Maglev Freight Conveyor Systems

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ABSTRACT: The Electric Cargo Conveyor or ECCO system uses an electrodynamic form of maglev technology different than the maglev technology associated with numerous passenger systems proposed and built over the last half century. The Office of Naval Research investigating military applications of freight movement, states: “The most likely first commercial application of maglev technology in the United States will be a freight conveyor.” This presentation describes background and public policy considerations that went into the ECCO concept development, including the economic, social and institutional benefits of implementing such a system. Particular benefits of the ECCO system are reduction of congestion, air, and noise pollution, higher container throughputs than road or rail, potential to pay for itself with the farebox, and a long predicted operational lifetime.

1 INTRODUCTION

Cities naturally grow up around ports, reducing availability of low cost land for port expansion. Inevitably, the result is traffic congestion along road systems originally intended for local deliveries and commuters. It makes sense to quickly and effectively move containers from the Port to inland locations for processing and transport to their final destinations. The Electric Cargo Conveyor or ECCO system answers this need. ECCO does not rely on thousands of Diesel trucks congesting roadways to move containers, but rather uses a small footprint, grade-separated, elevated cargo conveyor, powered by the existing electrical grid. As it is all electric, this system emits no pollution along its path and can directly utilize renewable energy sources.

ECCO presently uses a form of maglev (magnetic levitation) technology very different from the maglev technology associated with numerous passenger systems proposed and built over the last half century. The ECCO system is an American maglev technology invented by Lawrence Livermore National Laboratory, licensed and prototyped by General Atomics (GA) of San Diego, CA. The ECCO shows such promise that the Office of Naval Research, after investigating military applications of freight movement, stated: “The most likely first commercial application of maglev technology in the United States will be a freight conveyor.”[1]

This paper describes background and public policy considerations that went into the ECCO concept development, including the economic, social and institutional benefits of implementing such a system. Particular benefits of the ECCO system are reduction of congestion, air, and noise pollution, higher container throughputs than road or rail, potentiality of paying for itself with a farebox, and a long term (predicted) operational lifetime.

1.1 *Background of ECCO Development*

California State University, Long Beach (CSULB), which is adjacent to the Port of Los Angeles/Long Beach (LA/LB), originated the ECCO concept in response to the community’s need for reducing congestion and pollution due to container movement at the Port. Approximately 43% of the containers coming through this Port travel through Southern California and continue on to the rest of the country. The projected increase in Port activity of 8% per year infers a healthy Southern California goods movement economy for years to come. The ECCO architecture offers a container throughput capacity exceeding those of conventional road and rail to permit such economic growth. Alternative proposals to enhance port throughput have involved expansions to conventional road and rail infrastructure, which only increases congestion and mobile source emissions, including NO_X, carbon monoxide, greenhouse gases, and Diesel Particulate Emissions (DPEs).

Adoption of catalytic converters and alternative fuel combustion engine technologies will certainly reduce emissions; unfortunately, increasing the number of container moves due to port growth off sets these gains. Additionally, these emission reduction technologies do not resolve the problem of increased congestion along interstates and highways, leading to lost productivity. This impact can be measured in billions of dollars per year.[2] Understandably, communities near the Port and along rail and road corridors connected to the Port have expressed health and safety concerns regarding potential effects of port expansion. Port representatives, environmental groups, business leaders and elected officials have all expressed considerable interest in the ECCO system as a potential solution for reducing port related pollution and congestion.

When CSULB representatives first developed the ECCO concept a few years ago, the only commercial maglev system in the world was the Shanghai maglev which uses a technology developed by TransRapid of Germany. The University contacted TransRapid to determine if moving shipping containers with maglev was possible. TransRapid had not previously considered the many advantages that freight transport offered over passenger transport, such as having a known ridership requiring few, fixed destinations and a willingness to travel anytime, 24/7. TransRapid confirmed the CSULB team's surmise that containers were a more predictable and likely more profitable ridership than passenger transport provides; TransRapid also determined that container movement was feasible with changes to their existing passenger system design. This encouraged the CSULB team to proceed with development of a cargo Maglev system. In 2005, CSULB demonstrated the feasibility of moving containers on an ECCO system. In 2006, CSULB together with GA demonstrated the reality of the ECCO system by creating and operating a full-scale container-carrying prototype.

