THE WORKINGS OF MAGLEV:
A NEW WAY TO TRAVEL

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EXECUTIVE SUMMARY

Maglev is a relatively new form of transportation and the term is derived from magnetic levitation. This report describes what maglev is, how it works, and will prove that maglev can be successfully constructed and provide many fully operational advantages. The different types of maglev technology were analyzed. Several case studies were examined to understand the different maglev projects whether operational, still in construction, or proposed. This report presents a plan to construct a maglev network using Maglev 2000 vehicles in the United States. A maglev system provides energy, environmental, economic, and quality of life benefits. An energy and cost analysis was performed to determine whether maglev provides value worth pursuing. Maglev has both a lower energy requirement and lower energy costs than other modes of transportation. Maglev trains have about one-third of the energy requirement and about one-third of energy cost of Amtrak trains. Compared to other maglev projects, the U.S. Maglev Network would be cheaper by a weighted average construction cost of $36 million per mile. Maglev could also be applied to convert the Honolulu Rail project in Hawaii from an elevated steel wheel on steel rail system into a maglev system. Due to the many benefits that Maglev offers and the proof that maglev can be implemented successfully, maglev could be the future of transportation not just in the United States but in the world. Maglev *will* improve the way that people travel.

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1 INTRODUCTION

Maglev is the newest mode of transportation that has been developed. It is not an ordinary train. Maglev is a shortened version of the term magnetic levitation. In a maglev system, high speed vehicles are magnetically levitated and propelled along elevated guideways. Maglev vehicles do not use wheels and do not have engines. Maglev was invented and patented in the United States by James Powell and Gordon Danby in 1966. The United States thereafter lost the lead the in the maglev industry. Through the years, several countries have been researching and developing their own maglev system. There are four maglev systems in operation (2 in China, 1 in Japan, and 1 in South Korea) as of 2016 with a few more still in the construction phase. Many countries such as Israel, India, Germany, and Switzerland are performing studies to implement and construct maglev systems. To date, the United States does not have one maglev system in operation. Maglev has energy, environmental, economic, and societal benefits that allow it to outperform the other means of mass transportation. Hawaii is currently constructing the Honolulu Rail project that uses steel wheels rail. There is a slim possibility that the Honolulu rail could be converted into a maglev line.

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2 A NEW MODE OF TRANSPORTATION

Maglev is more than just a faster train. Maglev is a new mode of transportation that was invented after the introduction of airplanes. It is different from other modes of transportation through various ways.

Maglev vehicles do not have wheels. Maglev vehicles are magnetically levitated above a guideway and move without any mechanical contact (Powell and Danby, 2011). By floating on a guideway and having no wheels, there are no friction energy loses and no point loads acting on the guideway. In contrast to the damage done on roads by trucks, there is no wear and tear on guideway due to the maglev vehicles' levitation.

Maglev vehicles do not have engines. Rather than use engines, maglev vehicles are "magnetically propelled along the guideway by a small alternating current (AC) that pushes the vehicle's superconducting magnets (Powell and Danby, 2011). The frequency of the AC determines the speed. Frequency increases speed up the vehicle; frequency decreases slow it. By not having an engine, maglev vehicles do not emit the greenhouse gases into the environment that cars, airplanes, and ships release.

Unlike airplanes, maglev vehicles do not travel in the atmosphere. While airplanes fly in the atmosphere, Maglev vehicles levitate on a guideway. In a low-pressure tunnel, maglev vehicles can reach a speed greater than 300 miles per hour (mph) and have a lower energy cost. By traveling in a low-pressure tunnel and not being affected by air drag as an airplane would, maglev vehicles can achieve high speeds without using much energy.

Maglev travel is energy efficient. Rather than use fossil fuels, a maglev vehicle uses a magnetic field to propel itself (Bonsor, 2000). According to Powell, a person driving in a 20 miles per gallon (mpg) and 60 mph car uses 2 kilowatt hours of gasoline energy. In contrast, a

maglev vehicle traveling at 300 mph only consumes 0.06 kilowatt hours of electrical energy. Involving costs where a gallon of gasoline is $3, a car traveling a thousand miles at 20 mph will take 16 hours to complete the trip at a price of $150; however, a maglev vehicles traveling at 300 mph can travel a thousand miles in a little over three hours at a cost of $5.

Maglev travel is noiseless and comfortable (Danby and Powell, 2013). Since there are no engines for maglev vehicles, all you can hear is the sound of air. The only noise is from voices of people chatting. Unlike other forms of travel, maglev travel is free of vibration and bumpiness. Riding in a maglev vehicle is as comfortable as sitting down on a chair. Maglev travel is comfortable because maglev compensates for any introduction of external forces to ensure that there is not any vibration of the vehicle when traveling.

3 HOW MAGLEV WORKS

3.1 Magnets

Maglev works by using magnets to levitate and thrust along a pathway. There are three main types of magnets that can be used for used for maglev: permanent magnets, electromagnets, and superconducting magnets.

Permanent magnets are those used for refrigerator magnets and toys. When a permanent magnet is made, an external magnetic field aligns the movements of the electrons in the atom. Permanent magnets create their own magnetic field all the time. When the external magnetic field is removed, the electron movements remain locked in place (Wilson, 2007). The permanent magnet's magnetic field lasts until it is damaged by heating or high stress. Electric power is not needed to maintain the magnetic field.

Electromagnets are used in electric motors, transformers, and even speakers. A conductive wire is wrapped around a piece of metal (Brian et al., 2000). A magnetic field around the looped or coiled wire is created by adding a current from a source of electricity to the system. As long as current flows through the conducting wires, the electromagnets continue to work. An electromagnet's conducting wire consumes electric power and turns the power into heat due to the electrical resistance of the wire. This results in losses that limit the strength and spatial extent of the magnetic field. These losses are known as I^2R losses (Power $P = I^2R$), in which I is the current (in amperage) and R is the resistance (in ohms).

Superconducting magnets are basically electromagnets that act like permanent magnets (Powell et al., 2011). Just like an electromagnet, a superconducting magnet's magnetic field is generated by flowing an electrical current through a coil of wire. The difference is that since a

superconductor does not have electrical resistance, the current will remain after the electrical leads that charged the magnets are removed.

Superconducting magnets are more powerful than permanent magnets and electromagnets in the strength of magnetic field and spatial extent of the field. Currently, maglev systems use either permanent magnets or electromagnets, which limits the capabilities of the systems. Maglev systems in operations have a half of an inch (1/2") clearance between the magnetically levitated vehicle and the guideway. Moreover, they cannot carry heavy loads such as heavy duty trucks. On the contrary, superconducting magnets increase the levitation clearance a range of 4 to 6 inches. In addition, maglev with superconducting magnets can transport heavy loads such as highway trucks and 100-ton concrete blocks. Basically, the strength of the superconducting magnets provides stability so that external forces like hurricanes do not affect the maglev vehicles' levitation on the guideway.

3.2 Maglev Systems

There are currently four different maglev systems that have been developed. The first system has electromagnets on the maglev vehicle that are attracted to the iron rails on the guideway. An example of the first system is shown in Figure 1. In the second system, the maglev vehicle consists of permanent magnets that generate a repelling force between the magnets on the maglev vehicle and those on the guideway. The third system also uses permanent magnets but they induce currents in aluminum loops on the guideway in order to generate repelling forces. The fourth system, shown in Figure 2 and Figure 3, involves superconducting magnets that induce currents in aluminum loops that are located on the guideway. The fourth system can consist of either dipole or quadrupole magnets.

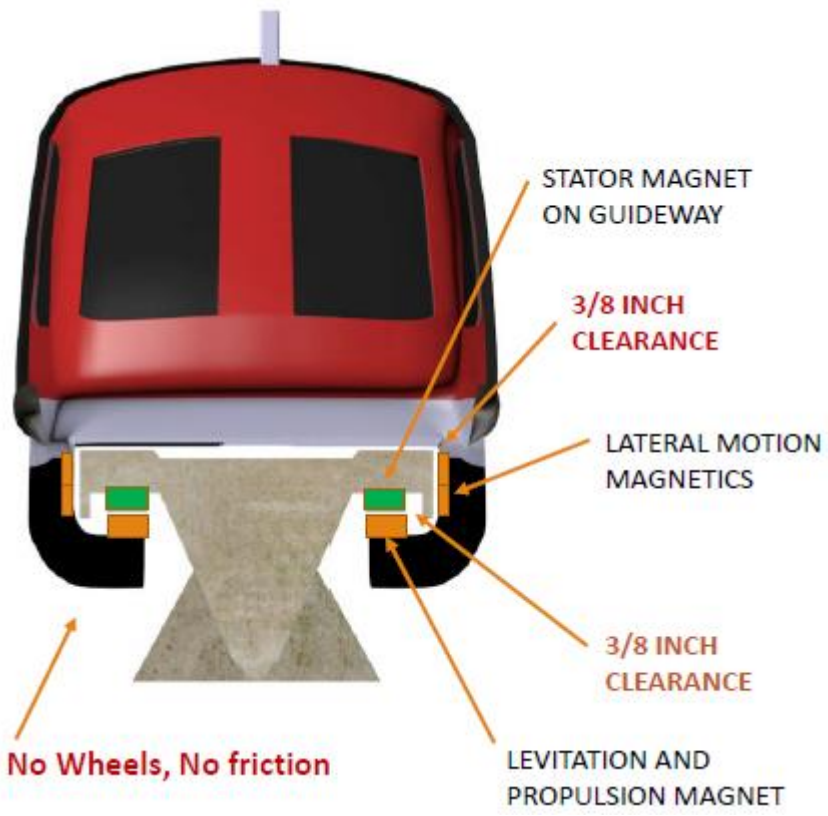

Figure 1. German Electromagnetic Transrapid Maglev (Source: http://t.magneticglide.com/assets/future_trans.pdf)

Systems 1, 2, and 3 are limited in their capabilities because their lifting power is not strong enough to carry heavy trucks, automobiles, and freight. In those three systems, the gap between the maglev vehicle and guideway is about ½ inch, which increases the construction cost due to the precision that must be maintained on the guideway. Since systems 1, 2 and 3 can only carry passengers, they will not generate as much revenue as system 4, which can transport heavy trucks as well as passengers. System 4 has a bigger gap of 4 inches or more between the maglev vehicle and the guideway, thus reducing the extra construction costs to build precise guideways. The benefits of system 4 include lower construction costs, greater levitation gap, higher revenue, and the capability to carry heavy trucks and freight.

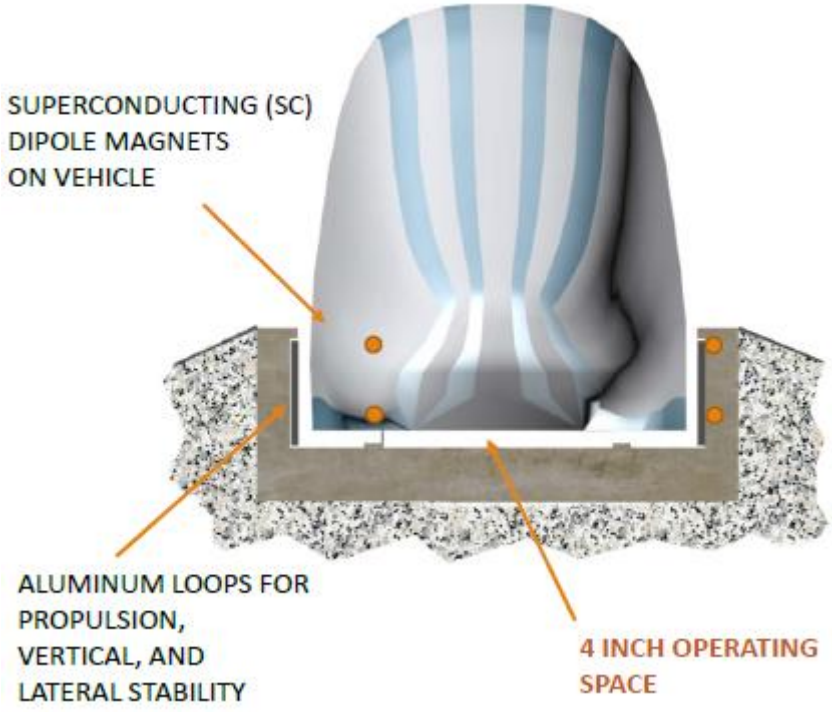

Figure 2. JR Superconducting Maglev (Dipole) (Source: http://t.magneticglide.com/assets/future_trans.pdf)

Stability is an important factor for the four systems. Systems 2, 3, and 4 are inherently stable whereas system 1 is inherently unstable. Being stable means that when a maglev vehicle's gap from guideway decreases, a magnetic repelling force automatically increases without servo control. The inherent stability of the maglev vehicle gives the vehicle the ability to maintain a safe gap between the vehicle and the guideway even when external forces such as wind act on it. By system 1 being inherently unstable, it means that when its vehicle's electromagnets get closer to the iron rails from the guideway, the lift force for constant current in the electromagnet windings becomes stronger. If the current is not reduced, the maglev vehicle will be pulled onto the guideway resulting in a crash. To deal with this dilemma of instability, the 1st generation German Transrapid Maglev system uses rapid servo control of the electromagnets on the vehicle.

When the distance between the maglev vehicle's electromagnets and the guideway's iron rails decreases, the servo control system decreases the current. When the gap between the electromagnets and iron rails increases, the servo control system will do the opposite and increase the current. The maglev vehicle will continue to maintain a safe distance from the guideway as long as the servo control system works.

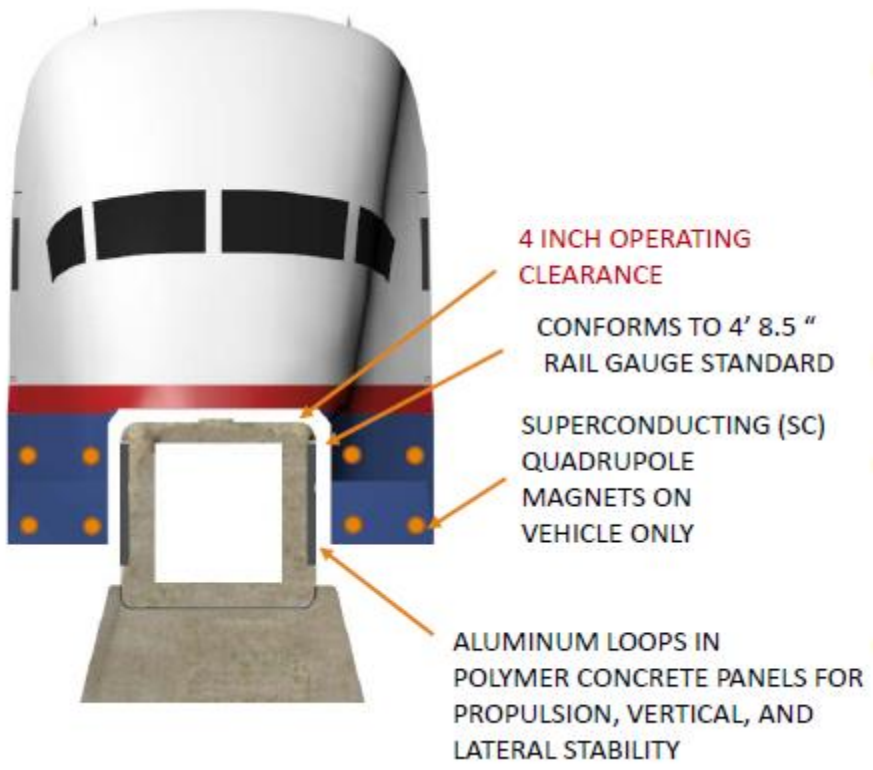

Figure 3. Powell and Danby's Superconducting Maglev 2000 (Quadrupole) (Source: http://t.magneticglide.com/assets/future_trans.pdf)

Japan Railways preferred the superconducting maglev and created their own design. The Japanese Maglev system uses a series of aluminum loops that is placed on the sides of a U-shaped guideway. The loops are not electrically powered. Moreover, the loops are separate components with no connections between sequential loops. When the maglev vehicle passes the loops, the superconducting magnets induce electric current onto the loops. The interaction

between the superconducting magnets and the induced loops provides levitation and stability. The vehicle will be stable vertically, laterally, and in the pitch, yaw, and roll directions. There is very little magnetic drag that acts on the vehicle because of the I^2R resistive electrical losses in the aluminum conductor.

