CHAPTER 3

TRANSPORTATION FOR SUSTAINABLE DEVELOPMENT

3.1 Introduction

System engineering methodologies have been created to develop and implement large multifaceted systems like ITS. These methodologies are commonly used in defense and aerospace programs and in technology-based systems, such as computers and communications. The initial step common to the initiation of major new systems is the development of a system architecture. A system architecture is the framework that describes how the system components interact and work together to achieve total system goals. It describes the operation of the system, what each component of the system does and what information is exchanged among the components.

Important to the development of any new technology is the creation of a system-wide architecture. And the need for such an architecture is no different for the creation of an Automated Highway System. Presently, there is no such system architecture for the AHS, but the NAHSC has mandated by December 2001 that a prototype AHS should be demonstrated. Through this process an appropriate architecture will hopefully be developed.

The advantage of quickly developing an architecture can be seen in the success of many electronic products, including the cellular phone and the personal computer. Defining a system's architecture early on allows for many different companies to develop competing yet compatible products used in the system. This helps the establishment of a new system or technology by lowering prices quicker and promoting further development. This is essential for an AHS to work since consumers will be required to either purchase additional equipment for existing vehicles or radically changed hybrid vehicles that would be much more expensive than existing vehicles.

A thoughtfully designed architecture will ensure that the deployment of user services occurs within the most sensible system framework. It will also ensure that a nationally compatible system linking all modes of transportation emerges, instead of local or regional pockets that will not accommodate intercity travel or cross-country goods movements. The establishment of a national AHS/Maglev architecture will not only ensure national compatibility but also be beneficial to individual stakeholders. An architecture will allow stakeholders to adopt elements of the system in the manner and timeframe for their choosing and will serve as the foundation for standards that can reduce duplication of effort by the stakeholders, speed the introduction of products and services, and reduce the risk for the private sector developing these products and services, as well as the public sector who may be deploying the various systems.

Potential AHS alternatives can be classified according to system structural, system operational, and vehicle subsystem technological elements. The structural aspects are concerned with the decision making capability allocated between a vehicle and the guideway, the characteristics of the control and sensing equipment contained within the guideway, the traveling unit configuration, and certain of the vehicle's structural and equipment considerations. The operational aspects 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 the chassis subsystem, the power/propulsion subsystem and the vehicle longitudinal and lateral control subsystem.

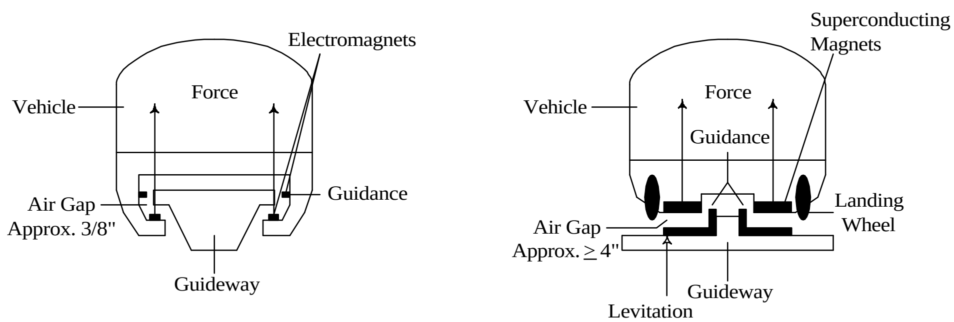
3.2 Magnetic Levitation Systems

To achieve high speeds and be suspended over a magnetic levitation track, the power source equipped onto the maglev vehicles needs to be lightweight. Conventional power generators cannot produce enough propulsion and lift force to efficiently operate the system. The technology of magnetically levitated vehicle is made possible through the use of superconducting magnets.

When cooled down below a specific temperature, certain metals or alloys reach state of zero electrical resistance or superconductivity. The superconductive materials will allow electric currents to flow through without loss, thus enabling large currents to be carried in relatively small conductors. The amount of current carried can generate dozens of time stronger magnetic fields than that of permanent magnets. Superconductivity technology has proved that it can sufficiently provide the required properties, i.e. magnetic fields, excitation, current densities, and coil dimensions, to fit within desirable sizes of maglev vehicles and guideways. Furthermore, since the system is achieved through electromagnetic induction, it consumes no electricity or power supplies other than the small amount needed to refrigerate the system to the desired temperature.

