High-speed surface transportation corridor: A conceptual framework

Final report

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ABSTRACT

Efficient transportation is indispensable for economic growth and prosperity. In this study we propose the development of a high-speed surface corridor and compatible vehicles. We present a conceptual framework for this corridor and vehicle. This proposed concept will improve the efficiency, flexibility, convenience, and environmental impact of transporting people and materials. Our concept is to have trucks and cars travel through these corridors at speeds of over 250 mph without discontinuity. These vehicles will have the ability to use existing roads as well as the proposed corridor. We will explore the application of current and emerging technologies for developing such high-speed surface corridors to link major destinations such as Los Angeles and Chicago.

Key Words: Transportation, Planning and Design, Vehicles and Equipment

Subject Categories: Design, Highways, Vehicles

“Better Journey Time, Better Business”

(IMechE Conference Transaction, 1996).

1. Introduction

Efficient transportation is indispensable for economic growth and prosperity, especially when the national and regional economies become globally interconnected. Throughout the world, bottlenecks in the transport systems are becoming worse while environmental concerns are mounting. There is a need to move goods and people quickly, safely and conveniently across the nation. This has resulted in a large amount of effort being devoted to the development of transportation methods and corridors across the countries and regions.

Within the continental United States, businesses and people prefer roads to any other form of transportation. This is because road transportation affords the greatest flexibility for the traveler. First it allows for point-to-point transportation. In addition, it allows for a flexible schedule. The popularity of this mode is evidenced by the continually increasing congestion of the nation's highways. This is occurring despite the massive investments in the construction of new highways and rising fuel costs.

Roads provide a convenience that other forms of transportation do not. In most cases, rail, water and air transportation all require at least one additional transportation mode between the source and the destination as compared to road transportation. For example, when products leave a factory for a retail outlet, they may leave using a rail network directly from the factory, but will need to be unloaded and reloaded onto a tractor trailer for delivery to the retail store. Similarly, if a passenger wishes to use a public transportation system like a commercial airline, they will need to use road transportation at both ends of their trip. These transshipments add to costs, delays and inconvenience. While road transportation is by far the cheapest and most convenient method under most circumstances, current technology leads to the emission of substantial amounts of green-house gasses. Furthermore, the constantly explosive demands have resulted in congestions everywhere around the United States, especially around metropolitan areas such as New York, Chicago, Los Angeles and Salt Lake City.

Among all freight transportation modes, an intermodal system has been strongly advocated because of environmental concerns, overall efficiency, and the benefits of co-ordination of modes to cope with growing transport flows (OECD, 1997). More importantly, intermodal transportation issues in general have become an important policy issue (Bontekoning et al., 2004). Political support for the development of intermodal transport has been evidenced in the transportation plans of many European nations as well as the United States (Bontekoning et al., 2004; Sakalys and Palsaitis, 2006). For example, the United States government released the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) to present a new vision of the transportation system. ISTEA is a policy to develop “a National Intermodal Transportation System that is economically efficient and environmentally sound, provides the foundation for the Nation to compete in the global economy and will move people and goods in an energy efficient manner” (Abbasi, 1996).

Intermodal traffic has been increasing rapidly. By 2001, there were 9.2 million intermodal shipments per year in the United States, up threefold from 20 years ago. However, the intermodal transport system has not been able to solve the congestion problems. The United States faces severe congestion at a number of ports, rail lines, highway corridors, and interchange points.

In addition to intermodal transportation, high speed rail has been introduced as an innovative, efficient, and environmentally friendly way of transportation. High speed rail is commonly defined as trains that are electronically propelled at speeds exceeding 150 miles per hour (mph), and many trains have been tested in excess of 320 mph (IHSRS, 2007). Realistic benefits of high speed rail have been realized by many nations in the world as evidenced by the expansion in high speed rail corridors. For example, Japan was the first country to introduce a high speed rail, "bullet train" – Shinkansen, in 1964. In 1981, France inaugurated a 255-mile high speed rail link between Paris and Lyon, cutting travel time from four hours to two hours. In 1991, Germany opened a 203-mile high speed rail service between Hanover and Wurzburg and a 62-mile high speed rail service between Mannheim and Stuttgart. Many other nations also followed such as Italy and Spain (1992), Sweden (1998), and Netherlands (2000). Today, the world's fastest train had been recorded as a magnetic levitation train built by the Japanese that can reach 361 mph. This was recorded on December 2, 2003 (IHSRS, 2007). On April 3, 2007 a French high speed train broke the world speed record for steel-on-steel rail when it achieved a speed of 357 mph (Malone, 2007). However, most of these corridors have been developed and mainly devoted to the transporting of people over short distances.

With more goods being transported and more people traveling for work and leisure, the pressure on the transportation system has never been higher. Besides, the pressures have been multiplied with the emergence of the Internet and supply chain management. Many firms exploiting supply chain management capabilities are using a hybrid "push-pull" strategy. This "push-pull" strategy allows them to apply a push-based approach to the production stage and a pull-based one to market stages. Transportation needs have been considerably reshaped, especially in the grocery, book, and general retail industries. Fulfillment strategies have shifted from cases and bulk shipments to single items and smaller size shipments. Dynamic and flexible pricing are therefore also important to cope with increasing variability in demand. Internet and e-commerce make the situations even tougher by "training" customers to order at the last minute. The strains created by last-minute fulfillment need to be matched by strengthening the supply end of the chain. With more customers, and more small shipments, it will be increasingly difficult for current transportation systems to provide reliability, flexibility, cost savings, and efficiency in the delivery system.

Around the world in general and in the United States in particular, we are experiencing strong shifts from national markets into global markets. Therefore, freight volumes will grow strongly. Transport systems hence, need to be more efficient, reliable, timely, door-to-door, flexible and visible.

The aim of this research is to present a conceptual framework for a high-speed surface corridor that can be developed in any nation or across national boundaries. This proposed corridor must be able to increase the efficiency, flexibility, convenience, and environmental impact of transporting people as well as materials. Our concept is to have trucks and cars travel through these corridors at speeds of over 250mph without discontinuity while still having the ability to use existing roads at convenience. This paper is organized as follows:

- Section 2 discusses the forces that have come together to manifest the need for this kind of high-speed surface corridor;

- Section 3 discusses in detail the benefits of developing and utilizing the high-speed surface corridor
- Section 4 presents the current and emerging technologies that can be applied to develop the high-speed surface corridor.
- Section 5 explains in detail the high-speed surface corridor concept describes how this high-speed surface corridor will work;
- Section 6 details a simulation study that shows the benefits of such a system.
- Section 7 concludes with the discussion on the applicability of this high-speed surface corridor.

2. Drivers of high speed surface corridor

The drivers for a more efficient transportation system come from two directions, the needs of society and problems with current systems. The needs of society consist of the growth of trade (import and export) which then increases the transportation demands due to the increase in the amount of freight to be transported and the distances they need to be moved. Besides the needs of society, serious issues with the current systems are calling for a better transportation method. The limited on current energy resources has led to large fluctuations in the price of fuel is one of these drivers. In addition, negative global impacts of current transportation modes have asked for consideration of more environmental friendly transport. Last but not least is the hidden cost of current transportation systems such as accidents, negative physical and mental impacts from pollution and noise, etc.