There is a second set of aluminum loops on the guideway that carries an applied AC current wave. This current wave places a force on the superconducting magnets, thus propelling the vehicle along the guideway. The frequency of the AC current controls the vehicle's speed. In order to increase speed, the AC frequency is increased. There is an electrical grid that supplies power to the AC unit. The grid delivers power to increase the vehicle's kinetic energy and allow the maglev vehicle to accelerate. As the maglev vehicle continues to travel at constant speed, the grip supplies power for the maglev to overcome air drag. Kinetic energy is returned to the grid when the maglev vehicle breaks and slows down.

A safety feature of the Japanese magnetic propulsion system is known as the Linear Synchronous Motor (LSM). This motor locks the vehicle's speed into the speed of the AC current wave. By having the same speed, LSM ensures that maglev vehicles on the guideway maintain a safe fixed distance between each other. maglev vehicles that run on the same guideway cannot collide with one another while there is still the possibility of conventional trains having crashes on a railroad track.

4 MAGLEV TECHNOLOGY

4.1 Levitation

4.1.1 Electromagnetic Suspension (EMS)

The Electromagnetic suspension system uses attractive forces in order to levitate ("Magnetic Levitation"). The magnets on the maglev vehicle are attracted to the conductors on the underside of the guideway. The attractive forces are strong enough to overcome gravitational forces; thus, the attraction allows the maglev to levitate on the track. The electromagnets can only conduct electricity when there is a power supply available.

For an EMS system, the maglev vehicle contains guidance magnets that will guide the vehicle along the pathway. Moreover, the guidance magnets guide the vehicle so that it does not hit the track and cause damage. Figure 4 shows the configuration of the EMS system. With this system, the maglev vehicle levitates about ½ inch above the guideway. Due to the characteristics of the magnetic circuit, this system is inherently unstable.

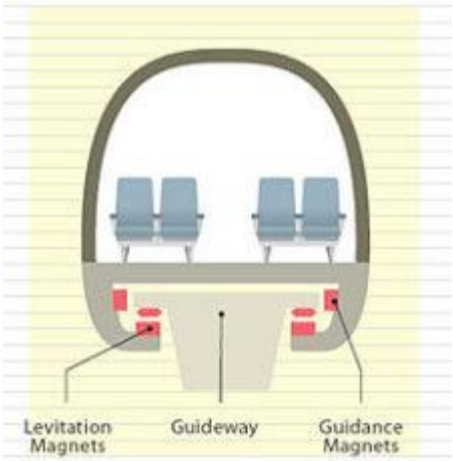

Figure 4. Electromagnetic Suspension System (Source: http://emt18.blogspot.com/2008/10/maglev-suspension-systems.html)

4.1.2 Electrodynamic Suspension (EDS)

Unlike the EMS system, the Electrodynamic Suspension System (EDS) uses magnets to create repulsive forces (Bonsor, 2000). An example of an EDS system is shown in Figure 5. Induced currents flow through coils and generate a magnetic field when the magnets on the vehicle move forward on the coils located on the guideway. The repulsive force between the magnetic coils on the guideway and the magnets on the vehicle creates a levitation that overcomes gravitational forces. Another difference between EMS and EDS maglev systems is that EDS systems involve the use of super-cooled superconducting electromagnets. Superconducting electromagnets can continue to conduct electricity after the power supply has shut down. The EDS maglev vehicles can levitate about four inches which is much higher than the EMS system. This system is stable and suitable for high speed operation.

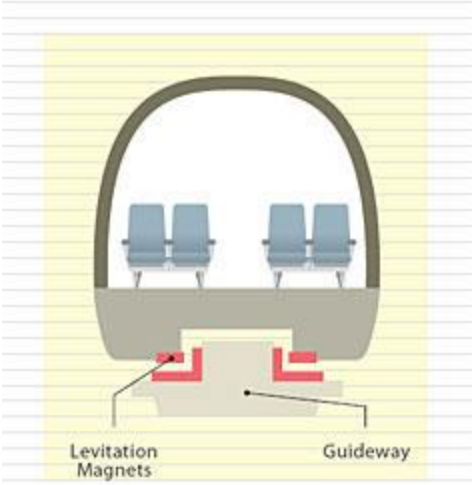

Figure 5. Electrodynamic Suspension System (Source: http://emt18.blogspot.com/2008/10/maglev-suspension-systems.html)

The EDS system has drawbacks because the maglev vehicle must roll on rubber tires until it reaches a speed of about 62 mph (100 km/h). The 62 mph speed is needed in order to acquire enough induced currents for levitation. Though wheels are needed, this could be useful

in the event of a power outage. Another disadvantage is that EDS systems produce magnetic fields with high intensity; thus, the passenger section of the train must be shielded from the magnetic field to protect passengers with pacemakers and magnetic data storages such as credit cards and hard drives.

4.1.3 Inductrack

The Inductrack is a newer type of EDS system that uses permanent room-temperature magnets as portrayed in Figure 6. Permanent magnets have not been used due to the theory that they would not create enough levitating force. The Inductrack deals with this problem by arranging the magnets in a Halbach array. The magnets are arranged in a way that the intensity of the magnetic field concentrates above the array. Essentially, the track is an array of electrically-shorted circuits comprised of insulated wire. The vehicle levitates due a magnetic field repelling the permanent magnets as the train travels on the guideway. There are two designs; Inducktrack I is for high speeds while Inductrack II is for low speeds.

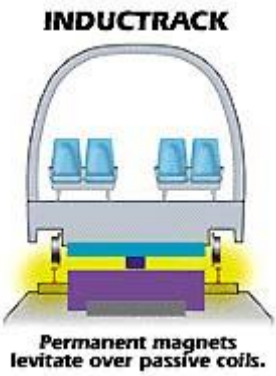

Figure 6. Inductrack System (Source: http://ninpope-physics.comuv.com/maglev/howitworks.php)

4.2 Propulsion

4.2.1 Linear Induction Motor (LIM)

A maglev train gains its propulsion forces from a linear motor (Lee et all, 2006). A linear motor is a rotary motor whose stator, rotor, and windings have been cut open, flattened, and placed on the guideway. Basically, in a linear motor, the stator is unwrapped and laid flat so that the rotor can move past the stator in a straight line (Woodford, 2016). A linear motor is better than a rotary motor because of the lower amount of vibration and noise produced from the mechanical contact of components such as chains and gearboxes.

In a Linear Induction Motor (LIM), magnetic fields are generated by the primary part, a stator, across the air gap. Then Electromotive Forces (EMF) in the secondary part, a conducting sheet, are induced by the magnetic field. The EMF produces currents that interact with the air gap flux; thus, the thrust force (also known as Lorenz's force) is generated.

There are two types of LIM. There is a short primary type (SP) in which stator coils are on the vehicle and conducting sheets are on the guideway. There is a long primary type (LP) in which stator coils are on the guideway and conducting sheets are on the vehicle. The LP type has a higher construction cost than the SP type but it does not need a current collector for operation. This makes the LP type better for high speed maglev because the transfer of energy using a current collector is difficult at high speeds. The SP type is more economical because it is easier to lay aluminum sheets on the guideway. A drawback is that the SP type has a low energy efficiency due to drag force and leakage inductance caused from the end effect. The SP type is used for low- to medium-speed maglev because the current collector limits the SP to not exceed 300 kilometers per hour (kph).

4.2.2 Linear Synchronous Motor (LSM)

The Linear synchronous motor (LSM) is similar to the LIM except that LSM has a magnetic source within itself. The thrust force is created by the interaction between the magnetic field and the currents. The speed of the maglev vehicle is controlled by the controller's frequency. The LSM uses either electromagnets or superconducting magnets. The LSM system is preferred for maglev vehicles because it has a higher efficiency and power factor than the LIM (Lee et al., 2006). The economical efficiency of the electric power consumption is an important factor for high-speed travel.

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5 MAGLEV 2000 (USA)

Even though Japan's 1st generation superconducting maglev system is successful and safe, it has limitations. For Japan's model, the guideway was expensive to build and maglev vehicles can only carry passengers. Moreover, Japan's maglev vehicles cannot travel on existing railroads. Also, in order to switch to off-line stations for loading and unloading, the vehicles must use mechanical switches while moving at a slow speed.

To deal with the limitations, James Powell and Gordon Danby (2011) designed the 2nd generation superconducting maglev system. The Maglev 2000 system is cheaper to build and is able to carry passengers, heavy highway trucks, and freight. In addition, the Maglev 2000 system can function at 300 mph on elevated guideways and at lower speeds on existing railroad tracks. Another advantage is that Powell and Danby's model can switch electronically instead of mechanically at high speed to off-line stations for unloading and loading.

Powell and Danby (2011) used superconducting magnetic quadrupoles on 2nd generation maglev vehicles to improve upon the system used in Japan. Japan's 1st generation system uses a superconducting dipole. Dipoles have two magnetic poles, a North and South pole. In contrast, quadrupoles have four magnetic poles, two North and two South poles. The quadrupole provides Maglev 2000 vehicles with the ability to travel on both elevated monorail beams and flat planar surfaces as shown in Figure 7. This advantage allows for a smooth transition between the two different types of guideway.

In order for the Maglev 2000 vehicle to travel along a monorail guideway, the sides of the quadrupole magnets interact with aluminum loop panels on the sides of the monorail beam. This causes the maglev vehicle to levitate as well as provide stability. There is a second set of aluminum loops panels that magnetically boosts the maglev vehicle. When approaching an off-

line station, there is a transition from the monorail beam onto a planar surface switch section. On the planar surface, there are two sets of aluminum panels, one that is closed circuited and another that is open circuited. If a maglev vehicle is supposed to pass an off-line station, traffic control will close Panel A so that induced current will flow and open circuits at Panel B. If a maglev is supposed to stop at an off-line station, traffic control will open the circuits at Panel A and close circuits at Panel B. The planar surface transitions into two monorail beam guideways. One monorail guideway is for the route back to the main high-speed guideway while the other monorail guideway is for the vehicle to stop at the off-line station. When the maglev vehicle leaves the off-line station, there is another planar surface switch section that allow it to transition onto the main high-speed guideway.

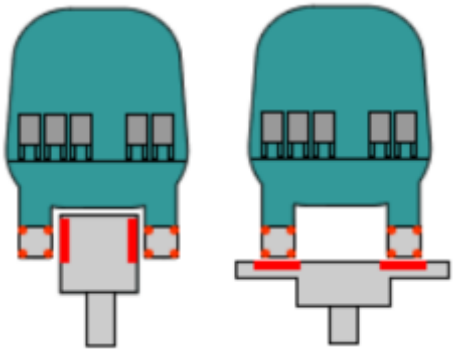

Figure 7. Comparison of Maglev 2000 on Monorail and Planar Guideway (Source: http://www.maglev2000.com/works/how-04-b.html)

In addition to operating on monorail beams, Maglev 2000 vehicles have the ability to function on existing railroad tracks by attaching aluminum loops panels to the crossties of the railroad tracks. Due to the aluminum loops, a maglev vehicle can move along the tracks without wheels or mechanical contact. Even with the aluminum loop panels attached to existing railroad tracks, steel wheels trains can continue to travel along the tracks.

The flexibility of the Maglev 2000 system enables maglev vehicles to navigate from city to city at 300 mph on elevated monorail guideways as well as travel on existing railroad tracks at about 100 mph inside the urban and suburban parts of the city.

The Maglev 2000 quadrupole magnet is superior to Japan's superconducting dipole magnet in terms of the magnetic fringe field strength. The strength of the quadrupole magnet's magnetic field that extends outside of the magnet is much smaller than of that of dipole magnets. With quadrupole magnets, the magnetic field strength in the vehicle can be the same strength as the natural magnetic fields that surround the people on Earth whereas with dipole magnets, the strength of the magnetic fringe field is higher than Earth's natural field. While there is not proof that a strong field strength is harmful to people's well-being, the use of quadrupoles to have the same field strength as Earth's field removes the worry of having negative impacts on people's health.

The Maglev 2000 is Powell and Danby's (2011) latest maglev vehicle. Gordon Danby died in 2016 but the Powell team is continuing research to keep up with the ongoing maglev technology in the world. In addition, Powell and Danby (2011) hoped to build their Maglev 2000 system in the United States and then make it an export product for implementation in other countries.

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6 HISTORY OF MAGLEV FIRST ROUND (IN USA)

James Powell and Gordon Danby (2011) invented the Superconducting Maglev in 1966. Shortly after publishing their article, maglev was developing as an intriguing idea. In that year, the U.S. Office of High Speed Ground Transport was searching for alternatives for a high speed transport system. The reason for the new transportation system was to find a way to travel faster than railroad trains.

Three maglev programs were started in the U.S. but Powell and Danby (2011) were not involved but continued to work on the maglev in their laboratory. Scientists and engineers from various countries such as Japan and Germany visited Powell and Danby to discuss maglev. Powell and Danby (2011) carried on with their research and published more articles about maglev in addition to improving their designs.

In the 1970s, the U.S. Office of High Speed Ground Transport stopped research and development of maglev due to their evaluation that automobiles and airplanes were enough to meet the needs of U.S. transport. Germany and Japan, however, continued with their research and development (R&D) programs for maglev. During this time, both countries developed maglev vehicles of their own. While Germany and Japan made progress on maglev, the U.S. remained stagnant.

Japan Railways tested several maglev vehicles on its test track in Miyazaki. Japan Railways started with the ML-500 then eventually the MLU-001 that reached a speed of 400 kph. In 1989, the MLU-002 was created but only reached a speed of 394 kph.

In the meantime, Germany worked on their own model, the Transrapid Electromagnet Maglev System. The German maglev program mainly focused on researching about Electromagnetic maglev. A number of maglev systems that were tested included the

Prinzzipfahreg and the TR series. By 1989, Germany created the TR 07 that achieved a speed of 436 kph.

