIFETIME VEHICLE NORMAL (yr)

NOTE ALVM-AVE LIFETIME VEHICLE MULTIPLIER (DIM)
A  ALVM1.K=TABLE(ALVM1.T,(MV.K/MVN)/1E4,1,1,1,2)
T  ALVM1T=1/.98/.97/.95/.93/.92
A  ALVM2.K=TABLE(ALVM2.T,(MV.K/MVN)/1E4,11,211,50)
T  ALVM2T=.92/.90/.85/.80/.75
L  WMSCA.K=WMSCA.J-(DT)(WRR.JK)
N  WMSCA=WMSCAN

NOTE WMSCA-WGT MAGLEV SUPERCONDUCTOR CRYOSTAT ASSEMBLIES (LB)
C  WMSCAN=1200

NOTE WMSCAN-WGT MAGLEV SUPERCONDUCTOR CRYOSTAT ASSEMBLIES NORMAL (LB)
R  WRR.KL=CLIP((WMSCA.K-WMSCP.K)/ADT,0,WMSCA.K,WMSCP.K)

NOTE WRR-WEIGHT REDUCTION RATE (LB/yr)
C  ADT=10

NOTE ADT-ASSEMBLY DEVELOPMENT TIME (yr)
A  WMSCP.K=WMSCPN*WMSCP.M.K

NOTE WMSCP-WGT MAGLEV SUPERCONDUCTOR CRYOSTAT PROTOTYPE (LB)
C  WMSCP.M=600

NOTE WMSCP.M-WGT MAGLEV SUPERCONDUCTOR CRYOSTAT PROTOTYPE NORMAL (LB)
A  WMSCP.M=TABLE(WMSCP.MT,HTSB.K,HTSBN,0,2,1)
T  WMSCP.MT=.2/.5/.25

NOTE WMSCP.M-WGT MAGLEV SUPERCONDUCTOR CRYOSTAT PROTOTYPE MULT (DIM)
C  HTSBN=100E6

NOTE HTSBN-HIGH TEMPERATURE SUPERCONDUCTING BUDGET NORMAL ($/yr)
A  HTSB.K=HTSBN*HTSB.M.K
NOTE  HTSB-HIGH TEMPERATURE SUPERCONDUCTING BUDGET ($/YR)
A    HTSBM.K=TABHL(HTSBMT.,(VD,K/VDN),1,31,10)
T    HTSBMT=0/1/1.52

NOTE  HTSBM-HIGH TEMPERATURE SUPERCONDUCTING BUDGET MULT (DIM)
C    WMVN=6000

NOTE  WMVN-WGT MAGLEV VEHICLE NORMAL (LB)
A    WMV.K=MAX(WMSCA.K/FATVW.K,3000)

NOTE  WMV-WGT MAGLEV VEHICLE (LB)
A    FATVW.K=FATVWN*FATVWM.K

NOTE  FATVWN-FRACT ASSEMBLY TO VEHICLE WEIGHT (DIM)
C    FATVWN=.2

NOTE  FATVWM-FRACT ASSEMBLY TO VEHICLE WEIGHT NORMAL (DIM)
A    FATVWM.K=TABHL(FAVWM.T,WMSCA.K/WMSCAN,0,1,1)
T    FAVWM.T=.25/1

NOTE  FATVWM-FRACT ASSEMBLY TO VEHICLE WEIGHT MULTIPLIER (DIM)

NOTE  ****************************************CONTROL STATEMENT********************************************

NOTE  C    DT=.125
N    TIME=2000
C    LENGTH=2050
C    PLTPER=1
C    PRTPER=10
PRINT  VP,VPCD,VD,REV,MV,WMV
PLOT  MV=V/VD=D
PLOT  WMV=W/VP=P,VPCD=!
PLOT  REV=R
RUN
QUIT
Appendix B. National Development Model 2

NOTE

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NOTE NATIONAL DEVELOPMENT MODEL 2 (NDM-2)

NOTE

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NOTE INDUSTRIAL SECTOR

NOTE

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L IC.K=IC.J+(DT)(CF.JK*(1+AROI*DT)-CD.JK)

N IC=ICN

NOTE IC-INDUSTRIAL CAPITAL ($)  

C ICN=19E12

NOTE ICN-INDUSTRIAL CAPITAL INITIAL ($)  

C AROI=.025

NOTE AROI-ANNUAL RATE OF INFLATION (1/YR)  

R CD.KL=IC.K/LIC

NOTE CD-CAPITAL DEPRECIATION ($/YR)  

C LIC=25

NOTE LIC-LIFETIME INDUSTRIAL CAPITAL (YR)  

R CF.KL=FGNPCF*GNP.K

NOTE CF-CAPITAL FORMATION ($/YR)  

C FGNPCF=.2

NOTE FGNPCF-FRACT GNP TO CAPITAL FORMATION (DIM)  

A GNP.K=IP.K

NOTE GNP-GROSS NATIONAL PRODUCT ($/YR)  

A IP.K=IO.K*(1-FIOI.K)

NOTE IP-INDUSTRIAL PRODUCT ($)  

A IO.K=IC.K*CUF.K/COR.K

NOTE IO-INDUSTRIAL OUTPUT ($/YR)  

A FIOI.K=FIORM+FIOIF.K

NOTE FIOI-FRACT INDUSTRIAL OUTPUT TO INPUT (DIM)  

C FIORM=.2

NOTE FIORM-FRACT INDUSTRIAL OUTPUT TO RAW MATERIALS (DIM)  

A FIOIF.K=FIOIFN*FIOIFM.K
NOTE  FIOIF-FRACT INDUSTRIAL OUTPUT TO INFRASTRUCTURE (DIM)
C  FiOIFN=.4

NOTE  FIOIFN-FRACT INDUSTRIAL OUTPUT TO INFRA NORMAL (DIM)
A  FIOIFM.K=TABX(T(FIOIFT,(ICCI.K/IFCI.K)/(ICN/IFN),0,2,.5)

