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Study to Determine the Need for Innovative Technologies for Container Transportation System

FINAL REPORT

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Submitted by

Dr. Lazar N. Spasovic
National Center for Transportation and Industrial Productivity
New Jersey Institute of Technology
University Heights, Newark, NJ 07102-1982

NJDOT Research Project Manager
Dr. Nazhat Aboobaker

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16. **Abstract**

New Jersey ports have been experiencing tremendous growth in container volumes in recent years and it is anticipated that this trend will continue in the future. This may present a problem for the transportation network supporting the traffic coming to and from the port facilities. Currently most of the containers are brought to and picked up from the port by trucks and, while approximately 10% of containers are handled by trains. Projected growth in container traffic along with expected growth of commuter traffic in the region will cause more than significant increase in congestion, which will ultimately completely deteriorate performance of the transportation system in the region as well as performance of the transportation network around ports and within the port terminals themselves. In this situation port authority and port operators look for the ways to avoid problems that can emerge as the result of the traffic growth. One way to do so is to investigate the feasibility of using innovative transportation modes as the alternative to trucks and trains. This study will identify technologies that should be considered as candidates for container movement from and to the port, considering different travel distances. Economic analysis show whether these technologies are feasible or not, but it also evaluates external effects of the applied technology, such as pollution, reduction in congestion, socio-economic impacts and land use disruption.

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- Dr. Lazar N. Spasovic (Principal Investigator), Professor of Civil Engineering and Director of the National Center for Transportation and Industrial Productivity,
- Dr. John Schuring, Professor and Chair of the Department of Civil and Environmental Engineering,
- Branislav Dimitrijevic, Transportation Engineer at the International Intermodal Transportation Center at NJIT,
- George Fallat, PE, Deputy Director of the International Intermodal Transportation Center, and
- Frank Perrone, Research Assistant, Department of Civil and Environmental Engineering.

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EXECUTIVE SUMMARY

In order to accommodate the increase in container traffic, and to capitalize on the tremendous economic growth opportunities, the Port Authority of New York and New Jersey (PANYNJ) and other regional transportation agencies, as well as port operators, initiated a number of improvement projects designed to increase the port capacity. While these projects focus primarily on improving waterborne access and terminal operations, there is serious concern as to the ability of the existing regional highway and rail network to handle the anticipated increase in goods movement. Under these conditions, the regional transportation network requires a major expansion to create the much needed additional freight transport capacity.

Having these trends in mind and knowing the ability to expand current highway and rail network is limited, the New Jersey Department of Transportation (NJDOT), the Port Authority of New York and New Jersey (PANYNJ), and the port terminal operators, are seeking innovative ways to improve land access to and from New Jersey's principal port terminals.

This study, initiated by the NJDOT, is an effort to examine "unconventional" transportation modes to move intermodal containers in New Jersey. Study objectives are threefold:

- ❑ To identify and describe innovative transportation technologies that can be used to move freight, with a focus on those systems that are suitable for transport of intermodal containers.
- ❑ To develop a methodological framework for evaluation and comparison of the innovative technologies.
- ❑ To apply the evaluation framework to test feasibility and applicability of selected innovative technologies using several case studies in New Jersey.

The reviewed technologies include those currently in commercial operation, emerging technologies that are undergoing prototype tests, and those that are still in design and conceptual stage. Some of the technologies have been applied in people mover systems (conveyors, amusement parks, manufacturing facilities), and, if modified, could have a high potential for use in container transport.

The innovative technologies are classified into three major categories:

1. Technologies utilizing fixed guideway – rail and monorail.

2. Automated guided vehicles (AGV).

3. Fast freight ferry technologies.

There are several innovative designs of vehicles utilizing fixed guideway. Three of them were selected as the most promising ones: AutoGo (suspended monorail utilizing linear induction motors), CargoRail (rubber-tired vehicles on the steel guideway with rotary electrical motors), and CargoMover (automated, self-propelled flatbed railcar developed by Siemens). AGV technology is already in full commercial operation in European Container Terminal (ECT) in Port of Rotterdam, and is also selected for the analysis.

Technologies were compared among themselves and with "conventional" rail and truck service. The evaluation framework and methodology used to compare alternative technologies are based on multicriteria decision analysis model. This approach allows the analysis and evaluation of investment alternatives over multiple objectives using different decision criteria, both monetary and non-monetary.

Using proposed methodology, alternative technologies were compared based on cost, safety, travel time, reliability, intermodal compatibility and expandability of the system, environmental and ecological impacts and socio-economic impacts.

In order to test the applicability of innovative technologies for container transport four case studies have been developed. Each case study represents a different geographic area adjacent to Port Newark/Elizabeth. In each case study route alignments are defined for each alternative technology. Technologies are then analyzed based on their technical characteristics. Evaluation methodology was used to evaluate, score, and rank alternatives for each case study.

The following conclusions are reached as the result of the study:

1. Analyzed innovative technologies have very good potential to be efficiently used for container transfer between port terminals and inland intermodal stations.

2. CargoRail, an automated system with fixed guideway and rubber-tired vehicles, has the highest overall scores. Based on this, it can be considered the most promising of all tested technologies.

3. All of the innovative technologies evaluated become more attractive as the container volume increases. There is a definite presence of economies of scale of traffic density wherein the unit cost will decrease as the result of an increase traffic volume on the route.

4. The criteria weighting scheme has some impact on the ratings, however the scheme used in the analysis appears to yield robust results.

Findings from one of the case studies are schematically presented in figures 1 and 2.

Research efforts following this study should concentrate on several aspects of implementation of innovative technologies for container transport:

- Look with some more detail into technical and economic characteristics and performance of innovative technologies. Lack of accurate and reliable information is probably the most sensitive part of this analysis.
- Extend the routes and analyze the characteristics of innovative freight transportation systems in longer haul.
- Develop a detailed analysis of actual applications for the most promising innovative technologies. This analysis should include optimization of operating regimes, simulation of system operations, and detailed cost analysis.
- Examine potential interactions between innovative technologies and existing and planned transportation improvement projects and initiatives in the region, such as Portway, Brownfields Redevelopment, Port Inland Distribution Network (PIDN) concept, etc.

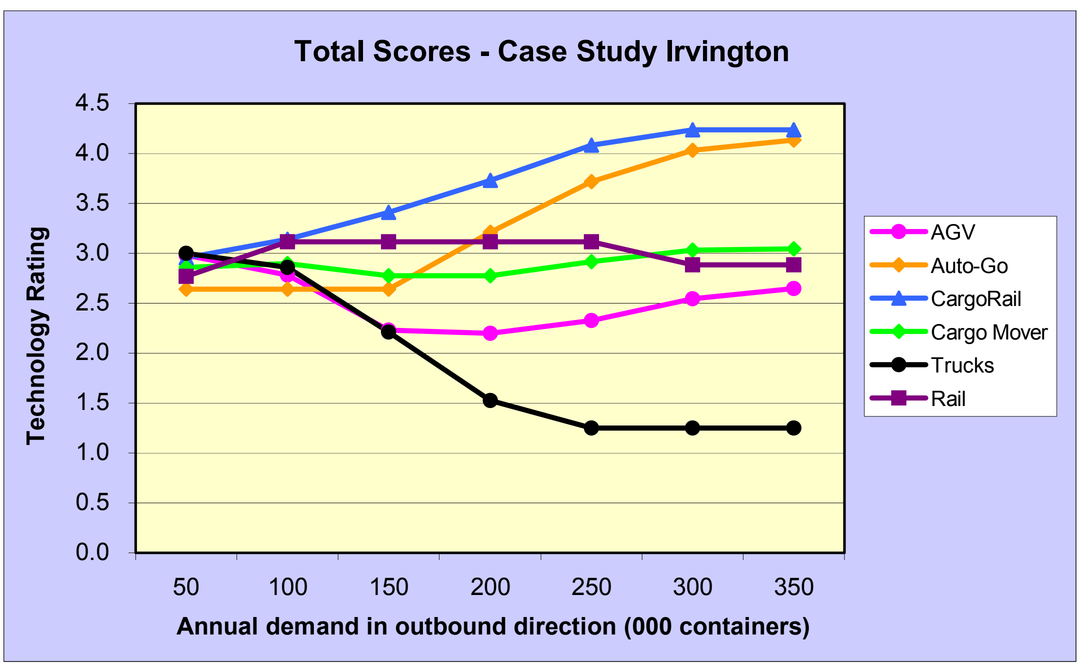

Figure 1. Total scores for alternative technologies – Case Study Irvington

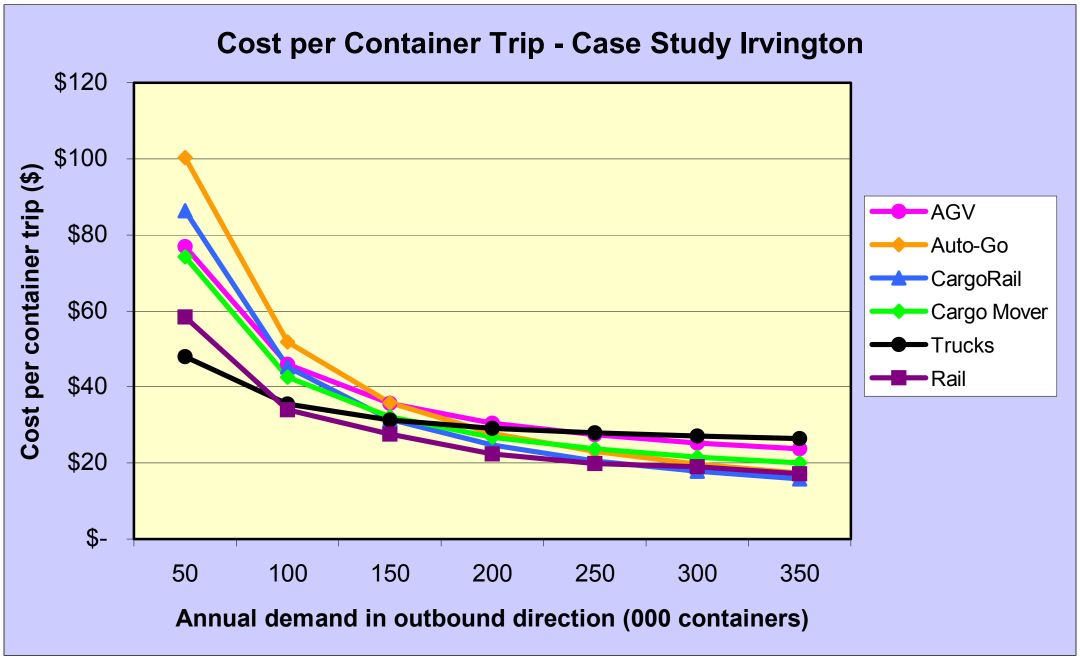

Figure 2. Total system cost per container trip for alternative technologies – Case Study Irvington

BACKGROUND AND OBJECTIVES

Background

As an international freight hub, New Jersey depends upon an efficient system of freight "intermodality", i.e. the ability to move goods between transport modes. Within the freight movement industry, the concept of "intermodality" is implemented by transporting goods in large metal boxes or "intermodal containers", which can be loaded and unloaded directly between freight transport modes. Goods movement is therefore often measured in terms of twenty-foot long intermodal containers, or Twenty-Foot Equivalent Units (TEUs). One TEU container typically measures approximately 8 feet wide by 20 feet in length and 8 feet deep. More common, however, are the larger 40-feet long by 8-foot wide intermodal containers. The smaller single TEU container has a maximum container cargo load of approximately 50,000 pounds while the larger double TEU containers have a maximum cargo load of nearly 60,000 pounds.

The northern New Jersey region houses the third largest port in the country and the largest on the East Coast as well as one of the nation's largest air cargo hubs. A key rail terminus for trans-Atlantic rail freight, New Jersey is also a terminus point for additional incoming goods to the region from Asian export markets via the rail "land bridge" originating from the West Coast. For example, at Port Newark and Port Elizabeth, the State's premier intermodal facility, the current annual volume of approximately 2.5 million TEUs is projected to double within ten years, and by the year 2040 the volume is expected to increase by more than six-fold [(10)].

In order to accommodate the increase in container traffic, and to capitalize on the tremendous economic growth opportunities, the Port Authority of New York and New Jersey (PANYNJ) and other regional transportation agencies, as well as port operators, initiated a number of improvement projects designed to increase the port capacity. The deepening of key shipping channels to 50 ft will enable the Ports to accommodate a new class of large post-Panamax ships that are increasingly being used by international ocean carriers. This project is expected to be completed by 2009 [(17)]. Rail facilities on the landside are being expanded with the construction of the new ExpressRail terminal in Port Elizabeth, which is expected to increase rail capacity five-fold. Many technological improvements have also been made inside the terminals including installation of large cranes with longer reaches, introduction of modern cargo-handling equipment such as straddle-carriers, and gate vehicle and driver identification systems. In addition, terminal layouts have been redesigned. These improvements create efficiencies and are capable of increasing terminal throughput and capacity.
While these projects focus primarily on improving waterborne access and terminal operations, there is serious concern as to the ability of the existing regional highway and

rail network to handle the anticipated increase in goods movement. According to the Comprehensive Port Improvement Plan (CPIP)[1], 88% of the Port's current container volume is transported by trucks, while rail carries approximately 12%. The predominant movement of goods via truck coupled with the tremendous growth in the Port's container traffic places more pressure on already congested highways in the port area. In addition to congestion, which according to a recent study (9) would increase at a higher rate than a corresponding increase in traffic, increased truck volume on already congested highways creates other problems, such as decreased energy efficiency and reduced air quality. While rail operators would gain additional revenue from increased intermodal operations, it is questionable if they will be able to significantly grow with the current infrastructure. Rail infrastructure that supports the Port's operations is already struggling to meet the needs of the rail-bound port traffic and will need significant improvements and capacity upgrades to support future growth.

Under these conditions, the regional transportation network requires a major expansion to create the much needed additional freight transport capacity. Some steps have been made or are underway, such as construction of the Portway, a dedicated freight route from the Port to major outlaying terminals, reconfiguration of the local street network around the Port, and capacity upgrades on the New Jersey Turnpike. Further improvements to the freight rail infrastructure have also been planned, including track upgrades, raising overhead clearances on certain corridors to allow movement of double-stack trains, and adding a second track on Chemical Coast Secondary Line. However, the ability to add capacity for future freight container movement via conventional modes, such as truck or rail, is limited. The use of barge transport to move containers from the Port to selected inland sites and thus staging the truck pick-up and delivery of containers away from the Port is promising from the perspective of reducing congestion. However, the application of this system is limited by the availability of sites to which the containers can be moved in the feeder operation, their proximity to the waterways, and the type of cargo that would be conducive for such a move.

Given the trends from above, the New Jersey Department of Transportation (NJDOT), the Port Authority of New York and New Jersey (PANYNJ), and the port terminal operators, are seeking innovative ways to improve land access to and from New Jersey's principal port terminals. This study, initiated by the NJDOT, is an effort to examine "unconventional" transportation modes to move intermodal containers in New Jersey.

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1 Comprehensive Port Improvement Plan (CPIP) for the Port of NY and NJ is a project initiated by a team of Federal, State and local agencies to determine how best to plan for handling the region's future cargo volumes, while protecting the environment and being a good neighbor to the surrounding communities. It focuses on developments related to Ports of New York and New Jersey. More information on CPIP can be found on it's website at http://www.cpiponline.org/.

Study Objectives

This study identifies and describes innovative transportation technologies that can be used to move freight, with a focus on those systems that are suitable for transport of intermodal containers. From a variety of interesting concepts, ideas, and operation-ready technologies that potentially can be applied in freight transport, the most promising technologies have been selected that provide fast, efficient, and cost effective local and regional freight transport within a 100 mile radius from a port. The relevant information, including cost, technical, and operating characteristics have been gathered and analyzed for all identified technologies.

Next, the study develops a methodological framework for evaluation and comparison of the innovative technologies. A set of performance criteria has been designed that includes commonly used monetary factors, as well as non-monetary impacts of technology implementation, such as air pollution, reduction in congestion, noise, land use disruption, improved economic development, etc. The proposed evaluation methodology enables the comparison of alternatives over multiple criteria and ranks the alternatives based on their overall performance score.

Finally, four case studies are developed for actual origin and destination points in the Port Newark/Elizabeth area. Methodological framework was used to demonstrate the feasibility and applicability of selected technologies for designed case study routes. While the case studies examine the feasibility of technologies in the port area, the analysis methodology is intended to be transferable to a wide range of locations. The case studies provide stakeholders, especially regional transportation agencies and organizations, as well as nearby communities, with a better understanding of the impacts of implementation of these technologies and their advantages or disadvantages compared to the existing conventional transportation modes, trucks and rail. The case studies also provide real, comparative data for real technologies serving real locations in New Jersey.

REVIEW OF INNOVATIVE TECHNOLOGIES FOR CONTAINER TRANSPORT

Introduction

This chapter of the report gives an overview of the innovative technologies suitable for transport of cargo containers.

The reviewed technologies include those currently in commercial operation, emerging technologies that are undergoing prototype tests, and those that are still in design and conceptual stage. Some of the technologies have been applied in people mover systems (conveyors, amusement parks, manufacturing facilities), and, if modified, could have a high potential for use in container transport. Information about these technologies has been gathered through a variety of sources, including transportation industry magazines and publications, research reports, technology vendor's brochures, Internet, and contacts with public, quasi-public and private sector companies and organizations involved in the design, development, and popularization of innovative transportation systems.

For the purpose of this report reviewed technologies are classified into three categories based on their technical and performance characteristics:

1. Technologies utilizing fixed guideway – rail and monorail.
2. Automated guided vehicles (AGV).
3. Fast freight ferry technologies.

The following sections contain descriptions of the most promising technologies within each category.

Technologies Utilizing Fixed Guideway – Rail and Monorail

Conventional railway systems are the most commonly recognized form of fixed guideway transportation systems. Freight railroads still provide service with trains operated by engineers, consisting of one or more locomotives that push or pull sequence of freight cars of common or mixed design and purpose. Nevertheless, automation technology is being increasingly applied to rail systems, and innovative concepts incorporating automation into conventional systems have been developed.

CargoMover

CargoMover is an example of automated rail technology developed by the German company Siemens Transportation AG in collaboration with Aachen Technical College and the Technical University of Braunschweig. CargoMover is, in essence, a redesigned, self-propelled, automated flatbed rail freight car with a payload of up to 60 tons. The current design uses low-emission, low-noise diesel motor. Siemens suggests that alternative traction systems, such as electric motors, and even emission-free fuel cell motors can be applied as well. The vehicle is fully automated, controlled by the central computer and directed by wireless communication. The path of the vehicle is pre-programmed. The algorithm that supports the system controls and manages interactions between the CargoMover and other vehicles along the way, so that higher priority passenger and freight services on a given corridor are not blocked or delayed. This type of control leads to better utilization of the capacity available in the rail network.

The system provides for high level of safety through a combination of electronic interlocking system controlled from the main control office that monitors movement of each vehicle in the network. CargoMover also features pioneering sensor technology mounted on the vehicle itself that substitutes for the driver's eyes and hands. The vehicle is equipped with laser and radar sensors to constantly monitor the area ahead the vehicle for blockages, and to stop the vehicle in the event that any obstacles occur on its way. The video camera enables the control office to get a direct picture of what is happening in front of the CargoMover.

CargoMover is designed for local and regional freight transport, of up to 100 miles (150 km) with a top speed of 55 mi/h (90 km/h). It automatically transports cargo without delays from traffic congestion, without switching or train-formation and with minimal air pollution emissions.

Siemens also developed a system called *Mobiler* for trans-loading swap bodies1 or containers between railcars and trucks. This equipment can be installed on CargoMover and thus eliminates the need for intermodal ramps and cranes, or other special equipment for container transfer between railcars and trucks.

[1] SWAP bodies are lightweight containers that are usually 23.6 feet long, 8.5 feet wide, and 9.5 feet high, used mostly in Europe but not used much in the US because of incompatibility with American cargo handling equipment. They have the added advantage of having their own "legs" which can be extended when not loaded on a chassis, thus freeing the chassis to haul other SWAP bodies.

CargoMover technology is designed to utilize the European Train Control System (ETCS) and GSM-R (Global System for Communications for Railways)2 control and wireless systems. These systems are currently being deployed on several railway systems in Western Europe. CargoMover can also operate in conjunction with other train control systems. Siemens is currently testing two CargoMovers and is expecting a series production to start in 2005.

Figure 3. CargoMover (Siemens Transportation) at the tradeshow in Berlin, Germany (courtesy of Siemens Transportation)

CargoRail

Besides concepts that aim to use the existing railway network, there are numerous ideas and designs for novel transportation systems with dedicated fixed rail guideway. CargoRail, a concept developed by the MegaRail Transportation Systems, Inc. of Fort Worth, Texas, employs rubber-tired vehicles (referred to as "Cargo Ferries") that would move along an elevated guideway that is separated from other modes (Figure 4).

The electrical motors mounted on each wheel propel Cargo Ferries. Three-phase electric power is supplied through electrified rails and conventional carbon power shoes mounted on the vehicle that contact power rails. Multiple motor systems and power collector assemblies at each wheel provide back up for continued operation.

[2] More details about ETCS and GSM_R deployment can be found at project websites at: http://etcs.uic.asso.fr/ and http://gsm-r.uic.asso.fr/.

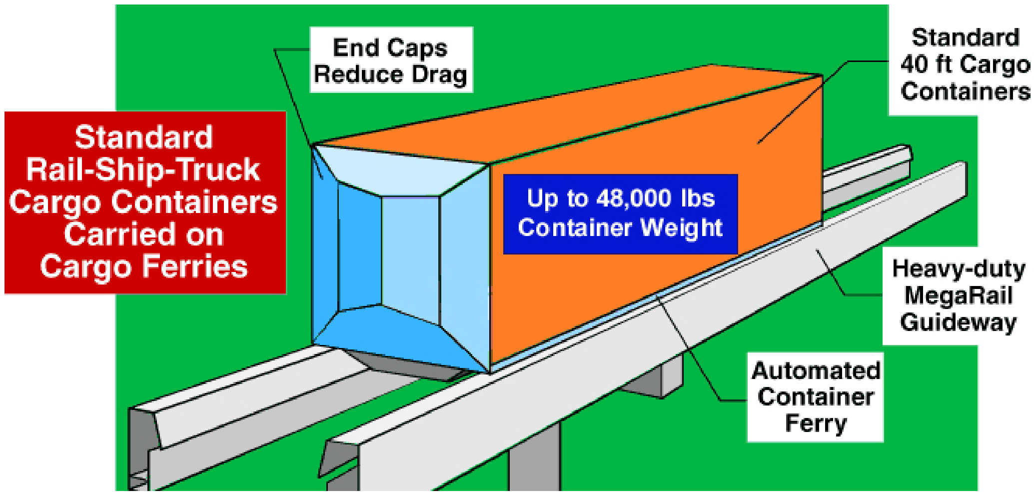

Figure 4. Schematic picture of the CargoRail "Freight Ferry" on the guideway (courtesy of MegaRail Transportation Systems, Inc.)

While each vehicle operates individually, they are fully automated and controlled by a computer. Vehicles operate on enclosed weatherproof guideway, which ensures safe, all-weather operation shown in Figure 5. Their tires are flat-proof, avoiding roll-overs.

MegaRail Transportation Systems claims that this system is ready for a non-stop, 24-hour, 7-day a week operation at operational speeds of up to 75 mi/h (120 km/h). The maximum designed payload per vehicle is 50,000 lbs. Vehicles could be used for transport of trailers and trucks, as well as containers.

This system is still under development. In 2000, the concept was presented to the Port of Houston Authority in Houston, Texas, as a possible solution to the problem of transporting containers to and from the container piers at the Port's terminals.

System designers proposed to connect the Port's terminals directly with a remote intermodal terminal 35 miles inland. This proposal is currently not being pursued and neither prototype nor tests have been made. However, MegaRail

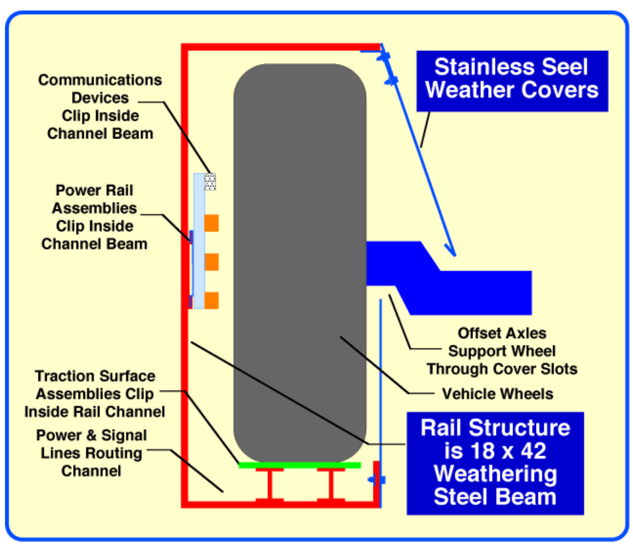

Figure 5. CargoRail enclosed guiderail and wheel (courtesy of MegaRail Transportation Systems, Inc.)