7 HISTORY OF MAGLEV SECOND ROUND (IN USA)

In 1987, Senator Daniel Patrick Moynihan contacted Powell and Danby to discuss maglev (Powell and Danby, 2011). He had experienced a terrible train ride from New York to Washington and wanted to discover a better way to travel. Senator Moynihan was introduced to the idea of maglev and advocated for it. He had a vision for maglev in the U.S. and pictured building maglev routes along Interstates and federal highways. Senator Moynihan had hoped that the people of the U.S. will not see a tag that said "Maglev: Invented by American Scientists, Made in West Germany" (Powell and Danby, 2011). Powell and Danby were selected by Senator Moynihan to form and serve as co-chairmen of a Maglev Technology Advisory Committee (MTAC). Their purpose was to review the status and potential benefits of maglev for the U.S. as well as prepare a report of their findings. Along with other Senators, Senator Moynihan pushed for maglev and achieved a funding of $10 million. They knew that this was not enough to keep up with the research of Germany and Japan. The senators sought a $750 million maglev program but it was turned down when it reached the Transportation and Infrastructure Committee in the House of Representatives. Once again, R&D for U.S. maglev was stopped.

Powell and Danby (2011) still persisted with continued research. In 1996, the Florida Department of Transportation (FDOT) and National High Magnetic Field Laboratory of Florida State University funded a program for 2nd generation superconducting maglev. In addition, the Federal Railroad Administration (FRA) provided funds so that Powell and Danby could continue to work on their Maglev 2000 design. Their study was a proposed maglev route from Cape Canaveral Seaport to the Titusville Airport. This study was one of seven studies being performed for a possible maglev route in the U.S. Only Powell and Danby's study involved

superconducting maglev while the other studies wanted to use the German Transrapid Maglev System. Unfortunately, the two finalists of the seven studies both involved the use of the Transrapid System. In 2001, the Federal Transit Administration (FTA) and FDOT granted $1 million each to maglev 2000 to study urban maglev systems. In total, Powell and Danby (2011) received about 14 million dollars to research about Maglev 2000 versus Germany and Japan that received billions of dollars to develop their own maglev systems.

8 SAMPLE DESIGN OF MAGLEV

To develop the Maglev 2000 system, Powell and Danby (2011) focused on four main components: the superconducting quadrupole magnets, the aluminum loop guideway panels, the guideway beams, and the maglev vehicle body. The superconducting quadrupole magnet is considered the heart of the Maglev 2000 system. There are two superconducting loops in the magnet module that carry oppositely directed superconducting alternating currents. This results in four magnetic poles. The two loops can be a single joined circuit or two unconnected circuits. The advantage of the four poles is that quadrupole can interact with both a monorail beam guideway and a planar guideway. The vertical face of the quadrupole can interact with aluminum loops located vertically on the sides of a monorail guideway beam and the bottom surface of the quadrupole can interact with aluminum loops positioned on a planar guideway beneath the maglev vehicle.

For maglev vehicles to operate and levitate on existing railroads, aluminum loop guideway panels can be mounted on the crossties of railroad tracks. The panels do not interfere with conventional trains so trains may continue to use the railroads. The two superconducting loops used for the Maglev 2000 quadrupole each have 600 turns of NbTi superconducting wire with a design current of 1,000 Amps in the NbTi. The superconducting winding is porous, with has small gaps between the NbTi wires. This provides the capability for liquid Helium flow to keep a 4.2 Kelvin (K) temperature while at the same time providing stability against flux jumps and micro movements. The superconducting loops are wrapped with a thin sheet of high purity aluminum to protect the NbTi superconductor from external magnetic field fluctuations. Then the superconducting loops are covered in a stainless steel jacket and wrapped once again with aluminum for addition shielding.

Powell and Danby (2011) considered a basic design for the monorail beam guideway. It was a hollow box beam made with reinforced concrete through the use of post tension construction. The beam was 22 meters long and weighed 34,000 kilograms (kg). The beam was tensioned to have a 0.5 centimeters (cm) upwards camber at the middle of beam and would be flattened out when the maglev vehicle is on the beam. To construct the 20-meter long Maglev 2000 test vehicle, Powell and Danby used an aluminum chassis. Figure 8 shows a drawing of the Maglev 2000 vehicle.

Figure 8. Image of Maglev 2000 Vehicle on Monorail Guideway (Magnetic Glide, n.d.) (Source: http://www.magneticglide.com/assets/components.pdf)

9 MAGLEV IN OPERATION (CHINA, JAPAN, AND SOUTH KOREA)

9.1 Shanghai Maglev Line (China)

China is a country with an immense land mass and it has the largest population in the world. Studies were performed to forecast future needs and development of railways in China for the beginning of the 21st century. Based on the study, the population of China will reach about 1.47 billion by 2050 and about 75% will be town citizens (Luguang, 2002). Moreover, the average railway person-riding rate will increase from 0.8 to 3 times per year and the average travel distance will increase from 360 km to 460-500 km. Thus, there was a need for a high-speed passenger transportation system due to the development of the economy and the progress of the society. In addition, the level of high speed passenger rail line in China was not up to par with other countries. In the late 1980s, China started their research of maglev technology. Back in 1999, experts believed that China should construct a high-speed maglev system in Beijing or Shanghai because maglev offers many advantages and not many developed countries have implemented a maglev system (SMTDC, n.d.). Shanghai was chosen as the preferred location instead of Beijing. There was no operational maglev lines in the world at that time so China intended to be the first to develop and construct a maglev line. In August of the year 2000, the Shanghai Maglev Transportation Development Co., Ltd. (SMTDC) was founded to achieve the construction and operation of the Shanghai Maglev Project. A maglev guideway for the German Transrapid was selected.

In March 1, 2001, the construction for the Shanghai Maglev line began. In December 31, 2002, the Shanghai Maglev demonstration and operation line celebrated its opening ceremony to become the first operational maglev system in the world (Luguang, 2006). This was the beginning of maglev transportation becoming a reality. It was on this day that the

Chinese succeeded in a trial run to lead the way for maglev operations in the world. By the end of 2003, system commissioning on both tracks was finished. In April 2004, commercial operation of the Shanghai line began. A picture of the Shanghai Maglev in operation is shown in Figure 9. Being the first operational maglev system, the Shanghai Maglev addressed concerns with the application of maglev. First, it proved that the Transrapid technology was able to be put into practice with good safety and reliability. Second, it showed people that it is possible to reach high speeds with maglev trains. Third, the construction project lasted about four years starting from studies to reaching the operational speed of 430 kph. This project duration for the Shanghai Maglev is way shorter when compared to the construction period of high speed railway. Fourth, the Shanghai Maglev reached a 500 kph test speed, which set a precedence for future high speed maglev development.

Figure 9. Shanghai Maglev (Source: http://www.maglev.net/best-photos-shanghai-maglev)

The Shanghai Maglev runs every ten minutes between 6:45 a.m. and 9:40 p.m. The Shanghai Maglev system was built by Transrapid International, a German company. The total cost of the project was $1.58 billion. One of the many advantages with the Transrapid system was the high speed. Since China has a large population and vast land, the Transrapid system was the most suitable maglev system for China. While the maglev equipment was provided by Transrapid International, China performed the civil engineering, manufacturing and installation work. According to the Shanghai Transport Centre, the cost for the Shanghai Maglev was about half of cost compared to constructing a traditional metro system ("Shanghai Maglev – All," 2013). The Shanghai Maglev line is 30 kilometers (km) (18.6 miles) long and connects the Pudong Airport to the Lujiazui financial district. The Shanghai Maglev line has three sets of five-section TR-08 trains with an average capacity of 100 passengers per section. There are only two terminal stations with each being a 210-meter long and 7-meter wide platform. The double track route starts from the Longyang Road Station of the subway line no. 2 and ends at the Pudong International Airport Station. It can finish a one-way trip in seven minutes and reach top speeds of 431 kph (268 mph). The trains have the ability to go much faster because a five-carriage Shanghai Maglev train achieved a top speed of 501 kph (311 mph) during testing in 2003; however, the operational train must start decelerating past halfway because of the limited length of the alignment. Currently, the Shanghai Maglev is rated one of the safest transportation systems in the world by carrying out and passing over 300 safety assessments. There is an independent body that oversees safety and closely monitors all systems. There has only been one accident since 2004 in which a malfunctioning battery started a small fire. Fortunately, no one was hurt in the incident. It is noted here that the German development continued until a major accident in 2006 that was the result of human error. The train was allowed to leave the

station while a maintenance vehicle was still on the guideway and 23 people were killed in the resulting collision. Automatic collision avoidance can be used in operational systems but the accident, in effect, halted German development.

The Shanghai Maglev system consists of four major parts: the guideway, vehicle, power supply, and operation control. Since Shanghai is positioned on soft ground on the coast, Germany's recommendation for using steel girders was not practical for such a large project. China used local resources to develop a new type of pre-stressed hybrid girder guideway system (Xiangming). This new girder system was based on the German straight hybrid girder but much lower in cost than the steel girder system. The Shanghai line was difficult to build but China was able to overcome problems such creeping of concrete, the girder deformation due to temperature variation, and the uneven settlement of foundation on soft ground. The guideway directs the trains along the path and transmits the load from the train onto the ground. The superstructure of the guideway is mainly composed of welded steel or reinforced concrete guideway beams for connecting the reinforced concrete piers and foundation.

The maglev vehicle contains electromagnets for levitation as well as propulsion. It has an iron core and long stator winding of the synchronous linear motor. The vehicle is comprised of magnets mounted on the chassis included with a secondary suspension system and vehicle section. The vehicle also includes on-board batteries, an emergency braking system, and a levitation control system.

The Shanghai Maglev power supply system consists of substations, trackside feeder cables, switch stations, and other power supply equipment. The power supply system energizes the long stator windings on the guideway in order to give power to the maglev vehicle. A high voltage alternating current is transferred from the power grid onto the long stator winding on

the guideway through guideway stations and switch stations so that a propulsion force will generate between the stator and the vehicle's magnets.

The operation control system is needed for the entire maglev system to operate. Included with this system are all the equipment to be used in security guarantee control, execution and plan. In addition, an operation control center, a communication system, a decentralized control system, and an on-board control system are all parts of the operation control system.

9.2 Linimo (Japan)

Linimo is considered the world first commercial urban maglev. Rather than be designed for high speed travel, Linimo is a commuter train system. It opened in 2005 just in time for the World Expo 2005. The Linimo Maglev line in Japan was constructed to comply with the World Expo's theme of ecological co-existence, renewable technology and the wonders of nature (Glenn, 2011). The Linimo line runs from the Higashiyama Subway line at Fujigaoka to Yakusa where the Expo's satellite grounds are located. It is operated by the Aichi Rapid Transit Company. The Linimo Maglev vehicles levitate at eight millimeters (mm) above the guideway and can reach a top speed of 100 kph. Figure 10 shows a picture of a Linimo Maglev vehicle. Linimo was attractive because the maglev system does not create rolling noises as loud as conventional trains.

There are nine stations for the 8.9 km (5.5 mile) line. The construction cost of the guideway was about $575 million, higher than necessary because it was built before the maglev technology was selected, whereas the price of the maglev vehicles was $380 million (Glenn, 2011). The line had 31,000 daily passengers during the Expo, dropping to 12,000 daily

passengers after the event. Since the Expo has ended, the Linimo serves the local community every day from 5:50 a.m. to 12:05 a.m.

On two occasions in March 2005, during the Expo, the train was unable to levitate due to number of people inside the train exceeding the design capacity of 244 passengers per train. As soon as the extra people were removed, the train immediately re-levitated. Linimo has had to be closed for safety precautions when the wind speed exceeds 25 meters per second (m/s), which happens quite often.

Figure 10. Linimo Maglev (Source: http://www.n-sharyo.co.jp/business/tetsudo_e/pages/hsst.htm)

9.3 Incheon Airport Maglev Line (South Korea)

Between 1989 and 2003, South Korea developed maglev prototypes. In 1989, the Korea Institute of Machinery and Materials (KIMM) was given funding to start an R&D project for a

low-to-medium speed maglev system (Shin et al., 2008). The South Korean maglev uses an electromagnetic suspension (EMS) and linear induction motor (LIM) propulsion. This type of system allows the maglev to operate without the need for wheels and without noise and vibration. KIMM constructed test tracks and developed the UTM-01 (Urban Transit Maglev) in 1998 (Park et al., 2009). Together with Hyundai-Rotem, KIMM eventually improved the vehicle into the UTM-02. The Ministry of Land, Transport, and Maritime Affairs started the Urban Maglev Program in 2006 (Shin et al., 2011). The program consisted of three core projects: systems engineering, vehicle development, and demonstration line construction. Systems engineering involved testing the systems such as RAMS and LCC. Vehicle development was comprised of testing the levitation and stability of the vehicle. The last core project was to incorporate the maglev vehicle onto a demonstration line and enhance the system. Since 2007, South Korea had been using the Incheon Airplane Maglev line as a test project. By 2009, the maglev vehicles were built and tested until 2011. Construction of the Incheon Airport line took two years and was finally finished in 2012. This maglev line was supposed to open in 2013 after a year of testing; however, it remained closed to the public for four years to correct problems that were exposed in the test runs and to reinforce safety measures. These problems included the jostling of trains in strong winds and the risk of rain causing a short circuit. To build the maglev line, pre-cast pre-stressed concrete girders and pre-cast concrete slabs were tested to be used for the straight line sections (Yeo et al., 2008). The curved sections of the maglev line used an open steel box girder. The curved guideways cannot be continuous more than two spans because negative bending cracks can occur in the precast slab on a central support. The twin block rail track system was tested and it was proven that it reduced the second dead load of the girders. To cope with arrangement of gauge between rails, a temporary rail jib

was installed. To deal with track irregularities, a rail support bracket was recommended. The total project cost was about $342 million. The construction cost per kilometer was $35.16 million, which is close to the cost of other light rails that ranged from $33-44 million (Kyu-Won, 2016). Still, maglev was cheaper than regular trains that would have cost $82-123 million per kilometer.

On February 1, 2016, reporters were given the opportunity by the Ministry of Land, Infrastructure, and Transport and the Korea Institute of Machinery and Materials (KIMM) to test ride on the maglev train. (Kyu-Won, 2016). According to the reporters, there was an occasional squeaking sound and little vibration. In addition, reporters said that the ride had less noise and vibration when compared to other train technologies. On February 3, 2016, South Korea started passenger operations on Incheon International Airport Maglev (Medimorec, 2016). With this accomplishment, South Korea became the second nation in the world to launch urban maglev technology. A portion of the Incheon Airport line is shown in Figure 11. The maglev system was developed by Hyundai Rotem and the Korea Institute of Machinery and Materials; thus, the maglev train is completely maglev technology developed by the country. KIMM and Hyundai enhanced their UTM-02 model to achieve the nominal air gap of 8 mm with a maximum fluctuation of plus/minus 3 mm at a 110 kph speed. The South Korean Maglev trains are called “Ecobee” which combines “eco-friendly” with “bee”. The 6.1 km (3.8 miles) Incheon Airport Maglev line consists of six stations. Though the maglev trains were designed for speeds up to 110 kph (68.4 mph), the trains will run at a maximum speed of 80 kph (49.7 mph) (Korea Times, 2016). The line consists of four maglev trains with up to seven trains available and each train contains two carriages. Each train can carry up to 230 passengers and operates between 9:00 a.m. and 6:00 p.m. at 15-minute intervals.

Through the completion of this project, the Ministry and KIMM believed that this will lead to the maglev train industry in South Korea. Countries such as Malaysia, Indonesia, Russia, and the United States have expressed interest in adopting South Korea's maglev technology, but projects did not happen because the technology did reach the market in South Korea. The Incheon Airport Maglev line was viewed as a test project, but now South Korea has the ability to sell their maglev technology. Since maglev is growing around the world, this project signals a direction towards the use of maglev trains instead of conventional trains.