There are several types of total and partial magnetic levitation systems. The two most favorable types that are currently applied to magnetic levitation transportation are (1) the feedback-controlled electromagnetic levitation (EML), and (2) superconductor-based electrodynamic levitation (EDL). An important advantage of the electrodynamic system is that the vehicles can be lightweight, streamlined construction similar to aircraft. Magnetically supported over virtually their entire length and carrying only relatively lightweight cryogenic magnets for both suspension and propulsion purposes, they do not require the massive track infrastructure essential in present-day railway systems. Taking personal maglev vehicle operating characteristics into account, one can determine that the EDL type is more compatible to essential merging and lane changing maneuvers, and the possibility of integrating the maglev system to the existing freeway.

As shown in Figure 3.1, EDL system architecture consists of two components: vehicle magnets and track conductors. As a vehicle travels over the track, the sheet conductor is exposed to a rapidly changing magnetic field from the vehicle magnets. This induces an eddy current in the conductor to flow opposing to the magnetic field and prevent it from penetrating the sheet conductor. Hence, the current generates a propelling magnetic force to support levitated vehicle over the track.



(a) electromagnetic levitation (EML) (b) electrodynamic levitation (EDL)

Figure 3.1 Comparison between two types of maglev vehicles currently in use.

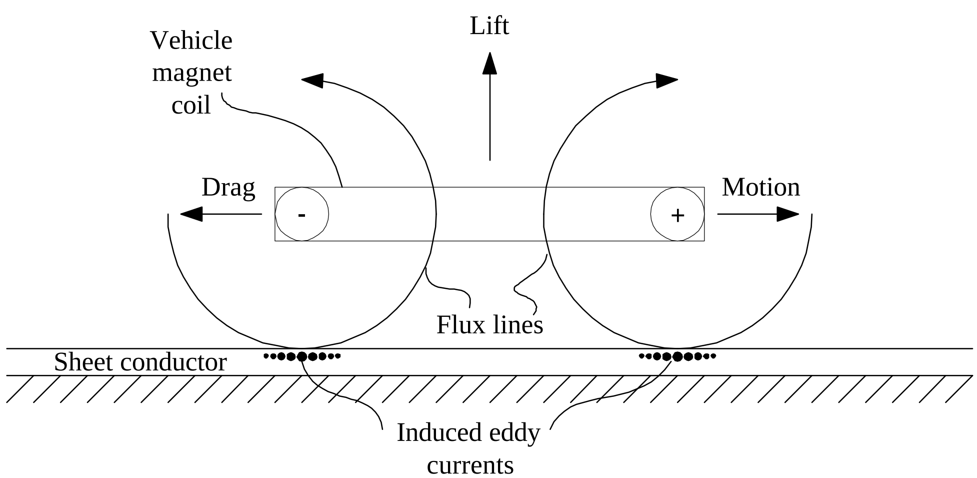


Figure 3.2 Magnetic levitation system for electrodynamic levitation

Various types of alloys including barium-lanthanum-copper oxide, yttrium-barium-copper oxide, and niobium-tin, have been utilized as superconducting materials. For the maglev, a bundle of extremely fine niobium-titanium alloy (superconductive metal) wire is embedded in a copper matrix in order to improve the stability of superconductivity. This wire is cooled with liquid helium (ca-269°C, boiling point 4.2K) to a superconductive state. In order to maintain such low temperature, liquid helium is contained in a cryostat tank and fed through multi-wall vacuum-insulated vessels.

Such superconducting coils are capable of producing considerably strong magnetic fields up to 2-3 Tesla, thus creating stray magnetic fields. This stray magnetic field is undesirable since it can be harmful to passengers. Several approaches for magnetic screening are proposed. Some of which experience problems due to high cost and considerable weight increase. To date, the most favorable method is to shield stray field with another set of coils positioned on the opposite polar alignment over the main coils. The "bucking" coils will effectively cancel the field in the passenger compartment while increasing the requirement of superconductor in the order of 30 percent and weighing only 10 percent of the vehicle gross weight [39].

