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ANALYSIS OF INTERMODAL VESSEL-TO-RAIL CONNECTIVITY

Final Report

by

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DISCLAIMER

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EXECUTIVE SUMMARY

Vessel-to-rail intermodal transportation is a competitive intermodal transportation mode since it integrates the advantages of both rail transportation and water transportation. Rail freight transportation, being very much popular these days for its large transportation capacity, low cost, and environmental protection, have a significant role to play in increasing the efficiency of port operation. Rail freight has a faster and more reliable role to play for transporting containers from ships to another places since it is least affected by weather and traffic condition.

This report identified the critical components of a vessel-rail intermodal system, analyzed the significance of each of them, compared the competitiveness of the Port of Houston among the similar ports collecting information from the port officials and the public database, pinpointed the gap between the existing condition of the POH and state of the art practices. The study found that the main parameters to evaluate the efficiency of the vessel-to-rail intermodal system are drayage cost, On-Dock Rail Intermodal Yard, Terminal location, its capacity, and Operational quipments facility cranes. Comparing it with the competitive ports in the U.S., it was found that the Port of Houston significantly lacks facilities in On-Dock Rail Yard and Operational equipments. While comparing the top 10 container ports of the U.S., the Port of Houston is one of three ports that does not have any on-dock rail facility. In terms of crane ownership, the Port of Houston ranks 6th. While considering the number of Super Post-Panamax cranes, it stands 8th among the top 10. From these statistics, it was evident that to cope with the containerized traffic in the future, the port should improve its terminal capacity and initiate new terminals at convenient locations with optimum infrastructural facilities. The report focused on the feasibility of the Rail Intermodal System compared to the truck freight of the Port of Houston. The analysis found that drayage cost is the driving factor in making Rail more competitive with Truck Freights. The study quantified that reducing drayage cost by 15 percent to percent can make rail competitive in the 400 Miles corridor.

Chapter 1. Introduction

1.1 Problem Statement

Freight transportation is a crucial element of the economy and development of regions. However, its dramatic growth in the road sector is rapidly offsetting the benefits through such impacts as congestion, noise, pollution, and environmental damage. Alternative transportation solutions such as a combined transportation network can help to reduce these impacts. To make transportation more efficient in the entire logistic chain, different modes of transportation are used, depending on availability, capacity, and costs. The transportation market is moving toward intermodal transportation since it combines several modes into a continuously integrated system that can provide a more reliable, profitable, flexible, and sustainable service concerning classical unimodal transportation. The intermodal solution consists of taking advantage of the operational benefits (as cost, capacity, flexibility, and environmental sustainability) of transportation modes, then merging them into a single transportation chain.

Rail intermodal is the long-haul movement of shipping containers and truck trailers by rail. It is combined with a truck or water movement at one or both ends. Container rail-water intermodal transportation broadly means with the premise of rail transportation and water transportation as the main, compatible with other modes of transportation to accomplish the complete transfer of the containers. It is the form of rail transportation organization that focuses on collecting and distributing port containers and takes ports as the origin and destination of transportation. For a long time, the railway has operated mainly on the narrow concept which led to limited operation and the lack of competition. America's economy is growing, and the need to move more freight will grow, too. Recent forecasts from the Federal Highway Administration (FHWA) found that total freight shipments in the U.S will rise from an estimated 18.6 billion tons in 2018 to 24.1 billion tons in 2040, which is a 30 percent increase. The domestic share of intermodal traffic is more extensive than once because large freight volumes used to be moved solely by truck have been converted to rail intermodal. Containers accounted for 47 percent of intermodal volume in 1990, 69 percent in 2000, and 92 percent in 2019. Unlike trailers, containers can be "double stacked," sharply increasing intermodal rail productivity and helping to ensure there is sufficient traffic density to keep rail intermodal cost-competitive with all-truck movements.

With the increased traffic in the maritime ports in the United States, the traffic congestion in the highways associated with the ports is likely to be increased simultaneously. The growing numbers will slowly captivate the capacity of the roads, and truck movements will be a significant burden on the economy, causing delays and money. The intermodal rail system can be the perfect substitute for reducing congestion while coping with the increasing demand for freight in the maritime ports. According to the National Freight Strategic Plan forecast, the rail freight movement will increase almost 25 percent in 2045 from what it was in 2020. FHWA in 2017 released a study of intermodal freight connectors, which found that, in 2013, trucks experienced more than one million hours of delay annually on intermodal freight connectors nationwide. The study also modeled nationwide results showing that intermodal port connectors accounted for 37 percent of the total costs of delay on intermodal freight connectors, followed by airports and intermodal rail connectors with 32 percent and 23 percent, respectively. Although the rail intermodal is not free from the fault of delay, with the right kind of planning, it can provide the best possible solution to freight congestion. Additional to this benefit, rail intermodal can provide the advantage of being fuel-efficient, proving it more valuable when it comes to being environmentally friendly. By moving long-distance freight from the highway to rail rights-of-way, more existing highway capacity is left for use for personal travel in automobiles and light trucks and local delivery of goods. While not every freight commodity is conducive to being shipped by container, those can often be transported for most of their total movement by rail just as efficiently as by truck. It is eminent that the ports with growing traffic should adapt the rail intermodal system more efficiently than ever to be able to handle the emerging growth of export and import in the maritime ports.

1.2 Research Goal and Objectives

The Port of Houston is currently the 6th ranked U.S. container port by total TEU (twenty-foot equivalent unit) and it is the largest gulf coast container port, serving 69 percent of the total container traffic. From 2001 to 2020, the container growth both as import and export increased over 200 percent (POH Website). As a fast-growing port, the Port of Houston Authority was the first to introduce double-stack rail cargo and has always been a forerunner among other ports. Additionally, it has grown to be an important port because of its large tonnage handling capacity and its impact on the nation's economy. The Port of Houston operates a vessel-to-rail intermodal system which would be a good case study for the intermodal vessel-to-rail connectivity analysis. With the growth in the economy which results in increased port activities, like every other port in the U.S., the Port of Houston is gradually approaching capacity and sees the need for expansion of infrastructure needed for service efficiency provided. The intermodal system will require advancement since there will be the need for a corresponding ability to serve this expected growth.

This report aims to evaluate the efficiency of the Vessel-to-Rail Intermodal operation of the Port of Houston and recommend effective measures to ensure the system's competitiveness in handling and servicing future economic growth. To fulfill this goal, the following objectives are set-

- Identify the critical components of a Vessel-to-Rail Intermodal system,
- Analyze the significance of the components,
- Compare the competitiveness of the Port of Houston among the similar ports,
- Pinpoint the gap between the existing condition of the POH and state of the art practices,
- Evaluating the feasibility of the Rail Intermodal System compared to the truck freight of the Port of Houston.

1.3 Expected Contribution

To accomplish the objectives of the study, several tasks have been undertaken to investigate the importance of each aspect of Vessel-to-Rail Intermodal system in the Port of Houston. The findings of this research will help future to predict hourly ridership, choose future station locations and improve and rebalance the bicycle efficiency in large cities.

1.4 Report Overview

The remainder of this report is organized as follows: Chapter 2 provides background information regarding intermodal transportation in general and the different components of the vessel-rail intermodal system. Chapter 3 presents additional information related to the Port of Houston and describes the state of art practices and the idea to analyze the feasibility of rail intermodal against trucks. Chapter 4 summarizes the analysis results of the thesis based on the data and information gathered within the process. Chapter 5 concludes with a summary, discusses the directions for future research, and recommends improvement tactics for the Rail Intermodal System to be more competent.

Chapter 2. Literature Review

Before analyzing the vessel-to-rail intermodal system of the Port of Houston to measure its competitiveness with similar ports, it is important to have an understanding of the intermodal operation and how it works in maritime ports. Chapter 2 will provide a brief description of intermodal transportation, its advantage over other types of transportation, various elements of the system, and the basic structure and activities of a typical marine container terminal.

2.1 Intermodal Transportation

Intermodal transportation uses two or more modes, or carriers, to transport goods (freight) from shipper to consignee. In other words, intermodal freight transportation involves the hauling of freight in an intermodal container or vehicle, using multiple modes of transportation without changing modes. Special standardized containers are used for intermodal transportation of cargo on trucks, freight trains, and ships. Generally, intermodal transportation is the best fit when the following conditions are in motion:

- Intermodal transportation is appropriate for shipping intermediate and finished goods.
- Packages are in load units of less than 25 tons.
- The longer distance a consignment needs to move, the more likely it is that intermodal will be a better choice. Freight that moves more than 300 miles, or longer per day, are great candidates for intermodal transportation.
- Cargo with intermediate values is most likely to be suitable to be moved via intermodal.
- Intermodal transportation should be preferred when cargo flow needs to be uninterrupted. For example, sending multiple less-than-truckload (LTL) shipments to the same location throughout the week, the intermodal freight should be considered.

The intermodal process starts with an empty truck arriving at the consignee point. The shipper or transporter in charge loads the container at the back of the truck. It is also possible that the goods can be transferred directly from the ship to a rail/barge depending on the available facility of the port. Until they reach their destination, nobody will likely to handle these goods from this point. The goods travel to a rail yard, truck terminal, or barge station through the road network. Here, the logistics company moves the containers onto another medium of transportation. That mode might transfer the container to a railroad station in the destination city or go to a shipping port. The shipping company moves these containers through the maritime network to the destination. The container is unloaded in the port and transferred to another truck. They may put it on another train for more inland transportation and then to the truck. This truck may deliver the container to its final destination.

2.2 Advantages of Intermodal Freight Transportation

A company can reduce delivery times by using intermodal freight transportation. The use of containers also allows an effective relocation of goods from one mode of transportation to another. Since it deducts time in loading and unloading multiple times, the process subsequently saves time. In addition to that, shippers enjoy lower prices, along with low handling costs, since the loading/unloading is less than usual. Most industries use intermodal transfer, and it is simple to achieve economies of scale and ensure increased capacity. The process allows companies to use reverse logistics to fill up large containers. The containers do not need handling during shifting between the modes of transport. The use of containers limits the risk of damage to the goods. Besides, a certain level of security is ensured when they are in transit. Using containers reduces the chances of theft. Finally, intermodal transportation has proven to be eco-friendly over the years. Reducing a shipment's carbon footprint minimizes the environmental damage it causes.

2.3 Disadvantages of Intermodal Freight Transportation

Reducing cost through intermodal transportation largely depends on the product's structure. Usually, the containers are heavy, which needs various cranes for transferring from one to another leading to higher infrastructure costs. In addition, additional facilities might need to be designed to ensure an efficient system, which also adds to the infrastructural cost. Although many companies prefer intermodal transportation because of its low cost, it can sometimes be slower in some situations. For example, the railroad may not offer direct routes to all destinations, thus increasing the delivery time. Intermodal transportation depends on more than one transit mode, making it prone to chain breaking at some point. Besides, different businesses may be in charge of transport, which requires more logistical coordination and increases risk. Some or many modes of transportation can be impacted by adverse weather conditions, which can also be another cause of delay.

2.4 Vessel-to-Rail Freight Intermodal System

Modern logistics is a new type of integrated management based on customers' needs and combines various logistic activities. Rail intermodal is the long-haul shipping containers combined with a truck or water movement at one or both ends. Intermodal allows railroads, ocean carriers, trucking companies, and intermodal customers to take advantage of the best attributes of various transportation modes to produce an efficient and cost-effective overall freight movement. Container rail-water intermodal transportation broadly means with the premise of rail transportation and water transportation as the main, compatible with other modes of transportation to accomplish the complete transfer of the containers. It is the form of rail transportation organization that focuses on collecting and distributing port containers and takes ports as the origin and destination of transportation. For a long time, the railway has operated mainly on the narrow concept that led to limited operation and competition.

When rethinking logistics strategies, the primary two questions are: "How can this benefit my business?" and "What is the value proposition?". In answer to these questions, the following benefits of vessel-to-rail connectivity can be used:

- **Lower costs:** Shippers can enjoy lower rates, more predictable pricing, and the flexibility of loading and unloading goods in a dropped trailer environment, which reduces the handling costs. On average, railroads are three to four times more fuel-efficient than trucks, meaning that higher fuel prices put trucks at a relative disadvantage vis-à-vis railroads.
- **Environmentally friendly:** Trains only emit approximately 5.4 pounds of carbon dioxide per 100 ton-miles, whereas trucks emit about 19.8 pounds. One train, on average, can move one ton more than 470 miles on one gallon of fuel which lowers greenhouse gas emissions by 75 percent comparative to Trucks (AAR-American Association of Railroads). Therefore, Shippers can significantly reduce their carbon footprint by going intermodal,
- **Reliability, capacity, and safety advantages:** Shippers have more access to equipment and standardized transit schedules. As companies move their freight to intermodal, there is also the opportunity to streamline their reverse logistics, providing additional savings.

The need for moving more freights will grow with the growth of the US economy. Recent studies by the FHWA found that total U.S. freight shipments will increase by 30 percent in 2040. The domestic share of intermodal traffic is more significant than once because the large volumes of freight used to be moved solely by truck have been converted to rail intermodal. Containers accounted for 47 percent of intermodal volume in 1990, 69 percent in 2000, and 92 percent in 2019(The US Bureau of Transportation Statistics). Unlike trailers, containers can be "double stacked," sharply increasing intermodal rail productivity and helping to ensure there is sufficient traffic density to keep rail intermodal cost-competitive with all-truck movements.

2.5 Elements of Vessel-Rail Intermodal System

2.5.1 Container

An intermodal container is a large standardized shipping unit that is designed and built for intermodal freight transportation. Such containers can be used across different modes of transportation – from ship to rail to truck – without unloading and reloading their cargoes. Intermodal containers are primarily used to store and transport materials and products. It is an efficient and secure way to transport goods in the global containerized intermodal freight transportation system, but smaller numbers in regional use. Their dimensions are standardized by the International Standards Organization (ISO), and most containers are 20 or 40 feet (Huynh, 2005). Figure 2.1 refers to a typical 20-foot container. The term TEU (twenty-foot equivalent unit) refers to one container with a length of twenty feet.