Figure 11. Incheon Airport Maglev (Source: https://commons.wikimedia.org/wiki/File:Incheon_Airport_Maglev_1-04.jpg)

9.4 Changsha (China)

On May 6, 2016, China's low speed maglev started operations. The Changsha Maglev line runs from Changsha's south railway station to the local airport with one stop in between (Xinhua, 2016). More than 90 percent of the rail track for the Changsha line consists of being constructed on elevated platforms (Liu, 2015). The travel time for the 18.55 km line is about

19 minutes and 30 seconds. The Changsha Maglev train can carry 363 passengers at a maximum speed of 100 kph. The maglev trains were designed and manufactured by CRRC Zhuzhou Locomotive Co., Ltd. Construction for the Changsha line began on May 2014 while its trial run began in December 2015 (Borromeo, 2016). By completing this project, China joined Germany, Japan and South Korea as one of the countries to invest in medium- and low-speed maglev, otherwise known as urban maglev. The Changsha Maglev is believed to reduce the amount of traffic in these busy areas. The Changsha Huanghua International Airport has flight routes to more than 90 cities around the world and the Changsha South Railway Station is known as the "Golden Cross" of the Shanghai-Kunming and Beijing-Guangzhou railway lines. Figure 12 shows an image of the Changsha Maglev line.

Figure 12. Changsha Maglev (Source: http://www.enghunan.gov.cn/news/Localnews/201605/t20160509_3054807.html

10 MAGLEV IN CONSTRUCTION

10.1 Chuo Shinkansen Maglev Line (Japan)

On December 17, 2014, ceremonies were held at Shinagawa and Nagoya station sites to signal the start of the first phase of Central Japan Railway's Chuo Shinkansen superconducting maglev line ("Work Starts on Chuo," 2014). Central Japan Railway Company (JR Central) is developing the project in addition to overseeing the construction and financial aspects of the project ("Chuo Shinkansen."). The Chuo Shinkansen Maglev line will connect Tokyo, Nagoya, and Osaka. This maglev line will provide a more direct line between the cities and reduce the travel time when compared with the existing Tokaido Shinkansen line. Rather than being 90 minutes to travel on the Tokaido Shinkansen line, the Chuo Shinkansen Maglev line from Tokyo to Nagoya will take about 40 minutes. The ride from Tokyo to Osaka will be about 67 minutes.

Phase 1 consists of constructing the line between Tokyo and Nagoya while phase 2 extends the line from Nagoya to Osaka. Phase 1, which is about 290 km, is anticipated to be operational in 2027. The total length of the maglev line is 500 km. Most of the line will consist of underground tunnels. The line will be designed for a maximum speed of 505 kph. Phase 1 includes the construction of six stations. Phase 2 was expected to be operational in 2045 but there are plans to finish the connection to Osaka by 2037 ("Tokyo-Osaka…Start Sooner," 2016).

The Yamanashi Maglev test line was built mainly for running tests for the Chuo Shinkansen project. The test line is shown in Figure 13; the picture was taken during a run in typhoon-generated wind and rain conditions. The maglev vehicles for this project are the Series L0 maglev trains. In April 2015, a Series L0 maglev train achieved a world record top speed of

603 kph (374 mph) on the test line. When the Chuo Shinkansen line is complete, the Series L0 maglev trains will travel at 500 kph which is much faster than the conventional Tokaido Shinkansen operating speed of 320 kph (GCR Staff, 2016). The JR Central maglev trains use an electro-dynamic suspension (EDS) system. This means that the maglev vehicle has superconducting magnetic coils that react with the guideway's levitation coils to produce reactive forces. The reason for the EDS instead of EMS system is for the wider air gap, which is safer for when earthquakes occur (Maglev Board, n.d.). The JR Central maglev system is driven by a Linear Synchronous Motor (LSM) System, which supplies power to the coils at the guideway.

Figure 13. Yamanashi Maglev Test Line (Source: http://www.raillynews.com/2013/japans-500kmh-maglev-train-undergoes-first-successful-test-run-video/)

10.2 skyTran (Israel and Nigeria)

skyTran, a NASA Space Act company, has developed its own maglev system. According to Jerry Sanders, skyTran's CEO, the system would turn a two hour commute into a ten minute trip (Garfield, 2016). The company will construct and finish their first ever track in Lagos, Nigeria by 2020. skyTran built a 900-foot test track on Israel Aerospace Industries' campus near Tel Aviv in 2015. skyTran expects to start constructing a 25-mile track in Lagos, Nigeria by the end of 2016; however, the exact route has not yet been determined. The skyTran system was developed by Doug Malewicki, an engineer at NASA's Ames Research Center. The system consists of 300-pound pods that use magnets to hang from slender rails. The monorail is designed to be 20 feet above the roads. Sanders describes one of the reason for having the pods above ground is that "the only way to get around traffic is to literally go above traffic." There are four different types of steel and aluminum pods that can be used to seat two people, seat four people, seat a disabled person, or carry large cargo.

skyTran's aluminum rail levitates by using a combination of gravity, magnets, and a short burst of electricity. The pod can glide and accelerate without any additional power once it attains a speed of 10 mph. Sanders says that skyTran uses the same amount of electricity as two hair dryers. skyTran's pods can travel at 155 mph. The pods in Lagos will most likely travel in the 45 to 65 mph range, but the city could increase its speed if needed.

skyTran estimates that their maglev system will cost about $13 million per mile compared to a subway system that can cost at least $160 million for the same distance. Passengers can request a ride by entering their pick-up location and destination in the skyTran app. Similar to Uber, the system will allow passengers to schedule a pick-up using their smartphones, but the skyTran will travel up to 150 mph (Morris, 2015). They will be able to

ride on the first pod that shows up at their location. The pods will travel with the passengers to their destinations. Once at the station, the pod will move to another rail so that another pod that is behind can continue with its route. Figure 14 shows an example of the skyTran system. By having multiple rails at stations, the pods won't have to stop for traffic. Sanders says that one of the goals is to make driving in cities history because people cannot afford to spend many hours each day being stuck in traffic (Garfield, 2016).

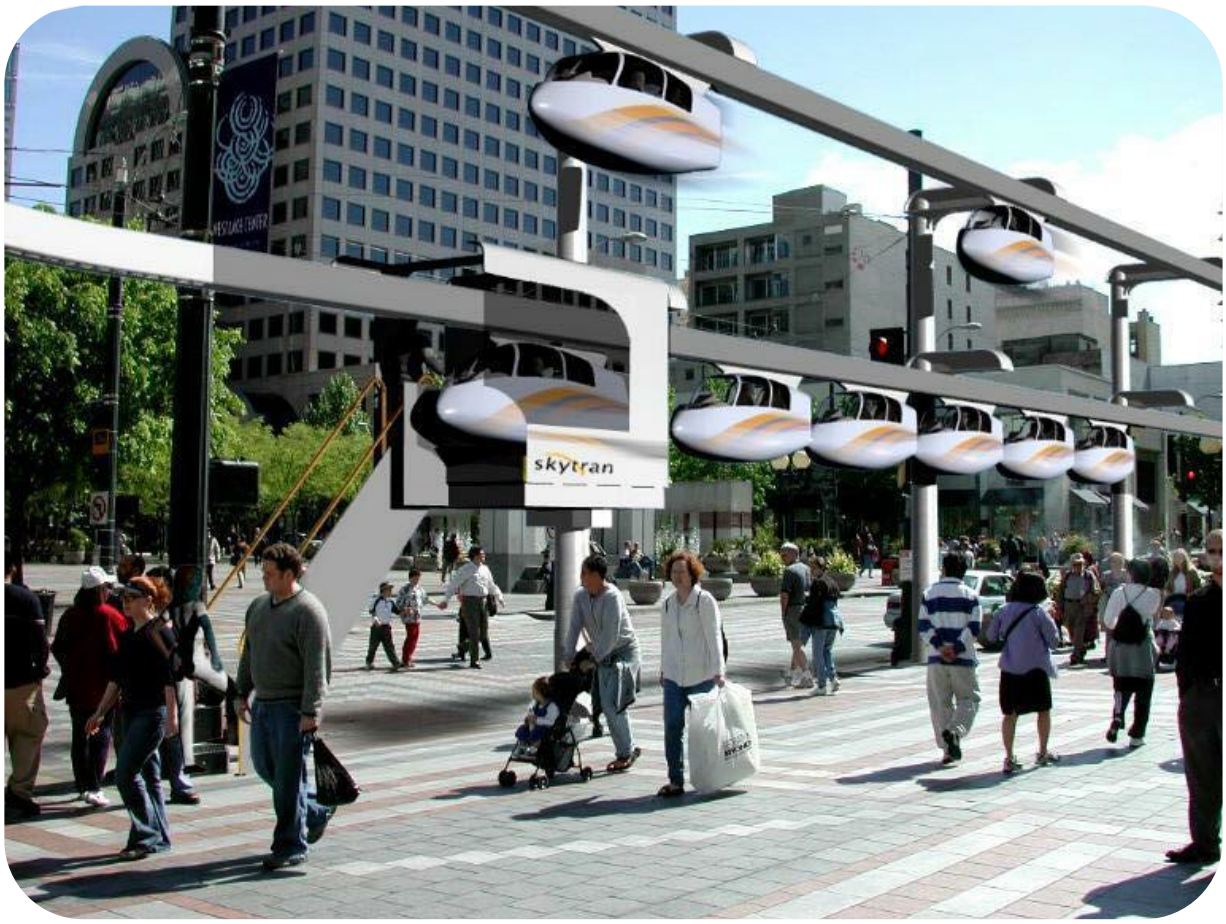

Figure 14. SkyTran Maglev Pods (Source: https://upload.wikimedia.org/wikipedia/en/a/ac/SkyTran_Seattle2.jpg)

11 Proposed Maglev

11.1 Baltimore and Washington DC, USA

In November 2015, the State of Maryland received a $27.8 million grant from the U.S. Department of Transportation to conduct a feasibility study of a superconducting maglev train line between Baltimore and Washington DC using JR Central's SCMaglev. (Griggs, 2015). Current trips from Baltimore to Washington DC take about an hour by car, an hour and 15 minutes by commuter rail, and 40 minutes by Amtrak's Acela Express. A new maglev route between the two cities could reduce travel time to 15 minutes. The government of Japan pledged $2 million for a feasibility study (Calvert, 2016). Northeast Maglev is the company advocating for the 40-mile line with an intermediate station at the Washington International Thurgood Marshall Airport. Wayne Rogers, the chief executive at Northeast Maglev, expressed that "Maglev would revolutionize how people live and work throughout the region." Rogers believes the project could break ground in about 3-4 years. As of September 2016, the route is being planned, potential environmental impacts are being assessed, and public meetings are being prepared for (Associated Press, 2016). The Baltimore Washington DC Maglev project would cost from $10 to $12 billion. The funding is expected to be provided by the private sector, the federal government, and the Japanese. If the project goes according to plan, the first maglev train for this line could be operational by 2026 (Burnett, 2016). Northeast Maglev plans to eventually expand the line in order to connect Washington DC and New York City with a travel time of under an hour (with perhaps a further extension to Boston).

11.2 India

India just recently expressed interest in maglev systems. Three high speed rail firms approached Indian Railways to test their high speed train technologies while it was conducting trials of the Talgo train ("Maglev Rail Firms," 2016). On August 4, 2016, Indian Railways floated a tender to explore maglev train opportunities in India (Jacob, 2016). Indian Railways have their eyes set on a 500 kph maglev train. Hemant Kumar has said that "Besides transporting passengers, such trains can also be utilized for faster movement of goods" ("Indian Railway Floats," 2016). The route of the maglev train has not been determined yet but a 15 km long rail track will be constructed to test the maglev train. High speed rail companies from the U.S., Switzerland, Germany, and Japan have expressed interest in developing a maglev line with Indian Railways. The trial stretch will be provided by the demonstrating company, and then Indian Railways will conduct a safety audit and finalize the project. Aida Schulman, vice president at SwissRapide, has said that "Financing infrastructure will be a major hurdle." However, she added that a successful demonstration could make private financing available for the project. The project is still in the conceptual stage.

11.3 London and France

CRRC Corp Ltd., China's largest rail transportation equipment maker, are developing high speed cross-border maglev trains that can travel at 400 kph (250 mph) (Rambhai, 2016). With these cross-border maglev trains, a trip from London to France (through the Channel Tunnel) will take only 34 minutes. The cross-border maglev system will consist of alternating on different track sizes. This new train would consume 10 percent less energy than the current

operational trains in China (Williams, 2016). maglev consumes less energy because it is propelled through the use of magnets and it does not have engines.

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12 U.S. NATIONAL MAGLEV NETWORK

Dr. James Powell and Dr. Gordon Danby created a plan for maglev in the U.S called the U.S. Maglev Network. This plan has four phases over a twenty-year duration with each taking five years.

Since the technology for Maglev 2000 has been created, Phase 1 is geared towards completing the development and certification of the 2nd generation Maglev 2000 system. The materials and manufacturing methods for the Maglev 2000 system have already been developed so the next step is assembly and test of full scale prototypes at operational conditions. The reason for testing is to certify safety and reliability and to see if small "tweaks" should be made. In addition, phase 1 includes obtaining environmental and regulatory approval and meetings with investors who would fund the project.

Figure 15. First Maglev Wave (Magnetic Glide, n.d.) (Source: http://www.magneticglide.com/assets/america-project.pdf)

Phase 2, termed the "First Maglev Wave", consists of creating the East and West Coast Networks. These two networks will serve twenty-six states as well as cities in Canada such as Vancouver, Montreal, and Toronto. This phase will build a total of 6,230 maglev route miles. Figure 15 highlights in the blue both East and West Coast Network routes. Table 1 shows the number of states and population that would be served from the East and West Coast Network.

Table 1. Population and States in First Maglev Wave (Source: Info Please, U.S. Population by State; Danby and Powell, 2013)

Maglev Network	**States in Network**	**Population of States in Network (millions)**	**Population Living Within 15 Miles of Maglev Stations (millions)**	**Route Miles In Network**
East Coast/Midwest Network	MN, WI, IL, IN, OH, PA, NY, MA, VT, NH, MN, ME, RI, DE, MD, VA, NC, SC, GA, FL, including Washington DC, Toronto, and Montreal	160.4	93.8	2,006
West Coast Network	CA, NV, OR, WA including Vancouver	53.7	45.5	4,224
Total for First Maglev Wave	24 States including Washington DC, Toronto, Montreal, and Vancouver	214.1	139.3	6,230

Phase 3 is the Second Maglev Wave that involves building three transcontinental routes that connect the East and West Coast Networks. Moreover, five North South routes will be added to the network. The second wave will increase the total maglev route miles by 12,600 miles. Figure 16 highlights in the green the routes that would be by added by the Second Maglev Wave.

Figure 16. Second Maglev Wave (Magnetic Glide, n.d.) (Source: http://www.magneticglide.com/assets/america-project.pdf)

Phase 4 is constructing a maglev route along the U.S. I-40 as well as various routes to improve and enhance efficiency in the interconnections for the routes between the First and Second Maglev Waves. By the end of the last phase, the Maglev Network will have a total of 29,000 route miles. The Third Maglev Wave will constructional additional maglev lines as shown in red in Figure 17. Table 2 shows the population and states that will be served once the Third Maglev wave is complete.

