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16. Abstract

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EXPORT GROWTH, ENERGY COSTS AND SUSTAINABLE SUPPLY CHAINS

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Research Report SWUTC/10/476660-00069-1

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Abstract

The report examines sustainable supply chains in North America and the role played by rail intermodal operations in lowering ten-mile fuel and emission costs. It examines whether current systems favor imports over exports – a current complaint from some shippers – and whether the development of inland intermodal ports offers a solution to moving future freight into and out of large metropolitan areas. The work is the second of five inter-related UTCP studies examining key changes in intermodal freight transportation in the United States at both national and state levels. It highlights the important role played by rail operations in developing sustainable freight supply chains serving future export and import flows. The major product of the work – a basic rail cost model – serves as a tool to sharpen current metropolitan freight planning and is designed to be enhanced and calibrated by users to address more specific regional issues such as multi-modal corridors.

Executive Summary

Chapter 1: Background

The work is the second of five inter-related UTCP studies examining key changes in intermodal freight transportation in the United States at both national and state levels. The first examined changes over the last decade in rail intermodal systems in the United States and the likelihood that a more enhanced role could be played by railroads in moving future volumes of North American continental freight efficiently and competitively. The third examined the impacts on the key U.S. global import and export supply chains of the new, larger locks on the Panama Canal, due to be opened in 2014, which will permit larger ships to serve Gulf and North Atlantic ports more competitively from Asian centers of production. The fourth study examines the impact of developing effective freight systems in those merging metropolitan areas predicted to form coherent productive regions – termed Mega-Regions by urban planners. The fifth study evaluates the operation of reduced or near-zero delivery trucks which will need to be introduced where non-attainment air quality restrictions are in place.

Supply Chains: Import and Export

The global economy peaked in early 2007 after a 10-year period of virtually consistent growth which had fueled demand for both U.S. imports and exports. Imports had grown to substantially exceed exports in value, in part because of the global transportation system which, as containerization replaced break-bulk handling, enabled companies to outsource key manufacturing and assembly activities to regions with lower production and labor costs. Global supply chains to the U.S. had been continuously refined since the late 1970s largely on the basis of import needs which became increasingly dominated by product routes originating from Asia.

U.S. transport investments between 1994 and 2007 were largely channeled into West Coast terminals, rail corridors, modal economies of scale, inland ports and improved dray operations at key terminals—both marine and rail. However, U.S. dollar weakness after 2006 made several U.S. goods and commodities more competitive in world markets and, as a result, export growth began to exert stresses in the intermodal export system, most notably in container scarcities and problems reliably booking slots on outgoing U.S east coast containerships. This study arose from a simple question – did the much vaunted multi-modal containerized system favor imports over exports? While the study was underway, oil prices rose substantially and posed a second related question – how did energy prices factor into supply chain efficiencies?

U.S. Export Growth

The fall in value of the U.S. dollar on foreign exchanges created one group of beneficiaries – U.S. exporters, who were able to compete more effectively in world markets. As export opportunities grew, the logistics sector found that while it could adjust relatively quickly to the movement of some commodities (like grains and chemicals), intermodal flows were impacted by several factors, including shortages of boxes and specialized container, problems moving product on corridors serving export ports, and at times unreliable booked export slots on ships serving East Coast ports.

Most of these will be addressed over time if export demand remains strong. The unreliability issue associated with booked slots is more intractable since exports tend to be heavier and the ship captain has to calculate – almost in real time – how much can be loaded to enable the ship to pass through the typical East Coast port channels. While this is not an insurmountable problem, it is unlikely that additional Federal funding will be readily available for dredging channels so that they meet the needs of fully-laden containerships.

Study and Report Outline

Three factors underpin the work undertaken in this study. One examines export corridor efficiencies and the second recognizes that supply chain sustainability requires rail plays an enhanced role in moving goods. Rail, with its superior fuel consumption on a ton/mile basis and corresponding lower emission levels should play a key role if transportation sustainability is to be reached. Finally, rail analysis is challenging because few models exist at a planning level that can evaluate rail impacts on freight flows. Accordingly, a basic rail model was developed precisely for this purpose and is the primary product of the study.

The second chapter summarizes the pertinent elements to the study title derived from a literature review of the import-export process. The third chapter discusses existing import and export processes and global supply chains including challenges currently faced by both exporters and importers. A future supply chain concept is introduced and its benefits, challenges, and applications are discussed in the fourth chapter. An intermodal rail costing model, developed as the principal product of this study, is then presented in the fifth chapter, and the model is calibrated and validated in the sixth chapter. Chapter seven comprises using the rail model in two case studies examining the proposed supply chain concept, and chapter eight reports the final conclusions and recommendations for future researchers working in this area.

Chapter 2: Literature Review

The literature review demonstrates that a range of relevant studies pertaining to import and exports span over several decades. Research is continually refining the import-export processes – either in the public domain or within the business models of individual companies. Freight consolidation is seen as a major step to building a sustainable supply chain but research to validate this step needs to be strengthened. In the next chapter, the existing import and export processes are introduced and the challenges currently facing the industry discussed.

Chapter 3: Import-Export Processes and Global Supply Chains

Several tables and figures are used to describe the supply chain functions and key stakeholders. Detailed descriptions of both processes reveal that though the functions vary, the processes utilize similar stakeholders, equipment and infrastructure. The survey results revealed the challenges currently faced by stakeholders and the dependence of the current system on trucking. Highway congestion, air pollution, waste of energy, time delays, and an increase in maintenance costs are the result of the current system. Fuel price increases result in higher transportation costs experienced the most by shippers located in the hinterland. There is a need for a more sustainable system than what currently exists. The next chapter presents such a system, and investigates the benefits and challenges of implementing the new system.

Chapter 4: Future Import-Export Supply Chains

This chapter examines the impact of a centralized freight facility serving a marine gateway and global supply route. It evaluates the benefits of the so-called dry port concept and places it in a variety of settings including Mega-Regional planning. Implementing a centralized freight facility is a step in the right direction for the import-export process. Benefits include reduced truck traffic, decreased travel times, decrease in congestion, reduced emissions, reduced fuel use and lower transport cost. However, the challenges associated with implementing the concept cannot be ignored. All the above benefits must be realized, most importantly faster travel times, in order to be able to convince shippers and forwarders that a centralized freight facility does work. Infrastructural and public policy changes will also be necessary to promote the concept. Finally, an implementation of the concept of Mega-Regional planning will be a great improvement to the current freight movement system. In the next chapter, an intermodal rail costing model is introduced to provide researchers with a tool to assist in further studies of the dry port concept and general rail planning at a macro level.

Chapter 5: The Intermodal Rail Cost Model (IRCM)

Estimating private costs of freight rail service is inherently complex. Nevertheless, an understanding and ability to approximate rail line-haul operations is essential in understanding whether innovative developments like the dry port are cost effective. Over the years, economists and government organizations have developed models to estimate the internal costs of freight rail services. Many of these models are either too case specific to be used for purposes of comparison or alternatively are too general to be useful. Econometric models tend to concentrate on the shape of the cost function and its implications for productivity growth and economies of scale, scope, and density. A recurring finding of these studies has been that the railroad industry is achieving productivity gains over time and through mergers, and that rail costs are non-linear in nature.

Federal agencies such as the Surface Transportation Board (STB) have limited tools at their disposal to determine the impacts of rail service changes and whether rates are in line with variable cost. For two decades, the Surface Transportation Board (STB) has used a model called the Uniform Rail Costing System (URCS). While the model has significant limitations, it is still the official tool used by the STB and as such serves as the first point of reference for this rail operations study. URCS is the STB's railroad general purpose costing system model used to estimate variable and total unit costs for Class I U.S. railroads. It uses system average units based on cost relationships and system data for Class I railroads. The data are updated annually by the STB although the basic structure of the model remains as it was developed and does not now reflect modern railroad operations.

The limitations of URCS and other models described in the main body of the report deemed it necessary to develop a transparent line-haul rail operation model to illustrate the contribution of the rail variable costs, and estimates fuel consumption and emissions to determining the costs and benefits of investments such as the dry port implementation. The benefits are derived from the modal shift from road to rail resulting in cost savings, reduced congestion at port cities, and reduced external environmental effects.

The mechanistic elements of the model are then described in detail. This model seeks to replace the currently Uniform Rail Costing Model and to provide a tool for policymakers and freight transport stakeholders to perform different freight movement analysis involving rail. The model is based on a simulation of the horsepower required to move a ton of cargo at a specified speed over a certain distance. The calculated horsepower is used in determining the fuel consumed which is translated into fuel cost and emissions generated. Maintenance costs are assumed to be fixed costs calculated based on the number of locomotives and rail cars used, and the distance traveled. Crew wages are also calculated as a daily rate determined by the travel time, and capital costs are determined on an hourly rate. The model also provides the capability for user-specified inputs. Despite its capabilities, the current state of the model limits the types of analysis that can be performed. These limitations, though numerous, can be addressed in future versions of the model. Upcoming versions of the model will seek to enhance the simulation of train movements, and provide the ability to capture the effects of traffic volume on unit cost. In the meantime, IRCM was tested, calibrated and compared with currently-available rail costing models, and the results presented in the next chapter.

Chapter 6: Model Validation and Calibration

The STB Uniform Rail Costing System was used as a point of reference to validate results obtained from IRCM. URCS is currently the only publicly available rail costing model and the primary model is used by the STB for a variety of statutory and non-statutory functions. Other econometric models have been developed by researchers over the years but most are intended to measure changes in rail productivity over time, as well as estimate the effects of mergers. Others are also either difficult to replicate or were developed for specific geographic regions or specific rail traffic.

In addition to URCS, results from the IRCM were submitted to rail industry experts for verification and comments. A noted rail expert—Dr. Bereskin—also performed several runs with his model and the results were then compared with the IRCM output. It should be noted that

IRCM is designed to produce cost differentials between alternative modal strategies and it is not designed to produce actual rail prices. Most models – for ships, barges, trucks and rail—behave in this fashion as there are always items related to total costs (like terminal operational costs) that are too difficult to capture. However, the research team is confident that the comparisons reported in the main body of the report adequately predict the influences of fuel cost, trip length, number of containers, and utilization ratio on overall line-haul operational costs.

Chapter 7: Case Studies Using the IRCM

A survey of thirty-two freight forwarding firms located in Texas examining the state economy reported that the majority of commodities transported have their origins or destinations in the "Texas Triangle" cities of Houston, Dallas-Ft. Worth and Austin-San Antonio. Improvements in current marine trade corridors like the expansion of the Panama Canal are expected to facilitate an increase in goods transported via the port of Houston. In the case studies presented in the chapter, an analysis of goods transported from the dry port to the Port of Houston is performed. The dry port is assumed to be located in Dallas-Fort Worth area and is roughly 275 miles from the Port. Dallas-Fort Worth is chosen because of its distance from the Port of Houston is typically regarded as too small to support truck-competitive rail service. The case studies examine various scenarios to identify conditions that would make rail transport competitive with trucking for short-haul distances.

The first case study determines a threshold quantity of goods to be transported from the centralized freight center to the port for short-haul rail to be competitive to trucking. This study is necessary to assist policymakers to decide whether it is worthwhile investing in short-haul freight rail based on the quantity of goods transported between the origin and destination points. Despite the advantages of rail, its delivery times are known to be slower than trucking and this does not tend to be favorable for shippers. The second case study seeks to determine if freight rail can move at faster speeds and still be cost effective and competitive with trucking.

Chapter 8: Conclusions and Recommendations

The study attempts to sharpen understanding of the import-export processes function in the U.S. for non-logisticians and to explore how rail can play a role in enhancing both the capacity and efficiency of current multi-modal supply chains. It examines the challenges faced by U.S. exporters and importers, and investigates an innovative solution to tackle these challenges. The dry port concept introduced by transportation geographers was discussed, and an intermodal rail costing model was used in determining whether this concept proved to be a more sustainable and energy efficient system than what currently exists. The model was then tested using a number of case studies and comparing it with other model outputs.

The study team recommendations for future work fall into two categories. The first relates to the rail model and the various improvements that could be made to address specific freight planning problems or opportunities where freight rail is being considered. The characteristics of rail operations are detailed and, at times, complex making it challenging to develop a model that can address several issues simultaneously yet be structured so that non-engineers with limited data are still able to derive useful output. It is hoped that the model can be improved with help from a Class 1 railroad company comparing actual company data with model predictions. The model should also be improved by calibrating operations related to different commodities where different combinations of engine power, train weight and speed are present.

The second category of activities where rail models can be of use lies in the planning sector. State Departments of Transportation are failing to raise sufficient revenues for lane capacity and one way to lower demand for additional lane miles is to move freight to other modes. Intermodal offers a competitive alternative to trucking over trip distances that exceed 500 miles and there are real opportunities to lower this distance, particularly if the dominant cost of drayage is resolved. Rail is superior in terms of energy per ton/mile costs and this makes it a vital transportation mode in addressing future freight needs. And, lower fuel consumption equates to lower emissions per ton/mile which constitutes a double benefit to metropolitan planners. Finally, supply chains have shown themselves capable of moving exports, and efficiently as imports, which suggests that new transportation multimodal freight improvements can be developed to serve the metropolitan population growth over the next 30 years. Rail models of the type developed in this study could to play a role in determining the shape, nature and efficiency of freight flows and future supply chains.

The report closes with appendices describing IRCM user manual, the export survey questionnaire and all references used in conducting the work.

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Disclaimer

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Chapter 1: Introduction

Background

In the first quarter of 2007, the global economy peaked after a 10-year period of virtually uninterrupted growth, which fueled demand for both U.S. imports and exports. Imports substantially exceeded exports in value, in part because of the efficiency of the global transportation system which, as containerization replaced break-bulk handling, enabled companies to outsource key operations to regions with lower production and labor costs. Global containerized supply chains to the U.S. had been continuously refined since the late 1970s largely on the basis of import characteristics which, after 1995, became increasingly dominated by routes originating from Asia.

Over the period from 1994 to 2007, U.S. transport investments were channeled into West Coast terminals[1], rail corridors[2], economies of scale[3], inland ports[4] and improved dray operations[5]. U.S. dollar weakness since 2006 made several U.S. goods and commodities more competitive in world markets and, as a result, export growth began to exert stresses in the intermodal export system, most notably in container scarcities[6] and problems reliably booking slots on outgoing east coast containerships[7]. This UTCP study arose from a simple question – did the much vaunted multi-modal containerized system favor imports over exports? While the study was underway, oil prices rose substantially and posed a second related question – how did energy prices factor into supply chain efficiencies?

Import and export processes play important roles in global supply chains and can lower effectiveness. For example, inefficiencies in these processes can result in increased cycle times, costs, inefficient resource allocation and increasing stress on the nation's transportation system. But is this is key reason for current difficulties faced by U.S. exporters? The importance of the

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[1] The 2002 20 mile Alameda rail corridor, connecting terminals at the Ports of Los Angeles and Long Beach with BNSF and UP trans-continental rail yards is a good example of such investments .

[2] Both Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) had trans-continental routes that were double tracked almost all their length by 2008

[3] Double-stack rail intermodal trains now typically operate at over 7000 ft in length

[4] The 1994 BNSF intermodal terminal at Alliance Inland Port near Fort Worth, Texas is probably the archetype for inland port development in the U.S.

[5] Examples comprise less polluting tractors, off-peak port access incentives and higher safety standards

[6] In the 1990s, large numbers of boxes grew at sites throughout the U.S. creating an entirely different set of problems.

[7] Export boxes are generally heavy and some vessels when fully loaded with such boxes exceeded the channel depth at many ports.

import and export processes has led researchers to understand, forecast and plan for changes in these processes and other related freight distribution processes. However, Thomchick et al. (2004) suggested that such processes are highly technical, intertwined, and are at times difficult to understand at a macro level. Another reason stems from the difficulty in obtaining quality data relating to importing and exporting supply chain operations. Finally, could it be that the problems were short-term in nature and would be addressed in the medium-term as export levels grew? After all, the logistics sector is renowned for its flexibility and responsiveness and the efficient import process was no accident – it was the result of a successive number of improvements made over the past 25 years. This was the case in Texas where research showed that market forces responded to higher import demand by making substantial investments in larger vessels, new terminals, improved drayage and recognition at both state and federal levels that freight corridors should be recognized and supported.[8]

The movement of international containers[9] on multi-state rail and highway corridors created a sequence of challenges for the logistics and transportation sectors. Congestion at port terminals, the imbalance between imports and exports, chassis pools, empty container storage areas,[10] fluctuating ocean shipping rates,[11] the jump in oil prices in 2006/7, and the recession have all impacted the flow of U.S. trade – imports and exports.

Current Recession and Transportation

Two shocks in particular – first the oil price and later the collapse of several domestic and international banks contributed to the worst U.S. recession since the Great Depression of the 1930s. Figure 1 shows the extent of the recession and a forecast, by HIS Global, of the forecasted recovery. HIS Global predicted a sharp "V" shaped recovery – more typical of recent recessions although not all economists or financial experts agree. Professor Roubini, from the Stern Business School at NYU, thought that a "U"-shaped recovery was more likely where growth

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8 A Texas perspective of this issue can be gained from Harrison et al., "Emerging Trade Corridors and Texas Transportation Planning" TxDOT Study 0-5973-2, 2010.

9 Larger domestic containers are a growing segment of rail intermodal business but tend to move on somewhat different corridors to those used by international shippers, whether they be importers or exporters.

10 For Texas see, Prozzi et al " What We Know About Containerized Freight Movement in Texas", TxDOT Study 0-4410-1, 2003

11 At times, the return cost of Trans-Pacific slot exceeded the container manufacturing cost in China (Containerization International, 2005)

could trend slowly in most advanced economies[12] and even fall into a "double dip" recession if the advanced nations did not get the exit strategy right.[13] Figure 1 shows the HIS Global forecast, together with two more predictions—first a more modest, slower recovery (dotted) and a second, shallower "U" shaped recovery (arrowed line) that could also incorporate a "double dip" feature not shown in the graph.

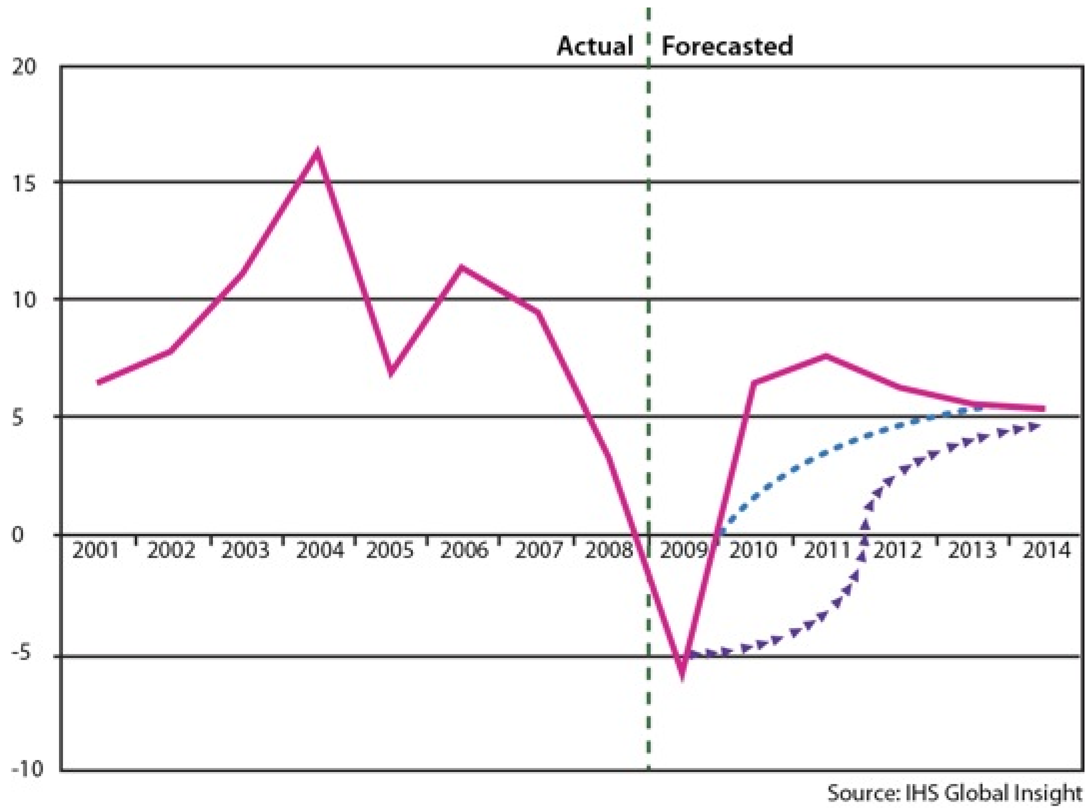

Figure 1: Percentage Change in Actual and Forecasted Global Trade, 2001-2014

The fall in aggregate U.S. trade volume has brought with it a reprieve from many of the transportation problems experienced during the 1995-2005 period. The U.S. has enjoyed, over the past 16 months, congestion-free ports, unclogged rail lines, an available pool of transportation workers, and more stable energy prices. While maritime shipping has struggled with over capacity, the Class 1 railroads have reduced working capital by storing cars and

[12] The exceptions being China and other South-East Asian economies

[13] Currently, there is no single exit strategy being promulgated – they range from the UK recent budget which aims to cut government spending by 20 percent to the November 2010 U.S. Federal Reserve plan to spend another $ 600 billion supporting liquidity

locomotives, carefully furloughing staff, increasing the level of track maintenance, re-negotiating long-term contracts, and raising their return on capital[14].

Export Growth

A parallel force to the export trade picture is the role of the U.S. dollar and its weakening as the trade currency of choice. This weakness accelerated over the past five years and has resulted in calls for setting crude oil prices in a basket of currencies,[15] volatility in currency prices and the upward move in the price of gold[16]. The fall in value of the U.S. dollar created one group of beneficiaries – U.S. exporters, who were able to compete more effectively in world markets. As export opportunities grew, the logistics sector found that while it could adjust relatively quickly to the movement of some commodities (like grains and chemicals), intermodal flows were impacted by several factors, including;

1. shortages of boxes and specialized containers
2. problems moving product on corridors serving export ports, and
3. unreliable booked export slots on ships serving East Coast ports.

Most of these will be addressed over time as long as export demand remains strong. Boxes and specialized containers will be re-positioned at more convenient sites as the market adjusts to the new demand. New corridor performance will improve – quite rapidly – as a "learning curve" builds experience. The unreliability issue associated with booked slots is more intractable since exports tend to be heavier and the ship captain has to calculate – almost in real time – how much can be loaded to enable the ship to pass through the typical East Coast port channels. While this is not an insurmountable problem, it is unlikely that additional Federal funding will be readily available for dredging channels so that they meet the needs of fully-laden containerships.

Three factors underpin the work in this study. The first examines export corridor efficiencies, and the second recognizes that supply chain sustainability requires rail plays an enhanced role in moving goods. Rail, with its superior fuel consumption on a ton/mile basis and its corresponding lower emission levels should play a key role if transportation sustainability is to be reached. Finally, rail analysis is challenging because few models exist at a planning level

[14] This success has not gone unnoticed and there has been calls to re-introduce rail regulation to (amongst other things) reduce "excessive" profits

[15] Most recently from Iran in 2009, although the 2010 weakness in the Euro would have rendered the basket – assuming the weighting remained as proposed – weaker than the dollar itself

[16] Gold price rose from $475 an ounce in 2005 to $1400 on November 5 2010

that can be employed to evaluate rail impacts on freight flows. Accordingly, a basic rail model was developed precisely for this purpose and is the primary product of this study.

Report Outline

The work is the second of five inter-related UTCP studies examining key changes in intermodal freight transportation in the United States at both national and state levels. The first[17] examined changes over the last decade in rail intermodal systems in the United States and the likelihood that a more enhanced role could be played by railroads in moving future volumes of North American continental freight efficiently and competitively. The third[18] examined the impacts on the key U.S. global import and export supply chains of the new, larger locks on the Panama Canal, due to be opened in 2014, which will permit larger ships to serve Gulf and North Atlantic ports more competitively from Asian centers of production. The fourth[19] study examines the impact of developing effective freight systems in those merging metropolitan areas predicted to form coherent productive regions – termed Mega-Regions by urban planners. The fifth[20] study evaluates the operation of reduced or near-zero delivery trucks which will need to be introduced where non-attainment air quality restrictions are in place.

This study highlights the importance of rail operations in developing sustainable freight supply chains serving future export and import flows. The major product of the work – a basic rail cost model – serves as a tool to sharpen current metropolitan freight planning, which can be enhanced and calibrated by users to address more specific regional issues such as multi-model corridors.

Report Organization

The second chapter summarizes the pertinent elements to the study title derived from a literature review of the import-export process. The third chapter discusses existing import and export processes and global supply chains including challenges currently faced by both exporters

[17] "The Potential for Improving Rail International Intermodal Services in Texas and the Southwest Region of the United States," SWUTC Project Report 473700-00076. Currently in draft form.
[18] "Evaluating the Impacts of the Panama Canal Expansion on the Texas and U.S. Economies," SWUTC Project Report 476660-00062. Currently in draft form.
[19] "Mega-Region Freight Movement: A Case Study of the Texas Triangle," SWUTC Project Report 476660-00075. Currently in draft form.
[20] "Hybrid Distribution Trucks: Costs and Benefits," SWUTC Project 476660-00080. Project in progress.

and importers. A future supply chain concept is introduced and its benefits, challenges, and applications are discussed in the fourth chapter. An intermodal rail costing model, developed as the principal product of this study, is then presented in the fifth chapter, and the model is calibrated and validated in the sixth chapter. Chapter seven comprises using the rail model in two case studies examining the proposed supply chain concept, and chapter eight reports the final conclusions and recommendations for future researchers working in this area.

Chapter 2: Literature Review

An abundance of import-export literature has developed over the past 30 years pertaining to topics such as legal and regulatory requirements, marketing tools and strategies, finance, policies to promote exports, export management and strategies, geography and export patterns, export trading companies, international logistics, terminal operations, port security, and information technology applications (Thomchick et al. (2004). A small selection of articles reviewed, which relate to the logistics and freight distribution areas of the import-export process, include:

Port Security	Sheffi et. al, (2003), Kumar et. al, (2008), Willis et al. (2004), Giermanski (2008), Erera et al. (2003)
Container Movements	Prozzi et. al, (2003), Cheu et al. (2003)
Information Technology	Holguin-Veras and Walton (1997), Jones and Walton (2002), Sideris et al. (2001)
Inland Port Location	Rodrigue (2006, 2008)
Freight Consolidation Centers, Inland Ports and Dry Ports.	Roso et al. (2009), Kawumaru and Lu (2008)
Terminal Operations	Brinati (1974), Pettering et. al (2009)

Several articles have been written regarding port terminal security, an area which garnered attention after the September 11 2001 attacks (Sheffi et. al, 2003, Kumar et. al, 2008, Willis et al. 2004, Giermanski, 2008). For example, Kumar et al. (2008) showed how the Six Sigma DMAIC approach can be utilized in assisting in standardizing container security and minimizing risks in supply chain design. The authors identified the major problems in the container shipment process and the impact that a standardized security approach could have on business results (Kumar et. al, 2008).