NOTE  FIOIFM-FRACT INDUST OUTPUT TO INFRA MULTIPLIER (DIM)
T  FIOIFT=.675/1/1.1/1.2

NOTE  FIOIFT-FIOIFM TABLE VAULES
L  ICCI.K=ICCI.J+(DT)(CF.JK-CD.JK)
N  ICCI=ICN

NOTE  ICCI-INDUSTRIAL CAPITAL CORRECTED FOR INFLATION ($)
A  COR.K=CORN.K*CORM.K

NOTE  COR-CAPITAL OUTPUT RATIO (1/YR)
A  CORN.K=CLIP(CORNV,1,TIME.K,2000.01)

NOTE  CORN-CAPITAL OUTPUT RATIO NORMAL (1/YR)
C  CORNVC=1

NOTE  CORNVC-CORN CLIP VALUE (1/YR)
A  CORM.K=TABX(T(CORT,POLR.K/5.,2.7,2,7)

NOTE  CORM-CAPITAL OUTPUT RATIO MULTIPLIER (DIM)
T  CORT=1/1.35

NOTE  CORT-CORM TABLE VALUES
A  CUF.K=TABX(T(CUFT,(1-UNEM.K),.5,5.5,.5)

NOTE  CUFT-CAPITAL UTILIZATION FACTOR (DIM)
T  CUFT=1/1.9/8/.7/55./.4/.3/.2/.1/.1

NOTE  CUFT-CUF TABLE VALUES
A  PCI.K=GNP.K/P.K

NOTE  PCI-PER CAPITA INCOME ($)PER CAPITA-YR)
N  GNPN=ION*(1-FIORM-FIOIFN)