2.1 Growth of trade

For more than a hundred years, globalization has always been associated with the growth of international trade. According to Bordo et al. (2003), globalization refers to international integration in commodity, capital, and labor markets. Rapid trade and output growth as well as major shifts in the relative size of the economies are results of globalization (WTO, 2008). The first episode of globalization and thus international trade began around the mid-19th century and ended with the commencement of World War I (WWI). This period was marked with the global trade growth averaging 3.8 percent annually (World Trade Report, 2008). The second episode of globalization and thus international trade boom began in the aftermath of World War II (WWII) and continues today. This period was recorded with a long expansion in trade growth of more than 8 percent annum during 1950-73 (World Trade Report, 2008). Trade growth slowed thereafter under the impact of two oil price shocks, a burst of inflation caused by monetary expansion and inadequate macroeconomic adjustment policies. However, international trade has been expanding again at a rapid rate since 1990s, partly driven by innovations in the information technology (IT) sector (WTO). The average expansion has been 6 percent annually for the 2000-07 period (World Trade Report, 2008).

Globalization has been growing stronger. Technological advances have improved the speed of transportation and communication. Developments in areas such as containerization in international shipping, information and communication technology have played a critical role in lowering the costs of global manufacturing and marketing and thus boosting international trade. In addition to technological advances, many governments have adopted economic policies favoring deregulation and the reduction or elimination of restrictions on international trade, foreign investments, and financial transactions. Furthermore, international trade has also increased through multilateral negotiations with preferential trade agreements. Political change has also been a critical driver of globalization and international trade. For example, China's economic reform, the fall of Berlin Wall, the collapse of the Soviet Union, and the increase in WTO members during the last decades have pushed globalization, economic integration, and trade further. On global trade performance of 2007, WTO emphasized the role of developing countries and the Commonwealth of Independent States (CIS) in expanding world output growth. According to WTO, developing countries' combined merchandise exports rose by 16% to $5 trillion and imports rose by 18%.

According to U.S. Census Bureau report for U.S. Traded in Goods – Balance of Payment for period from 1960 to 2007, there has been an upward trend of U.S. trade in goods from 1960 to 2007. For example, in the 20 years from 1987 to 2007, the United States increased both exports and imports almost five times. In the 47-years period of study, the United States had increased exports by more than 58 times and imports by almost 135 times. Strong growth in trade is directly associated with a rising demand for transporting freight. It is obvious that these will affect current transportation systems significantly.

2.2 Growth of freight

The U.S freight transportation system carries enormous quantities of goods and raw materials to support economic and industrial activities all across the nation and to meet consumer demands. The systems also handle large volumes of goods traded internationally and transported to and from the United States and places throughout the world. Transportation is vital to the U.S. economy by the fact that more than $1 out of every $10 produced in the U.S. gross domestic product (GDP) is related to transportation activity (USDOT BTS 2006).

Americans have been trained to take for granted the ability to buy imported fresh fruits, vegetables, and flowers at their local supermarkets; next-day delivery of goods purchased over the Internet; and tracking express packages online to know their whereabouts at any given time. All of these would not be possible if a vast transportation network was not available. However, the growth of domestic as well as international trade has dramatically increased the amount of goods needing transportation. According to Bureau of Transportation Statistics (BTS), the U.S. Department of Transportation's Research and Innovative Technology Administration (RITA) and the Federal Highway Administration (FHWA), over 19 billion tons of freight, valued at $13 trillion, was carried over 4.4 trillion ton miles in the United States in 2002. More importantly, in 2001 the Fourth Forum on Intermodal Freight Transport between Europe and the United States forecasts that freight will double by 2020. Similarly, FHWA forecasts that freight volumes are expected to increase greatly by the year 2020 (USDOT BTS, 2006). The current transportation network thus would be inadequate to handle increased volumes in freight. Moreover, the growth in the U.S. freight shipments has not been met by the improvements in transportation facilities. For example, according to FHWA, between 1980 and 2002, truck travel grew by more than 90 percent while lane-miles of public roads increased by only 5 percent (USDOT FHWA 2004). Also, over the past two decades as the rail industry consolidated, the mileage of rail roads operated by Class I railroads sharply declined from 165,000 miles in 1980 to about 99,000 miles in 2004 (AAR 2005a and AAR 2005b). The continued overall growth in the use of the national freight network relative to the infrastructure extent have posed many challenges such as congestion, delays, inefficient capacity management, and operational bottlenecks. Changes in freight delivery services and freight carrier operations, and improvements in freight logistics are needed. Evident trends in current freight activities illustrate the need and applicability of high speed surface corridors.

2.3 Characteristics of U.S. freight transportation system

Transportation mode

Whether measured by value, weight, or ton-miles, trucking as a single mode was the most frequently used mode, hauling an estimated 70 percent of the total value, 60 percent of the weight, and 34 percent of the overall ton-miles. Table 1 presents 2002 commercial freight activity in the United States by transportation mode (See Appendix).

Distance

Although, most U.S. freight shipments by value and tonnage move less than 250 miles, there is a trend towards longer distance transportation (DOTBTS, 2006). Specifically, almost 50 percent of the value ($4.6 trillion) had been shipped more than 250 miles. Furthermore, goods that move longer distance (250 miles or more) carried approximately 82 percent of ton-miles. Figure 1 shows U.S. Freight Shipment by Distance Shipped from 1993 to 2003 (See Appendix).

In addition to the growing percentage of goods being transported over long distances, the value of long-haul shipments has always been higher than goods shipped over short distances. On average, the value of long-haul shipments (more than 250 miles) was $1,400 per ton in 2002 as compared to $500 per ton for goods that were shipped less than 250 miles. Similarly, goods that moved 1,000 or more miles in 2002 had an average value of over $2,000 per ton, compared to an average of $430 per ton for goods shipped less than 100 miles (DOTBTS, 2006).

Size

Growth in parcel and express courier services and an increase in consumer purchases over the Internet are influencing shipment size and contributing to a rise in smaller sized shipments (USDOT BTS 2006). Lower weight shipments (less than 500 pounds) accounted for about 25 percent of the value of the commodity flow shipments but grew 53 percent by value between 1993 and 2002. Of these shipments, those weighing less than 100 pounds grew even faster at 65 percent by value. Table 2 displays freight shipments data by shipment weight for 1993 and 2002 (see Appendix). .

Growth in nation's freight shipments vs. Transportation mode

According to U.S. Department of Transportation, Bureau of Transportation Statistics (2006), between 1980 and 2004, the nation's freight ton-miles by all freight modes steadily increased, rising at an average annual growth rate of 1.2 percent annum (Figure 2, see Appendix). The steeper growth in air carrier mode again indicates the increased demand in shipping small packages at faster pace.

2.4 Limited transportation fuels

According to Western Governors' Association (WGA, 2008), fuels are the major component of transportation energy portfolio. Specifically, of the 20.7 million barrels of petroleum consumed each day in the United States in 2007, 70 percent is used in the transportation sector (See Appendix for Figure 3 – U.S. primary energy consumption by source and sector, 2007, USDOT EIA). In addition, the United States also consumes more energy from petroleum than from any other energy sources.