The amount of maglev Stations will depend on the size of the population of the city. The large Metropolitan areas such as Seattle, Dallas, Chicago, Los Angles, and New York will have multiple stations while smaller areas will have one or two maglev stations.

Figure 17. Third Maglev Wave (Magnetic Glide, n.d.) (Source: http://www.magneticglide.com/assets/america-project.pdf)

Table 2. Population and States in the US Maglev Network (Source: Info Please, U.S. Population by State; Danby and Powell et al. 2013)

Maglev Network	**States in Network**	**Population of States in Network (millions)**	**Population Living Within 15 Miles of Maglev Stations (millions)**	**Route Miles In Network**
First, Second, and Third Wave	All 48 States in the US Mainland including Washington DC, Toronto, Montreal, and Vancouver	324.1	238.7	29,000

12.1 U.S. West Coast Maglev Network

The U.S. West Coast Maglev Network would connect the metropolitan areas in California, Nevada, Oregon, Washington, and Vancouver, British Columbia. The total maglev route mileage for the West Coast Maglev Network would be 2000 miles.

The West Coast Maglev Network would be constructed on the rights-of-way along the I-5 and I-15 Interstate Highways. The I-5 corridor runs from San Diego north through Los Angeles, Sacramento, Eugene, Portland, Seattle and ends at the city of Vancouver in Canada. The I-15 corridor runs from Los Angeles to Las Vegas and serves cities such as San Bernardino, Riverside, and Ontario. There will be side maglev routes that connect to San Francisco, Oakland, the Bay Area, San Jose, Santa Cruz, Modesto, Merced, Fresno, Hanford-Visalia, Bakersfield and Oxnard and Ventura. Furthermore, Maglev 2000 vehicles in the West Coast Network can also travel in existing railroad tracks as long as those tracks are upgraded with low-cost aluminum loop panels.

The average speed for Amtrak trains is 60 mph. In Europe, the French TGV has the highest average speed for High Speed Rail, 130 mph. The average speed on the Interstate I-5 is arguably 50 mph with congestions and rest stops taken into account. The speed of an air passenger is derived from airline schedules with the addition of an hour for pre-flight activities such as boarding and check-in that are needed prior to departure. Table 3 shows a comparison of maglev, air, highway, conventional rail, and High Speed Rail trip times for various destinations. By looking at Table 3 one can perceive that maglev is the faster mode of transportation.

Once the five-year period for demonstrating and certifying the Maglev 2000 is complete, the West Coast Maglev Network can be constructed with private financing. Since

there a good return on investment for the maglev system, it is anticipated that investors will want to construct the maglev network as soon as possible. In order to attain a low construction cost, the plan would be to minimize field construction work and to maximize the use of mass production methods for the guideway components, which account for almost 90% of the total system cost. The components should be well designed so that they can be erected quickly at the guideway construction sites at a low cost with a small number of workers. The proposed maglev 2000 guideway construction methods are explained briefly. There will be nine construction segments in the West Coast Maglev Network. At least one beam and pier manufacturing plant will be located in each construction segment. The plants will manufacture reinforced concrete beams and piers. The beams will be used for the elevated monorail guideway whereas the pier will be erected on pre-poured concrete footings to support the elevated guideway beams. Sensors, electronic equipment, and thin panels that contain aluminum loops will be attached to the sides of the guideway beams at the plants. The equipment will be manufactured in another plant then shipped to the beam and pier plant. The finished guideway beams will be trucked to the where the guideway is being built. The pre-poured concrete footings should be cured several miles ahead when the piers start erection. The erection of the beams will begin once the piers are a couple of miles ahead.

At a production rate of eight 100-feet long beams per day, four beams can be erected on each end of the guideway per day. Through this rate, the guideway will expand by 200 feet per day. A mobile crane will be used to unload the beam from the truck and place it on top of the previously erected pier. The center of the beam will be positioned on top of the pier. Producing eight beams per day is quite conservative and the construction schedule can always be much faster by increasing the beam and pier production and erection rates.

Table 3. West Coast Trip Time Comparison for Different Transportation Modes (Source: Danby and Powell et al. 2013)

Trip	West Coast Maglev (Hours)	Airplane (Hours)	Conventional Rail (Hours)	High Speed Rail (Hours)	Highway (Hours)
San Diego to Seattle	4 Hrs 30 min	4 Hrs	21 Hrs	9 Hrs 40 min	25 Hrs 15 min
San Francisco to Los Angeles	1 Hr 45 min	2 Hr 30 min	6 Hrs	3 Hrs 45 min	9 Hrs 40 min
Portland to San Francisco	2 Hrs 30 min	2 Hr 45 min	10 Hrs 45 min	4 Hrs 50 min	12 Hrs 45 min
Los Angeles to Las Vegas	1 Hr	2 Hr	4 Hrs 40 min	2 Hrs 10 min	5 Hrs 30 min

For Powell and Danby's plan, 15 beams will be manufactured per day at each plant. Construction of all segments will begin on the same day. Table 4 shows the construction time and number of beam and pier manufacturing plants for each segment. The segment from Portland to Eugene would be the first segment to be completed. That segment would be complete in 28 months. The second segment to be completed is the San Diego to Los Angeles route, which would take 29 months. The Los Angeles to Sacramento segment would take longest to construct with a duration of 42 months. The West Coast Maglev Network would take four years to construct, but the First Maglev Wave would have a construction schedule of five years to account for any delays and unforeseen problems. The beam and pier production rates could be increased for a faster construction time if wanted. Some segments such as the San Diego to Los Angeles route, the Anaheim to Los Angeles route, and the Eugene to Portland route could start operation even before the completion of the total West Coast Network. The Los Angeles to Sacramento segment construction schedule could be modified to finish faster.

Table 4. Construction Time for West Coast Maglev Network Segments (Source: Danby and Powell et al. 2013)

Segment Location	Segment Length (miles)	Number of Beam and Pier Plants	Time to Construct Segment (Years)	Time to Construct Segment (Months)
San Diego to Los Angeles	125	1	2.4	29
Anaheim to Las Vegas	275	2	2.7	32
Los Angeles to Sacramento	540	3	3.5	42
Sacramento to San Francisco, Oakland, San Jose	160	1	3.1	37
Sacramento to Eugene	460	3	3.0	36
Eugene to Portland	120	1	2.3	28
Portland to Seattle	175	1	3.3	40
Seattle to Vancouver	140	1	2.7	32

12.2 U.S. East Coast Maglev Network

The U.S. East Coast Maglev Network consists of three routes that connect together. They are the Northeast-Midwest Maglev Network Section, the Mid-Atlantic Section and the Southeast Maglev Network Section. In total the East Coast network would be 4,224 miles.

In the Northeast-Midwest Section, metropolitan areas in New York, New Jersey, Massachusetts, Ohio, Pennsylvania, Delaware, Maryland, Washington DC, Virginia, Indiana, Illinois, Michigan, and the Canadian cities of Montreal and Toronto would be serviced. The Northeast-Midwest Section includes a New York state section that runs northwards along the I-87 from Manhattan to Albany to the Montreal, Canada. This is a route that goes West along

the I-90 from Albany to Buffalo and Niagara Falls. The New York state section would be extended to form the Northeast-Midwest Section. From Buffalo, the maglev route would extend westwards towards Toledo until reaching Chicago. The line would extend northwards from Buffalo to Toronto and from Toledo to Detroit. Going eastwards, the network would extend from Albany to Boston along the I-90. Moreover, there would be a line connecting Montauk to Manhattan by building a line through Long Island. The Northeast-Midwest Section would be completed by running southwards along the I-95 from Manhattan to Richmond. By doing so, the cities of Trenton, Philadelphia, Wilmington, Baltimore, and Washington, DC would be a part of the maglev line. The Northeast-Midwest Section would have a total distance of 2,100 miles.

The Mid-Atlantic section would connect the Port of Baltimore, Baltimore Washington Internal, Dulles International, Richmond International and Norfolk International airports to Washington DC's Union Railway Station and Metrorail Commuter Rail hub.

The Southeast Section connects the rest of the states along the East Coast, which include North Carolina, South Carolina, Georgia, and Florida. Through the Southeast Section, the cities of Raleigh, Charlotte, Columbia, Savannah, Jacksonville, Daytona Beach, Tampa, and Miami would be connected to the East Coast Maglev Network. The Southeast Section would complete the East Coast Maglev Network.

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13 POWER AND ELECTRICITY USAGE

According to Danby and Powell (2013), a Maglev 2000 vehicle carrying 100 passengers at 300 mph only consumes four megawatts (electricity) of propulsion power. Danby and Powell conducted a series of tests in their laboratory to determine the power requirements. It was discovered that for a maglev to run at 300 mph, a force of 6,738 pounds was needed. By using a 6,738-pound force and 300 mph with a conversion factor, a value of four megawatts (electricity) was attained. The reason for low power consumption is that maglev does not use engines. Maglev requires electricity in order to send a current along aluminum coils to create a magnetic field. The magnetic field reacts with the magnets on the maglev vehicles to propel the vehicles. Per passenger mile, a maglev vehicle consumes 508 BTU (0.54 megajoules). Based on the U.S. Department of Transportation Energy (USDOT) intensity data per passenger mile, automobiles consume 3,877 British Thermal Units (BTU) (4.09 megajoules), airplanes consume 2,329 BTU (2.46 megajoules), and Amtrak trains consume 1,629 BTU (1.72 megajoules). The USDOT obtained their BTU values by calculating the fuel consumption and the BTU/gallon value for each transportation mode. A summary of the energy consumption for different modes of travel is shown in Table 5. To obtain the amount of megajoules, the amount of BTU was divided by 947.817. For example, 508 divided by 0.00105506 is equal to 0.5359, which rounds up to 0.54. To find the energy intensity of kilowatts (kW), the amount of BTU has to be divided by 3,412.14[1] (Convert Units, 2017).

The energy efficiencies of various modes of transportation in terms of barrels of oil or oil equivalent (BOE) per 10,000 passenger miles are shown in Figure 18 (Danby and Powell, 2013). The barrels of oil requirements per 10,000 passenger miles are from the United States

[1] 3,412.14 is the conversion factor to convert BTU into kW.

Department of Energy's Transportation Data Book, and the data were found by attaining the amount of barrels of oil that each mode used per 10,000 passenger miles. Danby and Powell tested their Maglev 2000 to determine how much oil was needed. When compared to other modes of transportation, maglev uses the least number of barrels with 0.46 BOE per 10,000 passenger miles. The next closest to maglev, intercity buses, consume almost two BOE per 10,000 passenger miles. Automobiles, SUVs, transit buses, and airplanes consume above seven BOE per 10,000 passenger miles. Maglev has low energy consumption because it does not have energy losses due to mechanical friction. Maglev only loses energy to induced air drag as well as I^2R losses in the aluminum guideway loops. As stated earlier, maglev does not have engines, allowing it to reduce the energy consumption.

Table 5. Energy Intensity Per Passenger Mile (Source: USDOT, Energy Intensity of Passenger Modes; Danby and Powell, 2013)

Mode	**BTU**	**Megajoules[2]**	**kW (electricity)[3]**	**Source**
Maglev	508	0.54	0.149	Danby and Powell
Automobiles	3,877	4.09	1.14	USDOT
Air	2,329	2.46	0.683	USDOT
Amtrak	1,629	1.72	0.477	USDOT

Table 6 shows the energy requirements per passenger mile for an intercity maglev vehicle at various speeds. The total drag powers were calculated by Danby and Powell (2013). For a 300 mph maglev, a force of 6,738 pounds was needed to find out that the power was 4,020 kW[4]. The basis for an intercity maglev vehicle is that it can carry 100 passengers with a frontal

[2] An example equation to find megajoules is: 508 BTU ÷ 947.817 = 0.54 megajoules
[3] An example equation to find kW is: 508 BTU ÷ 3412.14 = 0.149 kW
[4]The first step to find the power in kW is to multiply the force by the speed and to convert the unit to lb-ft/s. The equation to find power in kW is:

6,738 lbs * 300 miles/hour * 5280ft/mile ÷ 3600seconds/hour = 2964720 lb-ft/s

The next step is to convert to kW. The conversion factor from kW to lb-f/s is that 1kW = 737.56 lb-ft/s. The equation to convert to kW is: 2964720 lb*f/s ÷ 737.56 lb*f/s/kW = 4019.6 kW = 4020 kW

area of 11 m^2. Intercity maglev uses 300 kW(e) I^2R power because that was the amount of power required to move the maglev vehicle and to overcome I^2R energy losses. I is the current and R is the resistance within the system. Danby and Powell (2013) used a ,aglev LSM propulsion system that had a 90% efficiency when determining the power requirements. The reason for a 90% motor is that 100% is impossible to attain, and any value less than 90% is considered inefficient; thus, a 90% efficiency was the goal to obtain an efficient and effective system. For Total Drag Power/LSM[5], the values for Total Drag Power have to be divided by 0.90 because it is 90% efficient. For example, the total drag power per LSM efficiency of 4,460 kW(electricity, e) in Table 6 was determined by dividing the total drag power of 4,020 by 0.90. An intercity maglev vehicle that travels at 300 mph would consume 0.149kWh (e) per passenger mile[6]. For the values of Energy Per Passenger Mile, the values for Total Drag Power have be divided by 90 for efficiency and by the speed of the maglev vehicle. For example, a value of 0.149 kWh (e) was determined by dividing 4020kW by 90 and by 300 mph. To determine the cost per passenger mile, the power had to be converted to a cost. According to the United States Energy Information Administration, 1kWh costs $0.0983 (USEIA, 2016); thus, the energy per passenger mile can be converted to US dollars per passenger mile. The values of Energy Cost Per Passenger Mile[7] was determined by multiplying the values of energy per passenger mile in kWh (e) by $0.0983 per 1kWh (e). Considering that the cost per kWh (e) is $0.0983, the 300 mph maglev vehicle would cost **$0.015** per passenger mile.

Table 7, which is similar to Table 6, shows the energy requirements per passenger mile for an urban maglev vehicle at various speeds. The values for the urban maglev were attained

[5] An example equation to find total drag power per LSM efficiency is: 4020kW ÷ 0.90 = 4460kW efficiency
[6] An example equation to find energy per passenger mile is: 4020kW ÷ 90 ÷ 300mph = 0.149 kWh
[7] An example equation to find US dollar per passenger mile is: 0.149kWh * $0.0983/kWh = $0.015

using the same conversions for the intercity maglev. Urban maglev has the same basis as the intercity maglev except that its vehicles carry 60 passengers and use 200 kW(e) I^2R power. The following sentences provide the reasoning for urban maglev using 200 kW(e) I^2R power and carrying 60 passengers. Urban maglev vehicles only carry 60 passengers; the capacity is limited to 60 passengers because they only travel within a city at a slower speed due to making multiple stops in shorter distances than with the intercity maglev. An average bus carries about 50 passengers (The World Bank, n.d.). Since urban maglev would act as a public transit, it was assumed that urban maglev vehicles should carry 60 passengers. The urban maglev vehicles use 200 kW(e) I^2R instead of 300 kW(e) I^2R power because they carry almost two-thirds the number of the passengers that intercity maglev vehicles carry. Since urban maglev vehicles carry two-thirds of the number of passengers, they would require two-thirds of the amount of power. Sixty (60) passengers is close to two-thirds of 100 passengers and 200 kW is two-thirds the amount of 300 kW. The purpose of Table 6 and Table 7 is find the values for the last column in those tables, which is the Energy Cost Per Passenger Mile. The energy costs per mile can be compared with Amtrak's costs and can be used to determine the energy costs to run the U.S. Maglev Network. Figure 19 and Figure 20 shows a representation of the amount of energy per passenger mile that maglev uses versus the speed of the maglev vehicles. As the speed of maglev vehicles increase, the maglev vehicles use up more energy.