NOTE  GNPN-GROSS NATIONAL PRODUCT NORMAL ($)YR)
N  ION=ICN/CORN

NOTE  ION-INDUSTRIAL OUTPUT NORMAL ($)YR)
S  ICR.K=ICCI.K/ICN

NOTE  ICR-INDUSTRIAL CAPITAL RATIO (DIM)
NOTE
NOTE  ****************************************ENVIRONMENTAL SECTOR****************************************
NOTE
L \quad \text{POL.J}=\text{POL.J}+(\text{DT})(\frac{(\text{POL.G.J.K}/(1+\text{ARO}1\ast \text{DT}))-\text{POL.A.J.K}}{\text{POL.K}})
N \quad \text{POLN}=\text{POLN}
\text{NOTE} \quad \text{POLN-POLLUTION (UNITS)}
N \quad \text{POLN}=3\ast \text{CN}
\text{NOTE} \quad \text{POLN-POLLUTION INITIAL (UNITS)}
R \quad \text{POLA.KL}=\text{POLAN}\ast \text{POL.K}/\text{POLAT.K}
\text{NOTE} \quad \text{POLA-POLLUTION ABSORPTION (UNITS/yr)}
C \quad \text{POLAN}=0.5
\text{NOTE} \quad \text{POLAN-POLLUTION ABSORPTION NORMAL (DIM)}
A \quad \text{POLAT.K}=\text{POLATN}\ast \text{TABXT}(\text{POLATM},\text{POLR.K},0,10,1)
\text{NOTE} \quad \text{POLAT-POLLUTION ABSORPTION TIME (yr)}
C \quad \text{POLATN}=7.5
\text{NOTE} \quad \text{POLATN-POLLUTION ABSORPTION TIME NORMAL (yr)}
T \quad \text{POLATM}=0/1/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
\text{NOTE} \quad \text{POLATM-POLLUTION ABSORPTION TIME MULTIPLIER TABLE VALUES (DIM)}
R \quad \text{POLG.KL}=0.5\ast \text{UPG}
\text{NOTE} \quad \text{POLG-POLLUTION GENERATION (UNITS/yr)}
C \quad \text{UPG}=0.2
\text{NOTE} \quad \text{UPG-UNIT POLLUTION GENERATION (UNITS/\$-yr)}
A \quad \text{POLR.K}=\text{POL.K}/\text{POLN}
\text{NOTE} \quad \text{POLR-POLLUTION RATIO (DIM)}
\text{NOTE}
\text{NOTE} \quad \text{INFRASTRUCTURE SECTOR}\text{NOTE}
L \quad \text{IF.K}=\text{IF.J}+(\text{DT})(\text{IFI.J.K}-\text{IFD.J.K})
N \quad \text{IF}=\text{IFN}
\text{NOTE} \quad \text{IF-INFRASTRUCTURE ($)}
C \quad \text{IFN}=8E12
\text{NOTE} \quad \text{IFN-INFRASTRUCTURE INITIAL ($)}
R \quad \text{IFD.KL}=\text{IF.K}/\text{IF}
\text{NOTE} \quad \text{IFD-INFRASTRUCTURE DEPRECIATION ($/yr)}
C \quad \text{IF}=50
\text{NOTE} \quad \text{IF-INFRASTRUCTURE LIFETIME INFRASTRUCTURE (yr)}
R \quad \text{IFI.KL}=\text{GNP.K}/\text{FIGNP}
\text{NOTE} \quad \text{IFI-INFRASTRUCTURE INVESTMENT ($/yr)}
C  FGNPIF=.06
NOTE  FGNPIF-FRACT GNP TO INFRASTRUCTURE (DIM)
S  IFPCR.K=((IFCI,K/P,K)/(IFN/PN))
NOTE  IFPCR-INFRA CAPITAL PER CAPITA RATIO (DIM)
L  IFCI,K=IFCI.J+(DT)((IFI.K/(1+ARO1*DT))-IFD.JK)
N  IFCI=IFN
NOTE  IFCI-INFRASTRUCTURE CORRECTED FOR INFLATION ($)
S  IFR.K=IFCI.K/IFN
NOTE  IFR-INFRASTRUCTURE RATIO (DIM)
NOTE
NOTE  *****************************************SOCIAL DEVELOPMENT SECTOR*****************************************
NOTE
L  SDC.K=SDC.J+(DT)(SCI.JK-SCD.JK)
N  SDC=SDCN
NOTE  SDC-SOCIAL DEVELOPMENT CAPITAL ($)  
C  SDCN=6E12
NOTE  SDCN-SOCIAL DEVELOPMENT CAPITAL INITIAL ($)
R  SCD.KL=SCD.K/LSDC
NOTE  SCD-SOCIAL CAPITAL DEPRECIATION ($/YR)
C  LSDC=50
NOTE  LSDC-LIFETIME SOCIAL DEVELOPMENT CAPITAL (YR)
R  SCI.KL=GNP,K*FGNPSD
NOTE  SCI-SOCIAL CAPITAL INVESTMENT ($/YR)
C  FGNSDM=0.055
NOTE  FGNSDM-FRACT GNP TO SOCIAL DEVELOPMENT (DIM)
A  SDCPCR.K=((SDCC1.K/P.K)/(SDCN/PN))
NOTE  SDCPCR-SOCIAL DEVELOPMENT CAPITAL PER CAPITA RATIO (DIM)
L  SDCC1.K=SDCC1.J+(DT)((SCI.K/(1+ARO1*DT))-SCD.JK)
N  SDCC1=SDCN
NOTE  SDCC1-SOCIAL DEVELOPMENT CAPITAL CORRECTED FOR INFLATION ($)
S  SDCR.K=SDCC1.K/SDCN
NOTE  SDCR-SOCIAL DEVELOPMENT CAPITAL RATIO (DIM)
NOTE
NOTE  ******************************************DEMOGRAPHIC SECTOR**************************************************
L CP.K = MIN(CP.J+(DT)(CBR.JK-CDR.JK+RR.JK),PCA/LPP)
N CP = CPN
NOTE CP-CORRIDOR POPULATION (PERSONS)
C CPN = 0
NOTE CPN-CORRIDOR POPULATION INITIAL (PERSONS)
R CBR.KL = CP.K*F.K
NOTE CBR-CORRIDOR BIRTH RATE (PERSONS/YR)
A F.K = FN*FM.K
NOTE F-FERTILITY (1/YR)
C FN = .026
NOTE FN-FERTILITY NORMAL (1/YR)
A FM.K = PN/P.K
NOTE FM-FERTILITY MULTIPLIER (DIM)
N PN = NCPN + CPN
NOTE PN-POPULATION INITIAL (PERSONS)
A P.K = NCP.K+CP.K
NOTE P-POPULATION (PERSONS)
R CDR.KL = CP.K*M
NOTE CDR-CORRIDOR DEATH RATE (PERSONS/YR)
C M = .013
NOTE M-MORTALITY (1/YR)
R RR.KL = NCP.K*RF.K*R.M.K
NOTE RR-RELOCATION RATE (PERSONS/YR)
A RF.K = TABHL(RFT.TIME.K,2000,2100,25)
NOTE RF-RELOCATION FRACTION (1/YR)
T RFT = .01/.06/.04/.02/.005
NOTE RFT-RF TABLE VALUES
A RM.K = CLIP(0,1-LFO.K,CP.K/PCA,1/LPP)
NOTE RM-RELOCATION MULTIPLIER (DIM)
A LFO.K = CLIP(1,CP.K*LPP/CA.K,CP.K/CA.K,1/LPP)
NOTE LFO-LAND FRACTION OCCUPIED (DIM)
C LPP = .0008
NOTE LPP-LAND PER PERSON (SQ MI/PERSON)
L NCP.K = NCP.J+(DT)(NCBR.JK-NCDR.JK-RR.JK)
N NCP = NCPN
NOTE NCP-NON CORRIDOR POPULATION (PERSONS)
C NCPN=270E6
NOTE NCPN-NON CORRIDOR POPULATION INITIAL (PERSONS)
R NCBR.KL=NCP.K*F.K
NOTE NCBR-NON CORRIDOR BIRTH RATE (PERSONS/YR)
R NCDR.KL=NCP.K*M
NOTE NCDR-NON CORRIDOR DEATH RATE (PERSONS/YR)
L CA.K=CA.J+(DT)(CDV.JK)
N CA=CAN
NOTE CA-CORRIDOR AREA (SQ MI)
C CAN=1000
NOTE CAN-CORRIDOR AREA INITIAL (SQ MI)
R CDV.KL=CDB/CDC.K
NOTE CDV-CORRIDOR DEVELOPMENT (SQ MI/YR)
C CDB=10E9
NOTE CDB-CORRIDOR DEVELOPMENT BUDGET ($/YR)
A CDC.K=CLIP((CN/(1-FCD.K)**.05),10E15,(1-FCD.K),.01)
NOTE CDC-CORRIDOR DEVELOPMENT COSTS ($/SQ MI)
C CN=10E6
NOTE CN-CORRIDOR DEVELOP COSTS NORMAL ($/SQ MI)
A FCD.K=CA.K/PCA
NOTE FCD-FRACTION CORRIDOR DEVELOPMENT (DIM)
C PCA=100000
NOTE PCA-PROJECTED CORRIDOR AREA (SQ MI)
NOTE
NOTE ****************************************EMPLOYMENT SECTOR****************************************
NOTE
A JII.K=ICCI.K/ICLR.K
NOTE JII-JOBS IN INDUSTRY (PERSONS)
A ICLR.K=ICLRN*ICLRM.K
NOTE ICLR-INDUS CAPITAL LABOR RATIO ($/PERSON)
C ICLRN=19.03E4
NOTE ICLRN-INDUS CAPITAL LABOR RATIO NORMAL ($/PERSON)
A ICLRM.K=TA8XT(ICLRT,ICCI.K/ICN,1,8,1)
NOTE ICLRM-INDUS CAPITAL LABOR RATIO MULTIPLIER (DIM)
T ICLR=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
NOTE ICLR-ICLRM TABLE VALUES
A JIF.K=IFCI.K/IFCLR.K
NOTE JIF-JOBS IN INFRASTRUCTURE (PERSONS)
A IFCLR.K=IFCLR+IFCLR.M.K
NOTE IFCLR-INFRASTRUCTURE CAPITAL LABOR RATIO ($/PERSON)
C IFCLRN=88.6E4
NOTE IFCLRN-INFRASTRUCTURE CAPITAL LABOR RATIO NORMAL ($/PERSON)
A IFCLR.M.K=TBXT(IFCLR,IFCI.K/IFN,1,8,1)
NOTE IFCI.RM-INFRA CAPITAL LABOR RATIO MULTIPLIER (DIM)
T IFCLR=1/1.58/2.16/2.74/3.32/3.90/4.48/5.06
NOTE IFCLR-IFCLR.M TABLE VALUES
A JISD.K=SDCCI.K/SDCLR.K
NOTE JISD-JOBS IN SOCIAL DEVELOPMENT (PERSONS)
A SDCLR.K=SDCLRN*SDCLR.M.K
NOTE SDCLR-SOCIAL DEVELOP CAPITAL LABOR RATIO ($/PERSON)
C SDCLRN=33.2E4
NOTE SDCLRN-SOCIAL DEVELOP CAPITAL LABOR RATIO NORMAL ($/PERSON)
A SDCLR.M.K=TBXT(SDCRT,SDCCI.K/SDCN,1,8,1)
NOTE SDCLR.M-SOCIAL DEVELOP CAPITAL LABOR RATIO MULTIPLIER (DIM)
T SDCLRT=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
NOTE SDCLRT-SDCLR.M TABLE VALUES
A LF.K=P.K*LPF.K
NOTE LF-LABOR FORCE (PERSONS)
A LPF.K=LPFN*LPFM.K
NOTE LPF-LABOR PARTICIPATION FACTOR (DIM)
A LPFM.K=TBXT(LPFMT,TIME.K,2000,2050,10)
NOTE LPFM-LABOR PARTICIPATION FACTOR MULT (DIM)
T LPFMT=1/1.018/1.027/1.034/1.043/1.046
NOTE LPFM-LPFM TABLE VALUES
C LPFN=.5
NOTE LPFN-LABOR PARTICIPATION FACTOR NORMAL (DIM)
A WE.K=IP.K*JOBS.K
NOTE WE-WORKER EARNINGS ($/WORKER-YR)
A JOBS.K=JI.K+JIF.K+JISD.K
NOTE JOBS-JOBS (PERSONS)
A UNEM.K=(L.F.K-JOBS.K)/L.F.K
NOTE UNEM-UNEMPLOYMENT (DIM)
NOTE
NOTE ****************************************CONTROL STATEMENT****************************************
NOTE
C DT=.25
N TIME=2000
C LENGTH=2050
C PLTPER=1
C PRTPER=10
PRINT P,CP,NCP
PRINT GNP,PCI,WE,UNEM
PRINT FCD,IC,IF,SDC
PRINT ICR,IFR,SDCR
PRINT JOB,S,JII,JII,F,JSD
PRINT POLR,FCPCR,SDPCR
PRINT FIO,IP
NOTE BASELINE ____________________________________________________+
RUN B
C FGNPCF=.195
C FGNPIF=.055
C FGNPSD=.055
NOTE SOCIAL DEVELOPMENT POLICY ____________________________________+
NOTE RUN S
C FGNPCF=.215
C FGNPIF=.055
C FGNPSD=.045
NOTE INDUSTRIAL DEVELOPMENT POLICY ------------------------------------+
NOTE RUN I
C FGNPCF=.19
C FGNPIF=.075
C FGNPSD=.05
NOTE INFRASTRUCTURE DEVELOPMENT POLICY ----------------------------------+
RUN F
C   UPGL=.16
C   CORNCV=1.05
NOTE   ENVIRONMENTAL PROTECTION POLICY
NOTE   RUN E
QUIT
Appendix C. National Development Model