According to USDOT EIA (2008), transportation use leads growth in liquid fuels consumption. U.S. consumption of liquid fuels—including fuels from petroleum-based sources and, increasingly, those derived from non-petroleum primary fuels such as coal, biomass, and natural gas—will total 22.8 million barrels per day in 2030 (USDOT EIA, 2008). The total consumption will increase by 2.1 million barrels per day over the 2006 total figure. All of these increases in consumption are in the transportation sector, which will account for 73 percent of total liquid fuels consumption in 2030, up from 68 percent in 2006.

Gilbert and Perl (2007) studied that the growth in motorized movement of people is about 2% per year worldwide, totaling some 30 trillion person-kilometers; about a quarter (7.5 trillion person-kilometers) comprises travelling in, to, and from the U.S. In addition, motorized movement of freight grows twice faster (4%) per year, totaling some 60 trillion tonne-kilometers; about a sixth (10 trillion tonne-kilometers) comprises freight movement in, to, and from the U.S. Since 95% of travel and freight movement by land, sea, and air is fuelled by products of petroleum liquids, oil consumption also increased significantly (Gilbert and Perl, 2007).

It is recorded that the average growth in oil consumption by transportation is approximately 1.5%-2.0% (USDOE, 2007). Being the major freight transportation mode, the growth in oil consumption of heavy-truck is striking at 3.5% annual (USDOE, 2007). The growth in oil consumption of air transportation mode (freight and non-freight) also is catching up with an annual 1.8% rate (USDOE, 2007).

Unfortunately, petroleum and related liquid fuels are not unlimited resources. These energy sources are nonrenewable. According to DOE EIA (2006), total world crude oil reserves were only about 1,143.355 billion barrels. The same source reported in 2006 that the amount of proved producing reserves of crude oil within the U.S. is 20.972 billion barrels while the amount of proved nonproducing reserves of crude oil within the U.S. is only 5.174 billion barrels.

Over the last 30 years, America's demand for energy has grown unabated. However, the energy production companies had been fighting a losing battle to increase domestic oil production (Western Governors' Association, 2008). U.S. daily oil production has fallen from over 11 million barrels per day (mbpd) in 1970 to 5.1 mbpd in 2007. Although the difference between 20.7 mbpd consumption and 5.1 mbpd production was substituted by other sources of liquid fuels, the substitution reached only up to 3.6 mbpd in 2007. The United States has become more and more dependent on imported foreign oil. In 2007, more than half of the demanded petroleum was imported (UTDOE EIA, 2007). Unfortunately, much of that oil is imported from nations that are fragile, at best, and hostile to the U.S., at worst (See Appendix for Figure 4, UTDOE EIA, 2007).

This dependency has posed many challenges including political, social, as well as economic consequences. The U.S. has experienced unstable national security and fear for national security for almost a decade. It is not only vulnerable to oil supply shocks but also dependent upon the willingness of other countries to provide the supply we need. Making the matter worse was the drastic growing demand and competition for oil supply coming from rapidly industrializing countries like China and India. By importing oil, the U.S. has lost revenues and increased the trade deficit. Furthermore, the continual transportation fuel price volatility has seriously hindered economic productivity and growth. These reasons all point to a need to curb oil consumption and thus reduce dependency on imported oil in particular and reduce dependency on oil in general. The high speed surface corridor concept promotes the use of hybrid vehicles which are considered as the key to reducing the U.S. transportation system's use of petroleum-based fuels.

2.5 Global environmental impacts of current transportation system

Petroleum-based transportation was the biggest contributor to CO^2 emission in U.S. in 2007 and has always been one of the largest emitter among end-use sectors (DOE EIA, 2007). Transportation contributions have increased by 25 percent since 1990 and now account for approximately 2 billion metric tons of CO^2 emissions annually (DOE EIA, 2007).

CO_2 is known to be the most important cause of global warming. It is also evident that global warming is no longer a threat but a present danger to humankind, nations, and nature. A study by scientists at the World Health Organization (WHO) reported that 154,000 people die every year from the effects of global warming, from malaria to malnutrition and these numbers could almost double by 2020 (EcoBridge, 2008). In addition, there have been increasing numbers of storms, floods, killer heat waves, and weather-related natural disasters. According to Karl (1996), in recent decades U.S. has experienced a 20 percent increase in blizzards and heavy rainstorms. National Climatic Data Center reported that in July 1995, more than 1,000 people died from heat-related causes in a heat wave in the Midwest. 4 years later, in July 1999 another more than 250 people died from another heat wave that seared eastern U.S. The most destructive heat waves, however, were in June 2003 when 1,700 people died during the heat wave hit India and in the following August when 35,000 Europeans died. Damages from weather-related natural disasters (floods, storms, droughts, fires) have accumulated drastically every year for the U.S. in particular and worldwide in general. Estimated total damages worldwide for the entire decades of the 1980s were $83 billion while the figure for the 1990s soared above $340 billion which was a 300% increase (EcoBridge, 2008). In addition, there is evidence of glaciers melting due to rising temperatures which then directly cause a rise in sea levels. Many different regions around the world are in danger of being lost to rising seas (EcoBridge, 2008).

2.6 Hidden costs of current transport system

According to Levinson et al. (1996), hidden costs of transportation are often known as congestion (time), accidents, health impacts, pollution impacts, and noise and vibration (peace and quiet). Although some hidden costs can be quantified and others are not quantifiable, all of these costs are undeniable.

Congestion cost

Victoria Transport Policy Institute (VTPI) (2007) defines traffic congestion costs as consisting of "incremental delay, driver stress, vehicle costs, crash risk, and pollution resulting from interference between vehicles in the traffic stream". Each vehicle on a congested road system both imposes and bears congestion costs. More importantly, larger and heavier vehicles cause more congestion than smaller, lighter vehicles because they require more road space and are slower to accelerate (VTPI, 2007). In addition, congestion costs per vehicle-mile increase with speed because faster vehicles require more "shy distance" between them and other objects. Furthermore, congestion cost is considered to be inequitable because the costs imposed and borne vary significantly between modes (VTPI, 2007). For example, congestion costs imposed per passenger-mile are lower for bus and rideshare passengers, but they bear the same congestion delay costs as single occupant drivers. It is indisputable that even non-drivers are negatively impacted by traffic congestion. This is unfair and inefficient and it is obvious also that everyone can benefit from reduced congestion with a more effective transport system. The Texas Transportation Institute (2005) reported the congestion costs for 68 major U.S. urban regions totaling $78 billion in 1999. These costs were equivalent to 4.5 billion hours of delay and 6.8 billion gallons of excess fuel consumed. If including other regions, congestion costs for U.S can reach between $100-150 billion annually (VTPI, 2007).