Transportation Systems is currently testing its Personal Rapid Transit (PRT) system called MicroRail at the testing facility near Fort Worth, Texas, on the same type of guideway and with the same propulsion that would be used for the CargoRail system.

Monorail Systems

Monorail systems, similar to those employed for passenger travel, have the potential for being used for container transport. Monorail systems use a single rail as a guideway. In most cases, the rail is elevated, but monorails can also run at grade, below grade or in subway tunnels. Vehicles are either suspended below or straddle above a narrow guideway. Monorail vehicles are wider than the guideway that supports them.
There are many monorail systems currently in operation, but they are all used for various types of passenger transportation. As urban transit systems, they transport passengers between airport terminals (such as Newark's Liberty International Airport), or visitors in the theme parks. No monorail has been built so far for freight transport.

Most monorail systems currently in operation have electric propulsion using conventional rotary motors. The suspension for most of those monorails is based on combination of vertical and horizontal pneumatic rubber tires on the concrete or steel beams as a guideway. Figure 6 shows the suspension apparatus used for Seattle's monorail system.

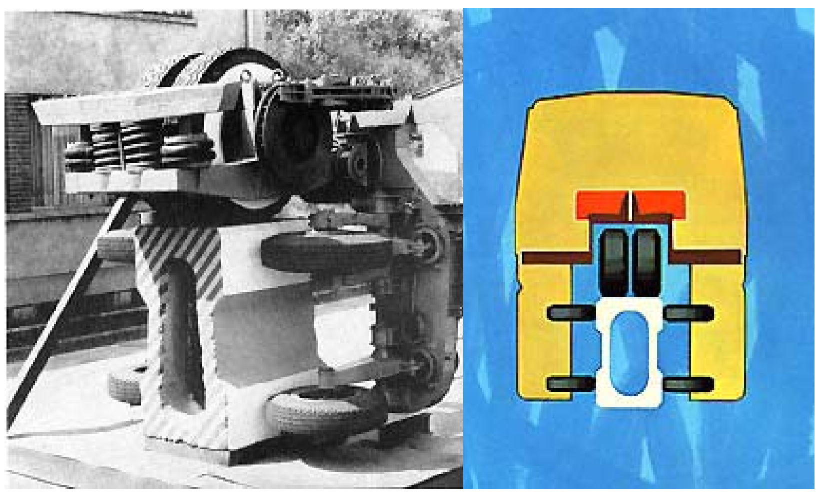

Figure 6. Bogie of the typical monorail vehicle; picture shows bogie with suspension and rubber tires used in Seattle monorail vehicles (obtained from Monorail Society website)

The vehicles ride on dual pneumatic rubber tires 39.5" (100 cm) in diameter and have horizontal pneumatic rubber tires 25" (63.5 cm) in diameter for stability and guiding. The bogies are self-contained units consisting of load carrying and stabilizing components. The "Airspring" suspension makes the ride smoother. The load-carrying wheels are steered (for curves) by the stabilizing wheels to prevent excessive tire treadwear.

More advanced types of propulsion that can be used for guided vehicles, especially monorail systems, are *linear induction motors*. Linear induction motors utilize electromagnetic force to produce linear mechanical force, rather than torque as in typical rotary electric motors.

Vehicles that use linear induction motors can have contact with the guideway through the wheels, or they can levitate on the cushion of air between the primary and secondary magnets mounted on the guideway and vehicles. The latter is often referred to as “magnetic levitation” or “*maglev*” technology.

Because there is only one moving part in the motor with no mechanical linkages nor metal-to-metal contacts (thus no wear in the assembly), linear induction motors have much lower maintenance costs than conventional motors. In addition, they can run at much higher speeds. No contact between the vehicle and the guideway also provides for a smoother ride. These systems are conducive to urban environments for they do not require extensive amounts of land. Furthermore, monorail systems can elevated above the existing facilities, using the medians of existing highways or right-of-ways. Systems that employ linear induction motors are also environmentally friendly as they generate very low noise and minimal air pollutant emissions. Such systems can also be automated, entirely controlled by a central computer.

Besides being widely used in manufacturing facilities for conveyors and assembly lines, on airports for baggage handling equipment, as well as in amusement parks, linear induction motors have already found their application in mass transit systems and other smaller people-mover systems. One of the first applications of linear induction motors was in Disneyworld in Orlando, Florida. This monorail system operates small trains that transport visitors of the theme park. Vehicles are propelled by linear induction motors and ride on a rubber tires. Larger transit system utilizing technology of linear induction motors called Skytrain was built in Vancouver, Canada, in 1986 for the World Expo. The system is currently successfully operating close to 30 kilometers of track on two lines connecting 31 stations in Vancouver area. Linear induction motors are also used in AirTrain vehicles on the JFK International Airport, as well as in several other smaller scale people-mover systems in United States, Europe and Japan.

Maglev technology is also approaching its commercial application. Germany based company *TransRapid* (a joint venture between Siemens and Thyssen-Krupp) has successfully launched its first maglev commercial project in Shanghai, China, with a promotional public ride on December 31st, 2002. This fully automated mass transit system runs between downtown Shanghai and Pudong International Airport, a 19 miles (30 km) long route. The top travel speed of the train is 265 mi/h (430 km/h), and the system is planned to commence full commercial operation by the end of 2003.

Figure 7. TransRapid train featuring cargo section (obtained from TransRapid website)

TransRapid also considered transporting cargo onboard their maglev trains. In addition to passengers, trains can also carry high-value cargo in specially designed cargo sections (Figure 7). These can be used for dedicated high-speed cargo trains or added to passenger trains for mixed service. Special container sections, each with a useful load of 17 metric tons, could be used for high-speed freight transport.

Similar projects to this one are currently considered for several locations in the U.S., Germany, Holland, and Japan. Research conducted on a possible application of maglev technology in the U.S. is being funded by the federal government through the Maglev Deployment Program (which is included in the Transportation Equity Act for the 21st Century (TEA-21)). As part of these efforts, several companies are currently developing linear induction motors that can be used for robust transportation vehicles and maglev trains. *The Segmented Rail Phased Induction Motor (SERAPHIM)*, developed at Sandia National Laboratories, is a new type of linear induction motor offering unique capabilities for high-thrust, high-speed propulsion for urban maglev transit, advanced monorail, and other forms of high-speed ground transportation. Northern Magnetics, Inc, the company that built motors for the vehicles in Disneyworld in Orlando, was acquired by Baldor Electric Company in 1998, but is still focused on development and production of advanced linear induction motors.

Linear induction motors, monorail technology, and automation systems that support their operation have not seen their full commercial application for freight movement. However, these technologies have a high potential for transporting intermodal containers. As part of a pilot study, Noell Crane Systems developed a linear motor-driven system for automatic, horizontal transport of containers in a marine port terminal. The system was constructed for demonstration purposes in the Eurokai Container Terminal in Hamburg, Germany, in 1996-1997 (Figure 8). This technology is known as *LMTT (linear motor-based transfer technology)*.

Two main design problems involved with the application of LMTT were interaction between the guiderail and the vehicle (i.e. maintaining the gap between the motor and the reaction plate), and turning movements (i.e. repositioning the wheels in turning position). According to its designers, this system is twice as efficient as ordinary horizontal transport systems, having high reliability, low operating costs, high positioning accuracy and a high degree of environmental compatibility. Several companies, including Noell Crane Systems, are currently developing similar systems employing linear motors for the transport of containers.

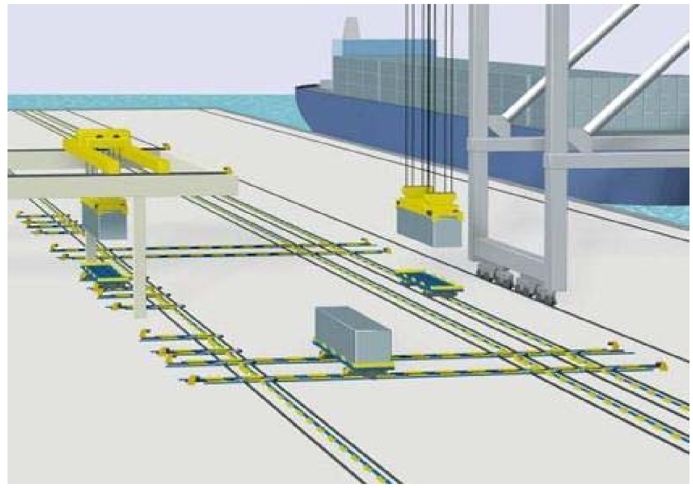

Figure 8. Schematic display of the Noell system tested in Eurokai Terminal in Hamburg, Germany (obtained from Noell Crane Systems website)

Titan Global Technologies Ltd., a New Jersey based company, developed a unique and very promising freight monorail concept called *Auto-GO*. Auto-GO is an overhead cargo container handling system for moving containers from port facilities to other inland intermodal facilities, and vice-versa. The system consists of overhead guiderail and shuttles that carry containers.

Auto-GO shuttles are fully automated using linear induction magnetic propulsion. The transportation process would start inside the terminal where a gantry crane drops off the container. The proprietary special cargo carrying system picks up the container and raises it by means of a specially designed bogie-spreader bar combination (Figure 9). The container is then secured on the container shuttle, and transported at 50 to 75 mi/h (80 – 120 km/h) to its final destination (Figure 10). The advantages of this technology, which combines overhead monorail system and linear induction propulsion, are as

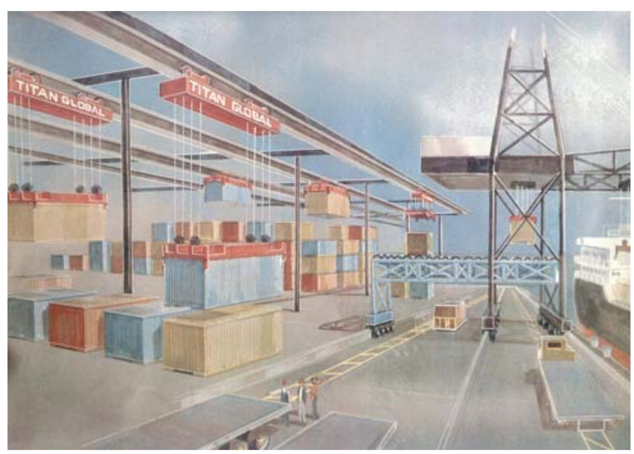

Figure 9. Auto-GO shuttles picking up containers (courtesy of Titan Global Technologies Ltd.)

follows:

- ❑ No interaction with surface traffic and therefore no accidents or delays in shipment due to surface traffic conditions.

- ❑ Reduced cargo handling (each container is handled only once from the point of origin to the point of destination).

- ❑ Improved security due to the cargo being high above ground.

- ❑ Economic efficiencies achieved through reduced operating and handling labor costs, since the system is fully automated, reduced waiting in traffic, and reduced administrative cost.

- ❑ Ability to operate in nearly any weather conditions. As the system does not rely on the use of ground transportation infrastructure, prevailing weather and road conditions would not impact operation of such a system. The only potential disruption may exist in heavy wind conditions, such as hurricane. In those cases the system would probably be out of operation.

- ❑ Low noise and very minimal air pollution emissions.

Titan Global Technologies Ltd. has built and tested 1:6 scale model of Auto-GO system in their facility in New Jersey. The model has all the capabilities of a full-scale system, including use of a linear induction motor, bogie-spreader, hoists, and a locking system that secures the container.

Figure 10. Transport of containers by the Auto-GO system (courtesy of Titan Global Technologies Ltd.)

The technologies used in Auto-GO system guideway, switches, and movement control system, have been tested in the field and use of linear induction motors have been proven in operation of the monorail people-movers that Titan built in Miami, Florida, Pomona, California, and Love Field in Dallas, Texas. The system in Miami was in full commercial operation for almost 30 years until 1992 when the operation ceased due to a severe hurricane. However, the guideway and vehicles had almost no damage. Bogie-spreader and locking system were designed in collaboration with August Design, a Pennsylvania based company that has designed several similar models in operation in various container handling systems.

Automated Guided Vehicles (AGV)

Figure 11. AGV operating in European Combined Terminal (ECT) in Rotterdam, Netherlands (obtained from Frog Systems website)

Automated Guided Vehicles (AGVs) employ driverless vehicles navigated and controlled by a computerized system. AGVs are no longer a new technology having been successfully used for many years in manufacturing plants, warehouses, airports, and other facilities, and for automated transport of various goods. Although most of the mentioned applications are indoor, several systems have been developed and deployed for various outdoor applications, some of them for moving large freight containers within or even outside marine container terminals.

Most notable example of such operation is Sea-Land's Delta Terminal in Rotterdam, Netherlands, also known as European Combined Terminal (ECT). ECT is the very first fully automated container terminal (ACT) in the world. All the containers in the terminal are handled by the Automated Stacking Cranes (ASC) and AGVs. Today, ECT operates more than 150 AGVs.

These vehicles can carry 20, 40, 45 and 50 ft containers, with the payload of up to 40 tons. AGVs can reach speeds of up to 5 mi/h ($\approx$ 8 km/h). The vehicles have been produced by Mannesmann Demag Gottwald GmbH (today Gottwald Port Technology) and they use a guidance system called Free Ranging On Grid (FROG), developed by Frog Systems of the Netherlands. FROG systems use a network of guide wires embedded in the pavement, and wire guidance controls inside the vehicles to navigate around the terminal. Figures 11 and 12 show an AGV used in the ECT.

As shown in Figure 11, the vehicle is entirely symmetrical and it can move in both directions at the same speed. The symmetry of the vehicles is required, since the orientation of the container placed on the AGV is very important for the container tracking and monitoring system. The vehicles have four driving wheels and are equipped on both sides with object detection sensors, which are in charge of detecting any obstacles to the AGV movement. AGVs in the ECT are navigated by a supervisory software control system. The supervisory software packages used in industrial and people mover applications are typically based on optimizing utilization of space. The supervisory control system used at ECT has been developed on the basis of a different philosophy, which optimizes container delivery based on the ship's loading/unloading order plan. This loading plan is vital to efficient utilization of the ships and terminal itself.

The investment costs for the automated terminal are 10 - 15% higher then those required for the corresponding un-automated terminal. According to an analysis conducted by the ECT, the savings from low operating and maintenance costs, especially low labor costs, and increased processing capacity more than offset the investment cost.[3]

Figure 12. AGV operating in winter conditions at ECT, Rotterdam (obtained from Frog Systems website)

The Port of Singapore was also considering deployment of several hundred AGVs after reconstructing the container terminals in the year 2000. The vehicles were developed by Kőgel Kamag, and Mitsui, Inc. Tadiran Communications developed sophisticated traffic management system and advanced system for vehicle control and navigation. Kőgel Kamag provides AGVs with electromagnetic guiding (guide wire), laser, GPS, or navigation based on electromagnetic transponders (reference marks). However, officials at the Port of Singapore decided at this time not to move forward with full commercial AGV deployment.

Figure 13. Kőgel Kamag AGV for Port of Singapore (obtained from Kőgel Kamag website)

[3] Frog Navigation Systems website at http://www.frog.nl/ accessed in June 2003

Mentor AGV, a Cleveland, Ohio, based company, was also bidding for the AGV contract for the Port of Singapore. They have designed an AGV system that is similar to the one developed for the ECT. Besides this model, Mentor AGV has several other designs for container moving applications for marine ports. Figures 14 and 15 show two such vehicles. Earlier vehicles have used navigation systems similar to those used in ECT (wires embedded in the ground). The company advanced the technology in the meantime and is now primarily using laser and radar navigation systems and can offer spot technology that is similar to gyrocompass. Their latest product is an AGV for towing tractor-trailers in El Paso through the X-ray scanning device developed for U.S. Department of Defense. They are also working on a new product for waste transport in New York City. This product is similar to Siemens' CargoMover discussed in section 2.2.1.

A pilot study using an AGV system was also ran by Thamesport in the United Kingdom. The system employed an AGV built by Terberg, which was guided by millimeter wave radar (MMWR) technology. AGVs were operating in conjunction with manned vehicles carrying containers within the terminal. The tests were concluded in 1999. However, no decision has been made about the long-term deployment of the AGVs in the terminal.

Figure 14. AGV for container handling developed by Mentor AGVs (courtesy of Mentor AGVs)

Figure 15. Another AGV for container handling by Mentor AGVs (courtesy of Mentor AGVs)

All of the above mentioned systems were designed to operate inside port terminals. There are also concepts that utilize AGV technology for moving freight outside the terminals. One such example is *CombiRoad* shown in Figure 16. This concept was developed in the Netherlands by a consortium of research institutes gathered under the Netherlands Organization for Applied Scientific Research (TNO) as well as several technology companies including Hollandia, Terberg, and Traxis. The concept is based on deploying unmanned, automatically controlled and navigated trucks carrying marine containers over dedicated tracks. This is a unique application for AGV systems in that this concept uses a fixed guideway to transport vehicles. Vehicles are propelled by electric motor, have rubber tires, and can transport standard marine containers at a maximum speed of 30 mi/h (~ 50 km/h). The system is fully automated with the vehicles guided from the point of origin to the destination. Vehicles are equipped with real time embedded control systems, which incorporate functions like obstacle detection, lateral control, and speed control.

Figure 16. CombiRoad vehicle at the testing facility in Ridderkerk, Netherlands (courtesy of TNO)

CombiRoad was designed to operate as a shuttle between large container terminals, such as Port of Rotterdam, and some inland intermodal or distribution center. A prototype of the CombiRoad vehicle was constructed in 1998 and it was tested at a facility in Ridderkerk, Netherlands. The CombiRoad designers promote the system as an economically attractive, efficient, safe and environmentally friendly way of moving freight. However, the system is not in operation yet and is still one of several concepts that are being considered for future applications. A freight mover technology similar to CombiRoad was developed at the Center for Advanced Transportation Technologies (CATT), a research center at University of South California (USC). The system, termed *"Automated Container Transport system between Inland Port and Terminal (ACTIPOT)"* is envisioned as a dedicated road where fully automated trucks would operate as a shuttle service between the main port terminal and an inland container terminal. This concept is currently in design stage.

Fast Freight Ferry Technologies

Although Fast Freight Ferry Technology is very promising, it has not been proven to be cost effective for short haul moves. Readers interested in these technologies are encouraged to read throughout this section; however, the fast freight ferry was not included as an alternative in the case study analysis.

Growing congestion and limited capacity of the landside transportation network have recently led to many initiatives to utilize coastal waters and inland waterways to provide a feeder service for the large seaports. Container-on-barge feeder service has been successfully implemented in Western Europe for years, especially on the river Rhine waterway system. At the same time, only few examples of similar service could be found in the U.S., mostly because this kind of service was previously considered more expensive and less efficient than conventional truck or rail service.

Recently, however, several companies have begun regular container barge feeder operation along the Atlantic coast and in Gulf of Mexico. Columbia Coastal Transport, a New Jersey based company and the largest container barge feeder operator, provides regular feeder service between several major seaports on the east coast as well as several South Atlantic ports and Freeport, Bahamas. SPM Container Lines provides similar service between Halifax, Portland, and Boston, and Osprey Lines operates barge shuttles and self-propelled small vessels in the Gulf of Mexico region. In March 2003, the Port Authority of New York and New Jersey (PANYNJ) and the Albany Port District Commission introduced Albany ExpressBarge – feeder service between the ports of New York and New Jersey and Albany. The service is operated by Columbia Coastal Transport and is part of a broader initiative to implement the concept of Port Inland Distribution Networks (PIDNs). PANYNJ is also analyzing potential feeder service between ports of New York and New Jersey and inland intermodal port terminals on Delaware River in South Jersey and Delaware (Camden, Salem, and Wilmington are considered as possible locations), in New Haven Connecticut, and Providence, Rhode Island.

The feeder services mentioned above are still very limited and represent a very small portion of the overall container transport to and from the seaports. Most of the lines already in service operate feeder service shuttles only operate once or twice a week depending on the demand. One of the reasons for the limited use of barge feeder server services to transport containers is the large amount of time required to deliver goods. Freight ferries lack the ability to effectively compete with more versatile truck and rail service, particularly for short haul movements and when transporting more expensive time sensitive cargo. However, this situation could be changed with the introduction of a new generation of vessels that could provide faster service. Several studies done by the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) at the California State University, Long Beach, National Ports and Waterways Institute (NPWI), and the Maritime Administration (MARAD) are looking at designing, building and deploying fast, ferry-like vessels for transporting containerized cargo.

In a study conducted by the National Ports and Waterways Institute the feasibility of introducing fast, freight-only ferries that would transport trailers and containers in an intermodal feeder service, similar to barges, along the U.S. East Coast and to points in Canada and Mexico was examined. The proposed system would use fast ferry-like vessels that could travel at fast as 40 knots. The study examined a route consisting of three interlocking loops between Halifax and Tuxpan, Mexico, with relay points at New York and Miami (Figure 17).

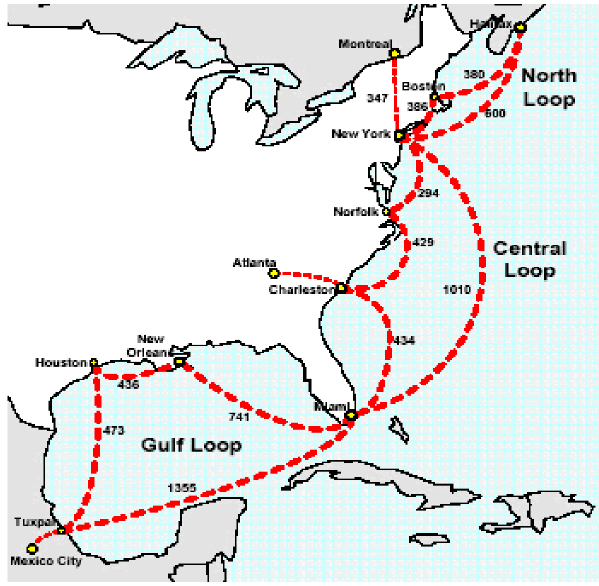

Figure 17. Map of the fast freight ferry system proposed by National Ports and Waterways Institute (obtained from CCDoTT website)

The system proposed in the study would require 16 vessels for 24 hours service. The initial cost for 16 mono-hull Roll On – Roll Off (Ro-Ro) vessels, and nine new port terminals was estimated at $790 million. It was also estimated that cost of service would be approximately equal to the cost of equivalent truck service, and would probably be as fast. However, the study does not consider the costs associated with congestion on highways, especially on I-95 corridor, and with anticipated growth of freight movement in the I-95 corridor, such a system could prove to be more favorable than use of conventional truck modes.

A similar example is planned for the modernization of regional ferry service at Alaska. Alaska Marine Highway System (AMHS) is currently conducting a program of adding fast, modern, efficient, environmentally-friendly vessels to its fleet and introducing new service that will provide faster transport of people and vehicles. They envisioned vessels that could provide fast ferry service between major regional centers for both passengers and cargo.

Figure 18. Artistic rendering of the future fast ferry vessel currently being built by Derecktor Shipyards for Alaska Marine Highway System (AMHS) (obtained from AMHS website)

Both systems mentioned above require fast, new vessels that would provide much faster and more efficient transport than barge. AMHS has already purchased two vessels from Derecktor Shipyards at a cost of nearly $70 Million. The vessel, shown in Figure 18, will have the capacity to carry 35 vehicles and 250 passengers at a service speed of 32 knots, about twice the speed of the current fleet. The first vessel is expected to begin service in 2004.

The vessels designed for AMHS could potentially be modified to serve freight-only transport, an application similar to the one discussed in the study by National Ports and Waterways Institute. Other vessel designs for freight transport applications are also being developed. An Australian shipbuilder, Austal, has developed designs for a high-speed vessel that will be used for container transport. These vessels would be catamarans and trimarans and would be capable of traveling at speeds of up to 40 knots, depending on hull designs and propulsion, and could carry 80 to 140 TEUs. Austal is currently building similar vessels for U.S. Army Marines (Figure 19-1). This vessel will be able to carry 950 soldiers and 550 tons of cargo at speed of 40 knots. The estimated cost is $50 Million.

