DEVELOPING A FRAMEWORK TO OPTIMIZE THE OPERATIONS OF AN INTERMODAL UNDERGROUND FREIGHT TRANSPORTATION TERMINAL USING SIMULATION

by

FATEMEH REZAEIFAR

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT ARLINGTON
August 2018

This dissertation is dedicated to my parents who are the hidden strength behind my success.

Acknowledgements

At the very outset, I would like to express my profound sense of gratitude to my doctoral advisor, Dr. Mohammad Najafi, for his invaluable guidance, constant scrutiny of the progress of the work, eminent supervision, and his professional experience, which he shared with me. It has been a great pleasure and honor to work with him. I am greatly indebted to my dissertation committee member, Dr. Huff, in the Department of Industrial Engineering, who patiently responded to my endless questions specifically on modelling task. I would also like to extend my thanks to other members of my dissertation committee, Drs. Mostafa Ghandehari, Kyung Hyun, Sharareh Kermanshachi and Madan Mehta for providing valuable comments. In addition, sincere thanks are extended to Dr. Siamak Ardekani for his support and advice.

Thanks also go to my friends and colleagues and all faculty and staff members of the Department of Civil Engineering for providing me with the resources, insights, and motivation needed to complete this dissertation and for making my time at the University of Texas at Arlington a great experience.

My parents and family have been a great source of inspiration to me. My progress is due to the endless love, encouragement, and support, which they have given me throughout the course of my research work.

August 14, 2018

Abstract

DEVELOPING A FRAMEWORK TO OPTIMIZE THE OPERATIONS OF AN INTERMODAL UNDERGROUND FREIGHT TRANSPORTATION TERMINAL USING SIMULATION

Fatemeh Rezaeifar, Ph.D.

The University of Texas at Arlington, 2018

Supervising Professor: Mohammad Najafi

According to the U.S. Department of Transportation (USDOT), by 2040, nearly 30,000 miles of our busiest highways will be clogged daily and it is important to increase the capacity of our transportation system. Construction of intermodal underground freight transportation (UFT) systems for freight movement through underground pipelines or tunnels, can increase the capacity of the existing shipping network. The intermodal terminal is a major component of the UFT's innovative infrastructure project. Increasing demand for container transportation systems in terminals will raise the risk of terminal congestion and delivery delay due to the increase in freight transportation system bottlenecks (traffic jams and extended terminal loading and unloading wait time) without an equivalent increase of stacking and handling capacity. Thus, it is essential to evaluate the current terminal capacity by studying the effect of different operational components on terminal performance. The objective of this dissertation is to develop a framework for optimizing the capacity of intermodal UFT terminals with discrete event simulation (DES) model. The terminal operations considered include speed, headway, number of gondolas (equipment used for carrying the freight) needed to carry containers, line capacity, number of handlers, stack-yard capacity, the conveyance system (tracks and power requirements), lifting equipment, and drayage performance. The expected annual shipped containers for the UFT system research case study is calculated mathematically and then the UFT system is simulated to build the base-model for this dissertation. For optimizing terminal operations, two different scenarios were simulated to test the variations of performance indicators. Scenario No. 1 considers a terminal with a stack-yard in the form of two small loops and the Scenario No. 2 is in the form of one large loop without a stack-yard. The outputs for all three models base model, scenario number one, and scenario number two are compared with the UFT annual expected shipped containers. The results show the number of shipped containers for Scenarios No. 1 and 2 are respectively 34% and 59% more than the annual expected shipped containers, which are 46% and 73% more than the base-model output. The findings confirmed percentages of base-model bottlenecks were reduced significantly in both scenarios. Additionally, compared with Scenario No. 1, Scenario No. 2, without a stack-yard, can handle 25% more containers per year.

Table of Contents

List of Illustrations

List of Tables

Chapter 1 Introduction and Background

1.1 Freight Transportation

The U.S. freight system serves the world's largest economy. This system spans the 24 million square miles of North America while linking it to international markets (TRB, 1992). Freight transport generally refers to the total movement of goods using inland transport on a given network. An integrated freight transportation network by supporting resource growth and extending interstate commerce, contributes to state economic development (Organization for Economic Cooperation and Development (OECD), 2018).

Freight travels over a broad network of highways, airways, railroads, pipelines, and waterways. In this way, existing and anticipated expansions in the number of freight vehicles, vessels, and other conveyances are enlarging the system as more components of the network approach or reach capacity, increasing maintenance requirements and affecting performance (BTS, 2017a).

Efficient freight movement is an essential foundation of our nation's economic firmness. Thus, enabling transportation professionals to improve their skills and knowledge to fully integrate freight movement into transportation system development and operations is the objective of the freight professional development program (U.S. DOT, 2015). It is obvious that a smooth-running freight transportation system is a fundamental element in any successful economy.

1.1.1 Importance of Freight Transportation in U.S. Economy

The transportation sector is an integral part of the U.S. economy. It employs millions of people and incorporates 8.9 percent of the Nation's economic activity as measured by gross domestic product (BTS, 2017b). The highly developed transportation system in the United States is a key factor in the nation's economic competitiveness.

Roads, railroads, inland waterway systems, seaports, and airports all help to link agricultural and natural resource zones, employment centers, and international portals.

Maintaining and improving an operative and efficient transportation infrastructure for the movement of people and freight continue to be important in today's worldwide marketplace, especially given projected population growth and increased domestic oil, gas, and agricultural production. The movement of urban goods, international supply chains, and logistics are also key to the future economic competitiveness of the U.S. (Transportation Research Board (TRB), 2015).

1.1.2 Freight Transportation Growth

According to the United States Department of Transportation (USDOT), Bureau of Transportation Statics (BTS), road infrastructure increased 5.2 percent from 2000 to 2015, while traffic volume increased 14 percent from 2,747 billion to 3,131 billion vehicle-miles traveled (BTS, 2017a).Notably, according to a 2015 US DOT report: "By 2040, nearly 30,000 miles of our busiest highways will be clogged on a daily basis" (U.S. DOT, 2015).

The freight forecast released by the American Trucking Association (ATA), shows the U.S. Freight Transportation Forecast up to 2028 projecting continued growth for freight transportation overall and for the trucking industry. The ATA projects that 15.18 billion tons of freight will be moved in 2017 by all modes—a figure that is estimated to rise by 36.6% to 20.73 billion tons in 2028 (ATA, 2014).

According to the ATA report (2014), Figures1-1 and 1-2 show the average annual growth of total freight tonnage (Evans and Furlong, 2003). Based on these Figures, the general freight shipments are forecast to rise 2.9% per year during the 2017-2023 period and 2.4% annually for the 2023-2028 periods.

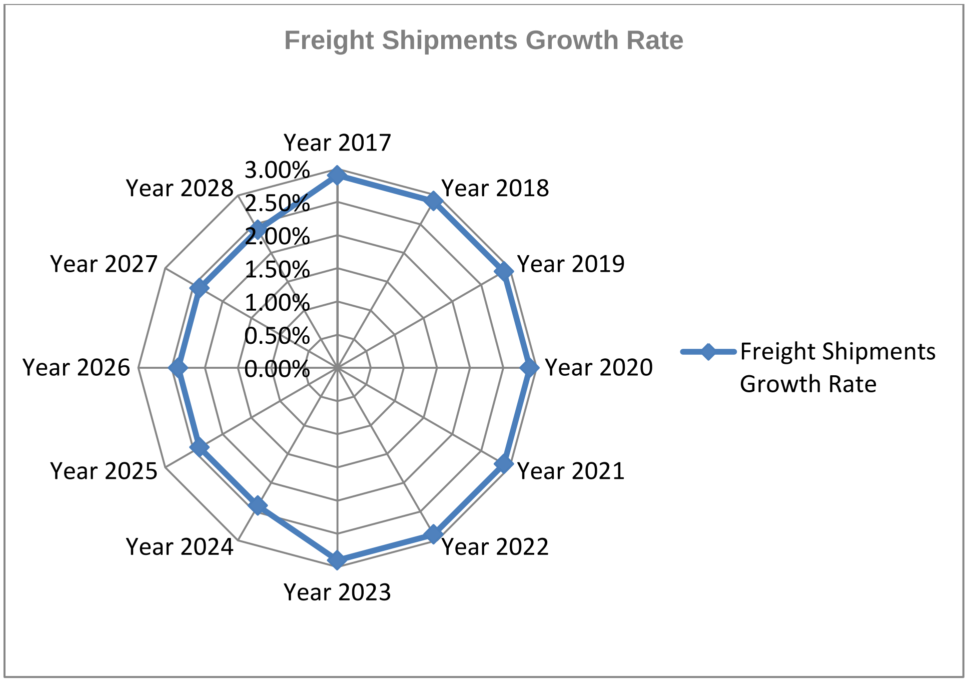


Figure 1-1 Freight Shipments Growth Rate
(Adapted from ATA, 2014)

Figure 1-2 General Freight Shipments, Average Annual Total
(Adapted from ATA, 2014)

The ATA U.S. Freight Transportation Forecast to 2025 (ATA, 2014) predicts further growth—not just for trucking industry, but for the entire freight sector.

Findings of the long-range freight forecast include:

- “Total freight tonnage will grow 23.5% from 2013 to 2025 and freight revenues will increase by 72%.
- Growth in overall freight volume is fixed at 2.8% per year from 2014 to 2019; then, it changes to 1.0% during the next six years, through 2025
- Trucking’s share of freight tonnage will increase from 69.1% in 2013 to 71.4% in 2025.
- Rail intermodal tonnage will grow 5.5% annually through 2019 and 5.1% a year through 2025— yet rail market share will reduce from 14.5% of all tonnage in 2013 to 13.8% in 2025” (ATA, 2014).

The rail intermodal report shows that U.S. rail intermodal volume in 2015 was a record 13.7 million containers and trailers, dropping only slightly to 13.5 million in 2016. Intermodal traffic set a record in 2013. U.S. railroads included 958,778 intermodal containers and trailers in December 2013, up 70,742 units (8.0%) over December 2012 with a weekly average of 239,695 (Figure 1-3).

For all of 2013, U.S. rail intermodal volume totaled a record 12,831,692 containers and trailers, up 4.6% (564,276 units) over 2012 and 549,471 units more than the previous record in 2006 (Association of American Railroads (AAR), 2014). Because rail traffic and the economy grow together most of the time, this upsurge in intermodal volume represents an increase in intermodal productivity as well as the American economy.

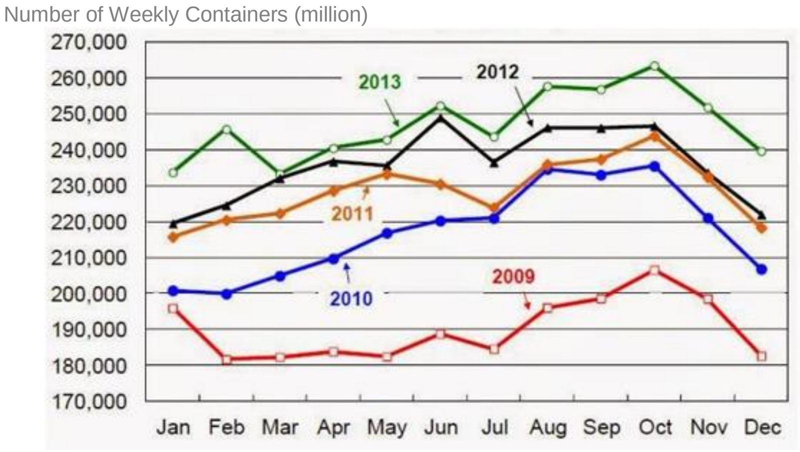


Figure 1-3 Average Weekly U.S. Rail Intermodal Traffic
(AAR, 2014)

1.1.3 Intermodal Transportation

The main players in intermodal transportation networks are shippers, who generate the demand for transportation; carriers, who supply the transportation services for moving the demand, and the intermodal network itself composed of multimodal services and terminals (Bektas and Crainic, 2007). An intermodal transportation chain is illustrated in Figure 1-4. In this illustration, loaded containers leave the shipper's facilities by truck to a rail yard, where they are loaded into trains and sent to a port to pass freight through a waterway and ultimately to another rail yard.

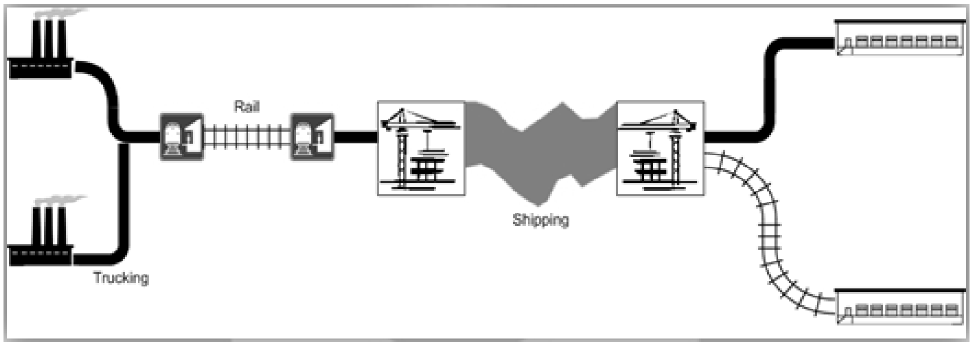


Figure 1-4 An Intermodal Transportation Network
(Bektas and Crainic, 2007)

Among all the transportation modes, trucks continue to be the most utilized mode of transportation for moving goods to and from both Canada and Mexico, conveying more than 60% of the freight transported (BTS, 2018). Trucks accounted for $721 billion of the $1.1 trillion in freight flow in 2017 with Canada and Mexico (Table 1-1). Additionally, based on a U.S. DOT report (2015), trucking growth as the main mode of freight travel forecasts a nearly 43% increase in tons delivered from 13.2 billion in 2012 to 18.8 billion in 2040. Rail remained the second largest mover of freight with 2.0 billion tons delivered in 2012 with a projected increase of 37% (2.8 billion tons) by 2040, followed by waterborne delivery of 975 million tons in 2012, projected to increase by10% or 1.1 billion tons in 2040.Airplanes delivered 15 million tons in 2012. Their delivery quota is projected to increase by 250% with an estimated 53 million tons in 2040 (Figure 1-5).

Figure 1-5 Freight Transportation Growth
(U.S. DOT, 2015)

Figure 1-6 covers all modes of transportation including freight movement by truck, which handles 67% of the total freight movement, with trains transporting 16%, ships moving 7%, pipelines conveying 6%, and airplanes carrying 4%.

The percent change in dollar value between 2016 and 2017 for all five major transportation modes—truck, rail, pipeline, air, and vessel—is illustrated in Figures 1-7 and 1-8. According to the U.S. Department of Transportation's Bureau of Transportation

Statistics (BTS, 2018), the major freight transportation modes carried more U.S. freight with Canada and Mexico by value in 2017 than in 2016.