Accident cost

Accident costs can be quantifiable under two forms. The first form considers accident cost as the number of physical impacts such as the number of accidents, the number of vehicles damaged, and the number of human injuries, disabilities or deaths. The other form is monetary values such as costs of vehicle damages, medical expenses, and disability compensation (VTPI, 2007). Victoria Transport Policy Institute (2007) reported that although United States has one of the lowest per-mile traffic fatality rates, the nation has one of the highest per capita traffic fatality rate due to high annual per capita vehicle travel

Center for National Truck Statistics (CNTS) (2000) also provided an alarming number of accident statistics related to trucks. For example, an average of about 5,000 trucks is involved in a fatal traffic accident each year. The number of persons killed in accidents involving a truck was 5,567 in 2000. There were 713 truck drivers killed in traffic accidents in 2000 and it was increased from 658 in 1998. In addition, traffic accidents involving trucks also caused the deaths of approximately 360 pedestrians and 70 bicyclists each year. Moreover, there are about 136,438 large trucks involve in nonfatal crashes annually, 54,961 large trucks involved in injury crashes, and 81,477 large trucks involved in tow away crashes. Some of the reasons associated with large truck crashes are interruption of the traffic flow, unfamiliarity with roadway, inadequate surveillance, driving too fast for conditions, illegal maneuver, inattention, fatigue, illness, brake problems, felt under work pressure from carrier, tire problems, following too close, cargo shift, alcohol, and illegal drugs use (CNTS, 2000). Monetary-wide, Wang, Knipling, and Blincoe (1999) estimated U.S. crash costs as totaling $432 billion in 1997. The U.S. Department of Transportation (DOT) also published a guidance memorandum recommending that each avoided accident fatality be valued at $3.0 million dollars, with a 7 percent annual discount rate for depreciating future costs.

Health cost

Health impacts are hidden costs that have been calling for more awareness in the past decade. Inadequate physical activity is a major contributor to various health problems like heart disease, hypertension, stroke, diabetes, obesity, osteoporosis, depression, and even some types of cancer (VTPI, 2007). However, for transportation drivers, especially on long-distance trips, exercise is a luxury and unaffordable since they require special time, effort, and expenditure. According to Murray (1996), cardiovascular disease are the leading causes of premature death and disability in developed countries, causing ten times as many lost years of productive life as road crashes.

Pollution cost

Air pollution tends to be overlooked but it is a serious matter causing damage to human health as well as ecological and esthetic degradation. In previous section, we discussed the visible global impacts of CO^2 emission. However, there are many other air pollutants emitted from vehicles that have been affecting the health of humans, leading to ecological changes and climate changes locally, regionally, and globally every day. U.S Environmental Protection Agency (USEPA) (2000) have investigated various types of vehicle pollution emissions in addition to CO^2 such as CO, CFC, HCFC, etc.

Noise cost

Noise refers to unwanted sounds and vibrations (VTPI, 2007). Transportation vehicles cause various types of noise including engine acceleration, tire/road contact, braking, horns, vibration, and infrasound (low frequency noise). Traffic noise indirectly affects life and the economy. For example, traffic noise can discourage outdoor activities or make some locations undesirable for housing or other land use purposes. It is, however, difficult to quantify or monetize noise costs.

3. Characteristics of the high-speed surface corridor

The foregoing discussion indicates that several trends seem to be coming together in such a way that the current transportation modes will become inadequate to fulfill international as well as national needs. In these are included the growth in traffic, trends in petroleum production, petroleum price instability, global environmental impacts and many hidden costs associated with the current transportation modes. The dependence on oil as the virtually primary source of energy for transportation makes the U.S. vulnerable due to factors beyond its control. Furthermore, there have been changes in the characteristics of transportation needs. Freight is being shipped over longer distances in smaller packets using modes that provide faster, on time and traceable packets. There is a need to look for alternate transportation technologies that use alternate sources of energy that are renewable and affordable. Gilbert and Perl (2007) suggest that only electricity could reasonably power acceptable levels of surface transportation. Therefore, a high-speed surface corridor that allows vehicles to travel at speeds in excess of 250 miles per hour will be well suited.

Some countries have implemented high-speed rail systems using steel-on-steel technologies. However, these efforts have been largely limited to the transportation of people over short distances. Due to the wear and tear as well as energy costs associated with these technologies, longer distance high speed trains that carry freight as well as people have not been feasible. Also, rail based transportation systems often require long loading and unloading times as compared to road transportation systems.

We propose a corridor that uses Magnetic Levitation (MagLev) technology. This corridor should support hybrid vehicles that can operate on conventional roads as well as on the magnetic tracks. This format would have several advantages that will greatly impact the effectiveness and efficiency of the transportation process. First, it will require electric power that is expected to become increasingly less dependent on carbon based energy. Consequently, as compared to road transportation, it will project a much smaller carbon footprint. Second, because there will be very little contact between moving parts, not only will there be little wear and tear on the vehicle and infrastructure, but the amount of noise emanating from the system will be much lower as compared to both rail and road systems. Third, the vehicles do not need any guidance from a "driver" while travelling on the magnetic track. This will result not only in substantial savings, but will also improve the quality of life of truck drivers who will not need to work away from their homes for long durations. Fourth, the magnetic tracks are raised above the ground so that they do not directly intersect with other modes of transportation. This coupled with the fact that all vehicles on the system travel at exactly the same speed, will result in a substantially reduced possibility of collisions or other unsafe situations. Finally, this concept is consistent with the tried and tested manufacturing concept of small lot sizes and just-in-time deliveries including waste reduction. A high-speed surface corridor used by commercial (trucks and trains) and noncommercial vehicles (personal use vehicles) will considerably increase the independence and convenience that passengers will not have when using high speed rail systems.

3.1 Energy efficient transportation mode

A MagLev system is substantially more energy efficient as compared to other modes. At 300 mph in open atmosphere, a MagLev train would consume only 0.4 megajoules per passenger mile, compared to 4 megajoules per passenger mile for a 20-miles-per-gallon car traveling at 60 mph. At 150mph in open atmosphere, a MagLev would consume just 0.1 megajoules per passenger mile, which is just 2.5% of the energy consumption of a typical car travelling at just 60 mph. In low-pressure tunnels or tubes (such as the one proposed for Switzerland's Metro system), energy consumption per passenger mile will equal to 10,000 miles per gallon in a traditional automobile.

3.2 Environmental friendly transportation mode

MagLev vehicles emit no pollution although the production of the needed electricity using fuels such as coal or natural gas does result in the emission of CO_2. However, the resulting CO_2 emission is much less than that from autos, trucks, and airplanes (Powell and Danby, 2005; IHSRS, 2007). MagLev vehicles are also quieter than autos, trucks, and airplanes and because it uses unobtrusive narrow-beam elevated guide-ways, its footprint on the land is much smaller than that of highways, airports, and railroad tracks. Its guide-way can flexibly adapt to the landscape (Transrapid, 2008). Gradients can be steeper (10%) and curves tighter.

3.3 Capacity

Intercity trucking is growing exponentially in America. Many U.S. Interstates carry more than 15,000 trucks per day. A MagLev system will reduce the congestion on the current transportation system, especially in already congested metropolitan areas. Although only transporting passengers, Shinkansen (Japan's "bullet train") is an example of how frequent, on-time, and reliable this type transportation mode can be. For example, the Shinkansen can dispatch trains every 3 minutes and the average delay on the Shinkansen lines is only 6 seconds (IHSRS, 2007). A MagLev guide-way can transport tens of thousands of passengers per day. The capacity of a transportation corridor depends upon the speed at which transporters can move in the corridor as well as the distance between the transporters at cruising speeds. In the case of MagLev systems, transporters can consistently move at speeds in excess of 250 mph and at the same time these transporters can be held apart electronically and be separated by just a few feet. Because all the transporters must move at exactly the same speed, there is no need to maintain a large gap between vehicles. Consequently, a large number of transporters can pass a given spot in any given duration.