In addition to the system for shaping and trapping magnetic flux, magnetic levitation requires a primary system for generating magnetic field and propulsion. The system must be capable of generating high thrust and lift force to overcome magnetic and aerodynamic drags. Magnetic drag is inversely proportional to speeds while aerodynamic drag is proportional to the square of the speed (v^2). Thus, it is intuitive that at low speeds the magnetic drag is considerably higher than the aerodynamic drag, and at high speeds vise versa. However, under low-speed operation, the vehicle is usually supported on wheels; and even at high speeds, the magnetic component can be nullified by utilizing some particular types of guideways. Therefore, the main design criterion is to subdue the aerodynamic component generated at high speeds.

Three classes of non-contact form of propulsion system are considered which are

(1) an on-board prime mover;

(2) "short-stator" linear motors with the active part on the vehicle; and

(3) "long-stator" linear motors with a passive vehicle

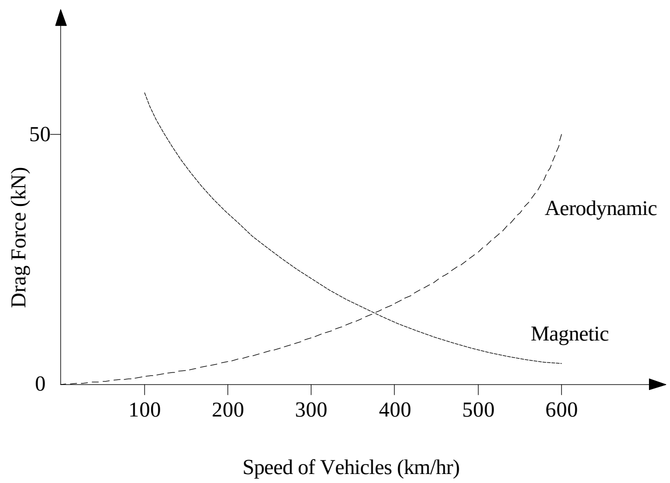


Figure 3.3 Drag forces versus speed

Because of low noise and air pollution, high power-to-weight ratio, and smaller weight and volume of equipment, the long-stator linear motors are the most favorable alternative among the three categories. EDL maglev long-stator linear motor incorporates a linear synchronous motor concept (LSM). Instead of directly activated power to the vehicles, each of the guideway block is energized by feeding alternated currents through a sequence of propulsion coils. Subsequently, the coils are activated to produce a traveling magnetic wave that propels the passive maglev vehicles.

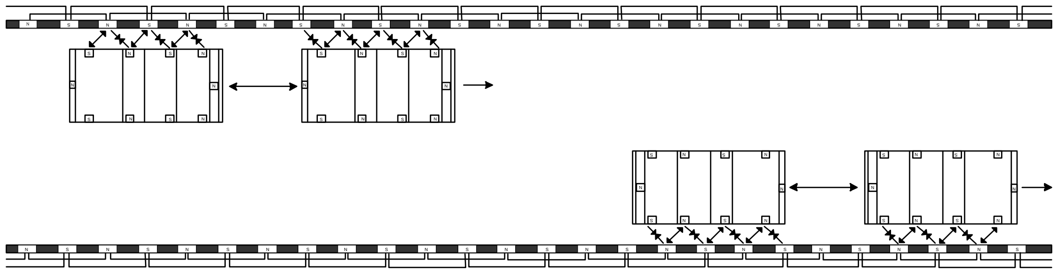
EDL can be classified into four categories according to types of conductors: viz.

- continuous sheet track:
- ladder track
- discrete coil track
- null-flux guideway.

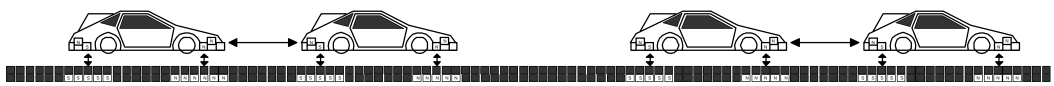
The first type of EDL guideways, continuous sheet track, is the most simplistic style of sheet conductor. It can be designed to essentially control the force on the magnetic wire element to be continuous at all speeds. The lift-to-drag ratio increases with speed but are relatively low compared with other types of designs. The fundamentals of ladder and discrete coil tracks are similar. They provide more lift-to-drag ratio and use less conductor materials. The forces are generated when moving vehicle coils pass each of the "steps" or coils. As a result, an important problem experienced with these two system types is fatigue occurring due to dynamic forces which would damage the components. In the null-flux system pairs of track coils are introduced on both sides of the guideway in order to nullify magnetic flux from the vehicle coil. Cancellation of the magnetic flux results in lower current requirements and less drag being generated. Null-flux tracks are complicated to construct but produce high lift-to drag ratio.