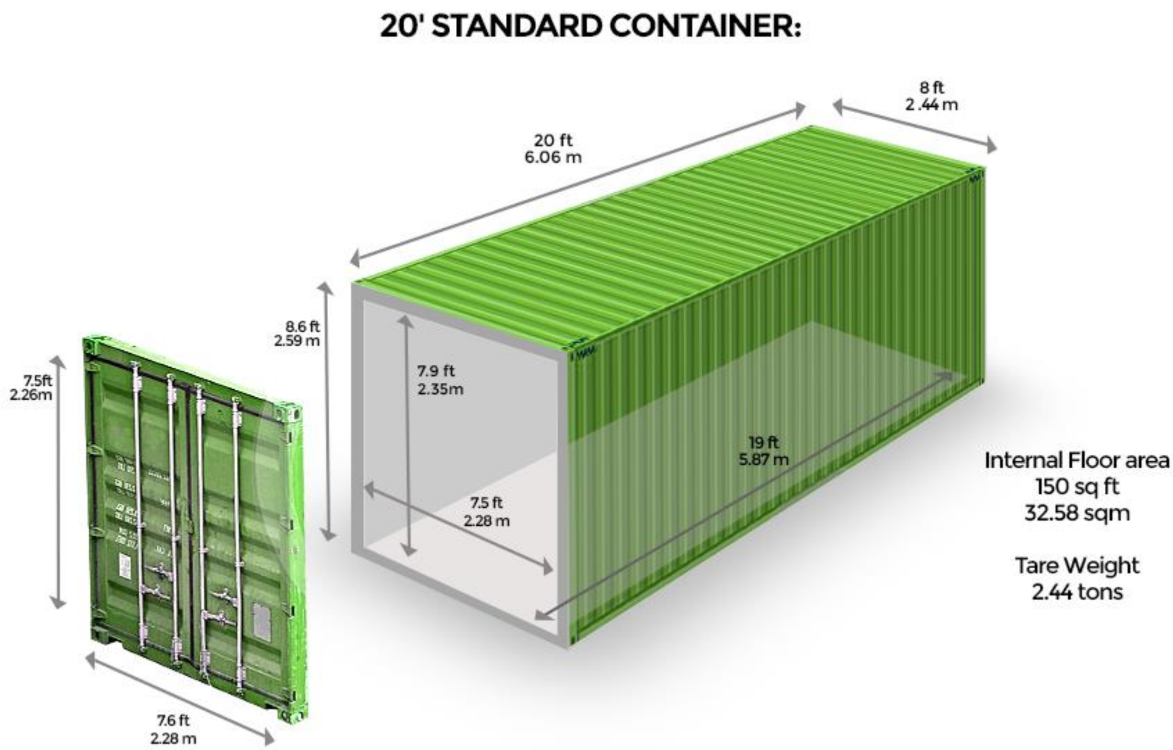

Figure 2.1: Standard Twenty-Feet Container (Source: Google Image)

2.5.2 Container Crane

Cranes are used for loading/ unloading containers on/from ships, organizing and stacking them (they are also used for the stranding of ships, dry storage, ship repair, or auxiliary operations). Depending on the type of transfer required for the freight, container cranes can be of different kinds. Container cranes have a supporting framework that can navigate the length of a quay or yard on a rail track. Instead of a hook, they are equipped with a specialized handling tool called a spreader. Cranes usually transport a single container at once. Some advanced cranes can pick up two to four 20-foot containers at once. Technological advancement of the container cranes affects the overall performance of the vessel-rail intermodal system and thus plays a pivotal role in the process.

2.5.2.1 Wharf Crane

Gantry (or wharf) crane is a large dockside crane used at container terminals for loading and unloading intermodal containers on/from container ships. Gantry cranes are positioned on the shore and can slide back and forth along a track as it works a vessel. They can lift anywhere from 40 to 100 tons and load or discharge between 25 to 50 containers per hour. These wharf cranes can process two containers at once and reach across 22 rows of containers on board a ship; that is, they have an outreach of 60 meters or more (Azab, 2016). There are different types of Gantry cranes depending on their lifting ability. The principal kinds are Panamax, Post-Panamax, and Super Post-Panamax. A Panamax crane can completely load and unload containers from a Panamax class container ship. These ships can pass through the Panama Canal, consisting of 12 to 13 containers in width. A Post-Panamax crane is a crane that can help a ship with 18 container width load and unload efficiently. A Super Post-Panamax crane is the heaviest of all cranes weighing almost 1,600 - 2,000 tonnes. The largest Super Post-Panamax cranes have an outreach of 26 container rows. Figure 2.2 shows the ship-to-shore gantry cranes which are used in marine terminals to load or unload container ships.

Figure 2.2: Ship-to-Shore Gantry Cranes (Source: Google Image)

2.5.2.2 Rubber Tire Gantry Crane

Rubber Tire Gantry (RTG) crane is a mobile gantry crane that is used in intermodal freight operations to ground or stack containers in the ports. RTGs typically straddle multiple lanes, with one lane reserved for container transfers. It provides mobility in the container's moving process, which helps to place the containers conveniently. RTGs are often run by diesel generator systems or three-phase current. RTG crane is suitable for spans of between five and eight containers wide and lifting height of 1 over 3 to 1 over six containers high. Figure 2.3 shows an RTG crane.

Figure 2.3: Rubber Tire Gantry (RTG) Crane (Source: Google Image/free3d.com)

2.5.2.3 Reach Stacker

A reach stacker is used for handling intermodal containers in port terminals. Reach stackers can transport a container short distances very quickly and piling them in various rows depending on its access. Compared to forklift trucks, Reach stackers have a more significant role in container handling in most ports because of their flexibility and higher stacking and storage capacity. Using reach stackers, container blocks can be kept 4-deep due to second-row access. They can also be used as empty stackers or empty container handlers to handle empty containers quickly and efficiently. Figure 2.4 shows a reach stacker in a port.

Figure 2.4: Reach Stacker (Source: Wikipedia)

2.5.2.4 Yard Truck

A yard truck is a vehicle used for moving trailers in or around commercial freight yards. It has been constructed to accommodate a hydraulic lifting fifth wheel allowing the operator to move trailers without exiting the cab or cranking the landing gear. Once a trailer has been moved, the operator can lower the trailer back to the ground and uncouple the fifth wheel without leaving the cab. A yard truck can normally move three units in the same amount of time that a standard tractor would move one unit. Unlike regular trucks that can travel on the road, yard trucks can only operate within the terminal (Azab, 2016).

2.6 Vessel-to-Rail Transfer Process

When a ship arrives at a terminal, import containers are unloaded by wharf or ship to shore cranes, which remove the containers from the ship's hold or deck and place them onto yard trucks, also known as vessel trucks. After receiving the container, the yard truck moves to the stack. The yard cranes then take the container off the yard trucks and store it in the stack. After a certain period, the containers are retrieved from the stack by the yard cranes and placed onto road trucks or trains for delivery to the recipient. The process is reversed for an export container. The container transferring process is shown in Figure 2.5.

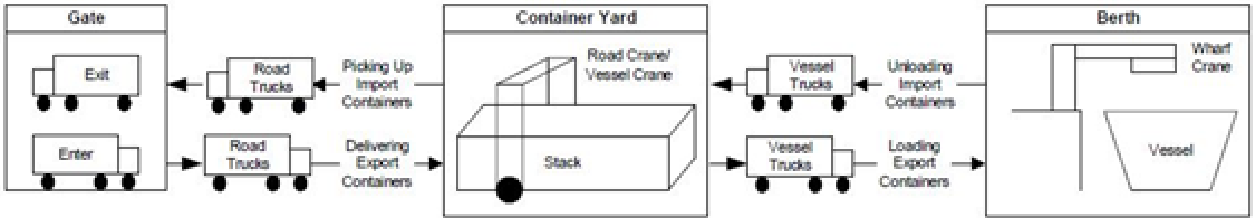

Figure 2.5: Container Transfer Process in Port Terminal (Source: Hyunh et al., 2005)

2.7 Rail Intermodal Yards

The core of the vessel-to-rail process is the Rail Intermodal Yards, where unit trains are loaded and unloaded by RTG or lift cranes from the yard trucks. The efficacy of the vessel-rail intermodal transportation system is analytically reliant on the progression by which marine cargoes are moved between ship and rail. The vessel-to-rail transfer process generally takes place in the intermodal rail yards. These yards are commonly categorized according to their relative location. The factors which should be considered along with the location of the yards are yard configuration, handling equipment, labor cost, type of traffic, operating system, and so on.

2.7.1 On-Dock Intermodal Container Yard

On-Dock Intermodal Container Yard refers to a container yard that is situated within the port area. Containers are offloaded from ships and moved to the on-dock container yard using straddle carriers or trucks and stored there until receivers deliver the cargoes. On-dock intermodal yards can be of different configurations.

2.7.1.1 Live On-Dock Intermodal Yard

When an intermodal yard is an essential part of a container yard and generally handles cargo containers in the same way, it is called a Live On-Dock Intermodal Yard. In this process, the same yard equipment is used in the container yard. In an RTG-based yard system, the boxes are transferred directly from the ship to the RTG without any intermediate storage either at the container yard or special buffer storage near the working tracks. The location of the working tracks is usually in between the container yard stacks. Since this configuration handles the cargo boxes from ship to the rail without any intermediate storage place, it is called Live On-Dock Intermodal Container Yard. This system is operationally considered efficient as it disregards additional lifting equipment and storage space for the cargo boxes. It is the fastest system that can handle the ship-to-rail process. However, it requires all the boxes to be customs pre-cleared, and the ship stowage is aligned with the rail stowage. To perceive the true advantage of this system, the unit trains are required to be dedicated and line-controlled.

2.7.1.2 Drop On-Dock Intermodal Yard

When an intermodal yard is inside the marine terminal but physically separated from the container yard, it is called a Drop On-Dock Intermodal Yard. In this system, the working tracks are located at the back of the terminal, and hence the transfer from ship to rail is indirect. The cargo boxes are stored in the container yard at first. After getting clearance from the customs, the boxes are released and transferred to the intermodal yard, loaded on rail cars by yard equipment.

Drop On-dock has the disadvantage of requiring an extra in terminal drayage compared to the live on-dock system. For a large terminal, this may involve covering a long distance and extra lift to and from the container yard stack, resulting in more cost. Another setback of this system is the longer processing time for customs clearance than the live on-dock system.

2.7.1.3 Double Storage On-Dock Intermodal Yard

Double Storage On-Dock Intermodal Yard is a sub-form of the drop-on-dock system. The only exception is that the boxes brought from the container yard are first placed in temporary storage at the intermodal yard. The temporary storage at the intermodal yard serves as a transitional buffer intended to enable cargo handling in the railcars. It reduces the waiting time for the handlers in the intermodal yard.

2.7.1.4 Advantage and Disadvantage of On-Dock Yard

The principal advantage of the On-Dock Intermodal Yard over the other two configurations is that the process is quick and efficient since it shortens the drayage. Therefore, it eventually reduces the overall transit time. The drawbacks of the on-dock system are as follows:

- The switching of trains to the marine terminals is performed by local service railroads, leading to additional costs and time.
- The road traffic of the marine terminals, which are located in the middle of the urban areas, is often interrupted by the switching trains.
- On-Dock Intermodal Yards ask for a large area of valued waterfront land, which could be used as a container yard instead. Additional container yard space increases the capacity of the marine terminal.
- On-Dock Intermodal Yards are usually small in size due to the obligation imposed by the shortage of space at marine terminals and the inability to incorporate long working tracks.
- The operation of On-Dock Intermodal Yards can be inefficient in terms of rail operation and cargo box handling due to their small size.

2.7.2 Near-Dock Intermodal Yard

2.7.2.1 Near-Dock Adjacent Intermodal Yard

Near-Dock Adjacent Intermodal Yards are usually located outside marine terminals and customs areas. These yards are often larger than the on-dock ones since it is hard to acquire ample space within the marine terminals. The advantages of this configuration are as follows:

- Since the intermodal yard is outside the marine terminal, it can serve several or even all the marine terminals in the port area.
- This configuration can save on cost and time if the yard is within the port's general area, enabling the hustlers to perform the drayage from the marine terminals that can be well-coordinated.
- Additional savings are possible if special gates can be arranged for processing the traffic to avoid waiting with the general traffic.

2.7.2.2 Near-Dock Non-Adjacent Intermodal Yard

This intermodal yard is the same as the Near-Dock Adjacent one except for the fact that the intermodal yard is located outside the port area. More often, it is located within a less than the five-mile radius. The drayage is mostly on public roads and requires using outside trucks. The traffic is generally processed through a regular gate. It also follows the regular checking of cargo documents and preparing an equipment interchange report similar to the process of typical dispatch via truck. The advantages of this particular configuration are as follows:

- Near-Dock Non-Adjacent Intermodal Yards allows handling both marine and domestic containers that Near-Dock Adjacent Intermodal Yards do not.
- It lowers the costs by not requiring special processing gates and equipment for its traffic.
- The yard location is away from the terminal, allowing less expensive non-port laborers, saving more money.
- It frees the valuable waterfront land, which can be used for container yards extending the capacity of terminals.
- Non-adjacent intermodal terminals are often larger and more efficient than adjacent terminals.

The main drawbacks of this system are that since the intermodal yard is outside the port area, it requires a higher drayage cost. Due to the long distance and no access to the special processing gate, it tends to take a longer time for the transferring process.

2.7.3 Off-Dock Intermodal Yard

Off-Dock Intermodal Yards can be located up to 20 miles away from a port area. They are quite similar to the Near-Dock Non-Adjacent configuration except for the fact that they are located in a much distant place. Due to the longer distance, cost and time increase simultaneously. The traffic composition handled by such yards is primarily domestic. The main advantage of this system is the large size of the yards.

Additionally, non-port inexpensive labor costs can save more money. This system offers a wider variety of services to domestic and marine terminals. Elimination of rail switching is another merit of this system. The cost savings in switching concerning truck drayage depends upon the number of cars and boxes per switch. The only setback is the extended distance from the port area, which increases the cost and transit time.

2.8 Comparative Analysis on Rail Intermodal Yards

A preliminary comparison can be prepared from the attributes that have already been discussed. It is quite conclusive that the decision of selecting the right system is complex, requires critical and careful observation of all the demand and factors involved, and asks for quantifying the weightage. Feasibility, land use, and financial issues are associated with the supply and demand chain of the maritime ports while choosing the perfect system suitable for any individual case. Table 2.1 shows the comparison of key attributes in port-related intermodal yards.