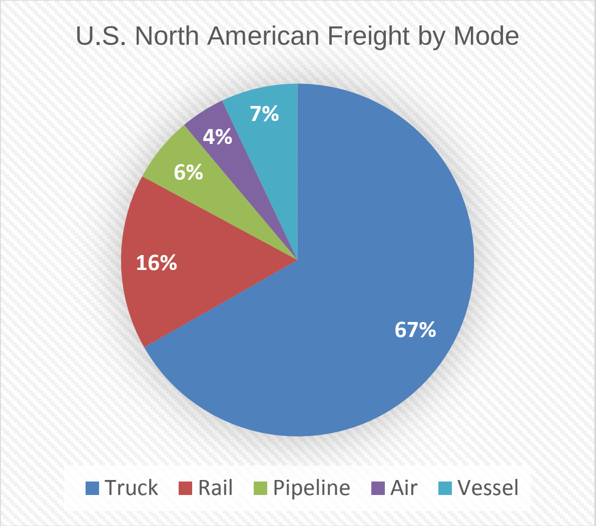


Figure 1-6 Distribution of U.S. North American Freight by Mode, 2017
(Adapted from BTS, 2018)

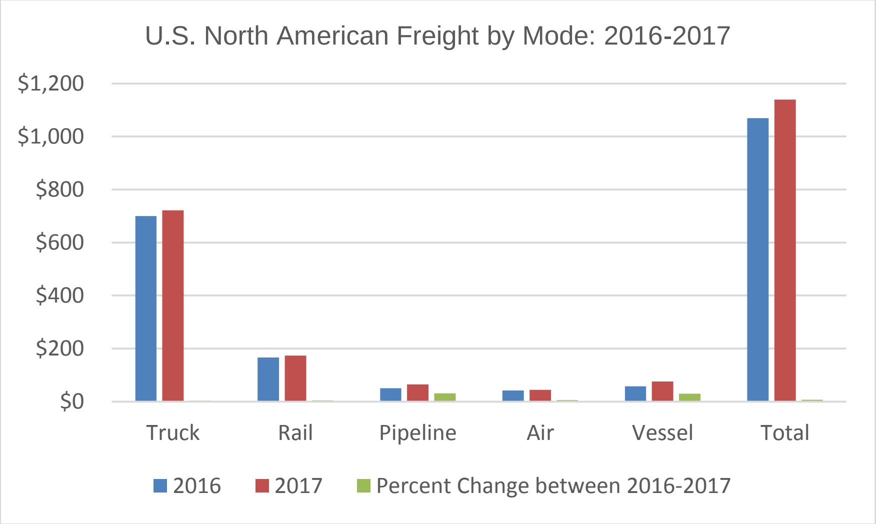


Figure 1-7 U.S. North American Freight by Mode: 2016-2017
(billions of 2016-2017 dollars)
(Adapted from BTS, 2018)

The shared values of freight moved by vessel rose by 1.2 percent and the pipeline share increased by 1.1 percent from 2016 to 2017. The dollar value of goods shipped by pipeline significantly increased by nearly 31.3% from 2016 to 2017, while vessels increased their freight income by 29.6% (Table 1-1). Although the pipeline and vessel modes experienced the most change, all modes experienced a percentage increase in dollars earned based on their 2016 incomes as compared to 2017 incomes.

Table 1-1 U.S. North American Freight by Mode: 2016-2017
(Adapted from BTS, 2018)

Mode	**2016**	**2017**	**Percent Change between 2016-2017**
Truck	$700	$721	3
Rail	$166	$174	5.2
Pipeline	$50	$65	31.3
Air	$42	$44	5.3
Vessel	$58	$76	29.6
Total	1,069	1,139	6.6

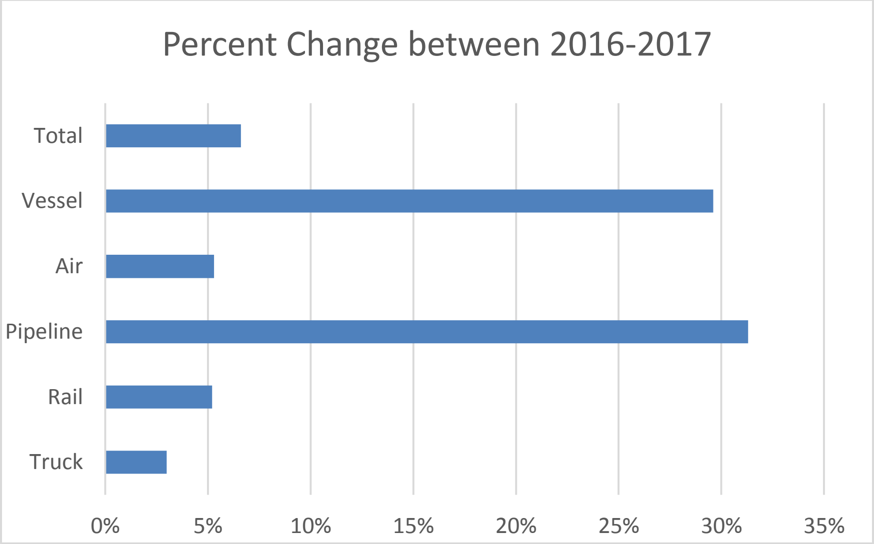


Figure 1-8 U.S. North American Freight by Mode: 2016-2017
(Adapted from BTS, 2018)

1.2 Underground Freight Transportation (UFT) Systems

Underground Freight Transportation (UFT) is defined as an automated technology to carry individual freight vehicles through underground pipelines with minimum impact on the surface (Najafi et al., 2016).

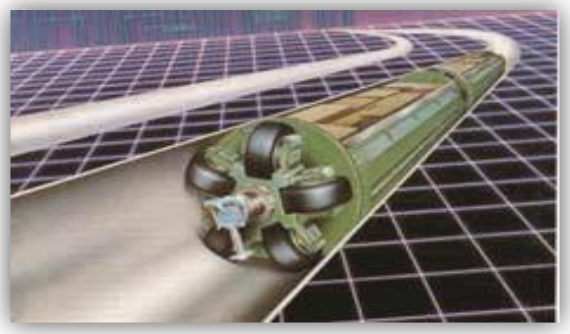


Figure 1-9 Tube Freight Transportation (Liu, 2006)

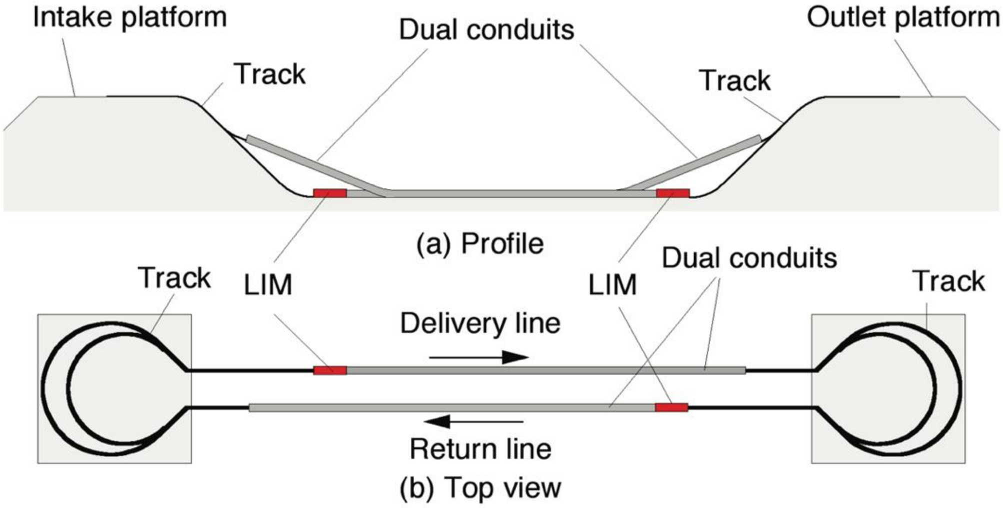


Figure 1-10 UFT System Layout by Liu (Liu and Lenau, 2005)

Underground freight transportation (UFT) is a class of automated transportation systems in which vehicles carry freight through tunnels and pipelines (Najafi, 2013) between intermodal terminals (Najafi et al., 2016). The UFT is a new intermodal system for freight transportation, which is designed to complement the current modes of transportation to help meet anticipated future growth in freight transportation (Najafi et al., 2016). This system is neither a conventional rail transportation system nor a replacement for the truck transportation system. This UFT project investigates the feasibility of employing a variety of underground freight mobility technologies. The primary goal is to improve speed, flow and headway to optimize available highway capacity.

Speed, flow, and headway strongly influence the UFT terminal design system, such as the number and performance characteristics of handlers and forklifts available for loading and unloading, number of loading and unloading berths, and the land area required for a terminal. According to the American Trucking Association's (ATA) report (TT-News, 2015) entitled "U.S. Freight Transportation Forecast to 2026," there will be a 29% increase in freight tonnage in the next decade. Based on the Texas Department of Transportation's 2013 Texas Truck Flow band studies (TxDOT, 2015; Rezaeifar et al., 2017), the current truck traffic on IH-45, between Houston and Dallas, is approximately 10,000 trucks per day. If IH-45 capacity remains unchanged for the next 10 years, a new UFT system could easily add capacity capable of handling 3,000 additional containers per day in both directions.

Being able to use a part of the space under existing highways when creating new UFT routes will greatly facilitate the construction of the tunnels built to accommodate the UFT capsules and reduce construction costs. The proposed UFT system design components includes the pipeline system, the vehicles (capsules and gondolas), the conveyance system (tracks and power requirements), and the terminal design needed to receive and direct the new intermodal load transfer systems (Najafi et al., 2016) (Figures 1-9 and 1-10).

1.2.1. UFT Freight and Vehicle Sizes

The proposed design components of UFT include the pipeline system, the vehicles (capsules and gondolas carrying UFT loads available in three different sizes), the conveyance system (tracks and power requirements), and the terminal design and intermodal load transfer systems (Najafi et al., 2016).

1.2.1.1 Freight Sizes

When the tunnels and vehicles were designed, three freight sizes were considered. The largest freight size was the standard shipping container (ISO 668:2013 standard container), which is, 8 ft wide, 9.5 ft high and 40 ft long (8 ft W × 9.5 ft H × 40 ft L), with a maximum gross weight of 68,000 lbs. An intermediate freight size considered was an International Air Transport Association (IATA) Type 6 standard crate (LD-11 crate), which is 5 ft W × 5.3 ft H × 10.4 ft L with a maximum gross weight of 7,000 lbs. Finally, the smallest size freight considered was a standard U.S. pallet size: 3.3 ft W × 3.3 ft H × 4 ft L, with a maximum gross weight of 4,600 lbs.

1.2.1.2 Vehicle Type

Closed vehicles are recommended for crates and pallets to prevent load spillage as well as to provide climate control when needed. Since linear induction motors (LIMs) are proposed in this project to propel the vehicles, an aluminum exterior (good conductor) and ferromagnetic steel interior are recommended. These vehicles are rectangular with dimensions for pallet loads set at 4.2 ft W × 4.5 ft H × 10 ft L and for crate loads, the dimensions were 5.6 ft W × 6.8 ft H × 22 ft L.

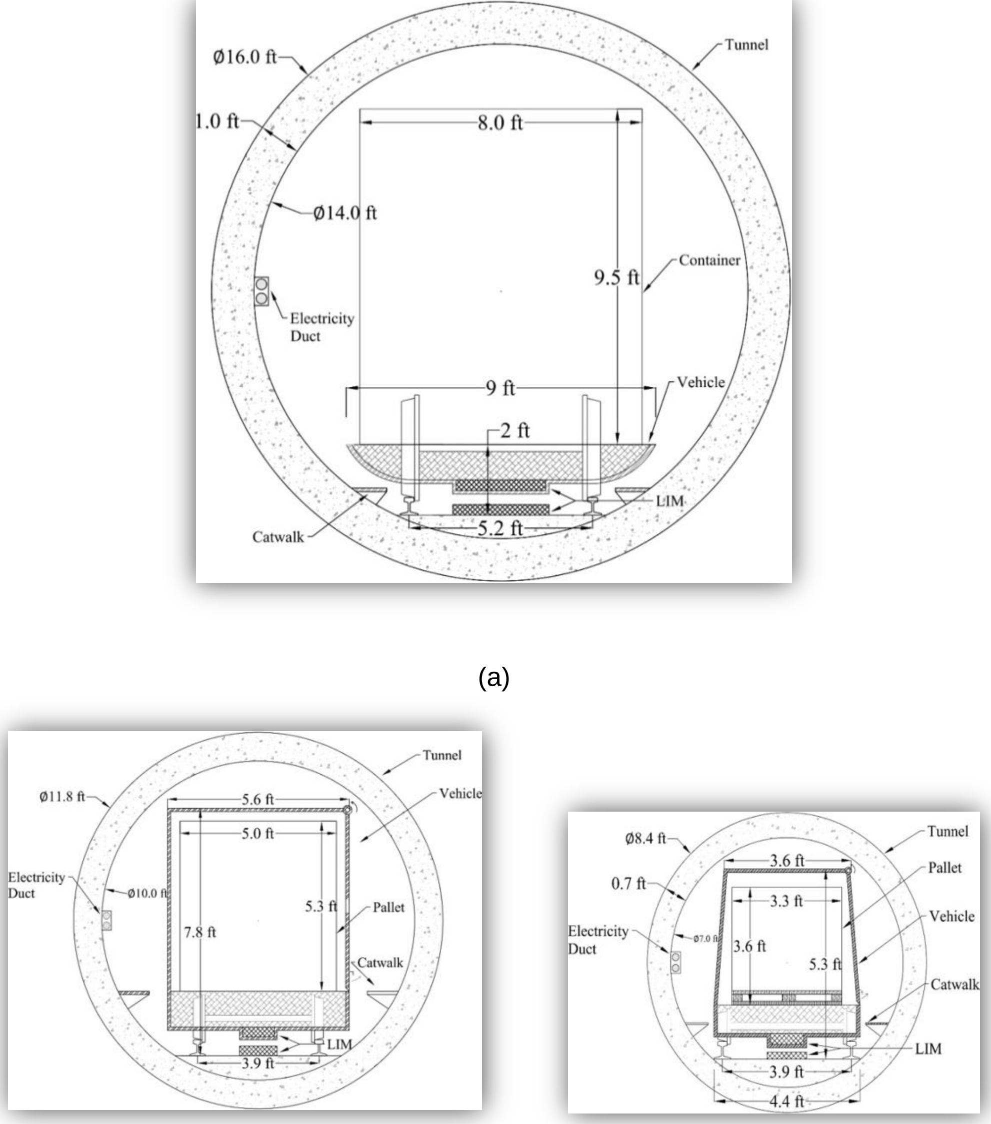
Table 1-2 Dimensions of Freight Types and Their Respective Vehicles (Najafi et al., 2016)

Freight Type	Vehicle
Pallets (3.3 ft W × 3.3 ft H × 4 ft L)	Rectangular External Dimensions: 4.2 ft W × 4.5 ft H ×10 ft L
Crates (5 ft W× 5.3 ft H × 10.4 ft L)	Rectangular External Dimensions: 5.6 ft W × 6.8 ft H × 22 ft L
Shipping Containers (8 ft W × 9.5 ft H × 40 ft L)	Rectangular External Dimensions: 9 ft W × 10.5 ft H × 49 ft L

Covered vehicles are not recommended for the standard shipping containers as there is little chance of load spillage in closed shipping containers. Also, the containers themselves can be climate-controlled if needed. Therefore, an open flat-bed vehicle design with a rectangular cross-section is recommended for shipping containers.