Figure 19. Fast Freight Ferry Technologies
19-1 (top left) West Pac Express vessel currently being built by the Austal for U.S. Army
19-2 (top right) Ro-Ro and container trimaran vessel designed by Kvaerner Masa-Yards
19-3 (bottom left) Ro-Ro and container pentamaran vessel designed by Kvaerner Masa-Yards
19-4 (bottom right) FastShip Atlantic vessel

Kvaerner Masa-Yards and FastShip Atlantic are also developing similar designs. Kvaerner Masa-Yards has developed several plans for a new generation of Ro-Ro vessels that could also potentially be used for container transport. Figures 19-2 and 19-3 show two such designs. FastShip Atlantic is developing concepts to transport containers between Philadelphia and ports in Western Europe using fast container ships that could move high-value freight at speeds of up to 45 knots (Figure 19-4).

METHODOLOGY FOR EVALUATING INNOVATIVE TRANSPORTATION TECHNOLOGIES

Introduction

Chapter II presented an overview of innovative transportation technologies. Reviewed technologies have different performance and operating characteristics. The purpose of this chapter is to describe the framework that is used to evaluate and rank these technologies for potential applications in northern New Jersey. It is anticipated that the methodology and framework set forth in this study could also be adapted and used for a variety of other applications where multiple alternatives are being considered.

The case study examples examine not only a number of potential technologies, but also look at actual locations and the impacts of changes in demand. Several origin-destination pairs were selected as case studies to determine which technologies would be preferable, while applying several decision variables, including construction costs, operating costs, and environmental impacts. Moreover, the development of case studies provides a decision-making framework for the selection of technologies.

For the purpose of the case studies, purchase of vehicles, installation of guideway and guidance systems, addressing geotechnical conditions, and acquisition of right-of-way translate into capital costs. Size of vehicle fleet for each alternative technology is determined based on service demand in terms of the number of containers to be moved per day, and operating characteristics of particular technology. Fleet size, in turn, impacts the total system cost. Each technological alternative (and its variant) would also result in benefits in terms of reduced congestion, reduced air pollution, etc., that would need to be quantified as well. The proposed framework considers these costs and benefits and seeks to identify the best alternative. In addition, changes in demand and how these changes impact the overall costs and benefits are also considered.

This chapter provides a brief review of the transportation project analysis methods with the discussion on the rationale behind the formulation of analysis framework and decision methods used in this study. It also explains elements of the analysis approach used to evaluate innovative technologies for container transport and select the one with the best performance.

Basic Characteristics of the Transportation Project Analysis

Traditional engineering economics methods can be used to ascertain the merit of transportation projects. These methods include: benefit and cost ratio, net present worth (or value), internal rate of return, payback period, to name a few. [8,14]. All of these methods try to identify, calculate, and compare costs and benefits of alternative projects and select the one with the optimal output.

While the assessment of costs is relatively straightforward in these methods, quantifying benefits associated with implementing a transportation project is complex, as engineering economics methods typically require that they be assigned a monetary value. There are a number of analytical tools to assign the dollar value to the benefits; however, some impacts such as congestion relief, safety improvements, air quality are often difficult to quantify financially. Some may not even be quantifiable (for example aesthetic appearance of the new transportation facility).[8] Environmental and societal impacts are often referred to as "external" effects of the transportation activities, since they are not directly reflected in monetary costs and benefits of project implementation. By externalizing these factors, benefit/cost analyses often do not capture the full value of beneficial impacts. However, the significance of all impacts, both positive and negative, needs to be considered in the decision making process.

An alternative to traditional engineering economics methods is an approach that captures and evaluates non-monetary, as well as monetary costs and benefits of transportation projects. Multicriteria analysis allows planners to consider factors such as environmental impacts and safety impacts when evaluating possible transportation investments without attaching a monetary value to them. Impacts of noise, air pollution and safety may be more easily comprehended by using volume-based measures such as noise reduction (in decibels), air pollution reduction (in tons of pollutants) and safety improvements (reduction in number of accidents), rather than dollars. Multicriteria approach allows planners to evaluate projects and evenly compare their impacts in both monetary and non-monetary terms.

Multicriteria Decision Analysis for Transportation Projects

Given the complexity of transportation project analysis, a multicriteria approach was adopted for the study of innovative transportation technologies. The main advantage of this approach is that it allows for analysis and evaluation of investment alternatives over multiple objectives. In case of transportation, these objectives can include improving mobility, reducing cost of transportation, reducing travel times, improving air quality, inducing economic development, reducing maintenance costs, etc. Some of the objectives can contradict each other, in which case one needs to consider trade-offs in weighing implementation impacts among projects. Multicriteria evaluation is also useful when one project is superior in meeting one major objective, while it lags behind other projects in satisfying other important objectives. In this case, the analysis provides for decision-making based on evaluation to the degree in which various projects meet all the decision criteria, while weighing importance of the conflicting objectives in impacting positive net results.

The authors of a recent study that was conducted at Texas Transportation Institute proposed a new framework for multimodal freight investment analysis – Multicriteria Cost Benefit Analysis (MCCBA).[14] The outlined methodology can be summarized in several basic steps:

1. Identify multiple investment alternatives.

2. Identify objectives and criteria by which the alternatives will be evaluated.

3. Evaluate performance measures for each criterion. This is done based on the developed rating scale of valuation functions for each performance measure.

4. Assign weight to each criterion that will reflect tradeoffs and conflicts associated with investment decisions. The weight structure reflects the importance of criteria relative to each other.

5. Rank the alternatives based on final scores.

Objectives and performance measures are chosen based on the type of projects that are being considered. Many authors offer generic lists of possible objectives and performance measures that can be used in the analysis. Commonly used criteria can be divided into several major categories, such as:

- Financial impacts: construction costs, maintenance costs, operation costs, revenues, increase or reduction of fares for transit systems.

- Socio-economic: land values, reduction of congestion, employment during construction, induced employment.

- Environmental impacts: change in noise levels, change in vehicle emissions, change in land use, energy consumption.

- System performance: compatibility with existing system, capacity expansion, technology reliability, and safety.

For each criterion, a performance measure is identified. For example, safety is expressed as reduction in accident rates. Each alternative is then evaluated on each criterion using a corresponding performance measure. Note that measures can differ from one criterion to another, not only in units, but in scale as well. For example, financial impacts are expressed in monetary terms, noise in decibels, safety in accident rates, while some of the measures are qualitative, like compatibility with the existing system, which could be graded on the scale from high to low compatibility. Occasionally lack of accurate data can result in developing a descriptive grading scale even for those measures that could be quantified.

Since different criteria can have different measures, it is necessary to develop a common denominator for all these measures. This is usually done by converting values of the performance measures for each alternative to numerical scores. Single-criteria value functions are defined for each performance measure to translate criteria-specific values into single-criteria scores, which follow a certain scale, e.g. 0-10 or 0-100.

There are many methods for developing value functions. The first step is to set the lower and upper bound for the values of the performance measure. This interval has to contain all the observed values for the particular performance measure. One approach for establishing these intervals is to make the highest observed value an upper bound and the lowest observed value the lower bound for each particular performance measure. Another way to do this is to determine an interval of values that the decision maker is willing to consider in the analysis, and set the lowest value on the interval as the lower bound and the highest value on the interval as the upper bound. The most favorable value of the two would then receive the highest score (e.g. 10), and the least favorable would receive the lowest score (e.g. 0). The values of the performance measure for each alternative, which are in the interval between the lower bound and the upper bound, are then converted into scores (e.g. on the interval from 0 to 10). This conversion is calculated using the single-criteria value function. This value function greatly depends on the type of measure and judgment of the decision maker, and can be as simple as a linear function, or more complex and based on special algorithms.[2,14] After this procedure is completed, each alternative has a score, which replaces the value of the performance measure in the further analysis. The procedure is then repeated for all the criteria and associated performance measures.

Before summarizing the single-criteria scores into the total scores for each alternative, it is necessary to ascertain the relative importance of each criterion, since they can widely differ from one another. In order to do this, each criterion is assigned a weight that reflects its importance relative to other criteria. Many different weighting systems can be used. Weights depend on the nature of the decision that is being made and are a result of decision maker's preferences. Very often weights are assigned arbitrarily.[13] There are also several analytical procedures for developing weighting schemes, such as: standardized, reciprocal, rank sum weighting, ratio rating, and indifference trade-offs method. These methods are not elaborated upon here since they are not used in this study, but reader is encouraged to find out more about this from the referenced literature.[14]

After calculating single-criteria scores and establishing weights for all the criteria, total scores for each alternative are calculated as the sum of products of individual criteria scores and their respective weights. The total score can be described as an overall index of project desirability

Multicriteria analysis is usually presented in the form of matrix. The matrix consists of a list of alternatives, list of criteria with associated performance measures, single-criterion scores for each criterion and each alternative, and total scores for each alternative.

An example of an evaluation matrix is given in Table 1. The single-criteria score of alternative i for criterion *j* is denoted by $a_{i,j}$. The weight of criterion j is denoted by w_j. The total score for alternative i is calculated as the sum of products of alternative valuations and corresponding criterion weights:

$$\sum_{j=1}^{15} a_{1,j} \cdot w_j \qquad (1)$$

In the final step of the analysis, the alternatives are ranked based on their total scores. Usually total scores are calculated. Several iterations may be made and sensitivity analysis is performed to determine the impact of different weighting schemes on the final results. This is especially important in those cases where more than one interest group is identified, since different interests put different weights on criteria.

Table 1. Structure of the multicriteria evaluation matrix

Criteria	Measure	Alternative 1	Alternative 2	. . . .	Alternative n	Weight*
SOCIO-ECONOMIC IMPACTS						
Land values	% increase in land value	$a_{1,1}$	$a_{2,1}$	. . . .	$a_{n,1}$	w_1
Employment due to construction work	person hours, or # of jobs per year	$a_{1,2}$	$a_{2,2}$	. . . .	$a_{n,2}$	w_2
Induced employment	# of created jobs	$a_{1,3}$	$a_{2,3}$	. . . .	$a_{n,3}$	w_3
Congestion	Reduction in VMTs or time/vehicle-mile, or in congestion cost	$a_{1,4}$	$a_{2,4}$	. . . .	$a_{n,4}$	w_4
ENVIRONMENTAL IMPACTS						
ROW land requirement	Total additional land required (in hectares)	$a_{1,5}$	$a_{2,5}$	. . . .	$a_{n,5}$	w_5
Air pollution	Quantity of each emission component produced or saved (in tons)	$a_{1,6}$	$a_{2,6}$	. . . .	$a_{n,6}$	w_6
Noise	Number of people / area exposed to excessive noise (e.g. 5dB or more)	$a_{1,7}$	$a_{2,7}$	. . . .	$a_{n,7}$	w_7
Energy	Energy consumption or savings	$a_{1,8}$	$a_{2,8}$	. . . .	$a_{n,8}$	w_8
FINANCIAL IMPACTS						
Capital cost	Cost of planning, design, land, and construction ($/year of operation)	$a_{1,9}$	$a_{2,9}$	. . . .	$a_{n,9}$	w_9
Annual operating cost (including maintenance cost)	$/ton-mile or $/pass-mile, or $/veh-mile	$a_{1,10}$	$a_{2,10}$	. . . .	$a_{n,10}$	w_{10}
Revenue	Revenue generated from the users of the innovative technology (in $)	$a_{1,11}$	$a_{2,11}$	. . . .	$a_{n,11}$	w_{11}
SYSTEM PERFORMANCE						
Capacity	Vehicles per day, or passengers per day, or tons per day	$a_{1,12}$	$a_{2,12}$	. . . .	$a_{n,12}$	w_{12}
Safety	Reduction in number of accidents or savings in accident cost	$a_{1,13}$	$a_{2,13}$	. . . .	$a_{n,13}$	w_{13}
Technology reliability	Estimated number of failures per 1000 hours of operation.	$a_{1,14}$	$a_{2,14}$	. . . .	$a_{n,14}$	w_{14}
Compatibility with existing system	Scale 1 - 5	$a_{1,15}$	$a_{2,15}$	. . . .	$a_{n,15}$	w_{15}
TOTAL SCORES		$\sum_{j=1}^{15} a_{1,j} \cdot w_j$	$\sum_{j=1}^{15} a_{2,j} \cdot w_j$	. . . .	$\sum_{j=1}^{15} a_{n,j} \cdot w_j$	

Multicriteria Decision Analysis Model For Evaluating Innovative Transportation Technologies

Following a general approach of the multicriteria decision analysis outlined in the previous section, the following objectives are defined for the selection of innovative technology for transport of cargo containers between port terminals and inland intermodal stations:

- Minimize investment and operating costs of the future system.
- Increase velocity and improve performance of the freight transportation system.
- Maximize social benefits for the nearby communities.
- Improve quality of life and minimize negative environmental impacts.

The above objectives are defined in consideration of specific transportation and quality of life issues facing northern New Jersey, most notably, traffic congestion, lack of capacity on the highway network, increasing truck traffic, air pollution, and expected growth in the number of intermodal containers entering the region over the next two decades.

For each objective, several criteria have been defined to evaluate specific impacts. Table 2 relates the stated objectives to the criteria and associated performance measures.

Calculation procedures used in case studies to determine the values of performance measures for alternative technologies are given in Appendix B.

After evaluating alternatives using defined performance measures, it is necessary to calculate single-criterion scores. This is done by following the procedure outlined in the previous section. Grading scale 0-5 is established for all the criteria scores. A score of five is assigned to the most favorable observed value of each performance measure, while a score of zero is assigned to the least favorable observed value. Scores for all alternatives are then calculated using respective single-criteria valuation functions. All single-criteria evaluation functions are linear. Therefore, single-criteria scores are calculated on the zero-to-five scale using the linear extrapolation on the interval between the most favorable and the least favorable value of the respective performance measure. Detailed explanation of the procedure and an example of the calculation are outlined in Appendix A.

Table 2. Description of evaluation criteria and performance measures

Objectives/Criteria	Description	Performance Measure*
MINIMIZE INVESTMENT AND OPERATING COSTS OF THE FUTURE SYSTEM		
Cost per container trip	Cost per container trip represents the ratio of total annual system cost and total annual number of container trips on selected route. The total cost includes construction cost, ROW land acquisition, fleet cost, operating and maintenance cost.	$/container trip
INCREASE VELOCITY AND IMPROVE PERFORMANCE OF THE FREIGHT TRANSPORTATION SYSTEM		
Travel time	Average container travel time between the terminals (port terminal and inland intermodal station), including loading and unloading.	Hours
Congestion relief	This criterion is measured as the reduction in number of truck trips on the highway network between two terminal points, as the result of diverting the containers to the new transportation technology. It is assumed that one container diverted will eliminate one truck round-trip of the highway.	Daily number of diverted truck trips
Safety	This criterion addresses safety level of each technology by assessing possibility of accidents or incidents with human casualties or injuries, or property damage, related to system operation. This is usually difficult to calculate, especially for new technologies that have not been tested in full commercial service. Experience with similar technologies and professional judgment of the research team members is used to assess the safety level for each technology.	Qualitative grading scale: 1 = Worst, 5 = Best
System reliability	This criterion measures the probability of system or vehicle failure. Using available data and comparison with similar technologies, research team assessed system reliability for each technology. Status of the technology (whether it is proven in operation, or if it is testing, proto-type or design phase) has been considered as a factor in evaluating reliability.	Qualitative grading scale: 1 = Low, 5 = High
Intermodal compatibility	This criterion measures the ability of the system to be efficiently integrated with the current container handling system inside the port terminal. It is assessed based on preliminary analyses of interactions between candidate technologies and handling system.	Qualitative grading scale: 1 = Low, 5 = High

Table 2. (Cont.) Description of evaluation criteria and performance measures

Objectives/Criteria	Description	Performance Measure
INCREASE VELOCITY AND IMPROVE PERFORMANCE OF THE FREIGHT TRANSPORTATION SYSTEM		
System expandability	This criterion measures the ability of the innovative technology to efficiently expand its capacity.	Qualitative grading scale: 1 = Worst, 5 = Best
MAXIMIZE SOCIAL BENEFITS FOR THE NEARBY COMMUNITIES		
Employment during construction	Employment related to the construction of the system.	Number of created jobs annually
Induced employment	Employment related to the long-term operation and maintenance of the system, and as a result of economic development in the region following the implementation of new technology	Number of created jobs annually
IMPROVE QUALITY OF LIFE AND MINIMIZE NEGATIVE ENVIRONMENTAL IMPACTS		
Air pollution	This criterion addresses negative impacts of the vehicle emissions related to alternative technologies. Average vehicle-born pollutant emissions are assessed for each alternative technology.	kg/TEU-mile
Land Requirement for ROW	Total additional land required for the system ROW. Since the project area lacks available space it would be desirable to use technology that can utilize existing ROW (or at least its part) without disruption of current freight operations.	Qualitative grading scale: 1 = Low, 5 = High
Hazardous and solid waste risk	Expected risk of encountering o hazardous and solid waste materials during construction related to technology implementation.	Qualitative grading scale: 1 = Minimum Impact, 5 = Maximum Impact
Disruption of the natural habitat	This criterion considers negative impacts of innovative technologies on the flora and fauna and disruption of wetlands.	Qualitative grading scale: 1 = Minimum Impact, 5 = Maximum Impact

* Note that overall assessments of qualitative measures would be calculated as the average of scores assigned by members of the research team.

In order to ascertain the importance of evaluation criteria, each one is assigned a weight. The weights reflect the criterion's relative importance in the analysis. The weighting scheme developed for the current study is listed in Table 3. This weighting scheme is based on research team members' professional judgment, and it also reflects extensive consultations with NJDOT and PANYNJ experts. The sum of all weight factors equals 100%.

In the end, total scores are calculated as the sum of products of individual criterion scores and their respective weights (this is already explained in the previous section). Alternatives are then ranked based on their total scores, with the technology receiving the highest total score being top ranking alternative.

Table 3. Decision criteria and related weights

Criteria	Weights
Cost per container trip	35%
Travel time	7%
Congestion relief	7%
Safety	7%
System reliability	3%
Intermodal compatibility	3%
System expandability	3%
Employment during construction	5%
Induced employment	15%
Air pollution	5%
Land Requirement for ROW	5%
Hazardous and solid waste risk	3%
Disruption of the natural habitat (including wetlands)	2%

CASE STUDIES

Introduction

In order to test the applicability of innovative technologies for container transport four case studies have been developed. Each case study represented a different geographic area and alignment. In each case, alternative transportation technologies have been analyzed and compared.

It is assumed that the technologies would operate in a shuttle service between the port terminal and inland intermodal station. These stations would provide a connection to the United States National Rail Network or United States National Highway Network, thus serving as a staging area for the port related containers. Introduction of the container transport service between the port and these sites would create additional capacity in the transportation network, especially in the area adjacent to the port terminals. In the case study analysis, the objective remained the same: move the containers in the most efficient way that would eliminate congestion and provide for expansion of the port to meet the expected growth in ocean born container volumes.

This chapter presents the alternative technologies selected for the case study analysis and defines assumptions about their operating regimes and parameters. This is followed by definitions of case studies in terms of location and travel routes. In the end we discuss the results of the analysis for each case study.

Technology Parameters and Operating Regimes

Using the information from Chapter 2 the following alternative technologies were considered in the analysis: AGV, AutoGo, CargoRail, CargoMover, conventional rail, and trucks. It is realistic to expect that these technologies would compete with the existing freight container transport modes such as conventional rail and truck. The cost and other factors associated with implementing innovative transportation concepts will be compared to those of rail and truck.

Operating regimes for alternative technologies were defined under following assumptions:

- The system would operate 365 days per year, 16 hours per day, divided into two 8-hour shifts.

- Outbound direction is defined as a movement from the port terminal to the intermodal station. The inbound direction is the reverse of the outbound.

- Vehicles would always be loaded in the outbound direction, while 80% of time they would have a loaded backhaul in the inbound direction.

- Fleet size is determined as a minimum number of vehicles needed to serve given container demand.

- The identical container handling equipment would be available in the port terminal and the intermodal station to load and unload containers. The capital cost and the operating cost of this equipment did not depend on the type of container mover technology. Therefore, it was not included in the total system operating cost analysis.

- All containers are 40ft long (a two TEU equivalents).

- Useful economic life of the infrastructure is 20 years.

- Cost of diesel is $1.77/gal[1].

- Cost of electricity is 0.07 $/kWh[2].

Following are the definitions of operating regimes and parameters specific to each alternative technology.

AGV

It is assumed that vehicles similar to those currently in operation in ECT, Rotterdam would be used. Vehicles would operate in the shuttle service between the port terminal and intermodal stations. Vehicle assignment is sequential - they would pick up the container at the origin point and transport it to the destination point. After the container is unloaded (lifted off), the vehicle is ready to pick up a new container and transport it in the opposite direction. If there were no backhaul load in the intermodal station, the vehicle would come back to the port terminal empty. Each AGV can carry one 40ft container.

Operating parameters for AGV are determined based on specifications obtained from manufacturer of vehicles currently in operation in ECT in Port of Rotterdam, Gottwald

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1 This figure was obtained from American Automobile Association's (AAA) Daily Fuel Gauge Report as an average daily retail price in May 2004.

2 This figure was obtained by inflating the data from the Energy Information Administration's statistics for 2002. The 2002 data is available online at http://www.eia.doe.gov/neic/quickfacts/quickelectric.htm#footer.

Port Technologies, and from the study on advanced port technologies conducted by the Center for Advanced Transportation Technologies at the University of South California [18]. Table 4 summarizes operating parameters for AGV used in the case study analysis.

Table 4. Summary of operating parameters for AGV

Parameters	Measure
Required width of the right-of-way:	15 ft per direction
Engine type:	230 kW diesel
Fuel (diesel) consumption:	3.17 gal/hour of operation
Average vehicle operating speed:	15 mi/h
Average loading/unloading time per container	5 minutes
Purchasing cost of a single vehicle	$500,000
Vehicle maintenance cost	$5 per hour of operation
Expected vehicle economic life	15 years
Engine emissions*	CO = 2.10 g/kWh, HC = 0.66 g/kWh, NOx = 5.00 g/kWh, PM = 0.10 g/kWh
Required personnel	2 persons in control room and 2 maintenance engineers. Assumed hourly wage is $35.

* Based on EURO III emission standard that AGV engines complies with.

AutoGo

AutoGo would be constructed as an overhead suspended monorail system. Although carrier vehicles have integrated hoists and spreaders to pick up and lift containers off and drop them on the ground or other vehicles, it is assumed that container handling equipment would be used for container transfer within the port terminal and the intermodal station area. Each vehicle can carry one 40ft container.

Vehicle assignment is sequential. After a container is delivered, the vehicle is ready to pick up a new container and transport it in the opposite direction. If there is no backhaul load in the intermodal station, the vehicle would return to the port terminal empty.

Operating parameters and technical characteristics are obtained from the vendor, Titan Global Technologies, and through the comparison with similar systems, such as CargoRail. They are summarized in Table 5.

Table 5. Summary of operating parameters for AutoGo

Parameters	Measure
Required width of the right-of-way	15 ft per direction (possibly above existing highway or railroad right-of-way)
Engine type	250 kW, linear induction motor
Electricity consumption	4 kWh/veh-mile
Average vehicle operating speed	45 mi/h
Average loading/unloading time per container	5 minutes
Purchasing cost of a single vehicle	$150,000
Vehicle maintenance cost	$1.00 per hour of operation
Expected vehicle economic life	20 years
Engine emissions	No emissions
Required personnel	2 persons in control room and 1 maintenance engineer. Assumed hourly wage is $35.

CargoRail

CargoRail would be constructed as an elevated system. Sequential vehicle assignment is assumed. If there is no backhaul load in the intermodal station, the vehicle would return to the port terminal empty. Container placement on the vehicle is similar to flatbed freight car – they are loaded on top of the carrier vehicle. Each vehicle can carry one 40ft container.

Operating parameters and technical characteristics are obtained from the vendor, MegaRail Transportation Systems, Inc, and are given in Table 6 below.

Table 6. Summary of operating parameters for CargoRail

Parameters	**Measure**
Required width of the right-of-way	15 ft per direction (possibly above existing highway or railroad right-of-way)
Engine type	4 permanent magnet electric motors, 300 kW total power
Electricity consumption	5 kWh/veh-mile
Average vehicle operating speed	45 mi/h
Average loading/unloading time per container	5 minutes
Purchasing cost of a single vehicle	$100,000
Vehicle maintenance cost	$1.00 per hour of operation
Expected vehicle economic life	20 years
Engine emissions	No emissions
Required personnel	2 persons in control room and 1 maintenance engineer. Assumed hourly wage is $35.

CargoMover

CargoMover operates as a self-propelled automated rail vehicle, similar to AGVs, except it travels over the conventional rail track. Each vehicle can carry two 40ft containers. Containers are loaded on top of the vehicle, similar to rail flatbed freight car. Vehicle assignment is sequential. If there is no backhaul load in the intermodal station, the vehicle would come back to the port terminal empty.