Table 2.1: Comparison of different configurations of Intermodal Yards

Configuration	Nature	Location	Traffic	Equipment
Live On-Dock	Live	Inside the customs area and within the terminal gate	International	Marine terminal
Drop On-Dock	Buffer	Inside the customs area and within the terminal gate	International	Marine Terminal
Double Storage On-Dock	Two-Stage	Inside the customs area and within the terminal gate	International	Marine Terminal
Near-Dock Adjacent	Two-Stage	Less than a one-mile radius	International	Marine Terminal
Near Dock Non-Adjacent	Two-Stage	1 to 5 miles away	Domestic	Non-Marine Terminal
Off-Dock	Two-stage	More than 5 miles away	Mainly Domestic	Non-Marine Terminal

To summarize the classification of intermodal rail yards, figure 2.6 illustrates the difference between each setting-

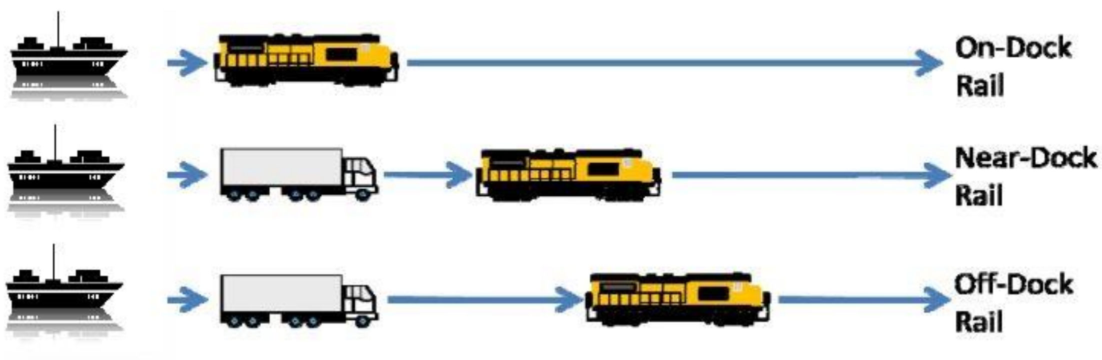

Figure 2.6: Different Rail Intermodal Yard Setting

2.9 Railroad Classification

The U.S. freight rail network runs on almost 140,000 route miles and is also considered the most cost-efficient rail freight in the world. The freight rail industry is worth around $80 Billion, and it is operated by seven Class-I railroads and 22 Regional and 584 local/Short Line railroads. It offers more than 167,000 jobs across the United States. It provides additional benefits that other modes of transportation cannot do, including reductions in road congestion, highway fatalities, fuel consumption, carbon footprint cost of logistics, and public infrastructure maintenance costs (AAR-Railroads-101).

U.S. freight railroads are owned by private organizations that are responsible for their line maintenance and improvement projects. Railroad owners invest significant revenues in maintaining and adding capacity to their system, spending nearly $25 billion annually, almost 19 percent of the total. The rail network is accounted for approximately 28 percent of U.S. freight movement by ton-miles. Rail is a cost-effective and efficient way to move almost any freight in the United States, which benefits producers and consumers. Rail continues to be unmatched by other modes for fuel efficiency due to technological advancement and innovation. Compared to trucks, Trains are four times more efficient, moving one ton of freight 470 miles on just a single gallon of diesel fuel. Rail's lower fuel consumption also leads to lower carbon emissions overall. Despite handling a third of all intercity freight volume, rail accounts for 2.0 percent of all transportation-related emissions(Source: Freight Rail Overview). The Fuel consumption can be assessed from the following figure.

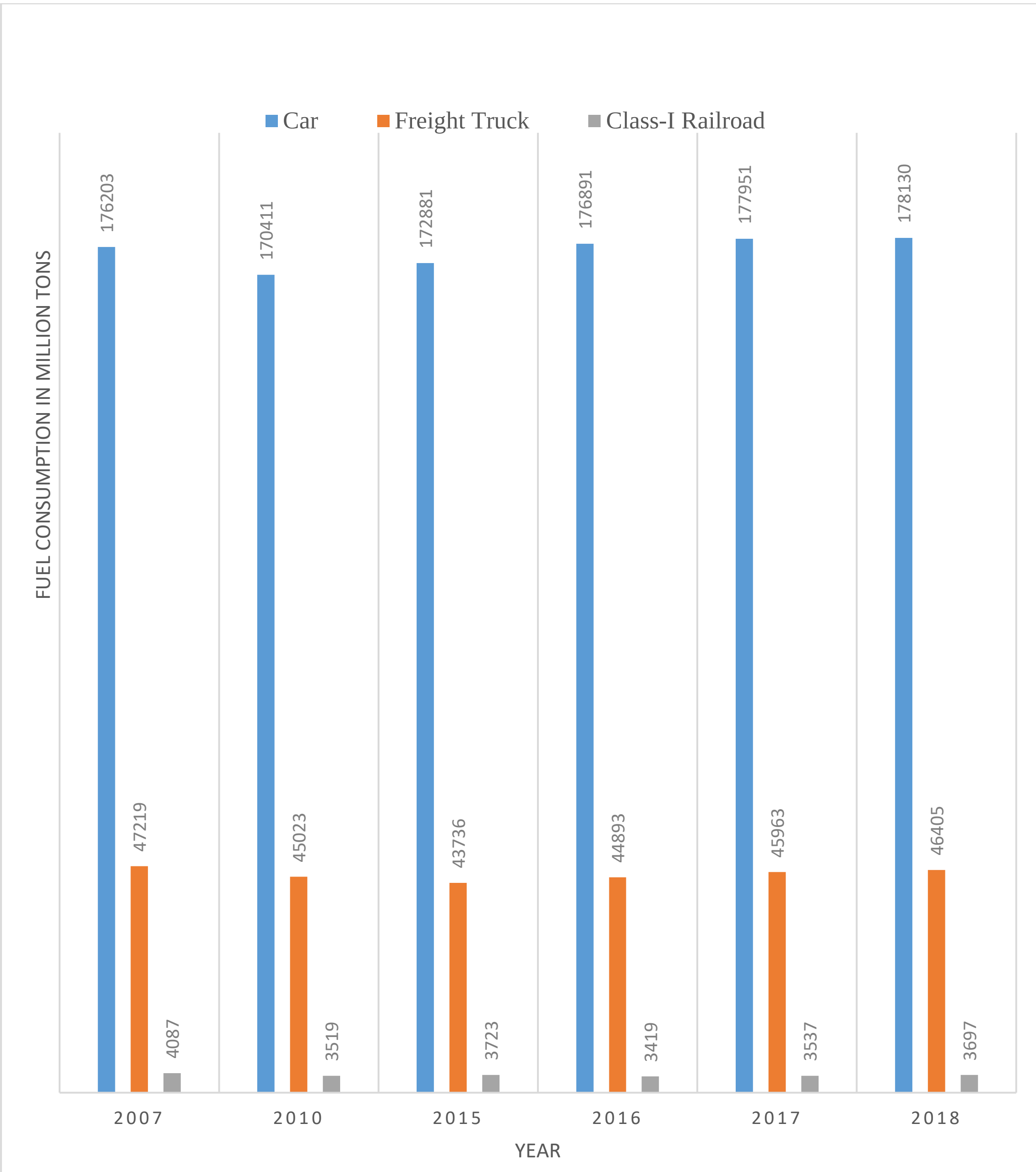

Figure 2.7: Comparison of Fuel Consumption in Different Modes of Transportation (Source: The US Bureau of Transportation Statistics)

Demographic trends and population pose an enormous challenge for the U.S. transportation infrastructure and the freight industry. Forecasts indicate that the United States is becoming more urbanized. Urbanized areas will increasingly converge into more extensive metropolitan networks, also known as megaregions, as the population increases. Consequently, these regions will call for a higher freight volume, which means more significant traffic congestion, increased carbon emissions, more frequent infrastructure maintenance, increased investments, and loss of economic productivity. According to the National Freight Strategic Plan (NFSP), the increase in rail freight and multimodal transportation is gradual, and in 2045, it is forecasted to be increased by 25 percent of what it is now. Figure 2.8 represents the actual forecast of the NFSP.

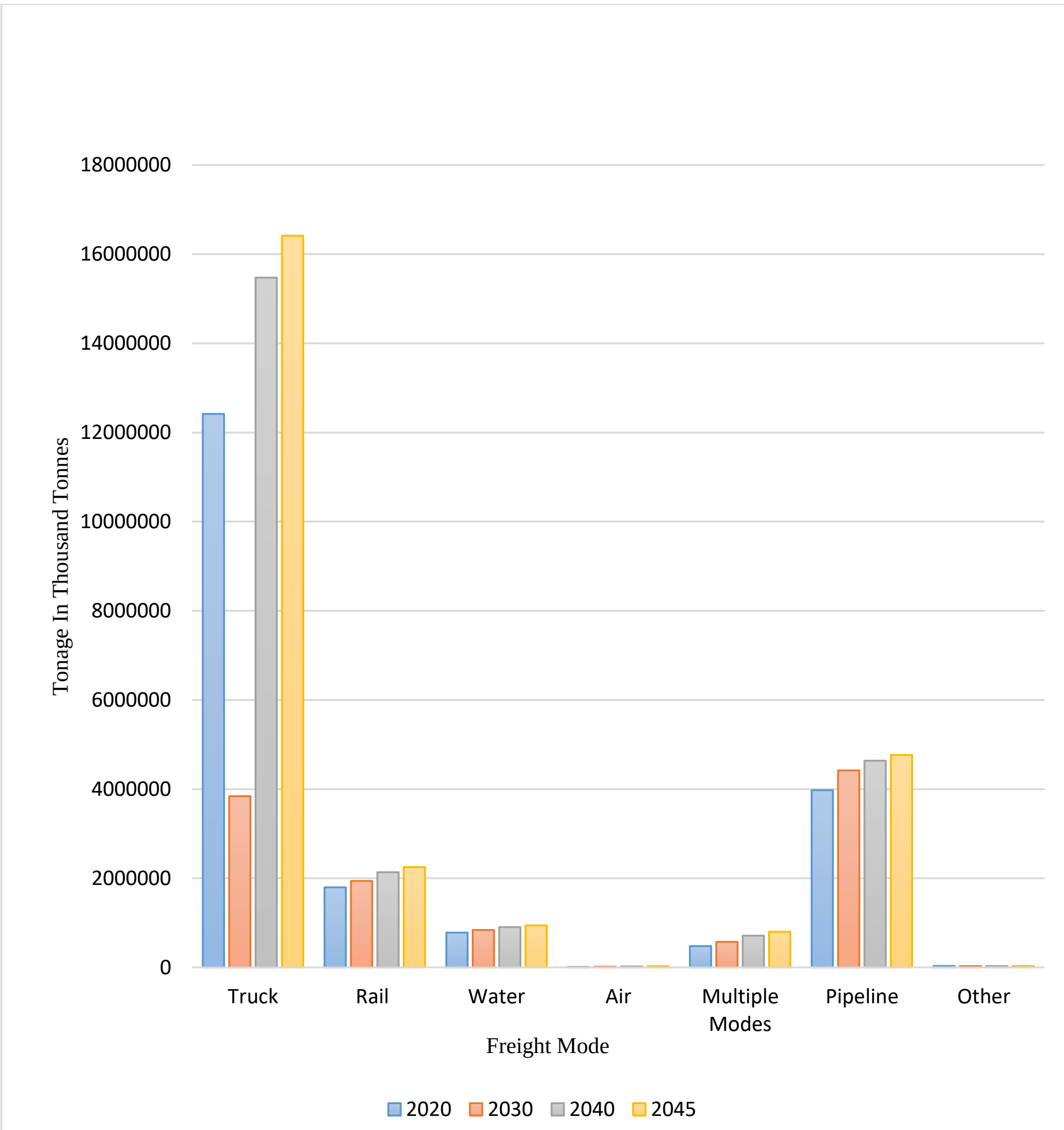

Figure 2.8: Forecast of Freight Transportation (Source: National Freight Strategic Plan)

Freight railroads in the United States should be prepared to meet increased freight demands by offering innovative transportation solutions. One of such is the intermodal transportation with double-stacked containers on railcars. With future population and economic growth, and the subsequent increase in freight, it is anticipated that railroads will keep making the necessary investments in the capacity required to move heavy and long-distance shipments.

Railroads are categorized based on their annual operating revenues. They must have tracking in the United States to fall under the revenue classes. The class to which a carrier fits is determined under the following revenue thresholds:

Class I - $447,621,226 or more. Class-I railroads play the most important role in an intermodal rail freight system since they ship different cargoes beyond state and country. The significance of Class-I railroads lies in their operational capability and financial potency.
Class I Railroads are:

- Amtrak
- BNSF Railway
- Canadian National Railway
- Canadian Pacific Railway
- CSX Transportation
- Kansas City Southern Railway
- Norfolk Southern Railway
- Union Pacific Railroad Company

Class II Railroad: Less than $447,621,226, but in excess of $35,809,698. Also known as Regional railroads.

Class III Railroads: $35,809,698 or less. Also known as Short Line railroad.

Chapter 3. Methodology

This thesis aims to study intermodal vessel-to-rail connectivity at marine ports with a case study of the port of Houston. For this purpose, the vessel-to-rail intermodal status of the contemporary ports will be discussed at length. The vessel-to-rail intermodal system and identifying its components and stakeholders will be crucial in this regard. The thesis will aim at identifying how the port uses the intermodal freight transportation system, how effective it is, and determine where there are gaps or opportunities to improve its use and effectiveness for the port of Houston. In this study, we will compare different aspects of the Rail Intermodal System of different ports with the Port of Houston to evaluate the competency of the system in comparison to others. The aim will be to focus on the state of art practices and finding out the gap in the system to develop a future improvement plan for the port of Houston. At the very least, the thesis will aim at analyzing the relative competitiveness of the Rail Intermodal system with the Truck system for the port of Houston to understand the stakeholder's perspective. In summary, the thesis will attempt to identify what are the different parameters of an intermodal rail system that makes it efficient, what are the key factors those the port of Houston is missing, what are the constraints to achieving the desired accomplishment, how they can be achieved, and lastly, if the Rail system is feasible enough to compete with its most viable alternative that is the Truck Freight.

3.1 Data Collection

In this portion, information and data regarding various components of the vessel-to-rail intermodal system of different ports of the U.S. that are likewise to the Port of Houston will be collected. The data and information will be compared and analyzed to evaluate the efficiency and productivity of the port of Houston. This portion will identify how the port of Houston uses the intermodal freight transportation system, how effective it is, and determine where there are gaps or opportunities to improve its use and effectiveness. The data were collected from verified official websites of the ports and various National Statistics agencies. For the Rail versus Truck feasibility analysis, we will use the distance data for the Rail from the American Railroad Association Map. For the truck, we will use the distance provided by Google Map. At the end of the comparative analysis, recommendations will be produced based on the results obtained from the study to improve the efficiency of the vessel-to-rail intermodal system. Documentation on all research findings and analysis will be made throughout the thesis.

3.2 The Port of Houston

The Port of Houston is a river port on the Gulf of Mexico in Harris County, Texas, and it is one of 10 seaports along Texas' 367-mile-long coastline along the Gulf of Mexico. It is accessed via the Gulf Intercostal Waterway and the Houston Ship Channel, connecting through Galveston Bay, as you see in figure 3.1. The Port of Houston is located about 290 nautical miles northeast of the Texas/Mexican border and about 470 nautical miles from the mouth of the Mississippi River.