The suggested vehicle dimensions are 9 ft W × 10.5 ft H × 49 ft L with 3-ft H walls. Containers are placed or retrieved from the top (see Figure 1-11).

Table 1-2 summarizes the types of loads (pallets, crates, and shipping containers), their typical dimensions, and the corresponding vehicle types and dimensions.



(a)

(b)

(c)

Figure 1-11 UFT Three Different Sizes. (a) is a shipping container size, (b) is a crate size, and (c) is a pallet size. (Najafi et al., 2016)

1.2.2. Comparison of UFT and Truck Transportation

Surface transportation is expected to grow by 2015 beyond current traffic levels with significant constraints on construction of new highways due to economic and environmental considerations. Figure 1-12 shows truck traffic growth from 1960 through 1990 with traffic forecasted through 2020 (FHWA, 1993).

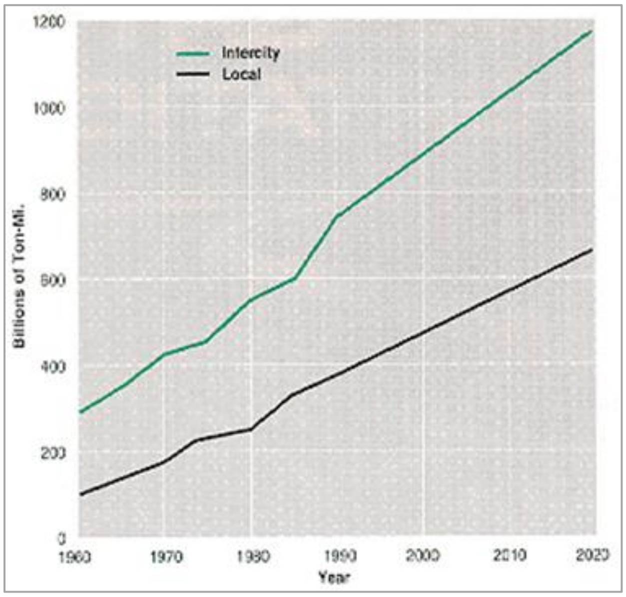


Figure 1-12 Truck Freight Growth, 1960- 2020 (FHWA, 1993)

As illustrated in Figure 1-13, a shortage of truck drivers is the result of an increase in freight movement needs. According to the American Trucking Associations (ATA) estimation, nearly 96,000 new truck drivers will be needed on an annual basis for the next 10 years (Turnbull, 2014). This demand is being fueled mainly by industry growth and by the retirement of current drivers. Also, it indicates that some drivers are leaving the industry or being pushed out of the industry due to hours of service limitations and other rules.

A shortage of 48,000 drivers is expected as the New Year approaches. If the current trend continues, a deficit of approximately 175,000 by 2024 is predictable (Turnbull, 2014). UFT will help the trucking industry by alleviating the need for drivers as the UFT alternative non-operator delivery can be used by trucking companies, and they can benefit financially.

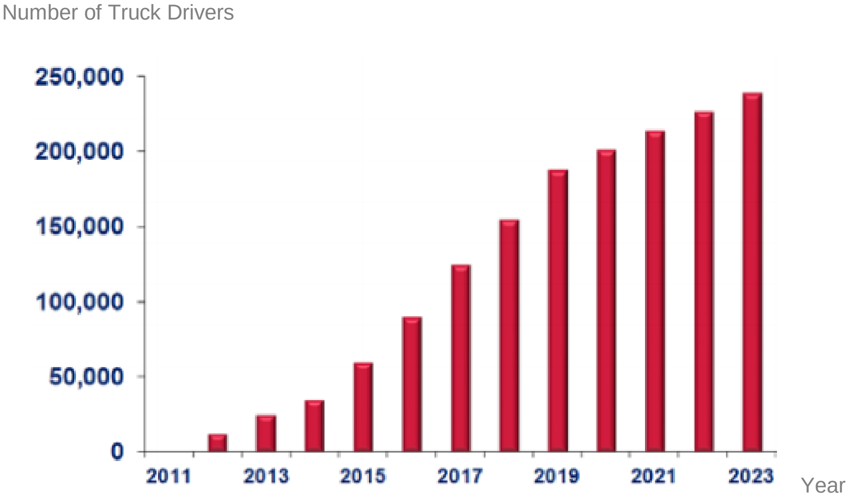
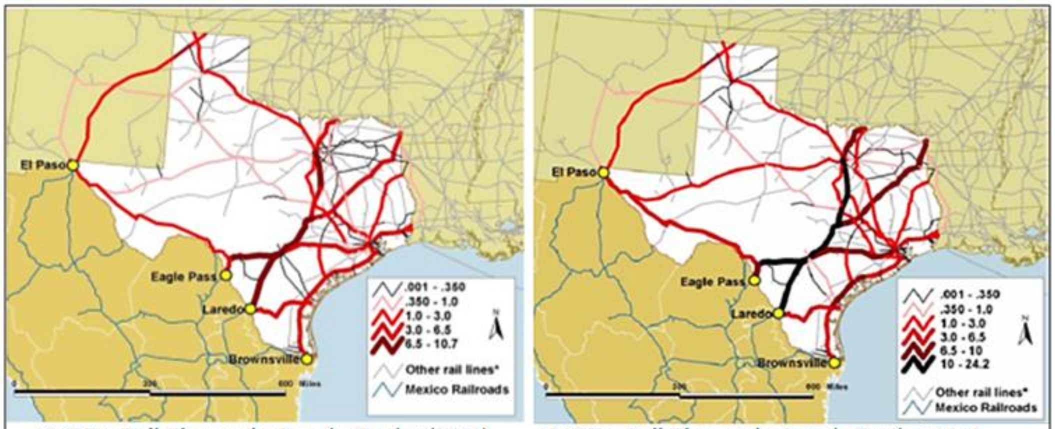


Figure 1-13 Projected Truck Driver Shortage (Turnbull, 2014)

The average annual operation and maintenance cost of a UFT for a 50-mile route is estimated to be approximately $55,500,000. Average operation and maintenance cost of a 50-mile UFT route is estimated at $30/container, whereas the average cost of freight transportation by is truck calculated as $100 for 50 miles (Najafi et al., 2016).

1.2.3 Texas Transportation and UFT system

The Texas transportation system is critical to the US due to the North American Free Trade Agreement (NAFTA) between the US, Mexico, and Canada with freight transportation in the Port of Houston serving as a first-ranked US port in foreign tonnage. According to a report prepared for TxDOT, NAFTA tonnage on Texas highways and railroads is expected to increase by nearly 207 percent from 2003 to 2030. Truck tonnage will grow by 251 percent while rail tonnage is forecasted to increase 118 percent. The number of trucks carrying NAFTA goods will increase by 263 percent and the number of rail units will grow by 195 percent. This will have a profound impact on the Texas highway and rail systems (Najafi et al., 2016). Figure 1-14 shows the Texas NAFTA gateway rail flows for 2003 and 2030.



NAFTA Rail Flow at the Laredo Border (2003)

(a)

NAFTA Rail Flow at the Laredo Border, 2030

(b)

Figure 1-14 Texas NAFTA Gateway Rail Flows (a) 2003 and (b) 2030 (TxDOT, 2007)

Additionally, larger ships will arrive in the Port of Houston due to Panama Canal expansion. The expansion of the Panama Canal will allow transit by ships of up to 12,600 TEUs (twenty-foot equivalent units) compared to the current approximate maximum of around 4,500 TEUs (Tran Systems, 2009). The larger size container vessels have many impacts on port operation. Because of lack of land adjacent to the Port of Houston, larger ships must spend more time in the port; hence, demands include more efficient container-hauling to avoid delays. Additionally, there will be more traffic congestion in the port due to a higher flow of containers between the berth and the yard (Najafi et al., 2016). Therefore, increasing the capacity of the freight transportation system in Texas is a must, while increased land development and population make the possibility of building new roads, widening existing roads, and building new railroad tracks very difficult if not impossible. By considering planning and design, construction methods, cost analysis, environmental impacts, financing means, and the stakeholder committee input, the UFT project for TxDOT (Najafi et al., 2016) examined the use of UFT in three proposed routes in Texas, specifically, the Port of Houston to Dallas, Port of Houston to a distribution center within 15 miles of the Port's point of origin, and the border crossing with Mexico in Laredo. Results showed that underground freight transportation is financially viable, feasible, greener, more cost-effective, and can become an important part of intermodal freight mobility in Texas (Najafi et al., 2016). Figure 1-15 illustrates the NAFTA Truck Traffic Flow on Texas Highways for 2003 and 2030. This dissertation only considers the Port of Houston route to a distribution center with a focus on the terminal task.

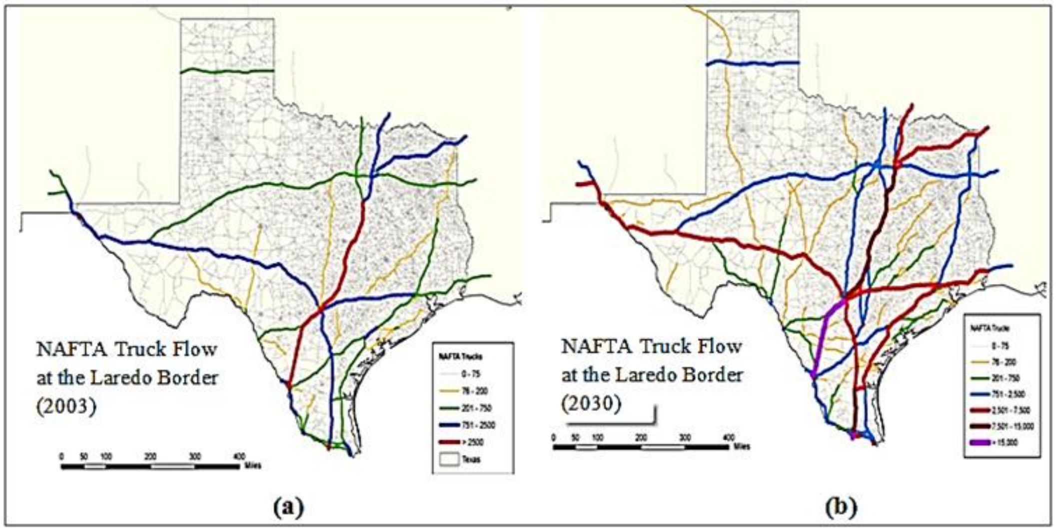


Figure 1-15 NAFTA Truck Traffic Flow on Texas Highways (a) 2003 and (b) 2030 (TxDOT, 2007)

1.2.4. UFT and Intermodal Transport Chain

Intermodal freight transportation—as a part of the freight system—refers to the movement of freight in containers using more than one mode of transportation during a single journey and in this way; it maximizes transportation efficiency by exploiting the comparative benefit of each mode in handling different types of freight movements (TRB, 1992). Intermodal freight transportation is generally defined as a chain made up of a number of transportation modes that are more or less coordinated and interact in intermodal terminals to ensure door-to-door service (Bektas and Crainic, 2007).

UFT terminal transfer containers use more than one mode of transportation. This system uses freight pipeline (i.e., underground tunnels) could be a major mode working with other modes such as rail and trucks in terminals. The underground freight transportation system in this research is connected to the Port of Houston for cargo import and export.

Understanding of loading/unloading processes and metrics such as the number of units, total vehicle length, and equipment utilization, which are used to evaluate loading configurations in intermodal UFT terminals, is a significant step toward the improvement of loading. UFT performance can definitely contribute to optimization of intermodal container freight terminal design and operation. Adopting these metrics would enable terminals to better understand how their loading practices affect intermodal terminal capacity and operation performance. Terminal capacity can be evaluated by studying the effect of facility design, equipment availability, and terminal parking spaces, with each factor providing different metrics of terminal performance.

1.3 Terminal Design

The principal role of terminal facilities is to provide the space and equipment to load and unload vehicles for safe transfer of loads between various modes. Transport terminals are among the largest constructions ever built. Not only has economic globalization been accompanied by a growing spatial influence on freight distribution based on the logistics of intermodal terminals such as ports, airports and rail yards, but also for the logistical distribution of centers (Rodrigue, 2011), which tend to concentrate at a few locations where they act as gateways of the global economy.

The terminal design specifications include rail facility design and layout, freight handling, highway access, planning and environmental considerations, and project time scales (Network rail, 2015). The development of individual freight terminals demands a detailed approach for freight flows, handling processes, equipment selection, the role of information communication technologies (ICTs) in freight transport, and the operational and control rules. Therefore, the design and operating analysis of these systems are significant components in providing a state-of-the-art functional design (Designing Cargo Terminals, 2015). The need and specifications for various elements at the terminal yard are defined based on the import and export items and their packaging methods (Najafi et al., 2016).

1.3.1. Intermodal Terminals

Containerization, which is a system of intermodal cargo transport using intermodal containers (Edmonds, 2017), has changed the layout and function of terminals. The role and function of freight terminals due to containerization changed (Shiri et al., 2018). Indirect transshipment is one of the major changes, which occurs via several modes of transportation in terminals (Table 1-3).

Containers can be loaded/ unloaded, stacked, and transported in long distances effectively without being opened or moved through different modes of transportation. All handling processes are done by using forklifts or cranes (Lewandowski, 2016), and it is totally mechanized. At intermodal terminals, containerized goods arrive on trains or trucks and are sorted and transferred by electric cranes to other trains or trucks for transport to their final destinations. In the other words, an intermodal terminal is a complex system whereby properly designed elements allow for their efficient operation, by means of transport such as ship, rail, pipeline or truck (Swieboda, 2016).

Disruption at transshipment points can cause a negative effect on the flow of loads in intermodal transport.