Figure 1. ECCO Will Greatly Reduce I-710 Truck Traffic from Ports of LA/LB.

1.2 Application Determines Maglev Technology Selection

The generic term Maglev actually entails a number of combinations of levitation and propulsion technologies. The two fundamental levitation technologies are Electro-Magnetic and Electro-Dynamic. In keeping with the non-contact concept, there are two basic propulsion technologies, linear synchronous and linear induction motor systems. Figure 2 is a matrix describing the four combinations of these technologies and a brief description of their characteristics and their applications, relative to existing, operational full scale commercial or prototype Maglev systems.

1.3 Levitation

TransRapid began development some 50 years ago of what is referred to as an Electro-Magnetic system. Batteries on board such a system energize powerful electromagnets wrapped around the guideway which lift the carriage up to ferrous metal plates on the bottom of the guideway. Levitation is accomplished by electronic feedback balancing the magnetic attractive force upwards with the gravitational force downwards. Desk toys that "float" model globes employ a similar concept, but in the case of the ECCO transportation system, the floating carriage with container is moving on the guideway at 90 miles per hour.

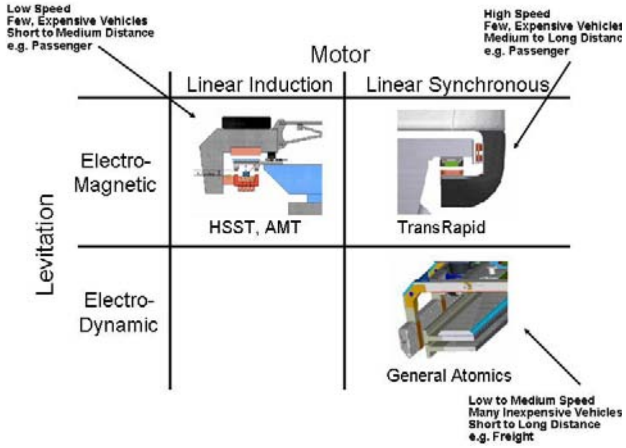

Figure 2. Maglev levitation and propulsion technology matrix

The most recent form of ECCO concept implementation utilizes a magnetic levitation technology developed in the United States. GA built the first operational full-scale Maglev test track in the United States, and the first full-scale cargo container chassis. The levitation technology used was an Electro-Dynamic system which pushes off the guideway instead being attracted to it. While this technology has been appealing for decades due to its simplicity and ruggedness resulting from its utilization of passive levitation, implementation has been possible only recently due to improvements in permanent magnet material residual field strength. In this approach, levitation is accomplished by moving permanent magnets mounted on the underside of the carriage over an electrically conducting metal surface such as copper or aluminum. This forward movement produces currents in the metal which in turn produce a magnetic field opposing the on-board magnets causing the carriage to lift off and levitate about an inch above the guideway. Just as an airplane uses wheels to reach forward speed until aerodynamic lift is achieved, the ECCO uses wheels until magnetic lift is achieved—the speed of a brisk walk—after which it can accelerate to speeds of up to 90 miles per hour or more. In contrast to the older Electro-Magnetic technology used in other Maglev systems around the world, the GA Electro-Dynamic technology can reduce vehicle cost and weight by eliminating the amount of electrical equipment that must be carried on board the vehicle. This is an especially important consideration for a cargo-carrying system transporting heavy loads. Another appealing feature of Electro-Dynamic Maglev technology is that it can tolerate an increased gap between the guideway and vehicle, reducing the precision with which the guideway must be manufactured and maintained.

Both systems are contact-free when levitated, which helps assure low lifecycle maintenance costs, an important factor in evaluating freight transport systems. By way of contrast, the high maintenance costs over decades of road and rail usage add greatly to these systems' total costs. In addition, the expected operational life for the ECCO infrastructure is more than 75 years.

