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THE SYSTEM DYNAMICS APPROACH TO DEVELOPING AVCS MAGLEV VEHICLE DEVELOPMENT MODEL

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AVCS maglev is the synergistic combination of Advanced Vehicle Control Systems (AVCS) and the high-speed magnetic levitation (Maglev) technology. AVCS maglev will provide a safe, high-speed, high-capacity, energy-efficient, environment-friendly intercity and intracity transportation system. The vehicles using the "magway" (maglev guideway), like present day automobiles, would be privately owned and could operate on ordinary highways and streets as well as the AVCS magways. In this paper, the AVCS Maglev Vehicle Development Model (VDM) 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 AVCS Maglev Vehicle Development Model is described in two complementary forms of the system dynamics modeling, causal diagrams and DYNAMO equations.

Keywords: AVCS maglev, Vehicle Development Model, causal diagram, DYNAMO

Features of AVCS Maglev Transportation System

Overview

AVCS maglev (Lee, 2002) is the synergistic combination of Advanced Vehicle Control Systems (AVCS) and the high-speed magnetic levitation (Maglev) technology. AVCS maglev vehicles would be designed with dual capabilities permitting them to run on maglev guideways (magways) as well as conventional roadways.

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. Since centrifugal force increases as the square of velocity, the guideway must allow the vehicle to bank with substantial angles.

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 (see Figure 1).

Features

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. 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.

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.

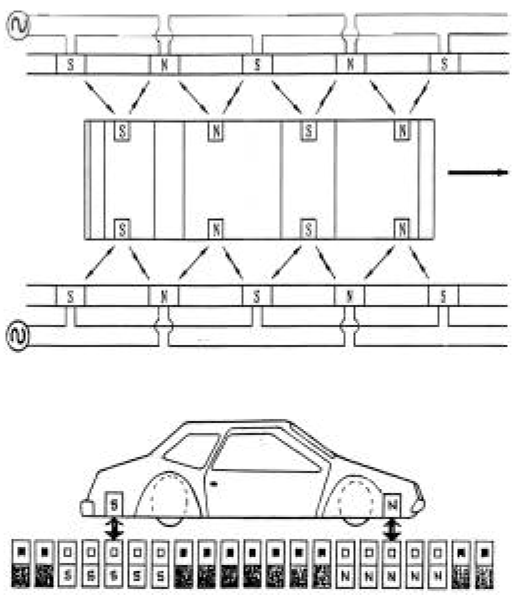

Figure 1. Principles of AVCS Maglev Levitation, Guidance and Propulsion

AVCS Maglev Vehicle Development Model

Overview

The AVCS Maglev Vehicle Development Model (VDM) is described in two complementary forms of the system dynamics modeling, causal diagrams and DYNAMO equations. The causal diagram not only portrays the cause and effect relationships between the independent variables and dependent variables of VDM 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. “L” represents the level variables such as the number of maglev vehicles and the weight of the superconductor-cryostat assemblies. “R” represents rate variables such as the vehicle production rate, vehicle discard rate, etc. The whole simulation process is illustrated in Figure 2.