Table 1-3 Changing Role and Function of Terminals (Rodrigue, 2008)

Conventional	Container
Small terminal surface	Large terminal surface
Direct transshipment possible	Indirect transshipment
Limited mechanization and automation	Advanced mechanization and automation
Improvisation in terminal operations	Organization and planning

Each of the 237 intermodal terminals in the U.S. is unique in terms of its size, layout, lifting equipment, personnel, management strategies, storage capability, gate service capacity, and other variables (IANA, 2011). Intermodal terminal components and their interactions facilitate their primary purpose, which is the successful exchange of trailers/containers between carriers and customers.

1.3.2. Planning and Design of Terminal for UFT

Planning and design process for the Underground Freight Transportation (UFT) system terminals and developing schematic designs for standard shipping containers, crates, and pallets were studied for a TxDOT project (Najafi et al., 2016). This study covered the UFT operational parameters necessary for running the system focusing on the schematic design of terminals. These include dimensioning of various terminal components such as main lines, bypass lines, layover and maintenance lines, loading/unloading platforms and cranes, container stack yards, and intermodal service roads.

Equations were developed to estimate the required headways, number of gondolas, and loading/unloading handler/forklift as a function of the container demand per day and the number of work hours. In this chapter, the capacity computations, headway, and the associated number of vehicles required for 250-mile pipeline tunnel between the Port of Houston (POH) and a distribution center known as South of Dallas (SOD), are based on an assumption of a 24-hour workday (three 8-hour shifts). In addition, the specifications for two other UFT lines are presented. These include the specifications for a 4-mile line at the Laredo border as well as a line between the Port of Houston and a satellite inland terminal 15 miles away.

Table 1-4 Five Different Routes for Implementing the UFT System (Najafi et al., 2016).

No	Route	Freight Type	Origin	Destination	Length (mile)
1	Dallas-Houston	Shipping Container	West side of Barbour's Cut Port, Houston	Dallas Logistic Hub, North of Union Pacific Intermodal Terminal, Lancaster	250
2	Laredo Border	Shipping Container	Southwest of the World Trade Bridge, Nuevo Laredo, Mexico	Intersection of IH-35 and US 59, North side of Union Pacific Intermodal Terminal, Laredo	4
3a	Houston Port – Satellite Dist. Center	Shipping Container	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15
3b	Houston Port – Satellite Dist. Center	Crate	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15
3c	Houston Port – Satellite Dist. Center	Pallet	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	15

The latter line was also reconfigured for capsules containing pallets or crates. Schematic terminal design configurations for each type of cargo (shipping containers, crates, and pallets) were presented. Table 1-4 shows five different routes for implementing the UFT system. The proposed UFT route connecting the Port of Houston to an inland satellite distribution center is shown in Figure 1-16.

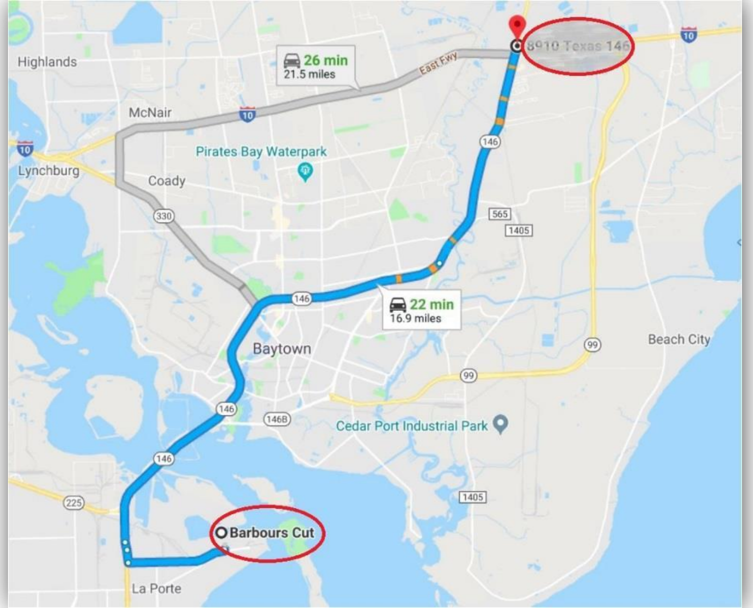


Figure 1-16 Proposed UFT Route Connecting Port of Houston to an Inland Satellite Distribution Center

Construction of underground freight transportation (UFT) systems for freight movement through underground pipelines or tunnels as a new intermodal transportation system can increase the capacity of existing goods movement network (Zahed et al., 2017). Terminal function—as one the important components of the UFT innovative infrastructure project in the intermodal transportation chain—for loading/unloading of any of the load types such as shipping containers, crates, and pallets) will be affected by any change in this system.

An annual increase in intermodal terminal capacity can increase the initial cost of all UFT system components, including the terminal construction cost. Considering the fact that UFT system capacity growth results in a system cost increase, evaluating intermodal terminal operations performance is important.

1.4 Optimization

1.4.1. Optimization in Transportation

Lai et al. (2007) developed an optimization model. That model minimized a train's gap lengths given a particular set of loads and rolling stock. The earlier model was expanded in 2008 by Lai et al. They accounted the uncertainty of incoming load types, and simulation loading of multiple trains. To develop their model, they used the machine vision system (Figure 1-17) to assess current train loading and unloading practices and future loading and unloading enhancements for model optimization.

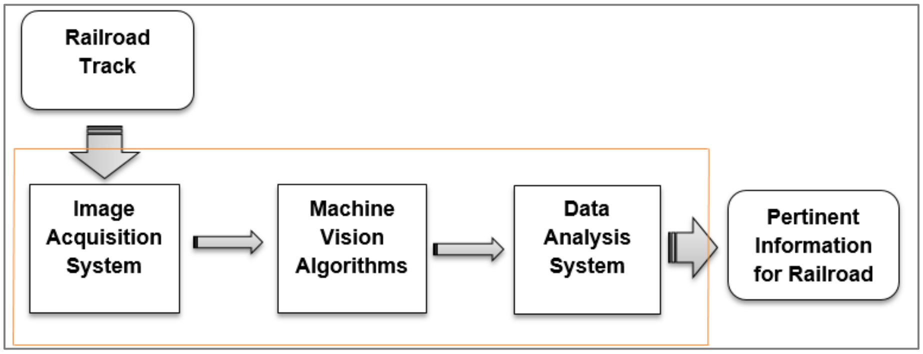


Figure 1-17 Machine Vision System Outline

Optimization in this research is maximizing the desired factors and minimizing undesired ones. Thus, the quest for optimization according to the Business Dictionary (2017) meant finding an alternative to the highest practical performance. In comparison, maximization means trying to achieve the maximum outcome without regard to cost or expense (Shafikhani et al., 2017; Shafikhani et al., 2018).

1.4.2. Intermodal Terminal Operations and Optimization

The intermodal terminal as a key component of the intermodal transport chain may belong to a given carrier, (e.g., rail yards) or be operated individually in support of public or private firms such as rail, sea, river, or ports. Terminals form the most critical components of the entire intermodal transportation chain as the efficiency of the chain greatly depends on the speed and reliability of the operations performed in each terminal (Bektas and Crainic, 2007).

When containerized traffic is of concern in an intermodal terminal, the operations performed are limited to the handling of the containers and not the cargo they contain. Terminal operations may also include cargo and vehicle sorting as well as consolidation, transport make up and break down, and vehicle transfer between facilities. Therefore, a study on the optimization of intermodal container freight terminal operations must satisfy terminal concerns to meet their main goals.

1.5 Objectives and Scope

The objectives of this dissertation are:

- To optimize the intermodal UFT terminal capacity (increasing the annual number of shipped items) through operational improvements.
- Secondary Objective
    - To investigate the different components affecting intermodal UFT terminal capacity and operation performance

The scope of this research includes:

- Intermodal terminal operations for UFT including speed, headway, number of gondolas, line capacity, number of handlers, stack-yard, the conveyance system (tracks and power requirements), lifting equipment, and drayage performance.

This dissertation does not include:

- Sorting containers in the port or stack-yard.
- Truck unavailability.

1.6 Hypotheses

The three hypotheses (H1–H3) of this dissertation are:

- H1: Using the model presented in this research, the efficiency of the intermodal UFT terminal can be improved by 50% compared to the base-model terminal.
- H2: Intermodal UFT terminal capacity and operation performances are affected by container loading/unloading methods including cycle time as an important factor.
- H3: Operation performances and the number of shipped items in intermodal terminals without stack-yard (nonstop cargo transfer from platforms to trucks) is at-least 20% more than terminals with stack-yard.

1.7 Research Needs

Worldwide trade demands of the intermodal freight transport industry are growing at unprecedented rates while the available land on which infrastructure improvements can be built is decreasing. This results in operation under severe constraints of land in addition to human resource controls. Constructing new infrastructure is costly and is not always practical; therefore, existing infrastructure must be managed more efficiently to create additional capacity. Advanced applications are required to maximize the efficiency of intermodal terminals and to provide for this increase in capacity.

The intermodal freight terminal (IFT) is the weakest link of the intermodal transportation chain system and a main generator of costs (Salucci, 2006). Therefore, the need to study and investigate issues relating to intermodal container terminals is necessary in order to boost their effectiveness and efficiency and make the intermodal freight transport more competitive and attractive (Steenken et al. 2004; Lai et al. 2007; Rodrigue, 2011).

Upgrading existing intermodal terminals and constructing new ones throughout the U.S to meet the rising demand for intermodal freight services is a must. To this end, physical expansion of terminal facilities besides increasing their capacity through more effective use of facilities has been considered (Gue 1995; Rickett 2013; Gudelj et al. 2010).

Previous research has directed on terminal optimization and simulation models to explain how different components affect capacity and operation performance (Ken 1983; Gudelj et al. 2010; Gambardella et al. 2001). Several literature reviews have categorized strategic, tactical, and operational planning problems in intermodal transport with the simulation-based approach (Crainic and Laporte 1997; Macharis and Bontekoning 2004; Bontekoning et al. 2004; Caris et al. 2008; Caris et al. 2013; Steadieseifi et al. 2014). This research continues the study of the TXDOT research project (Najafi 2016) for a schematic intermodal terminal for underground freight transportation (UFT) systems. Because this terminal was designed to transfer containers through the underground systems using the underground pipeline (or tunnel) as one of the modals in the category of intermodal transportation systems; therefore, it represents new research in this area, and the results will have an impressive effect on future works with the same approach. There is a need to investigate optimization of operations for an intermodal container terminal in order to increase their efficiency (Lai and Barkan, 2007).

1.8 Methodology

The findings of this dissertation are presented in the following stages:

- Review of technical literature and industry reports.
- Site visit to an intermodal terminal and freight facility to observe technology.
- Participation in industry association and committee meetings and deliberations.

Figure 1-18 describes the research structure and shows different activities. The research framework introduces all required steps which are listed below to achieve to the project goal. These steps are:

- Problem identification
- Literature review
- Defining hypotheses
- Data collection
- Devising methodology and research instruments
- Analysis of data
- Results and future recommendations (see Figure 1-18)

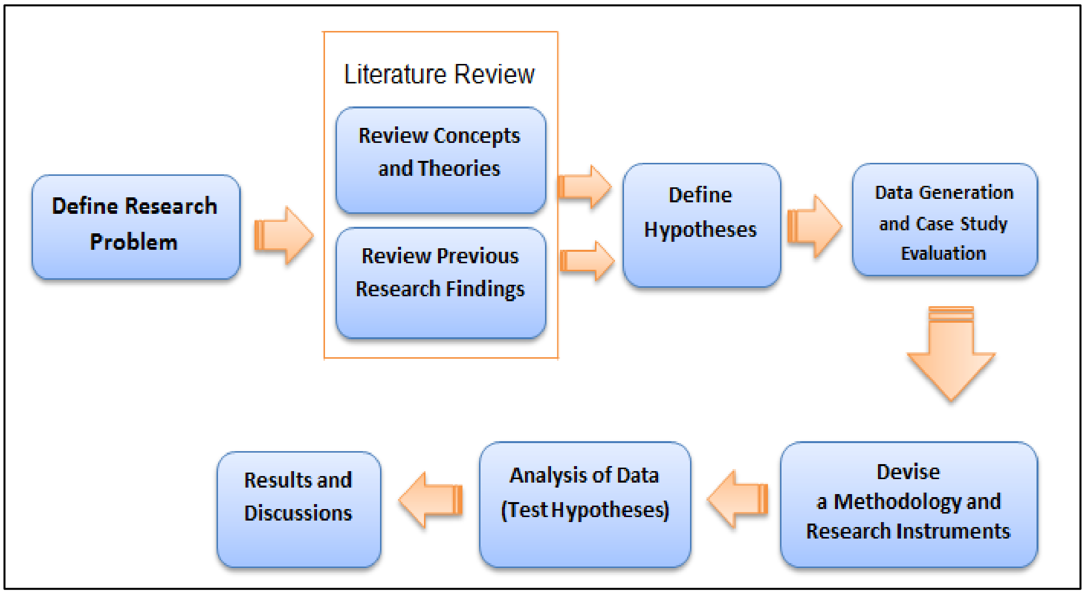


Figure 1-18 Framework for Research Methodology

Loading data analysis on major components of the intermodal processes provides a useful tool to evaluate terminal performance. Terminal loading data includes documentation of container movement, and loading/unloading equipment. Data is stored in a terminal computer network for each container as it passes in or out of the terminal gate, as it is lifted onto or off the railcar, and as it arrives or departs by train (outbound and inbound containers). However, intermodal terminal loading data have some limitations and available research does not provide a complete understanding of terminal performance. This dissertation utilizes simulation modeling and analysis to evaluate intermodal terminal operations performance.

The framework for this research methodology has seven steps. Evaluation of previous research to find deficiencies is the first step and requires defining the research problem. The second step is a comprehensive literature review including scholarly articles, books, and other sources such as dissertations, conference proceedings, published reports, and government documents. The third step explores research hypotheses as a starting point of further investigation. To achieve our research goals, data were collected from the case study of a recent TxDOT research project for a UFT intermodal terminal (Najafi et al., 2016). The fourth step generated additional required data based on mathematical calculations as well as real-world information from currently operating intermodal terminals. The information obtained from these terminals served as model input to obtain a meaningful output. The fifth step presents a methodology and the required research instruments (simulation-optimization tools) for developing the research goals. Data analysis in step six is the process of interpreting the meaning of the data we have generated, and displaying it in the form of tables, bar charts or graphs. Simulation model validation is achieved by comparing the simulation model outputs against the actual records needed to test the research hypothesis. Finally, results and future recommendations in the last step (No. 7) discuss the output of the dissertation. A research summary and recommendations for future studies are reviewed. Research results are validated by comparing the annual number of shipped items with model results. It can also be validated by applying model calculations of work needed to real work conditions needed for future research. For example, the results of this research can be applied on other intermodal terminals and the performance outcomes can be measured and compared.