Technical characteristics of the technology have been obtained from Siemens Transportation Systems, manufacturer of the CargoMover. Engineers from Siemens suggested that capacity of the system could be increased at a lower cost by coupling sensory vehicles (CargoMover) with conventional flat-bed cars. In this vehicle combination sensory vehicles would be placed on each end, and flatbed cars in the middle of the vehicle combination. The calculation performed in this exercise considers single-vehicle operation (individual sensory units only).

Table 7. Summary of operating parameters for CargoMover

Parameters	Measure
Engine type	400 kW diesel-electric engine
Fuel consumption	0.15 gal/veh-mile
Average vehicle operating speed	40 mi/h
Average loading/unloading time per container	5 minutes
Purchasing cost of a single vehicle	$1,000,000
Vehicle maintenance cost *	$1.25 per veh-mile
Expected vehicle economic life	20 years
Engine emissions **	CO = 1.65 g/kWh, HC = 0.41 g/kWh, NOx = 5.55 g/kWh, PM = 0.34 g/kWh
Required personnel	2 persons in control room and 1 maintenance engineer. Assumed hourly wage is $35.

* Based on average cost of maintenance for diesel-electric locomotive (20).

** Based on US EPA emission standards for locomotives, Tier 1 (model years 2002-2004), line haul. CargoMover engines comply with these standards.

Conventional Rail

It is assumed that trains would operate in a shuttle service between the port terminal and the inland intermodal station. Each train would be powered by a single locomotive and would consist of 20 flatbed freight cars. Each car can carry two 40 ft containers, single stacked. Locomotives haul the train between terminals and maneuver the cars inside the terminal if necessary. Locomotives can be dispatched to another task if the backhaul composition is not ready. When the new train is ready to depart, a locomotive is assigned to haul the train.

Average time to load and unload the train was estimated based on the information gathered from the ExpressRail yard operations in Port Newark. Presently, this yard can handle approximately 40 containers per hour. Technical characteristics and cost information for the analysis was obtained from the study "Rail Short Haul Intermodal Corridor Case Studies: Industry Context and Issues" (19) and the research paper entitled "Short Haul Rail Intermodal: Can It Compete with Truck?" (20). This information is summarized in Table 8.

Table 8. Summary of operating parameters for conventional rail

Parameters	Measure
Engine type	6000 kW diesel-electric engine
Fuel consumption	3 gal/veh-mile
Average vehicle operating speed	25 mi/h
Average loading (unloading) time per train	1.5 hours
Locomotive ownership cost	$350 per day
Locomotive maintenance cost	$1.25 per locomotive-mile
Flatbed car lease cost	$2.09 /hour
Flatbed car maintenance cost	$0.07 /car-mile
Engine emissions *	CO = 1.65 g/kWh, HC = 0.41 g/kWh, NOx = 5.55 g/kWh, PM = 0.34 g/kWh
Crew cost	$450 /shift

* Based on US EPA emission standards for locomotives, Tier 1 (model years 2002-2004), line haul. It is assumed that locomotive engines would comply with these standards.

Trucks

Trucks would pick up a load in the port terminal and transport it to the inland intermodal station. If there is a backhaul load at the intermodal station, the truck would pick it up and transport it to the port. Otherwise, the truck would leave the system. It is assumed that each truck can carry one 40 ft container. Average truck operating speed on the local highway network is estimated at 35 mi/h, while the pick-up and drop-off time is 10 minutes.

The truck operating costs are calculated using a model developed in "Intermodal Drayage Issues and Economics" (21), a report prepared for the Association of American Railroads by the Mercer Management Consulting in August 1992. The costs were inflated to the May 2004 level. The inflation factor was obtained from the Consumer Price Index table, provided by the U.S. Bureau of Labor Statistics. Table 9 lists elements of the costing model and updated estimates of the truck costs, as well as operating parameters.

Table 9. Summary of operating parameters for conventional rail

Parameters	Measure
Time based labor cost - includes driver hourly wage	$35 /hour
Time based truck operating cost - includes costs of truck ownership (capital depritiation) and maintenance	$9.56 /hour
Milage based truck cost includes cost of fuel and tires	$0.51 /veh-mile
Average vehicle operating speed	35 mi/h
Average container pick-up and drop-off time	10 minutes
Engine emissions *	CO = 20.79 g/kWh, HC = 1.74 g/kWh, NOx = 5.36 g/kWh, PM = 0.13 g/kWh

* Based on US EPA emission standards for heavy-duty trucks and bus engines, model years 1988-2004. It is assumed that truck engines would comply with these standards

Definition of Case Study Routes

Four case studies are:

1. Port Newark/Elizabeth – Irvington, Essex County
2. Port Newark/Elizabeth – Tremley Point, Union County
3. Port Newark/Elizabeth – South Kearny, Hudson County
4. Military Ocean Terminal Bayonne (MOTBY) – Greenville Yard, Jersey City, Hudson County

Port Newark/Elizabeth was chosen because it handles the majority of containerized ocean born cargo in New Jersey. It also has an active rail intermodal terminal, which means it has existing rail right-of-way that can be utilized by innovative technologies. MOTBY, on the other hand, was selected as it is planned to be redeveloped into a small container terminal and currently has very limited road and rail access. The study team in collaboratring with the NJDOT and the PANYNJ deemed it worthwhile to analyze if innovative technologies would provide an optimal solution for the container movement in and out of the these terminals.

Rationale behind the selection of inland sites is the following:

- Sites in Irvington, Tremley Point, and South Kearny are all in industrial zones and already house manufacturing and warehousing facilities.
- All of these sites have potential to be redeveloped into industrial parks.
- They have direct rail access through industrial sidings to the National Rail Network.
- They have direct highway access to the National Highway Network.
- Greenville yard currently serves as an intermodal rail yard and is operated by Conrail and New York Regional Railroad. It is close to MOTBY and it can serve as a satellite intermodal connector (or yard).

In order to calculate the required fleet size, costs, travel times, and other performance measures for the alternative technologies, it was necessary to define general alignments that these technologies would follow in each of the four case studies. The alignments utilize existing rail or highway right-of-way to the maximum possible extent. It is assumed that elevated guideways for AutoGO and CargoRail can be built over or next to existing highways or rail lines, and CargoMover can utilize existing rail track or rail right-of-way. AGVs require dedicated lanes or guideways, so it was assumed that its infrastructure would need to be built within existing right-of-way. All these considerations influenced the final definition of route alignments.

All proposed case study route alignments are located in a very challenging region from the geological, engineering, and ecological point of view. It is therefore very important to examine geo-technical and ecological properties of the underlying terrain in order to determine its impacts on construction of the infrastructure related to innovative technologies, as well as its complex environmental impacts arising from construction and implementation of each technology. For this purpose, the project team conducted a rather comprehensive geo-technical and engineering study of the proposed alignment that helped us understand the problems associated with the construction of transportation infrastructure in the studied region. The results of the geo-technical study were used to estimate construction costs and environmental impacts. The study results are explained in more details in Appendix C.

What follows is a brief description of route alignments for each of the four case studies. Alignments are also presented graphically using aerial photos of the study area. It is assumed that trucks would use the shortest route over the existing roadway network to move containers between port terminals and selected off-terminal sites. The routes can include only the roadways permitted for use by heavy trucks hauling cargo containers.

Assumed truck routes are shown on aerial photos for each case study as red lines and are primarily defined for the purpose of calculating distances between terminals.

Port Newark/Elizabeth – Irvington

In this case study, the following alignments are considered:

- Alignment 1: This alignment would be utilized by AGV, Auto-Go, and CargoRail technologies. It starts at Port Elizabeth and then follows New Jersey Turnpike northward to I-78. It then makes a left turn near the interchange with the I-78 and follows the I-78 alignment to the Irvington site. AGV would require construction of one lane in each direction, while guideway for AutoGo and CargoRail would be elevated and built above or next to the existing highway right-of-way. The alignment is 8.7 miles long.
- Alignment 2: This alignment would be utilized by CargoMover and conventional rail. It starts at the ExpressRail yard at Port Elizabeth and follows Chemical Coast Secondary Line up to Bayline Yard (just north of I-78). The alignment then turns left to track in the Bayline yard to connect to Lehigh Line south. After connecting to the Lehigh Line, it continues southward, until it reaches the switch to a siding leading to the Irvington site. The same assumption regarding utilizing the existing rail right-f-way hold as in the case of Alignment 2. The alignment is 9.5 miles long.

Alignments 1 and 2 and assumed truck route alignment for this case study are shown in Figure 28 in Appendix D.

Port Newark/Elizabeth – Tremley Point

Two alignments are proposed for the innovative technologies. They are shown in Figure 18 as yellow and green lines:

- Alignment 3: The alignment would be utilized by AGV, Auto-Go, and CargoRail technologies. It starts at Port Elizabeth and then follows the New Jersey Turnpike towards the south. It turns east between the Turnpike Exits 12 and 13 and north from Rahway River, to enter the Tremley Point site. It is assumed that the AGV would require construction of one lane in each direction, while guideways for AutoGo and CargoRail would be elevated and built above or next to the existing highway right-of-way. The alignment is 7.7 miles long.
- Alignment 4: The alignment would be utilized by CargoMover and conventional rail. It starts at the ExpressRail yard at Port Elizabeth and follows Chemical Coast Secondary Line south. It branches off onto the existing rail right-of-way leading to

the Tremley Point site. It is assumed that the alignment would be entirely double-tracked, so it would be necessary to build the second track wherever it does not currently exist. The alignment is 7.2 miles long.

Alignments 3 and 4 and assumed truck route alignment for this case study are shown in Figure 29 in Appendix D.

Port Newark/Elizabeth – South Kearny

In this case study, the innovative technologies would follow the following alignments:

- ❑ Alignment 5: The alignment would be utilized by AGV, Auto-Go, and CargoRail technologies. It starts at the Port Elizabeth and then uses local streets between the Port Elizabeth and the bridge across the Passaic River. The alignment in this segment passes through an industrial zone and in part follows the route of the PORTWAY[3], a dedicated truck route being built by NJDOT. After crossing the bridge into South Kearny peninsula it enters the site in the tip of the peninsula that will serve as the intemodal station. Again, it is assumed that AGV would require construction of one lane in each direction, while guideway for AutoGo and CargoRail would be elevated and built above or adjacent to existing highway/street right of way. The alignment is 6.2 miles long.

- ❑ Alignment 6: This alignment would be utilized by CargoMover and conventional rail. It starts at the ExpressRail yard at Port Elizabeth and follows the Chemical Coast Secondary Line up to the Bayline Yard (just north of I-78). The alignment then turns west onto the Bayline yard to connect to the Lehigh Line north. It follows the Lehigh Line right-of-way across the Passaic River to CSX yard in South Kearny. It branches off the yard via a siding and continues south to the envisioned intermodal station. It is assumed that the alignment would be entirely double-track, so it would be necessary to build the second track wherever it does not currently exist. This is taken into account when calculating construction costs. The alignment is 8 miles long.

Alignments 5 and 6 and assumed truck route alignment for this case study are shown in Figure 30 in Appendix D.

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[3] The Portway program is a series of 11 NJDOT projects that will improve access to and between the Newark-Elizabeth Air/Seaport Complex, intermodal rail facilities, trucking and warehousing/ transfer facilities and the regional surface transportation system. More information about Portway is available at NJDOT website http://www.state.nj.us/transportation/works/portway/projects.htm

MOTBY – Greenville Yard

Two alignments are proposed for this case study:

- Alignment 7: This alignment would be utilized by AGV, Auto-Go, and CargoRail technologies. It starts at the site of the future container terminal on the MOTBY property, continues through the industrial zone outside of the Global Marine Terminal and ends in the Greenville yard. It is assumed that AGV would require construction of one lane in each direction, while guideway for AutoGo and CargoRail would be elevated and built in the right-of-way used for access roads to local warehousing and manufacturing facilities. The alignment is 2.7 miles long.
- Alignment 8: This alignment would be utilized by CargoMover and conventional rail. It starts at the site of the future container terminal in MOTBY, follows the existing rail right-of-way outside the terminal and joins the track operated by Conrail that leads into the Greenville yard. Short length of the route and lower demand for container transport allow for a single track operation. The alignment is 3.5 miles long.

Alignments 7 and 8 and assumed truck route alignment for this case study are shown in Figure 31 in Appendix D.

Case Studies – Results of the Analysis

Technology Ratings Based on Multicriteria Analysis

The multicriteria analysis was conducted separately for each case study. Performance measures and corresponding criteria scores for alternative technologies were calculated for different demands that translated in annual volumes transported by each technology, as shown in Table 10.

For each case study, seven container demand data points were established, and performance measures calculated for each. Procedures for calculating performance measures are explained in detail in Appendix B.

The final scores for alternative technologies are shown in Figures 20 to 23. Figures show the change in rating as function of demand. For example, in Figure 20 for the demand level of 150,000 containers, the Cargo Rail (blue line with triangles) is the highest rated technology with the score of 3.44. Figures 20 to 23 can be used to find the alternative scores for each case study.

Table 10. Transportation demand used in the analysis, per case study

Case Study	Volumes* (in 000 containers)
Port Newark/Elizabeth - Irvington	50, 100, 150, 200, 250, 300, 350
Port Newark/Elizabeth – Tremley Point	50, 100, 150, 200, 250, 300, 350
Port Newark/Elizabeth – South Kearney	50, 100, 150, 200, 250, 300, 350
MOTBY	25, 50, 75, 100, 125, 150, 175

* Annual volumes in outbound direction (from port terminal to intermodal station)

The results of the analysis indicate that innovative technologies become more attractive (have a higher score) as the container volume increases. This conclusion holds true for all four case studies. The case studies differ only in the break-even points (i.e., the volume beyond which an innovative technologies become a dominant) as shown in Figures 20 to 23.

The analysis that follows is organized around the technologies. The score and performance of each technology is discussed and its potential for the service ascertained.

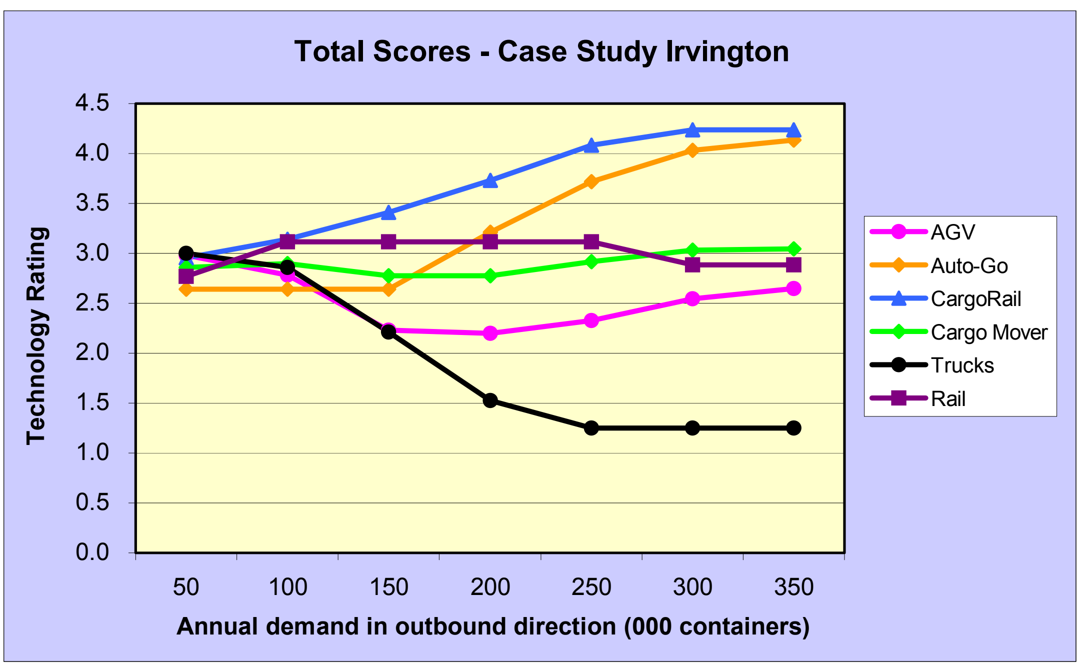

Figure 20. Total scores for alternative technologies – Case Study Irvington

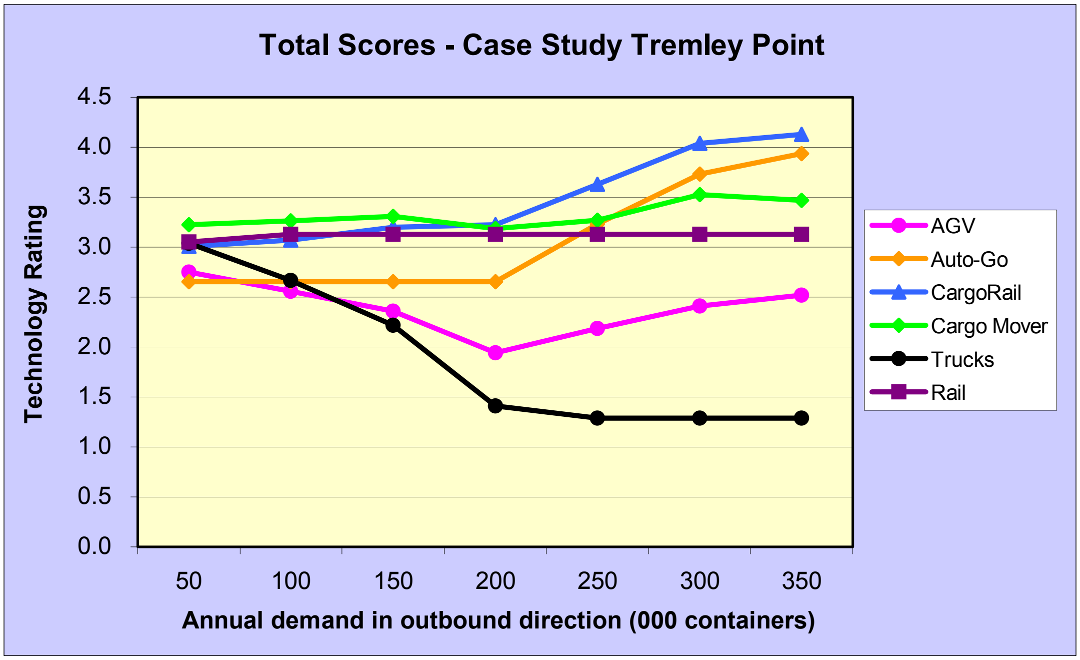

Figure 21. Total scores for alternative technologies – Case Study Tremley Point

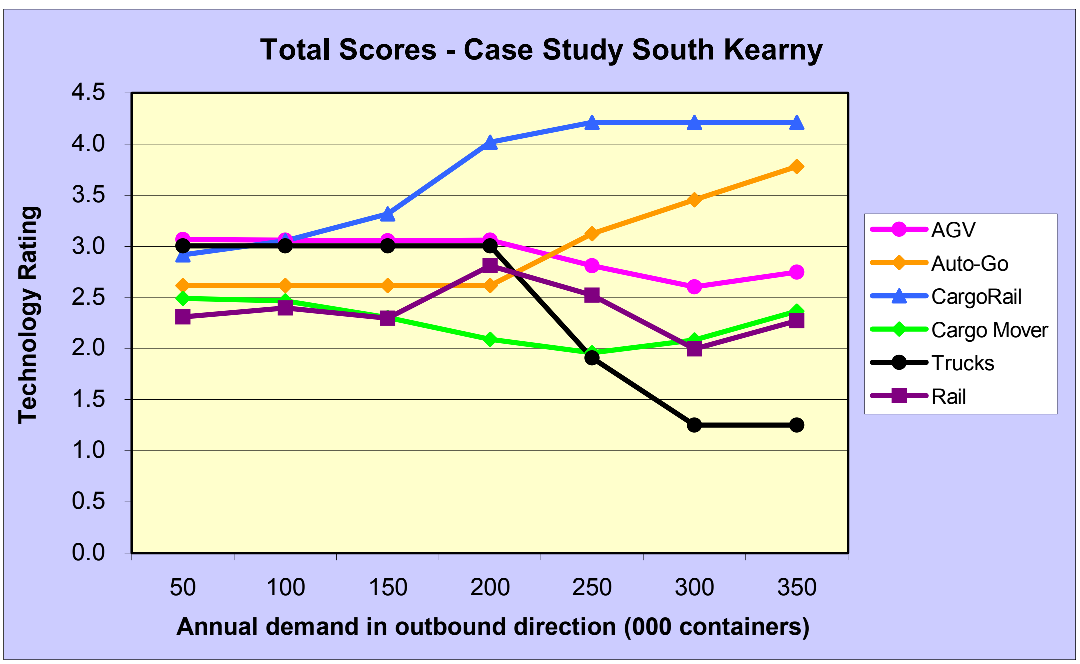

Figure 22. Total scores for alternative technologies – Case Study South Kearny

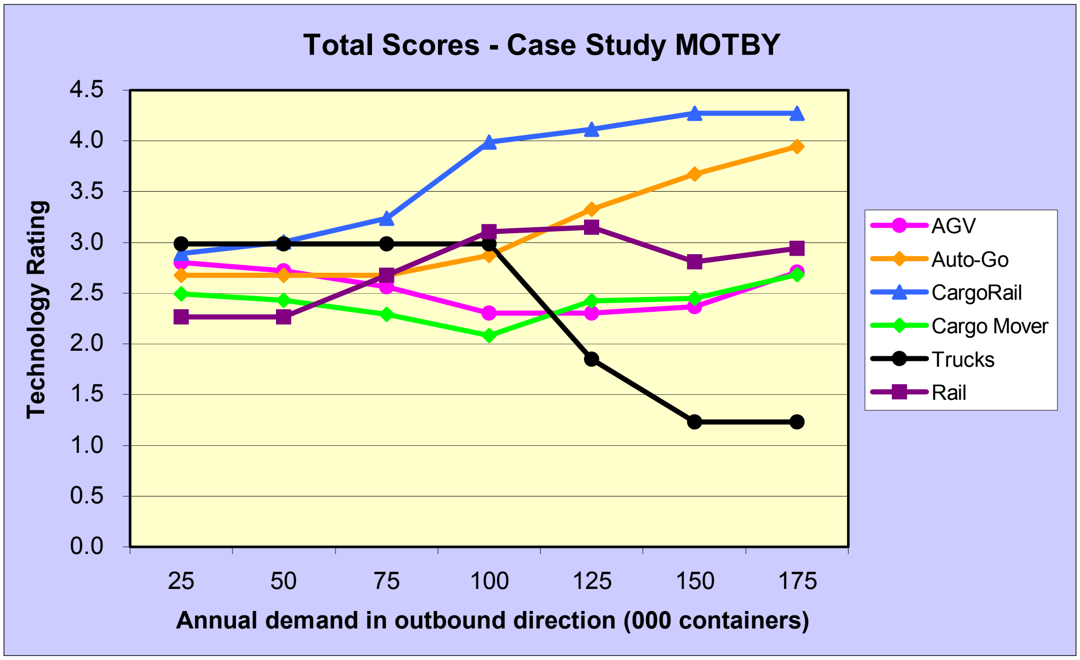

Figure 23. Total scores for alternative technologies – Case Study MOTBY

In 22 out of 28 analyzed cases (seven different demand levels in four case studies) CargoRail has the highest overall scores. In all but one case study, CargoRail becomes dominant when the outbound volume (port terminal to intermodal station) exceeds 100,000 containers. The only exception is Tremley Point case study where CargoMover is the best alternative for the volumes up to 200,000 containers. At volumes of 200,000 containers and above, CargoRail becomes the best.

For annual volumes above 200,000 containers, AutoGo ranks as the "second best" alternative, while it has lower ranking in the rest of the cases. Although it is very similar to CargoRail in terms of design and operation, AutoGo system is more expensive to build and has higher vehicle ownership cost, but it has lower operating and maintenance cost. Overall, high capital costs of AutoGo, especially compared to CargoRail, result in its lagging behind CargoRail in the final rankings for analyzed volumes.

CargoMover performs well only in the Tremley Point case study, mainly due to the fact that its alignment is the shortest. The short alignment translates into shorter travel time and smaller fleet size and thus vehicle costs. It utilizes existing rail track that also lowers the capital cost. In this case study CargoMover dominates in the range of 50,000 – 200,000 containers per year. Once the volume exceeds 200,000 containers, CargoRail becomes the best-ranked alternative (as discussed above and shown in Figure 21).

AGV is comparable with other technologies in the range of 50,000 – 100,000 containers. It is ranked No. 1 in the South Kearny case study (Figure 22). However, it under-performs other alternatives for higher container volumes. Reasons for this are primarily in AGVs low speed. The longer cycle time requires more vehicles to move the same container volume, thus larger fleet size and corresponding high fleet cost. Consequently, increase in transportation demand causes the AGV fleet size to grow much faster then in other technologies, which in turn makes the unit costs to drop at a slower pace with increase in volume. Among the innovative technologies, AGV receives lower ratings for safety, air pollution, and land requirement, which additionally weaken its overall ratings.