Based on Powell and Danby's (2011) research, maglev uses less than or equal to 0.149kWh (e) as shown in Table 5, which is considered to be a small amount of power when compared to an electric vehicle that uses 0.34KWh (e) per passenger mile (USDOE, n.d.). Because Amtrak uses 1,629 BTU per passenger mile, it uses 0.477kWh (e) per passenger mile as shown in Table 5. Table 8 shows a comparison of the energy consumption and energy costs

of maglev and Amtrak. By multiplying 0.477 kWh by $0.0938 per kWh, it costs $0.047[8] per passenger mile for Amtrak. Amtrak uses more than THREE times the amount of energy per passenger mile and costs more than THREE times per passenger mile than maglev. Hence, maglev is energy efficient and the energy costs are competitive. Eventually, it will be up to the United States government to determine how many maglev vehicles it wants for the country.

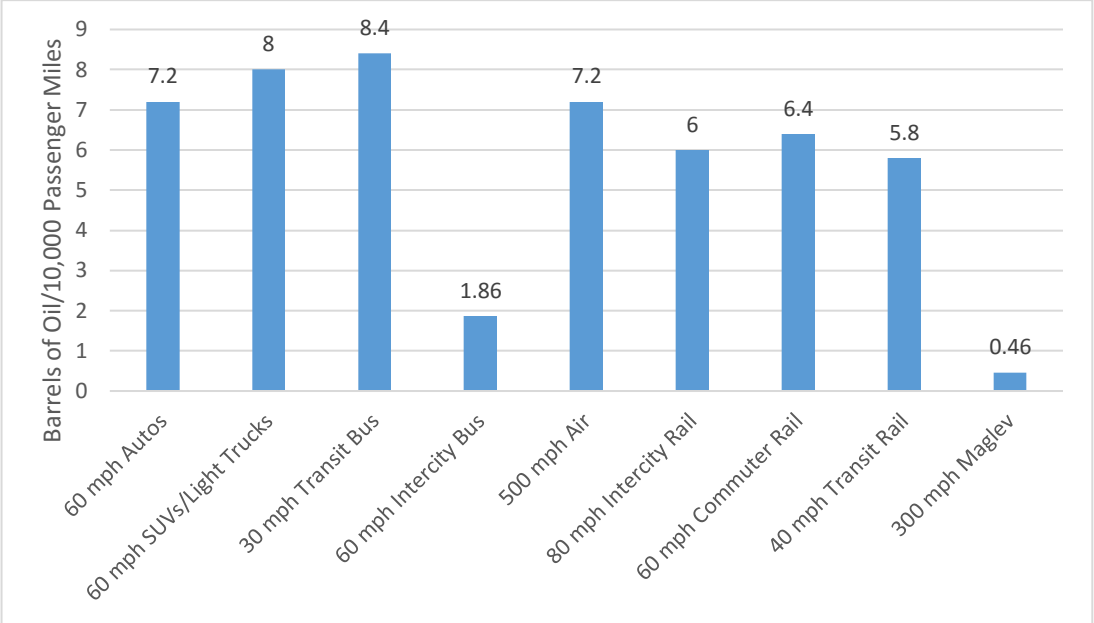

Figure 18. Barrels of Oil/10,000 Passenger Miles (Source: Danby and Powell et al. 2013)

Amtrak received more than 30.8 million passengers during the 2015 fiscal year (Amtrak, 2015). According to Amtrak, more than 84,600 passengers rode on more than 300 Amtrak trains each day. Danby and Powell's (2013) U.S. Maglev Network is similar to the routes of Amtrak except the U.S. Maglev Network has more interconnecting routes between cities. The U.S. Maglev Network can be seen in Figure 17. It can be assumed that if the U.S. Maglev Network were to be built, people would ride maglev instead of Amtrak. Considering that maglev has

[8] An example equation to find the energy cost per mile is: 0.477kWh * $0.0983/kWh = $0.047

more routes than Amtrak, people that were not previously served by Amtrak will most likely ride maglev. In addition, maglev would attract new passengers because of the quality of life benefits that maglev offers.

Table 6. Propulsion Power for Intercity Maglev (Source: Danby and Powell et al. 2013)

Speed (mph)	Air Drag Power (kW(e))	I^2R Drag Power (kW(e))	Total Drag Power (kW(e))	Total Drag Power/LSM (Eff kW(e))	Energy Per Passenger Mile (kWh(e)/PM)	Energy Cost/ PM ($/PM)
300	3720	300	4020	4460	0.149	$0.015
250	2150	300	2450	2720	0.109	$0.011
200	1100	300	1400	1550	0.078	$0.008
150	465	300	765	850	0.057	$0.006

(e)=electrical
LSM=Linear Synchronous Motor
PM=Passenger Mile
Eff=Efficiency

Table 7. Propulsion Power for Urban Maglev (Source: Danby and Powell et al. 2013)

Speed (mph)	Air Drag Power (kW(e))	I^2R Drag Power (kW(e))	Total Drag Power (kW(e))	Total Drag Power/LSM (Eff kW(e))	Energy Per Passenger Mile (kWh(e)/PM)	Energy Cost/ PM ($/PM)
150	465	200	665	740	0.082	$0.008
100	140	200	340	380	0.063	$0.006
75	66	200	260	240	0.064	$0.006

Amtrak directly serves 81 percent of the population in metropolitan statistical areas (Ohlemeier, 2000). Through the United States Census Bureau, the total population for metropolitan statistical areas is 275 million people (2015). That means that Amtrak serves 223 million people, which is 81 percent of 275 million; however, the U.S. Maglev Network is designed to directly serve 238.7 million people. That is an increase of almost 16 million people

being served. According to the USDOT, about 0.8 percent of Americans use trains as a means of transportation (USDOT, 2001). By accounting for 0.8 percent of the extra 16 million people being served, maglev would have an additional 128,000 yearly passengers. That number is about 350 daily passengers. It is estimated that maglev could serve 84,950 daily passengers by adding 350 to the 84,600 daily passengers that would ride maglev rather than Amtrak. Since each Maglev 2000 vehicle can carry 100 passengers, the U.S. Maglev Network would need 850 maglev train trips[9]. Based on the United States Department of Transportation's U.S. Passenger Miles statistics (2014), Amtrak had 6.675 billion passenger miles in 2014. By accounting for Amtrak's 84,600 daily passengers and 365 days in a year, the average miles traveled each day were 216 miles[10]. That average route trip in miles can be applied to the U.S. Maglev Network. Hence, the daily energy cost to run the U.S. Maglev Network is $275,238, which is shown in Table 9. The daily energy cost for a U.S. Maglev Network is less than half the price of Amtrak's daily energy cost. Passenger miles are determined by multiplying the number of passengers by the average number of miles a passenger travels. Then, the passenger miles are multiplied by the energy cost per passenger mile to determine the daily energy cost for the transportation mode. The yearly energy cost can be determined by multiplying the daily energy costs by 365 days. The yearly energy cost is $100,461,870.

It is assumed that there could be a scenario in which half of the 84,600 daily Amtrak passengers would ride on maglev instead. That means that the U.S. Maglev Network would have 42,300 daily passengers in addition to the new 350 daily passengers that maglev would attract. That is a total of 42,650 daily passengers for the U.S. Maglev Network. Table 10 shows

[9] The equation to find train trips is: 84,950 passengers ÷ 100 passengers per train trip = 849.5 = 850 train trips.
[10] The equation to find daily miles is:
6,675,000,000 passenger miles per year ÷ (84,600 daily passengers * 365 days per year) = 216 miles per day.

that $137,052 is the daily energy cost to run the U.S. Maglev Network if it attracted half of Amtrak's riders. Table 10 works similarly to Table 9 by multiplying the passenger miles by the energy cost per passenger mile to find the Daily Cost for the U.S. Maglev Network.

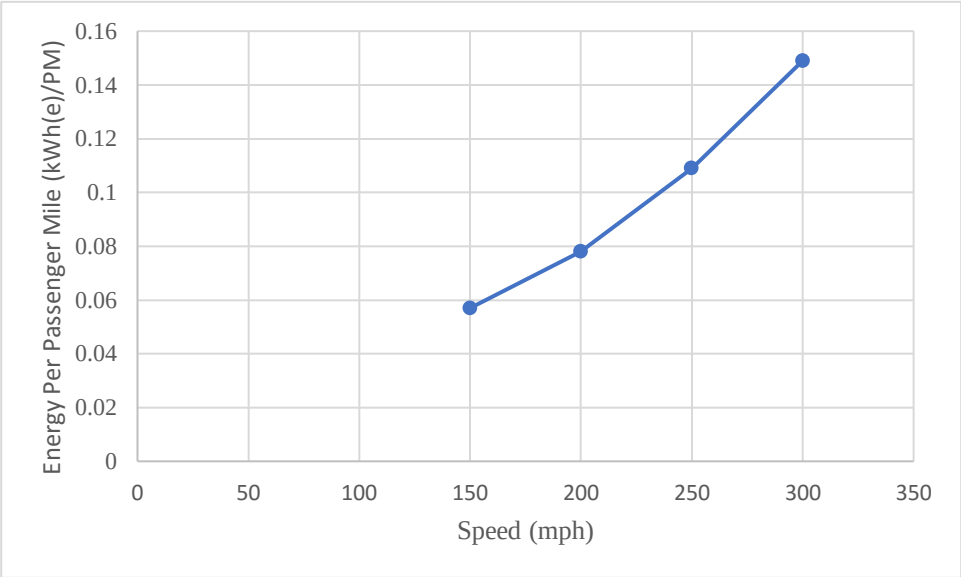

Figure 19. Energy Per Passenger Mile vs. Speed of Intercity Maglev Vehicles (Source: Danby and Powell et al. 2013)

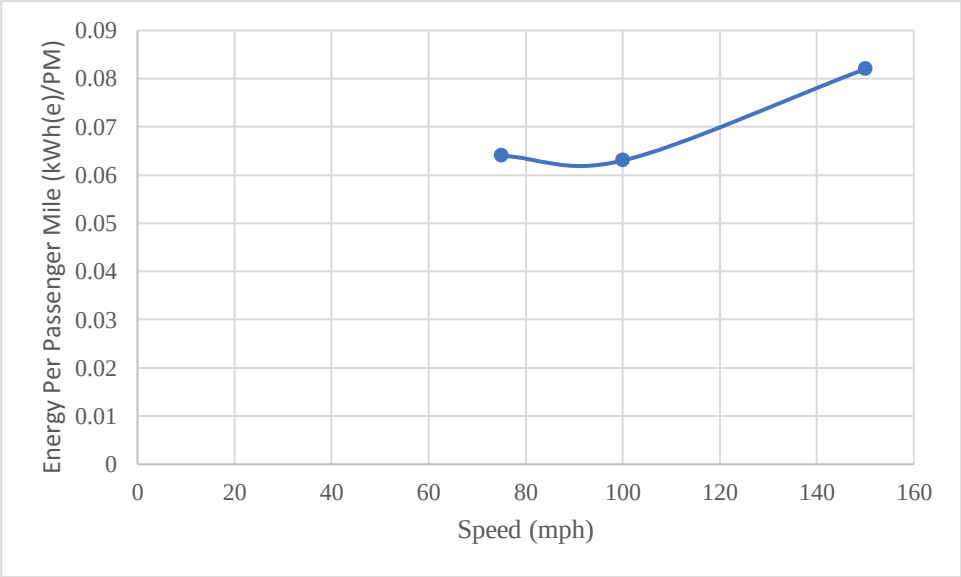

Figure 20. Energy Per Passenger Mile vs. Speed of Urban Maglev Vehicles (Source: Danby and Powell et al. 2013)

Table 8. Energy Comparison of Maglev and Amtrak

Mode	Energy Consumption Per Passenger Mile (kWh(e)/PM)	Energy Cost Per Passenger Mile ($/PM)
Maglev	0.149	$0.015
Amtrak	0.477	$0.047

Table 9. Daily Energy Cost Comparison of U.S. Maglev Network vs Amtrak

Transportation Mode	Daily Passengers (nos.)	Daily Miles (nos.)	Daily Passenger Miles (nos.)	Energy Cost Per Passenger Mile ($/PM)	Daily Energy Cost For Mode ($)
U.S. Maglev Network (29,000 miles)	84,950	216	18,349,200	$0.015	$275,238
Amtrak	84,600	216	18,273,600	$0.047	$858,859

Table 10. Daily Energy Cost of US Maglev Network if It Attracted Half of Amtrak's Passengers

Transportation Mode	Daily Passengers (nos.)	Daily Miles (nos.)	Daily Passenger Miles (nos.)	Energy Cost Per Passenger Mile ($/PM)	Daily Energy Cost For Network ($)
U.S. Maglev Network (29,000 miles)	42,300	216	9,136,800	$0.015	$137,052

Once the daily cost of the U.S. Maglev Network was obtained, an important piece of information was to determine the installed electric capacity needed to run the maglev system. The installed electric capacity is the amount of energy expressed in kilowatts a generator produces in an hour to run a system (CIA, 2014). For example, a 100-kilowatt generator will produce 100 kilowatt hours of electricity if it is continuously working for one hour. To

determine the installed electric capacity, the values for the energy intensity per passenger miles of maglev and the passenger miles were needed. The equation to determine the number of kilowatts required is: energy consumption per passenger mile times passenger miles equals installed electric capacity. Knowing the energy consumption from Table 8 and daily passenger miles from Table 9, one can determine the amount of kilowatts needed. Plugging in the known values, the amount of installed kilowatts needed to run the maglev system each hour is 113,917 kW[11]. The installed electric capacity can be rewritten as 113.9 MW.

A breakdown of the energy costs for each network of the U.S. Maglev Network was determined. Based on Amtrak, the West Coast and East Coast routes were the busiest. Thus, for each day it was assumed that 40% of the maglev passengers (33,980 passengers)[12] would be on the West Coast routes while another 40% of the maglev passengers (33,980 passengers)[13] would be on the East Coast routes. Moreover, it was assumed that 20% of the daily maglev passengers (16,990 passengers)[14] would be going cross country from Seattle to Boston. A summary of the breakdown for the daily maglev energy costs of the various networks can be seen in Table 11. Table 11 is similar to Table 9 in which the daily costs are determined by multiplying the passenger miles by the energy cost per passenger mile.

[11] The equation for the installed electric capacity is:

0.149 kW/passenger mile * 18,349,200 passenger miles = 113,917 kW

[12] The equation for the West Coast passengers is: 84,950 passengers * 0.40 = 33,980 passengers.

[13] The equation for the East Coast passengers is: 84,950 passengers * 0.40 = 33,980 passengers.

[14] The equation for the cross country passengers is: 84,950 passengers * 0.20 = 16,990 passengers.