1.9 Contribution to the Body of Knowledge

Contributions to the body of knowledge for this dissertation are shown through the achieved goals which include:

- Development of performance optimization attributes for intermodal UFT terminal projects through a better understanding of loading/unloading process.
- Identification of the above attributes and their impact on capacity and operational performance of intermodal UFT terminals, which contribute to optimization of operations and helps parties develop management strategies.
- Development of a new integrative simulation-optimization framework for the analysis of intermodal underground freight terminal systems that can be used to assess the operational performance.

The developed simulation-optimization framework is based on discrete-event simulation modeling which includes variables describing the model change at instantaneous discrete points in time (event times) for the number of containers in queue and server status. This simulation model used in this dissertation is uniquely capable of assessing real-world system complexity.

1.10 Dissertation Structure

This dissertation consists of 6 chapters. Chapter 1 presents the background study on freight transportation, importance of freight transportation in the U.S. economy, intermodal transportation, UFT, intermodal terminal, and optimization. Additionally, this chapter introduces research needs, objectives, scope, methodology, and contributions to the body of knowledge.

Chapter 2 provides a comprehensive review on intermodal freight terminals and related research based on a simulation-based approach in the intermodal transportation system. This chapter reviews previous studies about operation optimization and use of simulation techniques in intermodal container terminals.

Chapter 3 covers the planning and design process for UFT system terminals for Texas and explains the operational parameters for UFT terminals.

Chapter 4 presents the model development. This chapter discusses the simulation model approach for optimizing intermodal UFT terminal operations. To build a comprehensive model, additional required data for modeling inputs—based on the available data from chapter 3—is generated and presented in this chapter. This chapter supports the effort to develop an optimal option for intermodal UFT terminals by using simulation-optimization tools in WITNESS^{TM} (Lanner Group, 2008). Chapter 5 covers the details of the model implementation results in operations performance in two sections and provides comparison of results, validation and discussions in terms of the total number of shipped items for intermodal UFT terminals.

Chapter 6 presents results conclusions, limitations and recommendations for future research.

1.11 Chapter Summary

The volume of freight has grown significantly over the past few decades. Advanced applications are required to maximize the efficiency of intermodal UFT terminals and to provide the required capacity for future needs. To achieve the research goals and develop a new integrative simulation-optimization framework for intermodal underground freight terminals systems, this chapter included a problem statement, objectives , a work scope, three hypotheses, research needs, methodology, and contributions to the body of knowledge.

Chapter 2 Literature Review

2.1 Introduction

Chapter 2 reviews previous research related to intermodal freight terminals and a simulation-based approach. This chapter explores previous studies about operation optimization and the use of simulation techniques in intermodal container terminals.

2. 2 Intermodal Transportation

Intermodal freight terminals are critical elements in the total freight distribution chain. Intermodal terminals and, as the name indicates, always has more than one mode of transport transferring goods between terminals. In the last few decades, tax regulations, green policies (Macharis et al., 2011) and alternative options to move freight at a lower cost have promoted the use of intermodal transportation. Around 40% of the total freight volume in U.S. is intermodal shipments. This volume is forecasted to increase 3.25 times by 2040 (BTS, 2012). Therefore, to deal with the increasing freight demands and aging infrastructure, intermodal service providers need to continually plan for upgrades of their existing networks.

In the last 30 years the revolutionary development of container handling has increased the efficiency of worldwide trade by about 9.5% per year (Steenken et al., 2004). The increasing demand for container transportation results in various issues, including risk of terminal congestion, delivery delay, and economic loss. The first studies regarding intermodal terminals appeared in the early 1980s. Munford (1980) was one of the first to write about the problem of growing congestion at port gates.

2.2.1 Freight Service and Cost Continuum across Modes

Intermodal freight transport is the transportation of freight in an intermodal container using at least two transport modes (Shiri and Huynh, 2016; Shiri and Huynh, 2017; Shiri et al., 2018). Based on cargo characteristics, each mode tends to move different freight types and provide various types of services. Figure 2-1 defines the major modes of cargo transportation as truck, rail, marine, air, and pipeline and these modes provide a continuum of speed and service types (NASEM, 2011). One end of this figure shows fast and reliable delivery, but these also cost the most for high levels of service. The most expensive and fastest mode is air. Trucking provides rapid and flexible service for shippers at a higher cost than rail. In terms of cost per ton-mile, marine transport (ships) and pipelines are the least expensive but are less rapid and flexible (NASEM, 2011).

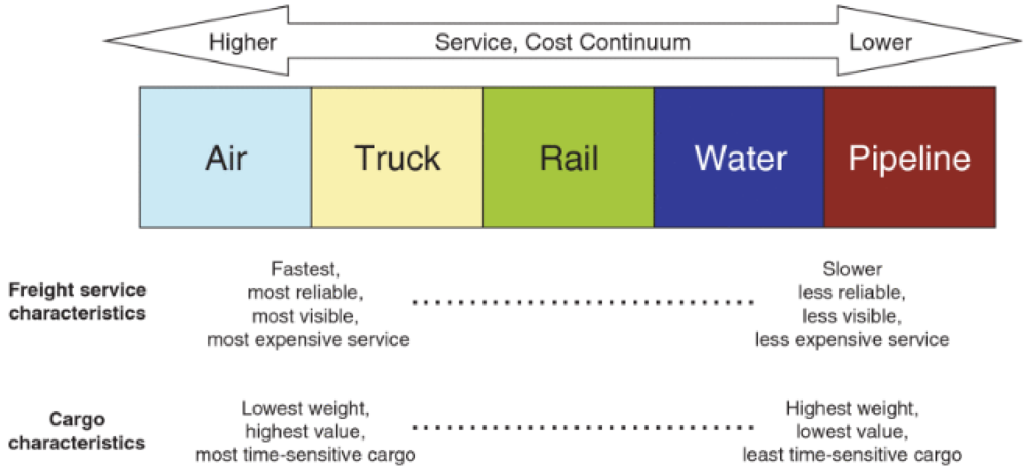


Figure 2-1 Freight Service and Cost Continuum across Modes (NASEM, 2011)

An intermodal terminal is a location for the transfer of freight from one transport mode to another, (e.g., between road and rail). Modes of transportation are trucks, rail, air, water, and pipeline. Figure 2-1 compares the four modes of transportation based on cost, speed, reliability, service cost, weight and value. Figure 2-2 shows different modes of transport including land, air and water.

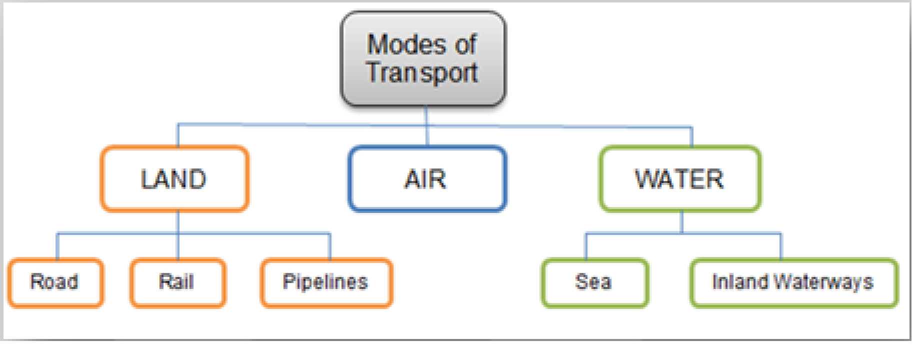


Figure 2-2 Modes of Freight Transportation

2.2.2 Freight Revenue by Mode and Distribution of the Intermodal Terminals

Today, intermodal is the largest single source of U.S. freight revenue. It represents a competitively priced, environmentally friendly alternative to excessive reliance on highways to transport freight.

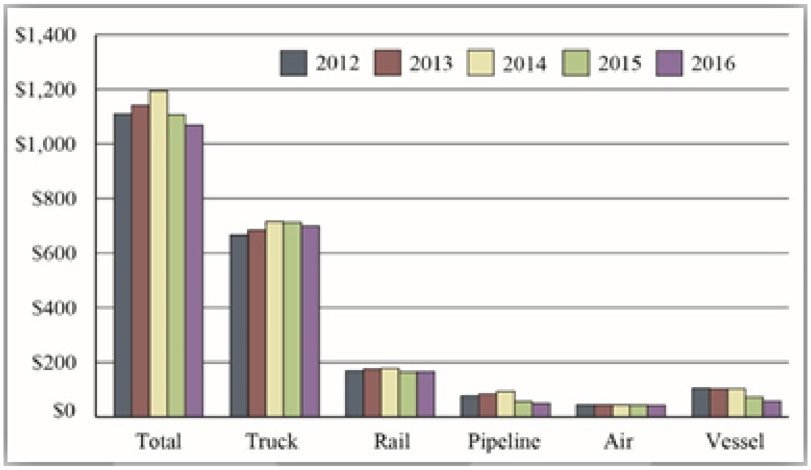


Figure 2-3 U.S. NAFTA Merchandise Trade by Mode
in billions of 2012-2016 Dollars (BTS, 2017c)

Intermodal freight is one of the highest and fast-growing sources of revenue for North American freight modes (Gallamore, 1998). The use of intermodal shipping decreases transportation costs, provides access to capacity, improves product flow and ultimately, improves profit. Optimizing freight network by integrating an intermodal solution into transportation investment can save over 20% (Intermodal, 2017). Figure 2-3 shows the U.S. NAFTA merchandise trade by mode from 2012 to 2016. According to this table, the truck mode shows the maximum amount of about $700 billion. On the other hand, air mode with around $20 billion presents the minimum merchandise trade.

Distribution of the intermodal terminals over the U.S is shown in Figure 2-4. As this Figure illustrates, the most congested locations in the southern U.S. are the states of Texas, Florida and Carolina.

Figure 2-4 U.S. Intermodal Terminal Map (Intermodal, 2017)

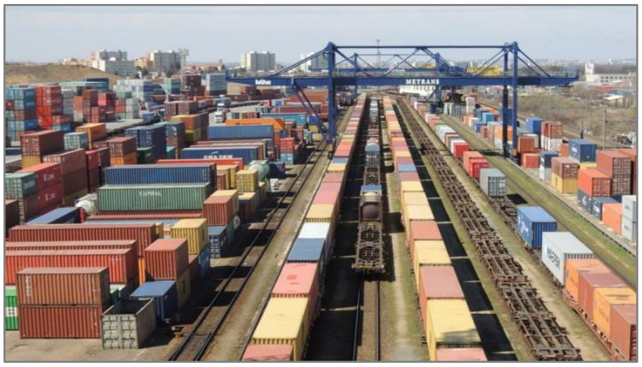


Figure 2-5 Container Intermodal Terminals (Terminal Operations, 2017)

2.2.3 Smart Infrastructure in Intermodal Freight Transportation

Intelligent transportation systems (ITS) provide a set of strategies for advancing transportation safety, mobility, and environmental sustainability by integrating communication and information technology applications into the management and operation of the transportation system through all modes (Haefner and Bieschke, 1998; Rezaeifar et al., 2012).

Figure 2-6 Intermodal freight,

(U.S. DOT, 2015)

Referring to the U.S.DOT, Figure 2-6 shows the smart infrastructure for intermodal freight transportation as divided into six steps: freight tracking, asset tracking, freight terminal processes, drayage operations, freight-highway connector system, and international border crossing process.

2.2.4 Freight Terminal Operations

Operations in freight transportation terminals are usually divided into two principle groups. The first category includes infrastructure such us unloading areas and model access, equipment (storing and lifting facilities), storage, and management for a broad area, for instance, gate access, maintenance, and information systems management are classified as core terminal operations. The second group is considered an added value based on the services of freight terminals, facilities such as distribution centers, trade facilitation, storage depot for container, and container services are involved (Rodrigue, 2008; Puppala et al., 2017). Table 2-1 shows this classification's details.

Table 2-1 Freight Transportation Terminals: Operations and Added Value (Adapted from Rodrigue, 2008)

Core (Operations)	Infrastructure	Model access (dock, siding, road), unloading areas
	Equipment	Intermodal lifting equipment, storing equipment
	Storage	Yard for empty and loaded containers
	Management	Administration, maintenance, access (gates), information systems
Ancillary (Added Value)	Trade facilitation	Free trade zone, logistical services
	Distribution centers	Trans loading, cross-docking, warehousing, light manufacturing, temperature controlled facilities (cold chain)
	Storage depot	Container depot, bulk storage
	Container services	Washing, preparation, repair, worthiness certification

2.3 Research Studies on Intermodal Terminal Optimization

Increasing the capacity of the intermodal freight terminals is a major reason for this study, while increased land development and population make the possibility of constructing new terminals very difficult and costly. The need to improve the capacity of the U.S. transportation system has motivated several studies on an underground freight transportation system. These studies aimed to accommodate a significant increase in freight volume without degrading the reliability of transportation service.

Findings from many of studies in the area of intermodal terminal optimization have been considered innovations in transportation. These include the Sydney Freight Circle for container transport from the Port of Sydney to seven distribution warehouses (Fiars, 2009), the container port expansion project in Shanghai (Guo et al., 2008), and any currently operating systems in the mining industry (Liu and Lenau, 2005; Kosugi, 1999). A similar system was designed for shipping standard containers in a 137-mile freight pipeline from the San Pedro Bay (SPB) Port Complex (in Los Angeles) to the inland regions of California by the Green Rail Intelligent Development (GRID) system. The following paragraphs review some outstanding research in this area.

2.3.1 Optimizing the Aerodynamic Efficiency of Intermodal Freight Trains

Lai (2007), in their research article titled “Optimizing the aerodynamic efficiency of intermodal freight trains” described their development of an aerodynamic loading assignment model based on an integer-programming framework for intermodal freight trains. This optimization model will help terminal managers to utilize more fuel-efficient trains through railway equipment use, operations, and policy. Researcher’s (Lai et al., 2007) results by implementation of the model, demonstrated a potential to reduce fuel consumption by 15 million gallons per year with $28,000,000 savings in a major railroad intermodal route.

2.3.2 Models and Method for Operations in Port Container Terminals

Gudelj et al. (2010), presented a study entitled “Models and method for operations in port container terminals.” Their research focuses on the allocation of containers on the terminal yard, allocation of ships to berths and cranes, scheduling priorities and operations to get the most out of performance based on some economic metrics. Port Koper and Terminal Koper were used as a case study by Gudelj et al. (2010). Slovenia became part of the European container port system in 2005, which spurred a growth in operations (Table 2-2, Figure 2-7) in this terminal and a need for terminal expansion (e.g., quay and yard extensions, new equipment, increased TEU capacity, and infrastructure developments) to meet the new demands. So, terminals are becoming more and more important. Research can help in the study of advanced models by representing, simulating, and reporting on-line control of the terminal activities for better terminal productivity (Gudelj et al., 2010; Liu, 2010).