3.4 Automated guided transportation mode and its related benefits

The Maglev vehicles can travel without human intervention. Not only does this have an impact on the operating cost of the system, it also has an impact on the lives of the truck drivers. Now they can remain closer to their homes and bring vehicles to the entrance of the guide-way rather than drive thousands of miles per week away from their families. These long distance drives also result in several health-related problems ranging from obesity to back and spine related maladies.

Researchers also suggest that a MagLev system may be safer than other transportation modes. This is because the distance between consecutive MagLev vehicles on a guide-way and the speed of the vehicles are automatically controlled and maintained by the frequency of the electric power fed to the guide-way. The possibility of collisions between vehicles on the guide-way is virtually nonexistent. In addition, because the guide-ways are elevated, there is no possibility of collisions with autos or trucks at grade crossings. There has never been a fatality due to a train accident in Shinkansen since the beginning of its service in 1964 (IHSRS, 2007). There was an accident on a MagLev system in Germany in 2006. However, the incident was attributed to human error. A test vehicle was routed to a section of the guide-way where a maintenance vehicle was parked.

3.5 Wear and Tear

The life of a MagLev guide-way is expected to be more than 50 years with minimal maintenance, because there is no mechanical contact and wear, and also because the vehicle loads are uniformly distributed, rather than concentrated at wheels. The guide-ways are usually elevated and can be built along current highway corridors.

4. What is MagLev?

Substantial research has already been done with regards to the technology itself. There are three primary types of MagLev technology: (1) electromagnetic suspension (EMS) which uses the attractive force of a magnet beneath a rail to lift the train up, (2) electrodynamic suspension (EDS) which uses a repulsive force between two magnetic fields to push the train away from the rail, and (3) stabilized permanent magnet suspension (SPM) uses opposing arrays of permanent magnets to levitate the train above the rail (Goodall, 1985; Heller, 1998; Post, 2000; Tsuchiya and Ohsaki, 2000).

According to IHSRS (2007), the German company Transrapid has developed attraction-force MagLev technology that is the first MagLev system in commercial use. This technology has been deployed in Shanghai, China where MagLev trains connect the city with its airport. This project in Shanghai is a 19-mile track and costs approximately $1.2 billion which is around $63 million per mile. In addition, on March 23 2007, the Chinese government approved a proposal for extending the line to Hongqiao Airport which is a near city of Hangzhou, the capital city of neighboring Zhejiang province. The expected cost for this project is $4.5 billion but will reduce the travelling time from two hours to thirty minutes (IHSRS, 2007). This also seems to be the technology being adopted in the US.

Although the development of MagLev infrastructure is very costly, (according to the Federal Railroad Administration, the initial average capital cost of available MagLev technologies ranges from $40 to $100 million per rail mile (IHSRS, 2007)), MagLev operating costs are only 3 cents per passenger per mile and 7 cents per ton mile, compared to 15 cents per passenger mile for airplanes, and 30 cents per ton mile for intercity trucks (Powell and Danby, 2005). If a closed loop MagLev system is developed between Los Angeles and Chicago, for example, with current estimated cost of $40 to $100 million per mile, the initial cost will be between $160 billion to $400 billion (the distance between Los Angeles and Chicago is about 2,019 miles, www.mapsonus.com).

If a closed loop MagLev system is developed between Los Angeles and New York, the initial cost will be between $220 billion to $556 billion (the distance between Los Angeles and New York is about 2,782 miles, www.mapsonus.com). Given that the life of the guide-way is expected to be 50 years, it will likely compare favorably with other modes. For example the U.S. currently spends about $300 billion annually on intercity trucking routes (Powell and Danby, 2005).

5. High-speed surface corridor conceptualization

The advantages of high speed transportation can be best achieved if one travels at high speeds for long distances. In most descriptions of high speed transportation systems, they are conceived as mass transit systems (trains) for moving people in and out of congested areas. The MagLev train linking Shanghai to its airport travels a total distance of 30 km in 7 min and 20 seconds. We are proposing a system of high-speed surface corridors capable of moving vehicles at speeds of over 250 mph over long distances; for instance from Los Angeles to Chicago which are two major transportation hubs in the U.S. The high-speed surface corridor will be a closed loop infrastructure with multiple entries and exits, perhaps every 250 miles or so. This corridor will allow for the transportation of people and freight. It will also allow for a variety of modes of transportation including cars, trucks and trains, all travelling at the same speed and controlled externally.

In contrast to what is being done in other parts of the world with respect to high-speed transportation, we are proposing a system that will not only consist of high-speed trains, but will also allow for the inclusion of other modes such as cars and trucks. This is essential for two reasons. First, given the psyche of the American people where independence is a very important criterion as far as transportation is concerned, any train based system will achieve only limited success. However, if the same system can be used by cars, the utilization and consequently the return on the investment can be increased substantially. This will allow users to have access to high-speed transportation as well as access to their own cars when they reach their destination thus reducing expenses and delays associated with renting a vehicle.

Furthermore, if the same system can also transport freight, then even greater returns can be achieved. As discussed above, the trend seems to be towards customers demanding quicker delivery of smaller packets. Rather than trying to move train loads, we have moved towards truck loads, and now we can move to even smaller containers of less than 15 tons each. These containers will not need a “driver”. This has two major benefits. First is cost. Second, currently truck drivers frequently stay away from home for long durations. This has a big impact on their lives, both in terms of their relationships and their health. Now we will be able to move smaller containers over long distances at lower costs and have an impact on the quality of life issues of truck drivers.

We propose that the technology that will be used for the MagLev guide ways should be such that it is amenable to the development of hybrid vehicles that are capable driving on conventional roads and highways as well as on the MagLev system.

6. Simulation Model

In order to be able to compare the performance of different transportation systems, we developed three simulation models using the ARENA software. We compared the performance of the three systems based upon the time that a “typical” entity would spend in the system as well as the average number of entities that would be in the system given a certain level traffic. The entity here is a generic term that could signify a car or a freight container. The first model looked at the option of transporting containers using trains, the second model looked at the option of using trucks and the last model looked at using a high speed magnetic levitation system that allowed containers and cars. These models are described below in detail.

6.1 Train Model

First, we developed a simulation model to study the performance of a conventional train system to study the amount of time a "typical" entity would take to get from a source to its destination as well as the average number of entities that would be in the system. We assume that all of the entities are of the same size and that all of them travel to the same destination. For example, all of the entities have to travel from Los Angeles to Chicago. We assume that the entities will be loaded on to a truck, brought to the railway loading area, loaded onto a waiting rail car, transported to Chicago, unloaded on to a truck and then delivered to the customer. The graphic of the simulation model is shown in Figure 5. The parameters used in the simulation model are given in Table 3.

6.2 Truck Model

A simulation model of a truck system was also developed and Figure 6 is a graphical representation of this model. In this system we make the same assumptions about the source and destination for the entities as in the Train model. Here, once the container has been loaded on to the truck, it proceeds to the highway and after traveling to the destination it exits the highway and drives to the final destination. There is no need to unload the truck and load the rail car or to unload the rail car and load the tuck. Table 4 details the values of the parameters used in the simulation. The travel times for trucks is longer than that for the train because of the legal restrictions for speed as well as scheduled rest times for drivers.