When dealing specifically with the import-export process, Erera et al. (2003) presented a background study of the US and Singapore sea cargo export processes but focused on how information technology could be used in improving port security. Thomchick et al., (2004) compared the elements of the import and export processes with the expertise that major firms possess and determined how important a particular element may be considered over time. The study identified regulatory compliance, third-party relationships, in-sourcing and outsourcing performance measurement, training programs and information technology as the factors of importance for both import and export managers. A study by Haughton et al (1999), evaluated the effectiveness of inter-firm (external) benchmarking in the import process.

In the area of container movement, Cheu et al. (2003) introduced a planning model to estimate the total distance, including empty trip distances, traveled by transport operators in transporting import and export containers between ports. A study by Prozzi et al. (2003) investigated container movements in the United States, and addressed questions like ownership, liability at different stages of a movement, types of container leases, tracking technologies, transfer costs, security risks, and scrappage policies. In information technology applications, Sideris et al. (2001) developed a logistics information tool aimed at improving marine terminal container handling operations and customer service quality. Jones and Walton (2002) suggested how current intelligent transportation system technologies used in tracking and managing containers in transit can also be utilized in the management of container stacks in marine terminals. Holguin-Veras and Walton (2007) discussed the role of information systems and information technology on the implementation of priority systems, and current utilization of information technology on the import-export processes in marine container terminals.

In the area of terminal operations, Brinati (1974) analyzed the queuing process at an offshore export terminal and determined the effect of the system's operational characteristics on the expected queue length of ships. Pettering et al. (2009) evaluated different yard crane deployment systems and determined an optimum block length that yields the highest quay crane work rate.

The freight consolidation center concept which is discussed in this paper has also been studied by authors like Roso et al. (2007), and Kawumaru and Lu (2008). Roso et al. (2007) examined the differences in CO_2 emissions, congestion and truck waiting times between transport systems with and without what he terms a dry port – an inland intermodal terminal directly connected to a seaport. However, findings on the effects such as travel time, fuel consumption, emissions, and cost associated with the implementation of a dry port as well as its benefits to stakeholders continues to remain scarce.

Summary

The literature review demonstrates that studies pertaining to import and exports span over several decades. Research is continually refining the import-export processes – either in the public domain or within the business models of individual companies. Freight consolidation is seen as a major step to building a sustainable supply chain but research to validate this step needs to be strengthened. In the next chapter, the existing import and export processes are introduced and the challenges currently facing the industry discussed.

Chapter 3: The Import-Export Processes and Global Supply Chains

Import and export processes involve various functions and stakeholders (Erera et. al, 2003; Holguin-Veras and Walton, 1997). The functions are the steps involved in moving product through the import-export process. Stakeholders are defined as individuals or companies involved during the import-export process beginning when the shipper initiates the process to when the goods reach the destination consignee. The various functions can be simplified as shown in Table 1 and can be further subdivided into two components – information flow and physical flow (see Table 2 and Table 3). The stakeholders involved in imports and exports include shippers/sellers, freight forwarders/customhouse brokers, land transport operators/drayage companies, ocean carriers, warehouse operators, equipment suppliers, regulators and port (marine terminal) operators.

Table 1: Major Steps in the Export (adapted from Erera et. al, 2003) and Import Processes

Export	Import
1. Manufacture or Assembly	1. Placing of order
2. Prepare export documentation	2. Pre-Screening (if applicable)
3. Process Shipment and Book Slots	3. Arrival of Goods
4. Obtain Empty Container	4. Process documents, bill of lading, etc.
5. Pick and Pack	5. Customs and Security Clearance
6. Deliver container to ports	6. Transportation of goods (multimodal)
7. Security clearance	7. Unload at Customer Facility
8. Departure to destination	8. Return empties

Table 2: Information Flow in the Export and Import Processes

Export	Import
1. Shipper receives permit from Regulatory Agencies 2. Shipper notifies Freight Forwarder 3. Carrier notifies Terminal Operator about departure 4. Forwarder processes documents e.g. bill of lading, etc. 5. Forwarder processes shipments and books slots 6. Carrier informs Forwarder of cargo receipt 7. Forwarder informs Shipper about shipping status **8.** Shipper notifies Consignee	1. Shipper notifies Consignee 2. Consignee notifies Broker 3. Carrier notifies Terminal Operator and Broker about arrival 4. Broker schedules pickup appointment 5. Broker and Carrier process documents, bill of lading, etc. 6. Commodities go through Customs and Security Clearance 7. Broker picks up commodities and notifies Consignee

Table 3: Physical Flow in the Export and Import Processes[21]

Export	Import
1. Pick up of shipment 2. Delivery to warehouse 3. Consolidation with like shipments 4. Delivery to port of export 5. Transport to storage 6. Transfer from storage to departure terminal **7.** Departure to Destination	1. Arrival of shipment 2. Transport to storage 3. Pick up from storage 4. Delivery to warehouse 5. Transloading 6. Delivery to consignee **7.** Return empties

Stakeholders are the foundation stones of international trade processes, and Erera et al. (2003) categorizes them into two types: (1) the key players who are mandatory in any import-export process, irrespective of the country; (2) the additional players introduced due to

[21] The processes in Tables 2 and 3 involve other sub-processes which are discussed further in the subsequent sections.

peculiarities of a specific import-export process. The supply chain is formed by the interactions of these players in various degrees. Their roles and responsibilities vary as shown in Table 4 and there is a great deal of interaction and information exchange between these various stakeholders (Holguin-Veras and Walton, 1997). However, the different stakeholders can actually be owned and operated by the same owner but can be segregated as they perform different functions.

Table 4: Roles and Responsibilities of the Stakeholders

Stakeholders	**Export** (adapted from Erera et. al, 2003)	**Import**
Shippers/Consignees	Clients	Clients
Freight Forwarders/Customhouse Brokers	• Assembles all export documentation and processes • Arrange for inspection and clearance by customs.	• Assembles all import documentation and processes • Arrange for inspection and clearance by customs.
Land Transport Operators/ Drayage Company	• Transport empty containers to warehouse • Transport goods from warehouse to port.	• Transport goods from terminal to warehouse/final destination • Transport empty containers from warehouse to container depot.
Ocean Carrier	• Coordinate the delivery of goods to the terminal • Given a load tendering agreement (Bill of Lading) • Coordinate the movement of containers with the marine terminal operator	• Coordinate the delivery of goods to the terminal • Provide a load tendering agreement (Bill of Lading) • Coordinate the movement of containers with the marine terminal operator.
Warehouse Operators[22]	• Perform value-added services, such as consolidation, labeling, and sub-assembly	• Perform sorting services such as unloading, transloading, and consolidation services
Regulators	• Government agents and trade organizations in charge of approving and inspecting goods being traded	• Government agents and trade organizations in charge of approving and inspecting goods being traded

[22] Freight Forwarders and Custom house Brokers may also provide Warehouse services

Table 4 continued: Roles and Responsibilities of the Stakeholders

Port (marine terminal) operators	• Coordinate work between the various stakeholders in the process of loading cargo. Marine terminal operators generally work for specific carriers but there are also publicly available terminals. The marine terminal operators have additional responsibilities including: o Clearing for Customs and other government agencies o May or may not inspect containers o Review the drayage contracts and confirm all interchange agreements • Ensures efficiency in terminal operations to meet environmental standards.	• Coordinate work between the various stakeholders in the process of discharging cargo.
Depot Operators	• Depot operators own and manage containers and are usually owned by the carrier and are based at the port terminals.	• Same as Exports

Note: According to Woods et al. (2002) warehouses and distribution centers are similar in nature except that distribution centers emphasize on the prompt movement of goods while on the other hand, warehouses are usually used for storage before future delivery to the final consignee.

3.1 THE EXPORT PROCESS

Exporting is an important part of international trade and is crucial for a nation's growth. In 2008, U.S. exports of goods and services grew to $1.84 trillion and comprised 13.1% of US Gross Domestic Product (GDP). In historical terms, exports were 9.5% of U.S. GDP five years earlier (2003) and 5.3% 40 years ago (1968) (ITA, 2009). The largest export markets for U.S. goods are Canada, Mexico, China, Japan and Germany. Exports of goods and services comprise a wide variety of commodities and activities which can be further disaggregated into critical needs for transportation services within the supply chain. As an example, exports can be further categorized into capital goods, natural resources, industrial supplies, insurance services, financial services, and professional and technical services. Capital goods – which include medicinal equipment, materials handling equipment, industrial engines, and other equipment – represent the largest goods export category (end-use) for the U.S. with $469.5 billion worth of exports in 2008 . Industrial supplies including fuel oil and other petroleum products and minerals is the largest growth category in dollar value representing $387.3 billion of U.S. exports in 2008, up $70.9 billion (or 22.4 percent) from 2007 . Foods, feeds, and beverages represented $108.4 billion of U.S. exports in 2008, and were the second largest export growth category (end-use) for the U.S., with exports rising $24.2 billion (or 28.7 percent) over 2007 (ITA, 2009). Each category requires different combinations of transportation modes, travel speeds, security treatment and monitoring.

The export process can be handled directly either by the shipper or licensed freight forwarder. The freight forwarder is in charge of coordinating the export process from the country of origin to the country of destination. Thomchick et al. (2004) state that some of the initial questions to be answered by exporters include: What is being exported? Where are the items going? Who will receive it? How will the items be used? And is an export license required?

Once the above questions have been addressed, the freight forwarder decides on the modes of transport and the type of packaging. The common modes of transport used in overseas shipping are sea, air and land. The choice of transport depends on the characteristics of the goods such as size, value, destination, required delivery time and cost. Sea transport is the most common and least expensive[23] mode of transport and is the preferred mode for most large and

[23] Particularly when measure on a ton-mile basis

low value commodities. Air transport is the preferred mode for small, high value, and time dependent commodities. Land transport (rail and trucks) is used to move goods to the nearest port of departure (except for goods bound for Canada, Mexico and Central America) or as one leg of a sea/land or air/land combination. The transport of goods to terminals is the major element of this study and operations within the terminals are not examined, in part because of the wide literature on terminal operations of all types[24].

The final consideration in the export transport process is documentation. The necessary documents for exports include packing lists, bills of lading, security, and export declarations. These documents are necessary in order for shipments to be permitted to pass through customs, loaded onto a carrier and transported to a foreign destination (AgMRC, 2009). Shippers have been subjected to providing increased documentation related to security and this is unlikely to diminish give the late 2010 attempt to blow up a cargo plane over the U.S.[25].

The Export Process Map

The process map shown in Figure 2 identifies each major step in the export process. As described by Erera et al. (2006), the shipper contacts a freight forwarder to make shipping arrangements, and provides the forwarder with shipment instructions which include shipping destination, consignee details, products, quantities, warehouse and delivery dates (Erera et al. 2003 in Kumar et. al, 2008). The freight forwarder then coordinates with the ocean carrier, land transport operators (if separate entity), regulators, and port operators. The forwarder books a slot with the ocean carrier weeks ahead of the scheduled departure. A land transport operator is then scheduled to pick up the shipment either from the shipper's location or the forwarder's warehouse.

If an empty container is required, a truck is first dispatched to pick up an empty container from a container depot, and, depending on the quantity, size, or type of shipment, the empty container is either transported to the shipper's location or the forwarder's warehouse for loading. Depending on when loading is complete, the truck may return to its origin without the loaded container and another truck may be dispatched instead. At the forwarder's warehouse, shipments

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24 For example, the Transportation Research Board has several committees which have supported a variety of analyses on modal terminal operations over the past two decades

25 The EU is also introducing new steps in 2011 to require shippers to declare import contents 24 hours before shipping to the Union.

are consolidated with other like items destined for the same location, and loaded into containers or palletized (air transport). A truck picks up the consolidated shipment and transports it to the port of export.

If an empty container is not required,[26] the land transport operator picks up the shipment from the shipper and either transports it to the port of export or drops it at the forwarder's warehouse. Should a shipment be transported to the forwarder's warehouse, the shipment is usually consolidated with other like items and then transported to the port of export.

The decision to choose a port can either be based on the service (rate, transit time, and material handling compatibility) available between the port of export and the port of import or other considerations such as the desire to consolidate cargo from various inland points (Woods et al., 2002). When transporting commodities to the port directly via rail, the choice usually depends upon a combination of port facilities and services offered by railroads and vessel operators. At a time when railroad rates had more structure, railroads offered lower rates for export/import traffic than domestic movements because of the understanding that export/import traffic is more sensitive to transportation costs (Woods et al., 2002).

Usually at the port of export, the cargo is first held in storage before being loaded onto a ship. Loose or break-bulk cargo is stored in a transit shed located next to the dock. Containers on the other hand are stacked in a yard close to where the vessels will moor. Some general cargo docks will have conventional rail tracks along their edges where rail flatcars are place and oversized or very heavy cargo is moved directly between the vessel and the rail car (Woods et al., 2002). In other port areas, barges can be used to carry the cargo between the shipper/consignee and the ocean vessel. The barge ties up next to the ocean vessel and cargo is transferred through a process called lightering, used often for oversized cargo (Woods et al., 2002). Once the vessel is loaded for departure, the vessel sets off to its port of destination.

[26] Bulk or hazardous materials are usually transferred directly to the port of export but this decision is dependent on the type of commodity and the agreement between the freight forwarder and shipper.

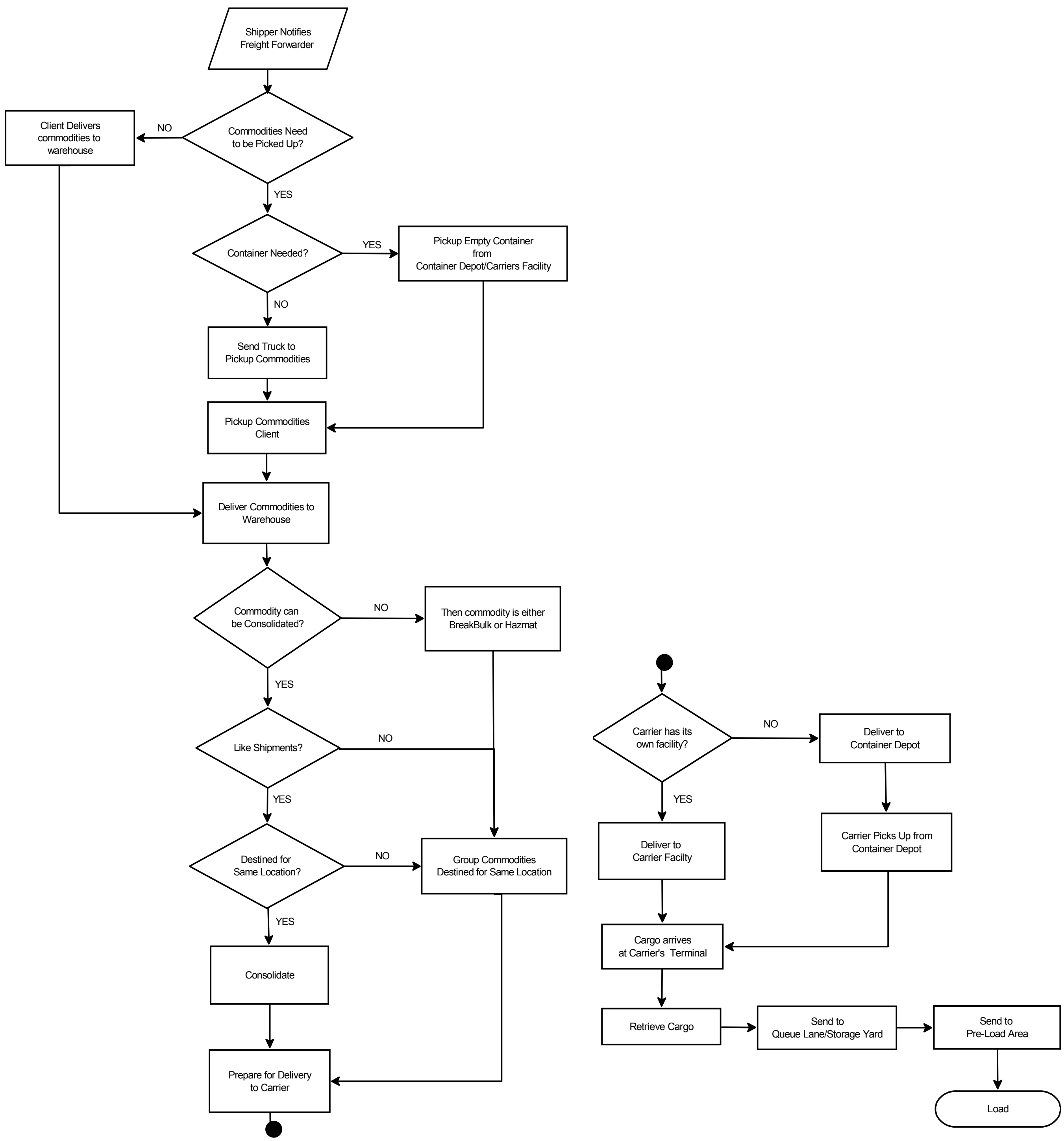


Figure 2: The Export Process Map

3.2 THE IMPORT PROCESS

Thomchick et al. (2004) reports that importing into the United States was first defined by the Tariff of 1789 and consists of (1) the classification of goods to determine their respective rate of duty, (2) the discerning of their country of origin, and (3) determining their time and place of arrival. Traditionally, data related to the import process was used for revenue collection, prohibition of illegal goods, and collection of statistics to determine the balance of trade . However, information concerning imports can be used by transportation planners to determine preferred ports of entries for various commodities, preferred transportation corridors, factors influencing delivery times, port-related operational issues such as congestion, and other factors that can be studied to improve upon the overall efficiency of the import process from the port to the final consignee.

As discussed earlier, the import process can be sub-divided into two interdependent supply chain flows; physical flow and information flow. As described by Thomchick et al. (2004), at the port of entry, foreign goods arrive with two key documents: a commercial invoice and a bill of lading. The commercial invoice discloses a general description of the goods' quantity and value. The bill of lading indicates the quantity and means of arrival including mode, vessel name, date of arrival, and country of origin. Duty rates are determined based on the above collected information and a Customs Entry document is prepared and filed with the appropriate government agency which ensures all regulatory requirements are fulfilled, and also uses the data to disclose the amount of revenue collected.

The Import Process Map

All shipments entering the USA must meet the customs laws of the country and it is the duty of the importer of record to ensure that all customs entry documents are filed with the U.S. customs service within five working days of the date of arrival of a shipment (Customs and Border Patrol, 2009). Haughton et al. (1999) defines the importer of record to be the owner, purchaser, or licensed customs broker appointed by the owner, purchaser, or consignee. According to Haughton et al. (1999), licensed customs brokers are the only third parties authorized by the tariff laws of the USA to act as agents for importers in the transaction of their customs business. Customs brokers may be individuals or firms and are often parts of international freight forwarding companies[27] (Haughton et. al, 1999).

Once import shipments arrive by air or vessel, they leave the terminal via truck or train. The shipments are first unloaded and kept in a storage yard where if the shipments are containers, they are stacked with other containers. When truck(s) or a train arrives to pick up the commodity, the shipment is placed on the truck(s) or train, and is required to clear customs. According to Haughton et al. (1999), the main reasons for customs inspections are (1) to determine if the goods can legally be imported into a country (2) to ensure the goods meet the country's regulatory requirements that are relevant to the specific product; and (3) to assess customs duty that may be payable on the imported goods. The importer of record must be knowledgeable of the regulatory requirements of the country to avoid any errors. Errors in filing customs entry can add to the cost of the import, through increased duties, taxes, or penalties, or through costly delays. Problems which occur in the customs clearance process include entry summary rejections, post-liquidation voluntary tenders, pre-liquidation revisions, and bills for additional duties (Haughton et. al, 1999).

After clearing customs, the shipment is transported to its final destination by the truck or train. The shipment can either be transported directly to the client or taken to the warehouse or an intermodal facility where additional processes like transloading occur. When containers are involved, the shipments are sorted and grouped by commodities destined for the same client or location. Once the container is unloaded, a truck returns the container to a container yard. Figure 3 shows a diagram outlining all the steps involved in the import process.

[27] Although large, experienced companies may handle customs clearance of imports in-house, most companies, and large and small, use customs brokers to some extent (Haughton et. al, 1999).

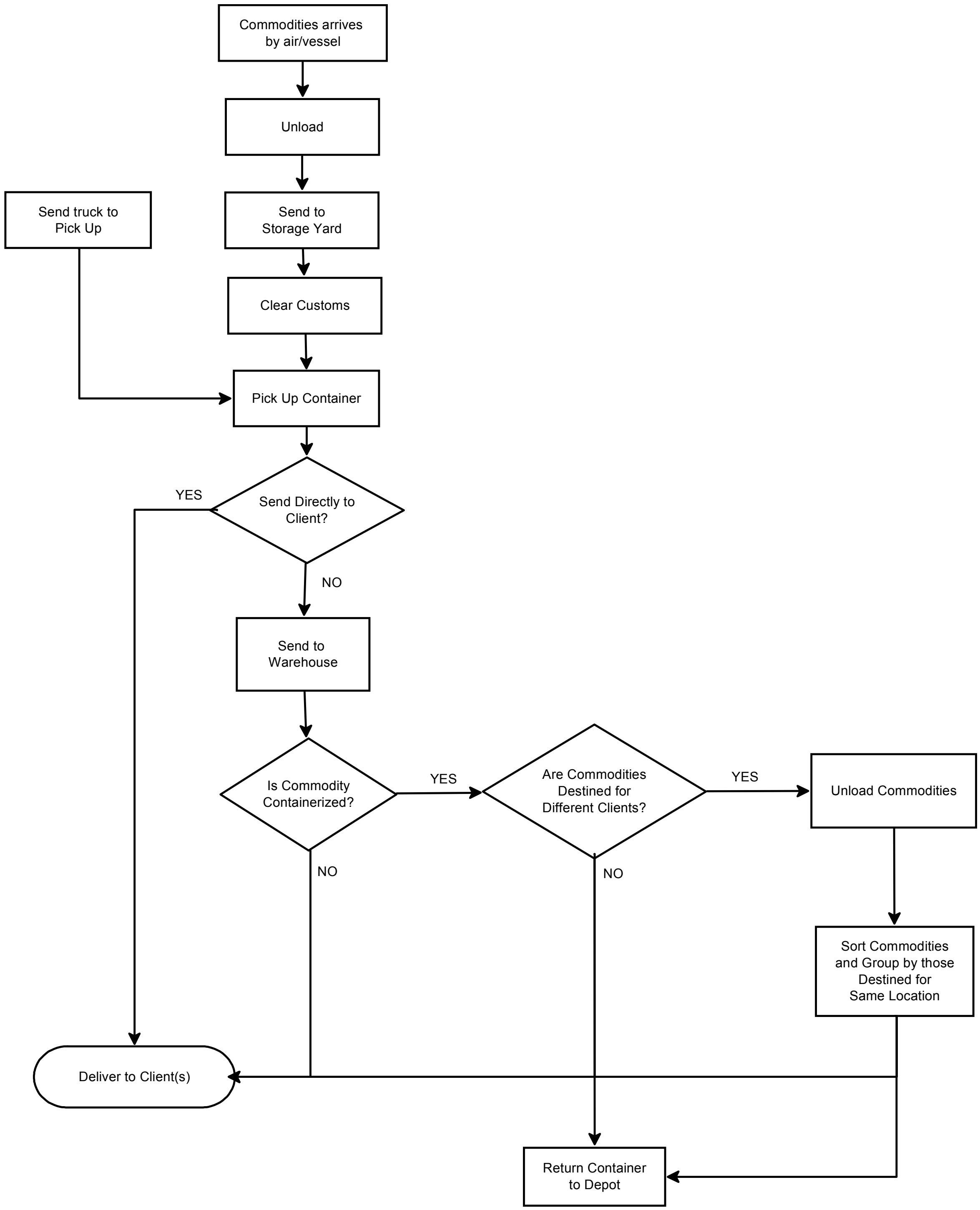


Figure 3: The Import Process Map

3.3 CHALLENGES IN THE EXPORT/IMPORT SUPPLY CHAIN

Sheffi et al. (2003) states that for firms operating on a lean supply/just-in-time base, disruptions in the supply chain could have adverse effects on the firm. Furthermore, "supply chains rely on the continuity of raw materials, parts and component flows, and a disruption in the transportation services could severely affect the continuity of operations."

The major problem with the current transportation system is that trucks are involved in almost every aspect of cargo movement – from pickup of the empty containers, to pickup from clients, to delivery to the freight forwarders warehouse and finally, delivery to the port of export (vice versa for imported goods). Rail is usually involved only at distances 500 miles or longer where double-stack intermodal is competitive to trucking (Resor and Blaze, 2003). Figure 4 illustrates the current transport network where trucking (conventional intermodal) is involved in the majority of trips and rail serves hinterlands at least 500 miles from the seaport.