Objectives, methods and results from Gudelj et al.'s (2010) study on port container terminals are summarized as follows:

The objective was to maximize terminal performance through solving problems related to allocation of containers and ships on the terminal yard and berth, respectively, and to improve scheduling priorities and operation. To achieve this research objective, simulation and optimization techniques were used as the research methodology. The use of optimization and simulation techniques is presented in the management of container terminals carried out by Gudelj et al. (2010) for Port KOPER and Terminal Koper as a case study. It proposed the Place Transition Net (Petri net) model and the genetic algorithm for solving the berth, scheduling container loading/unloading operations, and crane assignments problem. The main contribution of this paper was the development of a rule-based technique for the berth dispatching problem. They used the multi-objective fitness function to increase the container terminal production. The results show that the estimated objective value of container shipping cost has been reduced by about 18.69% (about 17.80 hours) and it was found that the two–

point crossover took longer time per simulation (about 50%) than the single-point crossover, but the difference in solutions is not significant.

Table 2-2 Container Terminal Capacity and Transshipment
from 2006 to 2015 (Horvat and Twrdy, 2008)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Capacity (1000 TEU)	300	350	400	600	600	600	800	800	800	1000
Traffic- 10% growth	218.9	305.6	385	423	465.9	512.5	563.5	620.2	682.2	750.4

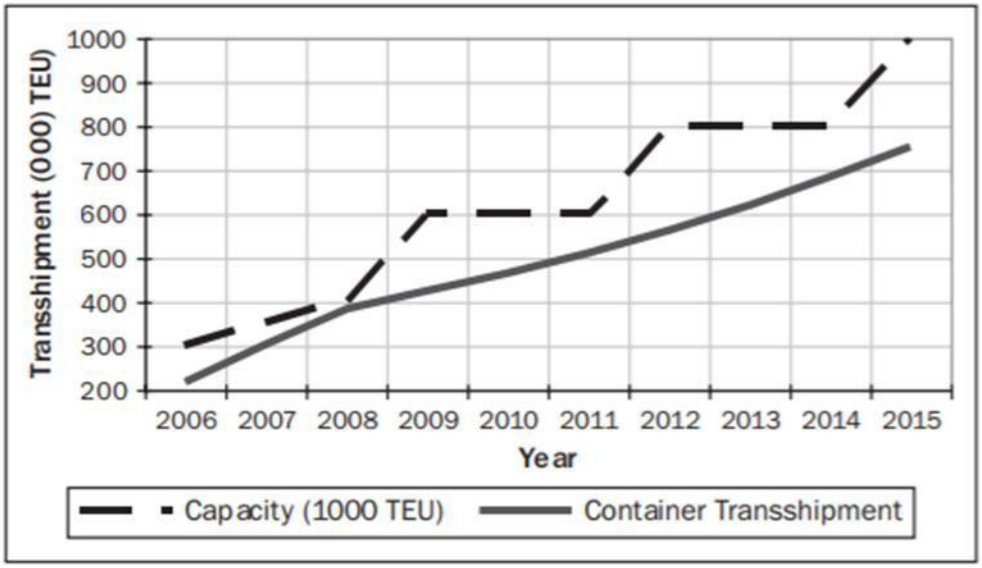


Figure 2-7 Container Transshipment Changes Regarding Container
Terminal Capacity from 2006 to 2015 (Horvat and Twrdy, 2008)

2.3.3 Loading Methods Effect on Intermodal Terminal Operations

Rickett (2013) studied intermodal terminal focuses on the “Intermodal train loading methods and their effect on intermodal terminal operations.” The objective of his research understood the loading/unloading processes at the intermodal terminal and how they could be affected by improving intermodal train loading. He reviewed terminal operations, terminal performance metrics, and intermodal train loading metrics and studied the potential solutions to maximize the loading efficiency. This research examined how railroads can reduce intermodal train fuel consumption and increase terminal operations performance through improved loading practices. Rickett (2013) also discussed loading metrics and machine vision technology, and how they can be applied to analyze current loading performance of intermodal trains.

The terminal loading data discussed thus far was used to assess and predict terminal performance. The loading data collected from terminals provided understanding into the train processes, the gate and lifting processes, and dwell time. Analysis of the loading data presented that goods dwell times and the loading processes are not synchronized, which results in reduced efficiency.

2.3.4 Machine Vision Analysis of the Energy Efficiency of Intermodal Freight Trains

In another study, Lai et al. (2007) investigated “Machine vision analysis of the energy efficiency of intermodal freight trains.” Authors used machine vision (MV) system to scan passing intermodal trains automatically and evaluate their aerodynamic efficiency. Machine vision algorithms were used to analyze images and to detect and measure gaps between loads. The scoring system was based on two elements: slot efficiency and aerodynamic coefficient. Results showed that the MV system can give feedback on the loading performance of trains to intermodal terminal managers, which gives them better decision-making criteria for their organizational strategies.

Sawadisavi et al. (2008) presented a study on machine vision inspection of railroad tracks, which supplemented manual inspections. Their MV research resulted in the development of a long-term predictive assessment of rail track system, which enabled a better understanding of track structure degradation and failure modes.

2.4 Simulation-Based Approach in Intermodal Transportation System

Based on a discrete-event model, which models the operation of a system as a discrete sequence of events in time—and simulates the behavior and performance of a real-life system—the operation of intermodal terminals can be simulated. A simulation tool for combined rail/road transport in intermodal terminals was the focus of an investigation by Rizzioli et al. (2002). A discrete-event model was used for the terminal and corridor simulation. The model simulated the internal processes of an integrated rail and road terminal to find out how an increase in intermodal traffic impacts terminal performance. The model processes used to determine the flow of intermodal transport units (ITUs) considered the loading /unloading of ITUs onto and from the train, storage of ITUs on the yard, and arrivals and departures of ITUs by truck. The model input scenarios included: train timetables and truck arrivals for IUT delivery and pick-up. Different input scenarios to evaluate the impact of new approaches on terminal performance were used to test the completed model.

2.4.1 Planning in Intermodal Freight

Several literature reviews exist categorizing strategic, tactical, and operational planning problems in intermodal transport with simulation-based approach. Crainic and Laporte (1997) studied planning problems in intermodal freight and in related research in the field of intermodal freight. Janssens et al. (2013) considered decision support in intermodal transportation and proposed a new research agenda in this area. Bontekoning et al. (2004) reviewed intermodal rail-truck freight transport literature. Steadieseifi, et al. (2014) also presented a literature review on multimodal freight transportation planning.

2.4.3 Transportation and Production Agent-based Simulator (TAPAS)

Holmgren et al. (2012) developed a transportation and production agent-based simulator (TAPAS). This multi-agent-based simulation used various transport chains to analyze infrastructure measures and transport-related policies. TAPAS is a micro-level simulator, which consists of two related layers. While a lower layer simulates physical activities, a higher level simulates interactions and decisions from a number of actors involved in the supply chain. Simulated decisions were based on transport quantity, routes, vehicles, modes, and the launching time for operations. The behavior of individual actors and the interactions between them was explained by using micro level simulation techniques.

2.5 Chapter Summary

This chapter reviewed previous research related to intermodal freight terminals. Freight revenue was tallied based on the transportation mode, distribution of intermodal terminals, and freight terminal operations income and costs. Additionally, previous studies about operation optimization and use of simulation techniques in intermodal container terminals were elaborated upon.

Chapter 3 Intermodal Terminal Design for UFT System

3.1 Introduction

Chapter 1 explained the intermodal transportation and UFT systems. Chapter 2 provided a review of intermodal terminals and related research in the simulation-based approach to the intermodal transportation system. This chapter reviews the Port of Houston-Dallas UFT terminal covered in the Najafi (2016) TxDOT project, which was the main source for generating data for the model development task. This case study covers the UFT operational parameters necessary for running the system focusing on the schematic design of terminals. A schematic design of the terminal includes dimensioning of various terminal components such as main lines, bypass lines, layover, and maintenance lines, loading/unloading platforms and cranes, as well as container stack yards and intermodal service roads.

3.2 Operational Parameters in UFT Terminal

3.2.1. Speed and Headway, Number of Gondolas, Line Capacity, Number of Handlers

3.2.1.1. Speed and Headway

The minimum achievable headways in a UFT line were controlled by the power requirements of the linear induction motors (LIMs) used to propel a fully loaded vehicle at the designed operating speed as well as meet safety requirements. The LIM system imposes limitations on the design and operations of a UFT line. Decreasing the headway between vehicles, for example, will overheat the LIM system.

Speed has a close relation to flow and headway and should also be comparable to other modes of freight transportation, such as trucks and trains. Keeping the minimum headway (h_{min}) should be determined as a way to prevent any collision in the system. This suggests that the headway between two successive gondolas should be large enough for the first gondola (equipment used for carrying the freight) to reach the top operating speed while providing enough time for the safe stopping of the second gondola. The time required to travel the length of a gondola should also be considered in this computation. The functional relation for the required minimum headway is shown in Equation 3-1 (Najafi et al.,2016).

$$h_{\min} = \frac{l}{1.47v} + 1.47(\frac{v}{a} + \frac{v}{d}) \quad \text{Equation 3-1}$$

Where:

h_{min} = minimum headway between gondolas (sec),

l = length of the gondola (ft),

v = running speed (mph),

a = acceleration rate (ft/sec^2), and

d = deceleration rate (ft/sec^2).

The coefficient 1.47 is for converting the speed from mph to ft/s.

The gondola should be long enough to accommodate 40-ft standard shipping containers. Schematic designs show that the length of a gondola should be a minimum of about 49 ft.

Similar to cruising speed, acceleration rate is also a variable in energy consumption. Since a high acceleration rate will increase energy consumption without a commensurate operational benefit. An acceleration rate of about 10 ft/sec^2 is recommended for the UFT system as it is small enough to reduce energy consumption and prevent containers from shifting yet large enough to minimize headways.

While energy consumption is not a major consideration in the deceleration case, having a high deceleration rate may result in shifting of containers or excessive shear force on the gondola chassis and axles. A deceleration rate of about 10 ft/sec^2 is also considered to be a reasonable value in this case, comparable to a rate at which a vehicle is normally brought to stop at a traffic signal. Considering an operating speed of 45 mph, acceleration and deceleration values of 10 ft/sec^2, and a gondola length of 49 ft. Equation 3-1 yields a minimum safe headway of approximately 14 seconds.

The LIM system also imposes limitations on the design and operations of a UFT line. Decreasing the headway between gondolas, for example, will overheat the LIM system (Najafi et al., 2016). A sufficiently long gap between successive vehicles is needed to let the LIM system cool down and sustain normal operations. Overheating the LIM system is both dangerous and energy consuming. Vehicles arrive at a LIM at the speed of about 44.8 miles per hour and depart at the speed of 45.2 miles per hour, resulting in an average speed of about 45 miles per hour. Based on the LIM experts consulted (Feghhi, 2015), a 30-second headway might be an optimum headway for a UFT system for standard shipping containers. It should be noted that for vehicles carrying crates or pallets, due to lighter gross weights, the minimum headways according to the LIM system requirements are 15 and 10 seconds, respectively (Feghhi, 2015). However, due to safety and handler's operational constraints at the terminals, a minimum operational headway of 20 seconds will be used for the latter two UFT systems as well. The design headway for the UFT system is primarily influenced by the number of containers to be processed in a day and the working hours per day at the origin and destination.

3.2.1.2 Number of Vehicles/ Gondolas

The term "vehicle" is used as a generic term to represent gondolas for standard shipping containers and capsules for crates and pallets. Gondolas, are open flat-bed vehicles each carrying a 40-ft standard shipping container. On the other hand, capsules (for crates and pallets, respectively) are covered vehicles each carrying two pallets or two crates at a time (Rezaeifar et al., 2017; Rezaeifar et al., 2018). Table 3-1 also provides different load types, sizes, maximum weights per gondolas/capsule, and routes for UFT system.

Table 3-1 Different Load Types for Specified Routes (Najafi et al., 2016)

Load Type	Size	Max. Load Weight (U.S. tons)	Max. Weight Per Gondola/Capsule (U.S. tons)	Route
Standard Shipping Container	Large	34	(34 * 1) + 5* = 39	Port of Houston – Dallas Laredo Border Port of Houston - Satellite Inland Terminal
Crate	Medium	3.5	(3.5 * 2) + 2.3 = 9.3	Port of Houston - Satellite Inland Terminal
Pallet	Small	2.3	(2.3 * 2) + 1 = 5.6	Port of Houston - Satellite Inland Terminal

* Empty gondola/capsule weight (U.S. tons)

The required number of gondolas in a UFT system depends on the system length, speed, and operational headway, as shown in Equation 3-2 (Najafi et al., 2016):

$$N_g = 7200\left(\frac{l}{v_* H_{Opr}}\right) + 1.47\left(\frac{v}{h_{Opr}}\right)\left(\frac{1}{a} + \frac{1}{d}\right) \qquad \text{Equation 3-2}$$

Where:

N_g = number of gondolas required,

H_{opr} = operating headway (sec),

l = total length of the line (miles),

v = running speed (mph),

a = acceleration rate (ft/sec^2), and

d = deceleration rate (ft/sec^2)

Equation 3-2 yields the required gondolas in the UFT system when the flow in both directions is equal. The capacity of the UFT system is defined for the condition when the system is working at the minimum operational headway. The minimum operational headway for the Port of Houston-Dallas UFT system is determined to be 30 seconds; hence, a total of 1,334 gondolas are needed for this system with the capacity of 1,500 containers per day per direction. If each handler can load and unload a gondola in 1.5 minutes, a rate within most handler specifications (Specifications available in handler companies' websites such as Kalmar (2016)), then six handlers will be sufficient to accommodate gondolas at 30-second headways. When the UFT system is handling flows lower than capacity, then not all gondolas are used. Some gondolas can be on stand-by in the terminal layover section.

3.2.1.3. Line Capacity

The capacity of a UFT system in terms of containers processed per day or per unit time (container flow) should be sufficiently high enough to justify the construction and operation of the system.

A UFT system with a lower headway will naturally have a higher freight transport capacity. The maximum number of freight loads the system can deliver in a 24-hour-day is the other definition of capacity. Equation 3-3 (Najafi et al., 2016) shows the relation between the minimum headway, working hours per day, and the system capacity.

$$C = 3{,}600 * (T / h_{min}) \qquad \text{Equation 3-3}$$

Where:

h_{min} = minimum design headway (sec),

T = working hours (hrs./day), and

C = system capacity (vehicles/day/direction).

Based on the estimated minimum headway of the shipping container system (30 sec) and a 24-hour workday, the system capacity is estimated to be 2,880 vehicles/day/direction.