Conventional transportation technologies of truck and rail are dominated by innovative technologies in all case studies. Truck is competitive in the MOTBY and Irvington cases at the volumes of 50,000 containers. Generally, overall ratings for trucks drop with an increase in volume. Conventional rail, on the other hand, receives very stable ratings in Irvington and Tremley Point case studies, but is ranked between second and fourth place for all analyzed container volumes (Figures 20 and 21). In the MOTBY and South Kearny cases, it starts off as the worst rated technology at the lowest volume, it improves the rating with increase in volume, but never manages to be ranked better than the second place (Figures 22 and 23).

Engineering Cost Analysis

The ratings shown above are composite scores of the criteria weighted by a subjective level of importance attached to these criteria. It is interesting to look at the “cost only” analysis of the innovative cargo mover technologies.

The analysis is shown in Figures 24 to 27. Figure 24, for example, shows that the truck is the lowest cost mode (on per unit basis) for the volumes up to 100,000 containers. For volumes between 100,000 and roughly 250,000 containers, rail becomes the lowest cost alternative, and for volumes greater than 250,000 CargoRail is the most economic alternative.

The figures show the cost advantage of truck and rail for annual volumes between 50,000 and 250,000 containers. This result is intuitive since they have lower capital cost than innovative technologies. However, as volumes grow capital cost per unit decreases, making the difference between technologies smaller. As we can see in Figures 24-27, CargoRail and AutoGo are the most expensive technologies for lower container volumes in all case studies. However, after certain brake-even point their unit costs become lower than those for trucks, and very close, in some cases at high demands even lower than rail unit cost (e.g. CargoRail in Soth Kearny case study,

Figure 26). This is mainly result of low operating costs for these two technologies, as well as the velocity of service they provide creating more capacity for container transfer than other alternatives. This helps a great deal in boosting the overall scores for these two technologies, thus moving their rankings upwards.

Sensitivity Analysis

It is important to understand just how robust these ratings are. Will they change substantially, with a small change in the weight that is placed on a particular criterion? To answer this question the stability of rankings was analyzed for each case study by changing the weights used in the model. For that purpose, the original weights placed on each criterion were modified, one at the time, by increasing and decreasing their values by 10%[4]. This was done for each case study and each volume level (there were 182 instances for each case study).

It was found that the ratings are very stable. The sensitivity analysis showed that rankings were impacted by a change in the weighting scheme in 7% – 12% instances, depending on the case study. The most impact, as one would expect, has weight assigned to the cost per container trip. Also, changes occurred more frequently for scenarios with volumes in lower end (Table 12). The analysis indicates that rankings are the most stable in Irvington case study (in 93% of instances rankings remain unaltered), while MOTBY showed the least stable rankings, but still quite satisfactory (in 88% of instances rankings remain unaltered). Findings of the sensitivity analysis are summarized in tables 11 and 12.

[4] In each iteration all other criteria weights were also modified accordingly, so that total sum of weights remains 100. This is done by preserving the original ratios among criteria weights.

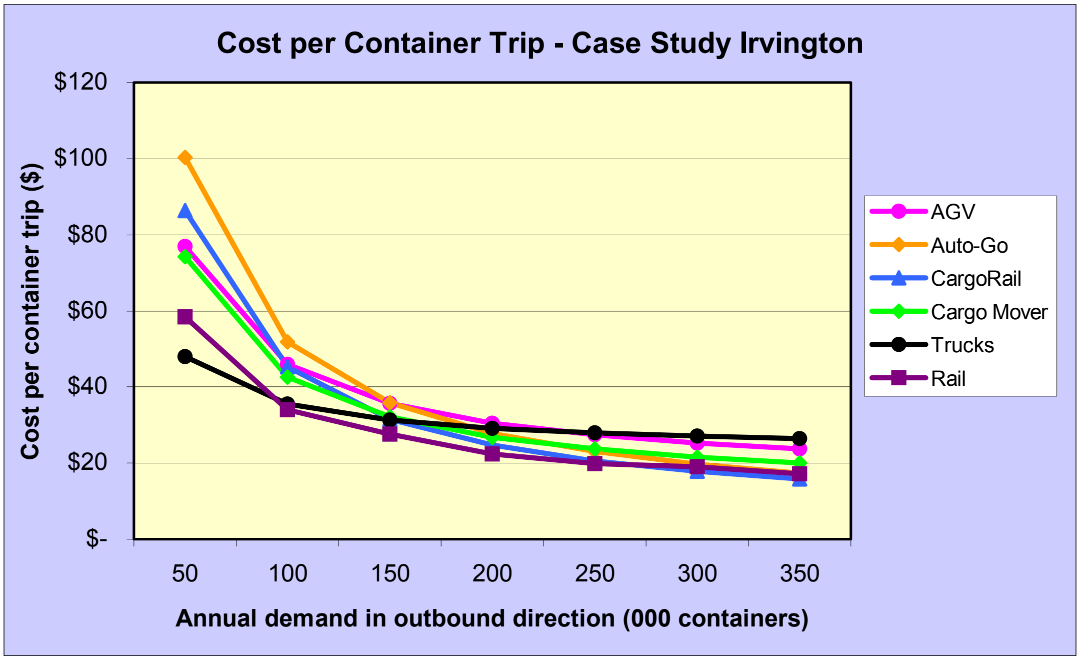

Figure 24. Total system cost per container trip for alternative technologies – Case Study Irvington

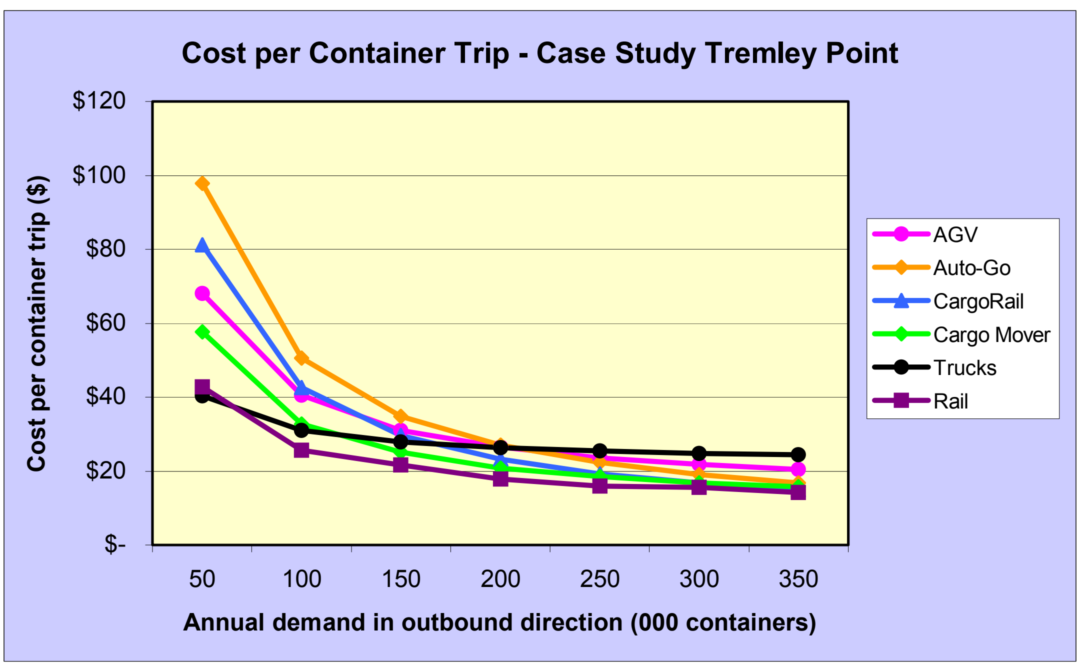

Figure 25. Total system cost per container trip for alternative technologies – Case Study Tremley Point

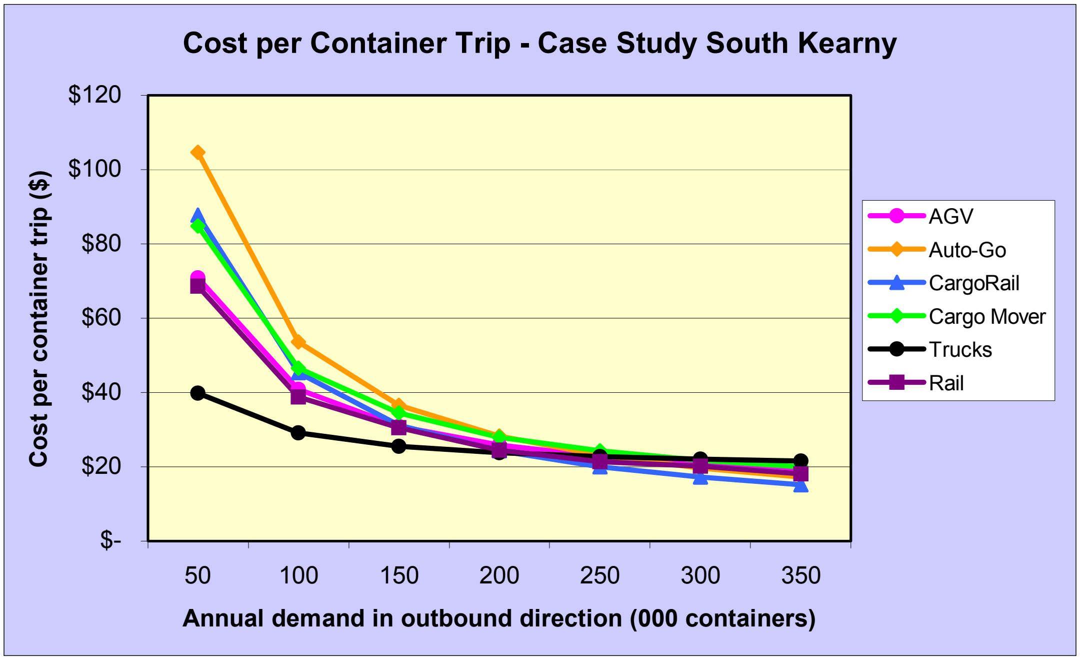

Figure 26. Total system cost per container trip for alternative technologies – Case Study South Kearny

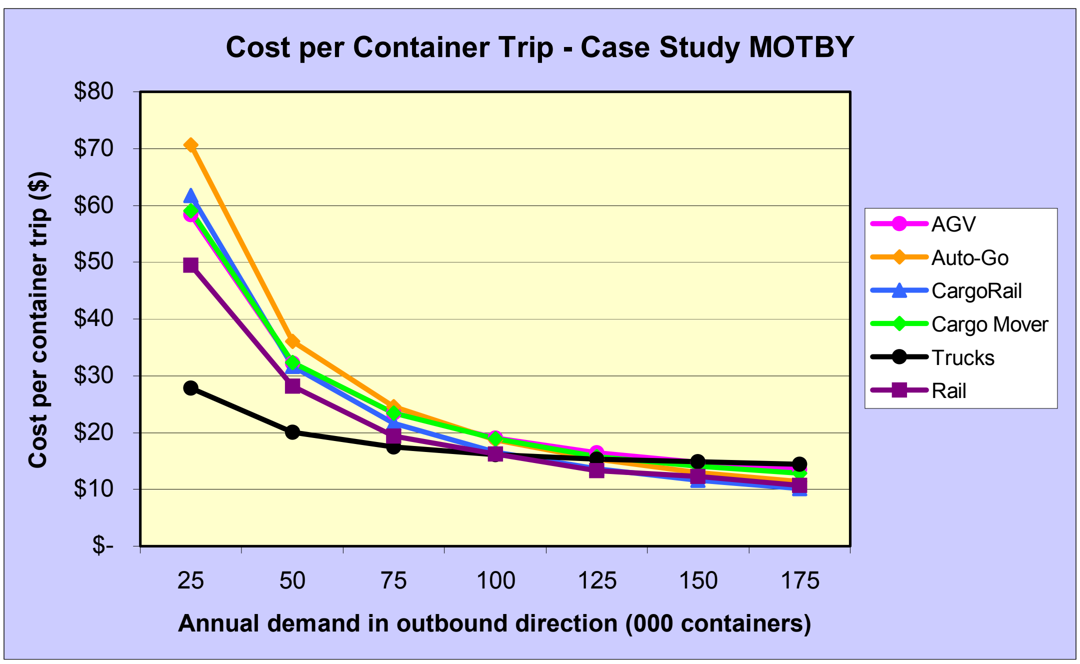

Figure 27. Total system cost per container trip for alternative technologies – Case Study MOTBY

Table 11. Percent rankings not altered from base scenario as the result of weight fluctuations (by criteria and case study)

		Case Study			
Criteria	**Weight Fluctuation**	**Irvington**	**Tremley Point**	**South Kearny**	**MOTBY**
Cost per Container Trip	+10%	57%	43%	29%	57%
	-10%	71%	57%	57%	43%
Travel Time	+10%	100%	86%	100%	86%
	-10%	86%	100%	86%	100%
Congestion Relief	+10%	86%	71%	100%	100%
	-10%	71%	86%	100%	86%
Safety	+10%	100%	71%	86%	86%
	-10%	100%	86%	100%	86%
System reliability	+10%	100%	100%	86%	100%
	-10%	100%	100%	100%	86%
Intermodal compatibility	+10%	100%	100%	100%	86%
	-10%	100%	100%	100%	100%
System expandability	+10%	100%	100%	100%	86%
	-10%	100%	100%	100%	100%
Employment during Construction	+10%	100%	86%	100%	86%
	-10%	100%	100%	86%	100%
Induced Employment	+10%	86%	86%	100%	86%
	-10%	57%	100%	71%	71%
Air Pollution	+10%	100%	86%	86%	86%
	-10%	100%	86%	100%	86%
Land Requirement	+10%	100%	86%	86%	86%
	-10%	100%	100%	100%	100%
Hazardous and solid waste risk	+10%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%
Disruption of the natural habitat	+10%	100%	100%	100%	100%
	-10%	100%	100%	100%	100%
Overall		**93%**	**90%**	**91%**	**88%**

Table 12. Percent rankings not altered from base scenario as the result of weight fluctuations (by volume and case study)

Design Volume* [containers/year]	Irvington	Tremley Point	South Kearny	MOTBY
50,000	85%	69%	92%	96%
100,000	81%	73%	77%	77%
150,000	88%	96%	81%	62%
200,000	96%	96%	92%	96%
250,000	100%	92%	96%	96%
300,000	100%	100%	100%	100%
350,000	100%	100%	100%	92%
Overall	**93%**	**90%**	**91%**	**88%**

* Volumes for MOTBY are in the range of 25,000-175,000 containers, with analysis increment of 25,000 containers

CONCLUSIONS AND FUTURE RESEARCH

Conclusions

This report presents a review of innovative technologies suitable for container movement between a port terminal and locations outside the port that would serve as intermodal terminals or transfer points, or final destinations of the containerized cargo. The technologies are described and their performance characteristics reviewed.

A methodology framework based on the multi-criteria analysis approach was developed to score and rank the technologies. The methodology includes both financial and non-financial decision criteria, such as air pollution, traffic congestion, environmental and ecological impacts, technology expandability, reliability, and safety.

The methodology was applied to four case studies in New Jersey. Case study routes were developed for locations that would connect with port terminal via a new technology. All selected locations have direct access to the National Highway Network and the National Rail Network. They also have potential to be developed as intermodal terminals or industrial centers where manufacturing or distribution facilities can take advantage of direct, fast, and efficient service to and from the Port.

In the numerical evaluation and decision analysis, innovative technologies were compared with conventional truck and rail service. The analysis was conducted using available data on alternative technologies gathered through a variety of sources. The analysis provides a comparison of market-ready technologies for real locations in New Jersey, putting a value on each technology's attractiveness.

The following conclusions were reached as the result of the study:

1. Analyzed innovative technologies have very good potential to be efficiently transport marine cargo containers between port terminals and inland intermodal stations.

2. CargoRail, an automated system with fixed guideway and rubber-tired vehicles, has the highest overall scores. Thus, it is considered the most promising of all the tested technologies.

3. All evaluated innovative technologies become more attractive as the container volume increases. There is a definite presence of economies of scale of traffic density wherein the unit cost will decrease as the result of an increase traffic volume on the route.

4. The sensitivity analysis showed that the criteria weighting scheme has some impact on the ratings; however, overall the scheme used in the analysis appears to yield robust results.

Future Research

The results of the analysis provide a good basis for in-depth evaluations of innovative technologies and their potential to be used for container transport nationwide. The main problem in the analysis was lack of data related to operation parameters of innovative technologies, especially operating costs and costs of infrastructure. In the analysis we used the best available estimates based on information obtained from technology vendors and using comparisons with other technologies. It would be good to update the calculations with more accurate numbers as they become available.

Case studies used in the analysis were concentrated on the area with a radius of 10 miles centered around the Port. Future studies can extend the routes and analyze the characteristics of innovative freight transportation systems in longer haul.

The results of the case study analysis showed the potential of individual technologies. It may be beneficial to go one step further and provide a detailed analysis of actual applications for the most promising innovative technologies. This analysis should include optimization of operating regimes, simulation of system operations, and detailed cost analysis. Multicriteria decision analysis framework developed in this study can be used to evaluate the different application scenarios.

Furthermore, the implementation of innovative technologies should be coordinated with current regional transportation improvement projects in an effort to provide enough capacity in the transportation network to efficiently handle the future demand for container transport. In New Jersey, specifically in the Port area, there are several projects and efforts that should be considered in this manner, such as the Portway project, the Brownfields Redevelopment Study, and the Port Inland Distribution Network concept. Implementation of innovative technologies could potentially provide benefits and added value to each one of these projects. Future research is needed to look at the interactions between them.

APPENDIX A

CALCULATION OF SINGLE CRITERIA SCORES

Calculation of Single Criteria Scores

In order to compare and summarize performance measures for each alternative technology, it is necessary to bring these measures to a common denominator. This is done by defining a single-criteria value function for each criterion that translates the corresponding performance measure to the single criteria score. Scores are assigned on the scale from zero to five. Zero is assigned to the least favorable observed value and five to the most favorable observed value among all the alternatives for respective performance measure. The conversion of performance measure values to scores is accomplished using single criteria valuation functions. Valuation function is defined for each criterion. In this analysis all the criteria have linear valuation functions.

To better explain the procedure that is used to calculate single-criteria scores, the following notation is established:

x_w - the least favorable observed value of the performance measures *t*

x_b - the most favorable observed value of the performance measure *t*

y_o - the lowest score on the scale for criterion *t* (value of the criterion valuation function)

$y_{\max}$ - the highest score on the scale for criterion *t* (value of the criterion valuation function)

x_i - any observed value of the performance measure *t*

$f_t(x_i)$ - valuation function of performance measure *t* for observed value x_i

$$f_t(x_w) = y_o,\ f_t(x_b) = y_{\max},\ f_t(x_i) = y_i \qquad (2)$$

Since there exists a linear functionality between the values of the performance measure and associated scores, the following equality can be derived:

$$\frac{y_{\max} - y_o}{y_i - y_o} = \frac{x_b - x_w}{x_i - x_w} \qquad (3)$$

Thus, y_i can be calculated using the following equation:

$$y_i = y_o + \frac{(y_{\max} - y_o)\cdot(x_i - x_w)}{x_b - x_w} \qquad (4)$$

This is illustrated in an example for the criterion “travel time”. The alternative technologies, their performance measure observed values and associated scores are shown in the table below:

<table>
<tr><th>Alternative</th><th>Performance Measure</th><th>Bounds of the performance measure interval</th><th>Score</th></tr>
<tr><td>A</td><td>2.0</td><td rowspan="3">1.9 = lower bound
(the most favorable observed value)

2.5 = upper bound
(the least favorable observed value)</td><td>4.17</td></tr>
<tr><td>B</td><td>2.5</td><td>0</td></tr>
<tr><td>C</td><td>1.9</td><td>5</td></tr>
</table>

Since we prefer shorter travel times so our goods could reach the destination faster, travel time of 1.9 hours (alternative C) is the most favorable outcome and receives a maximum score. The least favorable outcome would be the longest travel time, in this case 2.5 hours for alternative B. Therefore, alternative B will receive the minimum score. At the same time, 1.9 is the lower bound of the interval of values for the performance measure, while 2.5 represents the upper bound. If we define the lowest score to be zero, and highest score to be five, using the linear equation from above, the score for alternative A is:

$$f_t(2.0) = y_A = 0 + \frac{(5-0)\cdot(2-2.5)}{1.9-2.5} = 4.17 \qquad (5)$$

Appendix B

CALCULATION OF PERFORMANCE MEASURES

This section provides a detailed overview of procedures used to determine the values of performance measures for alternative technologies. Approach to evaluation and equations used in calculation procedures are explained for each performance measure.

Cost per Container Trip

Cost per container trip is defined as the ratio of total annual system cost and total number of container trips on selected route. Total annual system cost consists of construction cost, right-of-way acquisition cost, fleet ownership cost, system operating and maintenance cost.

Construction cost includes costs of labor, materials, equipment, and instrumentation costs. It also includes cost of guideway and control instrumentation, and cost of installing them. Overall construction cost greatly depends on geometric and geological characteristics of the soil and potential difficulties that can occur during construction at certain sites (e.g. contaminated soil that requires treatment and remediation).

Construction cost was calculated for each technology based on preliminary estimates of average infrastructure and instrumentation installation obtained from technology manufacturers and other standard sources. In the next step, series of adjustment factors were developed to account for engineering and geo-technical characteristics of the soil, necessity of building a new bridge or encroaching on an existing housing development, and regional adjustments for local construction market. The final estimate of construction costs is obtained by applying these adjustment factors to initial estimate. Detailed explanation of the procedure used in this calculation is given in Appendix C along with tables and geo-technical data used in evaluation.

Vehicle operating and maintenance costs were determined based on calculated fleet size necessary for system operation and unit costs outlined in the previous sections of this chapter, specific to each technology. Labor cost was also added to obtain the total operating costs.

Vehicle ownership cost was simply calculated as the ratio of fleet size and vehicle service life, multiplied by the purchasing cost of vehicle.

Total number of container trips is calculated as the function of total demand. Total demand is given as annual number of containers that need to be transported in outbound direction. Since it is assumed that 80% of inbound trips would also be loaded, total number of container trips is calculated as 1.8*[Annual demand in outbound direction].

Formulae used in calculation of costs for each technology are given herein.