NOTE                          National Development Model (NDM)

NOTE                          Industrial Sector

NOTE                          FOR A = MINING, MANUFA, CONSTR, SERVIC, AGRICL, MAGLEV

FOR-COMPUTE EQUATIONS SUBSCRIPTED A

L IC.K(A)=IC.J(A)+(DT)(CF.JK(A)*(1+AR0I*DT)-CD.JK(A))

N IC(A)=ICN(A)

NOTE IC - INDUSTRIAL CAPITAL ($)

T ICN(*)=.23E12/5.61E12/.9E12/11E12/.56E12/.7E12

NOTE ICN - INDUSTRIAL CAPITAL INITIAL ($)

C AR0I=.025

NOTE AR0I - ANNUAL RATE OF INFLATION (1/YR)

A TIC.K=SUM(IC.K)

NOTE TIC - TOTAL INDUSTRIAL CAPITAL ($)

A TICN.K=SUM(ICN)

NOTE TICN - TOTAL INDUSTRIAL CAPITAL INITIAL ($)

R CD.KL(A)=IC.K(A)/LIC(A)

NOTE CD - CAPITAL DEPRECIATION ($/YR)

T LIC(*)=25/25/25/25/25

NOTE LIC - LIFETIME INDUSTRIAL CAPITAL (YR)

R CF.KL(A)=FGNPCF(A)*GNP.K

NOTE CF - CAPITAL FORMATION ($/YR)


NOTE FGNPCF - FRACT GNP TO CAPITAL FORMATION (DIM)