3.3 Maglev Vehicle Characteristics

The AHS/Maglev concept being explored in this research would propel closely-spaced, individual vehicles at high speeds with full longitudinal and lateral control. The vehicle with superconducting magnets on board is propelled by the attractive and repulsive forces between the guideway and vehicle 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 of electromagnets alternately by the electric current supplied from the substation. The interaction between the superconducting magnets in the vehicle and the electromagnets on the guideway is the driving force of the Maglev vehicle. Spacing between vehicles and lateral movement such as in merging are accomplished by the placement of magnets on the vehicles and the guideways. Figure 3.4 illustrates how maglev vehicle positions are controlled on the guideway.



Plan View



Cross-Section

Figure 3.4 AHS Maglev Levitation, Propulsion and Guidance

Off the guideway, vehicles would be powered by electric motors. Since electrodynamic levitation depends on the relative motion between the vehicle magnets and the conducting track on the guideway to be able to generate the necessary lift and guidance forces, the eddy currents that would be induced at very low speeds would exclude so much of the magnetic flux that the lift force created would be less than the vehicle weight. Therefore, while the vehicle is at rest and until the necessary lift-off forces are generated (at around 50 km/hr) the wheeled suspension on the AHS/Maglev hybrid vehicles would be utilized. The wheels would be retractable as is the case for aircraft. In any case, some means of mechanical support would be essential for any type of levitated vehicle for reasons of safety and emergencies such as failure of power or equipment, and to enable the vehicle to be maneuvered in its unpowered state.

Cars and trucks will be hybrid vehicles and will use separate freeway roadways and Maglev guideways (“Magways”). This separation of traffic is long overdue and is being contemplated by many state DOT’s in the U.S. as they face the addition of more and more lanes to accommodate growing traffic demands. The use of the rights-of-way of the Interstate Highway System for the construction of the proposed AHS Maglev system is more than just a way of minimizing the cost of implementing the new system. The new system must be integrated with the old; there is no way that the guideways could be efficiently loaded and unloaded except by interfacing with the existing freeway system.

Three types of vehicles would be employed. Hybrid automobiles would measure 18 feet long, six feet wide, five feet high and would weigh 6,000 pounds, initially. With advances in superconductivity, the weight would eventually be brought down to about 4,000 pounds. Hybrid buses would measure 55 feet long, 10 feet wide, and 8 feet high, weighing about 50,000 pounds initially, and 40,000 pounds eventually. The third type of vehicle would be hybrid trucks with the same specifications as the buses except with variable weights. These projections were based upon a realistic air gap in the electrodynamic suspension system (12.5 cm), a conservative drag coefficient (0.25) and the provision of six large 0.90×0.25 m. magnets providing support and guidance at high speeds. Under these assumptions the HPM vehicle would be able to reach a top speed of 135 m/s (300 mph) while generating a total drag force of 4,560 Newtons [40]. It should be pointed out that anticipated breakthroughs in superconductivity would drastically reduce the size of the vehicle providing better operational economics. The size and weight of HPM vehicles would result in lighter Magways compared to those of their large Maglev train counterparts. Current air gap tolerances in large Maglev guideways dictate short spans between supporting elements to minimize the detrimental effect of guideway beam deflections. With vehicles weighing an order of magnitude less than a typical Maglev train the resulting deflections of an elevated Magway span would allow for a more economical implementation of this concept even if the Magway is elevated [41].

3.4 Need for a Broader System Architecture

Our transportation system is national in scope, enabling people and goods to move across jurisdictional boundaries with ease. To continue this free movement, Congress has directed U.S. DOT to promote the nationwide compatibility of ITS. To achieve this compatibility U.S. DOT is in the early stages of a program to develop a common ITS framework – a system architecture. Four alternative architectures have been developed as part of the ITS Architecture Development Program, with the goal of establishing a national ITS architecture. The details of this approach are reported in a U.S. DOT publication "ITS Architecture Development Program" available from ITS America.