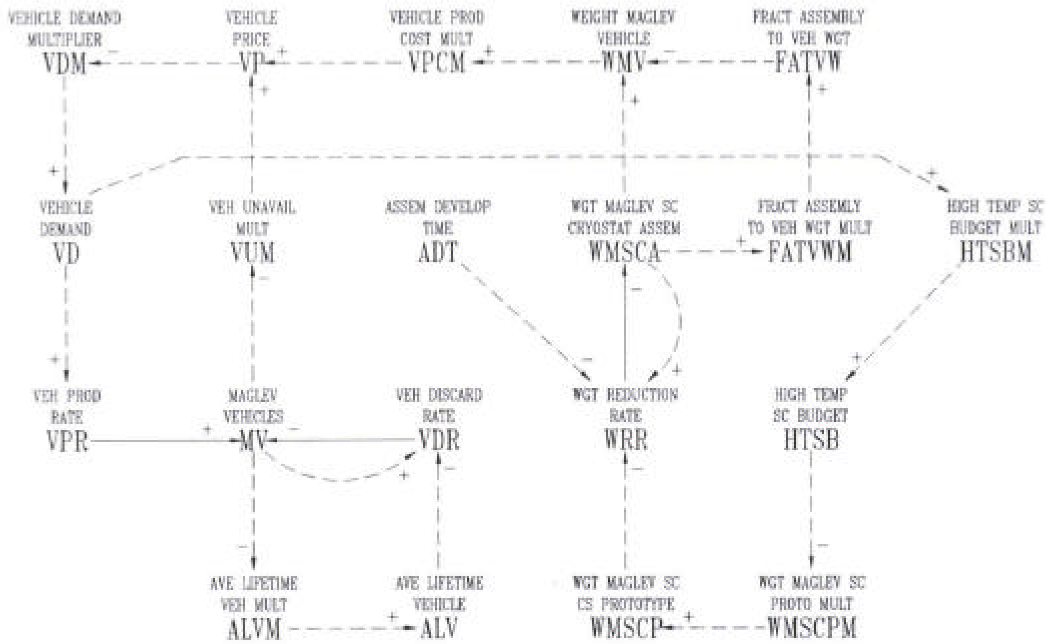

Figure 2. Causal Diagram for AVCS Maglev Vehicle Development Model

Model Description

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.

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   VDR.KL=CLIP(MV.K/ALV.K,0,(TIME.K-2000),10)
A   ALV.K=ALVN*ALVM.K
C   ALVN=15
A   ALVM.K=CLIP(ALVM2.K,ALVM1.K,(MV.K/MVN)/1E4,11)
A   ALVM1.K=TABHL(ALVM1T,(MV.K/MVN)/1E4,1,11,2)
T   ALVM1T=1/.98/.97/.95/.93/.92
A   ALVM2.K=TABHL(ALVM2T,(MV.K/MVN)/1E4,11,211,50)
T   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   WMV.K=MAX(WMSCA.K/FATVW.K,3000)
A   FATVW.K=FATVWN*FATVWM.K
A   FATVWM.K=TABHL(FAVWMT,WMSCA.K/WMSCAN,0,1,1)
T   FAVWMT=.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 MULTPLIER (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)

Simulation Results

The simulation results are presented in terms of the vehicle price, demand, sales revenue, and vehicular weight as summarized in Table 1.

Table 1. Simulation Results of AVCS Maglev Vehicle Development Model

Year	Number of Vehicles MV (veh)	Demand for Vehicles VD (veh/yr)	Vehicle Price VP ($/veh)	Veh. Price in Cur. Dollars VPCD ($/veh)	Revenue REV ($/yr)	Vehicle Weight WMV (lb)
2000	100	0.32 M	260.0 T	260.0 T	83 B	6,000
2010	44.5 M	9.29 M	44.3 T	56.8 T	528 B	5,161
2020	122.5 M	17.83 M	33.0 T	54.4 T	970 B	3,813
2030	185.3 M	20.00 M	26.0 T	55.0 T	1,099 B	3,000
2040	210.2 M	20.00 M	26.0 T	70.5 T	1,411 B	3,000
2050	218.9 M	20.00 M	26.0 T	90.5 T	1,811 B	3,000

Note: T = thousand, M = million and B = billion

The number of maglev vehicles reaches over 210 million in 2040, when the U.S. population is 379.6 million persons according to the National Development Model. There were 143 million automobiles in 1991, when the population was about 250 million persons (U.S. Bureau of the Census, 1993; Economist Intelligence Unit, 1992).

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 (The Economist Intelligence Unit, 1992).

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 Figures 3 to 5.