Figure 3. World's First Maglev Container Move at General Atomics San Diego, CA, June 2006.

1.4 Propulsion

To date, all forms of the ECCO concept use a form of Linear Motor. The Linear Synchronous Motor (LSM), places the stator in the guideway and the rotor on the vehicle. This is the so called "smart guideway, dumb vehicle" configuration. Note that the "dumb vehicle" with no motor or on board electronic control is actually more robust in an industrial application. The Linear Induction Motor (LIM), places the stator in the vehicle and the rotor on the guideway. This is the so called "smart vehicle, dumb guideway" configuration.

A short guideway utilizing many vehicles will likely be the best application of an LSM propulsion technology. LIM propulsion best serves longer guideways with fewer vehicles. To date, architected freight systems operate on relatively short distances, e.g., port terminal to rail head, thus the LSM propulsion was selected for the ECCO Freight System.

2 ADVANTAGES OF ECCO

2.1 ECCO Reduces Urban Congestion

Floating on a magnetic field rather than using wheels, ECCO exhibits enhanced flexibility over road and rail options via two inherent aspects; elevated infrastructure and superior grade climbing ability. When containers are placed on a rail car the entire weight is concentrated on a small area of the track. The same container loaded onto a truck chassis puts all its weight on the area where the tires are in contact with the road. In both cases the container's weight is focused onto small areas of rail or road and generates a moving pressure wave on the rail or road that requires a significant supporting infrastructure. This pressure wave can account for misalignment of rails, the unevenness of cement plates on highways, and washboards on asphalt surface streets. ECCO distributes a container's weight over a large bank of magnets whose surface area is thousands of times larger than the corresponding weight-bearing points of road or rail, thus eliminating the severe pressure gradients of wheeled vehicles. This produces minimum stress on guideway infrastructure, and reduces the size and cost of structures needed to elevate the system. The ECCO "footprint" (land requirement) is a series of reinforced concrete posts approximately one hundred feet apart to support the guideway. This reduced footprint permits the use of a number of existing rights-of-way, such as freeway medians, power line corridors, land adjacent to riverbeds, elevation over conventional rail, etc.

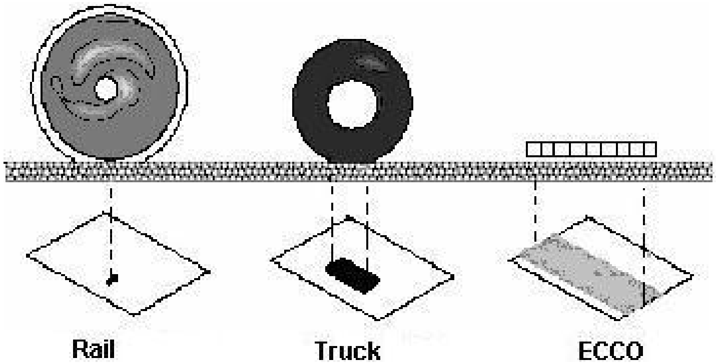

Figure 4. ECCO Replaces Wheels with Arrays of Magnets which Greatly Reduces Stress on the Guideway.

The superior grade-climbing ability of the ECCO system in tandem with its preferred architecture, an elevated guideway, allows this system to conform to existing geography and infrastructure. By using the linear synchronous motor built into the ECCO guideway, denser motor windings can be employed in guideway sections where extra power is needed, such as in climbing steep terrain or gaining height for water and grade crossings. This makes the climbing of uphill grades more efficient than the use of conventional motors on wheeled vehicles, which must be sized to climb the steepest grades even though they are infrequently used for hill-climbing.

On downhill grades, the same dense motor windings in the ECCO guideway enable regenerative braking, where much of the vehicle's kinetic energy can be recaptured as opposed to being burned off in the form of wasted heat energy by conventional braking systems.

Even with appropriately sized conventional diesel power plants, rail-based transport can only climb a 3% grade and road-based transport a 6% grade, whereas ECCO can climb a much steeper 10% grade (or more). An awkward issue faced by planners laying out a road or a rail system in an urban area is the approach to gain height for crossing navigable waterways and other transport thoroughfares. Large areas of at-grade land are required to bring the road or rail up to, and down from the necessary elevation. ECCO's steep climbing ability and its naturally elevated configuration provide planners with a flexible means of positioning high throughput container transport on top of an already over-burdened urban road and rail infrastructure.