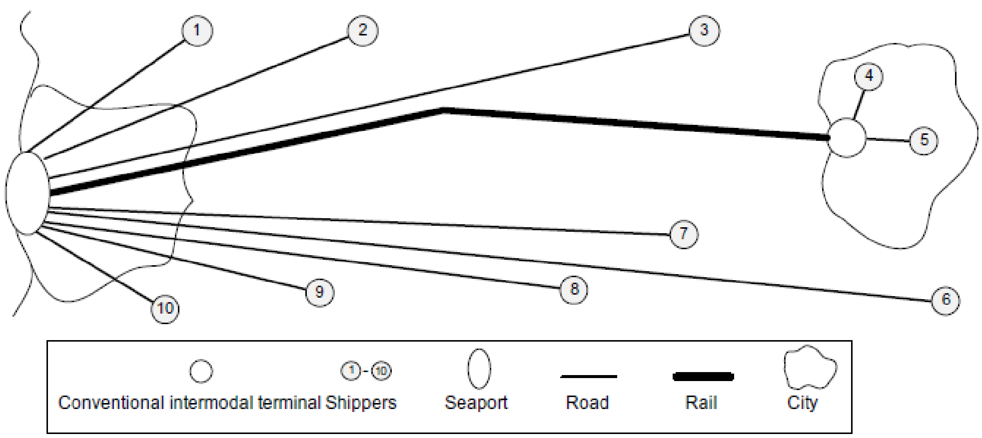


Figure 4: Sea port with connections to the hinterland
Source: Roso et al. (2009)

Highway congestion remains the ultimate source of transportation disruption in the import/export supply chains caused by the movement of commodities to and from the ports via trucks. In California for example, port-generated traffic has emerged as a major contributor to regional congestion (Jula, 2006). High truck volumes on roadways result in traffic congestion and long queues at terminal gates, which in turn result in air pollution, waste of energy, time delays, and an increase in maintenance costs (Barton, 2001 in Jula, 2006). In addition, current highway weight restrictions limit the amount of goods that can be transported as the combined weight of container and truck-trailer movements is sometimes greater than the allowable highway weight (Woods et. al, 2002). In a survey of thirty two freight forwarding firms located in Texas, highway congestion was ranked as more problematic for freight forwarders located in the hinterlands than for those located near the seaport. According to the Freight Analysis

Framework data, truck movements accounted for 99% of export goods and 100% of import goods moved between Dallas and the Port of Houston in 2002. Transportation cost associated with relocating containers and other equipment was also a source of concern for freight forwarders. Although repositioning costs rank lower than carrier costs, dock and terminal handling charges, and wharfage/demurrage costs, its significance cannot be entirely ignored.

Table 5 summarizes responses from forwarders located in the Dallas and Tarrant County.

In addition to the above transportation problems, recent fuel price increases are also becoming a source of concern for freight forwarders located in the hinterlands. Another persistent problem is finding the right type of containers or chassis, and the unavailability of containers (Woods et. al, 2002). Disruption in service caused by the unavailability of booking slots was also a major source of concern among freight forwarders. During economic growth, the ratio of containers to containership slots was always greater than one because of the growth in globally-traded containerized commodities (Prozzi et. al, 2003). Finally, labor disputes at ports are also a source of disruption in the import/export supply chain.

Table 5: Respondents from Dallas and Tarrant County

Rank of Factors affecting Exports	
Cost of fuel	1
Highway congestion	2
Reliability of booking slots	3
Unavailability of distribution/depot centers	4
High cost of relocating empty containers	5
Security and customs delays	6
Port congestion	7
Foreign regulations on certain commodity exports	7
Seasonal changes (e.g. currency devaluation)	9
Lack of options for port of export	10
Other	11

Rank of Factors affecting Imports	
Port congestion	1
Cost of fuel	2
Highway congestion	3
Security and customs delays	4
Lack of options for port of export	5
Unavailability of distribution/depot centers	6

3.4 Hazardous Materials Transportation

According to Wood et al. (2002), hazardous materials transportation is very important but can be a very complex procedure. Environmentally speaking, transportation is the weakest link in the hazardous material chain and therefore requires very high safety measures. Specialized warehouses and carriers are used, much different than non-hazardous goods; therefore, requiring exporters/importers of hazardous materials to seek specific advice on the commodity being shipped (Woods et al., 2002). International safety standards for packaging hazardous materials emphasize not just on the transport of the material, but on its storage and handling as well. U.S. DOT specifies exactly how hazardous materials are to be marked, labeled and described during transportation and failing to adhere to the applicable regulations results in severe civil and criminal penalties. Hazardous material transport regulations vary for both air and sea freight. For example, international air carriers limit the kind and the maximum quantity of hazardous materials being shipping on one aircraft. Transportation via sea freight is governed by regulations set forth by the International Maritime Organization (Woods et al., 2002).

In summary, hazardous material movements require special attention such as particular routes, ports, warehouses, vehicular equipment or even specialized carriers. In addition, a number of hazardous materials that may be moved by land or truck are prohibited in air transport (Woods et al., 2002). This study focuses more on the transport of consumer products, and due to its complexity, hazardous materials transport is excluded.

3.5 CHAPTER SUMMARY

The import and export processes involve various functions and stakeholders. Detailed descriptions of both processes reveal that though the functions vary, the processes utilize similar stakeholders, equipment and infrastructure. The survey results revealed the challenges currently faced by stakeholders and the dependence of the current system on trucking. Highway congestion, air pollution, waste of energy, time delays, and an increase in maintenance costs are the result of the current system. Fuel price increases result in higher transportation costs experienced the most by shippers located in the hinterland. There is a need for a more sustainable system than what currently exists. The next chapter presents such a system, and investigates the benefits and challenges of implementing the new system.

Chapter 4: Future Import-Export Supply Chains

Numerous enhancements can be made to improve the current export/import supply chain. A selection of these mentioned in the literature include developing new facilities and expanding current ones, deploying advanced technologies, improving operational characteristics at port terminals, and developing strategies to reduce truck traffic in urban centers (Ioannou, 2006). However, because of the scarcity of land at major ports, the option of developing or building new facilities is either not feasible or very costly (Pellegram, 2001, Roso, 2009; Ioannou et al., 2006). In recent years, advanced technologies have been developed such as global positioning system (GPS) tracking, radio frequency identification (RFID) tracking and other technologies which have facilitated improvements in the export/import supply chain.

Security is now the major driver behind a majority of the operational changes at marine and border terminals. It underpins a range of systems, including priority systems, VACIS—the gamma-ray non-invasive inspection system widely used for inspecting containers and trailers), Radiation Portal Monitors, and automated container identification using optical character recognition (OCR) systems (Orphan et al., 2009).s. However, the problem of truck traffic in port cities and urban centers still remains challenging and strategies are continually being explored to improve the situation. Among these strategies are restricting truck access at various times, revising building codes and zoning ordinances, assignment of truck only lanes, improving street design and exploring other technologies such as a centralized freight terminal. In an early study by the Battelle Research Institute of all the above proposed solutions, the centralized terminal approach was recommended as the best solution to solving urban congestion (McDermott, 1976).

The centralized terminal approach is a system which facilitates the efficient movement of goods within and outside of the city center. Such a facility will offer value-added services such as a container/chassis pool, an empty container depot, transloading services, intermodal (rail, air, truck) services, warehousing, customs and security clearance, and assembly/sub-assembly services.

The idea of a centralized freight facility directly connected to the port of export is nothing new. According to Roso et al. (2009), numerous authors such as Notteboom (2002), Notteboom and Winkelmans (2001), Robinson (2002), van Klink and van den Berg (1998) and Muller (1999) have studied the role and spatial coverage of such a facility. Muller (1999) investigated complementary concepts to that of the centralized freight facility such as land bridges, minibridges, and micro-bridges (Roso et al., 2009). Ideas like the depot-direct container "reuse" system which encourages empty containers to be stored, maintained and interchanged at off-dock container depots (Ioannou, 2006) and hub-and-spoke systems are similar concepts to the proposed facility.

The names given to centralized freight facilities however vary by location and author but are similar in concept: Gueterverkehrszentren in Germany, Plateformes Multimodales Logistiques in France, Freight villages in UK or Interporti in Italy. Roso et al. (2009) states that they all provide transshipment from one mode to another as well as auxiliary services such as warehouses, customs, maintenance workshops, insurance offices and other services (Roso et. al, 2009). Also, according to UN ECE (1998), an Inland Freight Terminal is ''any facility, other than a port or an airport, operated on a common-user basis, at which cargo in international trade is received or dispatched" (In Roso et al, 2009). Harrison et al. (2002) define an Inland Port as "a site away from traditional borders where international trade is processed and a value-added service are provided, and also promote more efficient multi-modal corridors." Van Klink (2000) defines inland terminals as:

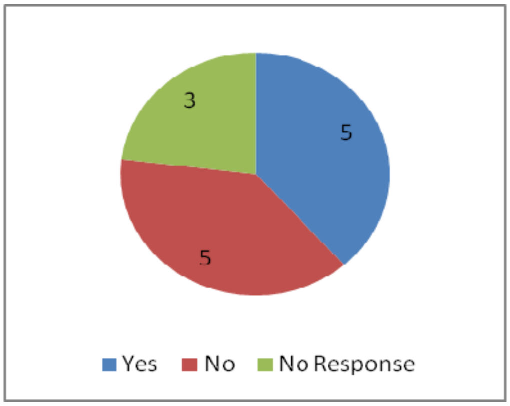
> "Extended gates" for sea ports, through which transport flows can be better, controlled and adjusted to match conditions in the port itself. In this way, inland terminals can help to improve land access to ports in both physical and psychological terms.

Finally, Leveque and Roso (2002) define terminal facilities using the dry port notion as:

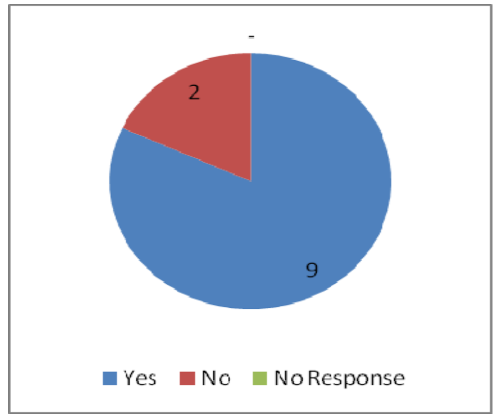
> A dry port is an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport.

Because of the similarity of the concepts the terms dry port or centralized freight facility are used interchangeably in this paper.

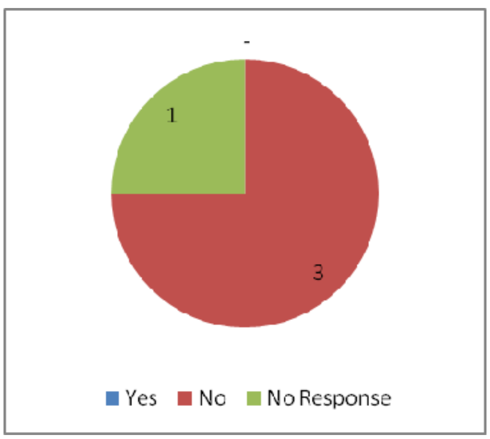
In the survey involving thirty-two freight forwarding companies in Texas, 42% of respondents expressed an interest in using such a facility. A majority of those who responded reside in hinterland areas such as Dallas and Tarrant County. A majority of those businesses which responded "No" are located near a port of export or import—e.g. companies located in Houston or Laredo were less interested in using such a facility. Another reason given by companies not interested in such a facility is their current business model. A new system might not be advantageous to their business and are therefore wary of using such a facility.



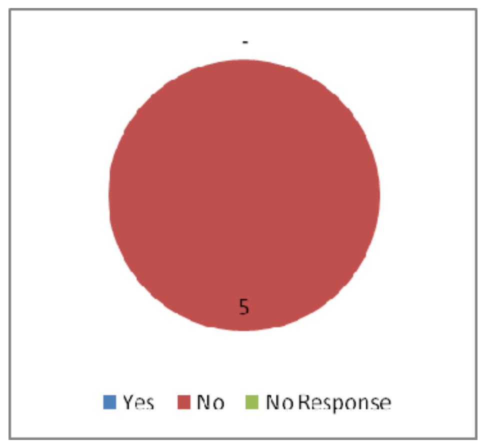
(a) Harris County



(b) Dallas and Tarrant County



(c) Webb County



(d) Other Counties (Travis, El-Paso, Tom Green)

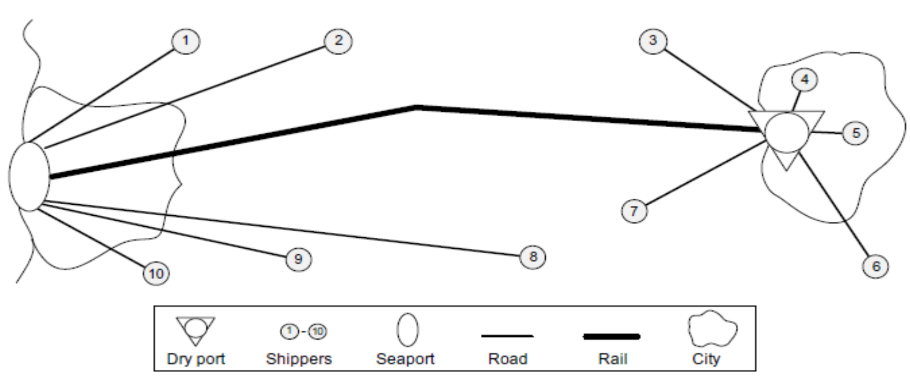
Figure 5: Breakdown of Survey Response by County

The challenges, costs and benefits of using such a facility were further investigated based on responses received from freight forwarders. Some of the parameters measured and compared with the current system of goods movement include travel time, fuel consumption, emissions, and costs.

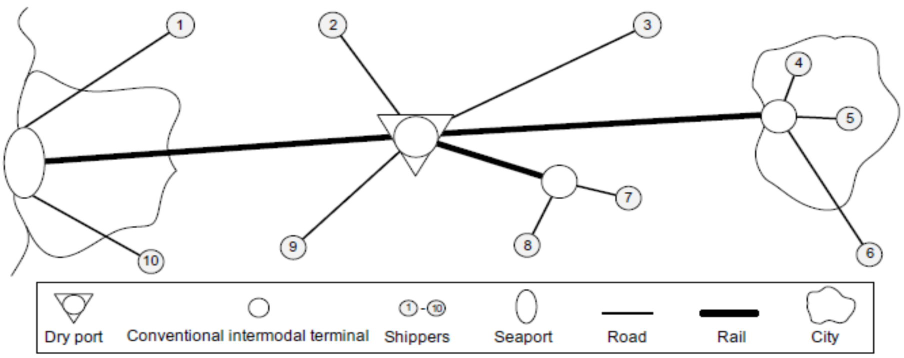
4.1 AN ILLUSTRATION OF THE DRY PORT CONCEPT

As noted earlier, the dry port is an inland intermodal terminal directly connected to a seaport with a high capacity transport means. High capacity transport is defined here as a system which facilitates a quick, efficient and cost effective transport mode with the ability of carrying a large quantity of goods on a single trip. Rodrigue (2008) reported "intermodal rail offers an opportunity to ship freight in and out of major port facilities to inland distribution centers" but Roso et al. (2009) adds, "rail transport is generally limited to serving major conurbations at rather long-distances from the port." Studies have shown that rail provides a competitive advantage over trucks in terms of volume and capacity. It has been found in the North American setting that rail is 4.3 times more energy efficient (455 ton-miles per gallon), has 4.7 times the capacity (216 million tons per mainline per year) and is 1.8 times less costly (2.7 cents per ton-mile) than trucking (Brown and Hatch, 2002).

The dry port concept does not seek to replace the port terminal and "goes beyond just using rail for high capacity transportation in the hinterland" (Roso et al., 2009). Instead, it complements the activities at the port terminals by diverting truck traffic used for long-distance transport. It also provides a strategy to relieve the port cities of additional truck traffic resulting in additional benefits such as reduction in port congestion, reduced emissions, reduced costs and decreased travel times. It also offers an alternative for hinterland shippers to have access to services which otherwise were available only at seaports, thereby reducing shipping cost and improving delivery times. An example of the dry port concept as illustrated by Roso et al. (2009) is shown in Figure 6.



(a) Sea port with a distant dry port



(b) Sea port with midrange dry port.

Figure 6: Two categories of dry ports based on distance and function.
Source: Roso et al. (2009)

The major difference between the midrange port and the distant port is that the midrange port "serves as a consolidation point for different rail services, implying that administration and technical equipment specific for sea transport … are just needed in one terminal" (Roso et al., 2009). But as illustrated for both distant and midrange dry ports, rail plays an important role in all instances. The rail facility seeks to divert truck traffic from the roadway resulting in less activity at ports, reduction in congestion, and reduction in other environmental externalities such as air quality and noise impacts (Muller, 2002).

4.2 BENEFITS OF THE DRY PORT CONCEPT

According to Roso et al. (2009), the benefits associated with a well implemented dry port include:

1. Provides same quality of service as a seaport but closer to inland shippers and at lower costs.
2. Modal shift from road to rail that result in reduced road congestion at seaports and its surroundings
3. Offers an environmentally friendly mode of transport
4. Serves as a buffer relieving the seaport's stacking area
5. Transfer activities currently causing congestion at the seaport to the dry port e.g. customs clearance, security clearance and empty container storage space.

6. Provides alternative modes of transport from hinterlands to seaports
7. Provides seaports the possibility of securing a market in the hinterland and increasing throughput without physical expansion of the existing port.

4.3 Challenges Associated with Implementing The Dry Port Concept

Though there are numerous benefits associated with implementing the dry port concept, this does not come without its challenges. There is a lack of sufficient research to determine if the benefits associated with implementing the dry port supersede the cost involved in building such a facility. In addition, improvements in environmental externalities such as congestion, air quality impacts and noise have not been adequately tested. Wood et al. (2002) further states that congestion problems occur at intermodal hubs especially as they become busier. They attribute the problems to backed-up trucks with trailers, inadequate transfer equipment, documentation delays, and misplaced and damaged containers. Another issue of concern by shippers is delivery times of intermodal service. According to Wood et al. (2002) there seems to be a negative perception of intermodal service by shippers who feel that they cannot count on having shipments arrive on time.

> As a result, many will build delay time into their production planning and therefore are less inclined to schedule delivery appointments the same day that shipments actually arrive at destination hubs....[28]

Despite benefits associated with the facility, shippers are most likely to adopt it if it provides faster shipment times than what is currently perceived. Finally, for the dry port concept to be successful as in any type of strategy that can be publicly adopted, "existing infrastructure systems, institutional and regulatory environments, socioeconomic and geographical characteristics, political climates, past and future changes in the logistics and supply chain management and market forces" (Kawumaru and Lu, 2008) will have to be effectively involved.

4.4 Examples of Dry Port Concept Implementation

A current example of dry port implementation is the Metroport facility in Auckland, New Zealand which is directly connected to the Port of Tauranga by rail. Another example is the Wiri Inland port (New Zealand) and rail exchange scheduled for completion in late 2009. The Wiri

[28] American Shipper, September 1989, p. 70 In Wood et al. (2002).

Inland port is located adjacent to two major freight highways and connected to the Waitemata seaport by rail. According to the Ports of Auckland website (2009), the inland port provides all the services of the traditional seaport such as a storage yard (including empties), an information exchange system and a customs facility. A full security program enables uninterrupted movement of containers between the inland port and the other ports. The proximity to New Zealand's manufacturing and warehousing facilities in South Auckland provides shipping lines and shippers the flexibility to tailor their supply chain requirements. Shippers have the ability to drop off and pick up cargo at Wiri instead of trucking it through central Auckland. Once fully operational, the initiative will save an estimated 100,000 truck movements per annum, creating significant community and environmental benefits (Ports of Auckland, 2009).

4.5 MEGAREGIONAL PLANNING

A megaregion is defined as a "network of metropolitan centers and their surrounding areas, connected by existing environmental, economic, cultural, and infrastructure relationships" (Ross et al., 2008) There are 10 known megaregions in the U.S. alone: *The Northeast* (excluding Richmond and Virginia Beach (VA)); *The Great Lakes* (including Minneapolis (MN), Chicago (IL), St. Louis (MO), Indianapolis (IN), Louisville (KY), Cincinnati (OH), Columbus (OH), Cleveland (OH), Detroit (MI), Pittsburgh (PA), Buffalo(NY)), *The Piedmont Atlantic* (excluding Knoxville (TN)); *Florida* (including Jacksonville, FL); *The Gulf Coast* (including coast areas of LA, MS, AL, TX and FL); *The Texas Triangle* (including Dallas-Fort Worth, Houston, San Antonio, Austin); *The Arizona Sun Corridor*; *The Cascadia*; *Northern California;* and *Southern California* (see Figure 7).

The goal of transportation planning at the megaregional level should be to identify the essential transportation links between major cities and to provide an efficient planning scheme which benefits both passenger travel and freight movement. Megaregions account for two-thirds of North America's population (Lang et. al, 2005), 77 % of employment in the United States, 81% of GRP, and 68% of CO_2 emissions (Ross et al., 2008). More than 77% of commodities from megaregions were moved to domestic destinations by truck and only 4-5 percent of commodities were carried by rail (Ross et al., 2008) (Figure 8). In 2005, approximately two-thirds of the total United States international trade took place in the 50 largest metropolitan areas (Puentes, 2008), and this number is expected to increase in the coming years.

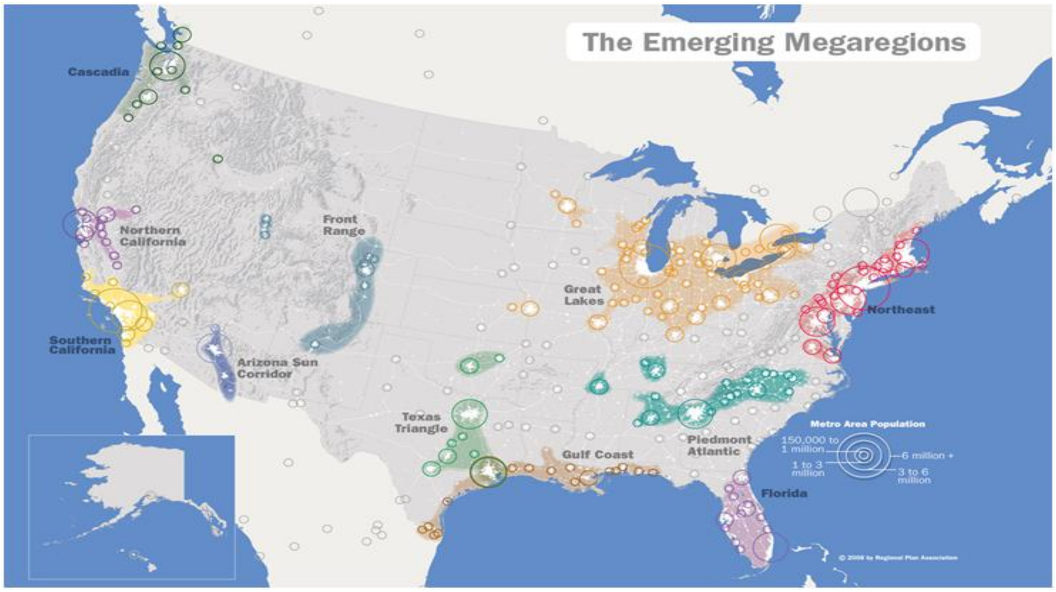
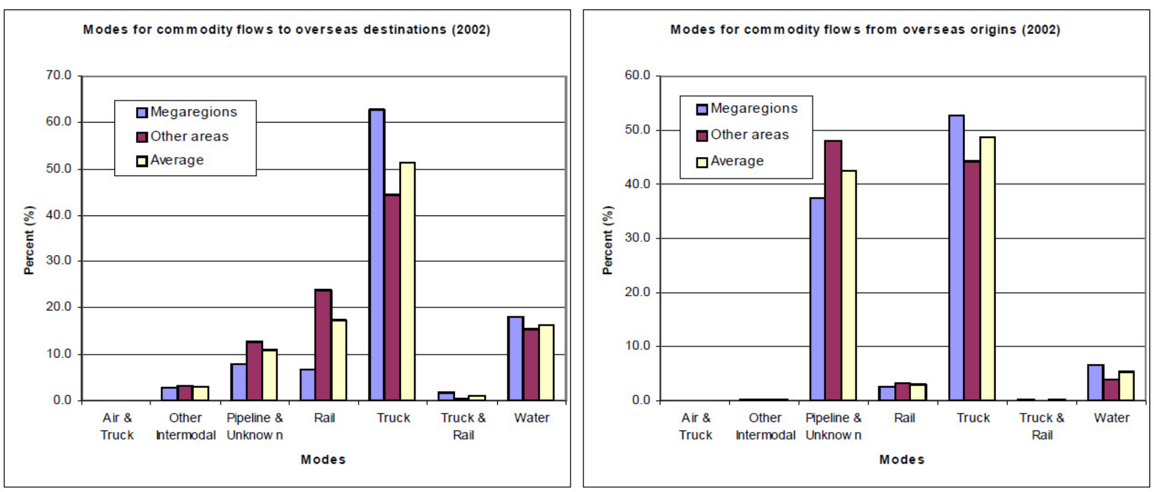


Figure 7: The RPA's Megaregion
Source: http://www.america2050.org/maps/



(a) Exports (b) Imports

Figure 8: Transportation modes for international traded goods
Source: Ross et al., 2008

With sufficient research, strategies like the dry port concept can be employed to assist in mitigating the impact of truck traffic on the national highway system. An example of how the concept can be applied is shown in Figure 9. Cities can have a dry port located at the outskirts and the dry ports interconnected by rail. Commodities destined for other cities would be transported via trucks to the facility, and then transported to the other facilities via rail. The ports can also serve as consolidated delivery facilities to replace the current "peddle-run" system as examined by Kawamura and Lu (2008). This will; however, take strict regulations such as restrictions on truck size and weight, and additional fees for operating large trucks in urban areas (Kawamura and Lu, 2008).

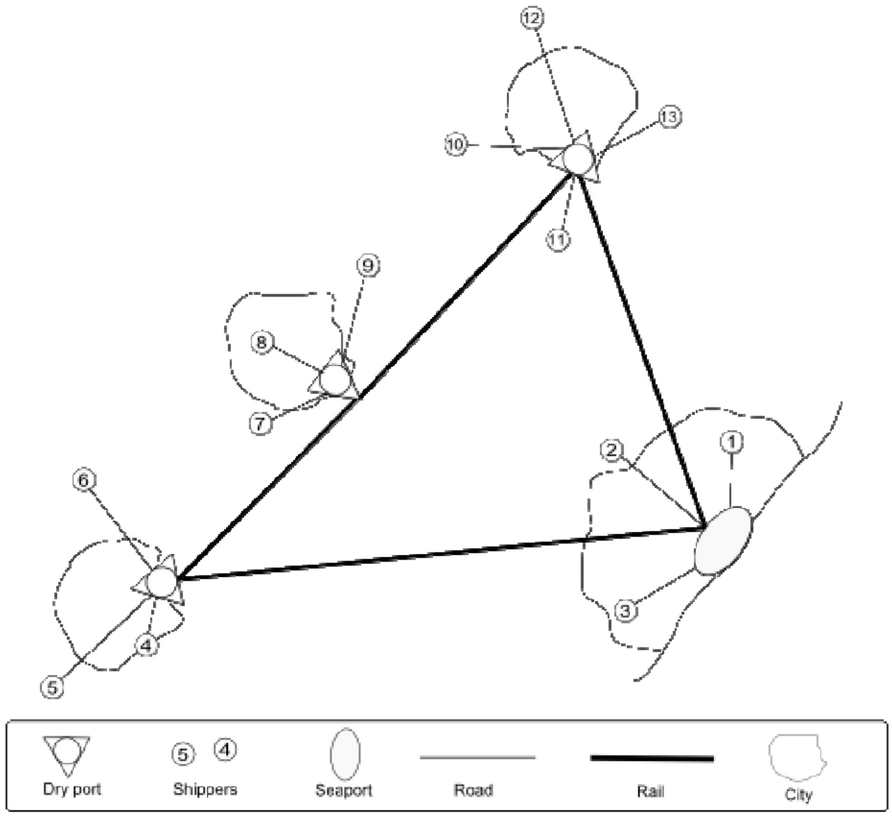


Figure 9: An example of how the dry port concept can be implemented in the Texas Triangle megaregion.