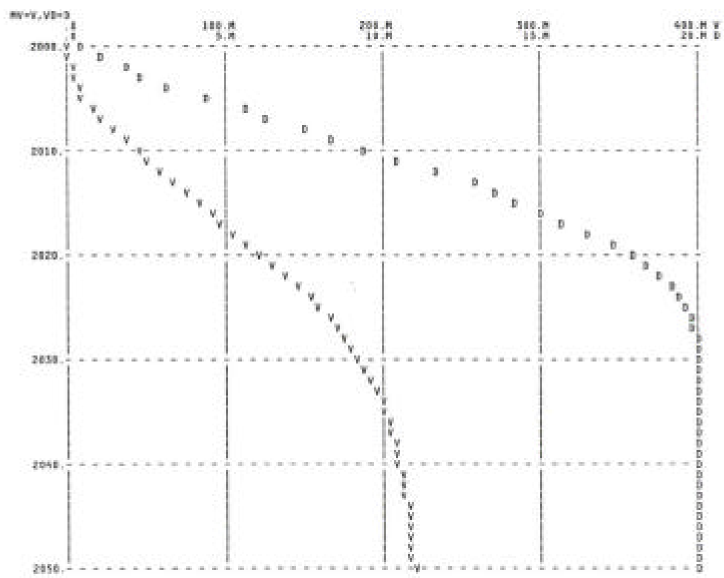

Figure 3. No. of AVCS Maglev Vehicles and Demand

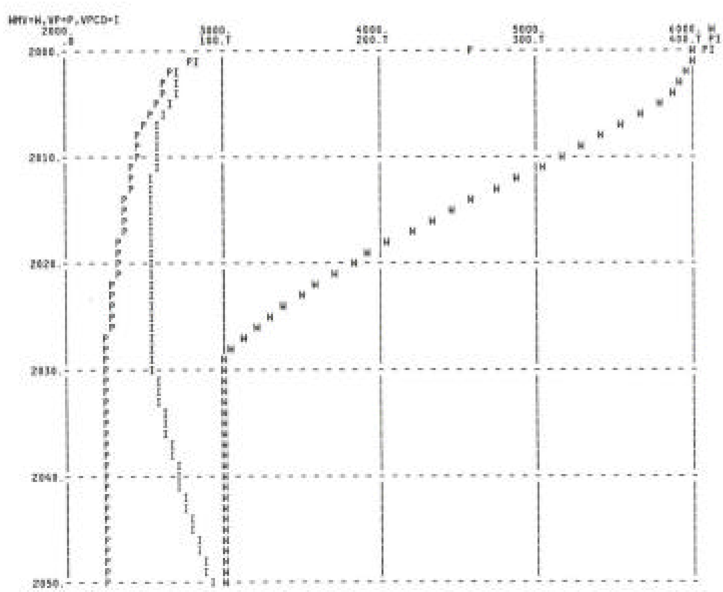

Figure 4. Vehicle Price (in Constant and Current Dollars) and Vehicle Weight

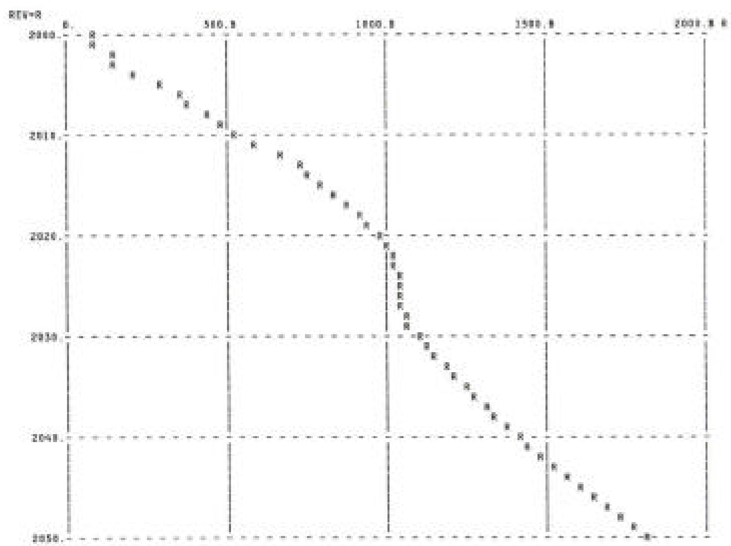

Figure 5. Revenue from Sales of Vehicles

Conclusions

Based on the analysis presented herein, several conclusions could be derived as follows:

- The price of vehicle 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 development of this technology will depend upon the amount of R&D budget allocated and the amount of R&D budget will increase as the demand for vehicles increases. In 2040 the price of vehicle will be $26,000 in the year 2000 constant dollars and $70,500 in the year 2040 current dollars. The revenue from the sales of maglev vehicles will amount to $1,411 billion, which corresponds to 3.4% of GNP.
- The AVCS Maglev Vehicle Development Model illustrates the relationship among important factors in reducing the weight and price of the vehicle. When the model is developed more in detail, it will provide more information which can be utilized in transportation policy-making process.

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