<u>Notation:</u>

D_o	-	Daily unidirectional freight demand (outbound direction) [FEU/day]
d	-	Daily unidirectional line capacity of a single vehicle (outbound direction) [FEU/day]
p_{res}	-	Equipment reserve factor (= 5%)
YR	-	Workdays per year [days]
t_{day}	-	Work hours per day (= 16 hours)
t_{shift}	-	Work hours per shift (= 8 hours)
t_{trans}	-	Trip time between terminals [hours]
t_L	-	Loading time (for a single container) [hours]
t_U	-	Unloading time (for a single container) [hours]
L	-	Distance between terminals [miles]
$[0.8]$	-	A factor to account for 80% of backhaul loaded trips
C_{OP}	-	Total annual operating and maintenance cost [$]
C_F	-	Total daily cost of fuel [$]
C_E	-	Total daily cost of electricity [$]
C_M	-	Total daily maintenance cost [$]
C_L	-	Total daily labor cost [$]
g_c	-	Average fuel (diesel) consumption of a single vehicle [gal/hour]
c_g	-	Average cost of diesel fuel [$/gal]
e_c	-	Average electricity consumption of a single vehicle [kWh/veh-mile]

c_e - Average cost of electricity [$/kWh]

P_{VM} - Total daily system-wide vehicle-miles traveled

P_{TEUm} - Total daily system-wide TEU-miles traveled

AGV

Vehicle cycle time

$$T_C^{AGV} = c_{AGV} \cdot t_L + t_{trans} + c_{AGV} \cdot t_U + [0.8] \cdot c_{AGV} \cdot t_L + t_{trans} + [0.8] \cdot c_{AGV} \cdot t_U \quad (6)$$

$$T_C^{AGV} = 2 \cdot \frac{L}{V_{AGV}} + 1.8 \cdot c_{AGV} \cdot (t_L + t_U) \quad (7)$$

where:

T_C^{AGV} - AGV cycle time [hours]

c_{AGV} - Cargo capacity of a single AGV vehicle [FEU/veh]

V_{AGV} - AGV operating speed [mi/h]

Fleet size

$$F_{AGV} = \frac{D_o}{d} \cdot (1 + p_{res}) = \frac{D_o}{\frac{t_{day}}{T_C^{AGV}} \cdot c_{AGV}} \cdot (1 + p_{res}) \quad (8)$$

where:

F_{AGV} - AGV fleet size [vehicles]

Annual operating and maintenance cost

$$C_{OP} = YR \cdot (C_F + C_M + C_L) \quad (9)$$

$$C_F = \frac{F_{AGV}}{1 + p_{res}} \cdot g_c \cdot c_g \cdot t_{day} \quad (10)$$

$$C_M = \frac{F_{AGV}}{1 + p_{res}} \cdot c_m \cdot t_{day} \tag{11}$$

$$C_L = n_e \cdot w_h \cdot t_{day} \tag{12}$$

where:

c_m - Average vehicle maintenance cost [$/veh-hour]
n_e - Number of employees per shift
w_h - Average hourly wage [$/hour]

$$\Rightarrow C_{OP} = YR \cdot \left(\frac{F_{AGV}}{1 + p_{res}} \cdot g_c \cdot c_g \cdot t_{day} + \frac{F_{AGV}}{1 + p_{res}} \cdot c_m \cdot t_{day} + n_e \cdot w_h \cdot t_{day} \right) \tag{13}$$

$$\Rightarrow C_{OP} = YR \cdot t_{day} \cdot \left[\frac{F_{AGV}}{1 + p_{res}} \left(g_c \cdot c_g + c_m \right) + n_e \cdot w_h \right] \tag{14}$$

Annual vehicle ownership/lease cost

$$C_{VEH} = \frac{F_{AGV} \cdot P_{AGV}}{T_{life}} \tag{15}$$

where:

T_{life} - AGV vehicle economic life [years]
P_{AGV} - Purchasing cost of a single AGV [$]

Total annual system cost

$$C_{AGV} = C_{CON} + C_{VEH} + C_{OP} \tag{16}$$

where:

C_{CON} - Annualized infrastructure construction costs [$]

Total vehicle-miles and TEU-miles traveled

$$P_{VM} = \frac{D_o}{c_{AGV}} \cdot 2L \tag{17}$$

$$P_{TEUm} = 2 \cdot D_o \cdot (1 + [0.8]) \cdot L \tag{18}$$

AutoGo and CargoRail

Vehicle cycle time

$$T_C = c_{veh} \cdot t_L + t_{trans} + c_{veh} \cdot t_U + [0.8] \cdot c_{veh} \cdot t_L + t_{trans} + [0.8] \cdot c_{veh} \cdot t_U \tag{19}$$

$$T_C = 2 \cdot \frac{L}{V_{veh}} + 1.8 \cdot c_{veh} \cdot (t_L + t_U) \tag{20}$$

where:

T_C - AutoGo/CargoRail vehicle cycle time [hours]
c_{veh} - Cargo capacity of a single AutoGo/CargoRail carrier vehicle [FEU/veh]
V_{veh} - AutoGo/CargoRail operating speed [mi/h]

Fleet size

$$F_{veh} = \frac{D_o}{d} \cdot (1 + p_{res}) = \frac{D_o}{\frac{t_{day}}{T_C} \cdot c_{veh}} \cdot (1 + p_{res}) \tag{21}$$

where:

F_{veh} - AutoGo/CargoRail fleet size [vehicles]

Annual operating and maintenance cost

$$C_{OP} = YR \cdot (C_E + C_M + C_L) \tag{22}$$

$$C_E = \frac{F_{veh}}{1 + p_{res}} \cdot \frac{t_{day}}{T_C} \cdot 2L \cdot e_c \cdot c_e \tag{23}$$

$$C_M = \frac{F_{veh}}{1 + p_{res}} \cdot c_m \cdot t_{day} \tag{24}$$

$$C_L = n_e \cdot w_h \cdot t_{day} \tag{25}$$

where:

c_m - Average vehicle maintenance cost [$/veh-hour]
n_e - Number of employees per shift
w_h - Average hourly wage [$/hour]

$$\Rightarrow C_{OP} = YR \cdot \left(\frac{F_{veh}}{1 + p_{res}} \cdot \frac{t_{day}}{T_C} \cdot 2 \cdot L \cdot e_c \cdot c_e + \frac{F_{veh}}{1 + p_{res}} \cdot c_m \cdot t_{day} + n_e \cdot w_h \cdot t_{day} \right) \tag{26}$$

$$\Rightarrow C_{OP} = YR \cdot t_{day} \cdot \left[\frac{F_{veh}}{1 + p_{res}} \left(\frac{2 \cdot L}{T_C} \cdot e_c \cdot c_e + c_m \right) + n_e \cdot w_h \right] \tag{27}$$

Annual vehicle ownership/lease cost

$$C_{VEH} = \frac{F_{veh} \cdot P_{veh}}{T_{life}} \tag{28}$$

where:

T_{life} - AutoGo/CargoRail vehicle economic life [years]
P_{AGo} - Purchasing cost of a single AutoGo/CargoRail carrier vehicle [$]

Total annual system cost

$$C_{AGo} = C_{CON} + C_{VEH} + C_{OP} \tag{29}$$

where:

C_{CON} - Annualized infrastructure construction costs [$]

Total vehicle-miles and TEU-miles traveled

$$P_{VM} = \frac{D_o}{c_{veh}} \cdot 2L \tag{30}$$

$$P_{TEUm} = 2 \cdot D_o \cdot (1 + [0.8]) \cdot L \tag{31}$$

CargoMover

Vehicle cycle time

$$T_C^{CM} = c_{CM} \cdot t_L + t_{trans} + c_{CM} \cdot t_U + [0.8] \cdot c_{CM} \cdot t_L + t_{trans} + [0.8] \cdot c_{CM} \cdot t_U \tag{32}$$

$$T_C^{CM} = 2 \cdot \frac{L}{V_{CM}} + 1.8 \cdot c_{CM} \cdot (t_L + t_U) \tag{33}$$

where:

T_C^{CM} - CargoMover cycle time [hours]
c_{CM} - Cargo capacity of a single CargoMover vehicle [FEU/veh]
V_{CM} - CargoMover operating speed [mi/h]

Fleet size

$$F_{CM} = \frac{D_o}{d} \cdot (1 + p_{res}) = \frac{D_o}{\frac{t_{day}}{T_C^{CM}} \cdot c_{CM}} \cdot (1 + p_{res}) \tag{34}$$

where:

F_{CM} - CargoMover fleet size [vehicles]

Annual operating and maintenance cost

$$C_{OP} = YR \cdot (C_E + C_M + C_L) \tag{35}$$

$$C_F = P_{VM} \cdot g_c \cdot c_g = \frac{D_o}{c_{CM}} \cdot 2 \cdot L \cdot g_c \cdot c_g \tag{36}$$

$$P_{VM} = \frac{D_o}{c_{CM}} \cdot 2 \cdot L$$ - Total daily system-wide vehicle-miles traveled (37)

$$C_M = P_{VM} \cdot c_m = \frac{D_o}{c_{CM}} \cdot 2 \cdot L \cdot c_m \qquad (38)$$

$$C_L = n_e \cdot w_h \cdot t_{day} \qquad (39)$$

where:

c_m - Average CargoMover vehicle maintenance cost [$/veh-mile]
n_e - Number of employees per shift
w_h - Average hourly wage [$/hour]

$$C_{OP} = YR \cdot \left(\frac{D_o}{c_{CM}} \cdot 2 \cdot L \cdot g_c \cdot c_g + \frac{D_o}{c_{CM}} \cdot 2 \cdot L \cdot c_m + n_e \cdot w_h \cdot t_{day} \right) \qquad (40)$$

$$C_{OP} = YR \cdot \left[\frac{D_o}{c_{CM}} \cdot 2 \cdot L \cdot (g_c \cdot c_g + c_m) + n_e \cdot w_h \cdot t_{day} \right] \qquad (41)$$

Annual vehicle ownership/lease cost

$$C_{VEH} = \frac{F_{CM} \cdot P_{CM}}{T_{life}} \qquad (42)$$

where:

T_{life} - CargoMover vehicle economic life [years]
P_{CM} - Purchasing cost of a single CargoMover vehicle [$]

Total annual system cost

$$C_{CM} = C_{CON} + C_{VEH} + C_{OP} \qquad (43)$$

where:

C_{CON} - Annualized infrastructure construction costs [$]

Total TEU-miles traveled

$$P_{TEUm} = 2 \cdot D_o \cdot (1 + [0.8]) \cdot L \tag{44}$$

Truck

One-way truck travel time including container pick-up and drop-off

$$T^{TR} = t_L + t_{trans} + t_U \tag{45}$$

$$T^{TR} = \frac{L}{V_{TR}} + t_L + t_U \tag{46}$$

where:

T^{TR} - One-way truck travel time including pick-up and drop-off [hours]
V_{CM} - Truck operating speed [mi/h]

Average cost of one-way truck trip

$$C_1 = T^{TR} \cdot \left(C_L^h + C_{OP}^h \right) + L \cdot C_M^m \tag{47}$$

where:

C_L^h - Time based labor cost (driver's wage) [$/hour]
C_{OP}^h - Time based truck operating cost (includes truck ownership and maintenance cost) [$/hour]
C_{OP}^m - Mileage based operating cost (fuel and tires) [$/mi]

Annual truck operating costs (including vehicle ownership)

$$C_{OP} = D_o \cdot (1 + [0.8]) \cdot C_1 \tag{48}$$

Total Annual System Cost

$$C_{TR} = C_{CON} + C_{OP} \tag{49}$$

where:

C_{CON} - Annualized infrastructure construction costs [$]

Total TEU-miles traveled

$$P_{TEUm} = 2 \cdot D_o \cdot 1.8 \cdot L \qquad (50)$$

Rail

Train cycle time

$$T_C^{train} = t_L + t_{trans} + t_U + [0.8] \cdot t_L + t_{trans} + [0.8] \cdot t_U \qquad (51)$$

$$T_C^{train} = 2 \cdot \frac{L}{V_{train}} + 1.8(t_L + t_U) \qquad (52)$$

where:

T_C^{train}	-	Train cycle time [hours]
T_L	-	Time to load a train [hours]
T_U	-	Time to unload a train [hours]
t_{trans}	-	Trip time between terminals [hours]
V_{train}	-	Train operating speed [mi/h]

Locomotive cycle time

$$T_C^{loc} = 2 \cdot t_{trans} + 2 \cdot T_{station} \qquad (53)$$

$$T_C^{loc} = 2 \cdot \frac{L}{V_{train}} + 2 \cdot T_{station} = 2 \cdot \left(\frac{L}{V_{train}} + T_{station} \right) \qquad (54)$$

where:

T_C^{loc}	-	Locomotive cycle time [hours]
$T_{station}$	-	Time that train spends in the station after the train arrival to maneuver the cars [hours]

Car fleet size – assuming fixed number of cars in each train

$$F_{cars} = \frac{D_o}{d} \cdot (1 + p_{res}) = \frac{D_o \cdot T_{train}}{t_{day} \cdot c_{car}} \cdot (1 + p_{res}) \qquad (55)$$

where:

F_{cars} - Fleet size (number of flatbed cars in operation)
c_{car} - Cargo capacity of a single flatbed rail car [FEU/car]

Locomotive fleet size

$$F_{loc} = \frac{D_o}{d} \cdot (1 + p_{res}) = \frac{D_o}{\frac{t_{day}}{T_C^{loc}} \cdot c_{car} \cdot n_{car}} \cdot (1 + p_{res}) \tag{56}$$

where:

F_{loc} - Required locomotive fleet size
n_{car} - Number of flatbed cars in one train composition

Operating and maintenance cost

$$C_{OP} = YR \cdot (C_F + C_M^{loc} + C_M^{car} + C_L) \tag{57}$$

$$C_F = \frac{D_o}{n_{car} \cdot c_{car}} \cdot 2 \cdot L \cdot g_c \cdot c_g \tag{58}$$

$$C_M^{loc} = \frac{D_o}{n_{car} \cdot c_{car}} \cdot 2 \cdot L \cdot c_m^{loc} \tag{59}$$

$$C_M^{car} = \frac{D_o}{c_{car}} \cdot 2 \cdot L \cdot c_m^{car} \tag{60}$$

$$C_L = \frac{F_{loc}}{1 + p_{res}} \cdot w_{crew} \cdot \frac{t_{day}}{t_{shift}} \tag{61}$$

where:

C_M^{loc} - Total daily locomotive maintenance cost [$]
C_M^{cars} - Total daily rail car maintenance cost [$]
c_m^{loc} - Average locomotive maintenance cost [$/locomotive-mile]
c_m^{car} - Average freight car maintenance cost [$/car-mile]

w_{crew} - Average locomotive crew cost per shift [$]

$$\Rightarrow C_{OP} = YR\left[\frac{D_o \cdot 2 \cdot L}{c_{car}} \cdot \left(\frac{g_c \cdot c_g}{n_{car}} + \frac{c_m^{loc}}{n_{car}} + c_m^{loc}\right) + \frac{F_{loc}}{1+p_{res}} \cdot w_{crew} \cdot \frac{t_{day}}{t_{shift}}\right] \qquad (62)$$

Annual vehicle ownership/lease cost

$$C_{VEH} = C_{VEH}^{loc} + C_{VEH}^{car} \qquad (63)$$

$$C_{VEH}^{loc} = YR \cdot F_{loc} \cdot C_{day}^{loc} \qquad (64)$$

$$C_{VEH}^{car} = YR \cdot t_{day} \cdot F_{cars} \cdot C_{hour}^{car} \qquad (65)$$

where:

C_{VEH}^{loc} - Average annual cost of owning/leasing a locomotive [$]
C_{VEH}^{car} - Average annual cost of owning/leasing a flatbed rail car [$]
C_{day}^{loc} - Average daily cost of owning/leasing a locomotive [$]
C_{day}^{car} - Average flatbed rail car lease rate per hour [$/hour]

$$C_{VEH} = YR \cdot \left(F_{loc} \cdot C_{day}^{loc} + t_{day} \cdot F_{cars} \cdot C_{hour}^{car}\right) \qquad (66)$$

Total annual system cost

$$C_{CM} = C_{CON} + C_{VEH} + C_{OP} \qquad (67)$$

where:

C_{CON} - Annualized infrastructure construction costs [$]

Travel Time

Average container travel time is calculated as sum of average container loading time, average container route time (equal to route length divided by the average vehicle speed), and average container unloading time. In case of conventional rail average container loading and unloading time is calculated as half of the train loading and unloading time. Instead of container loading and unloading time, in case of trucks we used average container pick-up and drop-off time.

Congestion Relief

Congestion relief was calculated as the number of truck trips that would be eliminated of the regional highway network between the port terminal and intermodal station as the result of implementation of alternative technology. This number would be equal to zero for truck alternative, and all other alternatives would have the same positive value equal to calculated number of truck trips necessary to transport demanded number of containers on daily bases.

Safety

Since in this case some of the alternatives are new technologies not yet in full commercial operation, the best way of evaluating alternatives on criteria of safety is to design a qualitative measure that would reflect safety level of each alternative relative to others. In the evaluation process members of the project team looked at characteristics of each technology and assigned them values representing their individual safety scores. Scores were chosen on the scale from 1 to 5, 1 being the worst from the aspect of safety and 5 being the best. Characteristics that were considered in the evaluation were potential conflicts with pedestrians, conflicts with highway vehicles, and conflicts among vehicles of the alternative systems. Table 13 gives the final individual scores calculated as the average scores received from project team members.

Table 13. Individual safety scores for alternative technologies

AGV	AutoGo	CargoRail	CargoMover	Trucks	Conventional Rail
3	5	5	4	1	4

System Reliability

The performance measure for system reliability is most often probability of system or vehicle failure. However, for most of the innovative technologies analyzed here this measure is not readily available. In fact, it is very difficult to determine since these systems are not yet in operation. Therefore, the best way to evaluate the alternatives on this criterion is to use descriptive or qualitative measure. Using available data and comparison with similar technologies, members of the research team assessed system reliability for each technology relative to each other. Status of the technology (whether it is proven in operation, or if it is in testing, proto-type or design phase) and potential of incidents or other events causing system failure have been considered as an important evaluation factor. Each alternative is assigned a score on the scale from 1 to 5, “1” defining “poor reliability”, and “5” defining “high reliability”. Final scores were calculated as the average received from project team members. They are shown in Table 14.

Table 14. Individual system reliability scores for alternative technologies

AGV	AutoGo	CargoRail	CargoMover	Trucks	Conventional Rail
3	3	3	3	4	5

Intermodal Compatibility

The ability of alternative technologies to be efficiently integrated with the current container handling system inside the port terminal, as well as in intermodal station, was also evaluated using qualitative grading scale. The main factors influencing the scores were type of loading equipment needed, access of the container handling equipment in intermodal terminals to carrier vehicles of the alternative technology, flexibility of carrier vehicles in terms of movement, and ability of alternative technology to be efficiently integrated with cargo handling equipment inside the port terminal, including gantry cranes. Overall scores for each technology are given in Table 15. Scores are on the scale from 1 to 5, “1” being defined as “low compatibility” and “5” as “highly compatible”.

Table 15. Individual intermodal compatibility scores for alternative technologies

AGV	AutoGo	CargoRail	CargoMover	Trucks	Conventional Rail
4	4	4	4	5	3

System Expandability

The major factor in evaluating alternatives on this criterion is the ability to expand the physical capacity of the system, or more specifically the ability to handle additional demand. Obviously, this should be done in a most efficient way and at minimal cost. The impact of the expansion on the entire transportation system also plays a big role in determining overall implications of the system expansion. For example, adding another trip on monorail system would not impact highway or rail traffic in the region, but adding another train or truck trip definitely would. With expected increase in port traffic and necessity of securing enough capacity to handle pick demand, this becomes very important issue.

Qualitative scores were used as performance measures of system expandability. They are summarized in Table 16 as averages of individual scores assigned by research team members. Score of “1” denotes the worst and score of “5” the best performance of the technology when it comes to this criterion.

Table 16. Individual system expandability scores for alternative technologies

AGV	AutoGo	CargoRail	CargoMover	Trucks	Conventional Rail
4	5	5	3	1	2

Employment During Construction and Induced Employment

Both employment during construction and induced employment are calculated using Transportation, Economic, and Land Use System (TELUS)[1] developed at NJIT. The job creation in both categories depends on type, duration, and cost of transportation improvement project. For example, each alternative will have construction and implementation (or operation) phase, and in each phase certain costs would be incurred. These phases can be considered as projects and number of jobs can be calculated on annual bases during the life of project. This information is entered in TELUS model and number of jobs created is estimated using economic input-output model for New Jersey. It is estimated that construction project for all alternatives would last 5 years, while operation was considered as perpetual project.

Air Pollution

Air pollution was expressed in terms of quantity of engine pollutant emissions generated by each technology. The quantity is calculated in kilograms per TEU-mile (kg/TEU-mile). In calculation it is assumed that fully loaded vehicles would engage 100% of installed power while traveling. Vehicle speed, i.e. traveled distance, total engine power, and emission rates obtained from vehicle specifications are then used to calculate average quantity of carbon monoxide (CO), hydro-carbons (HC), nitrogen oxides (NOx), and particulate matter (PM) emitted by the moving vehicle. Formulae used to calculate amount of average vehicle emissions for each technology are given below.

[1] More on TELUS can be found on project website at http://www.telus-national.org/index.html

AGV

$$EE = \frac{W_{AGV} \cdot \sum_i e_i}{1000 \cdot V_{AGV} \cdot c_{AGV} \cdot 2} \tag{68}$$

where:

EE - Average emissions from vehicle engine [kg/TEU-mile]
W_{AGV} - Power of the AGV engine [kW]
e_i - Average emission rate for emission component i [g/kWh]

AutoGo and CargoRail

These two technologies have electric propulsion, and therefore create “zero” emissions.

CargoMover

$$EE = \frac{W_{CM} \cdot \sum_i e_i}{1000 \cdot V_{CM} \cdot c_{CM} \cdot 2} \tag{69}$$

where:

EE - Average emissions from vehicle engine [kg/TEU-mile]
W_{CM} - Power of the AGV engine [kW]
e_i - Average emission rate for emission component i [g/kWh]

Truck

$$EE = \frac{W_{TR} \cdot \sum_i e_i}{1000 \cdot V_{TR} \cdot 2} \tag{70}$$

where:

EE - Average emissions from vehicle engine [kg/TEU-mile]
W_{TR} - Power of the truck engine [kW]
e_i - Average emission rate for emission component i [g/kWh]

Rail

$$EE = \frac{W_{loc} \cdot \sum_i e_i}{1000 \cdot V_{train} \cdot c_{car} \cdot n_{car} \cdot 2} \tag{71}$$

where:

EE - Average emissions from vehicle engine [kg/TEU-mile]

W_{loc} - Power of the locomotive engine [kW]

e_i - Average emission rate for emission component i [g/kWh]

Land Requirement for Right-of-Way (ROW)

With this measure we attempt to address the issue of scarcity of available land in the region surrounding New Jersey ports. Since the project area lacks available space it would be desirable to use technology that can utilize existing ROW (or at least its part) without disruption of current freight operations. Some of the alternatives, such as CargoRail and AutoGo, can be built as elevated systems entirely above existing highways or railroad tracks, while AGV, for example, requires construction of new dedicated highway facility. Conventional rail and CargoMover can utilize existing rail ROW, but on some route sections it is required to add the second track or switches, which requires acquisition of additional space for ROW. Similarly, trucks would operate over existing highway network, but in case of expansion required to support increase in traffic, additional space would be required for ROW.

With this in mind technologies are rated relative to each other using qualitative scale from “minimum land requirement” to “substantial land requirement”. In Table 17 these qualitative values are replaced with scores: “1” is equivalent to “minimum land requirement”, and “5” to “substantial land requirement”. Although route alignment plays a big role in determining these scores, it was found that selected routes are very similar when it comes to land availability and zoning adjacent to existing transportation facilities, except in case of Bayonne, which is indicated in the table.

Table 17. Individual land requirement scores for alternative technologies

AGV	AutoGo	CargoRail	CargoMover	Trucks	Conventional Rail
5	1	2	4	4*	4

* In case of MOTBY the score for trucks would be equal to 5, since entirely new truck facility would need to be built, just as in case of AGV.

Hazardous and Solid Waste Risk and Disruption of the Natural Habitat

Qualitative grading scales were developed as performance measures for these two criteria as well. Ratings of the environmental impacts for each alternative and case study alignment were assigned to each alternative based on degree of site disruption and invasion caused by corresponding technology, considering conditions specific to each case study. For example, since wetland impact is highly dependent on the physical encroachment of the technology upon the land, technologies such as suspended monorails or those that utilize existing railway corridors rated more favorably compared with an AGV technology that requires the construction of an entirely new highway. Similarly, in assessing the hazardous and solid waste risk, those technologies that cause a minimum of site disruption and/or can allow buried waste to remain in place will have a rating advantage. The scoring procedure was part of the geo-technical study conducted as part of the project and is discussed in more details in Appendix C. Tables with scores are also included in Appendix C.

Appendix C

EVALUATION OF ENGINEERING AND ENVIRONMENTAL CRITERIA

Introduction and Site Background

A significant component of the study was to analyze how engineering and environmental factors influence the rankings of the various freight mover technologies and case study alignments. The general approach was to first evaluate each technology based upon the assumption of "favorable" site conditions. These baseline ratings reflect the intrinsic characteristics of the technology only, such as structural support requirements, general adaptability to existing transportation links, and general potential for environmental encroachment. Three different performance criteria from the Multicriteria matrix were evaluated during this steps, namely property cost, construction cost, and environmental impact, since these criteria are most influenced by engineering and environmental factors (refer to tables 2 and 3).

After establishing baseline ratings, the next step was to determine appropriate "site adjustment factors". The function of these factors was to account for the actual site conditions encountered along each alignment. The adjustments were considered essential since the Port Newark/Port Elizabeth terminals are located within what can best be described as the most challenging real estate within the State of New Jersey. The challenges arise from the complex geological and ecological conditions that exist in the Port area, as well as the substantial development and other anthropogenic influences that have occurred over the last two centuries. These conditions and influences will now be briefly described.

The foremost challenge of the study area arises from the ubiquitous presence of the Hackensack Meadowlands, which is the remnant of an ancient glacial lake. The high variability and compressible nature of the soils that underlie the Meadowlands makes construction difficult, and more extensive foundations are required to support transportation systems compared with normal site conditions, leading to substantially higher construction costs. A related challenge of the study area is the widespread occurrence of wetlands, owing to the presence of the tidal marsh. Thus, wherever the freight mover alignments contact a wetland, appropriate protection and/or relocation will be required according to environmental regulations and practice. A third complicating factor is the large number of contaminated waste sites that exist throughout the region. The waste sites are a direct consequence of the industrialization of the Port area over the last two centuries, and they also reflect the fact that the marshy ground was a popular dump site for municipal and industrial waste in times past. Yet another challenge of this study area is the high density of current development and general congestion throughout the region. Not only does this escalate the construction costs, but, as is typical of highly developed areas, all of the "good land" is occupied first leaving behind properties that are least desirable from an engineering and environmental perspective. In some cases, it is these same properties that must now house the new freight mover system.