4.6 CHAPTER SUMMARY

Implementing a centralized freight facility is a step in the right direction for the import-export process. Benefits include reduced truck traffic, decreased travel times, decrease in congestion, reduced emissions, reduced fuel use and lower transport cost. However, the challenges associated with implementing the concept cannot be ignored. All the above benefits must be realized, most importantly faster travel times, in order to be able to convince shippers and forwarders that a centralized freight facility does work. Infrastructural and public policy changes will also be necessary to promote the concept. Finally, an implementation of the concept to megaregional planning will be a great improvement to the current freight movement system.

In the next chapter, an intermodal rail costing model is introduced to provide researchers with a tool to assist in further studies of the dry port concept.

Chapter 5: Intermodal Rail Costing Model (IRCM)

5.1 BACKGROUND

Estimating private costs of freight rail service is inherently complex. As stated by Forkenbrock 2001, factors which contribute to its complexity include joint production among rail companies (e.g., sharing trackage or rolling stock), economies of scale and density, and lack of data on specific expenditures pertaining to individual freight movements. The high capital cost required to construct and maintain rail service obscures the ability of outside analysts to determine how much it actually costs the railroad to transport any given shipment. Nevertheless, an understanding and ability to approximate rail line-haul operations is essential in understanding whether innovative developments like the dry port will be cost effective and worth pursuing.

Over the years, economists and government organizations have tried developing models to estimate the internal costs of freight rail services. Many of these models are either too case specific to be used for purposes of comparison or alternatively are too general to be useful. Econometric models such as those listed by Forkenbrock (2001) tend to concentrate on the shape of the cost function and its implications for productivity growth and economies of scale, scope, and density (Bereskin, 2001). A recurring finding of these studies has been that the railroad industry is achieving productivity gains over time and through mergers, and that rail costs are non-linear in nature (Bereskin, 2001 and Forkenbrock, 2001).

While economists such as Bereskin have developed highly-refined econometric models of rail cost that include track capacity, government agencies such as the Surface Transportation Board (STB) are more limited in the types of tools they can use in determining impacts of rail service change or whether rates are in line with variable cost. For two decades, the Surface Transportation Board (STB) has used a model called the Uniform Rail Costing System (URCS). While the model has significant limitations, it is still the official tool used by the STB and as such serves as the first point of reference for this rail operations study. The URCS model can be used for costing specific traffic with less concern for economic characteristics (Bereskin, 2001). URCS is the STB's railroad general purpose costing system that is used to estimate variable and total unit costs for Class I U.S. railroads. URCS uses system average units based on costs relationships and system data for Class I railroads. The data is updated annually by the STB; however, the basic structure of the model remains as it was when it was developed decades ago and does not reflect modern railroad operations. For example, there is no clear way to delineate double-stack intermodal as this technology was not widespread at the time of the model's development. For several reasons, the cost estimation method used by URCS is not entirely accurate. Four primary problems have been identified by researchers. First, the model uses linear "percent variable" equations to allocate expenses to specific operating activities based on a cross-sectional regression of cost data against traffic data for the Class I railroads of the 1980s, using a several-year time series. The equations therefore do not account for recent industry changes (e.g. mergers, increasing size, and traffic carried) which have affected operational costs of railroads (Bereskin, 2001). Furthermore, the linear nature of the model is contrary to the earlier stated finding that rail costs are non-linear in nature.

Secondly, URCS uses system averages based on data collected from Class I railroads. It "uses an accounting-based approach to costing, relying on annual operating expenses and traffic data reported by the railroads. This approach provides cost estimates on the average cost structure of individual railroads or regionalized groups of railroads. Average data on average railroad moves may not, in all cases, be appropriate for estimating a cost for a given railroad movement" (URCS Manual). System averages may not reflect the actual railroad rates charged by carriers, and may not reflect geographical location, technological improvements and system performance (AECOM, 2007). However, URCS gives users the flexibility of substituting cost data developed by the STB with user-generated cost.

The third primary problem with URCS is that it does not account for changes in fuel prices. The model does not have an input for fuel cost which we believe has a major influence in freight rail service rates. Finally, URCS does not have the ability to estimate emissions produced during line-haul operations. This is essential for comparison with other transport modes like trucks and having this ability in a single model makes it easier for researchers to test different scenarios. Recently the STB announced its intention to begin the process of replacing the URCS model due to its well-known limitations. This initiative, taken under chairman-elect Mulvey started with a hearing at the STB on April 30, 2009. Dr Gregory Bereskin, who aided the researchers in the development of this model, provided testimony to the STB.

Another promising rail costing model was the Rail Energy Cost Analysis Package (RECAP II), developed in 1985 by Smith (1985). RECAP II was built around AAR's Train Energy Model (TEM) and was enhanced by the development of a Driver program, a Cost model, and a matrix of data generated by the Track Maintenance Cost Model (Smith, 1985). It was built to assist railroad management in making operating and investment decisions that affect the cost of operation over specific routes. It was; however, written in FORTRAN and was accessible via an outdated DEC 20 computer. Presently, there is no other information available on this model except for the publication by Smith (1985) and an operating manual.

Because of the noted limitations of URCS and RECAP II, the researchers deemed it necessary to develop a transparent line-haul rail operation model to illustrate the contribution of the elements composing rail variable costs, and estimates fuel consumption and emissions in a way that is relevant for determining costs and benefits of dry port implementation. The benefits are derived from the modal shift from road to rail resulting in cost savings, reduced congestion at port cities, and reduced external environmental effects.

5.2 MODEL DESCRIPTION

The core equations governing the rail line-haul model were adapted from previous work by DeSalvo (1969), Hay (1982) and Avallone et al. (2006). DeSalvo (1969) investigated the various productivity relationships, isoquants, and returns to scale for the rail line-haul process. Some of his equations (mainly the resistance equations) have since been modified and published by Hay (1982) and Avallone et al. (2006). Numerous other improvements were made to DeSalvo's model such as estimating the operational differences between TOFC and double-stacked intermodal service, emissions produced during line-haul operations, ability to select multiple locomotives or car types, inclusion of a delay variable, inclusion of rail sidings variables, as well as the ability for users to test the effects of other excluded variables.

The model is mechanistic in nature and is based on factors such as cargo weight, energy consumption, and expert estimates of maintenance and crew labor costs. A deterministic model based on a large amount for data cannot be used as there is insufficient route specific data. URCS falls under this category of operating models and is based on system wide averages which, as mentioned earlier. may not be appropriate for estimating a cost for a given railroad movement. However, a comparison is made between this model and URCS to determine the difference between their estimates.

5.2.1 Cargo Weight, Number of Containers, and Rail Car Configuration

There are more than ten types of rail cars each having its own tare weight, cargo capacity, and load limit. The Intermodal Cost Model allows users to select any of the available rail cars and container types. Below are the equations governing this module.

c_i = *tare weight of rail car*

x_i = *tare weight of container (if intermodal service)*

k_i = *weight of cargo*

The weight of a single car, *w,* is therefore equivalent to

$$w_{c_i} = c_i + x_i + k_i \qquad (1)$$

For an intermodal double-stacked service

$$w_{s_i} = c_i + 2(x_i + k_i) \qquad (2)$$

Given a certain number of cars, N_c, or when simulating an intermodal TOFC service, the total weight of cargo will be

$$W_c = \sum_{i=1}^{N_C} w_{c_i} \qquad (3)$$

For an intermodal double-stacked service, given a certain number of containers, X, the total number of cars will be

$$N_x = \frac{X}{2} \qquad (4)$$

And the total weight of cargo will be

$$W_s = \sum_{i=1}^{N_x} w_{s_i} \qquad (5)$$

5.2.2 Locomotive(s)

The total number of locomotives is dependent on the horsepower of each locomotive and the desired horsepower per trailing ton ratio (HPTT). HPTT is determined by railroads, and varies by route and service type. It dictates the desired maximum speed of the train which in turn influences travel time and fuel consumption. The typical ratios used by Class I railroads varies between 2.5 to 3.5 HPTT for intermodal and less than 2.5 for coal and other heavier cargo. IRCM enables the user to specify the desired ratio and calculates the total HP required.

The total number of locomotives (N_L) is then calculated based on the required HP divided by the specified horsepower of each locomotive (HP_{L_i}).

$$N_L = \frac{HP_{required}}{HP_{L\,i}} \tag{6}$$

Given the weight of a single locomotive as w_{1_i}, the total weight of all the locomotives is equal to the sum

$$W_L = \sum_{i=1}^{N_L} w_{1_i} \tag{7}$$

The total weight of the train, W, can be calculated as

$$W = W_c + W_L \tag{8}$$

for a non-containerized movement or a TOFC service and

$$W = W_s + W_L \tag{9}$$

for a double-stacked service or

$$W = W_c + W_s + W_L \tag{10}$$

for a mix of single and double-stacked containers.[29]

5.2.3 Train in Motion

According to Hay (1982), train movement and speed are opposed by various forces (resistances) which must be overcome by propulsive force (tractive effort) of the locomotive. These forces contribute to the operation of the rail and the overall operating costs (Hay, 1982).

[29] The model gives the user the ability to specify a combination of single and double-stacked containers.

Internal resistance of the locomotive, resistances varying directly at the axle loading (journal friction, rolling resistance, and track resistance), flange resistance, air resistance, and track modulus resistance are always present during train movement. An expression for these resistances was developed empirically and known as the train resistance. Wind resistance, external axle loading resistance, curve resistance, grade resistance, acceleration resistance and inertia (starting) resistance are only present intermittently but are also estimated through empirical relationships (Hay, 1982) . IRCM currently calculates train speed as a function of tractive effort, train resistance, curve resistance and grade resistance.

5.2.3.1 Tractive Effort

Tractive effort is the force required to pull a train. It is determined via the equation

$$F_T = (hp_e - hp_a) \times 375 \times e/V \qquad (11)$$

Where

$TE = tractive\ effort\ in\ pounds$

$hp_e = engine\ shaft\ horsepower$

$hp_a = horsepower\ to\ auxiliaries$

$V = speed\ in\ miles\ per\ hour$

$e = efficiency\ which\ varies\ between\ 0.70\ (AC)\ and\ 0.8 - 0.85\ (DC)\ locomotives$

The most common interpretation (DeSalvo, 1969; Hay, 1982) for equation 11 is below, taking efficiency (e) as 0.82

$$F_T = \frac{308hp}{V} \qquad (12)$$

hp is the manufacturer's rated horsepower, and TE and V are as before (Hay, 1982). IRCM allows the user to input any desired efficiency as it varies greatly for AC and DC locomotives.

5.2.3.2 Train Resistance

Train resistance is modeled using the Basic Davis Equation, the Modified Davis Equation and the Adjusted Davis Equation. The Basic Davis Equation is known to result in resistances higher than the Modified and Adjusted versions but still relevant for calculating drag and flange friction resistance for locomotives.

Using the Basic Davis Equation, the train resistance for one locomotive is

$$R_l = 1.3w_l + 29a_l + bw_lV + cZV^2 \qquad (13)$$

Where

$R_l =$ *train resistance of a single locomotive*

$w_l =$ *weight of a single locomotive*

$a_l =$ *number of axles − locomotives*

$V =$ *train speed*

$Z =$ *locomotive cross − sectional area* $(120\ sq.ft)$

$b =$ *coefficient of flange friction* $(0.03$ *for locomotives*$)$

$c =$ *drag coefficient of air* $(0.0025$ *for locomotives*$)$

The total train resistance for all locomotives is the sum of all locomotive resistances

$$R_L = \sum_{i=1}^{N_L} R_{l_i}$$

$$R_L = 1.3W_L + 29A_L + bW_LV + cN_LZV^2 \qquad (14)$$

Where

$R_L =$ *total train resistance of all locomotives*

$W_L =$ *total weight of all locomotives*

$A_L =$ *total number of axles of all locomotives*

$N_L = number\ of\ locomotives$

Substituting the values of b, c and Z, the resistance function for all the locomotives is

$$R_L = 1.3W_L + 29A_L + 0.03W_L V + 0.3N_L V^2 \qquad (15)$$

Current improvements[30] in railroad operations resulted in the need to adjust the Basic Davis equation especially for rail cars (Hay, 1982). The modified Davis Equation is similar to AAR's equations and is appropriate for relatively high weights of 70 tons or more (RailSIM website, 2007). The modified Davis Equation for a single locomotive car is

$$R_{c_f} = 0.6w_c + 20a_c + 0.01Vw_c + KV^2 \qquad (16)$$

R_{c_f} = resistance of a single freight car

w_c = gross weight of a single freight car

a_c = number of axles of a single freight car

V = speeed in miles per hour

K = air resistance (drag) coefficient with values of 0.07 for conventional equipment, 0.0935 for containers, and 0.1600 for trailers on flatcars.

The total train resistance for all rail cars is

$$R_C = \sum_{i=1}^{N_C} R_{c_i} = 0.6W_C + 20A_C + 0.01VW_C + N_C KV^2 \qquad (17)$$

Where

R_C = total train resistance of all freight cars

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[30] Present improvements include improvement on car trucks, improved wheels, roller bearings, heavier loading per car, improved journal lubricants and lubricators, stiffer subgrades, and stiffer rails (Hay, 1985)

$W_C = total\ weight\ of\ all\ cars$

$A_C = total\ number\ of\ axles\ of\ all\ cars$

$N_L = number\ of\ cars$

The adjusted Davis equation is appropriate for intermodal trains, particularly those with double-stack containers or mixtures of different intermodal car types namely TOFC, single stack COFC, and double-stack COFC (RailSIM website, 2007).

$$R_{adj} = K_{adj}(0.6W_c + 20A_C + 0.01VW_c + KN_C V^2) \qquad (18)$$

Where

$R_{adj} = adjusted\ unit\ train\ resistance$

$R_D = conventional\ Davis\ resistance$

$K = an\ adjustment\ factor\ to\ modernize\ the\ Davis\ equation$

K_{adj} values	
1.00	Pre-1950 equipment
0.85	Conventional post-1950 cars
0.95	Container-on-flatcar
1.05	Trailer-on-flatcar and hopper cars
1.20	Empty, covered auto racks
1.30	Loaded auto racks
1.90	Empty, uncovered auto racks

Total train resistance is therefore equal to

$$F_u = R_L + R_C \qquad (19)$$

$$F_U = 1.3W_L + 29A_L + 0.03W_L V + 0.3N_L V^2 + K_{adj}(0.6W_C + 20A_C + 0.01VW_c + KN_C V^2) \qquad (20)$$

IRCM automatically varies the K and K_{adj} values based on the equipment selected by the user. Other modifications of the Davis equation have been developed for more specific applications all of which apply to the cars trailing locomotives. These equations though not included into IRCM, were developed by Tuthill and the Canadian National Railway (Avallone et al., 2006).

5.2.3.3 Grade Resistance

Grade resistance is taken as 20 lbs/ton per percent of grade. It is derived from a relationship between the angle of ascent (or descent) and gravitational forces acting on the train (Avallone et al., 2006). The number 20 is a result of the conversion from tons to pounds. Grade resistance, train weight, and percentage grade can therefore be expressed as

$$F_g = 20Wg \tag{21}$$

Where

F_g = grade resistance, in pounds

W = total weight of train (locomotive and cars), in tons

g = percentage gradient of terrain

5.2.3.4 Curve Resistance

According to Avallone et al. (2006) the behavior of rail vehicles in curve negotiation is the subject of several ongoing AAR studies. Recent studies indicate that flange and/or gage face lubrication can significantly reduce train resistance on tangent tracks (Avallone et al., 2006). However, for general estimates, for dry (unlubricated) rail with conventional trucks, the following expression is used

$$F_c = 0.8Wc \tag{22}$$

Where

$W = gross\ weight\ of\ train\ in\ tons$

$c = degree\ of\ curvature$

5.2.3.5 Train Cruising Speed

Train cruising speed can therefore be found using the equation of motion

$$F_T - F_u - F_g - F_c = 0 \quad (23)$$

Substituting into the above equation with the earlier defined F_T, F_u, F_g and F_c the equation of motion can be rewritten in the form

$$308hp - \left[1.3W_L + 0.6K_{adj}W_C + (20g + 0.8c)W + 29A_L + 20K_{adj}A_C\right]V - \left[0.03W_L + 0.01K_{adj}\right]V^2 - \left[0.3N_L + K_{adj}KN_C\right]V^3 \quad (24)$$

Solving the equation 24 iteratively, results in the determination of the trains cruising speed, *V*. On the other hand if the train's maximum speed is specified, IRCM varies the horsepower per trailing ton (hptt) ratio in order to calculate the required horsepower needed to power the train at the specified maximum speed. The relationship between maximum speed, hptt ratio, and required horsepower is further discussed in section 6.3.6 on this paper.

5.2.4 Fuel Consumption and Cost

Fuel consumption is calculated as a function of thermal efficiency, HP, and travel time. Thermal efficiency (η) is defined as ratio of work performed to energy consumed, and varies between 25 – 30 percent for a rail diesel engine (DeSalvo, 1969). To relate work and energy, the energy content of a gallon of fuel is assumed to be 138,700 Btu[31], and work defined as the product of horsepower and time is converted to Btu via the formulae 2544 Btu = 1 hp-hr.

$$Work = 1hp - hr = 2545\ Btu \tag{25}$$

$$Energy = 138{,}700\ Btu/gal \tag{26}$$

$$\eta = \frac{Work}{Energy} = \frac{2545\ gal}{138{,}700\ hp-hr} \tag{27}$$

Given a diesel engine with horsepower, HP, let n be equivalent to gallons of fuel consumed per hour.

$$\eta = \frac{2545\ HP}{138{,}700\ n} = 0.0183HP/n \tag{28}$$

The above equation can then be solved as

$$n = 0.0183HP/\eta \tag{29}$$

n is the gallons of fuel consumed per hour by a diesel locomotive with horsepower HP (DeSalvo, 1969). The model allows the user to specify the efficiency of the diesel engine as this varies with the type of locomotive. Current technological innovations have also increased locomotive fuel efficiency so the model allows users to correctly specify efficiencies greater than 30%. Using Table 6 as a guide, the user can adjust the thermal efficiency of the locomotive to the desired fuel consumption (gallons per hour) for a specified locomotive type. Future enhancements of the model will seek to include innovations that have increased fuel efficiency.

To calculate the cost of fuel, the user specifies a price (p) for a gallon of diesel fuel, and the fuel cost per hour (C_{f_h}) can be calculated as

$$C_{f_h} = p * n \tag{30}$$

[31] 138,700 Btu/gallon is the value reported by the Bureau of Transportation Statistics. Btu content of diesel however can vary between 129,500 Btu/gallon and 141,700. DeSalvo used 139,900 Btu/gal. in his analysis.

The total fuel cost per trip may be found by multiplying trip time (in hours) by fuel cost per hour. Trip time (*T*) is calculated by dividing the distance traveled (*D*) by the train cruising speed (*V*).

$$T = \frac{D}{V} \tag{31}$$

Therefore, given trip time (T) the fuel cost for a trip can be calculated as

$$C_F = p * n * T \tag{32}$$

$$C_F = p * \frac{0.0183HP}{\eta} * T \tag{33}$$

Table 6: Locomotive Fuel Use (Gallons per Hour)

Model	**Max Hp**	**Hp/Gal/Hr**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Idle**	**Low Idle**	**Dyn Brk**
SW1000 (8cyl)	1000	16.7	60	50	40	31	22	13	6	5.3	3	-	-
SW1500	1500	16.2	92.6	79.6	62.1	52.5	38.6	25.2	11.5	6.5	3.8	-	-
E7 (2 12cyl)	2000	10.8	186	150	120	92	68	46	30	14	7.2	-	-
E8 (2 12cyl)	2250	12	188	149	118	90	62	45	31	13	7.6	-	-
F/GP7	1500	16.1	93.1	75.3	59.6	45.7	33.3	23.4	14.5	6.5	3.5	-	-
SD/GP9	1750	16.2	108.1	82.2	67.7	51.5	36.8	23.6	13.4	4.4	3.5	-	-
GP15T	1500	18.7	80.4	69.8	53.4	42.2	31.7	23.4	12.6	6.4	1.9	-	10.5
GP30	2250	18	124.9	102.1	75.2	61.1	44.9	31	18.9	7.2	3.5	-	-
SD/GP35	2500	17.4	143.6	124.3	96.2	72.1	51.2	34.9	20.9	11	5	4	-
GP39 (12 cyl)	2300	17.9	128.2	102.6	80.1	58.2	40	26	15.1	6.5	4	-	16
SD/GP38	2000	16.3	122.4	102.8	83.1	63.8	46.8	31.4	16	7	4.6	3.8	15
SD/GP38-2	2000	16.3	122.9	103.2	82.4	64.1	47.5	32.8	17.8	7.8	4.6	3.5	15
SD45 (20cyl)	3600	18.6	194	176	127	92	68	48	28	10	6	4.7	25
Model	**Max Hp**	**Hp/Gal/Hr**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Idle**	**Low Idle**	**Dyn Brk**
SD/GP40	3000	17.9	167.7	145.8	108.5	79	57.2	41.4	24.9	7.4	5.5	4.3	21
SD/GP40-2	3000	18.2	164.4	133	100.2	79.7	60.5	44.1	25.4	9.3	5.2	4.1	18.4
SD/GP50	3600	19.8	181.4	161.7	133.5	85	63.9	46.7	24.2	12.6	3.1	-	9
GP50 (src2)	3600	19.1	188	161	115	87	62	43	28	16	5.2	4.1	26
F59 (12 cyl)	3030	20.1	150.4	118.5	81.9	67.9	52	36.2	19.9	12.2	-	2.6	4.8
SD60	3800	20.6	184.7	157.5	123.2	86.9	64.9	47.8	22.8	12	3.1	-	20.5
SD70MAC	**4000**	**20.8**	**191.9**	**165.1**	**130.4**	**86.2**	**63.8**	**46.7**	**22.3**	**11.7**	**3**	**-**	**22.6**

Table 6 continued: Locomotive Fuel Use (Gallons per Hour)

SD80 (20cyl)	5000	-	-	-	-	-	-	-	-	-	-	-	-
SD9043	4300	-	-	-	-	-	-	-	-	-	-	-	-
SD90H	6000	-	-	-	-	-	-	-	-	-	-	-	-
U23B/C	2350	21	112	92.5	80.6	63.5	47.7	27	17.3	11.9	3.5	-	-
U30B/C	3000	19.4	155	128	98	81	64	46	25	8	4	-	-
U30B/C (src2)	3000	20.1	149	127	102	81	62	34	22	16	5	-	26
Model	**Max Hp**	**Hp/Gal/Hr**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Idle**	**Low Idle**	**Dyn Brk**
B30-7A (12cyl)	3000	20.1	149.5	122.5	96	72	49.7	31.9	17.6	9.1	5	-	26
C30-7	3000	18.4	162.7	135.7	107	80.5	56.5	37	20.2	9.3	5	-	26
U33B/C	3300	20.2	163	138	110	87	65	36	23	16	5	-	26
B39-8	3900	20.7	188	162	130	100	73	48	23	11	3	-	13
C40-8	4000	20.7	193	162	130	100	72	47	23	11	3	2.5	14
C44-9	4400	20.9	210	-	-	-	-	-	-	-	3.6	3.5	-
C60AC	6000	-	-	-	-	-	-	-	-	-	-	-	-

All Models are 16 cylinders unless otherwise noted.
Source: http://www.alkrug.vcn.com/rrfacts/fueluse.htm

5.2.5 Locomotive Emissions

According to the EPA, there are several sets of locomotive emission standards. Each set is dependent on the date a locomotive was first manufactured. The first set of standards, Tier 0, applies to majority of locomotives manufactured before 2001 and the last set of standards, Tier 4, are the most stringent standards for locomotives to be manufactured from 2015 and later (EPA, 2009). IRCM's emission model is based on Tier 0 emission standards because majority of the locomotives currently in use by railroads fall under this category. The user can; however, choose between any of these standards when running the model. It should be noted that the emission rates provided by the EPA are approximations based on simplified assumptions as a single locomotive emission rate varies throughout its life as the engine ages and as ambient conditions change (EPA, 2009).

EPA emissions were estimated for two different types of operation: a low power cycle representing operation in a switch yard, and a higher power cycle representative of general line-haul operation (EPA, 2009). Line-haul emission rates are used in IRCM and future modifications of the model will include switch yard operations.

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.32	0.48	13.00	1.28
TIER 0	0.32	0.48	8.60	1.28
TIER 0+	0.20	0.30	7.20	1.28
TIER 1	0.32	0.47	6.70	1.28
TIER 1+	0.20	0.29	6.70	1.28
TIER2	0.18	0.26	4.95	1.28
TIER 2+ & TIER 3	0.08	0.13	4.95	1.28
TIER 4	0.015	0.04	1.00	1.28
+ INDICATES THAT THESE ARE THE REVISED STANDARDS IN 40 CFR PART 1033				

Figure 10: EPA Locomotive Line-Haul Emission Factors (g/bhp-hr)

Source: EPA, 2009

	PM_{10}	HC	NO_x	CO
UNCONTROLLED	0.44	1.01	17.40	1.83
TIER 0	0.44	1.01	12.60	1.83
TIER 0+	0.23	0.57	10.60	1.83
TIER 1	0.43	1.01	9.90	1.83
TIER 1+	0.23	0.57	9.90	1.83
TIER2	0.19	0.51	7.30	1.83
TIER 2+	0.11	0.26	7.30	1.83
TIER 3	0.08	0.26	4.50	1.83
TIER 4	0.015	0.08	1.00	1.83
+ INDICATES THAT THESE ARE THE REVISED STANDARDS IN 40 CFR PART 1033				

Figure 11: EPA Locomotive Switch Emission Factors (g/bhp-hr)

Source: EPA, 2009

The EPA provides conversion factors which relate fuel consumption (gal/hr) to usable power (bhp) of the locomotive engine. The difference is conversion factors can be traced to the locomotive age and duty cycle which tend to predict different emission rates for older locomotives and locomotives used for switching operations.