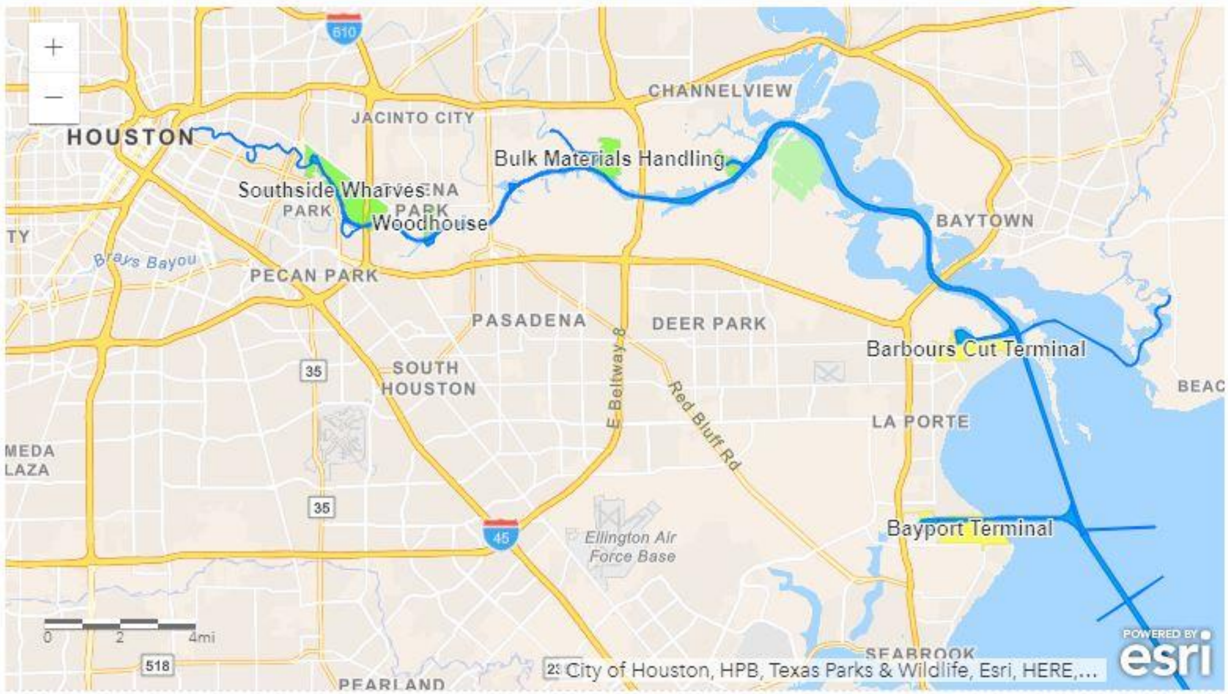

Figure 3.1: Port of Houston (Source: City of Houston GIS File)

Houston is located about 290 nautical miles northeast of the Texas/Mexican border and about 470 nautical miles from the mouth of the Mississippi River. Houston is the largest city in the state and the fourth most populous city in the United States. It is the largest port among the Gulf Coast ports and currently ranks 5th in container volume and 1st in waterborne tonnage. The growth of the port of Houston has been gradual yet steady. The following figure shows the growth of the port of Houston in an articulate way.

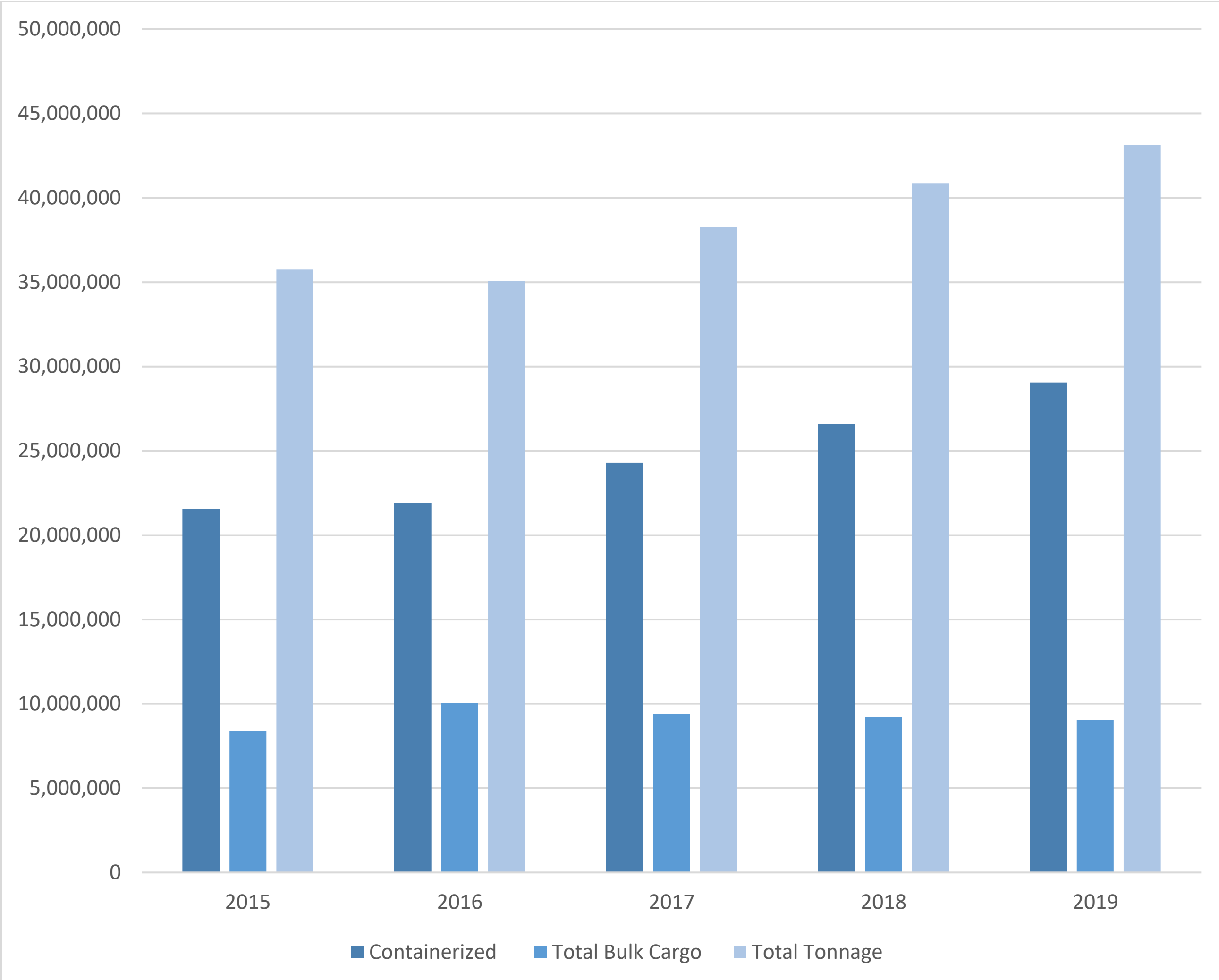

Figure 3.2: Port of Houston Annual Tonnage

The Greater Houston Port Bureau monitors vessel movements into 40 different terminals in the Port of Houston. The two container terminals are located relatively close to the Gulf of Mexico. The majority of the terminals are located in the Bayou part of the Houston Shipping Channel. The most common terminals are bulk liquids terminals handling petrochemical products, chemicals, and edible oils. The multi-purpose terminals process, amongst others, agricultural bulk products, steel products, containers, and ro/ro facilities for cars and heavy equipment.

3.3 PORT OF HOUSTON TERMINALS

3.3.1 BARBOURS CUT CONTAINER TERMINAL

Barbours Cut Container Terminal is owned and operated by the port authority. The terminal is located at the front of Galveston Bay and is 3.5 hours sailing time to open waters of the Gulf of Mexico. It has been entirely operational since 1977 and has grown to be one of the premier container-handling facilities in the U.S. Gulf of Mexico. The terminal has six berths which provide 6,000 feet of the continuous quay. The airport also includes a roll-on/roll-off platform, a lighter aboard ship (LASH) dock for loading barges, 230 acres of paved marshaling area, and 255,000 square feet of warehouse space. Barbours Cut terminal has an intermodal rail service available via the 42-acre near-dock rail ramp with four 2,700 ft working tracks.

The rail facility is located near the Barbours Cut container terminal dock. However, the facility is not operational at this moment. Previously, it was operated by ITS Technologies and Logistics, LLC on contract, and the primary railroad companies were BNSF, Union Pacific, and Port Terminal Railroad Association (PTRA). The last operational intermodal rail route was to Dallas once every week, and in 2019, Union Pacific decided to eliminate their operation in this route. The decision was a strategic one from Union Pacific's point of view since they moved their service to busier routes where there is more volume.

The rail ramp consists of 42.1 acres with four working tracks (each approximately 2,700 feet in length), five storage tracks (each about 2,250 feet in length), and 730 wheeled container spaces. The entire facility is paved with concrete and sustains wheeled operations only. The container handling method is three Mi-Jack 1000R series overhead cranes and each capable of 30 moves per hour.

Plans for this container terminal involve increasing the cargo handling efficiency and capacity by replacing the older Panamax cranes with larger Post-Panamax Ship-to-Shore cranes, lights and dock improvements, and yard reconfiguration. This improvement is expected to increase capacity from 1.2 million to 2 million TEUs when completed.

3.3.2 BAYPORT CONTAINER TERMINAL

Bayport Container Terminal is a major deep-water port in the Greater Houston area. This relatively new terminal, part of the Port of Houston, is designed to handle standardized cargo containers and offload the nearby Barbours Cut Terminal, which has no further room for expansion. The Bayport Terminal is situated along the Bayport Ship Channel off Galveston Bay, between La Porte, Texas, and Seabrook, Texas. This channel itself feeds into the larger Houston Ship Channel, which runs from Houston, through Galveston Bay, to the Gulf of Mexico. This Terminal, which is currently under construction, is considered the most modern and environmentally sensitive container terminal on the U.S. Gulf Coast. This state-of-the-art terminal will have a total of seven container berths with the capacity to handle 2.3 million TEUs on a complex which includes 376 acres of container yard and a 123-acre intermodal facility when the development is completed. The terminal has seven berths, and it features electronic data interchange capabilities and a computerized inventory control system that tracks the status and location of individual containers. Trucking access to and from the terminal gates is continuous, with two dedicated flyover ramps connecting Texas 146 and Port Road. The Bayport Auto Terminal opened for business at the Port of Houston in November 2016. The terminal was initially used for cruise operations but has been re-purposed to accommodate roll-on/roll-off operations for new inbound vehicles for auto distribution.

As part of the expansion plan, Lockwood, Andrews, & Newnam, Inc. (LAN, a consulting firm offering planning, engineering, and program management services) designed a 7,000-foot rail line to provide rail service into the Port of Houston Authority's future Bayport intermodal yard. This line will connect the existing Union Pacific rail corridor and SH 146, providing full rail access to the Port of Houston Authority's container operation. The design included a complete rail plan and profile design following Union Pacific Railroad (UPRR) design criteria and existing industry track turnouts relocation and numerous utility adjustments and significant relocations of the two industrial pipelines. The project included coordination with UPRR, TxDOT, and the City of Seabrook to approve and design signalized quiet zones for three state highway crossings.

3.3.3 BULK MATERIALS HANDLING PLANT TERMINAL

Kinder Morgan currently operates a bulk Material Handling Plant. The terminal has two berths, and the lengths of the berths are 800 ft (Ship Dock) and 400 ft (Barge Dock). The primary cargoes handled by this terminal are dry bulk, petcoke, and coal. PTRA serves the rail service; connects with BNSF and Union Pacific.

3.3.4 RICHARDSON STEEL TERMINAL

Richardson Companies currently operate Richardson Steel Terminal. The terminal has three berths, and the lengths of the berths are 650, 600, and 660 ft. The primary cargoes handled by this terminal are Breakbulk, Project Cargo, Heavy Lift, and roll-on/roll-off. The terminal owns mobile truck cranes up to 300 tons. The Union Pacific serves the rail service**.**

3.3.5 SIMS TERMINAL

TPC Group currently operates Sims Terminal. The terminal has three berths, and the project depth is 40 ft. The primary cargoes handled by this terminal are liquid. This facility services vessels, barges, trucks, and railcars and has certified truck scales and load-on-scale operations. PTRA serves the rail service.

3.3.6 OLD MANCHESTER TERMINAL

Westway Terminals currently operate the old Manchester Terminal. The terminal has two berths, and the project depth is 36 ft. The primary cargoes handled by this terminal are liquid. This facility can service vessels, barges, tank trucks, ISO containers, flex tanks, railcar, and tank storage. The rail service includes BNSF, Kansas City, and Union Pacific.

3.3.7 EMPIRE TERMINAL

Empire Stevedoring currently operates the empire Terminal. It has two berths, and the lengths of the berths are 827 ft. The primary cargoes handled by this terminal are breakbulk, project cargo, heavy lift, and bulk. It has uncovered storage of 8 acres and uncovered storage of 40,00 sq ft. Union Pacific serves the rail service

3.3.8 JACOB STERNS AND SONS

Jacob Sterns and Sons currently operate jacobs Sterns and Sons Terminal. It has three berths, and the project depth is 34 ft. The primary cargoes handled by this terminal are liquid. The facility serves vessels, barges, trucks, and rail cars, and it has certified truck scales and load-on-scale operations. PTRA operates the rail service.

3.3.9 TURNING BASIN TERMINAL

The Port of Houston's authority currently operates Turning Basin Terminal. It has 25 berths, and the length of the berths varies by docks. The channel depth of this terminal is 36 ft, and it has mobile truck cranes up to 300 tons. The primary cargoes handled by this terminal are breakbulk, project cargo, heavy lift, roll-on/roll-off, and U.S. AID cargoes. It has on-dock uncovered storage of 75 acres and covered storage of 27 acres; and off-dock 390 acres and 36 acres. The rail service is served through PTRA; connects to BNSF, Union Pacific, and KCS.

3.3.10 JACINTO PORT TERMINAL

Jacinto port Terminal is currently operated by Jacinto port International. The terminal has three berths, and the length of the berths are 660, 636, and 600 ft. The primary cargoes handled by this terminal are container, breakbulk, project cargo, and US Aid cargoes. It has uncovered storage of 7.5 acres and covered storage of 719,500 sq ft, including the refrigerator facility. The rail service is served through PTRA; connects to BNSF, Union Pacific, and KCS.

3.3.11 CARE TERMINAL

Gulf Stream Marine currently operates the Care Terminal. It has two berths, and the lengths of the berths are 500 ft and 618 ft. The primary cargoes handled by this terminal are breakbulk, project cargo, heavy lift, and bulk. The terminal has uncovered storage of 15 acres which is fully paved. PTRA serves the rail service; connects with BNSF and Union Pacific.