2.2 Load/Unload for Port Drayage

Anytime a new form of transport is introduced into a community with an already congested infrastructure and complex economy, like ports and cities, compatibility with existing conditions must be considered. Figure 5 demonstrates how the elevated ECCO might function at a port terminal with an elevated conveyor loop running parallel to a terminal's perimeter over existing rail and road, and a switched siding that descends to grade level for loading and unloading the containers in the terminal. The sketch shows that ECCO can use typical truck or rail load/unload labor and equipment processes. Note that the process and equipment depicted are not necessarily for a high-throughput system.

Figure 5. ECCO Is Compatible with Existing Road and Rail Infrastructure

The BEC GRID System, a multi-directional overhead material handling system, utilizes an overhead transfer unit (TU) to pick up and move containers. The military version of this system, the BEC Selective Storage and Retrieval System (SSRS), is capable of transferring fully loaded (55,000-lb) ISO (International Standards Organization) containers and can sort and pre-stage containers on a ship while at sea, speeding the container retrieval and deployment process without compromising the ship's container capacity or storage density. Currently, the system is being adapted to land-based use, including the port application that is relevant to an ECCO application.

Figure 6. ECCO Is Compatible with Existing Road and Rail Infrastructure

BEC engineers believe that their GRID System will successfully integrate with the ECCO system to move containers in the terminal-to-port configuration, shown in Figure 6. Urban congestion caused by rail-based transport is somewhat different from congestion produced by trucks on highways. For container moves by rail to be cost competitive with trucks, several containers must be moved on a single train chassis. A typical train segment can be a half-mile in length or longer. The congestion (and concomitant pollution) caused by roadway vehicles idling at numerous grade crossings waiting for slowly moving trains cannot be easily quantified.

2.3 ECCO Reduces Pollution

Compared to the use of drayage trucks for transporting containers, the ECCO system can greatly reduce emissions of oxides of nitrogen (NO_X), greenhouse gases such as carbon dioxide (CO_2), and Diesel Particulate Emissions (DPEs). Reducing all of these emissions is a high priority, evidenced by the California legislature's recent allocation of $1 billion in bond proceeds to mitigate the emissions resulting from goods movement. DPEs are different from gaseous pollutants in that it is concentrated in areas where diesel engines operate such as ports, truck/train intermodals, and along freeway and rail corridors. The effects of DPEs are devastating. More than thirty (30) human epidemiological studies have found that diesel exhaust increases cancer risks; and one 1999 California study found that diesel exhaust is responsible for seventy (70) percent of cancer risks from air pollution[3]. Recently, the danger of having homes and schools close to sources of DPE has been recognized[4]. The ECCO container transport approach can use electricity generated by modern natural gas fired power plants, which emit very low NO_X (as little as 0.1 grams/kWh – 10 to 20 times less per unit of energy consumed than typical container trucks). Notably, such a system emits zero DPE.

A quantitative discussion allows a visualization of the pollution reduction benefits of an ECCO conveyor system in an urban area. Assume first a scenario wherein 1000 (500 in both directions) 30 ton containers are moved per day (200,000 containers per year) through 10 miles of typical urban traffic using trucks with a 32 year age distribution peaking at around 10 years. The California Air Resources Board (CARB) EMFAC 2007 model predicts baseline levels for the assumed scenario of DPE and NO_X as shown in Table 1 below. The baseline ECCO system for this scenario is a single bidirectional guideway system covering the same distance, with capacity exceeding 1000 containers a day, moving containers at speeds averaging 90 mph between two terminals. The ECCO local pollution production estimates are shown in the table below (based on stationary electrical plant local pollution for generating the energy required for moving 1000 containers per day).

Many communities are currently proposing mandatory replacement of older polluting trucks with newer trucks having expensive pollution mitigation equipment. Although timely, this measure does not address the problem of increased traffic congestion due to port growth and the resultant increase in pollutant levels.