Locomotive Application	Conversion Factor (bhp-hr/gal)
Large Line-Haul and Passenger	20.8
Small Line-Haul	18.2
Switching	15.2

Figure 12: EPA Conversion Factors (bhp-hr/gal)
Source: EPA, 2009

Volatile organic compounds (VOC) are assumed to be equal to 1.053 times the HC emissions (EPA, 2009). Based on this assumption, it was possible to include VOC estimates in the model. Pollutants not included in the emission tables and the model include sulfur dioxide (SO_2) and carbon dioxide (CO_2) which are largely independent of engine parameters and primarily dependent on fuel properties (EPA, 2009).

5.2.6 Crew Labor Cost

The model assumes a fixed daily labor rate. Previous authors have used formulas to calculate crew wages based on distance traveled. This approach though appropriate may not necessarily be accurate as different railroads have different rates and formulas when determining crew wages. An adjustable fixed daily rate is therefore used so users can input actual known crew wages. The number of crew members is then multiplied by the specified daily rate to determine crew labor cost.

Salary.com estimates the U.S. national average annual salary (including benefits) for locomotive engineers as of September 2009 is approximately $85,462. Assuming 260 annual work days, the cost per 8-hour work shift can be estimated to be $328.70 a day and a figure of $330.00 per 8-hour work shift per day is used in this study.

5.2.7 Maintenance Cost

Track maintenance cost is determined by multiplying a known per-mile system average rate (c_{m_T}) by the number of cars and locomotives in operation since track maintenance costs can be associated with the amount of traffic on a particular road. Car maintenance cost is specified by the user on a per-mile (c_{m_C}) basis multiplied by the number of cars in operation. Locomotive maintenance cost is also specified by the user on a per mile value (c_{m_L}) basis, and multiplied by the number of locomotives in operation.

$$C_{M_T} = (N_C + N_L) * c_{m_T} \quad (33)$$

$$C_{M_C} = N_C * c_{m_C} \quad (34)$$

$$C_{M_L} = N_L * c_{m_L} \quad (35)$$

Total maintenance cost is calculated as

$$C_M = C_{M_T} + C_{M_C} + C_{M_L} \quad (36)$$

Where

$C_{M_T} = Total\ track\ maintenance\ cost$

$C_{M_C} = Total\ car\ maintenance\ cost$

$C_{M_L} = Total\ locomotive\ maintenance\ cost$

5.2.8 Capital Cost

Capital and investment cost are the most difficult to model. Railway capital costs include large investments in the construction of rail tracks, structures, rail yards, signals, and car and locomotive purchases. Without sufficient and reliable data, modeling investment cost associated with rail tracks, structures, rail yards and signals is almost impossible. IRCM therefore only accounts for investment costs associated with locomotive and car purchase. These are known as the locomotive ownership cost and the car ownership cost. Using the straight-line depreciation equation, depreciation charge per hour is determined and multiplied by the total trip time.

$$Hourly\ Depreciation = \frac{Cost\ of\ Asset - Scrap\ Value}{Life\ Span\ (years) \times 8760\frac{hrs}{years}} \times Trip\ Time\ (hrs) \times N \qquad (37)$$

Where

N = number of locomotives when calculating hourly depreciation of locomotives

N = number of cars when calculating hourly depreciation of cars

Unit Costs VERSUS Traffic Volume

As noted by Hay (1982), railroads incur continuing capital and maintenance costs regardless of whether equipment is used or not. These fixed or continuing costs are referred to as overhead costs. Overhead costs and direct costs are distributed over the volume of traffic handled. The greater the rail traffic, the lower the share of fixed cost borne by a single unit of traffic. This concept is illustrated in Figure 13 by Hay (1982). Unit cost decreases from point A to B as traffic volume increases. As volume increase keeps increasing from B to C, unit cost begins to increase again as congestion, delays and maintenance cost begin to build up. When additional capacity is provided at point D, unit cost begins to reduce again to point E (Hay, 1982). The graph also illustrates incremental costs as any increase in traffic x (e.g. x+1) results in decrease in unit cost y (i.e. y-y').

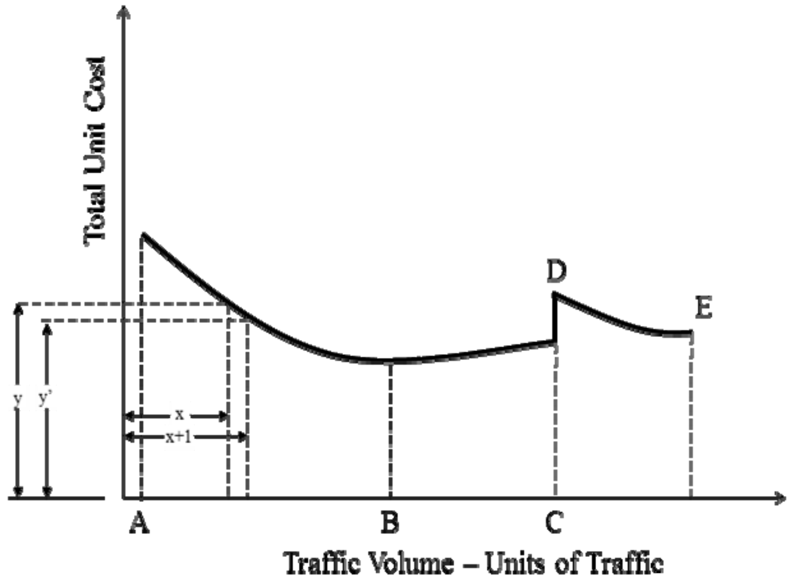


Figure 13: Illustration of Unit Cost versus Traffic Volume
Source: Hay, 1982

5.3 MODEL LIMITATIONS

The Intermodal Rail Costing Model is limited to line-haul movement operation and therefore does not account for terminal operations which include arrival operations, inspection operations, classification operations, assembly and disassembly operations, and the labor involved in the above operations. Terminal operations are a substantial part of railroad operations and the cost involved in running terminal operations cannot be ignored in railroad cost analysis. However, for purposes of this research, we assume that terminal operations and costs are the same for all origins and destinations, and the primary concern is to determine how cargo weight, number of cars, type of loading (TOFC or double-stack), rail track, car and locomotive maintenance, distance, travel time, delays, and capital investments influence line-haul movement operation costs. Also of significant interest is how varying fuel costs influence the rail industry. Loading and unloading operational costs are included to account for economies of scale in line-haul operations.

Capital investments such as road construction, right-of-way acquisition, grading, signal and interlock installation, stations and office buildings, and all other infrastructural investment costs are not included. These costs do have a significant influence in the overall rail operation costs but are ignored because of lack of sufficient supporting data and variability amongst the various rail companies. Other expenses ignored include equipment rentals, purchased services, and other indirect expenses (AECOM, 2007). Because this paper focuses on comparing rail corridors, it can be assumed that expenses are the same for all rail companies.

Excluding operational costs to the line-haul portion of the rail service might result in an underestimation of overall costs in certain cases.

Other operational limitations include an assumption of average speed. Resistance to motion affected by changes in grade, curvature, and wind resistance are not accounted for as these are route specific and beyond the scope of this current research. According to rail experts, trains are operated at full throttle whenever possible and acceleration and deceleration calculations are omitted because of relative insignificance in comparison to the entire trip. However, research work has been done over the years to calculate the time lost during acceleration and deceleration (DeSalvo, 1969). Traffic delay, on the other hand, can be specified by the user via a delay variable since the exact number of starts and stops during a trip is very route-specific and beyond the scope of this current research.

Concerning fuel consumption, the model assumes the train is running at full throttle. So for a SD70MAC, 4000hp locomotive running full throttle, the maximum gallons per hour consumed is 191.0[32]. When idling, locomotives consume 3-7 gallons of fuel each hour,[33] a small figure in comparison with running at full throttle. Locomotive idling is therefore ignored in this model except when calculating fuel consumption when a train stops at a siding. The model also assumes all the locomotives are identical and of the same horsepower. This might not necessarily be the case as railroad companies may use different locomotives with different horsepower to optimize fuel consumption or enhance tractive effort. An additional module is however included in the model to allow the user to specify another type of locomotive of different horsepower. Future enhancement of the model should enable users to choose multiple locomotives of varying horsepower.

Finally, there is insufficient data from the rail companies to enable modelers to adequately estimate capital, maintenance and administrative cost associated with each trip, thereby making the determination of actual prices almost impossible. Railroads are reluctant in sharing such data due to the competitive nature of the business. Depending on the commodity

[32] http://www.alkrug.vcn.com/rrfacts/fueluse.htm
[33] http://www.kimhotstart.com/68/

type, railroad monopoly, and the route being used, railroad companies have additional charges such as switch charges, hazmat, and other charges not currently captured in the model. In addition, railroads install and maintain traffic signals, construct sidings, develop double tracks and spend on other capital investments which cannot be captured by this model. Based on all these limitations, it is advised that IRCM be used only for rail cost comparison purposes only and not for determining railroad rates.

5.4 CHAPTER SUMMARY

Chapter five presented the Intermodal Rail Cost Model. This model seeks to replace the currently outdated Uniform Rail Costing Model and to provide a tool for policymakers and freight transport stakeholders to perform different freight movement analysis involving rail. The model is based on a simulation of the horsepower required to move a ton of cargo at a specified speed over a certain distance. The calculated horsepower is used in determining the fuel consumed which is translated into fuel cost and emissions generated. Maintenance costs are assumed to be fixed costs calculated based on the number of locomotives and rail cars used, and the distance traveled. Crew wages are also calculated as a daily rate determined by the travel time, and capital costs are determined on an hourly rate. The model also provides the capability for user-specified inputs. Despite its capabilities, the current state of the model limits the types of analysis that can be performed. These limitations, though numerous, can be addressed in future versions of the model. Upcoming versions of the model will seek to enhance the simulation of train movements, and provide the ability to capture the effects of traffic volume on unit cost. In the meantime, IRCM was tested, calibrated and compared with currently-available rail costing models, and the results presented in the next chapter.

Chapter 6: Model Validation and Calibration

Despite its stated limitations, STB's Uniform Rail Costing System was used a point of reference to validate results obtained from IRCM. URCS is currently the only publicly available rail costing model and the primary model "used by the STB for a variety of statutory and non-statutory functions" (STB Website, 2009). Other econometric models have been developed by researchers over the years but most are "intended to measure changes in rail productivity over time, as well as estimate the effects of mergers" (Forkenbrock, 2001). Others are also either difficult to replicate or were developed for specific geographic regions or specific rail traffic.

In addition to URCS, results from the IRCM were submitted to rail industry experts for verification and comments. Dr. Bereskin also performed several runs with his model and the results were then compared with the IRCM output. It should be noted that IRCM is designed to produce cost differentials between alternative modal strategies and it is not designed to produce actual rail prices. Most models – for ships, barges, trucks and rail—behave in this fashion as there are always items related to total costs (like terminal operational costs) that are too difficult to capture. However, the research team is confident that the comparisons that follow, adequately predict the influences of fuel cost, trip length, number of containers, and utilization ratio on overall line-haul operational costs.

6.1 MODEL COMPARISON WITH URCS

The following scenarios were modeled in URCS and compared with results from IRCM.

1. Change in distance traveled
2. Change in number of cars
3. Change in tons per car
4. Intermodal Double-stacking

Table 7: URCS Train Input Data

Freight Car Type	TOFC Flat
Number of Trailers per Flat Car	1
Intermodal Plan Code	1.0 [34]
Empty Loaded Ratio of Trailer	1.0
Line-haul Mile per Trailer Day	400
Empty Loaded Ratio	1.0 (no empty return mileage)
General Overhead Ratio	1.0
Tare Weight of Car	60 tons
Circuitry	1.0
Commodity	Household Appliances
Freight Car Ownership	Private
Type of Train	Unit

In addition to the above inputs, updated URCS 2007 data was used which contains STB approved 2007 cost of capital and was updated on November, 6th, 2008. Jurisdictional add-on charges were also excluded

[34] The railroad provides line haul service between intermodal terminals (ramp to ramp service). This plan excludes trailer costs and pickup and delivery service costs.)

Table 8: Assumptions used in IRCM

Price of Fuel per Gallon (2007 average values)	**$2.18**
Gallons consumed per hr per locomotive	183 gallons per hour (SD60 and SD70 MACs)
Track Maintenance	0.50 $per car/locomotive mile
Car Maintenance	0.12 $/mile
Locomotive Maintenance	2.10 $/mile
Average Daily Crew Wages	$330.00/day
Number of Crew Members	2.0
Average Horsepower Per Trailing Ton ratio	2.0

For each scenario, two kinds of railroads were tested: East and West railroads. East railroads comprise of railroads whose operations are usually in the eastern belt of the United States. Examples include Canadian National Railway (CN), CSX Transportation and Norfolk Southern (NS). West railroads, as the name implies, usually operate in the West belt of the United States. These included Burlington Northern Santa Fe (BNFS), Canadian Pacific (CP), Kansas City Southern (KCS), and Union Pacific (UP) railroads. The major difference between the East and West railroads can be attributed to disparities in fuel prices, wages, distance traveled, amount of commodities hauled and other factors which result in dissimilarities in operating costs and revenue generated.

6.1.1 Varying Distance

The first scenario that was tested involved varying the distances traveled and measuring how the models compared with each other when calculating total variable cost. The inputs below were used:

No. of Cars: 50
Tons per car: 20
Maximum Speed: 60mph

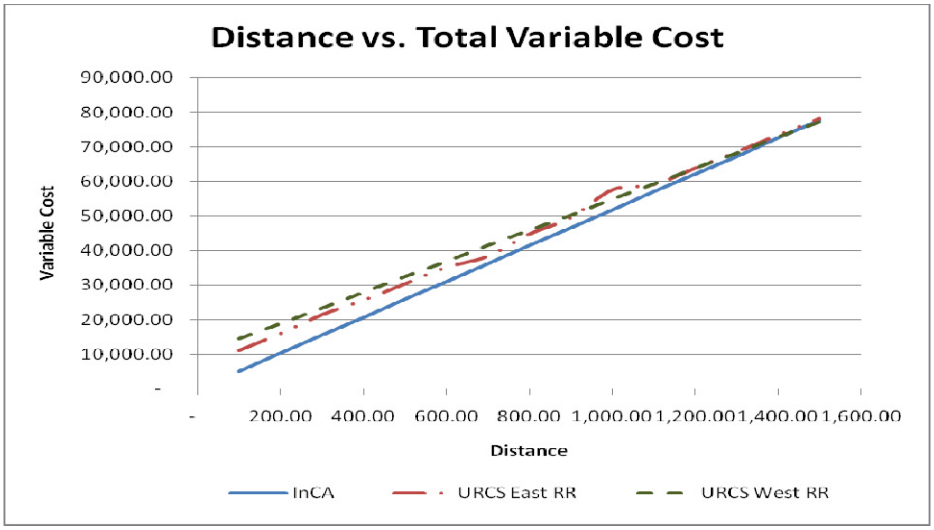


Figure 14: Distance and Total Variable Cost

The graphs seem to converge at distances greater than 1600 miles because the rate of change per 100 miles of variable cost is greater for the IRCM model than that of the URCS. This greater rate of change can be attributed to "fixed" maintenance costs specified in IRCM and calculated on a per-mile basis. As shown in the diagram below, the cost associated with maintenance is usually much greater than other operating costs, thus the reasoning stated above. Maintenance cost calculation for URCS is not known and it is almost impossible to determine how the various cost components influence the overall line-haul cost.

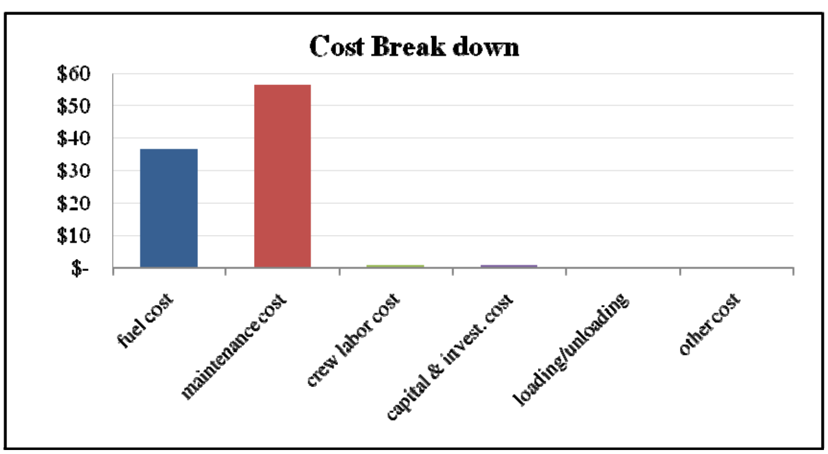


Figure 15: Sample Cost Breakdown Chart

6.1.2 Varying Number of Cars

The second trial involved varying the number of cars for both models. The following items were used in the modeling process and the results presented below.

Tons per car 20
Distance: 1000 miles
Railroad: East
Maximum Speed: 60 mph

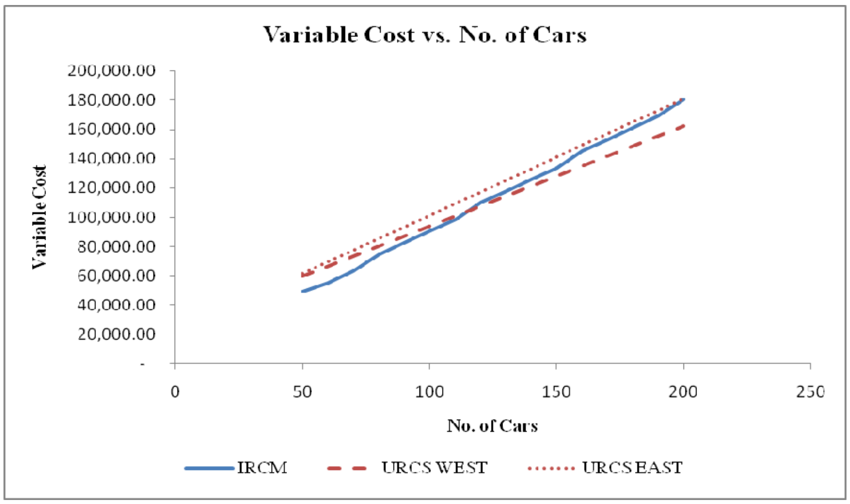


Figure 16: Comparison with URCS: Variable Cost vs. No. of Cars

URCS uses system averages and does not update the associated cost when an additional locomotive is required to meet the desired horsepower. IRCM on the other hand has the capability of determining the number of locomotives needed for each additional railcar, and calculates the associated costs. Despite the differences in calculations, it can be said that both models provide similar results as illustrated in Figure 16.

6.1.3 Varying Cargo Weight

The third trial involved varying the shipment weight as this is another common input for models. The results of this trial are presented below.

No. of Cars: 50
Distance: 1000 miles
Railroad: East
Max Speed: 60mph

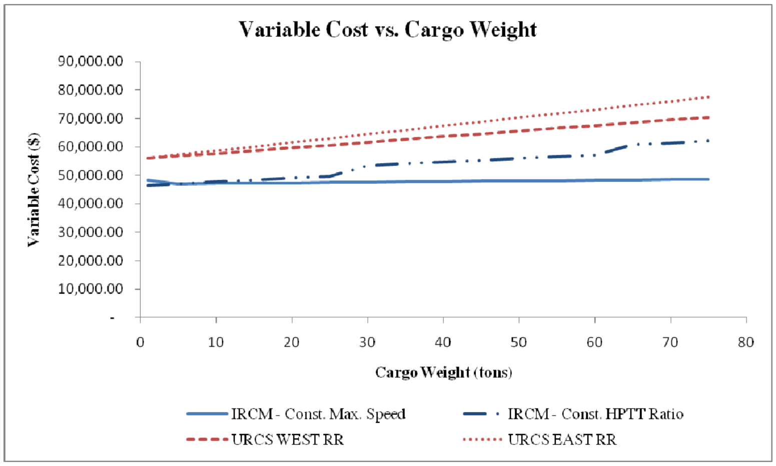
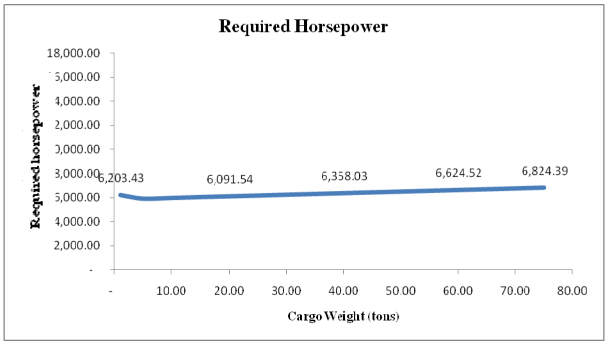
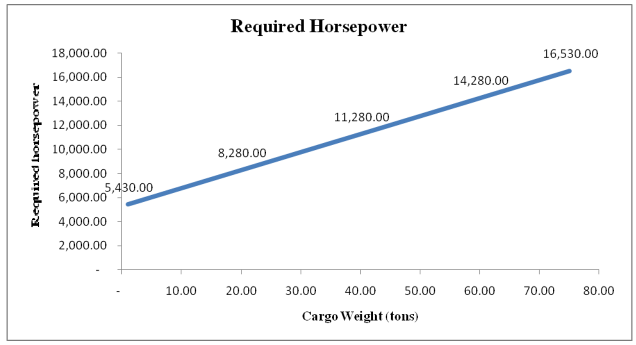


Figure 17: Comparison with URCS: Variable Cost vs. Cargo Weight

From Figure 17, it can be inferred that when the maximum speed constraint is set for IRCM, the change in costs associated with cargo weight is almost insignificant when compared with URCS. Since the speed is held constant, the HPTT ratio of the train decreases with increasing cargo weight. The result is a slight increase in the required horsepower needed to power the train even when cargo weight increases. It should be noted that the number of cars and car maintenance cost is constant he only component influencing cost is fuel price. Because the change in required horsepower is almost insignificant, change in fuel consumption is also insignificant, thus the minimum change in variable cost (see Figure 18 (a)). However, when the maximum speed constraint is relaxed and HPTT ratio is held constant, the required horsepower also increases, and so does fuel consumption and number of required locomotives; resulting in an increase in variable cost (see Figure 18 (b)).



(a) *The maximum speed constraint results in an almost insignificant change in required horsepower, resulting in minor changes in fuel consumption with increasing cargo weight and almost insignificant changes in variable cost.*



(b) *Setting the HPTT ratio constant results in considerable increases in required horsepower, resulting in significant changes in fuel consumption, and subsequently significant increases in variable cost.*

Figure 18: Comparison with URCS: Examining the influence of the maximum speed constraint

Further investigation of the IRCM maximum speed constraint is discussed in section 6.3.6 of this paper. URCS, on the other hand, uses system averages which remain constant no matter the cargo weight. What influences variable cost increases is currently unknown but can be attributed to some constant system average.

6.2 COMPARISON WITH BERESKIN'S MODEL

In addition to URCS, Dr. Bereskin offered to run a small number of scenarios with his econometric model. Below are the scenarios and results compared with IRCM and URCS.

6.2.1 Double-stack container train to simulate WEST railroad:

Container: 23.50 tons
Tare weight of 40ft container: 4 tons
Tare weight of well: 17 tons
Configuration: Double-stack
Gross weight of one well: 72.00 tons
Number of wells: 140
Number of containers: 280
Fuel Price: $1.80 a gallon
Maximum Speed: 60mph
Utilization ratio: 100%
Distance: 1466 miles
Empty Return Ratio: 50%
Track maintenance: $0.50 $ per car, per locomotive mile
Car maintenance $0.12 $/mile
Locomotive maintenance $2.10 $/mile

Dr. Bereskin used inputs provided by CTR and TTI to provide an estimate of rail line-haul cost using his own proprietary econometric model. Bereskin used a percent empty return ratio of 50% and estimated 2005 traffic levels with 2008 preliminary prices. The empty return ratio reflects the empty return mileage where 0% represents no empty return and 100% (2.0 in URCS) implies a 100% empty return of the freight car. Both URCS and IRCM do not have this feature so two estimates were done for each of these models. URCS 2007 data was also used for the analysis. Using these assumptions and the URCS model, the following estimates were derived:

Table 9: Comparison with Bereskin's Model: WEST Railroad

Cost	**IRCM**	**URCS**	**Bereskin**
Total Cost **(Variable or Average Cost)**	$354,938	$264,600	$231.959
Breakdown			
100% full	$178,459	$151,135	N/A
50% empty return	$176,479	$113,465	N/A

6.2.2 Double-stack container train to simulate EAST railroad:

Other inputs are same as above

Number of wells: 90
Number of containers: 180
Fuel Price: $2.00 a gallon
Speed: Varies
Utilization ratio: 100%
Distance: 1015 miles

Table 10: Comparison with Bereskin's Model: EAST Railroad

Cost	IRCM	URCS	Bereskin
Total Cost (Variable or Average Cost)	$164,257	$145,292	$112,286
Breakdown			
100% full	$82,618	84,050.34	N/A
50% empty return	$81,639	61,242.02	N/A

From the above analysis, IRCM cannot be said to be 100% accurate in predicting line-haul cost. However, the above estimates give some confidence to use the model in predicting the influence of fuel cost, trip length, number of containers, and utilization ratio on overall line-haul operational cost.