3.3.1.4. Number of Handlers

Handlers are one of the most essential and costly components of a UFT terminal. Handlers are used for both loading and unloading the shipping containers as well as for stacking the shipping containers in the stacking yard and for loading/unloading trucks. The operating characteristics of handlers are significantly influenced by the UFT system headways and capacity. The time required for handlers to load or unload a shipping container determines the number of platforms in each loading/unloading section of the terminal. A UFT system with a lower headway requires a higher number of handlers to accommodate freight arriving or departing. Equation 3-4 (Najafi et al., 2016) shows the relation between flow, UFT system working hours per day, the loading/ unloading time, and the number of loading and unloading pair platforms in a terminal design which is three loading and unloading platforms with minimum headways of 30 seconds and operating at full capacity.

$$N_c = Q * t / 3{,}600T \qquad \text{Equation 3-4}$$

Where:

N_c = number of handlers for loading/unloading,

t = loading/unloading time (sec),

T = working hours (hrs/day), and

Q = system flow (gondolas/day).

The total number of handlers needed in each terminal is twice the number of loading/unloading platforms—-the area in UFT terminals where vehicles stop for loading/unloading the freight—in pairs. Hence, a total of 12 handlers are needed in each terminal for container size systems. If we denote N_t to be the total number of handlers required in the system, then $N_t = 2N_c$. A number of additional (backup) handlers will also be needed, sometimes in case of emergency or breakdown of the operating handlers.

3.4 Terminal Design and Crew Size

The scope of this subtask is to develop a schematic design for the UFT system terminals for each of the three load types (shipping containers, crates, and pallets). The terminal design specifications include rail facility design and layout, freight handling, highway access, planning and environmental considerations, and project time scales (Network Rail Co., 2015). The development of individual cargo terminals demands a detailed approach for cargo flows, handling processes, equipment selection, the role of information communication technologies (ICTs) in freight transport, and the operational and control rules. Therefore, the design and operational analysis of these processes are significant components in providing a state-of-the-art functional design (Designing Cargo Terminals, 2015).

The first step in this part was rail facility design and layout. To this end, a schematic terminal design was developed which includes main lines (in which gondolas move), underpass lines (the lower level of a crossing of the main line), bypass shunts (a short lane for diverting the vehicles to the platforms for loading/unloading), truck service roads, handler locations,, land-side transfer areas (spaces between stack yards and truck roads for cargo transfer services), and container stack yards (an area where containers are stacked for a short time). See Figure 3-1 and Figure A2 in Appendix A

3.4.1. Schematic Design of Terminal

The UFT terminal design has three loading platforms and three unloading platforms. If necessary, the number of platforms can be expanded to handle additional container flows. However, a total of six platforms (three loading and three unloading) will be sufficient for the daily container flows specified in Table 3-6. There are a number of bypass shunts so incoming vehicles can be directed to the next available platform. Bypass shunts are designed to alleviate queueing of arriving vehicles during peak loading and unloading times. Unloading the cargo in each platform by using a handler is estimated to take about 90 seconds. In turn, the minimum headway between consecutive vehicles could be as low as 5 seconds (Equation 3-2). This creates a potential for a traffic back-up unless bypass shunts are available, which allow vehicles to continue down the line to the next available platform.

After unloading their cargos, vehicles are directed beyond the loading platform through the underpass lines. Underpass lines pass beneath the bypass shunts and are designed with an approximately 10% grade. They direct vehicles to the

service or allow a space for any necessary repairs. Layover lines and maintenance lines run parallel to loading platforms or, if need be, to the layover and maintenance lines as breaks in the main line allow vehicles to return to the main line when needed. Vehicles then pass underneath a second bypass shunt and proceed to the outgoing loading platform to be loaded with new cargo where they can then be directed to the outgoing main lines after loading.

Terminals for standard shipping containers (Figure 3-1) can also handle capsules carrying crates and pallets. However, if there are dedicated UFT lines for crate capsules or pallet capsules, smaller size terminals can be designed. Following the same plan as for the shipping container terminals, Figure A-2 in Appendix A, illustrates the schematic design of crate terminals with a total of 12 (same as the pallet capsule terminals) platforms (six loading and six unloading).

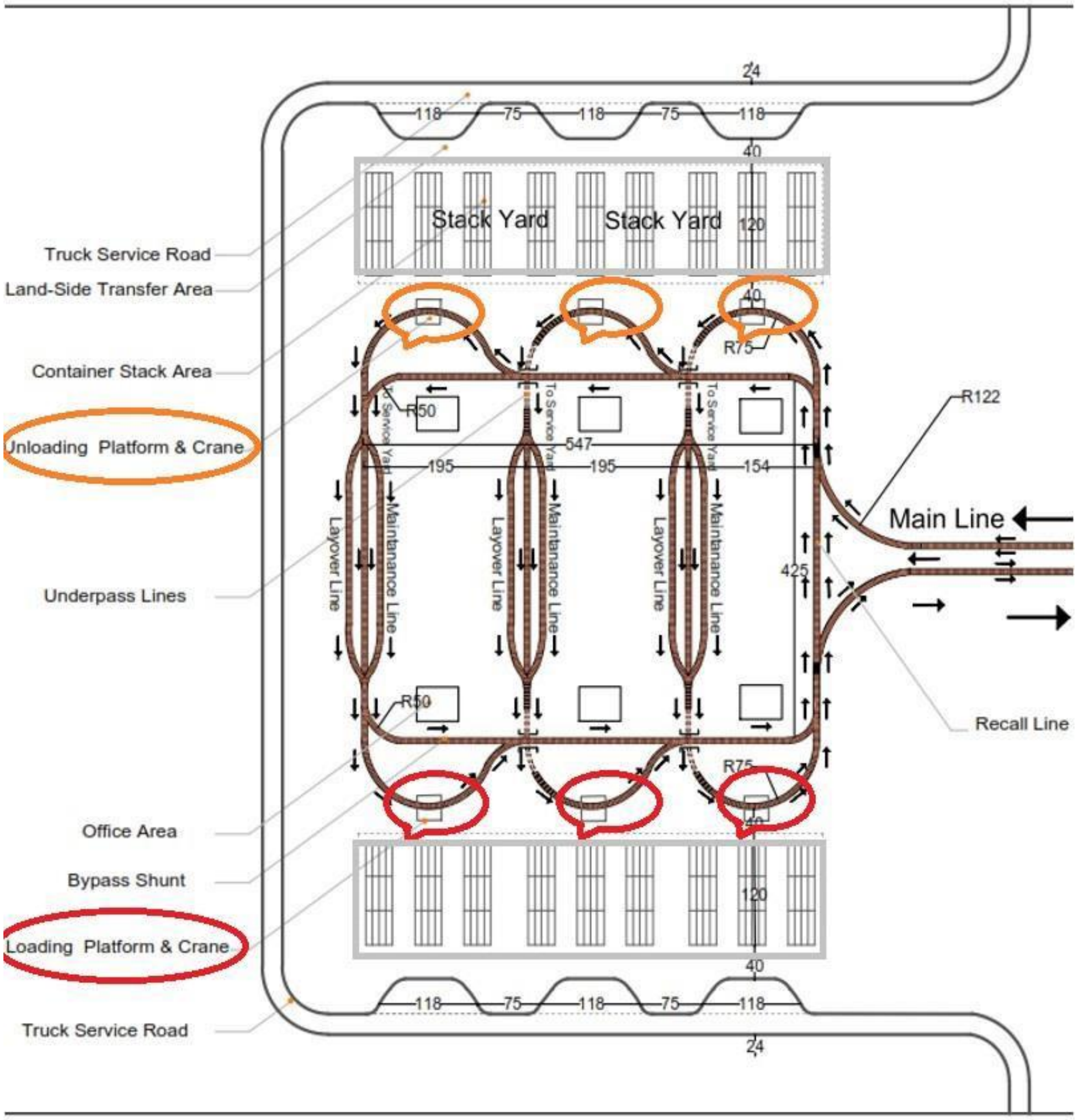


Figure 3-1 Terminal Layout and Dimensions for Vehicles (Gondolas) Carrying Standard Shipping Containers (Najafi et al., 2016)

3.4.1.1 Required Terminal Areas

The terminal area calculations entail required areas for handler operations, stack yards, truck access, service yard, and vehicles (gondolas or capsules) storage and parking. The following equation yields the terminal area based on the pair of loading/unloading platforms. Table 3-2 shows the total terminal area for each type of UFT system. It has a constant value (56,000 sq. yds. for container size) for the first pair of loading/unloading platforms (see Figure 3-1), and a variable section for each additional pair of loading/unloading platforms (24,000 sq. yds. for container size).

For Container UFTs: $A = 56{,}000 + 24{,}000\ (N - 1)$ Equation 3- 5

Where:

A= total terminal area (sq. yds.), and

N = number of loading/unloading platforms

The respective terminal area calculations for the two smaller UFT systems for crates and pallets are given in by Equations 3-6 and 3-7, respectively.

For Crate UFTs: $A = 29{,}500 + 14{,}700\ (N - 1$ Equation 3-6

For Pallet UFTs: $A = 11{,}980 + 5{,}990\ (N -1)$ Equation 3-7

Table 3-3 shows the total number of loading/unloading platforms for the Houston-Dallas line as 6, i.e., three pairs of loading/unloading platforms (N=3). Thus, Equation 3-5 (Najafi et al., 2016) yields a total terminal area of about 104,000 SY (21.5 acres) for the Houston-Dallas UFT line.

The respective area sizes for terminals handling crate capsules and pallet capsules are 21.3 acres (Equation 3-5) and 8.7 acres (Equation 3-6), respectively. These area estimates are based on 12 loading/unloading platforms for each of the two smaller UFT systems for crates and pallets.

Table 3-2 Total Terminal Area for Each Type of UFT System (Najafi et al., 2016).

UFT System	Total Terminal Area (SY)
Standard Shipping Container	56,000+(N-1)*24,000
Crate	29,500+(N-1)*14,700
Pallet	11,980+(N-1)*5,990

3.4.2. Crew Size

For each eight-hour operation shift, it is estimated that a total of 12 crew members will be needed at each terminal. These include two handler operators at each platform, one for loading/unloading of vehicles and the other for loading/unloading of trucks. This will yield a total of 12 crew members for a terminal with six platforms. For a 24-hour terminal operation, a total minimum of 36 crew members will be needed for all platforms for each terminal. The resulting operational specifications for each of the five routes for standard shipping containers (3 routes), crates (1 route) and pallets (1 route) are summarized in Table 3-3.

According to the Equation 3-1, the operational parameters are based on a 30-second minimum operating headway for shipping containers and 20 seconds for pallet and crate sizes. If the container volume is less than the line capacity, excess vehicles could be stored in the lay-over sections of each terminal, thus allowing higher than minimum operating headways. Alternatively, as discussed earlier, minimum headways could continue to be maintained by allowing some vehicles to circulate empty in the line.

Table 3-3 Summaries of Operational Parameters for Each Route (Najafi et al., 2016)

Route	Houston to Dallas	Laredo Border	Houston to Satellite	Houston to Satellite	Houston to Satellite
Cargo Type	Container	Container	Container	Crate	Pallet
Length (miles)	250	4	15	15	15
Speed (mph)	45	45	45	45	45
Min Headway (sec)	30	30	30	20	20
Capacity (Vehs/Day/Direction)	2,880	2,880	2,880	4,320	4,320
No. of Handlers (per terminal)	16*	16*	16*	N/A	N/A
No. of Forklifts (per terminal)	N/A	N/A	N/A	28*	28*
Vehicles(Gondolas)Circulating (at capacity conditions)	1,334	22	80	122	122
Fully-Loaded Veh. Weight (U.S. tons)	39	39	39	9.3	5.6
Loading/Unloading Platforms (per terminal)	6	6	6	12	12
Terminal Area (acres)	21.5	21.5	21.5	21.3	8.7

* Includes 4 back-up units, two on the loading side and two on the unloading side.

Table 3-3 included estimates of system capacity, the number of loading/unloading platforms, the estimated required terminal areas, and an estimate of the crew sizes for 24-hour operations.

3.5 Chapter Summary

This chapter covered the UFT necessary parameters within pipeline infrastructure for a 24-hour workday operation. The number of vehicles needed and the container capacity that can be handled per day were estimated for each of the three UFT lines. Schematic terminal design was also presented—one for each type of load. Furthermore, the required terminal area for each load type was also estimated. It was determined that the 250-mile UFT line between Houston and Dallas can offer a line capacity of 2,880 containers/day/direction which would require 1,334 vehicles circulating in the line at 30-second headways. The corresponding numbers of vehicles for the 15-mile Houston to inland satellite port and for the 4-mile Laredo border line were 80 and 22 vehicles, respectively. These lines also have a capacity of 2,880 containers/day/direction (entering or leaving terminal) for 30-second minimum headways. In order to determine the financial needs of all three designs, specific parameters were included for optimization. For instance, if operating at capacity, terminals for a standard shipping container would require three loading and three unloading platforms. Two handler cranes must be assigned to each platform, resulting in 12 operating handlers per terminal. Terminals for the crate and pallet size would need to have six loading and six unloading platforms and 24 operating handlers per terminal.

Chapter 4 Model Development

4.1 Introduction

This chapter deals with the methodology used in this dissertation for development of an intermodal UFT terminal operations performance model. It discusses the simulation model approach for optimizing intermodal UFT terminal operations. Detailed simulation modeling is explained in the following sections. The suitable problems for simulation modeling and appropriate software are discussed. Additionally, a comprehensive model, is built with additional required data for modeling inputs—based on the available data from the previous chapter—and presented in this chapter.

4.2 Simulation Modeling

In real-world systems, many projects cannot be solved mathematically due to their complexity. In this situation numerical, computer-based simulation can be used to copy the system behavior (Kelton et al., 2013). The simulation model is utilized before a new system built or an existing system is changed to reduce the failure rate and meet standard qualifications, which avoids "under or over-utilization of resources" (Maria, 1997) to eliminate unexpected bottlenecks, and to optimize the system performance.

Simulation plays a significant role in evaluating practical alternatives available either in support of major strategic organization, or in support of the continuous search for better performance at operational and strategic levels. Moreover, by allowing quick changes to the model logic and data, the simulation method supports sensitivity analysis as well. The simulation model can be employed to illustrate the power of simulation in determining how operations and facilities can be improved in different areas such as intermodal UFT terminals. This model can be used as an analysis tool for predicting the effect of changes on existing intermodal UFT terminal systems. The model is also a design tool that can be used to predict the performance of new systems.

4.2.1 Discrete Event Simulation and Optimization

Simulation is a broadly used analytical tool which permits the study of complex systems that cannot be modeled by other mathematical and statistical techniques. This simulation can be utilized to determine the situation of defined controllable inputs to a system and in this way direct the system outputs to perform at their most optimal conditions. This is the basis of simulation optimization (Hall and Bowden, 1998). Discrete event simulation (DES) models handle the operation of a system as a discrete sequence of events in time. Each event consists of a distinct change in the system's state at a specific point in time (Robinson, 2004). According to Matloff (2008):

> "This contrasts with continuous simulation in which the simulation continuously tracks the system dynamics over time. Instead of being event-based, this is called an activity-based simulation; time is broken up into small time slices and the system state is updated according to the set of activities happening in the time slice."