Results of Reconnaissance Investigation

The Port Newark/Port Elizabeth terminals are mostly located within the Hackensack Meadowlands, which is a remnant of the ancient glacial lake that formed from the meltwaters of the Wisconsin ice sheet at the end of the Pleistocene Epoch (~12,000 years before present). Slack water conditions towards the end of the glacial period led to the formation of a temporary lake in this area, causing the deposition of thick layers of silt and clay known as "varved" deposits in the bed of the glacial lake. These varved soils are characteristically poorly drained, have a very soft consistency, and are much less stable than soils encountered elsewhere in the state. In some locations the soft deposits extend to depth in excess of 100 ft, making it difficult to reach firm bearing for the supporting foundations.

Following the glacial period, rising sea levels transformed the area into a tidal marsh, which has persisted until the present. The brackish marsh environment led to the development of an organic soil layer at the ground surface known locally as "meadowmat". Meadowmat is composed of a mixture of peat and fine sediments and is also highly compressible. In recent times, variable amounts of fill materials have been placed throughout the Meadowlands region during construction of local roadways, railroads and buildings. In many areas, however, the emplaced fill has only partially stabilized the underlying natural sediments, and the glacial lake and marsh deposits remain compressible and potentially unstable at many locations.

In view of the complex geological, ecological, and anthropogenic history of the study area, it was decided to conduct a reconnaissance investigation to better define the engineering and environmental factors of the site and their influence on the case studies. Special effort was given to this aspect of the study, since it was felt that not only would these data facilitate the present analyses, but they would also benefit future planning and preliminary design of the selected freight mover system.

The principal information sources consulted for the reconnaissance investigation are listed in Table 18 (at the end of the text in this appendix), which includes published studies from federal, state, and regional agencies, as well as local universities. The reconnaissance investigation also identified two other important unpublished sources of geologic information within the study area. The first is the NJDOT archive of more than 70,000 boring logs on file for projects throughout the state. A visit to the Geotechnical Division of NJDOT in Trenton yielded 42 projects of interest within the study focus area, which are listed in Table 21. A second source of unpublished geologic data is the subsurface information from previous projects of the Port Authority of New York and New Jersey (PANYNJ) throughout the region. The Port Authority was contacted during the reconnaissance investigation, and they indicated that these data would be furnished once a freight mover alignment is selected.

In order to facilitate analysis of the alternative case study alignments, all collected reconnaissance data were digitized and converted into a GIS format. These GIS data are included on a CD enclosed with this report, which is viewable with ArcMap 8.0. For user's convenience, the data on the Reconnaissance Data CD have been organized into the following major thematic views: Geotechnical, Social-Political, and Environmental. Each view, in turn, contains a number of themes relating to the study area. A summary of the views and themes contained on the CD is provided in Tables 19A, and 19B. The Reconnaissance Data CD is accompanied by an explanatory text that outlines the basic navigation and identification commands to access the ArcMap GIS files.

Development of Construction Costs and Ratings

Construction costs for each case study alignment were developed using a parametric cost approach. The parametric method was chosen on account of the preliminary nature of the study, and also since only a limited amount of actual cost data are available for some of the prospective technologies. In fact, some have not yet been fully commercialized. The parametric approach assures a good confidence level with respect to relative costs among the various technologies, even if the absolute costs are not precisely known.

The general approach was to first estimate the bare construction cost per mile for each technology based upon information received from manufacturers and other standard sources. The bare cost reflects the intrinsic characteristics of the technology, such as structural support requirements, general adaptability to existing transportation links, and general potential for environmental encroachment. It also assumes that the site conditions are "favorable," which is definitely not the case in the Port area.

After establishing the bare unit costs, the next step was to apply a series of cost adjustment factors to reflect the local construction market. Market adjustments included both regional factors, e.g. local labor costs, and cost escalation due to Port area congestion. Market factors had a significant impact on technology costs, increasing construction costs up to 70% compared with bare costs.

The next step was to develop and apply "site adjustment factors" to reflect the actual engineering and environmental conditions present along a particular alignment. This factor is a composite of several engineering and environmental components, including foundation support, wetlands contact, and site contamination. The foundation support component reflects the general difficulty of the geologic conditions, which translates into higher construction costs since more extensive foundations are required to support the transportation system. The wetlands component reflects the amount of wetland contact along each alignment, since this negatively impacts on the flora and fauna, and it also affects construction and development costs. The third component, site contamination, is an adjustment for the likely risk of encountering hazardous or solid waste along each alignment, since such waste must be treated or remediated during construction.

The final step in determining construction costs was to apply ROW adjustment factors to reflect special costs such as building a new bridge or encroaching on an existing housing development. ROW adjustments were applied selectively to certain combinations of technology and alignment.

In order to aid quantification of the site adjustment factors, detailed logs of reconnaissance data were developed for each case study alignment. The logs were developed at 100 ft. stations summarizing six categories of data, including surficial geology (3 sources), bedrock geology, wetlands, and site contamination. The logs were used to calculate the ratios most influencing site adjustment: % deep foundation, % wetland contact, and average contaminated sites per mile in near vicinity. Copies of these supporting engineering and environmental logs are contained in Tables 26-31 at the end of this Appendix C. It is noted that the logs were formatted as “component links” to allow maximum flexibility when examining various origins and destinations for the case studies.

The component ratios were next merged into a single composite cost factor for each case alignment. The composite site factors and their components are summarized in Table 20. As indicated, the South Kearny alignment has the least favorable conditions, requiring a 1.92 adjustment factor. The Irvington alignment is the most favorable with a factor of 1.51. The other two alignments are intermediate between these two.

The final rating results for the construction cost and property cost criteria are presented in Tables 22-25.

Development of Environmental Ratings

A rating of the environmental impact for each combination technology and case study alignment was developed for the multi-criteria matrix. An important influence on the environmental ratings was the degree of site disruption and invasion caused by a particular technology. For example, since wetland impact is highly dependent on the physical encroachment of the technology upon the land, technologies such as suspended monorails or those that utilize existing railway corridors rated more favorably compared with an AGV technology that requires the construction of an entirely new guideway. Similarly, in assessing the hazardous and solid waste risk, those technologies that cause a minimum of site disruption and/or can allow buried waste to remain in place will have a rating advantage.

The environmental ratings also reflect the environmental sensitivity of each case study alignment as determined during the reconnaissance investigation. The same environmental factors developed for estimating construction costs were used to quantify environmental sensitivity (see Table 20). As may be expected, those alignments with high ratios of wetlands contact and/or significant numbers of contaminated sites rated more poorly than those with lower ratios and numbers.

The final rating results for the environmental impact criterion are presented in Tables 22-25.

Table 18. Summary of Reconnaissance Data Sources

Publication/Resource	Agency	Code	Date	Author/Location	Source Format
Glacial Sediments of New Jersey	NJGS	OFM 16	1995	Harper, Stanford, Witte	Hard Copy & Digital
Surficial Geologic Map of Northern NJ	USGS / NJGS	I-2540-C	2002	Stone, Stanford, Witte	Hard Copy**
Bedrock Geology Map of Northern NJ	USGS / NJGS	I-2540-A	1996	Drake, Herman, Volkert	Hard Copy & Digital
Geologic Map of Northern NJ	DEP / GS	psnjmap.pdf	1999	-	Digital
Engineering Soil Survey of NJ	Rutgers University	Report 2	1952	Rogers, Lueder	Hard Copy & Digital*
Engineering Soil Survey of NJ	Rutgers University	Report 4	1952	Rogers, Lueder	Hard Copy& Digital*
Engineering Soil Survey of NJ	Rutgers University	Report 5	1952	Rogers, Lueder	Hard Copy& Digital*
Bedrock Geology of North East Corridor	USGS	I-514-A	1967	-	Hard Copy & Digital*
Southern Access Railroad Project (Plans and Boring Logs)	PANYNJ	EWR-SL	1999	Port Authority / NJDOT	Digital
Soil Conservation: Union County	NJDEP	GIS Data	1999	NJDEP GIS Clearinghouse	Digital
Physiographic Provinces of NJ	NJGS	DGS02-7	1999	NJGS GIS Clearinghouse	Digital
Known Contaminated Sites	NJDEP	GIS Data	2001	NJDEP GIS Clearinghouse	Digital
New Jersey County Wetlands: Essex, Hudson, Union	NJDEP	GIS Data	1986	NJDEP GIS Clearinghouse	Digital
Glacial Sediments of New Jersey	NJDEP	GIS Data	1990	NJDEP GIS Clearinghouse	Digital
NJDOT Project Boring Log Data	NJDOT	Project Data	Varies	NJDOT	Hard Copy

*   Indicates Partially Digitized Vector Data of Hard Copy Reference

** Indicates Scanned Raster Data of Hard Copy Reference

Table 19A. Reconnaissance Data CD – Index of Information Layers

VIEW	THEME	COMMENTS
GEO-POLITICAL DATA	Regional Rail Lines	Vector Data
	New Jersey Roads State Wide	Vector Data
	USGS Quadrangle Grid	Vector Data
	Elizabeth 7.5 Minute Quadrangle	Raster Data (black and white)
	New Jersey 1997 Orthophotography	Raster Data (color)
	AGV Alignments (4)	Vector Data
	Rail Alignments (4)	Vector Data
	Fast Freight Ferry (1)	Vector Data
ENVIRONMENTAL DATA	2001 Known Contaminated Sites	Vector Data
	Hudson County Wetlands	Vector Data
	Essex County Wetlands	Vector Data
	Union County Wetlands	Vector Data
	Reference Alignment	Vector Data
	2000’ Station Intervals	Vector Data
GEOTECHNICAL DATA	Bedrock Geology	Vector Data and Raster Data Available
	Geological Features: Dikes and Folds	Vector Data
	USGS Rock Features	Vector Data: Digitized
	Physiographic Provinces	Vector Data
	Glacial Sediments	Vector Data
	Sediment Thickness	Vector Data
	Surficial Soils	Raster Data
	Union County Soils	Vector Data
	Partial Rutgers Soils Survey	Focus Area Only: Digitized
	Buried Valleys	Thalwegs of the NE Corridor: Digitized
	Reference Alignment	Vector Data
	2000’ Station Intervals	Vector Data

Table 19B. Reconnaissance Data CD – Index of Information Layers (Continued)

VIEW	THEME	COMMENTS
COMMON FILES	Municipal Boundaries	Vector Data
	County Boundaries	Vector Data
	Project Focus Area	Hudson, Essex, and Union Counties
	Regional Water Bodies	NJ Lakes, Major Rivers, Newark Bay, etc
	Focus Area Roads	Vector Data
ADDITIONAL FILES NOT LOADED	NJ Orthophotography	1997 State Aerial Photos (Raster Data)
	Bedrock Geology: I-2540-A	Limited to Focus Area (Raster Image)
	Surficial Geologic Map: I-2540-C	Limited to Focus Area (Raster Image)
	Southern Access Railroad Project (SARP)	SARP Boring Logs and Location Plans

Table 20. Summary of Site Adjustment Factors for Case Study Alignments

Case Study Alignment	Component Links	Approx. Length (miles)	Foundation Support Ratio	Wetlands Contact Ratio	Frequency of Contaminated Sites (Avg. sites/mile)		Composite Site Factor
					< 500 ft	500-1000 ft	
MOTBY	Same	3.4	0.64	0	1.2	1.2	1.64
Port Newark/Elizabeth to Tremley Point	South + Port Elizabeth + Port Newark	7.20 + 2.00 + 0.94 = 10.14	0.58 + 1.00 + 1.00 W.A. 0.70	0.14 + 0.00 + 0.00 W.A. 0.11	0.6 + 3.0 + 2.0 W.A. 1.20	1.5 + 2.0 + 0 W.A. 1.46	1.75
Port Newark/Elizabeth to Irvington	West + Port Elizabeth + Port Newark	6.60 + 2.00 + 0.94 = 9.54	0.27 + 1.00 + 1.00 W.A. 0.49	0.05 + 0.00 + 0.00 W.A. 0.03	3.40 + 3.00 + 2.00 W.A. 3.18	1.3 + 2.0 + 0.0 W.A. 1.32	1.51
Port Newark/Elizabeth to South Kearny	North + Port Elizabeth + Port Newark.	7.20 + 1.00 + 0.94 = 10.14	0.83 + 1.00 + 1.00 W.A. 0.88	0.11 + 0.00 + 0.00 W.A. 0.08	3.60 + 3.00 + 2.00 W.A. 3.33	3.80 + 2.00 + 0.00 W.A. 3.09	1.92

Table 21. NJDOT Boring Projects in Study Area

Description	Route	Contract
Section 5	78	C
Port Street	78	D
Haynes Street	78	E
5AD	78	H
Rahway Railroad, Elizabeth Avenue	78	F
Lehigh Valley Railroad-Frelin. Avenue	78	G
5CE Union	78	A
At Route 78	21	A
Riverside to William Street	21	NA
Randolph – Route 80, Bridge St.	21E	D,E
Viaduct Meeher Avenue to 1&9	22	A
Broad Street Bridge	22	NA
PBQD	280	A,B,C,D
Pleasant Valley Way to Scotland Avenue	280	NA
Stickle Bridge to NJ Turnpike	280	A,B
Roseville to Stickle Bridge	280	E
Section 7A	280	NA
7W Ramp to Route 21	280	NA
Section 9	280	NA
Leewellyn Park Noise Walls	280	NA
Section 3M,4N	280	NA
Merge	1 & 9	NA
2AG Waverly	1 & 9	NA
2AK Delancey to Raymond	1 & 9	NA
4T Elizabeth Viaduct	1 & 9	NA
Pulaski to Passaic River	1 & 9	NA
2AJ & 2AL	1 & 9	NA
(26) St. Paul's	1 & 9	NA
(25) St. Paul's	1 & 9	NA
(24) Amtrak at Route 3	1 & 9	NA
(23) NYSW Railroad	1 & 9	NA
Haynes Avenue	1 & 9	NA
7L and 7M	1 & 9	NA
7E and Green St. (Union)	1 & 9	NA
3M Rahway River	1 & 9	NA
Secaucus Road Overpass	1 & 9	NA
Extension, Newark Bay	440	A
Extension	440	B,C
NA	139	2, 3
NA	169/185	A
Turnpike Connector	169	A

* Not Available: (NA)

Table 22. Engineering and Environmental Ratings for West Link: Port Newark/Elizabeth to Irvington

Criteria	Measure	AGV	Auto-Go	Cargo Rail	Cargo Mover	Truck	Rail
Financial Impact							
Property cost	$ Mil./mile	0.75	0.5	0.5	0.25	0.2	0.25
Construction cost	$ Mil./mile	10	18	15	10	5	8
Environmental Impacts							
Hazardous and solid waste risk	Expected risk of encountering waste during construction	4	3	3	3	2	3
Disruption of natural habitat	Negative impacts on flora and fauna	2	1	1	1	1	1

Table 22 Notes:

- Categories logged and considered: Surficial Geology, Soil Survey, Bedrock Geology, Glacial Sediments, Wetlands, Contaminated Sites
- Length of Alignment = 37,784 ft = 7.2 miles
- Scale 1 to 5 (where 1 = minimum cost or impact)

Table 23. Engineering and Environmental Ratings for South Link: Port Newark/Elizabeth to Tremley Point

Criteria	Measure	AGV	Auto-Go	Cargo Rail	Cargo Mover	Truck	Rail
Financial Impact							
Property cost	$ Mil./mile	0.75	0.5	0.5	0.25	0.2	0.25
Construction cost	$ Mil./mile	10	20	16	10	4	7
Environmental Impacts							
Hazardous and solid waste risk	Expected risk of encountering waste during construction	3	2	2	2	1	2
Disruption of natural habitat	Negative impacts on flora and fauna	4	2	2	2	1	2

Table 23 Notes:

- Categories logged and considered: Surficial Geology, Soil Survey, Bedrock Geology, Glacial Sediments, Wetlands, Contaminated Sites
- Length of Alignment = 36,674 ft = 6.6 miles
- Scale 1 to 5 (where 1 = minimum cost or impact)

Table 24. Engineering and Environmental Ratings for North Link: Port Newark/Elizabeth to South Kearny

Criteria	Measure	AGV	Auto-Go	Cargo Rail	Cargo Mover	Truck	Rail
Financial Impact							
Property cost	$ Mil./mile	0.75	0.5	0.5	0.25	0.2	0.25
Construction cost	$ Mil./mile	14	27	22	15	6	12
Environmental Impacts							
Hazardous and solid waste risk	Expected risk of encountering waste during construction	5	3	3	3	2	3
Disruption of natural habitat	Negative impacts on flora and fauna	3	2	2	2	1	2

Table 24 Notes:

- Categories logged and considered: Surficial Geology, Soil Survey, Bedrock Geology, Glacial Sediments, Wetlands, Contaminated Sites
- Length of Alignment = 37,920 ft = 7.2 miles
- Scale 1 to 5 (where 1 = minimum cost or impact)

Table 25. Engineering and Environmental Ratings for Bayonne Link: MOTBY

Criteria	Measure	AGV	Auto-Go	Cargo Rail	Cargo Mover	Truck	Rail
Financial Impact							
Property cost	$ Mil./mile	0.75	0.5	0.5	0.25	0.2	0.25
Construction cost	$ Mil./mile	10	18	15	10	4	8
Environmental Impacts							
Hazardous and solid waste risk	Expected risk of encountering waste during construction	3	2	2	2	1	2
Disruption of natural habitat	Negative impacts on flora and fauna	1	1	1	1	1	1

Table 25 Notes:

- Categories logged and considered: Surficial Geology, Soil Survey, Bedrock Geology, Glacial Sediments, Wetlands, Contaminated Sites
- Length of Alignment = 37,920 ft = 7.2 miles
- Scale 1 to 5 (where 1 = minimum cost or impact)

Legend of Geological Descriptions In Tables 26-31

Surficial Geology – USGS Map I-2540-C Sheet 1 of 3

Tidal Marsh and Estuarine Deposits

- Peat and muck as much as 3.0 m thick, overlaying and interbedded with laminated and thinly bedded fine sands and silt as much as 76.2 m think in the Hudson River estuary and as much as 30.5 m thick in other valleys. Peat is decomposed, fibrous or matted, herbaceous and silty herbaceous material, muck is organic clayey silt. Thin surficial materials with scattered bedrock outcrops; linear topographic elements show the trend of bedrock structural features. Surficial materials generally are less than 3m thick.

Rahway Till

- Dark reddish brown to dark brown to yellowish brown sandy to silty to clayey till, containing commonly 5-20% pebbles, cobbles, and boulders of gneiss, sandstone, basalt, and quartzite. In areas underlain by shale and sandstone the matrix contains abundant shale and siltstone fragments and reddish brown silt and clay. Till is noncalcareous and chiefly compact, with a firm to hard consistency; gravel clasts are generally non weathered , sub angular to sub rounded; gravel clasts of fine-grained sandstone commonly are striated and rounded gravel clasts are abundant locally.

- Deposits contain few thin lenses of striated gravel, sand and silt; minor iron manganese stain is on joint faces locally. Thickness generally is 3.0-9.1m, locally as much as 15.2m in small drum lines. Unit includes brown to strong brown silty till, containing 5-35% pebbles, cobbles, and boulders of basalt or diabase, sandstone, gneiss, and quartzite. In areas underlain by basalt or diabase, and on sandstone and serpentinite bedrock east of the Palisades, till is compact to loose, of very soft to firm consistency, locally exhibiting sub horizontal fissility. Thickness generally is less than 1.8m.

Bedrock Geology – USGS Map I-2540-A Sheet 1 of 2

Newark Basin

- Contains early Mesozoic rocks of late Triassic to early Jurassic age, is a northeast-trending half garden bounded on the northwest by normal faults. The faults are braided, have subordinate splays, and are en echelon in many places. The Hopewell and Flemington faults comprise two major intabasinal fault systems. The basin is filled with a thick sequence of fluvial and lacustrine rocks and lava flows, the composite thickness of which is approximately 7,500m. Diabase sills as much as 480m thick, stocks, and dikes were intruded about the time of the earliest lava flows during the early Jurassic age. Triassic sedimentary rocks unconformably overlie crystalline rocks of the Manhattan prong along the eastern margin of the basin. The Newark basin is unconformably overlain by Cretaceous sediments of the Coastal Plain in the southeastern part of the map area.

Passaic Formation -Lower Jurassic and Upper Triassic

- Reddish brown to brownish purple and grayish-red siltstone and shale, maximum thickness 3,600m. At places contains mapped sandy mudstone and sandstone. Rocks of the Passaic Formation have been locally thermally metamorphosed to hornfels where in contact with the Orange Mountain Basalt, diabase dikes, and sheet like intrusions. Total thickness of formation ranges from 3,500 m to 3,600 m.

- (Newark Basin< Newark Super group <Brunswick Group)

Lockatong Formation (Upper Triassic)

- Cyclically deposited sequences consisting of light to dark gray greenish gray and black dolomitic or analcime-bearing silty argillite, laminated mudstone, silty to calcareous, argillaceous, very fine grained pyretic sandstone and siltstone and minor silty limestone. Two types of cycles are recognized: detrital and chemical. Detrital cycles average 5.2 m (17 ft) thick and chemical cycles average 3.2 m (10.5 ft) thick.

Rutgers Soil Survey (Essex, Union and Hudson Counties)

Significance of Diagonal Bar

- The use of two mapping symbols separated by a diagonal bar, as GM/GS indicates that both material are present at the ground surface, that the total area occupied by each may be assumed as roughly equal, and that the two are intermingled in areas to small to permit separate mapping.

Significance of Fractional Symbols

- The material denoted by the numerator of the fraction appears at the ground surface and is underlain at variable but usually shallow depths by the material indicated by the lower part of the fraction.

F

- Filled or made land: used without additional designation denotes areas in which the original surface has been covered by varying depths of fill material. The fill was placed, usually, to cover unsatisfactory soil conditions or to raise the ground surface above the water level. The fill material is frequently industrial or municipal waste.

MTM

- Tidal marsh of marine origin composed of silty clays deposited in salt water during the recessional period of the Wisconsin glaciation.

- Stratified silty clays and clays usually very soft and highly compressible. The top 2 to 5 feet of the marsh area consists of an organic layer of decomposed roots from tidal marsh plant growth. Since these materials were formed by the underwater settling of silt and clay-size particles and have never been subjected to more than their own submerged weight, they usually exhibit low densities (40-70 lbs. Cu. Ft.). Landform is characteristically flat at or near ocean tide level.

- Engineering classification: The deposits in the tidal marsh areas are the result of selective underwater sedimentation, consequently except for occasional lenses of loose sand the grains are almost all sufficiently small to pass the No. 200 sieve. In almost all cases the soil would be classified as HRB A-7, with Group Index between 15-20. Fills will usually be required to provide an acceptable pavement subgrade.

- The physical characteristics of the tidal marsh deposits make them extremely susceptible to consolidation. The possibility of large settlement of embankments and other structures must be anticipated.

GM

- Glacial ground moraine, composed of non-residual, unstratified materials deposits during the Wisconsin glaciation. Unassorted and heterogeneous including intermixed soil fractions which range from clay sizes to gravel, cobbles and boulders. Silts predominate, but some areas are characterized by intermingled deposits of stratified silty sands. The bulk of the materials are composed of particles derived from red shale's and sandstone. The depth to bedrock is usually greater than 10 feet and could be up to 90ft. And the landform is undulating to gently rolling ground surface which appears almost flat.

- Engineering Classification: Almost uniformly silty to considerable depth. In areas where stratified drift is highly intermingled sandy silts are widely distributed. In areas mapped GM-46 depressed positions and heavy textures create uniformly bad drainage conditions and pavement support is characterized as poor to very poor.

AR

- Recent alluvium composed of non-residual materials deposited by alluvial action and hence stratified. Termed recent because still subject to alluvial deposition. May include some stratified soils of glacial origin.

- These soils have been transported to their present location by surface water and stream flow and accordingly partake of the characteristics of the soils from which they originated. Underlying formations are variable depending on the nature of the area which the stream or river is traversing. Characterized by flat lowlands invariably adjacent to streams.

- Soils are variable usually quite silty with appreciable amounts of clay sizes and accumulations of organic material.

Engineering Classification: Transported alluvium varies considerably with stratified.