3.4 Highway Access

The Port of Houston is accessed by multiple major highways, including four interstate highways: I-10, I-45, I-69, and the I-610 Loop. In 2010, there were about 10,000 trucks per day serving the port. By 2015, according to the Economic Alliance Houston Port Regions, that number had grown to 25,000 to 30,000 trucks per day using the same roads. With increasing trade and cargo passing through the port, especially with commodities that move predominantly by road, such as containers, the number of trucks could significantly increase.

There is significant competition for road space between commuter and freight journeys in the port area. The competition has led to traffic congestion during peak commuter periods that coincide with port traffic. Even though Houston is a diversified port handling mostly petroleum-based tonnage, much port-related traffic is related to containerized cargo. While Houston’s container terminals typically have a 25-minute truck turnaround, the overall journey time for trucks serving the container terminals can be much longer due to the traffic and highway congesti

3.5 Railway Facility

The port terminals contain access to three Class I railroads and direct pipeline network access. Formed in 1924, the Port Terminal Railroad Association (PTRA) is made up of the Port of Houston Authority of Harris County, Houston Belt & Terminal Railway Co., and three Class I railroads, Union Pacific Railroad, BNSF Railway, and Kansas City Southern Railway Company (Figure 2-34). Operating on both sides of the Ship Channel, the PTRA has a total Yard Capacity of 5,000 railcars and pulls an average of 2,500 cars per day. The PTRA serves226 local customers from 7 serving yards and maintains 154 miles of track and 20 bridges. They can serve the entire U.S., Canada, and Mexico through their interchange connections. The Barbours Cut container terminal is adjacent to a rail ramp, as shown in Figure 3.3.

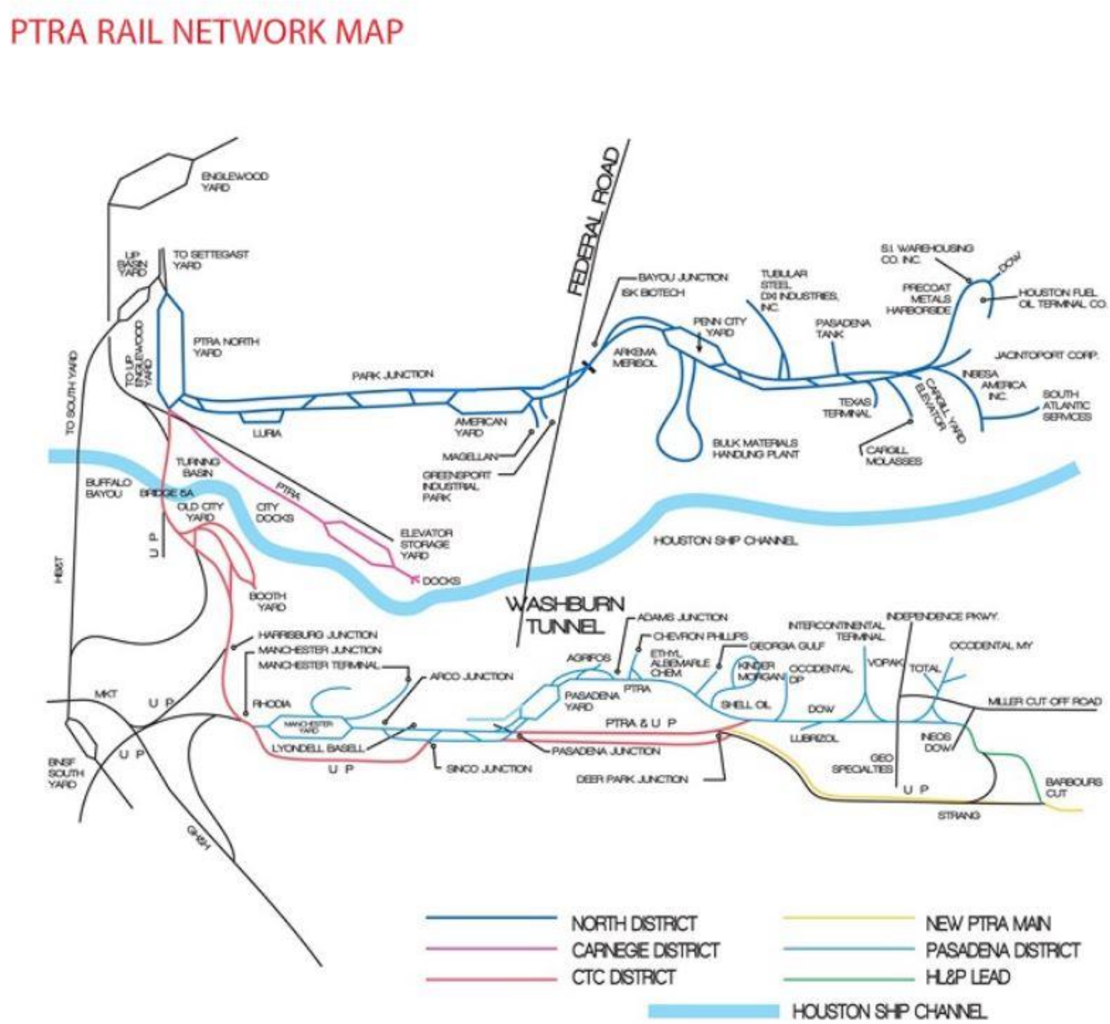

Figure 3.3: PTRA Rail Network (Source: PTRA Website)

The PTRA rail network consists of 42.1 acres with four working tracks (each approximately 2,700 feet in length), five storage tracks (each about 2,250 feet in length), and 730 wheeled container spaces. The entire facility is paved with concrete and sustains wheeled operations only. The container handling method is three Mi-Jack 1000R series overhead cranes and each capable of 30 moves per hour. PTRA has a total capacity of 5000 trailers in their yards. On an average day, PTRA pulls 2500 industry cars from 7 serving yards.

3.6 State of the Art Practices

The Port of Los Angeles is currently the largest port in the United States. The port was founded in 1907, and it possesses 43 miles of waterfront land. It has been the busiest container port in the western hemisphere for the past 20 years. In 2019, the Port of Los Angeles handled a total of 207.3 million metric revenue tons (MMRT), and the annual cargo value was $276 billion. It has 17 percent of the total market share of the United States and 40 percent of the west coast's market share. The Port of Los Angeles has created jobs for 150,000 in Los Angeles and 1.6 Million throughout the United States.

The Port of Los Angeles has America's most extensive and modern network of on-dock and near-dock rail services connecting the U.S. imports and exports to international markets. About 35 percent of intermodal containers utilize the port's rail network, including one near-dock rail yard and five on-dock rail yards that serve eight container terminals. The port's rail infrastructure consists of more than 65 miles of on-dock track for building and sorting double-stack trains. The average train consists of 30 double-stack cars, eliminating approximately 400 truck trips and related air pollution on each run. The port also has five off-dock mainline rail yards – three operated by Union Pacific Railroad and two operated by BNSF.

Approximately 26 percent of all cargo moving through the port utilizes the on-dock rail network. Pacific Harbor Line Inc. (PHL) is the short-line railroad that builds the on-dock trains and operates the intermodal rail network for the entire San Pedro Bay port complex. Using the Centralized Traffic Control (CTC) System, PHL manages all rail dispatching, switching, and maintenance services to ensure the safe, efficient movement of inbound and outbound train traffic.

The port's largest on-dock rail yard is located at the port's largest container terminal. APM Terminals and California United Terminals share the 484-acre Pier 400. The 48-acre intermodal facility offers 12 loading tracks, each approximately 2,450 feet long. Each track can handle eight 305-foot-long double-stack rail cars for a total capacity of 96 rail cars. It has six adjacent storage tracks, every 6,550 feet in length. Each of them can handle 21 305-foot-long double-stack rail cars for a total capacity of 126 rail cars. Tra-Pac On-dock Intermodal Facility was opened in 2016, and it is the newest and most technologically advanced on-dock rail facility at the Port of Los Angeles. The automated high-tech rail yard uses an integrated network of laser, a differential global positioning system (DGPS), and magnetic technologies to operate state-of-the-art rail-mounted gantry cranes that transfer containers to and from rail cars. It has eight working tracks on concrete ties, each approximately 2,600 feet long, and the loading and stacking tracks totaling about 16,200 feet. The rail yard is equipped with a 136-foot gauge rail-mounted gantry crane rail foundation and a Train-In-Motion system.

The near-dock rail yard is located approximately five miles north of the Ports of Los Angeles and Long Beach. The yard is operated by Union Pacific Railroad, and it serves both the ports, handling more than about 367,400 containers in 2015. It has sufficient land for a 250-acre rail yard operation, with on-site storage for more than 3,000 containers. The yard currently has six rubber-tire gantry overhead cranes and a side pick loader for lifting cargo containers. The port has invested more than $300 million over the ten years in railway-roadway grade separations and rail system projects to reduce truck trips and optimize cargo flow.

The Port Charleston in South Carolina is the fourth-largest port on the U.S. East Coast. The annual throughput in 2019 was 1.78 Million TEU, and 23.5 percent of the total TEU was handled by rail. The Port of Charleston has three container terminals, amongst which the Wando terminal does not have any rail connection. The other two terminals both have on-dock rail trackage. Between the two of them, Columbus street is a smaller facility with very limited rail trackage. The North Charleston is the only Charleston terminal with significant on-dock rail trackage totaling almost 2,500 ft and 185 acres. The berths are equipped with six gantry cranes, four of which are Post-Panamax. The port is connected to two class-I railroads, CSX and Norfolk Southern. The North Charleston Marine terminal has a well-designed and efficient on-dock intermodal yard consisting of two 1500 ft tracks. The capacity of the on-dock yard is limited, with an approximate estimate of 20,000 moves annually.

The Port of Jacksonville offers two Class-I railroads, CSX and Norfolk Southern, and regional railroad Florida East Coast Railway. It has three marine terminals and two intermodal container transfer facilities – one on-dock Intermodal Container Transfer Facility (ICTF) at the Talleyrand Marine Terminal; and one near-dock ICTF at the Dames Point Marine Terminal. The Talleyrand Marine Terminal has on-dock facilities run by Talleyrand terminal railroad inc. It is providing direct switching for Norfolk Southern and CSX. This terminal has 173 acres of land and 38 ft of water-side depth. It is equipped with six container cranes, two RTGs, one multi-purpose whirly crane, and three 40 ton container stackers.

The Port of Savannah is comprised of two terminals that serve 4.2 million TEU annually. The port is owned and operated by the Georgia Port Authority. Among the two terminals, Garden City is the largest terminal in the U.S., with a total area of 1,200 acres. The complete berth line is 9,700 ft equating a total of nine berths. The terminal has 18 gantry cranes, eight of which are Super Post-Panamax. The Ocean Terminal is a multi-purpose terminal that handles rolling and breakbulk cargoes. The Port of Savannah is equipped with 30 container cranes, 146 RTG cranes, and two miles of uninterrupted berthing space. The port plans to add six more container cranes and ten more RTGs by the end of 2020. It has connections to two Class-I railroads, CSX and Norfolk Southern. The Garden City terminal is a bustling intermodal gateway offering 38 train services per week for import and export cargo. The main intermodal yard in Savannah is located near the Garden City terminal. Since the yard directly connects to the marine terminal with no gate in between, it serves as an on-dock facility despite being a near-dock location. The ICTF is a large intermodal yard with a total of 150 acres. The port is planning an expansion project named the Mason Mega Rail project, which will deliver the largest on-dock intermodal rail facility for a port authority in North America, doubling the Port of Savannah's rail capacity to one million container lifts a year. It will increase the number of working tracks from 8 to 18 and cuts transit time by 24 hours to inland markets such as Memphis, St. Louis, Chicago, and Cincinnati.

The Port of Mobile is a deep-water port in Mobile, Alabama, and the only deep-water port in Alabama. The total annual throughput in 2018 was 26.8 million tons for the port of Mobile. According to a study by the University of Alabama, the forecasted growth in rail traffic due to automobile production from 2003 to 2008 increased by 171 percent. The port is served by six Class-I railroads. The port authority estimates that 60 percent of the current cargo volumes are carried via rail. This port is owned and operated by the Alabama State port authority. The near-dock ICTF is located approximately 1.5 miles from downtown Mobile and has an area of 76 acres. The access channel depth is 45 ft, and it has five working tracks of 8,100 ft each, five storage tracks, and a runaround track. It is connected directly to the marine terminal and serving both marine and domestic containers.

The Port of New Orleans is a modern deep-draft container terminal and the only container port in Louisiana. It is located on the Mississippi River near the Gulf of Mexico - with access to 30-plus major inland hubs such as Memphis, Chicago, and Canada via 14,500 miles of waterways. The Port of New Orleans facilities includes 40 berths, 20 million square feet of cargo-handling area, six ship-to-shore gantry cranes, and more than 3.1 million square feet of covered storage area. It has 840,000 annual TEU capacity and the ability to handle vessels up to 10,000 TEUs in size. The Port of New Orleans is a landlord port, and all cargo handling operations are performed by private terminal operators. Among the terminals of the Port of New Orleans, the Napoleon Avenue Terminal serves prominently. It is 65 acres in area and has a 45 ft access depth with two berths. Napoleon Avenue is enabled on-dock rail at Mississippi River

Intermodal Terminal with access to six Class-I railroads: BNSF; CN; CSX; Kansas City Southern; Norfolk Southern; and Union Pacific. It has six gantry cranes for easing the on-dock transfer process. The rail tracks leading to Napoleon Avenue are owned by the New Orleans Public Belt Railroad (NOPB). NOPB switches trail cars to and from this terminal using its locomotive and labor. NOPB can also use a storage yard adjacent to Napoleon Avenue. The terminal has a total berthage of 2,000 ft, of which 1400 ft is an open dock, and 600 ft is a transit shed. The terminal is a part of a larger complex with about 4,00 ft of berthage, including the Nashville Avenue terminal. It is also equipped with a computerized gate system and pre-gate parking. The Mississippi River Intermodal terminal is the other terminal in which the intermodal process occurs in the Port of New Orleans. This one is 12 acres in the area and serves as the container rail transfer station. It has two RTGs and 6,000 linear feet of working track for unloading and loading containers from railcars.

3.7 Rail Intermodal vs. Freight Truck feasibility

Rail intermodal has gained popularity for its reliability and environment-friendly aspect. Nevertheless, railroad tonnage is not growing as fast as truck traffic. The real problem is with the growing demand for containers in the ports, and the number is going take induce an unnatural burden on the highway network. The delays at the U.S. highway are not an uncommon phenomenon. The growing traffic at maritime ports will push its boundary if it keeps adding its major share to the truck rather than other feasible alternatives like rail freight. The introduction of double-stack rail cars in 1980 reduced the cost of rail haul. It made intermodal rail freight competitive for 500 miles or so, whereas it was not even considered for a distance less than 750 miles.