A GNP.K=SUM(IP.K)

NOTE GNP - GROSS NATIONAL PRODUCT ($/YR)

A IP.K(A)=IQ.K(A)*(1-FIOLK(A))

NOTE IP - INDUSTRIAL PRODUCT ($)

A IQ.K(A)=IC.K(A)*CUF.K(A)/COR.K(A)
NOTE  IO-INDUSTRIAL OUTPUT ($/YR)
A  FIOI.K(A)=FIOIRM(A)+FIOIF.K(A)

NOTE  FIOI-FRACT INDUSTRIAL OUTPUT TO INPUT (DIM)
T  FIOIRM(\*)=.2/.2/.2/.2/.2/.2

NOTE  FIOIRM-FRACT INDUSTRIAL OUTPUT TO RAW MATERIALS (DIM)
A  FIOIF.K(A)=FIOIFN(A)*FIOIFM.K(A)

NOTE  FIOIFN-FRACT INDUSTRIAL OUTPUT TO INFRA NORMAL (DIM)
A  FIOIFM.K(A)=TABXT(FIOIFT,(TICC.K/TIFCI.K)/(TICN.K/TIFN.K),0,2,5)

NOTE  FIOIFM-FRACT INDUST OUTPUT TO INFRA MULTIPLIER (DIM)
T  FIOIFT=.5/.75/1.1/1.1/1.2

NOTE  FIOIFT-FIOIFM TABLE VAULES
A  TICC.K=SUM(TICCI.K)

NOTE  TICCI-TOTAL INDUST CAPITAL CORRECTED FOR INFLATION ($)
L  ICCI.K(A)=ICCJ.K(A)+(DT)(CFJK(A)-CDJK(A))
N  ICCJ(A)=I2CN(A)

NOTE  ICCJ-INDUSTRIAL CAPITAL CORRECTED FOR INFLATION ($)
A  COR.K(A)=CORN.K(A)*CORM.K(A)

NOTE  COR-CAPITAL OUTPUT RATIO (1/YR)
A  CORN.K(A)=CLIP(CORNCV.K(A),1,TIME.K,2000.01)

NOTE  CORN-CAPITAL OUTPUT RATIO NORMAL (1/YR)
T  CORNCV(\*)=1/1/1/1/1/1

NOTE  CORNCV-CORN CLIP VALUE (1/YR)
A  CORM.K(A)=TABXT(CORT(\*,A),POLR.K/5.,2,7.2,7)

NOTE  CORT-CAPITAL OUTPUT RATIO MULTIPLIER (DIM)
T  CORT(\*,MINING)=1/1.35
T  CORT(\*,MANUFA)=1/1.35
T  CORT(\*,CONSTR)=1/1.35
T  CORT(\*,SERVIC)=1/1.35
T  CORT(\*,AGRICL)=1/1.35
T  CORT(\*,MAGLEV)=1/1.35

NOTE  CORT-CORM TABLE VAULES
A  CUF.K(A)=TABXT(CUFT(\*,A),(1-UNEM.K),5,5.5,5)

NOTE  CUF-CAPITAL UTILIZATION FACTOR (DIM)
CUFT('*,MINING)=1/1.9/8.7/55/4.3/2/1.1
CUFT('*,MANUFA)=1/1.9/8.7/55/4.3/2/1.1
CUFT('*,CONSTR)=1/1.9/8.7/55/4.3/2/1.1
CUFT('*,SERVIC)=1/1.9/8.7/55/4.3/2/1.1
CUFT('*,AGRICL)=1/1.9/8.7/55/4.3/2/1.1
CUFT('*,MAGLEV)=1/1.9/8.7/55/4.3/2/1.1