Table 26. Engineering and Environmental Assessment Log for West Link: North Link to Irvington

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
0+00	(Qm) Tidal Marsh and Estuarine Deposits			50-100’ thick		1<500’
20+00	(Qpt) Passaic Terrace Deposits	Filled or Manmade				1<500’ 4<1000’
40+00						1<500’ 8<1000’
60+00 Burried Valley (-230’)	(Qm) Tidal Marsh and Estuarine Deposits			Lake Bottom Deposits		2<500’ 1<1000’
80+00	Borders (Qpt) Passaic Terrace Deposits and (Qm) Tidal Marsh and Estuarine Deposits		Passaic Formation *Sandy Mudstone*	100-200’ thick		3<1000’
100+00		GO-12i			Essex County Herbaceous	
120+00	(Qpt) Passaic Terrace Deposits					3<500’ 2<1000’
140+00						1<500’ 1<1000’
160+00	(Qrez) Elizabeth Deposits	GMM-24ge/GS		50-100’ thick Fluvial Deposits		

Table 26. Engineering and Environmental Assessment Log for West Link: North Link to Irvington (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
180+00	(Qrez) Elizabeth Deposits	GMM-24ge/GS	Passaic Formation *Sandy Mudstone*	50-100’ thick Fluvial Deposits		
200+00		GMM-24g				
220+00						1<500’
240+00						1<500’ 2<1000’
260+00	(Qr) Rahway Till			Continuous Till 250-300’ thick		1<500’ 2<1000’
280+00		GM-4ig				2<500’ 2<1000’
300+00						5<500’
320+00		GM-42i/sh				8<500’ 1<1000’

Table 26. Engineering and Environmental Assessment Log for West Link: North Link to Irvington (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites	
340+00	(Qr) Rahway Till	GM-42i/sh	Passaic Formation *Sandstone and siltstone*	Continuous Till 50-100' thick		10<500'	
360+00 377+84						9<500' 2<1000'	
RATING	**Foundation Characteristics**				**Wetlands**	**Known Contaminated Sites (KCS)**	
	__73.5%__ Shallow; **__26.5%__** Deep				5.3 % Contact	<500'	3.35 sites/mi.
						500'-1000'	1.26 sites/mi.

Table 27. Engineering and Environmental Assessment Log for South Link: Port Elizabeth to Tremley Point

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
0+00						
20+00					Union County Herbaceous	
40+00	(Qm) Tidal Marsh and Estuarine Deposits	MTM		Lake Bottom Deposits *Silt, Clay, Some fine sand*		1<1000’
60+00				<50’ thick		
80+00			Passaic Formation Siltstone and *Shales* Max thickness 3600 m			1<1000’
100+00						
120+00	(Qr) Rahway Till			Continuous Till 50-100’ thick	Union County Herbaceous	3<500’
140+00		GM-4pi		250-300’ thick		2<1000’
160+00						3<1000’

Table 27. Engineering and Environmental Assessment Log for South Link: Port Elizabeth to Tremley Point (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
180+00 Elizabeth River	Rahway Till	GM-4pi	Passaic Formation Siltstone and *Shales* Max thickness 3600 m	Fluvial Deposits	Union County Herbaceous	
	Elizabeth Deposits	AR				
	Tidal Marsh			Lake Bottom		
200+00	(Qr) Rahway Till	GM-4pi		Continuous Till		1<1000’
220+00				Lake Bottom Deposits		1<500’
240+00	(Qm) Tidal Marsh and Estuarine deposits	MTM				
260+00						
280+00					Union County Herbaceous	
300+00		Fill or Manmade				1<1000’
320+00						

Table 27. Engineering and Environmental Assessment Log for South Link: Port Elizabeth to Tremley Point (Continued)

<table>
<tr><th>Station</th><th>Surficial Geology</th><th>Rutgers Survey</th><th>Bedrock Geology</th><th>Glacial Sediments</th><th>Wetlands</th><th colspan="2">Contaminated Sites</th></tr>
<tr><td rowspan="2">340+00
346+74</td><td>(Qm)
Tidal Marsh and Estuarine deposits</td><td rowspan="2">Fill or Manmade</td><td rowspan="2">Passaic Formation Siltstone and Shales
Max thickness 3600 m</td><td>Lake Bottom Deposits</td><td rowspan="2"></td><td colspan="2" rowspan="2">1<1000’</td></tr>
<tr><td>(Qr)
Rahway Till</td><td>Continuous Till</td></tr>
<tr><td rowspan="3">RATING</td><td colspan="4">Foundation Characteristics</td><td>Wetlands</td><td colspan="2">Known Contaminated Sites (KCS)</td></tr>
<tr><td colspan="4" rowspan="2"><u>42.3%</u> Shallow; <u>57.7%</u> Deep</td><td rowspan="2">14.4 % Contact</td><td><500’</td><td>0.62 sites/mi.</td></tr>
<tr><td>500’-1000’</td><td>1.52 sites/mi.</td></tr>
</table>

Table 28. Engineering and Environmental Assessment Log for North Link: Port Elizabeth to South Kearny

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
0+00		MTM				
20+00		Fill or Manmade				
40+00						
60+00	(Qm) Tidal Marsh and Estuarine Deposits					
80+00		Tidal Marsh	Passaic Formation *Sandy Mudstone* Max thickness 3600 m	Lake Bottom Deposits *Silt, Clay, Some fine sand* <50' thick	Essex County Herbaceous	1<1000'
100+00		Fill or Manmade			Essex County Herbaceous	1<1000'
120+00						2<500' 4<1000'
140+00	(Qpt) Passaic Terrace Deposits	GO-12i				3<1000'
160+00					Essex County Herbaceous	6<1000'

Table 28. Engineering and Environmental Assessment Log for North Link: Port Elizabeth to South Kearny (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
180+00	(Qpt) Passaic Terrace Deposits	GO-12i	Passaic Formation *Sandy Mudstone* Max thickness 3600 m	50-100’ thick Lake Bottom Deposits *Silt, Clay, Some fine sand* 100-150’ thick		5<500’ 5<1000’
		Fill or Manmade				
200+00						3<500’ 4<1000’
220+00	(Qm) Tidal Marsh and Estuarine Deposits	R				
240+00		Fill or Manmade				2<1000’
260+00						1<1000’
280+00						3<500’
300+00						7<500’
320+00						

Table 28. Engineering and Environmental Assessment Log for North Link: Port Elizabeth to South Kearny (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites	
340+00	Buried Valley	Fill or Manmade	*Sandy Mudstone*	50-100’ thick	Hudson County Herbaceous	3<500’	
360+00	(Qm) Tidal Marsh and Estuarine deposits		Passaic Formation *Siltstone and Shales*			1<500’	
379+20				<50’ thick		2<500’	
RATING	**Foundation Characteristics**				**Wetlands**	**Known Contaminated Sites (KCS)**	
	17.2% Shallow; **82.8%** Deep				**10.5%** Contact	<500’	3.62 sites/mi.
						500’-1000’	3.76 sites/mi.

Table 29. Engineering and Environmental Assessment Log for Bayonne Link: MOTBY

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites
0+00	(Qm) Tidal Marsh and Estuarine Deposits	F	Manhattan Schist, gneiss medium to coarse grain	Lake Bottom Deposits *Silt, Clay, Some fine sand* 50-100' thick		
20+00						
40+00			Stockton Formation			1<500'
60+00						3<5000'
80+00			Lockatong Formation			
100+00	(Qr) Rahway Till	GM-46ig	Jurassic Diabase	Continuous Till		
120+00						4<1000'
140+00			Lockatong Formation	Lake Bottom Deposits *Silt, Clay, Some fine sand* 100-150' thick		
160+00	(Qm) Tidal Marsh and Estuarine Deposits	F/GS	Stockton Formation			

Table 29. Engineering and Environmental Assessment Log for Bayonne Link: MOTBY (Continued)

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites	
180+00 181+98	(Qm) Tidal Marsh and Estuarine deposits	F/GS	Manhattan Schist	Lake Bottom Deposits *Silt, Clay, Some fine sand* 100-150' thick			
RATING	**Foundation Characteristics**				**Wetlands**	**Known Contaminated Sites (KCS)**	
	64.3% Shallow; **35.7%** Deep				**0%** Contact	<500'	1.2 sites/mi.
						500'-1000'	1.2 sites/mi.

Table 30. Engineering and Environmental Assessment Log for Port Newark Link

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites	
0+00	(Qm) Tidal Marsh and Estuarine deposits	MTM	Passaic Formation *Siltstone and Shales* Max thickness 3600 m	Lake Bottom Deposits *Silt, Clay, Some fine sand* 50-100' thick		1<500'	
20+00 40+00 49+46						1<500'	
RATING	Foundation Characteristics				Wetlands	Known Contaminated Sites (KCS)	
	<u>0.0%</u> Shallow; **<u>100%</u>** Deep				**<u>0.0%</u>** Contact	<500'	2 sites/mi.
						500'-1000'	0 sites/mi.

Table 31. Engineering and Environmental Assessment Log for Port Elizabeth Link

Station	Surficial Geology	Rutgers Survey	Bedrock Geology	Glacial Sediments	Wetlands	Contaminated Sites	
0+00	(Qm) Tidal Marsh and Estuarine deposits	Tidal Marsh and Manmade	*Sandy Mudstone*	Lake Bottom Deposits *Silt, Clay, Some fine sand* 50-100' thick		1<500' 2<1000'	
20+00 40+00 52+62			Passaic Formation *Siltstone and Shales* Max thickness 3600 m			2<500'	
RATING	**Foundation Characteristics**				**Wetlands**	**Known Contaminated Sites (KCS)**	
	<u>0.0%</u> Shallow; **<u>100%</u>** Deep				**<u>0.0%</u>** Contact	<500'	3 sites/mi.
						500'-1000'	2 sites/mi.

Appendix D

SCHEMATIC REPRESENTATION OF CASE STUDY ROUTE ALIGNMENTS

Aerial Photographs with Route Alignments for Analyzed Case Studies

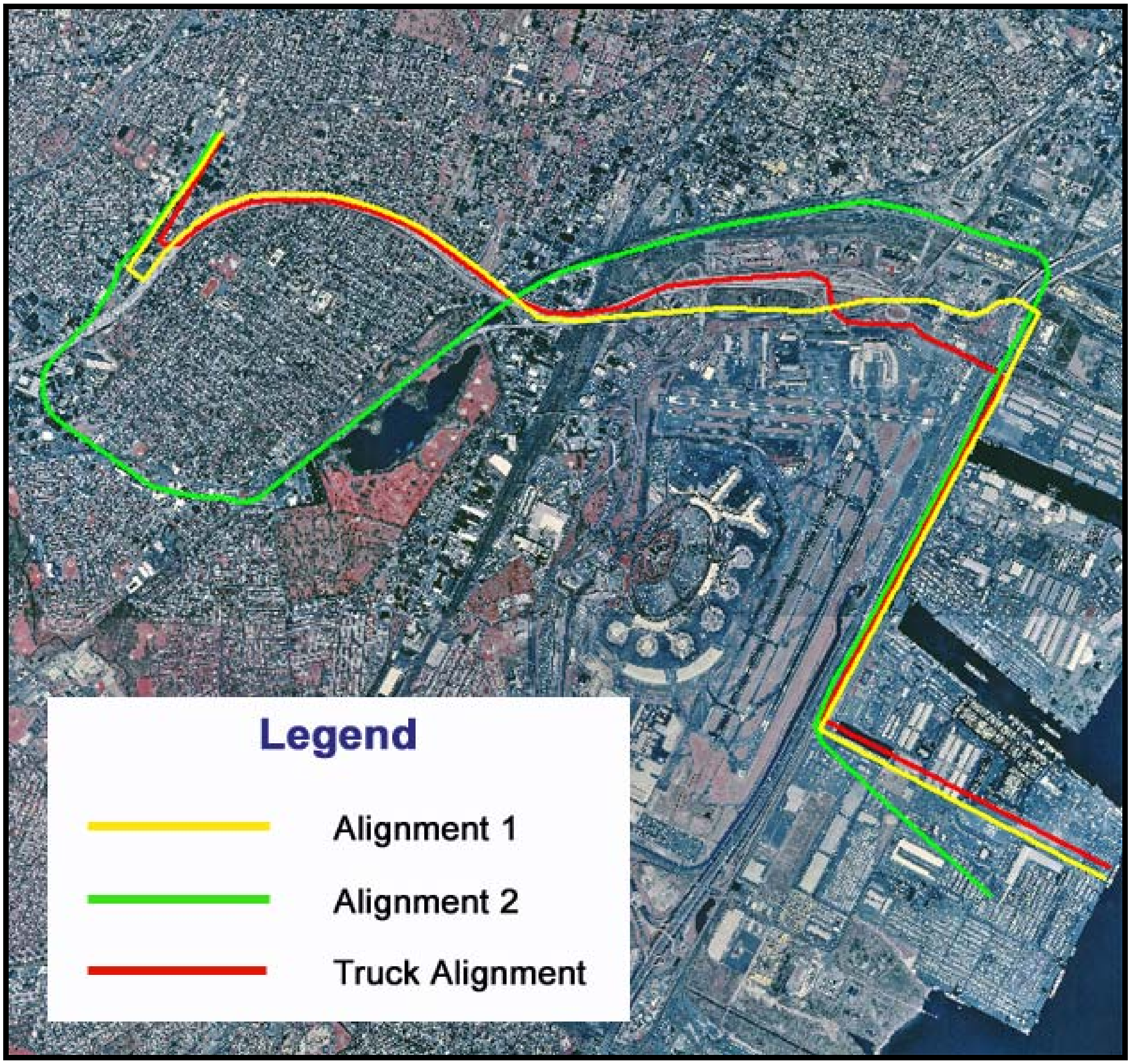

Figure 28. Schematic display of assumed route alignments – Case Study Irvington

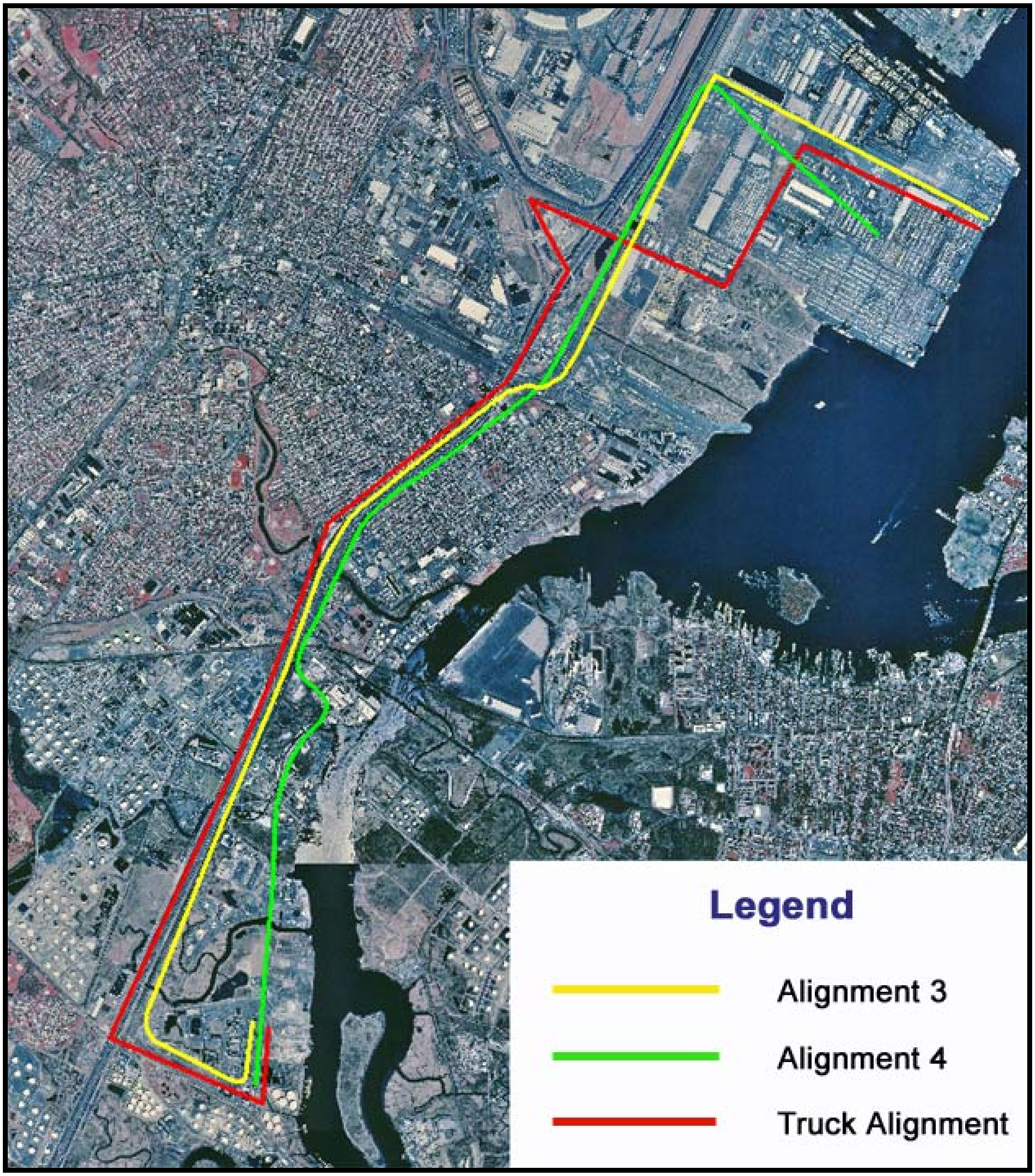

Figure 29. Schematic display of assumed route alignments – Case Study Tremley Point

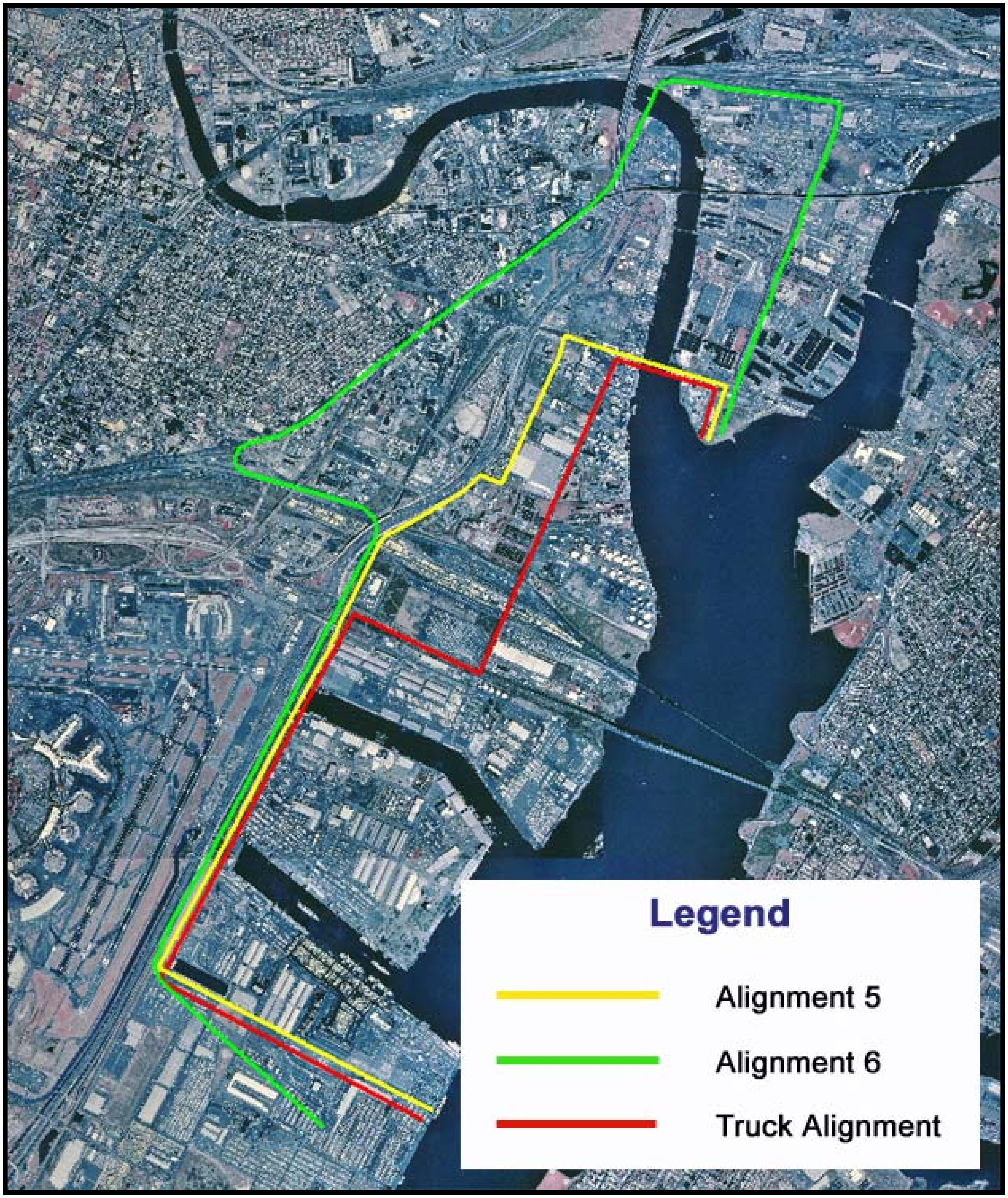

Figure 30. Schematic display of assumed route alignments – Case Study South Kearny

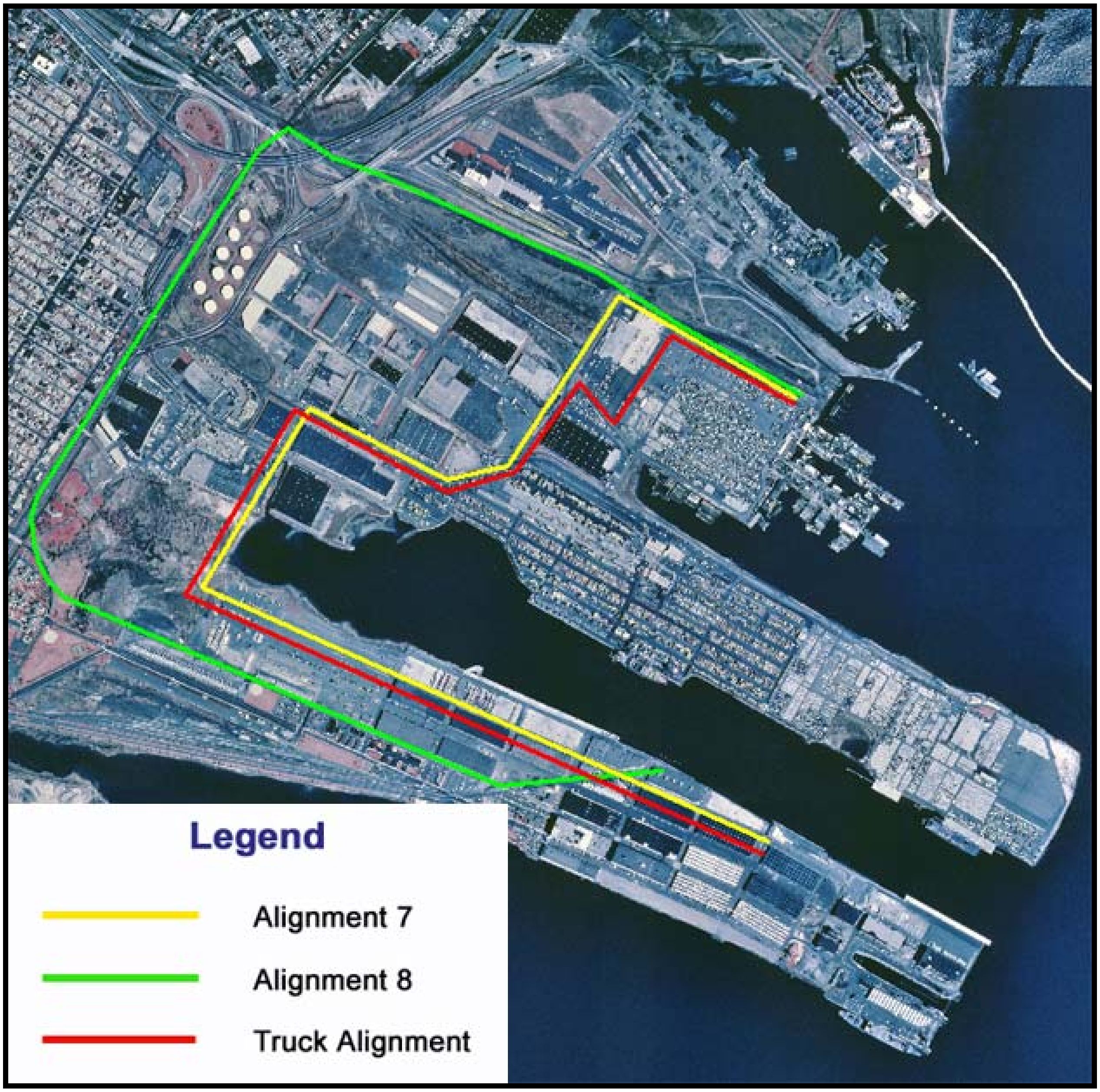

Figure 31. Schematic display of assumed route alignments – Case Study MOTBY

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