	Diesel Particulate Emission, PM_{30}	**Oxides of Nitrogen NO_X**
Baseline Truck {typical truck fleet moving 200,000 containers/year, 20 miles round trip }	6.9 tons/year	124.4 tons/year
New Truck {new truck fleet moving 200,000 containers/year, 20 miles round trip }	1.8 tons/year	48.5 tons/year
ECCO System {200,000 containers/year, 20 miles round trip}	0.0 tons/year	2.8 tons/year

Table 1 – ECCO Offers Substantial Pollution Reduction Over Truck Transport.

2.4 ECCO Reduces Dependence on Fossil Fuels

ECCO is projected to be at least (and potentially several times) as energy efficient as using container trucks. A typical container truck carrying a 20-ton load and achieving a fuel economy of 5 miles per gallon achieves 100 ton-miles of cargo transport per gallon of diesel fuel consumed. Based on an equivalent energy content of 40 kWh per gallon of diesel fuel, this works out to 2.5 ton-miles per kWh. GA has already achieved this level of energy efficiency on its ECCO test track in San Diego, and believes that future improvements could increase ECCO efficiency several times again.

Independently of fuel efficiency benefits, ECCO provides greater flexibility with respect to energy sources. ECCO can use energy produced with renewable hydroelectric, wind, and solar power, as well as the new generation of nuclear power plants, thus helping further to reduce dependence on fossil fuels. Natural gas-fired power plants, although fossil fuel based, are significantly cleaner than oil or coal power plants, and can also be a source of clean power for ECCO.

As previously explained, the motor of the ECCO container carriage is in the guideway. Electrical power is conserved by powering only those sections of the guideway where the ECCO carriage is traveling. This segmented powering design format has a number of additional safety and control advantages, as described in the next section.

2.5 Integration of Power Line Vaults with Alternate Freight Technology

As an example of how the integration of an elevated, small footprint, advanced technology freight system can influence urban planning, consider the possible relationship of a hypothetical ECCO system to an urban electric power grid. Consider in addition the difficulty of building new electrical generating plants near the cities which require the power produced. Such plants can be built and operated most effectively in isolated areas away from urban regions, but this option traditionally has not been exercised because of the expense of erecting and maintaining power distribution lines over long distances. Also, newly developed solar, wind, and geothermal sources of electric power tend to be located at significant distances away from where power is required. The postulated ECCO system’s ability to share the same rights-of-way as power distribution lines is relevant here. A fundamental premise of ECCO is that the system utilizes an elevated guideway through the city, reducing pollution and traffic congestion while moving freight to a remote area for container processing and storage. Fortuitously, the architecture required for this function conforms to the same land use requirements as those of remote power plants and renewable energy sources which require a means for energy transmission. Locating such power sources near inland freight off-loading terminals would allow the ECCO guideway to act as the backbone of the power grid.

An additional benefit of this rights-of-way sharing approach is the elimination of transmission line towers in large swaths of land. Cross-linked polyethylene transmission lines (XLPEs) can be incorporated into ECCO guideways, allowing power to be transmitted more effectively and maintained more effectively due to ready accessibility. Many urban communities would prefer to consolidate overhead lines into power line vaults; but the cost of these enclosures is significant and they must be elevated for safety reasons. The integration of XLPEs into alternative technology guideways, such as those employed by ECCO, reduces the cost of consolidating overhead electrical power transmission while allowing dual use (goods movement and power transmission) of existing and future transmission line rights-of-way.

Recently developed submarine power cables are ideal for such long distance (>100 miles) transmission of power as envisioned above. These cables use High Voltage DC rather than AC to efficiently achieve their enhanced, transmission distance.