In the next chapter, an attempt was made to justify the statistics. In simpler terms, we sought to find out if the claim is correct that rail intermodal cannot compete with the truck when the distance is less than 500 miles. The study also aims at identifying the key components to impede rail intermodal when it comes to shipping short-haul. All the collected data were analyzed using Microsoft Excel, and then conclusions were drawn and presented in Chapter 5.

Chapter 4. Results amd Discussion

The following section provides the competitiveness of the Vessel-to-Rail Intermodal status of the Port of Houston in terms of different parameters compared to other ports. The study focuses on parameters such as capacity, on-dock terminal, and lifting cranes which are the key components to make a Rail Intermodal System successful. Then, the relationship between distance and rail intermodal haul cost will be analyzed and presented with reference.

4.1 Containerized Terminal Area

When evaluating the efficiency of the port's vessel-rail intermodal system, it must be mentioned that the port facilities must be capable of supporting the demand traffic. In simpler words, it means that ports should have enough space in container yards for storing containers. To understand the relative stand of Port of Houston amongst the competitive U.S. ports, we have considered the top 10 containerized ports of the U.S. in 2018 in this study and analyzed different matrices. One of the matrices was the relationship between the container throughput and the available storage space in the terminals. Figure 4.1 illustrates this relationship.

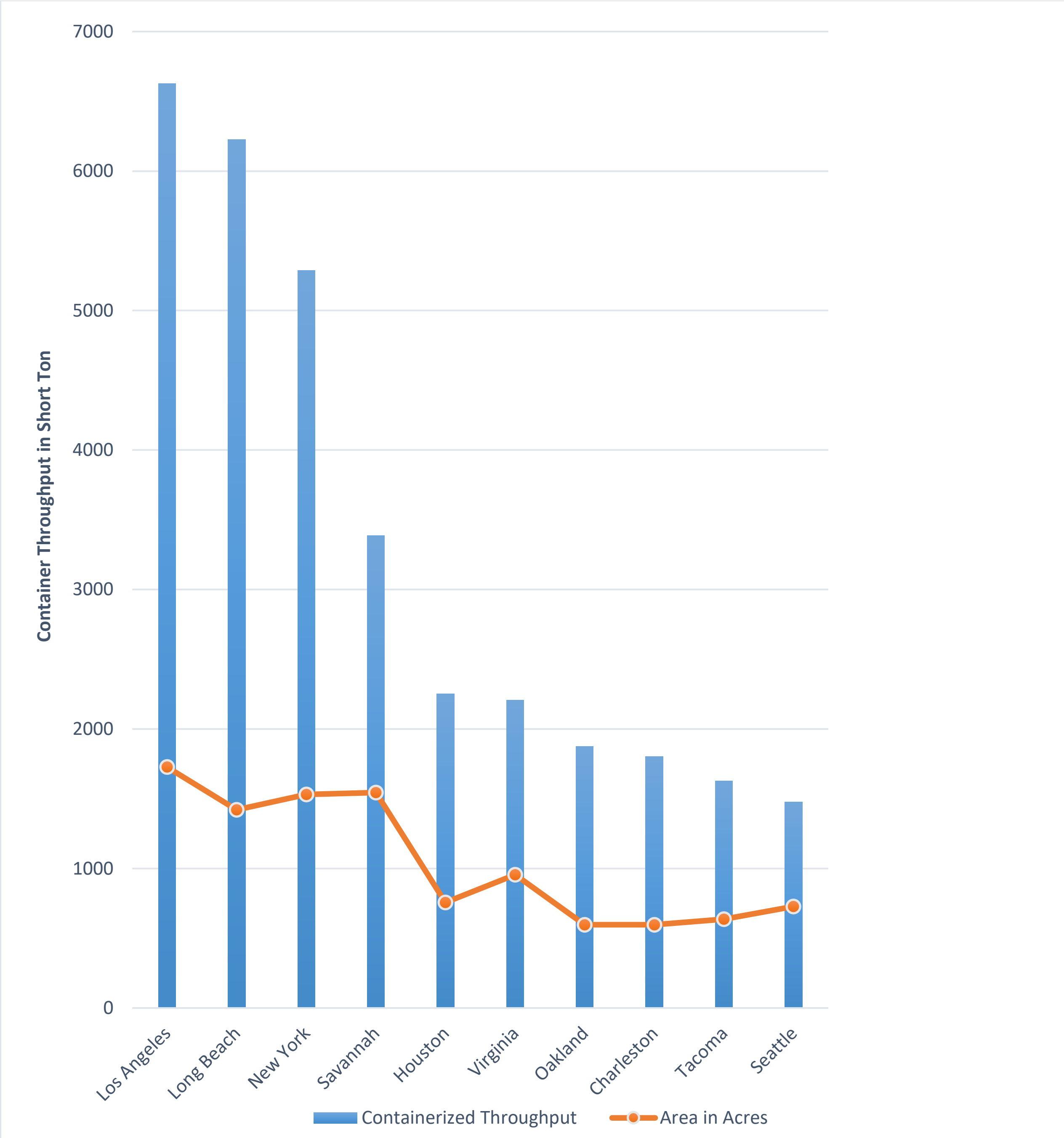

Figure 4.1: Comparison of Throughput and Containerized Terminal Area for Different Ports

As it can be seen, the Port of Houston stands 5th in the year 2018 when total containerized throughput is concerned. When it comes to the area, it ranks 6^{th,} and comparing it with Savannah Port which stands 4th in terms of throughput, the containerized area of the Port of Houston is almost 109 percent less than the Savannah port. In contrast, the throughput of it is only 50 percent greater than the Port of Houston. The Virginia port also, which ranks just after the Port of Houston in container throughput, has almost over 25 percent containerized area than the Port of Houston.

4.2 On-Dock Rail Terminal and Crane Facility

An on-dock rail terminal is a significant component of a vessel-rail intermodal system. To make the process efficient and reduce idle time, an on-dock rail terminal must be ensured. They are operationally considered to be most efficient as it disregards additional lifting equipment and storage space for the cargo boxes. It is the fastest system that can handle the ship-to-rail process.

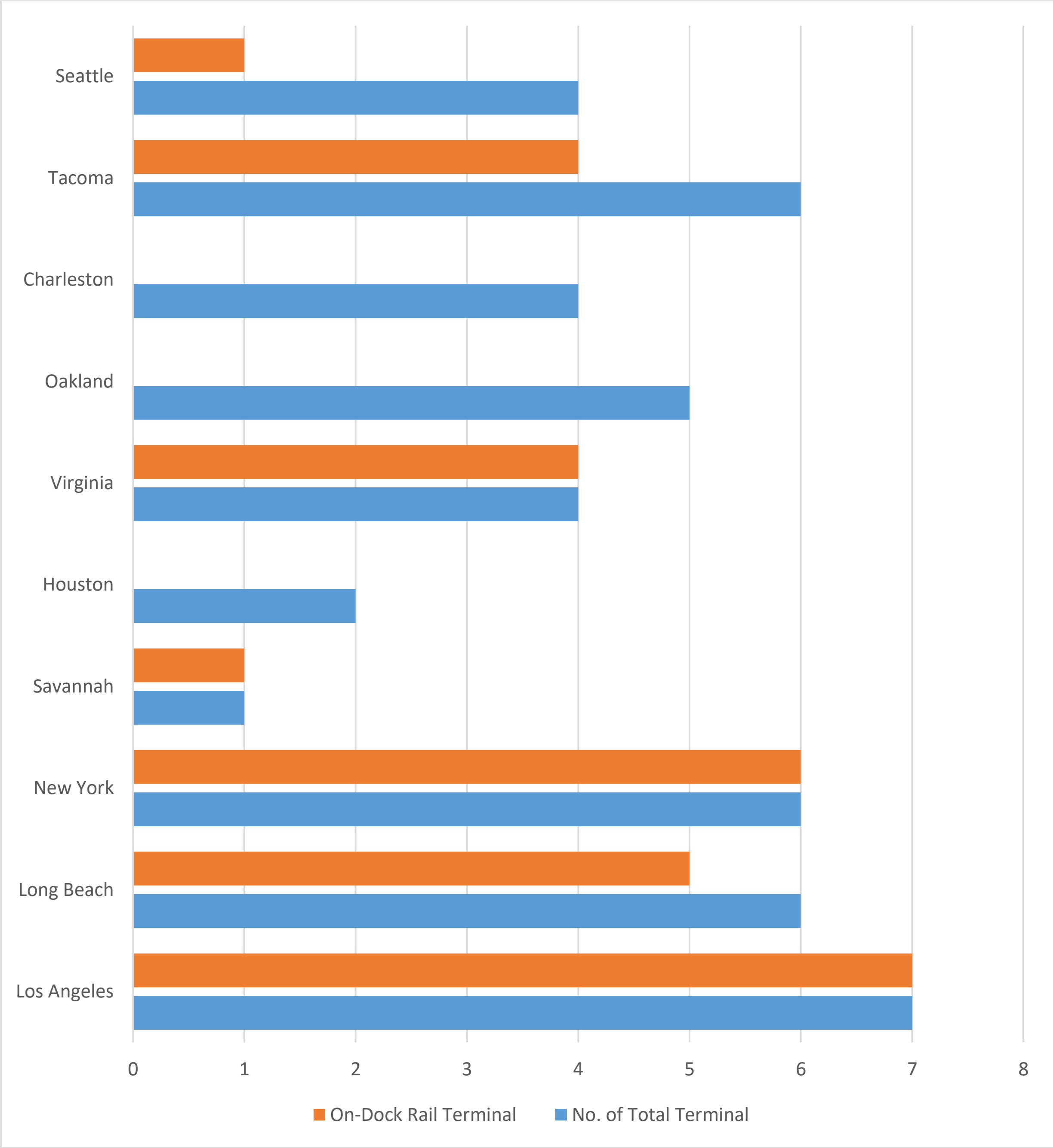

Figure 4.2: On-Dock Rail Terminal in Different Ports

Figure 4.2 shows the accurate representation of the Port of Houston's situation when it comes to the on-dock rail terminal facility. While comparing the top 10 container ports of the U.S., the Port of Houston is one of three ports that does not have any on-dock rail facility. All the top four ports which stand above the Port of Houston have at least one on-dock rail intermodal terminal. The mean of the on-dock rail terminal of the 10 Ports is 2.8 and the median 2.5.

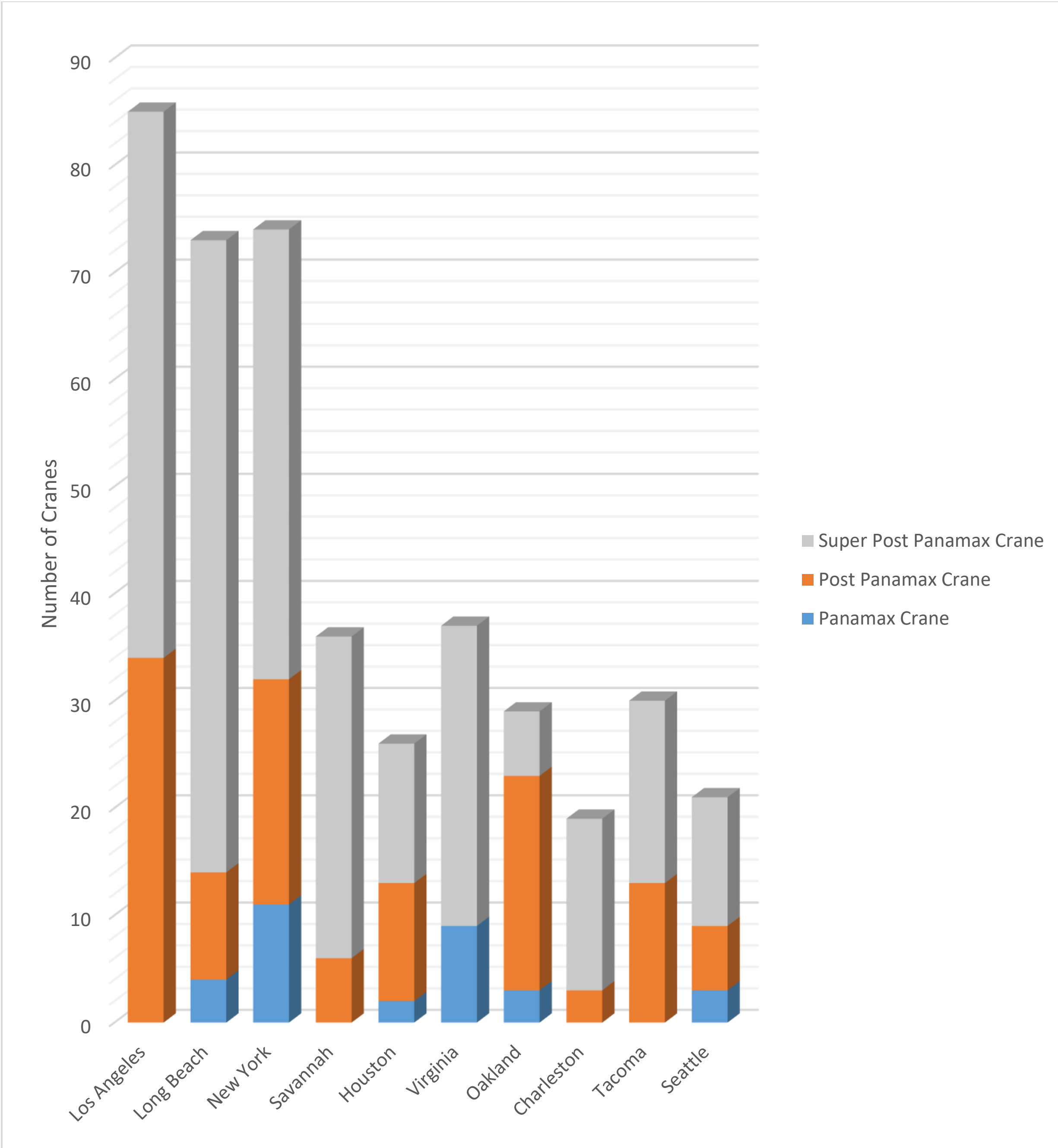

Figure 4.3: Comparison of Cranes in Top 10 Containerized Ports in the United States

Cranes are another crucial component of an efficient vessel-rail intermodal system. Figure 4.3 shows the number of cranes that each of the top 10 U.S. ports owns. In terms of crane ownership, the Port of Houston ranks 6th. While considering the number of Super Post-Panamax cranes, it stands 8th among the top 10. The number of total cranes owned by the Port of Houston is below the mean (43) and median (26) of the top 10 containerized ports in the United States.