Transportation victories over time and space that have transformed much of the world call for a sustained effort to hold on to hard-won gains. The 20th Century has witnessed the extension of economic activity from a local to regional and national scopes and finally to global dimensions. The continuing need is to keep pace with economic and social change with advances in transportation technology. AHS/Maglev is an example of a technology that will increase the capacity of a facility to move motor vehicle traffic ten-fold. Moreover it affords us the opportunity to provide for rational population distribution and assures that transportation serves a global society in furthering its unmet goals.

Any transportation system intended to serve society throughout the 21st Century and beyond must address a hierarchy of goals and issues ranging from the strategic (sustainable development) to the tactical (the concept of operations) and including the in-between (interfacing with the existing transportation system). In the past, transportation planning, policy, investment and operating decisions have been made in isolation from each other with incomplete information inputs from a broad base of disciplines and sectors, without a synthesizing instrumentality. A new approach is needed to promote the best informed decisions governing planning and management. The approach requires a realistic framework for allocating public sector-private sector effort, an instrumentality for generating the knowledge needed to conceive and implement the new transportation paradigm, and a strategic vision for rallying support.

The new approach to the problem begins with a strategic vision for society's AHS infrastructure. The strategic vision must be based on the concept of "sustainable development." The advent of sustainable development is new compared to the established economic theories, and even compared to the environmental movement which is also partly responsible for its creation. The concept that the term sustainable development embodies is simple. It is the reconciliation of economic development with protection of the environment, or the knowledge that infrastructure, the economy and the environment, instead of being discrete and separate entities are interconnected in fundamental and crucial ways.

3.5 Decision Support System (DSS)

To effect this new strategic vision, higher budgets will be a necessary, but not a sufficient, condition. A fundamental Decision Support System (DSS) with knowledge bases with contributions from the broad spectrum of science and engineering disciplines, and a methodology capable of synthesizing these contributions.

The role of the DSS is to help answer "what is, what would, and what if" questions. But, no DSS, no matter how inspired, can automatically solve a decision makers problems. A problem is a subjective presentation conceived by a decision maker confronted with a reality which is perceived to be unsatisfactory in light of observations and facts. Because of this subjective dimension, decision making or decision finding is more of a process based on knowledge than it is a problem-solving event obtained from some "black-box".

The key word is knowledge. One approach to knowledge is model driven; the other is data driven. In the view of the former, knowledge is understanding; in the case of the latter, knowledge is information. Understanding is a strategic approach to knowledge; information is a tactical approach gained piece by piece from data. The knowledge base should be obtained from both information and understanding; both a Data Base and a Model Base are needed. Ultimately, a DSS requires wisdom which is knowledge applied within a Value Base or value system so to be able to trade off economic growth and environmental deterioration, for example. Lastly, a Display Base is needed to interpret scenarios (see Fig 3.5).