6.3 Examining Other Cost Components

To continue validating and calibrating the model, different components of the model were tested to determine how each of them influences line-haul costs. Some of the components tested include fuel price, distance traveled, utilization ratio, cargo weight, and number of cars. Changes in ton-mile cost, TEU cost, and percentage of fuel cost amongst other items were measured, and the results shown in the graphs below. The following inputs were held constant throughout all the tests performed:

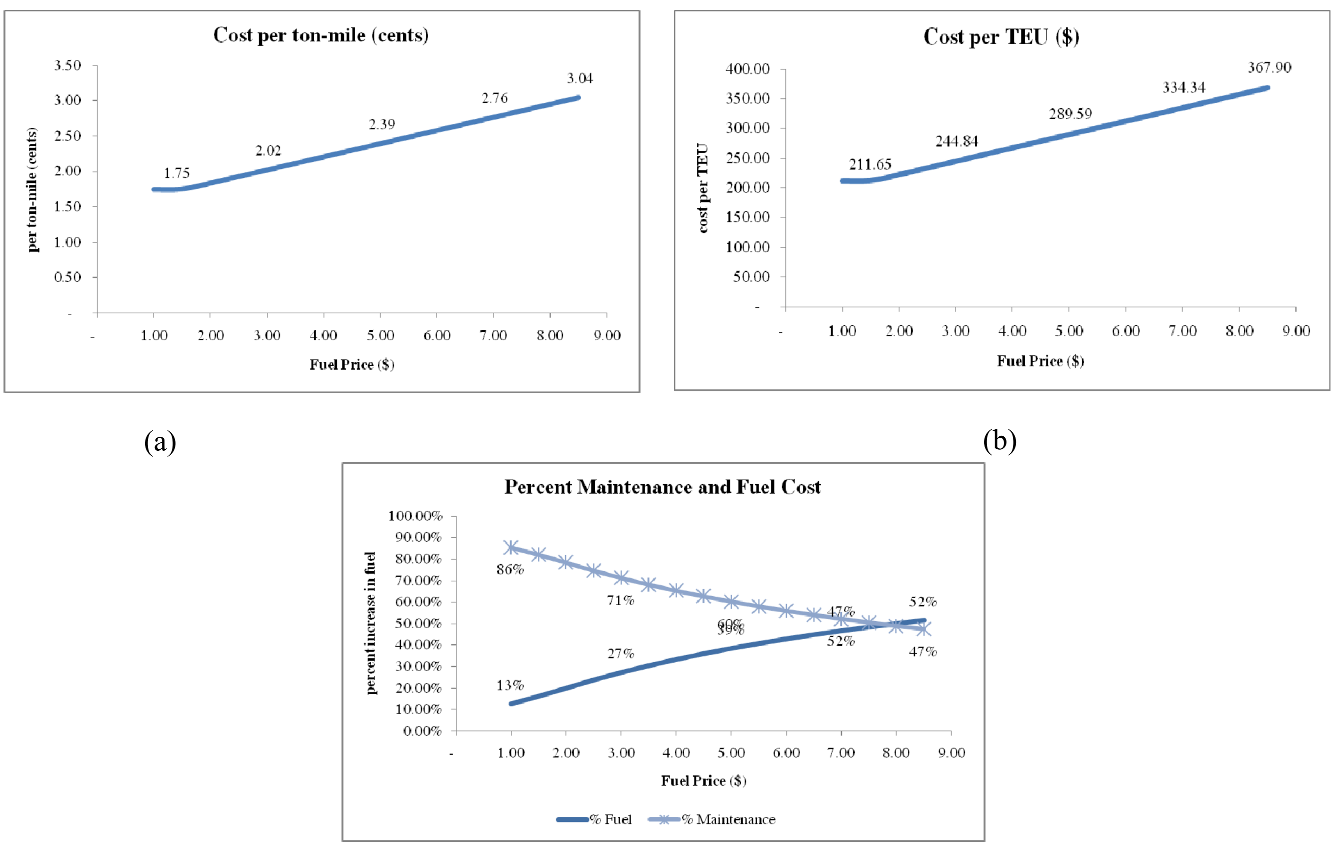
Track maintenance: $0.50 per car, per locomotive mile
Car maintenance: $0.12/mile
Locomotive maintenance: $2.10/mile
Tare weight of 40ft container: 4.2 tons
Tare weight of well: 17.60 tons
Cargo Weight: 20t tons
Configuration: Double-stacked

6.3.1 Varying Fuel Price

The inputs below were used and fuel price was varied from $1.00 a gallon to $8.50 a gallon in 50-cent increments.

Number of containers: 200
Fuel Price: Varied
Max Speed: 60mph
Utilization ratio: 100%
Distance: 1000 miles
Locomotive HP: 4,000 HP
Loading and Unloading Cost per container: $0.00

Model Output:



(a) (b)

(c)

Figure 19: Effect of increasing fuel price on variable cost

As shown in Figure 19 (a) and (b), the relationship between costs and fuel price is a linear one with costs increasing as fuel price increases. Figure 19 (c) demonstrates how the percentage of fuel in relation to other costs also increases with increasing prices. The rate of change for costs; however, is dependent on all the other fixed cost components like maintenance costs and crew wages.

6.3.2 Varying Trip Length

Trip length was varied from 100 to 1,600 miles at 100-mile increments. This analysis was performed to determine the influence of trip length on rail line-haul costs. A loading and unloading cost of $50.00 a container was included in the analysis to demonstrate economies of scale.

Number of containers: 200	Starting HPTT ratio: 2.5
Fuel Price: $2.50	Configuration: Double-stacked
Max Speed: 60 mph	Locomotive HP: 4,000 HP
Utilization ratio: 100%	Loading and Unloading Cost per container: $50.00

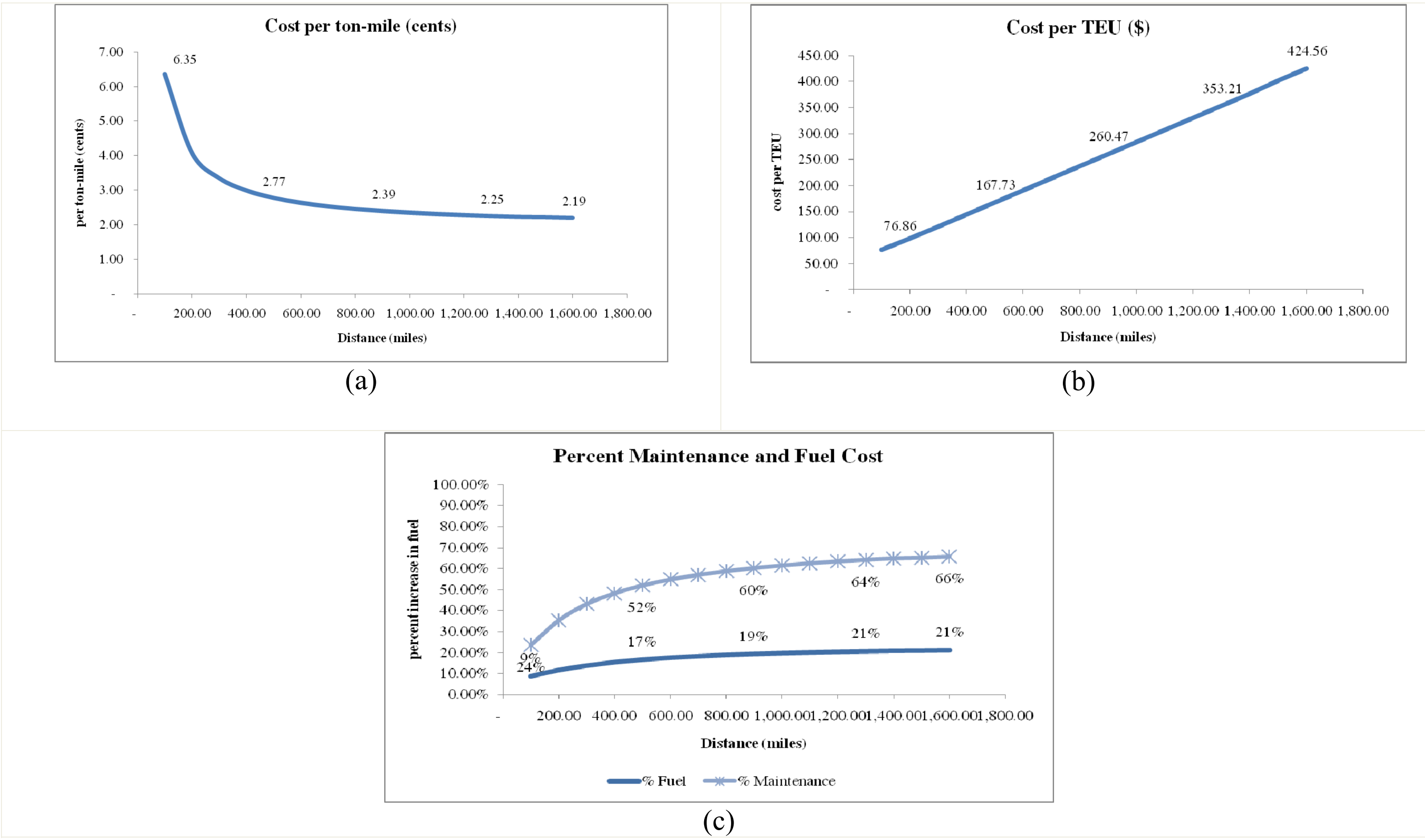


Figure 20: Effect of increasing distance on variable cost

Because of the loading and unloading cost input, the economies of scale attributed to railway distances is shown in Figure 20 (a) and (b). After 500 miles, line-haul costs begin to stabilize and this is the reason why rail is said to be more efficient for long distances compared to trucking. Fuel cost and maintenance cost also increase with increasing distance (Figure 20 (c)). Other components like required HP, train weight and number of locomotives remain constant.

Horsepower, Distance and Ton-mile Costs

By reducing the horsepower of the train,[35] cruising speed decreases and travel time increases. However, instead of an expected increase in ton-mile cost because of increased travel time, the opposite rather happens; ton-mile cost rather decreases. This happens because by decreasing the HPTT ratio, fuel consumption is reduced. Since fuel consumption is such a high percentage of operating cost in comparison to time dependent cost like crew wages, ton-mile cost will rather

[35] This is done by decreasing the HPTT ratio.

decrease than increase. Vice versa when HPTT ratio is increased, cruising speed increases and fuel consumption increases, thereby resulting in an increase in ton-mile cost (see Figure 21). What this means is that it might not be cost-effective to run trains at higher speeds as this will required more horsepower. Simulating this feature is not possible with URCS as there is no input for speed.

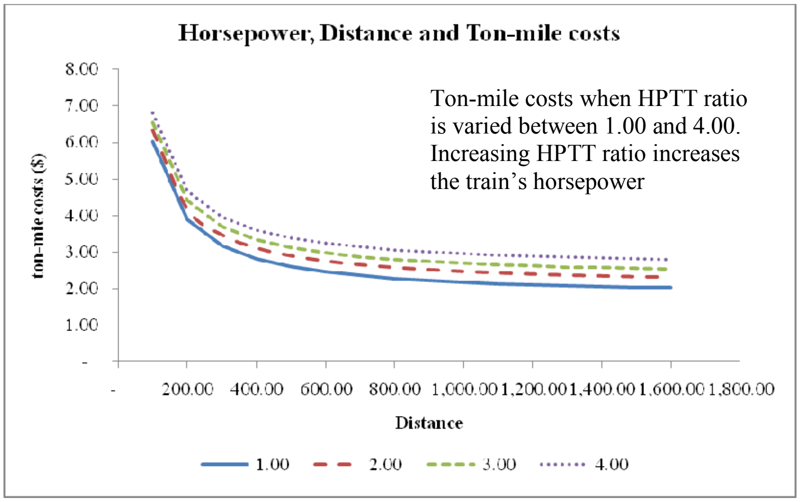


Figure 21: Horsepower, distance and ton-mile costs.

6.3.3 Utilization Ratio

Utilization ratio is the percentage of full to empty containers. Railroads are known to sometimes transport empties and this input enables users to simulate a train with a certain number of full containers. The following additional inputs were used.

Number of containers: 200	Max Speed: 60mph
Fuel Price: $2.50	Locomotive HP: 4,000 HP
Distance: 1000 miles	Loading and Unloading Cost per container: $0.00

As demonstrated in Figure 22 (a) and (b), it is cheaper and more cost-effective to transport full containers than empties. Figure 22 (c) also reveals how the required horsepower needed to power the train is dependent on the number of full containers (cargo weight). The number of locomotives Figure 22 (d) remains the same, independent of the train weight, as this is the number needed to power the train at 60 mph. Maintenance and fuel costs also do not change much as these are independent of whether the train is empty or full, as the number of cars being pulled does not change.

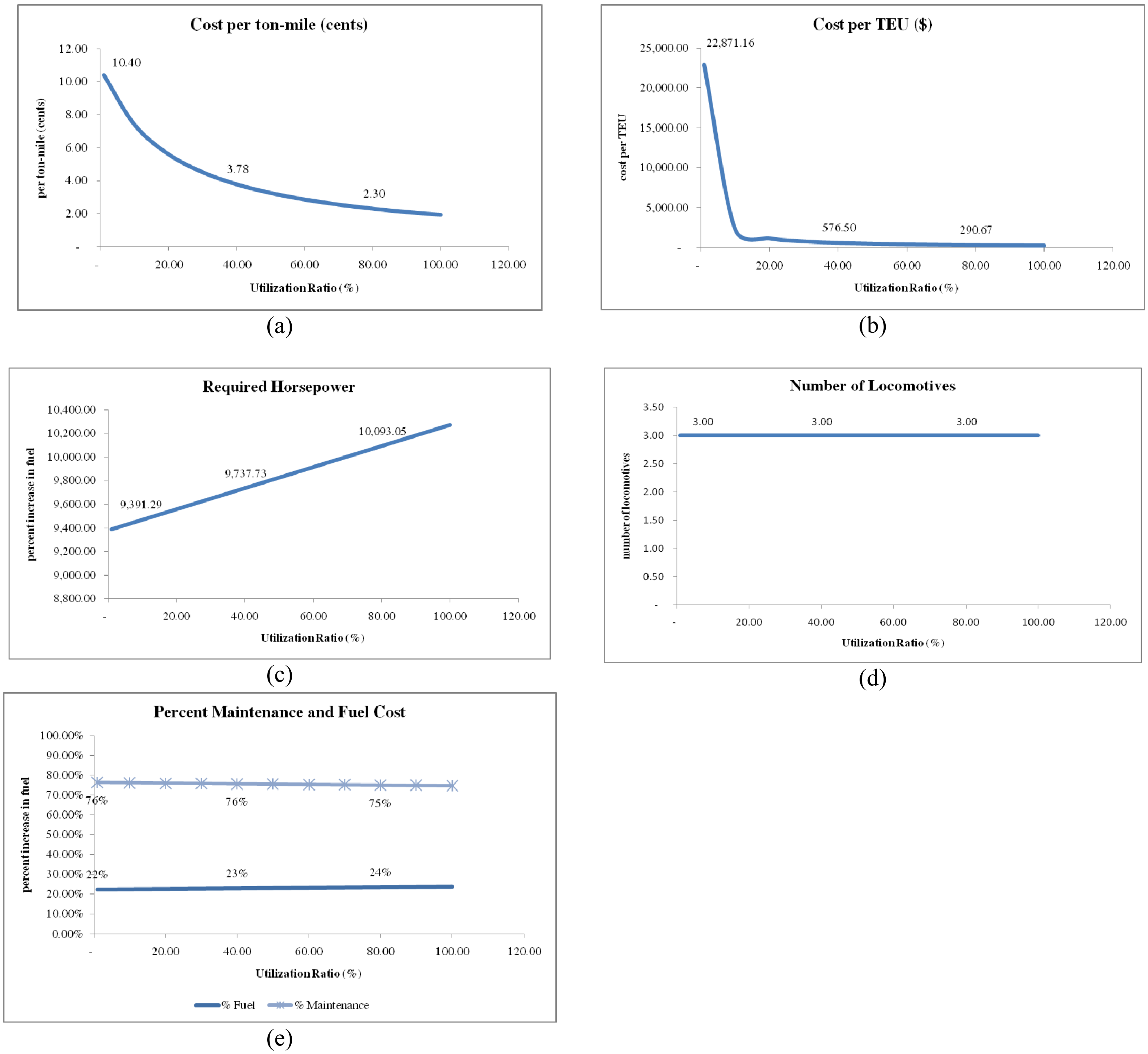


Figure 22: Utilization Ratio Analysis

6.3.4 Cargo Weight

The cargo weight of each car is a determinant of the overall weight of the train. The overall weight of the train determines the horsepower required to power the train at a given speed. Cargo weight was varied from 0 to 150 tons, in 10-ton increments, to simulate how cargo weight influences the various components of line-haul operation and associated costs. The containers are double-stacked so for each ton of increased cargo weight, the weight on a well[36] is increased by two.

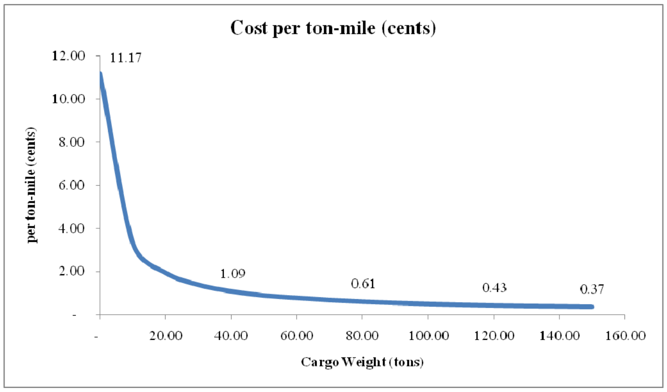
Number of containers: 200	Distance: 1000 miles
Configuration: Double-stacked	Max Speed: 60mph
Fuel Price: $2.50	Locomotive HP: 4,000 HP

Figure 23 (a) and (b) demonstrates how line-haul costs decrease with increasing cargo weight. This is a result of economies of scale whereby it is cheaper to move more tonnage over longer distances. Fuel cost; however, increases because of the need for additional horsepower and locomotives (Figure 23 (c), (d) and (e))

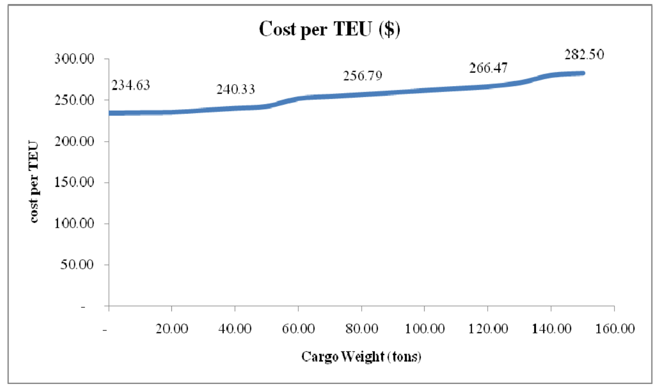
6.3.5 Number of Containers and Cars

Cargo weight and number of containers have similar impacts as both determine the overall train weight. Just like the simulation for cargo weight, varying the number of containers determines the horsepower required to power the train at a given speed. The number of containers was varied from 50 to 200 in increments of 10. Since the containers are double-stacked, for each two containers added, the number of cars increases by one. Therefore, this analysis can also be used to determine how increasing the number of cars influences line-haul operational costs.

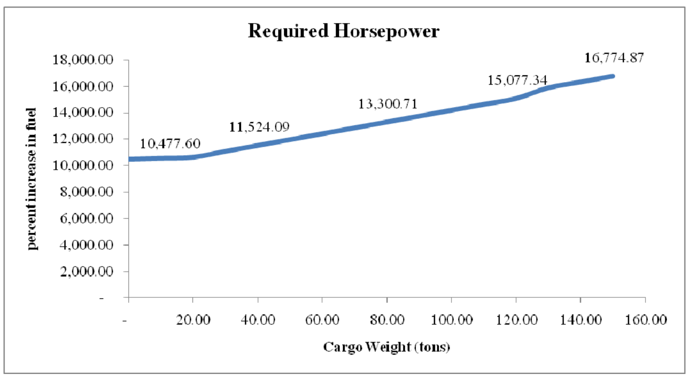
[36] Intermodal rail cars are made of 2, 3 or 5 articulated wells. Each well is capable of carrying at least a single container or double-stacked containers



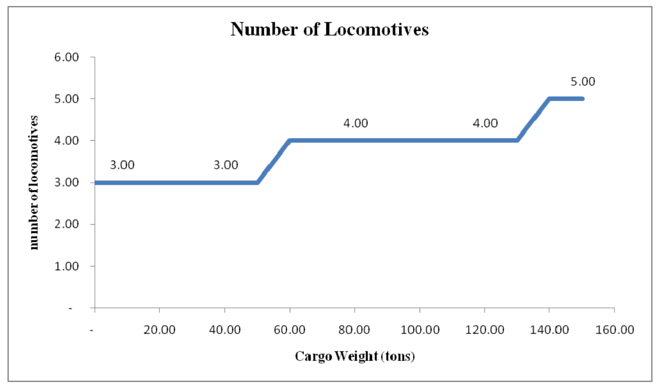
(a)



(b)



(c)



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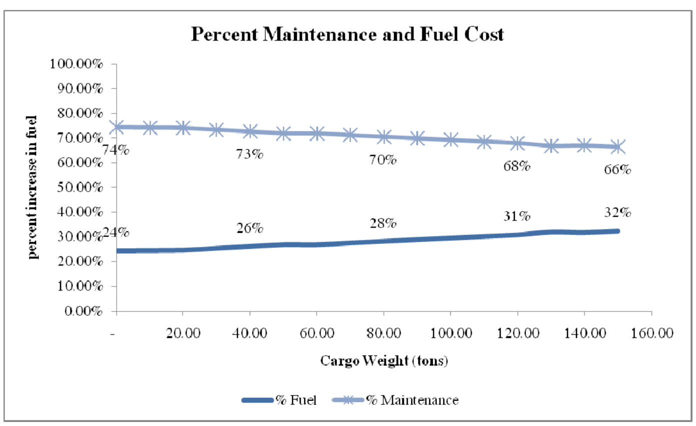


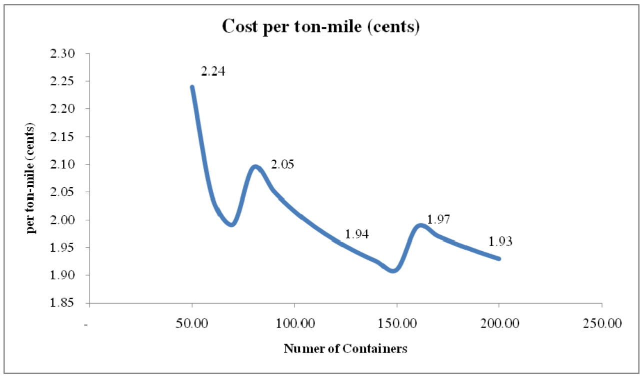
(e)

Figure 23: Cargo Weight Analysis

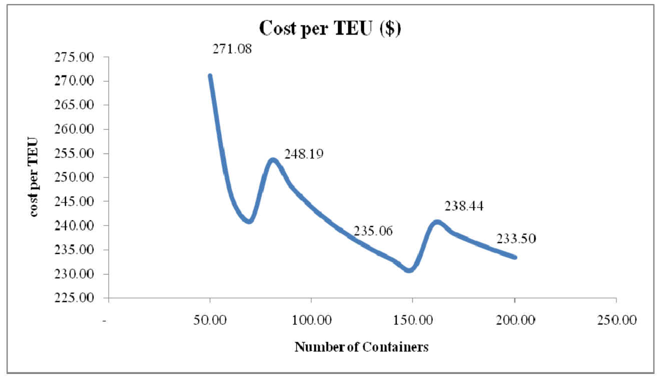
The inputs used in the number of cars analysis are below:

Fuel Price: \$2.50
Distance: 1000 miles
Starting HPTT: 2.5

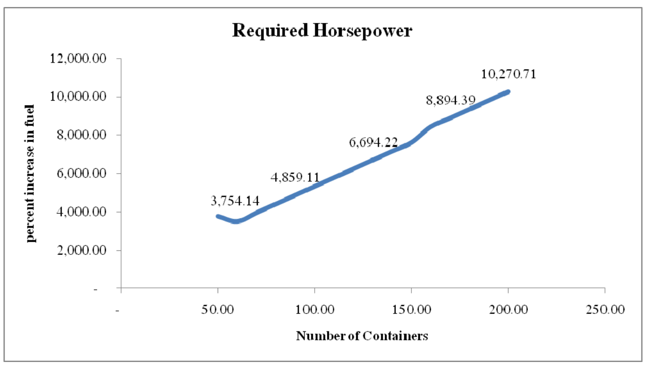
Max Speed: 60mph
Cargo Weight: 20 tons
Configuration: Double-stacked



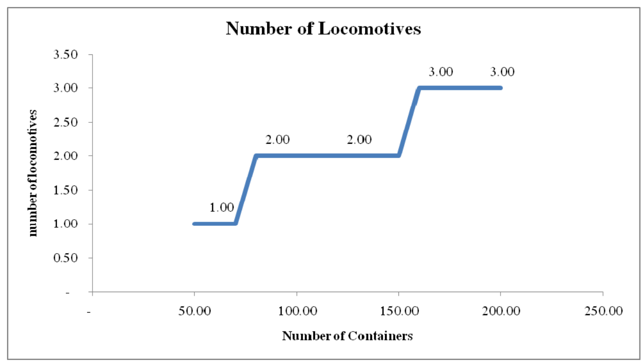
(a)



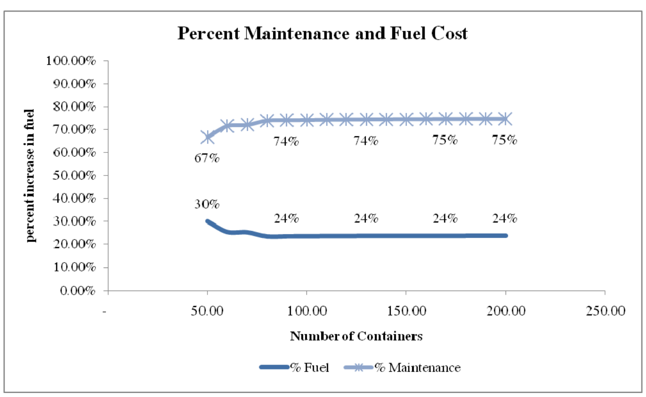
(b)



(c)



(d)



(e)

Figure 24: Number of Containers and Cars Analysis

Similar to changes in cargo weight, Figure 24 (a) and (b) demonstrates how line-haul cost decreases with increasing numbers of containers and cars. The humps in the graph signify the cost of adding a locomotive to meet the required horsepower (Figure 24 (c) and (d)). The percentage of fuel cost and maintenance cost; however, do not change much as both increase at almost the same rate with an increasing numbers of cars (Figure 24 (e)).

6.3.6 Maximum Speeds and Horsepower per Trailing Ton Ratios

Dingler et al. (2009) gathered information concerning typical weights, lengths and horsepower per trailing ton (HPTT) ratios for various train types from a TRB Workshop on Railroad Capacity and Corridor Planning (2002). HPTT ratio is a measure to calculate the horsepower required to power a certain cargo weight at a given speed. Based on the information gathered by the authors, the characteristics of four types of trains were published as shown below in Figure 25.