4.3 Rail Intermodal Suitability

With the revolution of double-stack rail cars, the rail intermodal was supposed to lift off the burden from the truck freight. Despite the revolutionary change, rail intermodal is still not preferred when the distance is less than 500 miles. Before the double-stack rail revolution was introduced, the common conception in the railroad industry was that rail could compete when the shipment has to travel more than 700 or 800 miles. Double-stack technology changed that situation by reducing direct movement costs by about 50 percent. The change in cost made rail competitive in the 500-mile corridor or so. Figure 4.4 shows the accurate picture of the U.S. rail intermodal share when it comes to freight transportation.

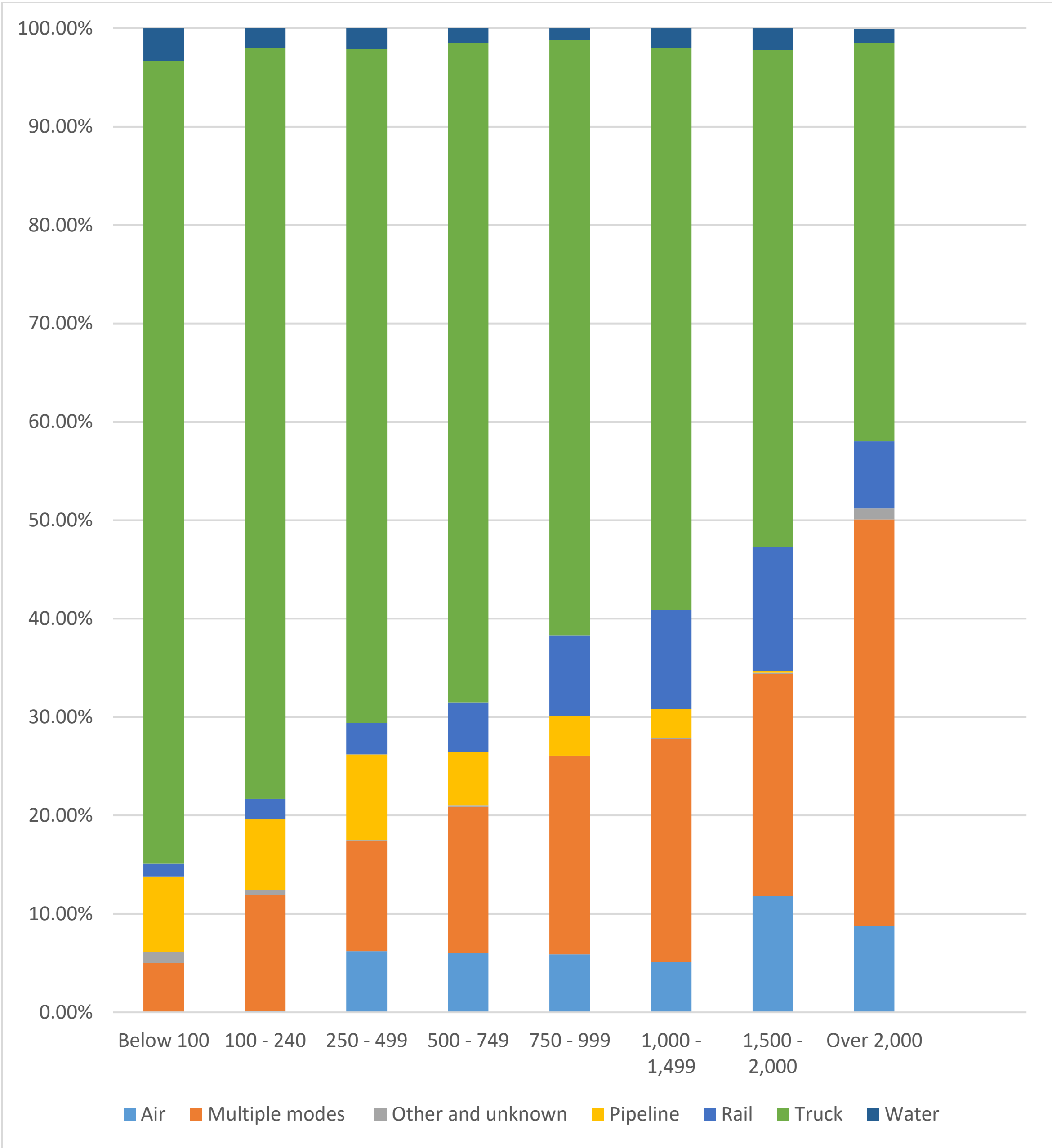

Figure 4.4: Mode of Transportation Share for Different Distance Band

This study considered the distance from the Port of Houston to adjacent ports to analyze the rail intermodal cost in the short-haul distance. It estimated the cost based on several parameters. To make a fair analysis, we considered distance from 50 miles to 1200 miles. The following table provides the other key components of this analysis

Table 4.1: Cost Components of Rail Intermodal Shipping

Cost Component	Value
Locomotive Ownership	$400 per day, typical for a high-horsepower locomotive
Locomotive Maintenance	$1.5 per mile (typical Class I average)
Car Ownership	$2.61 per hour, the rental rate for double-stack cars
Car Maintenance	$0.1 per mile
Crew Cost	$550 per shift (average wage plus fringe, current Class I labor contracts)
Fuel Cost	$0.001625 per gross ton-mile
Track Maintenance Cost	$0.00225 per gross ton-mile

It must be mentioned that there is no public database for these cost values. Railway and drayage companies do not share information on a public platform. The data were extracted from various sources such as peer-reviewed journals, articles, and websites to get a stochastic decision on the feasibility. The rail freights were assumed to carry 320 TEU in double-stack cars, which is the maximum limit. The truck data in the following figure was obtained from the analysis of cost per box against the distance.

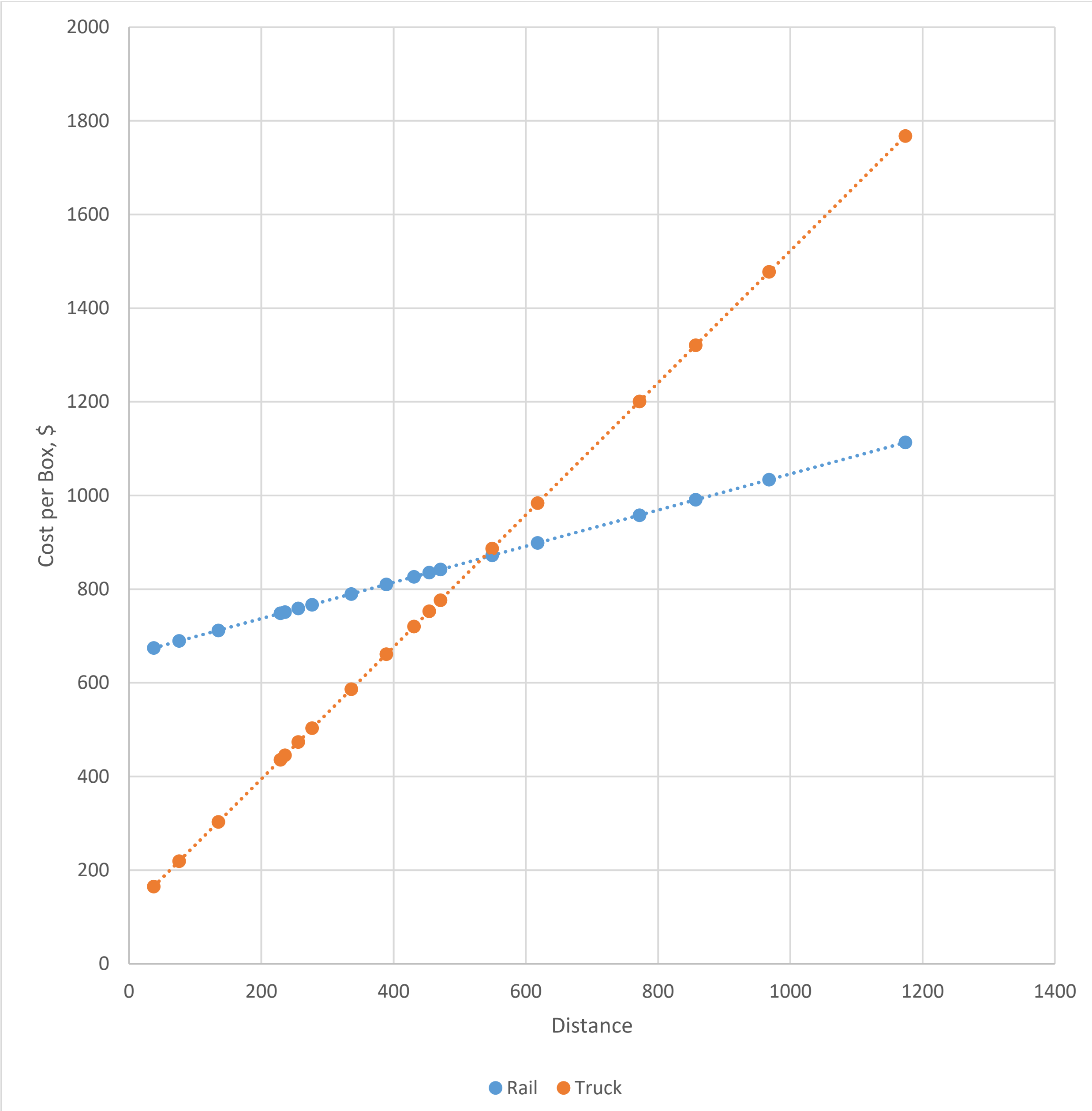

Figure 4.5: Comparison of Rail Intermodal and Truck Intermodal Cost

From the figure, it is articulated that the break-even distance for rail to compete with truck freight is slightly above 550 miles. The cost difference per TEU in the shorter distance (less than 200 miles) among these two modes is almost similar to the difference in the long haul (800 to 1200 miles). Rail intermodal is still feasible for a distance over 550 miles compared to a truck. Despite the revolution of the double-stack cars in the rail freight industry, it is pretty visible that it still must go a long way when competing with truck intermodal in the short-haul distance.

To identify the dominating cost component in intermodal rail shipping, we analyzed the components against different distance bands to identify the critical issues in the system. As we can see in Figure 4.6, it is quite visible that at all distance bands, drayage cost dominates. Drayage cost is least dominating at above 1000 miles distance which is most suitable for intermodal rail shipping. Even in its comfort area, drayage cost dominates significantly over the other components.

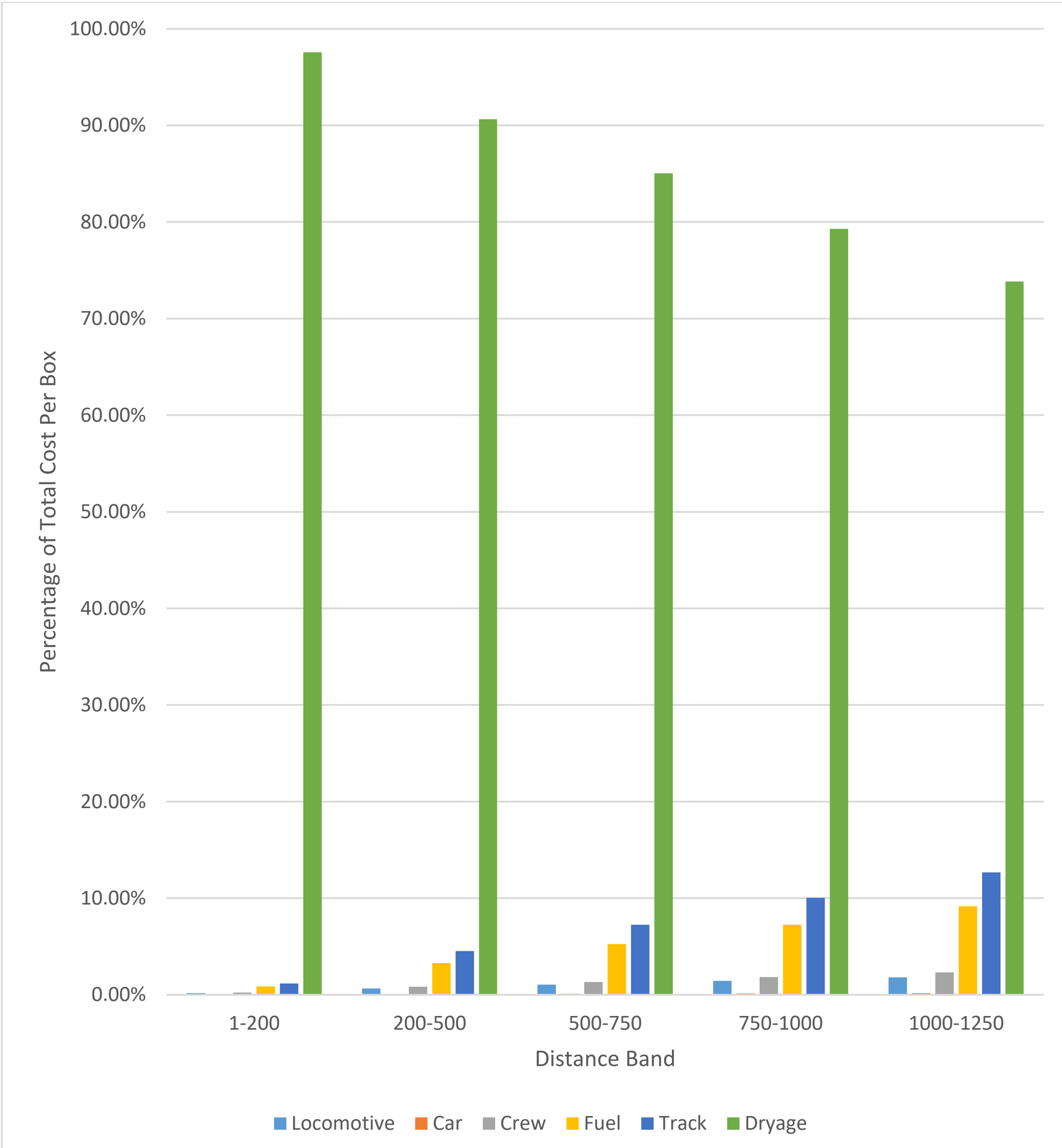

Figure 4.6: Rail Intermodal Freight Shipping Cost Breakdown against Different Distance Band

We analyzed the cost, attempted to figure out how the cost stands when there is a significant reduction in drayage. In this case, we applied a 15 percent and 25 percent reduction in drayage cost of rail intermodal and compared with the existing cost analyses of truck intermodal. Figure 4.7 shows how the comparison is represented.