2.6 *Integration of ECCO with Power Generation and Distribution*

In the year 2005, peak electricity demand reached 98% of theoretical peak loading for Southern California. This was a notable in that the load was not caused by excessive air conditioning use triggered by a heat wave. By way of background, the Southern California power grid is very close to its saturation point. New methods need to be found to expand the power grid capacity; however, land is at a premium and there is very limited open terrain where new power plants can be built. Even if land was available for new power plants (and concomitant electrical power line rights-of-way), their construction is not likely to be approved due to environmental and aesthetic concerns. Because of this, there is no option but to enhance the existing electric utility rights-of-way infrastructure to allow for increased electrical capacity without increasing the electric corridor’s physical footprint. One method is “reconductoring” or upgrading lines to improve consumer services, allow the reuse of existing rights-of-way to maximize transmission asset utilization, and avoid new rights-of-way issues. The cost of reconductoring a 230-kV circuit are on the order of $120,000 per mile, compared with $230,000 per mile for an all new steel-pole circuit. Reconductoring can only be done where the infrastructure capacity has not already been maximized. Where the capacity is already at maximum, a new approach to electricity transmission is needed to alleviate the width and height limitations placed on the transmission system by the fixed, limited size of the existing rights-of-way allocations.

Since high-capacity freight guideways are narrow, and smooth at-grade terrain is not needed; the ECCO or any other easily elevated, electrically driven alternative technology freight system can be constructed to coincide with power line rights-of-way. Integrating power line transmission with the guideways to supply existing power capacity or even significantly higher levels is a potential solution for the power bottleneck. For optimum compatibility of cargo movement technology with power transmission technology, as well as providing the potential for increased power capacity, conventional alternating current (AC) power transmission could be replaced by direct current (DC) power transmission for bringing electricity into urban areas, as well as for local distribution.

Figure 7. DC Transmission Line Route from Downtown LA to the Foot of the El Cajon Pass

2.7 *ECCO Potential for Increased Safety and Security*

The removal of container traffic intended for remote locations from the urban highway infrastructure and placing them on ECCO will improve traffic flow, increase productivity, and improve highway safety. Being entirely automated and grade-separated, the ECCO system has important safety benefits. The segmented linear synchronous motor in the guideway is operated by activating alternate sections of the guideway, which achieves a safe separation between container carriages as well as increasing the system’s energy efficiency.

An elevated, continuously moving container conveyor is implicitly more secure than grounded, stationary container. The ECCO system includes state-of-the-art closed circuit TV monitoring systems along the entire length of the guideway. Since the field of view for these systems is limited to the upper and lower portions of the guideway where the only motion is scheduled container traffic, any unscheduled movement or anomalous changes are recognized by machine vision software which can generate an alarm for real-time scrutiny by an ECCO system operator.

In addition to external monitoring along the system, unmanned ECCO carriages can have their contents examined by X-ray and neutron activation for contraband—while in transit. Present container X-ray imaging and active neutron scanning processes require a container be removed from the goods movement path for examination in facilities where humans are isolated from radiation. Every container moving along the ECCO conveyor, however, can pass through a shielded, active radiation security portal, thus providing a 100% safe and secure screening process. Again, machine vision software automates the inspection process and those images flagged for further analysis can be viewed at remote locations via the internet. The ECCO lends itself ideally to automated security inspection processes.

3 NEW PARADIGM FOR CONTAINER MOVEMENT

Maglev technology is a solution that can help alleviate the problems created by the technology which is responsible for the congestion and pollution many urban areas face today. This technology facilitates the needed balance between more and better jobs inherent in an expanding economy and quiet, clean, and congestion-free neighborhoods. Thus, ECCO's slogan, attributed to Albert Einstein: "One cannot solve problems with the same technologies that caused them."

End notes:

[1] The Impact of Magnetic Levitation Technology Development for Civilian and Military Utilization Final Report. (Sept. 2006 Sandia/Los Alamos Labs Study). Sponsored by the Office of Naval Research.

[2] The 2005 Urban Mobility Report. http//mobility.tamu/ums/report/

[3] Bailey Diane et. all Harboring Pollution The Dirty Truth About U.S. Ports, Natural Resources Defense Council Mar. 2004. http://www.nrdc.org/air/pollution/ports/ports2.pdf

[4]"Effect of exposure to traffic on lung development from 10 to 18 years of age", by Gauderman, et.al. dated 1/26/2007 www.thelancet.com