Intermodal	Unit Coal	Manifest	Passenger
90 cars	115 cars	70 cars	20 coaches
6,300 ft	6,325 feet	4,550 feet	1,500 feet
8,100 tons	16,445 tons	7,700 tons	835 tons
2.12 HP/Trailing Ton	0.78 HP/Trailing Ton	1.12 HP/Trailing Ton	5.09 HP/Trailing Ton
4 SD70 4,300 HP Locomotives	3 SD70 4,300 HP Locomotives	2 SD70 4,300 HP Locomotives	1 P42-DC 4,250 HP Locomotive
Maximum Speed: 70 mph	Maximum Speed: 50 mph	Maximum Speed: 60 mph	Maximum Speed: 79 mph

Figure 25: Train Types from TRB Workshop.
Source: Dingler et al.(2009)

The four train types in Figure 25 were then simulated in IRCM to test the reliability of the model's computation of HPTT ratios based on maximum train speed.

Table 11 represents the simulation results.

Table 11: IRCM Simulation Trains

Train Type	**90 intermodal flat cars**	**115 boxcars/gondolas**	**115 Hoppers**	**70 Gondolas**
Train Length	6,600 ft.	6860 ft.	6,760 ft.	4770 ft.
Cargo weight	50 tons	105 tons	110 tons	30 tons
Cargo and Car Weight	7560 tons	16,387 tons	16,186 tons	7525 tons
Train Weight	8360 tons	16,788 tons	16,586 tons	7925 tons
HPTT ratio	1.94	0.43	0.53	0.81
No. of Locomotives	4 4,400 HP Locomotives	2 4,400 HP Locomotives	2 4,400 HP Locomotives	2 4,400 HP Locomotives
Maximum Speed	70 mph	50 mph	50 mph	60 mph

The key observation from these findings is that HPTT ratio is dependent on cargo weight and varies with the specified maximum train speed. A more detailed analysis of this observation is presented in Figure 26. The following train inputs were used:

Number of containers: 100
Configuration: TOFC
Number of Cars: 100

Fuel Price: $2.50
Distance: 1000 miles
Starting HPTT: 2.5

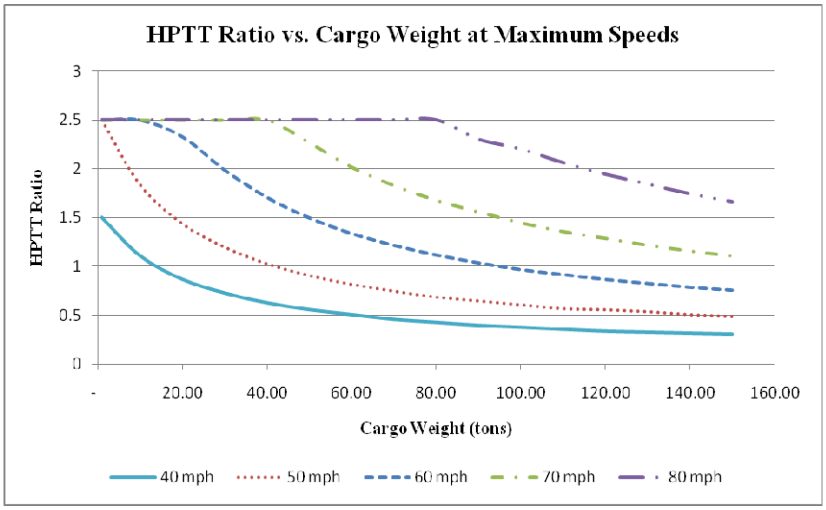


Figure 26: HPTT Ratio, Cargo Weight and Maximum Train Speeds

The graph demonstrates how HPTT ratio reduces with increasing train weight after maximum speeds have been achieved. For a certain cargo weight, once the maximum speed of the train is achieved, the HPTT ratio decreases thereby keeping the train at the specified maximum speed. The maximum speed constraint ensures that the HPTT ratio varies with cargo weight. So for example, for a 100 unit train whose maximum speed is set at 60 mph, for cargo weights greater than 20 tons, HPTT ratio will be less than 2.5. If this constraint is not set and HPTT ratio remains constant, the train will move as fast as 80 mph for cargo weight 80 tons or more. These speeds can be more astronomical for even higher HPTT ratios. Freight rail does not usually run more than 60 mph and not setting the maximum speed constraint may result in unrealistic freight rail speeds. As shown in

Table 11 for heavier cargo weights, the HPTT ratio is smaller for heavier trains than for lighter trains.

6.4 Chapter Summary

This analysis provides a better understanding of how train performance is influenced by cargo weight, number of containers (and cars), and desired maximum speed. The costs associated with varying these inputs were also determined. The model calculates higher costs from various fuel price increases and also estimates the marginal benefits of operating longer distance routes which are a result of economies of scale. Transporting empties is also expensive, and it is more cost-effective for trains to travel at slower speeds. However, where rail needs to be competitive with trucking, this is not an option.

Chapter 7: Case Studies

From the survey of thirty-two freight forwarding firms located in Texas, it was determined that a majority of commodities transported have their origins or destinations in the commonly known Texas Triangle cities of Houston, Dallas-Ft. Worth and Austin-San Antonio. Previous studies also indicated that a majority of the container movements were within the Houston area or within 100 miles from the Port of Houston (Prozzi et al., 2003). Commodities from Dallas-Fort Worth, Austin and San Antonio, accounted for roughly 77% of U.S. international trade via the Port of Houston in 2002. By 2035, traded commodities from these cities alone are forecasted to increase by 120% (FAF, 2002). Improvements in current trade corridors like the expansion of the Panama Canal are expected to facilitate an increase in goods transported via the port of Houston. In the case studies presented below, an analysis of goods transported from the dry port to the Port of Houston is performed. The dry port is assumed to be located in Dallas-Fort Worth area and is roughly 275 miles from the Port. Dallas-Fort Worth is chosen because of its distance from the Port of Houston. The case studies will examine various scenarios in an effort to identify conditions that would make rail transport competitive to trucking for short-haul distances.

The first study will try to determine a threshold quantity of goods to be transported from the centralized freight center to the port for short-haul rail to be competitive to trucking. This study is necessary to assist policymakers to decide whether it is worthwhile investing in short-haul freight rail based on the quantity of goods transported between the origin and destination points.

Despite the advantages of rail, its delivery times are known to be slower than trucking and this does not tend to be favorable for shippers. The second case study will seek to determine if freight rail can move at faster speeds and still be cost effective and competitive with trucking.

7.1 Case Study 1: Quantity of Goods and Short-haul Freight Movement

According to FAF 2002 data, 326 kilotons of exported goods were transported via truck or rail from Dallas through the Port of Houston. This number is expected to increase by 100% in 2010, 200% in 2015 and more than 500% by 2025. Should these projections be accurate, 662 kilotons of goods will be transported in 2015, and more than 2000 kilotons of goods by 2025. Using these assumptions[37], a study is performed to determine if it is viable for policymakers to begin investing in a centralized freight center with direct access from Dallas to the Port of Houston via rail. Using the FAF data, and assuming a 30% adoption rate by the private sector to use such a facility, the following data was generated.

Table 12: Projected kilotons of Exported Goods

Year	FAF Projected (ktons)	FEUs	TUEs	30% Adoption
2002	326.2	21,746.07	43,492.13	6,523.82
2010	662.0	44,132.33	88,264.65	13,239.70
2015	978.5	65,234.66	130,469.32	19,570.40
2020	1,509.0	100,598.64	201,197.28	30,179.59
2025	2,081.6	138,776.21	277,552.43	41,632.86
2030	**2,845.3**	**189,686.31**	**379,372.63**	**56,905.89**
2035	3,739.0	249,267.02	498,534.04	74,780.11

The second step is to determine how many trips can be made each day by the freight train to meet the daily demand. Different numbers of containers were tested to determine the optimum number of containers to be transported. The following train inputs were used:

Track maintenance: $0.50 $ per car, per locomotive mile
Car maintenance: $0.12 $/mile
Locomotive maintenance $2.10 $/mile
Average Crew Wages: $360/day
Number of Crew Members: 2
Tare weight of 40ft container: 4 tons
Tare weight of well: 17.60 tons
Configuration: Double-stacked
Cargo Weight per container: 15 tons
Fuel Price: $2.50
Max Train Speed: 65 mph

[37] In addition, one further assumption is: cargo weight: 15 tones per FEU (7.5 tons per TEU).

Utilization ratio: 100%
Distance: 275 miles
Loading and Unloading Cost per container: $50.00 a container

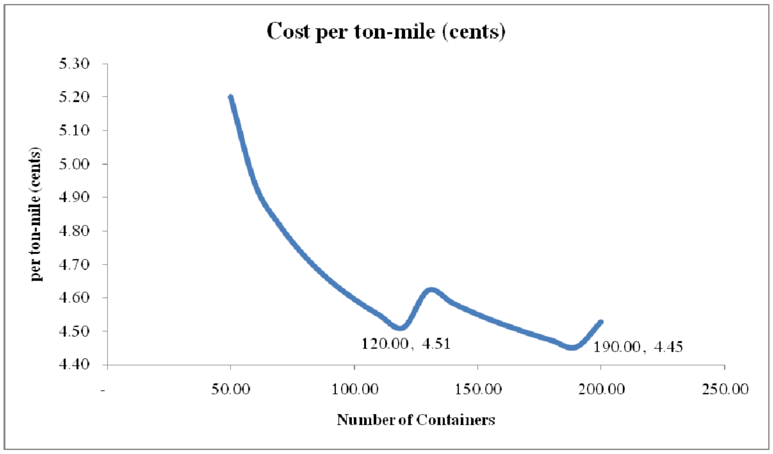


Figure 27: Determining optimum number of containers

From the graph in Figure 27, it is determined that the optimum number of containers that should be transported per train should be 120 containers or 190 containers. Using these two parameters, the number of train trips needed to meet demand is shown in

Table 13. The number of truck trips is also calculated for two kinds of scenarios – transporting 40-ft containers and transporting 53-ft containers.

Table 13: Number of Trips

Year	**2003**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
Number of Containers to be Transported	**6,524**	**13,240**	**19,570**	**30,180**	**41,633**	**56,906**	**74,780**
Containers per Train	**Number of Train Trips**						
120.00	54	110	163	251	347	474	623
190.00	34	70	103	159	219	300	394
Containers per Truck	**Number of Truck Trips**						
1- 40 ft unconsol.	*6,524*	*13,240*	*19,570*	*30,180*	*41,633*	*56,906*	*74,780*
1 - 53 ft consol.	*4,893*	*9,930*	*14,678*	*22,635*	*31,225*	*42,679*	*56,085*

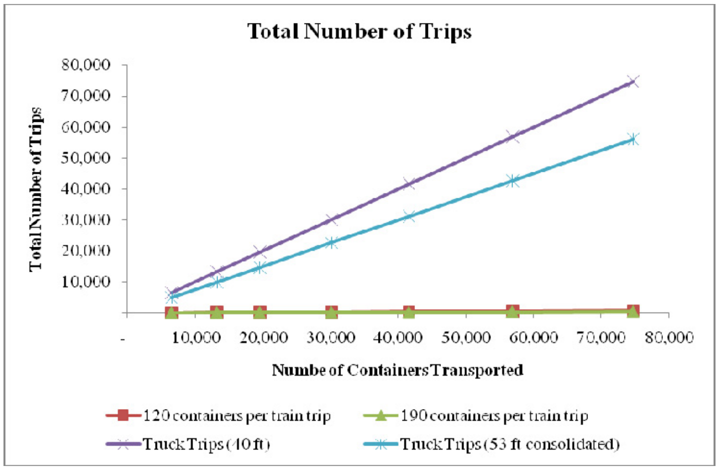


Figure 28: Case Study 1: Total Number of Trips

As the number of containers increase over the years the number of trips needed to transport these containers increase dramatically when being transported by trucks.

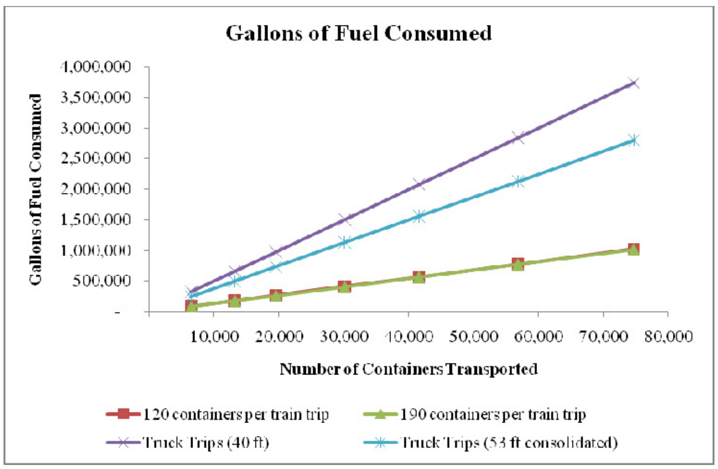


Figure 29: Case Study 1: Gallons of Fuel Consumed

Because of the increase in number of trips, the gallons of fuel consumed by the trucks also increase much faster than that of the trains.

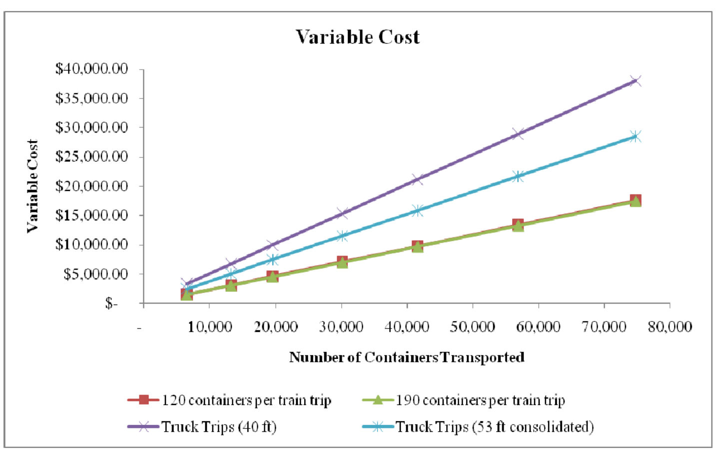


Figure 30: Case Study 1: Variable Cost

The cost associated with transporting the containers also increase as the number of trips increase. This is only the line-haul operations cost and does not include costs associated with improving upon the infrastructure

Case study 1 demonstrates that rail is most cost-effective and efficient when a transporting large quantities of commodities. Should international trade increase as forecasted, it would be important for policy makers to consider investing in rail infrastructure even for short-haul distances such as from Dallas to Houston. Though other costs such as capital investment are not considered in this study, the advantages of line-haul rail outweigh that of trucking in the long term.

7.2 CASE STUDY 2: VARYING DELIVERY TIMES

According to previous studies, a major concern amongst shippers is delivery time. Terms like just-in-time delivery and LTL are derived from quick and efficient delivery times. And in order for the dry port to be attractive to shippers, it needs to offer service delivery times comparable to current systems or even better. As stated earlier, the dry port is expected to be directly connected to the port of import/export by rail as it is noted to be environmentally-friendlier and carries more cargo on a single trip than trucking. Despite the advantages of rail, its delivery times are known to be slower than trucking. For example, the average speed of intermodal rail in 2008 was less than 40 mph (AAR, 2009).

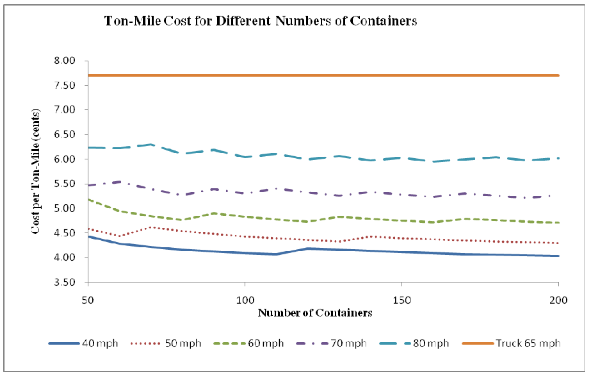
In this case study, the sensitivity of faster delivery times and associated costs are modeled to determine if rail can move at faster speeds and still have lower costs – making it more competitive to trucking. The following train inputs were used:

Track maintenance: $0.50 $ per car, per locomotive mile
Car maintenance: $0.12 $/mile
Locomotive maintenance $2.10 $/mile
Average Crew Wages: $360 /day
Number of Crew Members: 2
Tare weight of 40ft container: 4 tons
Tare weight of well: 17.60 tons
Cargo Weight per container: 15 tons
Fuel Price: $2.50
Utilization ratio: 100%
Distance: 275 miles
Starting HPTT ratio: 2.5
Loading and Unloading Cost per container: varied to demonstrate differences

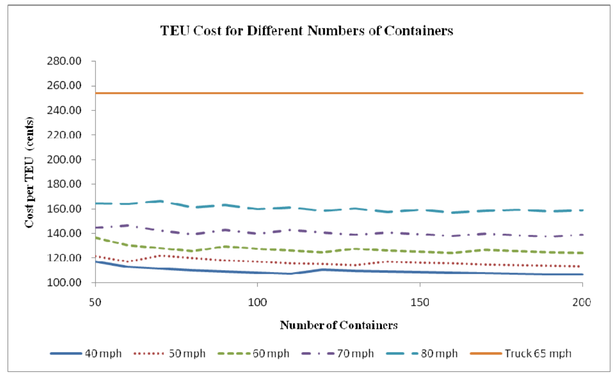
In addition to faster train speeds, the influence of loading and unloading cost is also examined to demonstrate how high terminal activity cost can influence rail despite the increase in speed.

7.2.1 Trailer on Flat Car Scheme

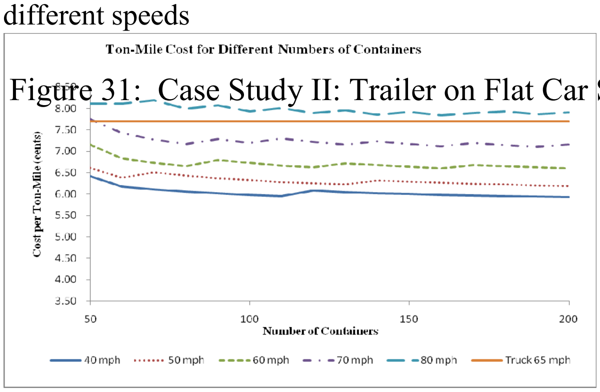
In these scenarios the trailer on flat car (TOFC) scheme is simulated. These scenarios represent when intermodal double-stacking is not possible.



(a) Ton-mile costs for TOFCs when there is no difference in loading and unloading cost per container between truck and rail, and rail travels at different speeds



(b) TEU costs for TOFCs when there is no difference in loading and unloading cost per container between truck and rail, and rail travels at different speeds



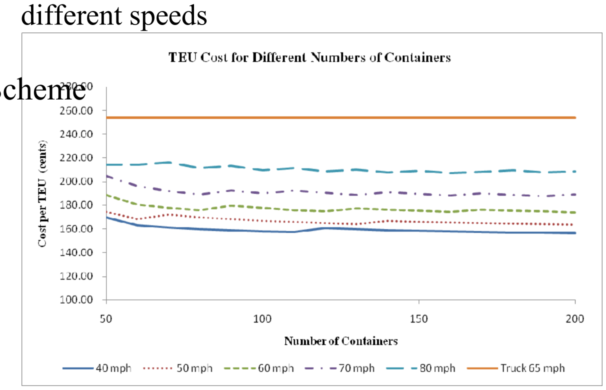
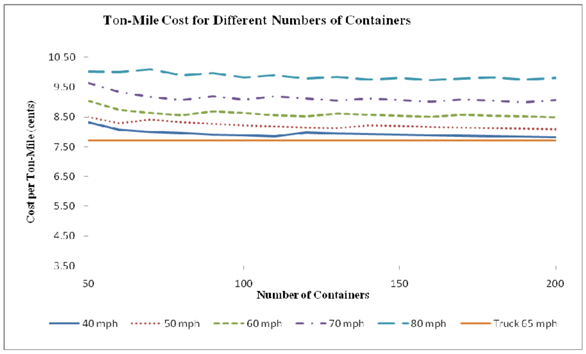


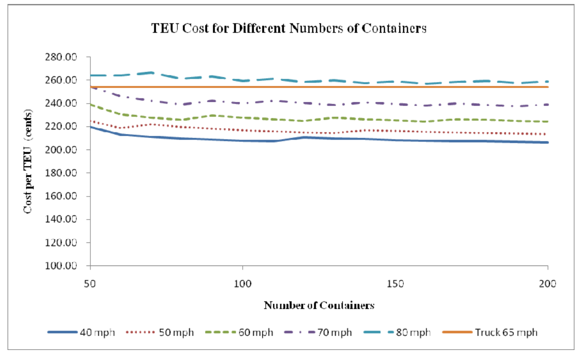
Figure 31: Case Study II: Trailer on Flat Car Scheme

(c) Ton-mile costs for TOFCs when there is a $100 difference ($50 loading and $50 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds

(d) TEU costs for TOFCs when there is a $100 difference ($50 loading and $50 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds



(e) Ton-mile costs for TOFCs when there is a $200 difference ($100 loading and $100 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds



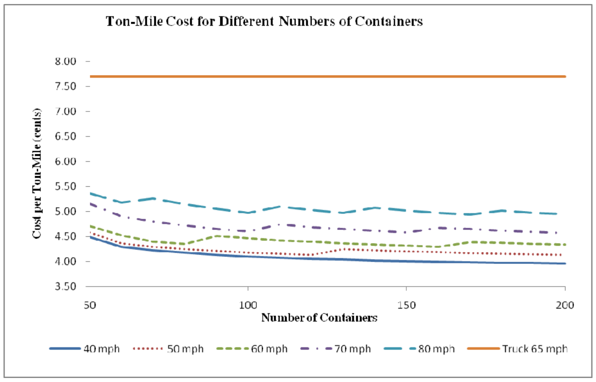
(f) TEU costs for TOFCs when there is a $200 difference ($100 loading and $100 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds

Figure 31 continued: Case Study II: Trailer on Flat Car Scheme

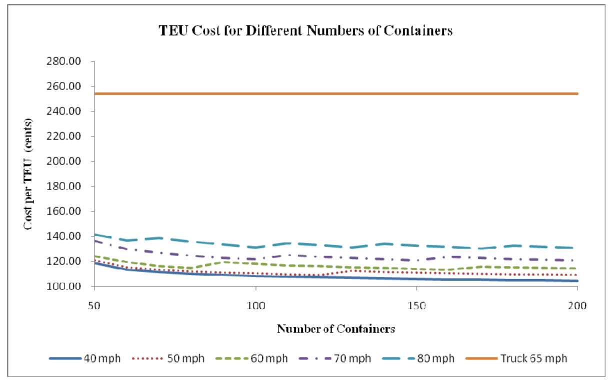
For TOFC intermodal trains, it can be said that even at higher speeds of 80 mph, freight rail can still be cheaper than trucking when there is little or no cost difference between loading and unloading cost per container (see Figure 31Figure (a) and (b)). However, for the higher loading and unloading costs of intermodal rail, the cost advantage over trucking diminishes for TOFC trains as illustrated in (see Figure 31 (c), (d), (e), and (f)).

7.2.2 Double-stacked Intermodal Scheme

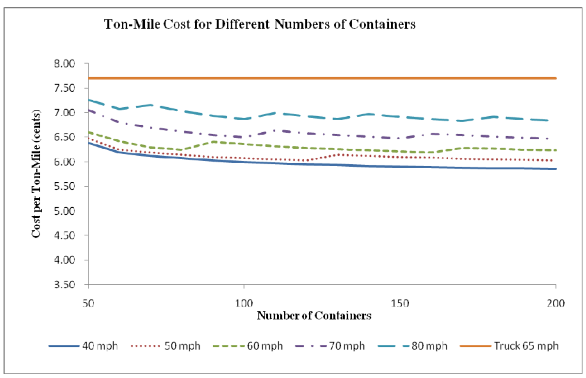
In the following scenarios the double-stacked intermodal scheme is simulated to examine the advantages of double-stacking.



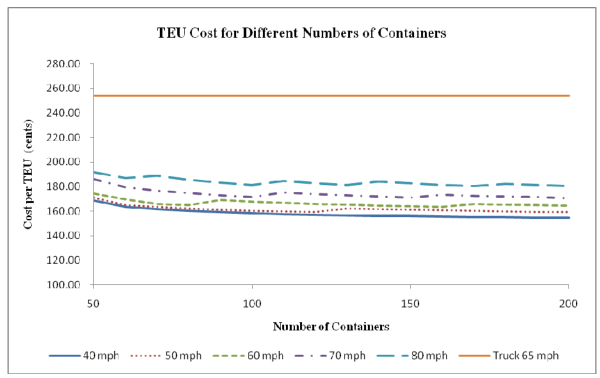
(a) Ton-mile costs for TOFCs when there is a $100 difference ($50 loading and $50 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds



(b) TEU costs for TOFCs when there is a $100 difference ($50 loading and $50 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds



(c) Ton-mile costs for TOFCs when there is a $200 difference ($100 loading and $100 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds



(d) TEU costs for TOFCs when there is a $200 difference ($100 loading and $100 unloading) in loading and unloading cost per container between truck and rail, and rail travels at different speeds

Figure 32: Case Study II: Double-stacked Intermodal Scheme

For double-stacked intermodal trains, freight rail remains cheaper than trucking even when loading and unloading cost difference is as high as $200 per container ($100x2). This reinforces the observation made by Resor and Blaze (2004) that for intermodal rail to be competitive for short-haul distances, terminal operations and drayage costs should remain low. Wood et al. (2002) further states that "double-stack rail service and its adoption and promotion by land and ocean carriers, has made it attractive to ship containers intact to inland destinations under mini- or micro-bridge rates, using a single bill of lading" (Wood et al., 2002). Reducing drayage cost will enable intermodal rail to be competitive with trucking at short-haul distances and even at speeds greater than 65 mph, the average speed of trucks on rural freeways.

Chapter 8: Conclusions

This study attempted to sharpen the understanding of the import-export processes function in the U.S. and how rail can play a role in enhancing both the capacity and efficiency of current supply chains. It examined the challenges faced by U.S. exporters and importers, and investigated an innovative solution to tackle these challenges. The dry port concept introduced by transportation geographers was discussed, and an intermodal rail costing model was used in determining whether this concept proved to be a more sustainable and energy efficient system than what currently exists.

The dry port concept is seen as a major step to a sustainable supply chain but further research needs to be done to explore the entire transportation chain, particularly as metropolitan areas are predicted to grow larger in the coming decade. The import and export processes involve various functions and stakeholders. Detailed description of both processes revealed that though the functions vary, the processes utilize similar stakeholders, equipment and infrastructure. The dry port concept will seek to provide a platform where all the functions involved in the import and export processes can be performed with minimal effect on the surrounding environment. The survey results also revealed an interest by stakeholders in using such a system as the current system's dependence on trucking poses a lot of challenges. Highway congestion, air pollution, waste of energy, time delays, and an increase in maintenance costs are the result of the current system. Fuel price increases also result in higher transportation costs experienced mostly by shippers located in the hinterland.