NOTE CUFT-CUF TABLE VALUES
A PCI.K=GNP.K/P.K
NOTE PCI-PER CAPITA INCOME ($)PER PERSON-YR
S TICR.K=TICCI.K/TICN.K
NOTE TICR-TOTAL INDUSTRIAL CAPITAL RATIO (DIM)
NOTE
NOTE *************************************************ENVIRONMENTAL SECTOR**************************************
NOTE
L POL.K(A)=POL.J(A)+(DT)((POLG.JK(A)/(1+ARQ.DT))-POLA.JK(A))
N POL(A)=POLN(A)
NOTE POL-POLLUTION (UNITS)
N POLN(A)=3*ICN(A)
NOTE POLN-POLLUTION INITIAL (UNITS)
R POLA.KL(A)=POLAN(A)*POL.K(A)/POLAT.K(A)
NOTE POLA-POLLUTION ABSORPTION (UNITS/YR)
T POLAN(*)=.5/5.5/5/5.5
NOTE POLAN-POLLUTION ABSORPTION NORMAL (DIM)
A POLAT.K(A)=POLATN(A)*TABXT(POLATM(,,A),POLR.K,0,10,1)
NOTE POLAT-POLLUTION ABSORPTION TIME (YR)
T POLATN(*)=7.5/7.5/7.5/7.5/7.5/7.5
NOTE POLATN-POLLUTION ABSORPTION TIME NORMAL (YR)
T POLATM('*,MINING)=0/1.06/1.09/1.10/1.12/1.13/1.14/1.15/1.16
T POLATM('*,MANUFA)=0/1.06/1.09/1.10/1.12/1.13/1.14/1.15/1.16
T POLATM('*,CONSTR)=0/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM('*,SERVIC)=0/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM('*,AGRICL)=0/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
T POLATM('*,MAGLEV)=0/1.06/1.09/1.10/1.11/1.12/1.13/1.14/1.15/1.16
NOTE POLATM-POLLUTION ABSORPTION TIME MULTIPLIER TABLE VALUES (DIM)
R POLG.KL(A)=IO.K(A)*UPG(A)
NOTE POLG-POLLUTION GENERATION (UNITS/yr)
T UPG(*)=2.1/2.2/2.2/2.2/2.
NOTE UPG-UNIT POLLUTION GENERATION (UNITS/$-yr)
A POLR.K=SUM(POL.K)/SUM(POLN)
NOTE POLR-POLLUTION RATIO (DIM)
NOTE
NOTE **************************************************************************INFRASTRUCTURE SECTOR**************************************************************************
NOTE
NOTE FOR B=1,8=HIWAY,RAIL,PORTS,AIRPRT,POWER,WATER,TELCOM,SEWER
NOTE FOR-COMPUTE EQUATIONS SUBSCRIPTED B
L IF.K(B)=IF.J(B)+(DT)/(IF.I.K(B)-IF.D.JK(B))
N IF(B)=IFN(B)
NOTE IF-INFRASTRUCTURE ($)
T IFN(*)=2.4E12/.16E12/.16E12/.4E12/1.2E12/.96E12/1.12E12/.12E12/1.6E12
NOTE IFN-INFRASTRUCTURE INITIAL ($)
A TIF.K=SUM(IF.K)
NOTE TIF-TOTAL INFRASTRUCTURE ($)
A TIFN.K=SUM(IFN)
NOTE TIFN-TOTAL INFRASTRUCTURE INITIAL ($)
R IFD.KL(B)=IF.K(B)/LIF(B)
NOTE IFD-INFRASTRUCTURE DEPRECIATION ($/yr)
T LIF(*)=50/50/50/50/50/50/50/50
NOTE LIF-LIFETIME INFRASTRUCTURE (yr)
R IFI.KL(B)=GNP.K*FGNPIF(B)
NOTE IFI-INFRASTRUCTURE INVESTMENT ($/yr)
NOTE FGNPIF-FRACT GNP TO INFRASTRUCTURE (DIM)
S IFCPKR.K=(TIFCI.K/P.K)/(TIFN.K/PN)
NOTE IFCPKR-INFRA CAPITAL PER CAPITA RATIO (DIM)
L IFCI.K(B)=IFCI.J(B)+(DT)/((IFI.JK(B)/(1+ARO*DT))-IFD.JK(B))
N IFCI(B)=IFN(B)
NOTE IFCI-INFRASTRUCTURE CORRECTED FOR INFLATION ($)
A TIFCI.K=SUM(IFCI.K)
NOTE TIFCI-TOTAL INFRASTRUCTURE CORRECTED FOR INFLATION ($)
S TIFR.K=TIFCI.K/TIFN.K
NOTE  TIFR-TOTAL INFRASTRUCTURE RATIO (DIM)
NOTE  **********************************SOCIAL DEVELOPMENT SECTOR**************************
NOTE
FOR  C=1,4=HEALTH,EDUCAT,HOUSE,WELFRE
NOTE FOR-COMPUTE EQUATIONS SUBSCRIPTED C
L  SDC.K(C)=SCD.J(C)+(DT)(SCI.JK(C)-SCD.JK(C))
N  SDC(C)=SDCN(C)
NOTE  SDC-SOCIAL DEVELOPMENT CAPITAL ($)
T  SDCN(*)=1.4E12/2.9E12/3E12/1.4E12
NOTE SDCN-SOCIAL DEVELOPMENT CAPITAL INITIAL ($)
A  TSDC.K=SUM(SDC.K)
NOTE  TSDC-TOTAL SOCIAL DEVELOPMENT CAPITAL ($)
A  TSDCN.K=SUM(SDCN)
NOTE TSDCN-TOTAL SOCIAL DEVELOPMENT CAPITAL INITIAL ($)
R  SCD.KL(C)=SDC.K(C)/LSDC(C)
NOTE  SCD-SOCIAL CAPITAL DEPRECIATION ($/YR)
T  LSDC(*)=50/50/50/50
NOTE  LSDC-LIFETIME SOCIAL DEVELOPMENT CAPITAL (YR)
R  SCI.KL(C)=GNP.K*FGNPSD(C)
NOTE  SCI-SOCIAL CAPITAL INVESTMENT ($/YR)
T  FGNPSD(*)=.013/.026/.003/.013
NOTE  FGNPSD-FRACT GNP TO SOCIAL DEVELOPMENT (DIM)
S  SDCPCR.K=(TSDCCI.K/P.K)/(TSDCN.K/PN)
NOTE  SDCPCR-SOCIAL DEVELOPMENT CAPITAL PER CAPITA RATIO (DIM)
L  SDCCI.K(C)=SDCCI.J(C)+(DT)((SCI.JK(C)/(1+ARO*DT))-SCD.JK(C))
N  SDCCI(C)=SDCN(C)
NOTE  SDCCI-SOCIAL DEVELOP CAPITAL CORRECTED FOR INFLATION ($)
A  TSDCCI.K=SUM(SDCCI.K)
NOTE TSDCCI-TOTAL SOCIAL DEVELOP CAPITAL CORRECTED FOR INFLATION ($)
S  TSDCR.K=TSDCCI.K/TSDCN.K
NOTE  TSDCR-TOTAL SOCIAL DEVELOP CAPITAL RATIO (DIM)
NOTE  ****************************************DEMOGRAPHIC SECTOR*****************************************
NOTE