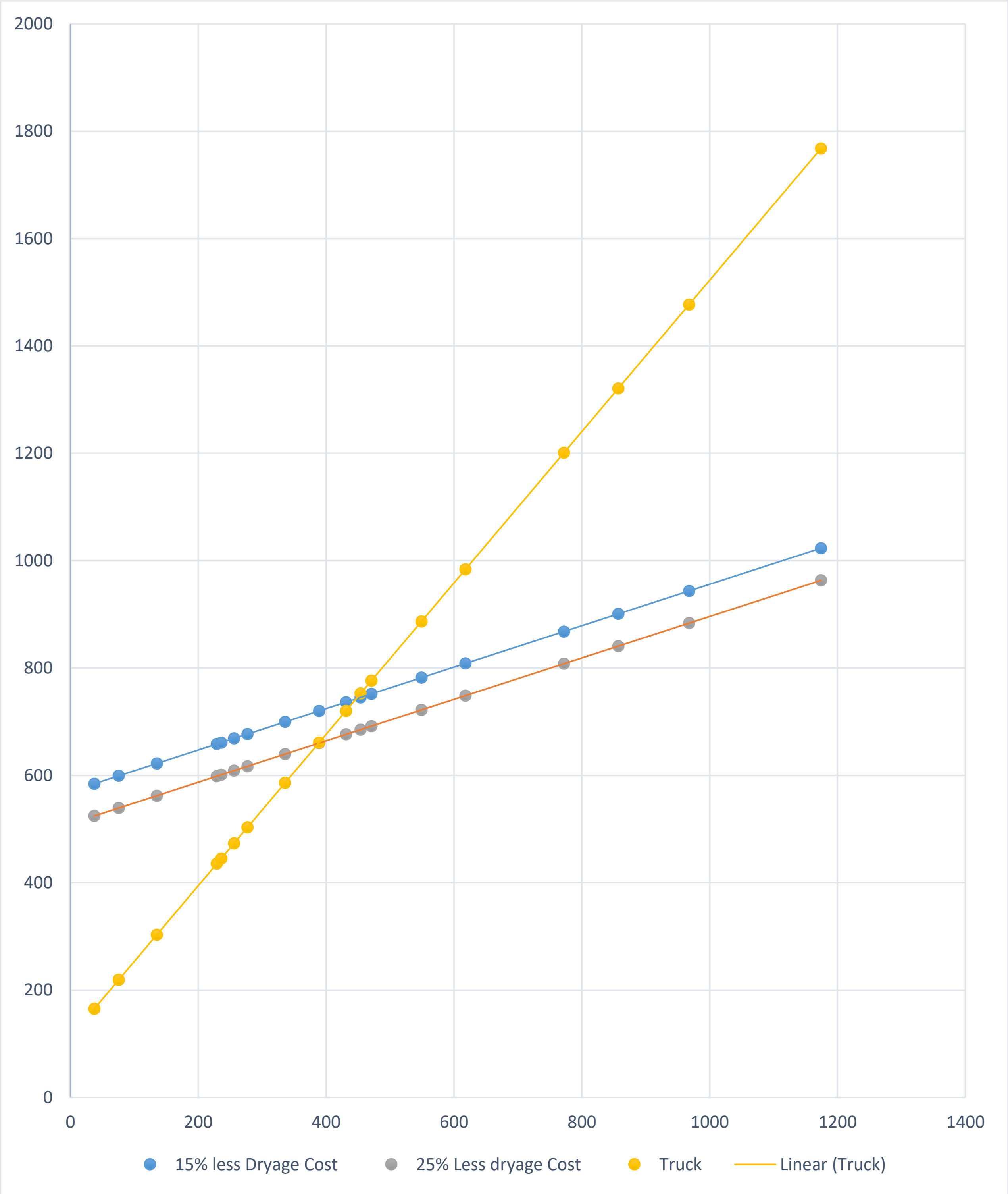

Figure 4.7: Comparison of Truck Freight and Rail Intermodal after Drayage Cost Reduction

It is visible that the drayage cost is the driving factor in making rail intermodal more competitive. When we analyzed the cost per box with a 15 percent drayage cost reduction, it was observed that the rail intermodal could compete with the truck from distances just above 400 miles. Moreover, when the drayage cost was reduced by 25 percent, rail intermodal seemed feasible even under 400 miles threshold. The analysis depicted the hold that drayage cost took in rail intermodal freight shipping and indicated the key focus area to make rail intermodal more competitive and feasible in short-haul distances.

Chapter 5. Conclusion and Recommendation

5.1 Introduction

A thorough literature review on the components of the vessel-rail intermodal system in Ports was conducted in this study. The aim was to identify the system's key stakeholding elements and find out the gap between the state-of-the-art practices and the Port of Houston situation. In addition, Rail intermodal shipping competitiveness was analyzed for the Port of Houston at short-haul distances to pinpoint where the improvements can occur.

5.2 Summary

The key summary from the study are highlighted section wise.

5.2.1 Intermodal Transportation

- Intermodal Transportation is most suitable when freight products are finished goods and weighs less than 25 ton.
- When freight goods need longer distance haul, intermodal shipping is the most feasible option for maintaining the integrity of the products.
- Intermodal freight transportation allows effective relocation of goods from one mode to another, ensuring increased capacity and economies of scale.
- The use of containers in intermodal transport limits the risk of damage to the goods and reduces theft risk.
- Intermodal transportation can associate with higher infrastructure costs and require additional facilities depending on the modes of transportation.

5.2.2 Vessel-Rail Intermodal System

- Vessel-rail intermodal system primarily means the use of rail and water transportation as the main, compatible with other modes of transportation to accomplish the complete transfer process of the containers from one place to another.
- Rail intermodal benefits the logistic situation by providing a lower cost option in comparatively long distances. It is more fuel-efficient than other modes, which brings down the cost and establishes itself as an environmentally friendly option.
- Rail intermodal has proven to be more reliable with enhanced capacity and safety advantages over the years. The double-stack revolution has emerged as a blessing for accommodating more containers in a single train.

5.2.3 Elements of Water-Rail Intermodal System

- Container: An Intermodal Container is a large, standardized shipping box built for intermodal freight transportation. Their dimensions are standardized by ISO, and most containers are 20 or 40 feet long. The term TEU is used to refer to one container with twenty feet in length.
- Container Cranes: The cranes are to load/unload container ships and then transfer the containers to drayage trucks or directly to the rail cars. Depending on their capacity, location, and type of transfer required, container cranes can be of different kinds.

- Rail Intermodal Yards: These yards are places where unit trains are loaded and unloaded by RTG or lift cranes. The efficacy of the water-rail system is massively dependent on the process by which containers are transferred between ship to rail.
- On-Dock Intermodal Yards: They are container yards which are located within port areas. Depending on the configuration, On-Dock Intermodal Yards can be of several kinds. The main advantage of these kinds of yards is that the transfer process is quick and efficient since it shortens the drayage, saving time. They do ask for extensive and valuable waterfront lands taking up the capacity of the marine terminal. These yards are usually small in size, and the switching of trains in them, which are generally performed by local service railroads, can also lead to additional costs.
- Near-Dock Intermodal Yards: These yards are usually located outside marine terminals and customs areas. They are generally larger than On-Dock Yards since they do not occupy valuable port lands. The main drawback of the system is that since the intermodal yards are located outside port areas, they ask for a higher drayage cost. Due to the long-distance, it is prone to take a longer time for the transferring process.
- Off-Dock Intermodal Yards: These yards are similar to Near-Dock Yards. The only difference is that the distance from the port is longer and generally is near 20 miles. The drawbacks are higher drayage cost, lack of efficiency, and higher processing time.
- Class-I Railroads: Class-I railroads play the most crucial role in an Intermodal Rail Freight System since it ships different types of cargoes beyond the states and the country. Class-I Railroad is determined if the carrier has revenue thresholds of $447,621,226 or more. The significance of Class-I railroads lies in their operational capability and financial potency. There are currently 8 Class-I railroad carriers in the United States.

5.2.4 Port of Houston Competitiveness

- The Port of Houston ranks 1st in total waterborne tonnage and currently ranks 5th in container volume. It is the largest among the gulf coast ports.
- The Port of Houston has two container terminals located relatively close to the Gulf of Mexico and are administered by the Port Authority.
- Barbours Cut and Bayport Terminals are the two terminals that move the containers in the Port of Houston. None of them has an On-Dock Intermodal Yard. Both container terminals have undertaken the initiative to expand their storage capacity and intermodal freight moving efficiency by replacing the older Panamax crane with Post-Panamax cranes, dock improvements, yard configuration, and adding new rail tracks.
- The Port of Houston is connected by three class-I railways, BNSF, Union Pacific, and KCS. The PTRA does the internal container switching.
- There are other terminals in which mostly breakbulk, bulk, roll-on/roll-off, project, heavy lift, liquid, and coal cargoes are handled.
- The Port of Houston is connected to multiple major highways, including I-10, I-45, I-69, and the I-610 loop. According to the Bureau of Transportation Statistics, the connection with I-45 is already one of the most congested links in the United States. The other highways are also congested during peak commuter periods.
- PTRA has seven serving yards and a total of 5,00 railcars capacity. It pulls an average of 2,500 cars per day.
- Despite being 5th in Containerized Cargo shipping, the Port of Houston does not have any on-dock rail terminal. The four top containerized ports have at least more than one On-

Dock Rail Intermodal Yard (even the 6^{th} ranked port has, too). The Port of Houston is also lagging in the total containerized capacity and cargo crane ownership compared to the other top ports.

5.2.5 Rail Intermodal Freight Feasibility Analysis

- Double-Stack Rail Cars brought a revolution in intermodal rail transportation, reducing the cost for shipping per box, despite that rail is not preferred when the distance is less than 500 miles.
- The analysis showed that the break-even distance for rail intermodal to compete with truck freight is above 550 miles. It is always better to avail the rail intermodal when the distance is over 600 miles.
- Rail intermodal costs are counted as a round trip. On the other hand, truck freight can take up shipping consignment while returning from one destination due to their flexible nature. If truck freights were counted as a round trip cost, or the rail shipping cost could be turned into a single trip, the rail intermodal would have been more cost-efficient than the truck ones.
- The dominating cost component in Rail Intermodal Shipping is the drayage and lifting costs. On average, the drayage cost takes over 80 to 85 percent of the total cost per box, depending on different distances.

- Reduction in drayage cost alone can push rail intermodal compete with truck significantly. Our analysis based on distance from the Port of Houston found that a 15 percent decrease in drayage cost makes the rail intermodal feasible over around 400 miles distance. When the reduction was increased to 25 percent, it was observed that it could even compete under the 400 miles distance.
- The following recommendations can be made in light of the conducted research in this thesis to help make rail intermodal more competitive.

5.3 Recommendations

5.3.1 The Port of Houston

- The Port of Houston lacks an On-Dock rail terminal and port operational facility compared to similar ports in the US. The On-Dock rail terminal and sufficient crane facilities have been helpful for the unhindered and efficient port operation, and the Port of Houston must respond to this emerging need.
- The existing containerized capacity to containerized cargo volume ratio does not match comparing with similar ports. The increased port traffic is likely to exceed the capacity in the coming days, proving detrimental to an efficient port operation.
- The Intermodal Rail operation should be resumed to match the gradual container traffic growth at the Port of Houston. The public-Private partnership should be strengthened to ensure an efficient and functional port operation.
- The congestion around the highways of POH is likely to increase more if the growing traffic demand is entirely put on the freight truck. The Vessel-to-Rail Intermodal transportation should be guaranteed effective immediately to ensure that the incoming future port traffic is not clogging up the highways around the Port area and leaving significant carbon footprints.

5.3.2 Drayage

Drayage costs can be reduced by improving intermodal connectors. FHWA has a program established for this reason that connects ports and rail yards to the highway network. Technology has a significant role to play in this regard. An efficient method for matching available dray drivers in the shortest possible time can be a tangible way to increase dray productivity. Researchers should put more effort into bringing the technology up to speed to reduce the drayage cost and make the rail more feasible.

5.3.3 On-Dock Rail

On-Dock Rail does not necessarily mean "on the port waterfront." Even if it is within the premises of the port terminal, the direct shipping from ship to rail can significantly reduce handling costs compared to the dray movements through the highways and public streets. Given the concerns that are already present about the lack of capacity in the roads against the uprising demand of freight, the incentive to construct on-dock rail terminals and reduce drayage costs should be higher than ever. The benefits of fewer trucks on the highways should justify the public subsidies for the construction and operation of container terminals with On-Dock Rail Intermodal Yards. Gate congestion which is also a matter of great concern in busy ports, can also be alleviated with On-Dock Rail Intermodal Yard, which subsequently will save cost and time.

5.3.4 Terminal Location and Capacity

The suburbanization of intermodal rail terminals affects lengthening the time and cost of dray movements. This makes rail intermodal even less competitive. Increasing capacity and the lifting facility at the intermodal yards will also increase the efficiency of the system. Public-private partnerships that reduce terminal and dray costs will undoubtedly bring more intermodal traffic to the railroads. However, the question of capacity to accommodate increased traffic will still be there. To cope with the containerized traffic in the future, the Ports should improve their terminal capacity and initiate new terminals at convenient locations with optimum infrastructural facilities.

5.3.5 Recommendations from other research

- According to the American Association of State Highway and Transportation Officials (AASHTO) research, with an annual investment of $4 billion in railroads, the rail market share will grow slightly. The study found that the amount of investment is justified by the public policy benefits of reduced investment in highway networks, reduced accidents and congestion, and improved environment.
- Morlok et al. found that a centrally managed drayage operation could decrease drayage cost by 43 to 62 percent, which would render rail competitive even in the 150-mile corridor.

5.4 Conclusion

Rail intermodal has proved that it can compete with trucks. The double-stack rail cars have emerged as a revolution bringing more capable of hauling and reducing the cost per box and carbon emission. However, the spectacular the uprising has been, the growth of rail intermodal has been on a slow side compared to the truck traffic growth. Without increasing infrastructural capability and enormous investment in railroad, the growing demand for freight traffic will have to be carried out by the already burdened highway network. There is a clear role of public-private ownership in the Port of Houston and technology innovation initiative to construct on-dock rail terminals, increase operational facility, add rail network capacity, reduce drayage cost, and bring order to the fragmented drayage industry. Rail intermodal can provide so many benefits over the trucks. If the drayage, terminal capacity, location, and configuration issues can be addressed, it can even compete with a truck within 150 miles corridor. To cope with the increasing growth of the maritime traffic, the Port of Houston must ensure smooth operation of Vessel-to-Rail system which should start by opening up the Rail Service and later on expanding on-dock rail yard facility, increasing terminal capacity and enhancing other operational facilities like cranes and yard trucks.

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