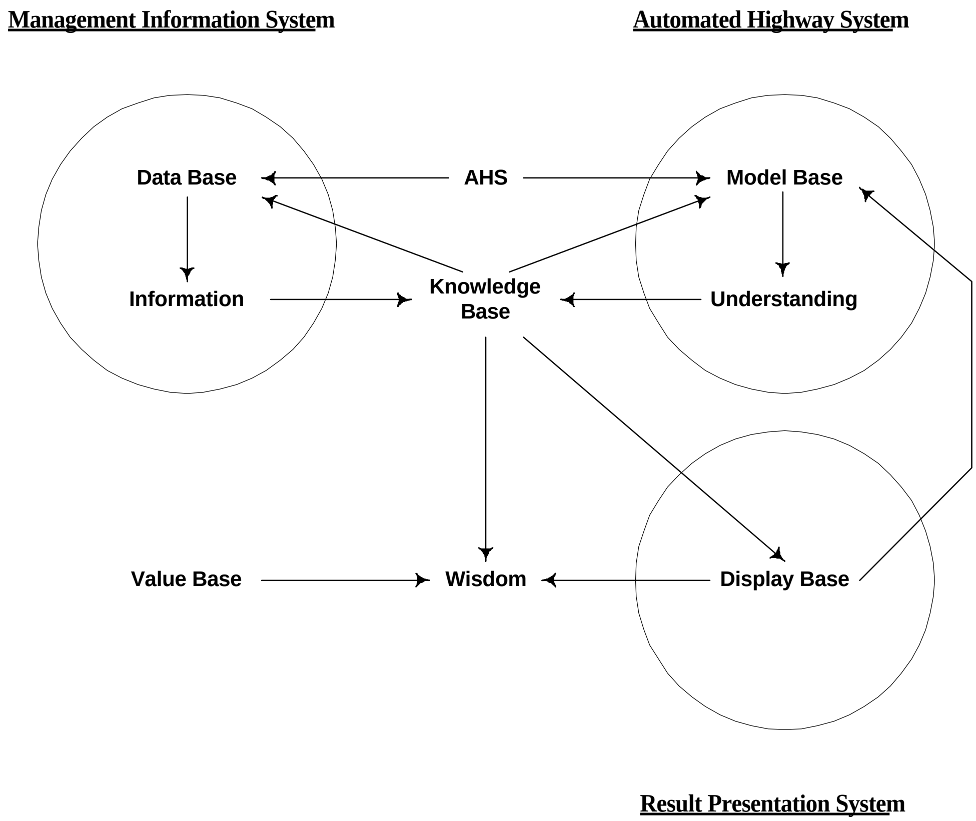


Figure 3.5 Decision support system elements

The requirements of the Model Base of the DSS are dictated by the system to be modeled. Sustainable development systems range from global policies to address global warming to individual concept of operations alternatives to ensure safety, efficiency and financial viability. The principal aim is to develop enough understanding of AHS Maglev and its impacts, many of which can have environmental and economic consequences, to plan, engineer and manage them.

Traditional economic analysis to determine feasibility is concerned with problems assumed to occur in a single time period ranging from a year to a few decades. This sort of static analysis is inadequate for analyzing sustainable development. In designing a sustainable society, events that are usually related through more than one period of time must be considered. This transition from static to dynamic analysis involves more than just adding together individual static time periods.

A body of dynamic behavior and principles of structure is emerging that allows us to organize and understand the development process of a region or a whole nation – a process dominated by feedback in that it features the synthesis of demand and supply functions. For the demand function, we are seeking the infrastructure improvements required to accommodate a certain socioeconomic load; for the supply function we want to know the level of service obtained for a certain infrastructure improvement. Since higher levels of service attract socioeconomic activity, the feedback loop is closed.

3.6 System Dynamics

It is believed that three complementary forms of models should be used in the Model Base of the DSS: (1) a verbal model, a narrative description of the system, (2) a structural model, a diagrammatic display of variable interrelationships arrived at through specific rules of formation and (3) a mathematical model, the set of equations describing interrelationships developed from the structural models.

The system dynamics methodology fits this description. It is based on engineering principles, especially feedback system analysis [42]. A causal diagram depicts the relation, in form of information flow, between decision policies, rate, level and other variables. A policy is an independent variable defining the action of a decision maker. A rate variable describes the flow of information from one area to another. A level variable represents an accumulation of the information that varies over time. An example of a simple system dynamics causal diagram is shown in Figure 3.6.

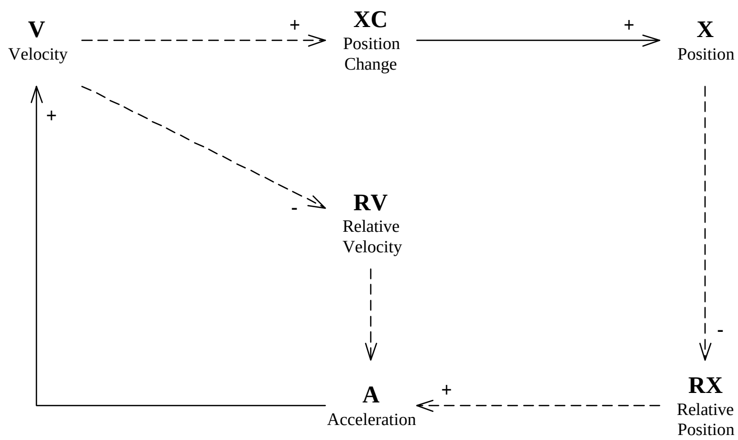


Figure 3.6 Vehicle longitudinal feedback control diagram based on GM's car following model

The model is the backbone of the Decision Support System. Through the model, the AHS Maglev is conceptualized as causal chains linking decision variables such as number of guideway lanes and platoon size to measures of effectiveness such as safety, user benefits, non-user benefits and benefit cost ratios. Alternative courses of action can be evaluated by changing the values of decision variables and comparing the resulting values of the measures of effectiveness.