Appendix C. National Development Model
L CP.K=MIN(CP.J+(DT)(CBR.JK-CDR.JK+RR.JK),PCA/LPP)
N CP=CPN
NOTE CP-CORRIDOR POPULATION (PERSONS)
C CPN=0
NOTE CPN-CORRIDOR POPULATION INITIAL (PERSONS)
R CBR.KL=CP.K*F.K
NOTE CBR-CORRIDOR BIRTH RATE (PERSONS/YR)
A F.K=FN*FM.K
NOTE F-FERTILITY (1/YR)
C FN=.026
NOTE FN-FERTILITY NORMAL (1/YR)
A FM.K=PN/P.K
NOTE FM-FERTILITY MULTIPLIER (DIM)
N PN=CPN+NCPN
NOTE PN-POPULATION INITIAL (PERSONS)
A P.K=CP.K+NCP.K
NOTE P-POPULATION (PERSONS)
R CDR.KL=CP.K*M
NOTE CDR-CORRIDOR DEATH RATE (PERSONS/YR)
C M=.013
NOTE M-MORTALITY (1/YR)
R RR.KL=NCP.K*RF.K*RM.K
NOTE RR-RELOCATION RATE (PERSONS/YR)
A RF.K=TABHL(RFT,TIME.K,2000,2100,25)
NOTE RF-RELOCATION FRACTION (1/YR)
T RFT=.01/.06/.04/.02/.005
NOTE RFT-RF TABLE VALUES
A RM.K=CLIP(0,1-LFO.K,CP.K/PCA,1/LPP)
NOTE RM-RELOCATION MULTIPLIER (DIM)
A LFC.K=CLIP(1,CP.K*LPP/CA.K,CP.K/CA.K,1/LPP)
NOTE LFO-LAND FRACTION OCCUPIED (DIM)
C LPP=.0008
NOTE LPP-LAND PER PERSON (SQ MI/PERSON)
L NCP.K=NCB.KJ+(DT)(NCBR.JK-NCDR.JK-RR.JK)
N NCP=NCPN
NOTE NCP-NON CORRIDOR POPULATION (PERSONS)
C NCPN=270E6
NOTE NCPN-NON CORRIDOR POPULATION INITIAL (PERSONS)
R NCBR.KL=NCP.K*F.K
NOTE NCBR-NON CORRIDOR BIRTH RATE (PERSONS/YR)
R NCDR.KL=NCP.K*M
NOTE NCDR-NON CORRIDOR DEATH RATE (PERSONS/YR)
L CA.K=CA.J+(DT)(CDV.JK)
N CA=CAN
NOTE CA-CORRIDOR AREA (SQ MI)
C CAN=1000
NOTE CAN-CORRIDOR AREA INITIAL (SQ MI)
R CDV.KL=CDV/CDC.K
NOTE CDV-CORRIDOR DEVELOPMENT (SQ MI/YR)
C CDB=10E9
NOTE CDB-CORRIDOR DEVELOPMENT BUDGET ($/YR)
A CDC.K=CLIP((CN/(1-FCD.K)**.05),10E15,(1-FCD.K),.01)
NOTE CDC-CORRIDOR DEVELOPMENT COSTS ($/SQ MI)
C CN=10E6
NOTE CN-CORRIDOR DEVELOP COSTS NORMAL ($/SQ MI)
A FCD.K=CA.K/PCA
NOTE FCD-FRACTION CORRIDOR DEVELOPMENT (DIM)
C PCA=100000
NOTE PCA-PROJECTED CORRIDOR AREA (SQ MI)
NOTE
NOTE **************************************************EMPLOYMENT SECTOR**************************************************
NOTE
A JII.K(A)=ICCI.K(A)/ICLR.K(A)
NOTE JII-JOBS IN INDUSTRY (PERSONS)
A ICLR.K(A)=ICLRN(A)*ICLRM.K(A)
NOTE ICLR-INDUS CAPITAL LABOR RATIO ($/PERSON)
T ICLRN(*)=19.03E4/19.03E4/19.03E4/19.03E4/19.03E4/19.03E4
NOTE ICLRN-INDUS CAPITAL LABOR RATIO NORMAL ($/PERSON)
A ICLR.M.K(A)=TABXT(ICLRT(*,A),ICCI.K(A)/ICN(A),1,8,1)
NOTE ICLR.M-INDUS CAPITAL LABOR RATIO MULTIPLIER (DIM)
T ICLR(*,1)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T ICLR(*,2)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T ICLR(*,3)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T ICLR(*,4)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T ICLR(*,5)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07
T ICLR(*,6)=1/1.63/2.24/2.82/3.39/3.95/4.51/5.07

NOTE ICLR=ICLRM TABLE VALUES
A JIF.J(K)=IFCI.K(B)/IFCLR.K(B)

NOTE JIF-JOBS IN INFRASTRUCTURE (PERSONS)
A IFCLR.K(B)=IFCLRN(B)*IFCLRM.K(B)

NOTE IFCLR-INFRASTRUCTURE CAPITAL LABOR RATIO ($/PERSON)
T IFCLRN(*)=88.6E4/88.6E4/88.6E4/88.6E4/88.6E4/88.6E4/88.6E4

NOTE IFCLRM-INFRA CAPITAL LABOR RATIO NORMAL ($/PERSON)
A IFCLRM.K(B)=TABXT(IFCLR(*,B),IFCI.K(B)/IFN(B),1,8,1)

NOTE IFCLRM-INFRA CAPITAL LABOR RATIO MULTIPLIER (DIM)
T IFCLR(*,1)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,2)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,3)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,4)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,5)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,6)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,7)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06
T IFCLR(*,8)=1/1.58/2.15/2.74/3.32/3.90/4.48/5.06

NOTE IIF=IFCLRT-IFCLRM TABLE VALUES
A JSD.K(C)=SDCCI.K(C)/SDCLR.K(C)

NOTE JSD-JOBS IN SOCIAL DEVELOPMENT (PERSONS)
A SDCLR.K(C)=SDCLRN(C)*SDCLRM.K(C)

NOTE SDCLR-SOCIAL DEVELOP CAPITAL LABOR RATIO ($/PERSON)
T SDCLRN(*)=33.2E4/33.2E4/33.2E4/33.2E4

NOTE SDCLRM-SOCIAL DEVELOP CAPITAL LABOR RATIO NORMAL ($/PERSON)
A SDCLRM.K(C)=TABXT(SDCLRT(*,C),SDCCI.K(C)/SDCN(C),1,8,1)