6.3 MagLev System Model

A simulation model of the MagLev system was also developed and is shown in Figure 7. In this system, each entity is loaded onto a vehicle that is capable of travelling on surface roads and also traveling on Magnetic Levitaion (MagLev) systems. After the entities are loaded on the vehicle, it travels to the MagLev system entry point, the driver leaves the vehicle which then travels towards its destination at a high speed using the MagLev system, exits the system where it is met by a driver who then drives it to the final customer using the conventional road system. It travels at a high speed on the MagLev system and no breaks are required because there is no driver. Table 5 details the values of the parameters used in the simulation.

6.4 System Performance

The simulation models were run for 10 replications of a simulated time of 1000 hours of operation of which the first 200 hours were used to achieve steady state. The performace of the three systems is presented in Table 6. The simulation models show that the the truck system may take a longer time (146.04 hrs compared to 117.31 hrs) but provides much greater certainty in the time taken as evidenced by the tighter confidence interval (0.08 hrs compared to 1.35 hrs). This is a reason most businesses prefer this mode of transportation. The MagLev system results in a much shorter time in system with an even tighter confidence interval. This means that time to reach destination is reduced substantially. In addition, there is a large difference in the number of containers in the system. In the train system there were 710 entities in the system on average as compared to 877 in the truck system. The MagLev system had just 82 entities in the system. This shows that the capacity of the MagLev system is substantially higher due to the higher speeds that can be achieved. Consequently, it can be argued that one “lane” of MagLev will be able to replace several lanes of conventional roadways and/or railways. This can reduce the amount of capital invenstment required to achieve the same level of operation.

7. Conclusion

There is a need to find environmentally friendly ways to transport materials over long distances quickly. This is because the demand for transportation is increasing with increasing global trade where the points of consumption and production are widely separated. There is also an expectation on the part of customers that they place small orders and that these orders get delivered quickly.

Furthermore, American travelers want to reach their destination faster and have individual flexibility. They want to be able to travel whenever they want and not be inconvenienced by train schedules.

One of the ways that these objectives can be achieved is through a high speed surface corridor using Magnetic Levitation technology. This technology can produce substantial benefits in terms of reducing the environmental impact of transportation, but also result in social and economic benefits.

APPENDIX

Table 1 - Commercial Freight Activity in the U.S. by Transportation Model: 2002

Transportation Model	Modal estimates			Relative shares (percent)		
	Value (billion$)	Tons (million)	Ton-miles (billion)	Value	Tons	Ton-miles
All modes	**13,052**	**19,487**	**4,409**	**100.0**	**100.0**	**100.0**
Single modes	**11,599**	**18,894**	**4,073**	**88.9**	**97.0**	**92.4**
Truck	9,075	11,712	1,515	69.5	60.1	34.4
Rail	392	1,979	1,372	3.0	10.2	31.1
Water	673	1,668	485	5.2	8.6	11.0
Air (incl. truck and air)	563	6	13	4.3	-	0.3
Pipeline	896	3,529	688	6.9	18.1	15.6
Multiple modes	**1,121**	**229**	**233**	**8.6**	**1.2**	**5.3**
Parcel-postal-courier	1,022	27	21	7.8	0.1	0.5
Truck and rail	77	52	50	0.6	0.3	1.1
Other multiple modes	22	150	162	0.2	0.8	3.7
Unknown modes	**331**	**365**	**103**	**2.5**	**1.9**	**2.3**

(Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2006)

Table 2 - Freight Shipments by Shipment Weight: 1993 and 2002

Shipment weight	Value (billions$) 1993	Value (billions$) 2002	Value (% share) 1993	Value (% share) 2002	Percent change, 1993-2002
Less than 500 pounds	1,368	2,099	23.4	25.0	53.4
500 to 999 pounds	319	430	5.5	5.1	34.9
1,000 to 49,999 pounds	3,411	4,857	58.3	57.8	42.4
50,000 pounds or more	749	1,012	12.8	12.0	35.1
All shipment sizes	**5,846**	**8,397**	**100.0**	**100.0**	**43.6**

Shipment weight	Tons (millions) 1993	Tons (millions) 2002	Tons (% share) 1993	Tons (% share) 2002	Percent change, 1993-2002
Less than 500 pounds	109	118	1.1	1.0	8.0
500 to 999 pounds	65	77	0.7	0.7	18.8
1,000 to 49,999 pounds	3,830	5,068	39.5	43.4	32.3
50,000 pounds or more	5,685	6,405	58.7	54.9	12.7
All shipment sizes	**9,688**	**11,668**	**100.0**	**100.0**	**20.4**

Shipment weight	Ton-miles (billions) 1993	Ton-miles (billions) 2002	Ton-miles (% share) 1993	Ton-miles (% share) 2002	Percent change, 1993-2002
Less than 500 pounds	29	37	1.2	1.2	28.9
500 to 999 pounds	13	17	0.6	0.6	28.0
1,000 to 49,999 pounds	728	1,038	30.1	33.1	42.6
50,000 pounds or more	1,651	2,046	68.2	65.2	23.9
All shipment sizes	**2,421**	**3,138**	**100.0**	**100.0**	**29.6**

(Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2006)

Table 3 - Parameters Used in the "Train" Simulation Model

Activity	Distribution and Value
New Container	New containers are introduced into the model with inter-arrival times that are distributed according to the Exponential distrbution with a mean of 10 minutes
Travel to Rail Head	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes
Loading at the Railway Head	Two cranes unload the container from the trucks on to waiting railway cars. The time taken by each of the cranes follws a

	Triangular distribution with a minimum of 10 minutes, maximum of 30 minutes and a most likely time of 20 minutes
Travel	The travel time is assumed to be distributed according to the Triangular distribution with a minimum of 3 days, a maximum of 5 days and a most likely time of 4 days
Unloading	Two cranes unload the rail cars on to waiting trucks. The time to unload is assumed to be the same as the time to load
Travel to customer	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes

Table 4 - Parameters Used in the "Truck" Simulation Model

Activity	Distribution and Value
New Consignment	Inter-arrival times are distributed according to the Exponential distrbution with a mean of 10 minutes
Travel to Highway	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes
Travel	The travel time is assumed to be distributed according to the Triangular distribution with a minimum of 5 days, a maximum of 7 days and a most likely time of 6 days.
Travel to customer	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes

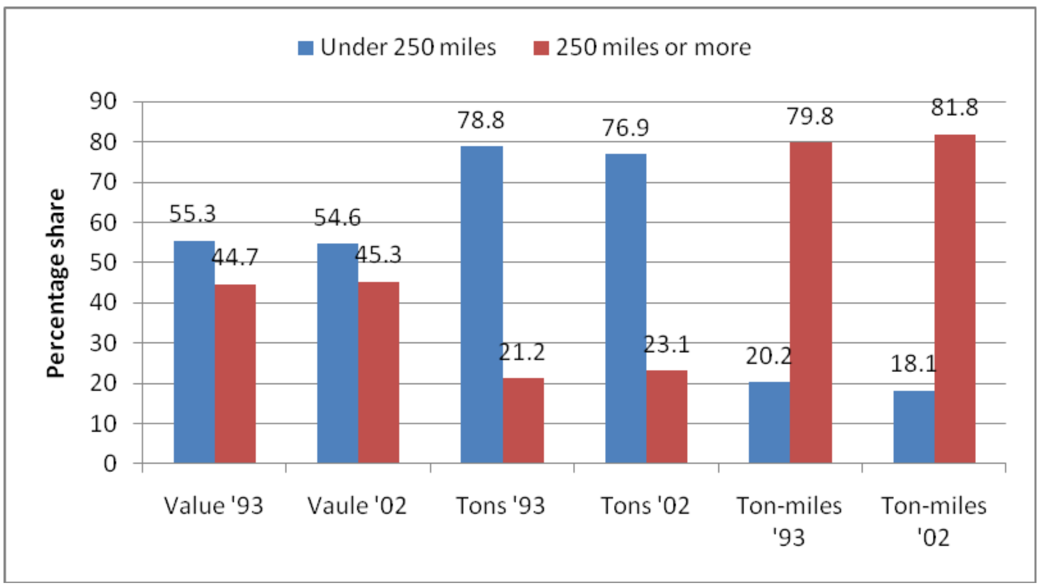
Table 5 - Parameters Used in the "MagLev" Simulation Model