Table 11. Daily Energy Cost to Run US Maglev Network

Route	**Daily Passengers (nos.)**	**Daily Miles (nos.)**	**Daily Passenger Miles (nos.)**	**Energy Cost Per Passenger Mile ($/PM)**	**Daily Energy Cost For Trips ($)**
West Coast	33,980	216	7,339,680	$0.015	$110,095
East Coast	33,980	216	7,339,680	$0.015	$110,095
Cross Country	16,990	216	3,669,840	$0.015	$55047
Total	84,700				**$275,238**

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14 COST OF MAGLEV

14.1 Cost of Maglev Projects

The cost of constructing maglev lines varied from project to project. The Shanghai Maglev had the highest cost but the reason for this could be that it was the first operational maglev system in the world. As newer maglev projects were built and urban maglev was introduced, the maglev project costs have decreased. A summary of the costs and length for different maglev projects are shown in Table 12. The 2016 costs for the various projects were determined using a CPI inflation calculator provided by the United States Department of Labor's Bureau of Labor Statistics (USDOL, n.d.). Most of the maglev projects consist of elevated guideways. However, the Chuo Shinkansen uses an underground tunnel for its guideway.

Table 12. Maglev Project Costs

Maglev Project (Year of Cost)	Country	Total Project Cost Including Trains ($)	2016 Costs With CPI Inflation ($)	Length (miles)	Project Cost Per Mile ($)
Shanghai (2004)	China	$1,580,000,000	$2,021,873,054	18.6	$108,700,000
Linimo (2005)	Japan	$922,000,000	$1,141,188,623	5.5	$207,500,000
Incheon Airport (2012)	SK	$342,000,000	$360,076,126	3.8	$94,700,000
Changsha (2016)	China	$674,000,000	$674,000,000	11.5	$58,600,000
Chuo Shinkansen (2016)	Japan	$90,000,000,000	$90,000,000,000	310.7	$289,700,000
Skytran (2016)	Israel	N/A	N/A	N/A	$13,000,000
Baltimore Washington DC (2016)	USA	$12,000,000,000	$12,000,000,000	40	$300,000,000
U.S. Maglev Network (2013)	USA	$970,000,000,000[15]	$999,355,000,000	29,000	$34,500,000

[15] The total project cost for the US Maglev Network is the estimate from Danby and Powell (2013)

The Shanghai Maglev line had a total cost of $1.58 billion ("Shanghai Maglev – All," 2013). The length of the Shanghai line is 18.6 miles.

According to a maglev conference in 2004, the estimated project budget for the Linimo Maglev was 100 billion YEN ($922 million) (Yasuda et al., 2004). The construction cost of the Linimo line was about $575 million while the cost for the Linimo Maglev trains was about $380 million (Glenn, 2011).

The total project cost for the Incheon Airport Maglev line was about $342 million (Medimorec, 2016). The construction cost per kilometer was $35.16 million (Kyu-Won, 2016). This equates to about $56.6 million per mile considering that the line was 3.8 miles.

The newest urban maglev line, the Changsha line, had a total project cost of around 4.3 million yuan ($674 million) ("Maglev Line," 2015). The construction cost for the Changsha line was 150 million yuan ($21.9 million) per kilometer leaving $270 million for the cost of the maglev trains (Xinhua, 2016). Another source projected the Changsha line construction cost at 195 million yuan ($28.5 million) per kilometer ("Changsha Maglev Starts," 2015). Per mile, the cost for the Changsha line can range from $35.2 million to $45.9 million.

The Chuo Shinkansen is a maglev line that will connect Tokyo to Nagoya to Osaka. The project is currently in the construction stage but the entire project is valued at $90 billion (GCR Staff, 2016). The first phase, which is constructing the line from Tokyo to Nagoya, will cost about $47 billion. According to "Tokyo-Osaka Maglev Train," 2015, the construction cost of the Tokyo-Nagoya line is estimated at 5.5 trillion yen ($49.8 billion). With the connection to Osaka, the total project cost will be about 9 trillion yen ($83 billion).

The proposed Baltimore Washington DC Maglev project has an expected cost of $10 to $12 billion (Associated Press, 2016). A total of $30 million has been awarded to study the feasibility of that project with $28 million being from the federal government and $2 million being from the Japanese government.

14.2 Cost of U.S. National Maglev Network

According to Danby and Powell et al. (2013), "A 2-way Maglev 2000 monorail guideway built along the right-of-way alongside the Interstate Highways will cost about $30 million per mile." Danby and Powell et al. (2013) estimated the costs for the Maglev 2000 based on an analysis of the fabrication cost of various components as well as their experience in fabricating Maglev 2000 prototypes. This cost is much lower in cost than 1st generation maglev systems such as the Shanghai Maglev that can cost between $60 million and $100 million per mile. Danby and Powell's maglev system is cheaper because the Maglev 2000 guideways are much smaller than the 1st generation guideways (2013). Maglev 2000 guideways consist of an elevated reinforced concrete beam with a square section view while 1st generation maglev guideways are U-shaped and more complicated to build. In addition, Maglev 2000 guideway beams, piers, and aluminum loop panels can be mass-produced in factories, transported by trucks, and erected with conventional cranes at a low cost. By mass-producing the materials, the costs could be cheaper. Moreover, there is a reduction of expensive, large-scale field construction by prefabricating the beams. Thus, the Maglev 2000 guideways will not require as much costly field construction as the 1st generation maglev systems.

For the $30 million cost per two-way mile, Powell and Danby (2011) estimated that $2,660,000 would go towards material costs. The materials include the aluminum loops and the

concrete and steel rebars for the beams and piers. Per two-way mile, the beams would need 3,000 cubic yards of concrete and 420 cubic yards of polymer concrete, while each pier would need 1,500 cubic yards of concrete. The beams require 170 tons of stainless steel rebar whereas the piers need 85 tons of steel rebar. A total of 330 tons of aluminum loops per two-mile is required. There are also the costs for manufacturing labor, the operating cost of manufacturing equipment, the electric power switches for the Linear Synchronous Motor Propulsion System, the pre-poured concrete footings, and the erection of beams and piers by conventional cranes. When accounting for the necessary materials, equipment, and labor needed for the construction of the maglev guideway, the costs of the Maglev 2000 system per mile is $30 million.

For Danby and Powell's U.S. Maglev Network, the total cost would be $970 billion (2013). Based on the several maglev projects as shown in Table 12, the range for project cost per mile is from $58.6 million to $300 million. Danby and Powell's cost of $30 million per mile for their Maglev 2000 is cheaper than all of the other maglev projects. The price would be $870 billion for the elevated guideways and the maglev vehicles while $100 billion would be used to build the stations. By adjusting the costs using the 2016 CPI inflation[16], the total cost of the project would be $999.355 billion as shown in Table 12. The project cost of the U.S. Maglev Network would be $34.5 million per mile. The station costs would be increased from $100 billion to $103.7 billion. Danby and Powell's plan includes 29,000 miles of maglev elevated guideways. There would be a West Coast and East Coast line with several routes connecting the West to East Coast. Figure 17 shows the layout of Danby and Powell's US Maglev line.

[16] The equation to find 2016 costs of the US Maglev Network is: $970,000,000,000 * 1.036 = $1,000,000,000,000.

14.3 Country Cost Indexes

Since the United States has not constructed a maglev system, an analysis was performed to determine the costs if the completed maglev projects were built in the United States. To do this, the country indexes had to be determined. The CIA World Factbook (2015) was used to find out a country's Purchasing Power Parity (PPP) and Official Exchange Rate (OER). By dividing the PPP by the OER, the country cost indexes were determined. Table 13 shows the conversion to obtain the country cost indexes for China, Japan, South Korea, and the United States.

Table 13. Country Cost Index

Country	GDP Purchasing Power Parity (US $)	GDP Official Exchange Rate (US $)	Country Cost Index (nos.)
China	$19.39 trillion	$10.98 trillion	1.77
Japan	$4.38 trillion	$4.123 trillion	1.06
South Korea	$1.849 trillion	$1.377 trillion	1.34
United States	$17.95 trillion	$17.95 trillion	1

Once the country cost indexes were found, the project costs could be converted to determine the cost if that project were to be built in the United States. Table 14 shows the construction costs per mile to build the completed maglev projects in the United States. The farthest right column[17] of Table 14 was calculated by dividing the construction cost of project per mile by the country's cost index. If the Shanghai Maglev were to be built in the United States, it would cost $192.4 million per mile while it cost $108.7 million per mile to be built in China. The cost per mile of $192.4 million was determined by multiplying $108.7 million by the China cost index of 1.77. The range of project cost per mile for maglev projects if built in

[17] A sample equation to find the cost per mile if built in the US is: $108,700,000 * 1.77 = $192,400,000.

the United States would be from to $103.7 million to $220 million. However, the estimated and more reliable cost of the Maglev 2000 system would cost $34.5 million per mile, which is cheaper than the maglev projects that have finished construction.

Because each country has a different cost index, it was determined that a weighted average should be used to compare the price of maglev projects to the U.S. Maglev Network. The country cost indexes are considered as weights to be applied to the construction costs. The first step to determine the weighted average is to determine the total project costs by multiplying the costs per mile of the maglev projects if built in the United States for the Shanghai, Linimo, Incheon Airport, and Changsha Maglev by the length of each project. Simply, one can multiply the second column by the third column of Table 15. The total project costs if built in the US for the various projects are shown in the fourth column of Table 15. The sum of the project costs if built in the US is $6,464,000,000[18]. The next step is to divide that number by the sum of the total project miles, which is 39.4[19]. The weighted average for maglev projects if built in the United States was calculated to about $164 million[20] per mile. The project cost for the U.S. Maglev Network, which is $34.5 million per mile, is $129.5 million[21] or five times cheaper per mile than the weighted average of the maglev projects that are operational.

[18] The equation for the sum of the costs if Maglev projects built in the United States is:
$3,579,000,000 + $1,210,000,000 + $482,000,000 + $1,193,000,000 = $6,464,000
[19] The equation for the sum of project lengths: 18.6 + 5.5 + 3.8 + 11.5 = 39.4
[20] The equation for weighted average is: $6,464,000,000 ÷ 39.4 miles = $164 million
[21] The equation to find $129.5 million is: $164 million - $34.5 million = $129.5 million

Table 14. Project Costs Per Mile If Projects Were Built in the United States

Maglev Project	**Country**	**Project Cost Per Mile ($)**	**Country Cost Index (nos.)**	**Cost Per Mile If Built In the US ($)**
Shanghai	China	$108,700,000	1.77	$192,400,000
Linimo	Japan	$207,500,000	1.06	$220,000,000
Incheon Airport	South Korea	$94,700,000	1.34	$126,900,000
Changsha	China	$58,600,000	1.77	$103,700,000
National Maglev Network	United States	$34,500,000	1	$34,500,000

Table 15. Total Project Cost if Built in the United States

Maglev Project (1)	**Cost Per Mile If Built In the US ($) (2)**	**Length (miles) (3)**	**Project Cost If Built In the US ($) (4) = (2 * 3)**
Shanghai	$192,400,000	18.6	$3,579,000,000
Linimo	$220,000,000	5.5	$1,210,000,000
Incheon Airport	$126,900,000	3.8	$482,000,000
Changsha	$103,700,000	11.5	$1,193,000,000
Total		39.4	$6,464,000,000
Weighted Average = $6,464,000,000 ÷ 39.4 = $164 million			

14.4 Economy of Scale

Economies of scale is the term used to describe the cost advantage that occurs with an increased output of a product (Investopedia, n.d.). This means that the more quantity of a good produced, the lower the per unit fixed costs. Basically, it is cheaper to produce more goods. The reason is that the costs are spread over a large number of goods produced. Economies of scale can be applied to U.S. Maglev Network because the project involves mass producing beams,

piers, aluminum coils, and maglev vehicles. This massive project consists of building 29,000 miles of guideway, 29,000 piers, and 1,014 maglev vehicles. Building the U.S. Maglev Network could be cheaper to construct than the other maglev projects because the U.S. Maglev Network is such a massive project that needs a lot of materials and equipment. Danby and Powell's 2013 construction cost per mile for their 29,000-mile maglev system is $34.5 million in 2016 costs. It is assumed that Danby and Powell used economies of scale for their 2013 construction costs because the construction cost of the U.S. Maglev Network is low compared to the weighted average of the other maglev projects. Danby and Powell's 2013 maglev construction costs can be trusted because they were the inventors of maglev and conducted research and cost estimates for many years on the implementation of maglev technology. Though Means (2015) has a cost multiplier graph there, it is only for buildings and not applicable for railways and roadways. Transferring overseas costs of Table 15 to US costs for a 29,000 mile network will be effective for an estimate analysis because the numbers of Powell and Danby are more reliable and trustworthy. Moreover, it is not altogether clear that overseas contractors in Korea, China, and Japan, used exactly the same building technology as Powell and Danby. Hence, any additional economy of scale adjustment is not indicated or necessary.

15 BENEFITS OF MAGLEV

In order to think of maglev as a serious means of transportation, one has to think of benefits that arise with the introduction of maglev systems. Maglev has many benefits in regards to energy, the environment, the economy, and society. When compared to other modes of transportation, maglev is beneficial in many aspects.

15.1 Energy Benefits

Maglev is beneficial in terms of energy because it uses less energy than other means of transportation. In addition, maglev is energy efficient. Automobiles use about four megajoules per passenger mile while maglev vehicles consume only 0.25 megajoules per passenger mile (Danby et al., 2013). With the trend going towards energy efficiency, Maglev is an excellent mode of transportation.

15.2 Environmental Benefits

Maglev is better for the environment because it is cleaner than other modes of transportation. Rather than consume oil for power, maglev runs on electricity. Maglev can decrease the world's consumption of oil. By using electricity, maglev eliminates emitting of baneful gas and environmental pollution (Liu et al., 2006). With an electric grid, the power can be obtained from cleaner and renewable energy options such as wind, solar, and tidal power. Due to maglev's high energy efficiency, the carbon dioxide emission from maglev is much less than that from automobiles and airplanes (Luu et al., 2005). Powell and Danby's Maglev 2000 does not emit carbon dioxide. Maglev will reduce the number of vehicles on highways, in turn reducing the amount of carbon dioxide emission into the environment. By reducing air

pollution, maglev is much greener than a conventional train. Since maglev guideways are elevated, less land is used. The magnetic field inside the maglev vehicles is equal to Earth's magnetic field, which is smaller than that of a color television set (Liu et al., 2006).

15.3 Economic Benefits

There is little maintenance needed for maglev systems due to uniform force distribution and no abrasion (Liu et al., 2006). Unlike traditional rail, there is little need for replacing and repairing mechanical parts. With ongoing advances in technology, improved electronic and mechanical devices will make maintenance simpler and easier for maglev. Considerable amounts of money can be saved by minimal requirements for monthly or yearly maintenance.

With very little chance of accidents when using maglev, people will not be at risk for injuries. Without injuries, much will be saved on medical bills. Maglev also will reduce the number of drivers on the freeways and highways. By doing so, congestion could be decreased, further saving money.

Powell and Danby predicted that the U.S. Maglev Network will save about $300 billion per year. The reasons for the high savings are lower costs for passenger travel, truck and freight transport, reduced highway congestions and maintenance costs, and reduced medical costs from accidents. With $300 billion in annual savings, almost $1,000 per person can be saved considering that the United States has a population of over 300 million people.