NOTE SDCLR=SDCLRM-SOCIAL DEVELOP CAPITAL LABOR RATIO MULTIPLIER (DIM)
T SDCLRT(*,1)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T SDCLRT(*,2)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T SDCLRT(*,3)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13
T SDCLRT(*,.4)=1/1.62/2.23/2.83/3.42/4.00/4.57/5.13

NOTE SDCLRT-SDCLRM TABLE VALUES
A LF.K=P.K*LPF.K

NOTE LF-LABOR FORCE (PERSONS)
A LPF.K=LPFN*LPFM.K

NOTE LPF-LABOR PARTICIPATION FACTOR (DIM)
A LPFM.K=TABXT(LPFMT,TIME.K,2000,2050,10)

NOTE LPFM-LABOR PARTICIPATION FACTOR MULT (DIM)
T LPFM.T=1/1.018/1.027/1.034/1.043/1.048

NOTE LPFM-LPFM TABLE VALUES
C LPFN=.5

NOTE LPFN-LABOR PARTICIPATION FACTOR NORMAL (DIM)
S WE.K=SUM(IP.K)/JOBS.K

NOTE WE-WORKER EARNINGS ($/WORKER-YR)
A JOBS.K=TJII.K+TJIIF.K+TJISD.K

NOTE JOBS-JOBS (PERSONS)
A TJII.K=SUM(JII.K)

NOTE TJII-TOTAL JOBS IN INDUSTRY (PERSONS)
A TJIIF.K=SUM(JIIF.K)

NOTE TJIIIF-TOTAL JOBS IN INFRASTRUCTURE (PERSONS)
A TJISD.K=SUM(JISD.K)

NOTE TJISD-TOTAL JOBS IN SOCIAL DEVELOPMENT (PERSONS)
A UNEM.K=(LF.K-JOBS.K)/LF.K

NOTE UNEM-UNEMPLOYMENT (DIM)

NOTE

NOTE ******************************************CONTROL STATEMENT***********************************

NOTE
C DT=.25
N TIME=2000
C LENGTH=2050
C PLTPER=1
C PRTPER=10
PRINT P,CP,NCP
PRINT GNP,PCI,WE,UNEM
PRINT FCD,TIC,TIF,TSDC
PRINT TICR, TIFR, TSDCR, LF
PRINT JOBS, TJII, TJIF, TJISD
PRINT POLR, IFCPCR, SOCPAR
PRINT FIOI(*)
PRINT COR(*)
PRINT JISD(*)
PRINT JIII(*)
PRINT JJIF(*)
PRINT IP(*)

PLOT P=P, CP=C, LF=L
SAVE GNP, PCL, WE, UNEM, FCO
SAVE TIC, TIF, TSDC, TICR, TIFR, TSDCR
SAVE LF, JOBS, TJII, TJIF, TJISD, POLR, IFCPCR, SOCPAR

A CMPPER.K=STEP(CMPR, LONG)
C CMPR=0
N SAVPER=LONG

SPEC LONG=1
NOTE BASELINE

RUN B
T FGNPCF(*)=.0020475/.0517725/.010725/.11544/.00429/.010725
T FGNPSD(*)=.015362/.030731/.003545/.015362
NOTE SOCIAL DEVELOPMENT POLICY

RUN S
T FGNPCF(*)=.0022575/.0570825/.011825/.12728/.00473/.011825
T FGNPSD(*)=.01063/.02129/.00245/.01063
NOTE INDUSTRIAL DEVELOPMENT POLICY

RUN I
T FGNPCF(*)=.001995/.050445/.01045/.11248/.00418/.01045
T FGNPSD(*)=.0118/.0236/.0028/.0118
NOTE INFRASTRUCTURE DEVELOPMENT POLICY

RUN F
T UPG(*)=.17/.18/.16/.16/.16/.17
T CORNCV(*)=1.05/1.05/1.05/1.05/1.05/1.05
NOTE ENVIRONMENTAL PROTECTION POLICY

C PLOT GNP.B=B,GNP.S=S,GNP.I=I,GNP.F=F,GNP.E=E
C PLOT PCI.B=B,PCI.S=S,PCI.I=I,PCI.F=F,PCI.E=E
C PLOT JOBS.B=B,JOBS.S=S,JOBS.I=I,JOBS.F=F,JOBS.E=E
C PLOT TJI.B=B,TJI.S=S,TJI.I=I,TJI.F=F,TJI.E=E
C PLOT TJIIF.B=B,TJIIF.S=S,TJIIF.I=I,TJIIF.F=F,TJIIF.E=E
C PLOT TJISD.B=B,TJISD.S=S,TJISD.I=I,TJISD.F=F,TJISD.E=E
C PLOT POLR.B=B,POLR.S=S,POLR.I=I,POLR.F=F,POLR.E=E
C PLOT IFCPCR.B=B,IFCPCR.S=S,IFCPCR.I=I,IFCPCR.F=F,IFCPCR.E=E
C PLOT SDCPCR.B=B,SDCPCR.S=S,SDCPCR.I=I,SDCPCR.F=F,SDCPCR.E=E
RUN E
QUIT
Vita

Sang Hyup Lee was born in Pusan, Korea on October 17, 1958. After graduating from Dong-A High School in February of 1977, he attended Seoul National University (in Seoul, Korea), where he received a Bachelor of Science degree in Mechanical Design and Production Engineering in February of 1982. After finishing his military service, he undertook graduate studies at Virginia Polytechnic Institute and State University. He was awarded a Master of Science degree in Engineering Science and Mechanics at Virginia Polytechnic Institute and State University in May of 1989. He completed his Ph.D. degree in Civil Engineering at Virginia Polytechnic Institute and State University in September of 1994.

Sang Hyup Lee