Implementing a centralized multi-modal freight facility is a step in the right direction for the import-export process. Benefits include reduced truck traffic, decreased travel times, decrease in congestion, reduced emissions, reduced fuel use and lower transport cost as illustrated in the two case studies. However, the challenges associated with implementing the concept remain to be addressed, particularly at the level of regional planning. Infrastructural and public policy changes will be necessary to promote the concept and more research is needed to ensure that freight – often neglected in metropolitan planning – is recognized as critical to economic success.

FUTURE RESEARCH

The study team recommendations for future work fall into two categories. The first relates to the rail model and the various improvements that could be made to address specific freight planning problems or opportunities where freight rail is being considered. The characteristics of rail operations are detailed and, at times, complex making it challenging to develop a model that can address several issues simultaneously yet be structured so that non-engineers with limited data are still able to derive useful output. It is hoped that the model can be improved with help from a Class 1 railroad company comparing actual company data with model predictions. The model should also be improved by calibrating operations related to different commodities where different combinations of engine power, train weight and speed are present.

The second category of activities where rail models are useful lie in the planning sector. State Departments of Transportation are failing to raise sufficient revenues from traditional sources and one way to lower user demand for additional lane miles is to move freight to other competing modes. Intermodal offers a competitive alternative to trucking over trip distances that exceed 500 miles and there are real opportunities to lower this distance, particularly if the dominant cost of drayage is resolved. Rail is superior in terms of energy per ton/mile costs and this makes it a vital transportation mode in addressing freight needs in future. And, lower fuel consumption equates to lower emissions per ton/mile which constitutes a double benefit to metropolitan planners. Finally, supply chains have shown themselves capable of moving exports and efficiently as imports which suggests that new transportation multimodal freight solutions can be developed to serve the metropolitan population growth expected over the next 30 years. Rail models, of the type developed in this study, are expected to play vital roles in determining the shape, nature and efficiency of freight flows and future supply chains.

Appendix A: Intermodal Rail Costing Model (IRCM) User Manual

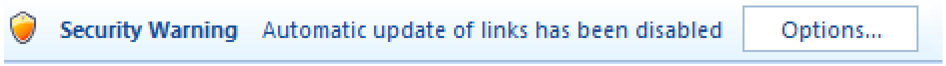
IRCM is made up of twelve modules, some of which require user input and others mainly for performing calculations. The modules are:

1. Cargo Weight, Number of Containers and Rail Car Configuration Module
2. Locomotive(s) Configuration Module
3. Train Data Summary
4. Locomotive(s) Performance Module
5. Basic Trip Details Modules
6. Fuel Consumption and Cost Module
7. Rail Emissions Module
8. Maintenance Cost Module
9. Crew Labor Cost Module
10. Capital Cost Module
11. Loading and Unloading Cost Module
12. Total Rail Cost Output Module

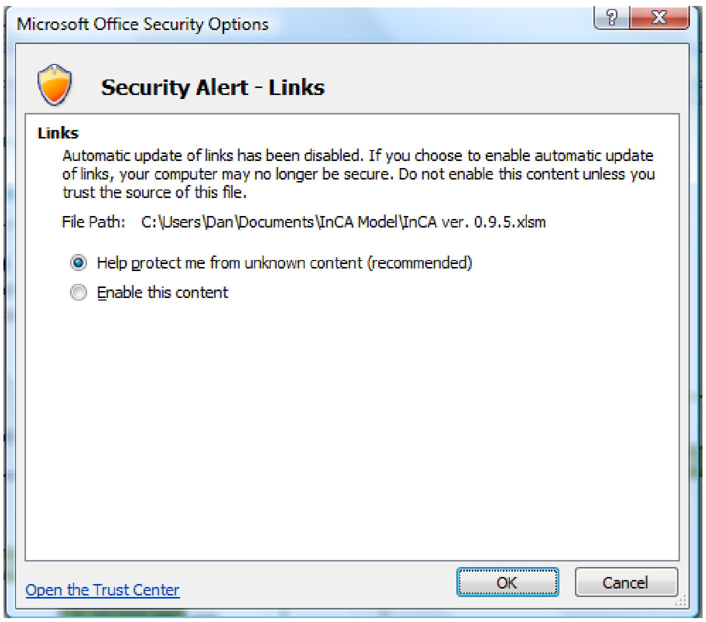
IRCM is available as a macro-enabled Excel spreadsheet and requires **Microsoft Excel 2007** or later to run.

Chapter 1 Model Setup

To start the model, the user will have to open the file **IRCM ver. 1.00.xlsm**. After opening the file, macros need to be enabled.



Clicking on the **Options** button will open the Microsoft Office Security Options window.



Select **Enable this content** and click the **OK** button.
Macros are currently enabled.

Chapter 2 Train Data Input

Cargo Weight, Number of Containers, and Rail Cars Module

1) Select between different types of containers. The choices available are:

- *20 ft. Dry*
- *20 ft. Reefer*
- *40 ft Dry*
- *45 ft. H. Cube*
- *No Containers*
- *Reefer 40 ft.*

Cargo Weight, Number of Containers, and Rail Car Configuration Module

required [x]		Input/Output	
x	select type of container (20ft., 40ft., 45ft. HC)	40 ft Dry	type
	tare weight of one 40 ft Dry	4.20	tons
x	input cargo weight per container	15.00	tons
	gross weight of one container	19.20	tons
x	select type of car	Container Carriers (5-unit)	car type
	tare weight of car	17.60	tons
x	input number of containers	200.00	containers
x	are containers double stacked?	Yes	
	gross weight of one car	56.00	tons
	required no. of double stacked Container Carriers (5-unit)	100.00	wells
x	utilization ratio (no. of full containers)	100%	percent
	number of full containers	200.00	
	number of empty containers	-	
	total number of wells (intermodal)	100.00	wells
	total TEU - full	400.00	TEU
	total TEU - empty	-	TEU
	gross weight of full cars/containers	3,840.00	tons
	gross weight of empy cars/containers	-	tons
	total gross weight of all cars and containers	5,600.00	tons
	length of car	53.00	ft
	number of axles	4.00	axles
	k-value	0.09	
	k-adj-value	0.95	

2) Input Cargo weight in tons

3) Select type of rail car. Choices available are:

- *Auto Transporters*
- *Boxcars*
- *Center Partition Railcars*
- *Container Carriers (5-unit)*
- *Gondolas*
- *High Cube Box Cars*
- *Hoppers*
- *Intermodal Flatcars*
- *Other Flatcars*
- *Tankers*

4) Input number of containers

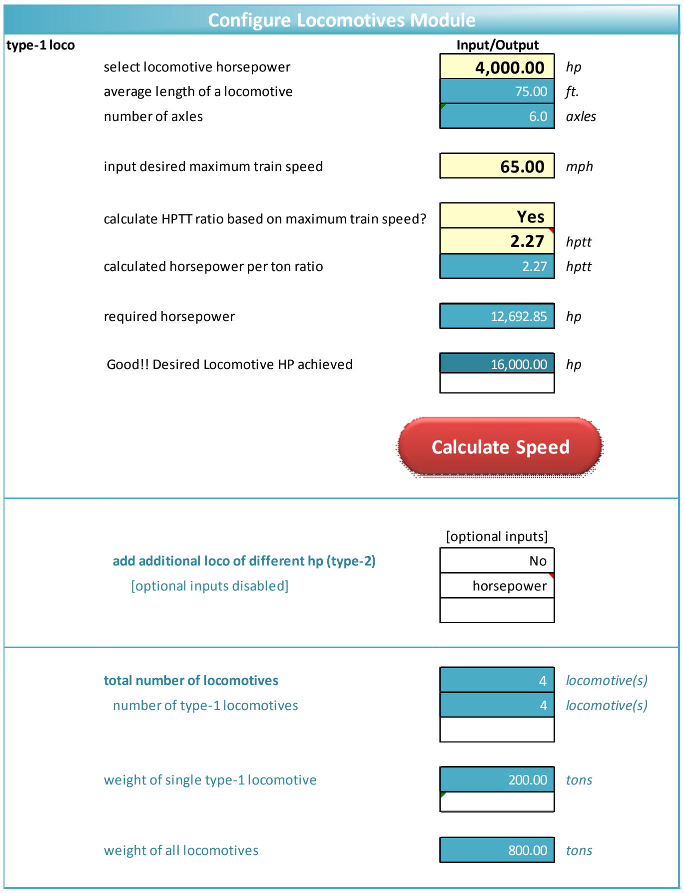
5) Select *Yes* or *No* to specify if shipment is double-stacked or not

6) Input Utilization Ratio i.e. the ratio of full to empty containers expressed as a percentage.

Locomotive(s) Configuration Module

1) Select a locomotive of your choice based on the manufacturer's rated horsepower. Choices available are:

- *2,000.00 hp*
- *3,000.00 hp*
- *3,500.00 hp*
- *3,800.00 hp*
- *4,000.00 hp*
- *4,400.00 hp*
- *5,000.00 hp*
- *6,000.00 hp*



2) Input the desired maximum train speed in mph.

3) Decide on whether HPTT ratio should be calculated based on specified maximum train speed or HPTT ratio kept constant (i.e. maximum speed constraint is ignored).

4) If a constant HPTT ratio simulation is desired, input the ratio.

Optional: An additional locomotive of a different horsepower can also be selected.

5) Click on the **Calculate Speed** button to perform train speed calculation.

Train Data Summary

The train data summary table provides a general idea of the train's cargo weight, train weight, length of train, number of cars, and number of locomotives.

Train Data Summary	Input/Output	
weight of cargo	3,840	*tons*
gross weight of train	**6,400**	*tons*
length of cars	5,300	*ft*
length of locomotives	300	*ft*
length of train	**5,600**	*ft*
total number of cars (or wells for intermodal trains)	100	*cars*
total number of locomotives	4	*locomotives*
total number of axles - locomotives	24	*axles*
total number of axles - cars	400	*axles*

Locomotive(s) Performance Module

The locomotive performance module is used in calculating the speed of the train. Clicking the **Calculate Speed** button calculates the train speed.

Locomotive Performance Module (Used in Calculating Train Speed)	Input/Output	
iterated speed	65.00	*mph*
equation of motion	(0.00)	
cruising speed	**65.00**	*mph*
difference from maximum speed equation	-	*mph*
tractive effort	**60,144.56**	*lbs/ton*

Calculate Speed

Chapter 3 Route Information Section

Basic Trip Details Module

Basic Trip Details Module	View Rail Maps	
required [x]	Input/Output	
x select railroad company	BNSF	
x select origin	ALLIANCE	
x select destination	CHICAGO	
default distance	963.00	miles
percentage grade of terrain	0.00%	%
curve of c degrees	-	degress °
estimated cruising speed	65.00	mph
number of sidings to be used	-	sidings
estimated wait time per siding	-	mins
total siding stop delay	-	hrs
calculated travel time	14.82	hrs
USER SPECIFIED INPUTS	[optional]	
compare with my inputs?	Yes	yes/no
x input distance	275.00	miles
percentage grade of terrain	0.00%	%
curve of c degrees	-	degress °
x input speed	65.00	mph
number of sidings to be used	-	sidings
estimated wait time per siding	-	mins
total siding stop delay	-	hrs
calculated time travel time	4.23	hrs
TRIP SUMMARY (Use for final check)		
distance used in calculations	275.00	miles
percentage grade of terrain	0.00%	%
curve of c degrees	-	degress °
trip speed	65.00	mph
total siding stop delay	-	hrs
trip time used in calculations	4.23	hrs

Calculate Speed

Basic Trip Details Module enables users to select a route based on pre-specified data or input custom trip data.

For pre-specified data, user must

1) Select a railroad company. Currently available options are
- *BNSF*
- *UP*
- *KCS*

Note: Rail maps are available for reference.

2) Select origin and destination based on available railroad routes.

3) Input average grade of terrain. Leave blank if not known.

4) Input average track curvature. Leave blank if not known.

5) Input number of sidings (low-speed track section where trains stop temporarily to allow other trains to pass)

6) Input estimated wait time per siding

7) Click the **Calculate Speed** button

For user specified data:

1) Select **Yes** for “compare with my inputs?”

2) Input distance

3) Input average grade of terrain. Leave blank if not known.

4) Input average track curvature. Leave blank if not known.

5) Input number of sidings (low-speed track section where trains stop temporarily to allow other trains to pass)

6) Input estimated wait time per siding

7) Click the **Calculate Speed** button

Chapter 4 Cost Functions

Fuel Consumption and Cost Module

Fuel Consumption & Cost Module ($$$)

	Input/Output	
x price per gallon of fuel (p)	$ 2.50	*$ USD*
x thermal efficiency of diesel-electric engine (decimal)(η)	0.35	*(25-30%)*
total horsepower of locomotives	12,692.85	*hp*
fuel surcharge (optional)	$ -	*$/mile*
total fuel surcharge	$ -	*$$$*
Total Fuel cost per trip	$ 7,019.42	*$$$*
ton-miles per gallon *(compare with AAR claim)*	376.10	*ton-miles per gal.*
gallons consumed per hr per locomotive	165.91	*gals/hr/loco.*
total gallons consumed per locomotive	701.94	*gals*
fuel cost per gross ton mile	$ 0.0040	*gross ton mile*
GTM/gallon of fuel	627	*GTM/gal*
total gallons consumed per hr	663.65	*gals/hr*

1) Input fuel price per gallon

2) Input thermal efficiency of locomotive engines in decimals. Default is between 25-30%. A higher efficiency can be specified because of technological innovations and variances in locomotives. View *gallons consumed per hr per locomotive* to ensure a reasonable estimate between 150 to 220 gallons per hour is specified.

Rail Emissions Module

Select between the different sets of EPA locomotive emission standards to view emissions generated.

Rail Emission Module

		Input/Output	
gallons of fuel consumed		2,807.77	*gals*
select TIER		Tier 0	
Pollutants (g/gal)		emission factors	
	HC	0.03	metric tons
	CO	0.07	metric tons
	NOx	0.50	metric tons
	PM	0.02	metric tons
	VOC	0.03	metric tons

Maintenance Cost Module

Maintenance Cost Module ($$$)

	Input/Output	
track maintenance	$ 0.50	*$ per car, per loco. mile*
car maintenance	$ 0.12	*$/mile*
locomotive maintenance	$ 2.10	*$/mile*
Total maintenance	$ 19,910.00	*$$$*
track only maintenance cost per gross ton-mile	0.0113	*$/ton-mile*

1) Input track maintenance cost per car per locomotive per mile if different from default.

2) Input per mile car maintenance cost

3) Input per mile locomotive maintenance cost

Crew Labor Cost Module

Crew Labor Cost Module ($$$)	Input/Output	
average crew wages	$ 360.00	$/day
number of crew members	2.00	number
other crew labor wages	$ -	$/hr
	-	number
other crew labor wages (per mile calculation)	$ -	$/mile
	-	number
Total Labor Cost	$ 720.00	$$$

1) Input average crew wages per day

2) Input number of crew members

3) Input any other known crew wages on per hour or per mile basis.

Capital Cost Module

1) Input cost of one rail car if known.

2) Input cost of one locomotive if known.

3) Input rail equipment life.

4) Input equipment salvage value.

Capital Cost Module ($$$)	Input/Output	
cost of one (1) car	$ 39,000.00	$$$
cost of one (1) locomotive	$ 2,000,000.00	$$$
rail equipment life (years)	30.00	years
salvage value (percentage)	10%	percent'
hourly depreciation of one (1) car	0.13	$/hr
all cars	13.36	$/hr
hourly depreciation of one (1) locomotive	6.85	$/hr
all locomotives	27.40	$/hr
annual interest rate	0%	percent
hourly interest charge for one car	-	$/hr
all cars	-	$/hr
hourly interest charge for one (1) locomotive	-	$/hr
all locomotives	-	$/hr
Total Depreciation and Interest charges	$ 172.42	$$$

Loading and Unloading Cost Module

Loading and Unloading Cost Module ($$$) (experimental)		
set input to 0 if not in use	Input/Output	
loading cost per unit container	$ 50.00	
unloading cost per unit container	$ 50.00	
Total Loading and Unloading Cost (experimental)	$ 20,000.00	$$$

Input loading and unloading cost if including terminal operations cost estimates.

Other Cost Calculation Module

Other Cost Calculation Module ($$$)		
	Input/Output	
other	0%	*percent*
other		*$/hr*
other		*$/hr*
other		*$/mile*
other		*$/mile*
Total Other Cost	$ -	*$$$*

This is an optional module which allows users to input cost not specified in the above modules. Units include

- A percentage increase of overall cost
- Per hour cost
- Per mile cost

Total Rail Cost Output Module

Total Rail Cost ($$$)		
	Input/Output	
Total Rail Cost	$47,821.84	*$$$*
per ton-mile (cents)	4.53	*cents/ton-mile*
per TEU	$ 119.55	*$/TEU*
per FEU	$ 478.22	*$/FEU*
per mile	$ 173.90	*$/mile*
per TEU-mile	0.43	*$/TEU-mile*
per ton	$ 12.45	*$/ton*
percentage fuel	15%	%
percentage maintenance	42%	%
cost per carload	$ 478.22	$/carload
Cost Break Down		
fuel cost	$ 7,019.42	*$ USD*
maintenance cost	$ 19,910.00	*$ USD*
crew labor cost	$ 720.00	*$ USD*
capital & invest. cost	$ 172.42	*$ USD*
loading/unloading	$ 20,000.00	*$ USD*
other cost	$ -	*$ USD*

The rail cost output module presents the final cost estimates of the train trip. Cost estimates are specified in different units such as per ton-mile, per TEU, per mile, and per ton. The cost of fuel and maintenance as a percentage of overall cost is also displayed. A cost breakdown chart of all the earlier specified cost functions is also displayed. Cost breakdown charts also display the various cost components as a pie chart and a bar graph.

Chapter 5 Model Default Data Tables

Containers			
container	**tare wt.**	**TEUs**	**max. payload (tons)**
20 ft. Dry	2.50	1.0	24.00
20 ft. Reefer	3.20	1.0	24.00
40 ft Dry	4.20	2.0	30.00
45 ft. H. Cube	4.50	2.0	30.00
No Containers	-	-	30.00
Reefer 40 ft.	4.80	2.0	30.50

Rail Cars (Single unit data)							
type	tare weight (tons)	max gross wt.	length	cost	axles	K values	Kadj values
Auto Transporters	74.00	130.0	145.33	N/A	4	0.0700	1.30
Boxcars	37.10	143.0	58.35	N/A	4	0.0700	0.85
Center Partition Railcars	30.50	143.0	80.53	N/A	4	0.0700	0.85
Container Carriers (5-unit)	17.60	100.0	53.00	39,000.00	4	0.0935	0.95
Gondolas	37.50	143.0	66.00	N/A	4	0.0700	0.85
High Cube Box Cars	39.65	143.0	67.88	N/A	4	0.0700	0.85
Hoppers	30.75	143.0	58.00	N/A	4	0.0700	1.05
Intermodal Flatcars	31.00	100.0	70.00	85,000.00	4	0.0935	0.95
Other Flatcars	31.00	100.0	90.00	N/A	4	0.1600	1.05
Tankers	32.85	131.5	57.13	N/A	4	0.0700	0.85

Locomotives				
horsepower	wt. (tons)	length (ft.)	cost	axles
2,000	190	75.0	N/A	6
3,000	195	75.0	N/A	6
3,500	200	75.0	N/A	6
3,800	200	75.0	N/A	6
4,000	200	75.0	N/A	6
4,400	200	75.0	N/A	6
5,000	200	75.0	N/A	6
6,000	200	75.0	N/A	6

K_{adj} values	
equipment	Kadj
Pre-1950 equipment	1.00
Conventional post-1950 cars	0.85
Container-on-flatcar	0.95
Trailer-on-flatcar and hopper cars	1.05
Empty, covered auto racks	1.20
Loaded auto racks	1.30
Empty, uncovered auto racks	1.90

Line-Haul Emission Factors (g/gal)					
	HC	CO	NOx	PM	VOC
Uncontrolled	10.00	26.60	270.40	6.70	10.53
Tier 0	10.00	26.60	178.00	6.70	10.53
Tier 1	9.80	26.60	139.00	6.70	10.32
Tier 2	5.40	26.60	103.00	3.60	5.69
Tier 3	2.70	26.60	103.00	1.66	2.84
Tier 4	0.83	26.60	20.80	0.31	0.87

Appendix B: Survey Questionnaire

The Center for Transportation Research at the University of Texas, Austin is performing a study to examine the challenges faced by transportation stakeholders in the delivery of goods and services to importers and exporters in the state of Texas.

The objective of this study is to gain a better understanding of the movement of imported and exported goods and to develop a model to facilitate the efficient flow of both the import and export supply chains. We are currently seeking the assistance of transportation stakeholders involved in the import and export supply chains in an effort to characterize and gain a better understanding of how improvements can be made to the import and export supply chains.

Please be assured that your responses would be regarded as strictly confidential and under no circumstances would individual respondents be identified. This questionnaire will take approximately 5 - 7 minutes to complete and you have the option to request for a copy of the survey results.

If you have any questions regarding this study, please do not hesitate to contact me personally at (512) 320-9977 or my research supervisor, Robert Harrison, the Deputy Director of the Center for Transportation Research, at (512) 232-3113.
Visit us at http://www.utexas.edu/research/ctr/

Sincerely,
Dan Seedah,
Center for Transportation Research
University of Texas at Austin
P: (512) 320-9977
E: dseedah@mail.utexas.edu
F: (512) 232-3070

1. Would you be interested in obtaining an electronic copy of the survey findings?
   - ( ) Yes
   - ( ) No

2. If Yes, please enter your email address:

   ____

3. Please specify which stakeholder group you represent:
   (check all that apply)
   - ( ) Freight Forwarder
   - ( ) Trucking Company
   - ( ) Ocean Carrier
   - ( ) Container Lessor
   - ( ) Railroad Company

( ) Drayage Company
( ) Shipper

4. Which TEXAS COUNTY is your company located in?

____

5. Which commodities constitute the majority of the cargo you transport?
e.g. unprocessed soybean, bottled water, synthetic resin, milled rice, salt, fertilizers, kerosene, computer equipment, televisions

Com. A ________________________________

Com. B ________________________________

Com. C ________________________________

6. Of the exported goods moved, where do you PICK UP your commodities from?
[ ] % within the county your business is located
[ ] % within the Texas Triangle (Dallas, Houston, San Antonio)
[ ] % in the rest of Texas
[ ] % in another U.S. State
[ ] % Other

7. Of the imported goods moved, where is the FINAL DESTINATION of the commodities you transport?
[ ] % within the county your business is located
[ ] % within the Texas Triangle (Dallas, Houston, San Antonio)
[ ] % in the rest of Texas
[ ] % in another U.S. State
[ ] % in Mexico
[ ] % Other

8. Would you consider using a freight consolidation center, which offers value added services, located on the outskirts of the city, and is directly connected to the port/terminal of IMPORT?
( ) Yes
( ) No

9. Would you consider using a freight consolidation center, which offers value added services, located on the outskirts of the city, and is directly connected to the port/terminal of EXPORT?
( ) Yes
( ) No

10. If you answered Yes to any of the questions above, what services would you like to see offered at such a facility?(check all that apply)
( ) Container/Chassis pool
( ) Empty Container Depot

(   ) Transloading Services
(   ) Intermodal (Rail, Air, Truck) services
(   ) Warehousing
(   ) Customs and Security Clearance
(   ) Assembly/Sub-Assembly services
(   ) Other (please specify)

11. Which of the following factors influence your EXPORT supply chain? (check all that apply)

(   ) Port congestion
(   ) Lack of alternative export ports
(   ) Highway congestion
(   ) Security and customs delays
(   ) Cost of fuel
(   ) High cost of relocating empty containers
(   ) Reliability of booking slots
(   ) Foreign regulations on certain commodity exports
(   ) Seasonal changes (e.g. currency devaluation)
(   ) Unavailability of distribution/depot centers
(   ) Other (please specify)

12. Please RANK the Top 5 factors which influence your EXPORT supply chain - with 1 being the MOST influential and 5 being the least influential:

_____ Port congestion
_____ Lack of options for port of export
_____ Highway congestion
_____ Security and customs delays
_____ Cost of Fuel
_____ High cost of relocating empty containers
_____ Reliability of booking slots
_____ Foreign regulations on certain commodity exports
_____ Seasonal changes (e.g. currency devaluation)
_____ Unavailability of distribution/depot centers
_____ other (specified above)

13. Which of the following factors influence the efficiency of your IMPORT supply chain? (check all that apply)

(   ) Port congestion
(   ) Lack of alternative import ports
(   ) Highway congestion
(   ) Security and customs delays
(   ) Cost of Fuel
(   ) Unavailability of distribution/depot centers
(   ) Other (please specify)

14. Please RANK the Top 5 factors which influence your IMPORT supply chain - with 1 being the MOST influential and 5 being the least influential:

_____ Port congestion
_____ Lack of alternative import ports
_____ Highway congestion
_____ Security and customs delays
_____ Cost of Fuel
_____ Unavailability of distribution/depot centers
_____ Other (specified above)

15. Are the challenges in your IMPORT AND EXPORT SUPPLY CHAINS commodity specific? If **Yes**, please explain briefly.

16. Please describe briefly how you move cargo in your EXPORT SUPPLY CHAIN:
Example: *Commodities are picked up from inland points via trucks, rail, etc into warehouses at port cities; consolidated with other kind shipments; then trucked to the port of export.*
17. Please describe briefly how you move cargo in your IMPORT SUPPLY CHAIN:
Example : *Containers are picked up at the marine terminal, rail yard etc., stripped at the warehouse, and delivered via truck, rail, or LTL carrier to inland points.*

18. In your opinion, how has the Automated Exported System (AES) improved the efficiency of your EXPORT supply chain? (check all that apply)

( ) One-stop filing
( ) Cost savings for company
( ) Convenience of automation
( ) Reduced paperwork
( ) No improvement
( ) Worse done before
( ) Other (please specify)__________________

19. In your opinion, what are some of the detriments of AES to your supply chain?
e.g. pre-departure requirements result in delays

20. If applicable, please RANK the different cost components involved in moving a container between an origin and destination in the United States from HIGHEST to LOWEST?

_____ Container lease or ownership costs
_____ Carrier costs
_____ Dock and terminal handling charges, including lifting and moving the container
_____ Wharfage/Demurrage costs
_____ Repositioning costs
_____ Other (please specify) ____________________

22. Do you have any other comments?

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