The determination of the values of output variables for a given set of parameter values is, in effect, "solving the model". The model to be developed can be solved in two ways: (1) analytically and (2) by computer simulation. Where analytical solutions for portions of the model are possible, they can be presented in equation form with the output variable expressed as a mathematical function of input variables and as nomographs. However, in some complex models, analytical solution may not be simply determined. Computer simulations can be applied to model and solve these problems. They are capable of detecting and recording changes in the state of the system in a very short period of time. Once a simulation program is developed, it can be repeatedly analyze and experiment with the problem under different conditions. Simulation solutions can be expressed as plots of variables of interest over time.

3.7 Scenario Analysis

The magnetic levitation transportation system analysis consists of microscopic and macroscopic parts. First, the microscopic parts including the vehicle position control schemes and merging and weaving maneuvers will be examined. This will be done under a range of guideway geometry assumptions that are compatible with the existing freeway networks. Different vehicle characteristics and properties, and guideway magnetic constants are tested in different scenarios.

Looking into a broader scope, after the microscopic part is completed, platooning on the guideway and traffic assignment will be performed based on the established control laws. Several scenarios of platooning will be tested to determine the number of vehicle in a platoon that provides optimal tradeoffs between capacity and safety. Traffic assignment will be examined to decide number of lanes and other geometric aspects of the guideway. The benefit-cost model will be included in this step to achieve optimal results. If necessary, the guideway geometric design will be reevaluated and the whole process will be repeated to be compatible with the final result.

3.8 Sensitivity Analysis

In practical system dynamics model construction, often some of the policy parameters are not known exactly, hence are estimated with intuitive judgment. It is necessary to be able to determine the effect of alteration of these components to the system by measuring the magnitude and direction of system behavior. The optimum solution of the system can be updated under different policy variations by means of sensitivity analysis.

Sensitivity analysis is a dominant part of the system dynamics modeling. It allows the decision makers to compare the results under different scenarios and obtain a better understanding of the system without the extensive task of resolving the whole problem. Moreover, at the early stages of problem formulation, some critical factors may be disregarded. Sensitivity analysis can identify critical data needs [43] and update the solution in such a way that take care of missing data [44].

In this study, the policy parameters that will be investigated can be classified into two categories: initial values and constants. The initial values involve initial conditions of the maglev vehicles, i.e., positions, speeds, accelerations and jerks. The constants include the policy on allocating the magnetic constants, vehicle physical and aerodynamic properties, and the geometric design of the guideway.

3.9 Model Validation

A model, as an exemplification of a real system, is created to describe and explain the functional essence of the system with adequate detail in order to be used for investigation, experimentation and decision making. Considering large amounts of time and money needed for development, it is realized that no model can be expected to be absolutely valid over a long period. A model is considered valid if it is a sufficient representation of the system to predict precise results within an acceptable range of confidence according to the study purpose.

Tsang [45] concludes, from Robert G. Sargent’s presentation, that the validation should be accomplished through steps. First, the assumptions underlying the model have to be realized. Then the static validity is performed by investigating the conceptual model to obtain better awareness of the elements, its functions and interrelations among one another. The model behavior is subsequently explored in detail by testing its typical and extreme cases to identify the initial condition and the realm of the model ability. Several further studies should be performed and compared to the existing or predicted data. These processes should be planned for a periodic review.

Generally, a model validation mainly involves comparison of the simulation results and one or more of (1) results from existing theoretical models, (2) results from developed analytical models, and (3) historical data. The system dynamic model requires three parts of validation that relate to its structure and behavior [46]. The three parts of validation are:

1. Testing the suitability to the designed purposes. Focusing on structure, this includes dimension consistency, extreme conditions with equations, and boundary adequacy on important variables and policy levels. Focusing on behavior, this includes parameter and structural sensitivity on behavior characteristics and policy conclusions.

2. Testing consistency with reality. Focusing on structure, this includes static validity on rates and levels, information feedback and delays, and parameter values on conceptual and numerical fits. Focusing on behavior, this includes replication of reference modes, unexpected behavior, extreme condition simulations, and statistical test.

3. Contributing to the utility and effectiveness of a suitably consistent model. Focusing on structure, this includes appropriateness of model characteristics presenting to audience, i.e., size, simplicity, and aggregation or detail of the model. Focusing on behavior, this includes counter-intuitive behavior and generation of insights.