Activity	Distribution and Value
Consignment Creation	Inter-arrival times are distributed according to the Exponential distrbution with a mean of 10 minutes
Travel to MagLev System	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes
Travel	The travel time is assumed to be distributed according to the Triangular distribution with a minimum of 600 minutes, a maximum of 800 minutes and a most likely time of 700 minutes.
Travel to customer	Travel times are distributed according to the Triangular distribution with a minimum of 30 minutes, a maximum of 90 minutes and a most likely time of 60 minutes

Table 6 - Performance of the Three Systems (Mean and 95% Confidence Interval)

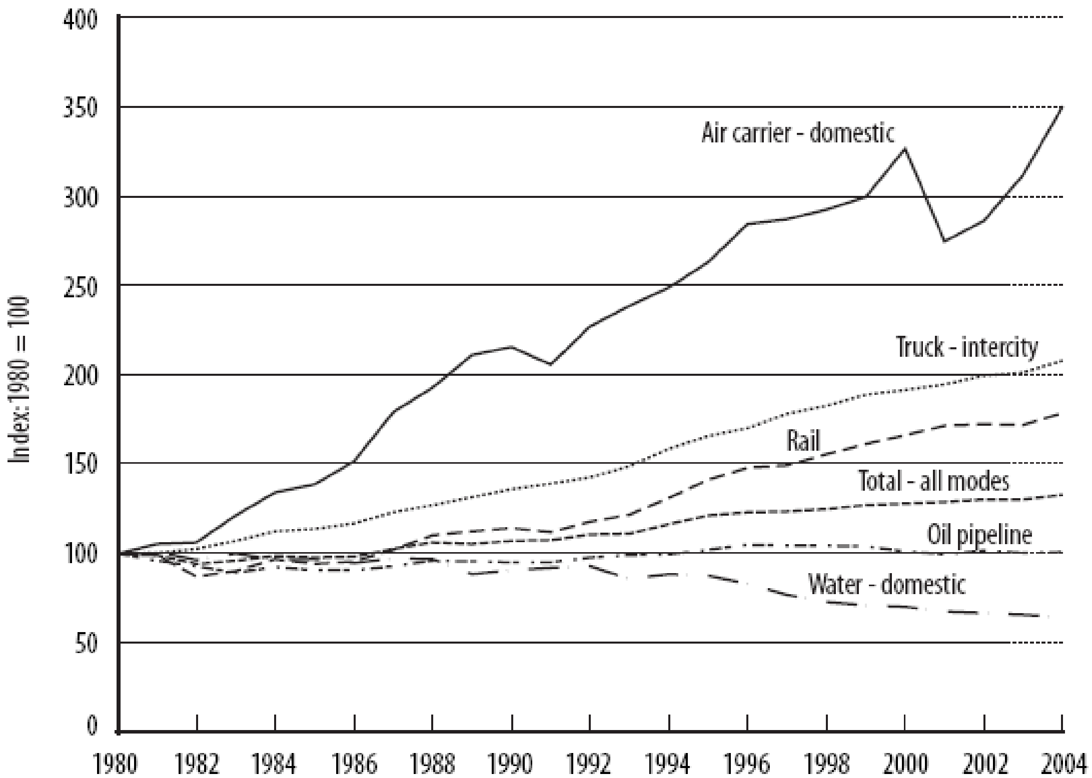
Measure	Train	Truck	MagLev
Average Time in System (hours)	117.31 ± 1.35	146.04 ± 0.08	13.67 ± 0.01
Wait Time (hours)	18.87 ± 0.48	-	-
Containers Delivered	4857.40 ± 60.06	4796.10 ± 41.51	4782.40 ± 55.10
Loading Queue	50.35 ± 0.335	-	-
Unloading Queue	59.59 ± 2.86	-	-
Containers in the System	710.80 ± 8.95	877.11 ± 8.20	81.77 ± 0.93

Figure 1 - U.S. Freight Shipments by Distance Shipped: 1993 and 2002



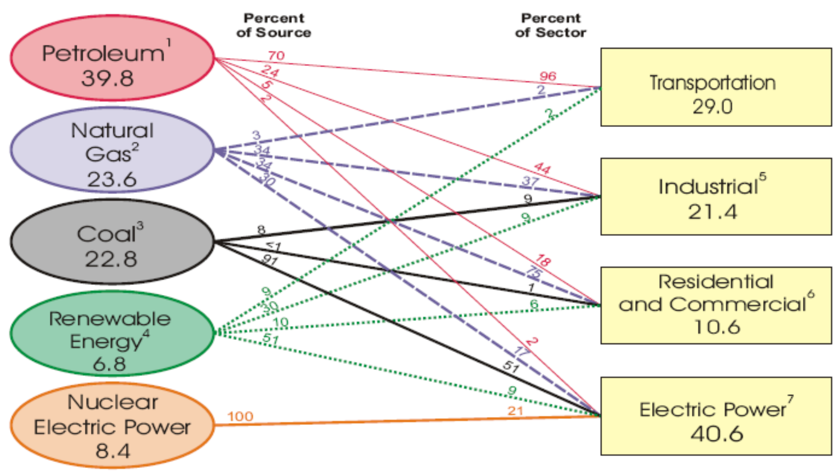
(Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2006)

Figure 2 - Growth in U.S. Domestic Freight Ton-Miles by Mode: 1980 - 2004



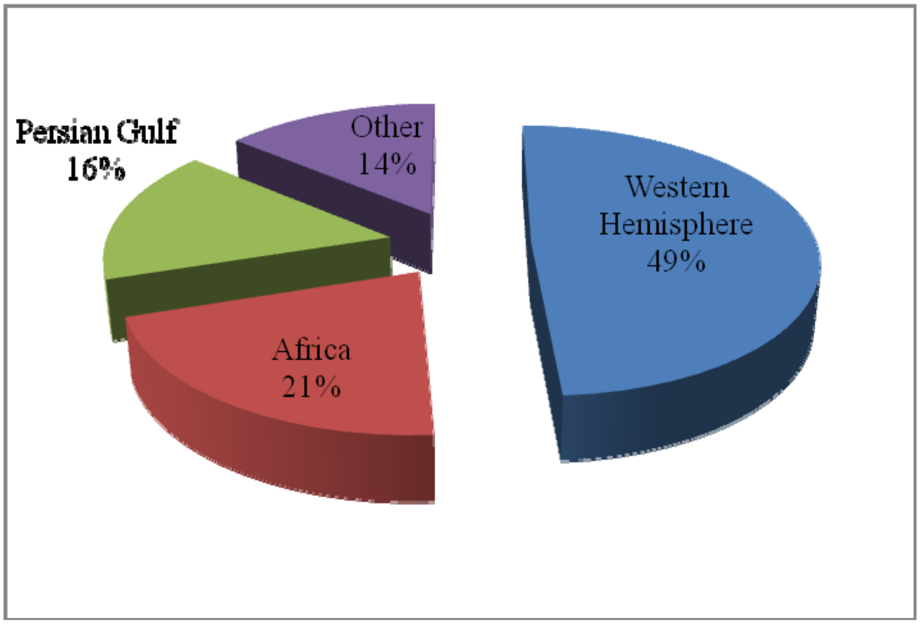
(Source: U.S. Department of Transportation, Bureau of Transportation Statistics, 2006)