15.4 Societal Benefits

Maglev is better for public health because it is much safer than traveling on highways. Each year in the U.S., about 35,000 lives are lost due to crashes and about two million people

are injured on the country's highways (Powell et al., 2013). By having more people ride on maglev vehicles, there will be less automobiles on highways thereby reducing the risk of traffic accidents. In addition, with fewer drivers on the highways, there will be less congestion. Maglev will not have accidents that occur with conventional rail due to its mechanic and electrical structure. Unlike conventional rail, there is not a risk of maglev accidents with automobiles because the maglev guideways are elevated. Moreover, a maglev vehicle cannot be derailed due to the superconducting magnets that keep the vehicle in contact with the guideway (Luu et al., 2005). In addition, it is not possible for maglev vehicles to collide with each other because the speed of the maglev vehicles and the distance between them are controlled and maintained by the frequency of the electric power inputted to the guideway.

Maglev improves the quality of life for traveling passengers. Passengers can enjoy a comfortable ride because the maglev suspension systems produce little or no vibration. Maglev vehicles that travel at 250 kph create vibrations that have KB of 0.1, which is lower than the human threshold of perception. Since there is not mechanical contact with the track, the maglev ride will be calm. Furthermore, no mechanical contact allows maglev vehicles to operate at low noise levels (Luu et al., 2005). By making maglev more streamlined, aerodynamic noise can be reduced. Taking a ride in a maglev vehicle will be less bumpy and noisy compared to other means of transportation. Maglev will allow passengers to be comfortable and enjoy traveling to various destinations.

Maglev can provide passengers with a comfortable way to travel. Airports are becoming more congested each year and people have to wait in long lines when passing through security checkpoints. Maglev can offer another way for passengers to travel fast. Even though airplanes are still the fastest way to travel, Maglev can compete with airplanes by traveling long distances

at high speeds of 300 mph and arriving at downtown stations. With that kind of speed, maglev passengers can reach their destination in a short duration. People will not have to sit in traffic and dread the long commute times to home or work. Traveling at fast speeds allow passengers to save time to do hobbies they like and to enjoy life.

16 HONOLULU RAIL TRANSIT PROJECT

The state of Hawaii is in the process of constructing a steel wheels on steel rails rapid transit network in Honolulu. The 20-mile rail route runs from East Kapolei to Ala Moana with a total of 21 stations and transit centers (HART, N.D.). Figure 21 shows a map of the Honolulu Rail line and its stations. Stops along the route include places such as Aloha Stadium, The Honolulu International Airport, and a number of shopping centers. The Honolulu Rail is an elevated rail transit meaning that the trains do not cross paths with cars or pedestrians at street level. There will be a single fare for the train and TheBus so that riders can use both modes of public transit in the same day. The trains will operate every day from 4 a.m. to midnight with trains arriving at stations about every five minutes during peak travel hours.

Figure 21. Map of Honolulu Rail Line (Source: http://hartdocs.honolulu.gov/docushare/dsweb/Get/Document-19327/20160930-hart-interim-plan.pdf)

Public transit is important in order to travel in the urban and suburban areas. Public transportation plays an integral role in providing a better quality of life by helping with the United States' economy, energy, and environment. It can reduce congestion, reduce gasoline consumption, and reduce carbon footprint (APTA, 2016). Though public transit has many positives, there are problems associated with this mode of transit.

From an initial cost of $3.72 billion in 2008, the cost of the Honolulu Rail project was estimated at $5.12 billion in 2012, and then to $6.57 billion in 2015 (Pereira, 2015). In June 2016, Honolulu city council members voted to cap spending for rail at $6.8 billion but the Honolulu Authority for Rapid Transportation estimated the project at $7.9 billion (Lincoln, 2016). The Federal Transit Administration estimated that the cost will be closer to $8.1 billion while Jacobs Engineering Group, the Project Management Oversight Contractor assessed that the cost could be as high as $10.8 billion. Based on the several news sources, the project is way over budget.

The selected type of train for the Honolulu Rail is steel-on-steel technology (HART, N.D.). On the Honolulu transit website, HART claims that the "new steel-on-steel system is quiet, smooth, efficient and uses one of the most advanced control technologies in the world." In addition, HART advertises the steel-on-steel technology as the "most reliable, proven technology." The steel rail trains will have a top speed of 55 mph. Even though the rail is elevated, since there are 21 stations in 20 miles, Honolulu Mayor Kirk Caldwell says that "this system is going to go an average of 30 miles an hour" (Mangieri, 2016).

17 CONVERSION OF HONOLULU'S RAIL TO MAGLEV

17.1 Maglev Conversion Plan

Based on HART's description, it seems like steel rail was the top choice of rail transit due to its benefits and costs. However, four of five city-appointed transit system experts that examined train technology agreed that steel technology was the nosiest (Hao, 2008). The Federal Transit Administration indicated that maglev vehicles are the least noisy when compared to steel-wheel and rubber wheeled rail vehicles (Carman, 2008).

Honolulu Rail project can be described as ugly due to high costs. By comparing the estimated cost of the steel rail with the budget, one has to wonder how Hawaii is going to finish the Honolulu rail project. Hawaii currently does not have the funding to complete the project and it is likely that the funding will have to come from local taxpayers.

Frank Genadio and Professor Amarjit Singh (2010b) described a plan that could have been used to build an urban maglev system in Oahu. In 2010, the high speed maglev supplier (Mitsubishi-Itochu) estimated that Honolulu's 20-mile guideway could be constructed for $570 million less than steel wheel rail (Genadio and Singh, 2010b). The proposal for maglev never went forward. Honolulu's City Council, in effect, abrogated its responsibility to select the rail technology, enabling the mayor to announce his support for steel wheels rail. Four members of a (so called) expert five-member panel recommended steel wheels rail and stated that maglev is unproven; however, maglev is a proven future technology that has been successfully applied in countries such as Japan, Germany, and China (Singh, 2008).

As of December 2016, half of the Honolulu's steel rail guideway has been constructed. Kiewit, a general contractor, has built the West Oahu/Farrington Guideway and the Kamehameha Highway Guideway. The first half of Honolulu's steel rail extends from East

Kapolei to Aloha Stadium. The continuation of the rail project from Aloha Stadium to Ala Moana has yet to be built. Genadio (2017) has revised his proposal, based on newer American technology devised by Powell and Danby as a way to convert the current system in place into an urban maglev system. By acting soon, Hawaii could build the maglev guideway for the rest of Honolulu's rail project then convert the existing guideway to allow for maglev vehicles by adding aluminum loops to the guideways that Kiewit has already finished.

Genadio (2017) has taken into consideration that the available funds derived from local sources augmented by $1.55 billion in federal funds will be about $6.8 billion through 2027 to construct rail. This amount is not adequate for completion of the 20-mile steel wheels plan but is more than enough to complete it through conversion to maglev if the steel wheels guideway goes no further than 12 miles, which means it stops at the airport rather than go to Middle Street. Successful completion of the current plan would bode well for key future extensions that would be viewed favorably for additional federal support under the New Starts program. It is estimated that the construction of the rail until the Middle Street station will cost about $6.22 billion for 16 miles of rail. That would leave about $580 million left from the $6.8 billion in available funds to finish the project. The amount of $580 million is not enough to finish the entire project. The proposal calls for a pause in the current plan to modify the tracks and maintenance yard, and to redesign the current construction plans. With the modified plan, the project cost to the Middle Street station would be $4.99 billion[22], saving about $1.81 billion in available funding. With the $1.81 billion, the rail system could be converted into a maglev system. The plan for the Honolulu rail to maglev conversion are as follows:

[22] $6.22 billion * 12 miles/16 miles = $4.665 billion; Give and take about 5% for safety and, will give us a cost of $4.99 billion.

- Stop construction of two-way steel wheel steel rail guideways after 12-mile milestone.
- Convert the 12 miles of two-way steel rail guideways into maglev guideways by attaching aluminum loops onto the guideway.
- From the end of the 12 miles of converted maglev guideways, build eight miles of two-way elevated maglev only guideways

Converting twelve guideway miles into maglev use for the East Kapolei to Middle Street stations, which would cost $120 million. From there, eight miles of maglev-only guideways are proposed to the Ala Moana Center, which would cost $400 million[23]. Other costs would go towards modification of the maintenance facility, buying forty new maglev rail cars, contract renegotiation and manufacturing start-ups to build maglev cars and guideways instead of steel wheel cars and guideways, and unexpected costs. The project cost for the maglev conversion plan, which is about $910 million, is shown in Table 16. In total, the total project to finish the Honolulu rail system and convert it into a maglev system would be $5.9 billion[24]. That would leave $900 million in a contingency fund, or literally saved from the total cost.

17.2 Maglev Extension: Bells and Whistles

Much can be accomplished with a little more than $1 billion to ENHANCE the maglev conversion plan. Hawaii can construct twelve new maglev one-way and two-way miles (Items 1 and 2 of Table 17). New two-way maglev guideways will be added west from the current terminus in East Kapolei to the still-expanding Ko Olina resort and the short distance to the

[23] Maglev-only guideways would cost $50 million per guideway by adjusting Powell and Danby's (2013) maglev costs of $30 million per mile for Hawaii's high costs; $50 million * 8 = $400 million.
[24] $4.99 billion + $0.91 billion = $5.9 billion

Hawaii Convention Center from the final destination of Ala Moana Shopping Center[25]. Six new one-way miles will form a loop from the new stations at the Hawaii Convention Center through Waikiki and around to the University of Hawaii at Manoa and back to the Center. Genadio's (2016) plan involves constructing five new two-way stations and five new one-way stations as well as adding 15 more four-car maglev trains to enhance service, all within the additional $1 billion. The breakdown of the costs for Genadio's (2016) maglev extension plan in Hawaii can be seen in Table 17. It was estimated that sixty new maglev vehicles would be added to forty steel wheel rail cars delivered under the current contract.

The total cost to convert Honolulu steel rail into maglev would cost about $910 million, which makes the total budget about $900 million under the budget that is available. The rest of the budget could go towards unexpected problems and costs, as a contingency fund, or else go towards a $1.0598 billion project as seen in Table 17 to enhance the maglev line to better serve the local community. Table 16 and Table 17 estimates are conservative. Real costs could be 25-30% less.

17.3 Advantages of Maglev

Besides meeting the rail project budget, there are many advantages associated with maglev. Maglev is less noisy than steel rail, which would be appealing to all the residents living near the rail route. When compared to steel wheel rail, maglev systems are more than twice as quiet and are safer due to the vehicle wrapping around the guideway beam and because it cannot derail (Genadio and Singh, 2010b). Due to lower friction, maglev vehicles are more efficient and able to climb grade better than conventional trains (Singh, 2008). Riding in a maglev would

[25] Item 2 of Table 17; Total length = 6 miles

be smooth and comfortable compared to steel trains that are bumpy. People would love the idea that maglev uses electricity instead of fossil fuels. Moreover, the Maglev 2000 does not emit carbon dioxide into the atmosphere. Maglev erases the possibility of collisions thereby increasing safety. People may think of maglev as unproven, but the Mitsubishi-Ithochu HSST Urban Maglev has been in revenue operations for 12 years with extremely high reliability service (Genadio and Singh, 2010a). When compared with other mass transit alternatives, maglev has lower construction costs, lower maintenance and operating costs, the lowest noise level, and the lightest construction impact on the community (Genadio and Singh, 2010a). With more people wanting to travel on maglev due to its benefits, the roads and highways will be less congested. Due to its marvelous benefits, maglev would attract the people of Hawaii and make its case over steel rail.

Table 16. Cost for Maglev Conversion Plan in Honolulu (Source: Genadio, 2017)

Item	**Scope**	**Unit Cost ($)**	**Quantity (nos.)**	**Total Cost ($)**
1	Convert Two-way Guideways for Maglev Use	$10,000,000 per mile	12 miles	$120,000,000
2	Modification of Maintenance and Storage Facility	$50,000,000	1 lump sum	$50,000,000
3	Maglev-Only Two-way Guideways	$50,000,000 per mile	8 miles	$400,000,000
4	Maglev Vehicles	$5,000,000 per car	40 cars	$200,000,000
5	Contract Renegotiation, Manufacturing Start-up	$100,000,000	1 lump sum	$100,000,000
6	Unexpected Costs	$40,000,000	1 lump sum	$40,000,000
	Total			**$910,000,000**

Table 17. Cost for Maglev Extension Plan in Honolulu (Source: Genadio, 2016)

Item	**Scope**	**Unit Cost ($)**	**Quantity (nos.)**	**Total Cost ($)**
1	One-way Guideways	$33,300,000 per mile	6 miles	$199,800,000
2	Two-way Guideways	$50,000,000 per mile	6 miles	$300,000,000
3	One-Way Stations	$20,000,000 per station	5 stations	$100,000,000
4	Two-Way Stations	$30,000,000 per station	5 stations	$150,000,000
5	Maglev Vehicles	$5,000,000 per car	60 cars	$300,000,000
6	Parking Lot at Kapolei Judiciary Complex	$10,000,000	1 lump sum	$10,000,000
	Total			$1,059,800,000

18 SUMMARY AND CONCLUSION

Maglev is a relatively new mode of transportation where vehicles are magnetically levitated and thrusted on an elevated track. Maglev stands for magnetic levitation. Maglev provides energy, environmental, economical, and societal benefits. With all the benefits that maglev provides, it should be considered as the best way to travel. Maglev is a clean and energy efficient mode of travel. Maglev vehicles can levitate using superconducting magnets or electromagnets. Some maglev vehicles are propelled by a linear motor in which the interaction between an electric current and a magnetic field provides a thrust force to the vehicle. Maglev has a lower construction cost than conventional trains and uses less energy than other forms of transportation. Maglev was invented in the United States by Powell and Danby in 1966; however, they have not received sufficient funding to implement a maglev system in the United States. That allowed other countries such as China and Japan to develop and construct their own maglev systems. Maglev lines are currently operating in China, Japan, and South Korea. Japan and Israel are in the process of constructing maglev lines. The maglev projects that are currently operational have proven that maglev works. Meanwhile, the United States, Germany, and Switzerland have expressed an interest in building a maglev line. Even though they lacked funding, Powell and Danby continued on with research to develop the Maglev 2000 to keep up with other countries' improved maglev technology. Despite the government not committing to using maglev in the United States, Danby and Powell et al. (2013) have devised a U.S. Maglev Network that could be used as plan to build maglev in the country. The U.S. Maglev Network would use their Maglev 2000 system. The Honolulu Rail project in Hawaii, which uses steel wheels on steel rails technology, is currently in development. The project is way over budget at about $8-10 billion. Thus, Genadio (2017) have produced a plan to convert Honolulu's steel

rail project into a maglev project to meet the budget and for the people of Hawaii to enjoy the benefits that maglev offers.

Maglev has been proven successfully in other countries so the United States should consider it as an alternative type of transportation. The United States has lost the lead on being the frontrunner for maglev technology, but it still has the chance to become the leader in maglev by supporting and implementing Powell and Danby's U.S. Maglev Network and other American-designed maglev systems. Meanwhile, countries in Asia such as China, Japan, and South Korea have constructed maglev guideways and are in the process of building more. Those countries have leapfrogged the United States as the leaders of maglev technology. As Senator Moynihan said, he did not want to see a tag that read "Maglev: Invented by American Scientists, Made in West Germany" (Powell and Danby, 2011). Now is the opportunity to construct a maglev line in the United States in order to improve the way people travel and to cement the United States as a leader in technology. Maglev is the future of 21st Century transportation and it will change the lives of many people for the better. The United States needs to revolutionize and apply this futuristic technology or else be stuck in past.

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