Figure 3 - U.S. Energy Consumption by Source and Sector: 2007 (Quadrillion BTU)



(Source: U.S. Department of Energy, Energy Information Administration, 2007)

Figure 4 - Sources of U.S. Petroleum Imports: 2007



(Source: Department of Energy, Energy Information Administration, 2007)

Figure 5 - Simulation Model for "Train" Option

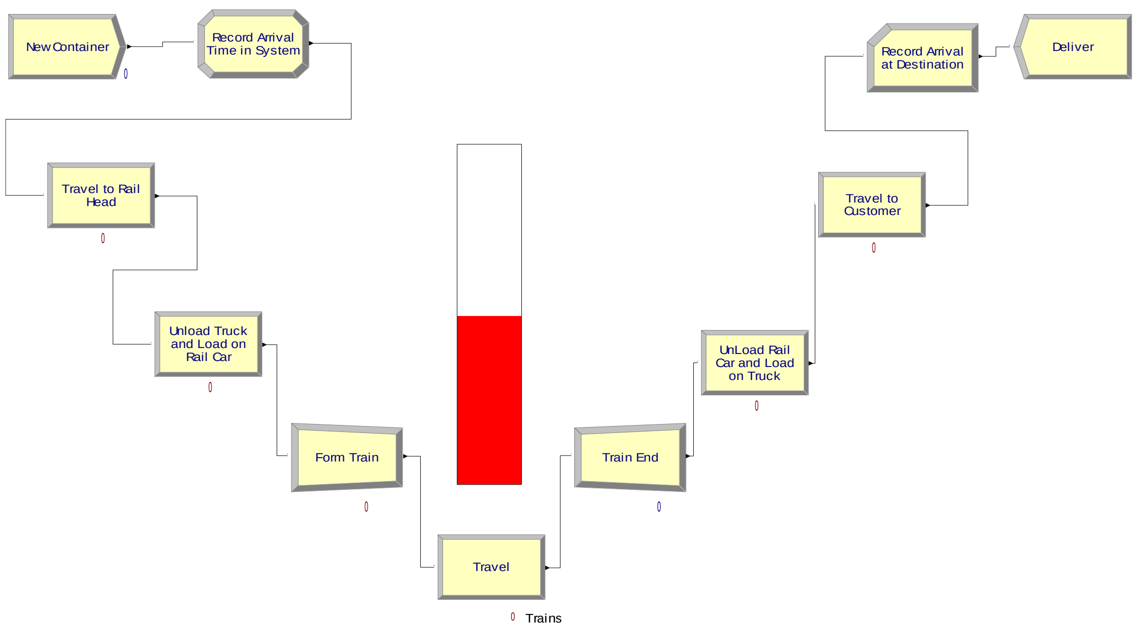


Figure 6 - Simulation Model for "Truck" Option

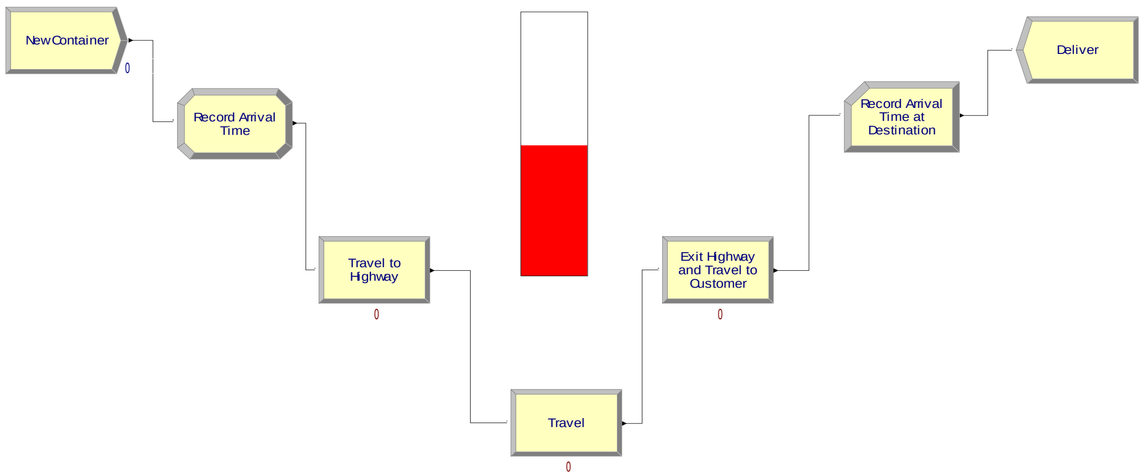
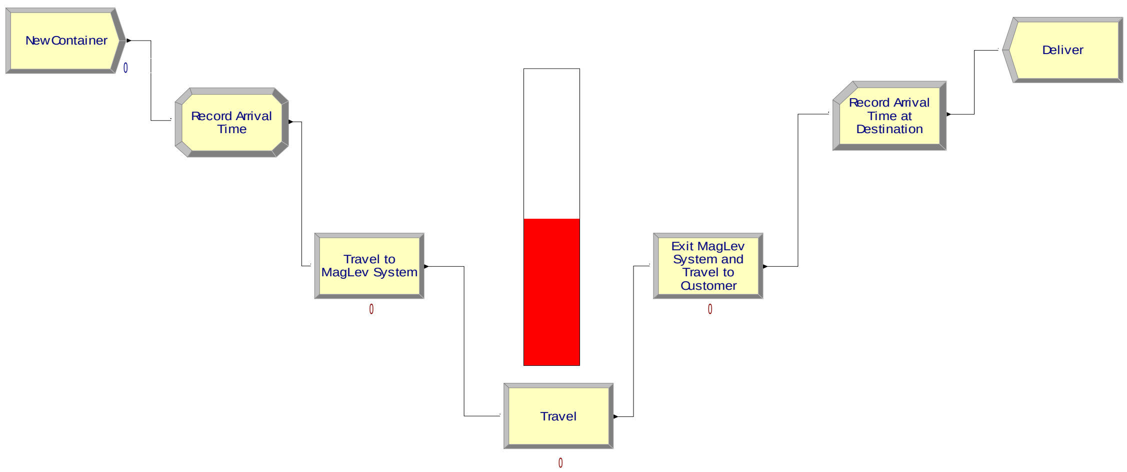


Figure 7 - Simulation Model for the "MagLev" Option



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