Among other things, this is owing to its potential to simulate and follow the stochastic and dynamic properties of distinct procedures, and thereby anticipate their performance.

Simulation optimization is an exceptionally valuable method for exploring the behavior of many business processes varying from manufacturing layouts to the operation of modern contact centers. The simulation optimization technique is used when exploring a set of applicable input values (decision variables) to produce the desired results (Olafsson and Kim, 2002).

4.3 Basic Simulation Model Procedure

The components of the basic simulation process as Figure 4-1 shows are divided into four main sections:

4.3.1 Conceptual Design

Thorough comprehension of a mechanism is the first phase and a vital step in basic simulation modeling. The first level of mapping is done in this stage to determine the dependencies which might be in the mechanism.

4.3.2 Input Analysis

The second phase is analyzing the input data and specifying corresponding distributions and procedures to the simulation software. Our task for real-world data is to fit standard or empirical distributions to these data that can be used to generate samples during the simulation. If real-world data is not available, we can use general rules based on experience or practice as well as sensitivity analysis for this task.

4.3.3 Model Development, Verification and Validation

The third phase of systematic simulation modeling is verification and validation which certifies that simulation output results are accurate compared to the real system being modeled.

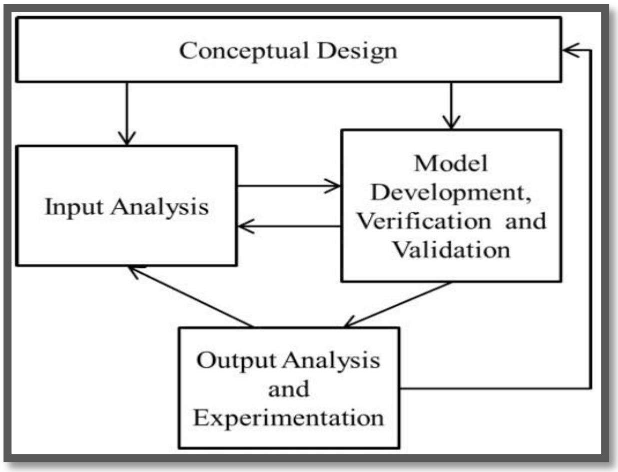


Figure 4-1 The Simulation Process (Kelton et al., 2013)

A conceptual model is built by “coding” and is transformed into an executable simulation model explained for model development. The focus in this section is on collecting accurate evidence and should be continued until it is satisfied based on real system mechanisms.

4.3.4 Output Analysis and Experimentation

The final stage in a simulation is experimentation and output analysis, which provides a means for evaluating the simulation performance and making proper decisions. Output analysis takes the individual observations generated by the simulation, characterizes the underlying random variables, and draws assumptions about the system being modeled. The concept behind “experimentation” simply means systematically varying simulation input data and modeling the structure to investigate the output and different system configurations (Kelton et al., 2013). The simulation process is shown in the Figure 4-1.

4.5 Developing a Simulation Model

For simulation study to be effective, the simulation method contents are established by following predetermined steps. Despite the prevailing circumstances of the study objective and the problem type, the procedure by which the simulation is accomplished stays constant. The following outlines the steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis (Simulation Steps and Criteria, 2013).

4.5.1 Step 1. Problem Identification

The very first step to develop a simulation model is to clearly determine the goal of the study and what problems are expected to be solved by the simulation. Note that it is of high importance to come to a conclusion that simulation is the proper approach for investigation.

4.5.2 Step 2. Formulate the problem

In the simulation problem formulation, the first step requires identifying the boundaries of the system. The goal of the study is then finalized as the requirements are established through investigation. In the third step, criteria to which different system configurations will be compared and evaluated must be defined. Briefly identify at this stage, the configurations of interest and formulate hypotheses about system performance. The time frame of the study is another parameter which should be clearly defined. For instance, will the model be used for a one-time decision (e.g., capital expenditure) or over a period of time on a regular basis (e.g., air traffic scheduling). Problems must be formulated as precisely as possible (Maria, 1997).

4.5.3 Step 3. Collect and process real system data

After formulating the model, type of data to be collected is determined. New data is collected and/or existing data is gathered. Then data is fitted to a theoretical distribution diagram.

4.5.4 Step 4. Formulate and develop a model

What makes a model the proper one is to understand how the actual system behaves and to determine the basic requirements of the model. Thus, creating a flow chart of how the system operates facilitates understanding of what variables are involved and how these variables could interact.

4.5.5 Step 5. Validate the model

Two different concepts might be used in a simulation process: verification and validation. Verification means that the model behaves as desired, while validation suggests that the model reflects reality. In other words verification is necessary but not sufficient to answer the goal of a simulation. However, validation proves that no significant difference exists between the model and real system.

4.5.6 Step 6. Document model for future use

The model is translated into programming language. Documentation consists of the written report and/or presentation.

4.5.7 Step 7. Select appropriate experimental design

Experimentation is defined as developing the alternative models, executing the simulation runs, and statistically comparing and evaluating the alternative system performance with that of the real system.

4.5.8 Step 8. Perform simulation runs

Accomplish runs according to the above mentioned steps.

4.5.9 Step 9. Interpret and present results

In the final stages of simulation, the resultant output data must be profoundly interpreted and displayed graphically (e.g., pie charts, histograms). At the end, conclusions will be documented. In other words, the results should be identified, recommended and justified (Sadowski et al., 1998).

4.5.10 Step 10. Recommend further course of action

To increase the accuracy, additional experiments may include performing the sensitivity analysis. (Maria, 1997).

Not all the steps are required or even possible, depending on the nature of the algorithms, purpose, and results. On the other hand, additional steps may have to be completed. Figure 4-2 shows the simulation model steps.

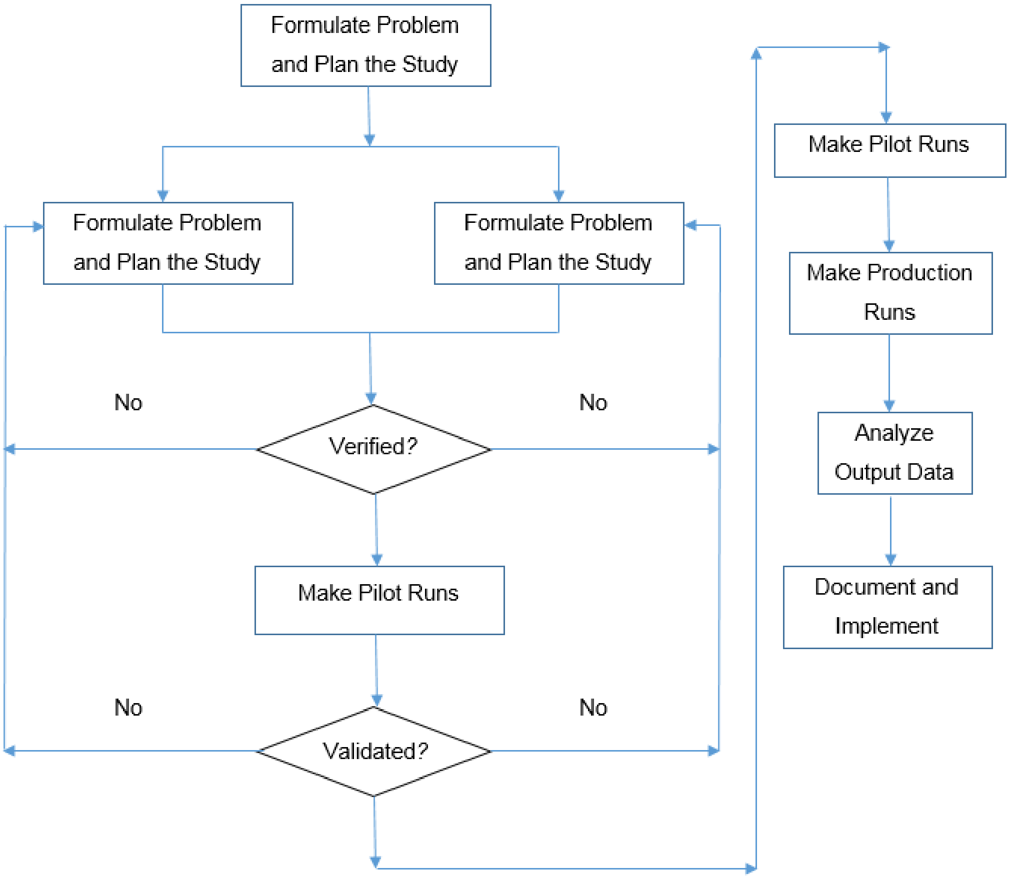


Figure 4-2 Simulation Model Development (Banks et al., 2004)

4.6 Decision for Simulation Modeling

As mentioned before, the first concept to remember is that not every problem can be solved by simulation. However, if the required steps are carefully taken, the probability of the investigation’s success can increase. In the past, simulations required a trained specialist who was familiar with the complexity of the project. Now Thanks to the availability of software, simulations can be created by any untrained individuals and they might result in incorrect output. In this situation, blame should be put on the inappropriate application of simulation not on simulation as an approach. Since in some cases, simulation is the best approach to realize system effectiveness, here are a number of situations in which simulation results are the only appropriate solution:

- Simulation is preferred when processes in the real world are too costly or impossible
- Analytical solutions can be complicated or impossible; however, a mathematical model can be formulated by large scale queuing models

Validating a mathematical model defining the system can be expensive or impossible because of the lack of data or sufficient resources (Maria, 1997).

A number of parameters should be taken into consideration to determine if simulation is an appropriate solution to resolve a particular problem as described in the following sections:

4.6.1 Problem Types

Simulation has been applied to an extensive variety of situations. The use of simulation does not work if a problem can be solved by common sense or a logical approach. Furthermore, mathematical equations or using algorithms are other ways of solving a problem which are less costly than simulation.

The alternative to simulation is direct experimentation which is an easier and quicker way than simulation to get results. It should be noted that performing direct experiments has to be considered from the standpoint of how the real system is interpreted, if so, another methodology should be taken into consideration because the real system plays another role in deciding to simulate. As a general note, if a system is too complex and not understandable then simulation is not that helpful. This situation mostly takes place when human behavior is involved (Simulation Steps and Criteria, 2013).

4.6.2 Availability of Resources

The two most important factors for a simulation study are the determining resources, i.e., people and time. Most importantly, a simulation must have a skillful analyst that has enough experience to determine the model levels in detail and verify the output results. In other words, without an experienced analyst, the model may result in unreliable output. Furthermore, time allocation for a simulation should not be so limited that the simulator must use shortcuts when designing the model. In other words, enough time should be allotted to be considered a resource for performing any essential changes needed to validate the output and verify the results.

4.6.3 Cost

Obviously, in each step of the simulation process, cost should be taken into consideration, and simulation should not be performed if the cost exceeds the potential savings.

4.6.4 Availability of Data

The necessary data for the simulation must be identified, located, and collectible; otherwise, simulation may result in unreliable and useless output that cannot be compared to real system performance, which is vital to verifying the model. The model should be kept to examine the system’s response to parameters encountered by the real system (Simulation Steps and Criteria, 2013). However, the model maintenance level depends on its flexibility and ability to answer the original questions which represent the goal of modeling.

4.7 Simulation and Manufacturing

Simulation is widely used in manufacturing. It allows engineers to predict performance of an existing or planned system and to compare different solutions for a design issue. Simulation can also quantify system performance which includes:

- Throughput under average and peak loads;
- System cycle time (how long it takes to produce one part);
- Utilization of resource, labor, and machines;
- Bottlenecks and block points;
- Queuing at work locations;
- Queuing and delays caused by material-handling devices and systems;
- Work in Process (WIP) storage needs;
- Staffing requirements;
- Effectiveness of scheduling systems;
- Effectiveness of control systems (Macomber, J. H., 2018).

Simulation may be used as an experimental process in which some of the parameters or relationships in a system are varied enough to compare output results. If the simulation is based upon a valid mathematical model, the output will mirror the results of a real system over a period of time (Macomber, J. H., 2018).

4.8 Simulation Software

Simulation models are created using software designed to represent common system components, and record how they perform over time. There are several simulation software programs for modeling.

Simulation packages are of two types: application-oriented simulators and simulation languages. Simulation languages require a group of programming expertise; however, they offer more flexibility than application-oriented simulators. Application-oriented simulators such as WITNESS^{TM} (Lanner Group 2008) are easier to learn and have modeling constructs closely related to the application. Simulation (Maria, 1997), which is used for this research project's goals—is simple but can still be used for constructing complicated models, WITNESS^{TM} (Lanner Group, 2008) is a suitable software as it provides sufficient facilities.

4.8.1 WITNESS^{TM}

WITNESS^{TM} (Lanner Group, 2008) is one of the simulators that can find the best solutions for the simulation model. A measure of performance which is fully customizable can be chosen and parameters that are allowed to be changed are set, then the optimizer will perform the experiments to find the best resolution.

For the simulation-optimization modeling, the software WITNESS^{TM} (Lanner Group, 2008 is used to test different terminal layouts operations performance and combines continuous flows with DES to address a wide range of problems in the most efficient and appropriate way possible using hierarchical networks (Huff, 2018). Continuous elements enable the modeling of processes that include cargos flowing through pipes where high volumes of parts pass at a defined speed. For optimizing handler operations on containers, different scenarios were simulated to test the variations of performance indicators.

4.9 Generating Additional Intermodal UFT Terminal Operations Data for Simulation Modeling Inputs

4.9.1 The Case Study Route for Model Examination

The capacity computations, headway, and the associated number of vehicles required for a 15-mile pipeline tunnel between the Port of Houston and a satellite distribution center—a selected route from TxDOT UFT research—were based on a 24-hour work day (three 8-hour shifts).

A schematic illustrates a designed container terminal from the 2016 TxDOT project (Najafi et al., 2016) and serves as a case study for the application of this dissertation simulation model. This intermodal terminal located in the Inland Satellite

Dist. Center Terminal of Baytown, Texas for about 15 miles away from the Port of Houston.

Table 4-2 shows the origin and destination of the proposed route, freight type (standard shipping container) and the route length.

Table 4-1 Defined Route for Implementing the UFT System (Najafi et al., 2016).

Route	Origin	Destination	Freight Type	Length (mile)
Houston Port-Satellite Dist. Center	West side of Barbour's Cut Port, Houston	Truck Terminal on Northeast side of IH-10 and SH 146, Houston	Shipping Container	15

4.9.2 Required Time for Loading/Unloading in Proposed Route

The number of gondolas circulating between Houston and Dallas (250 miles) is 1,334, and the number of gondolas circulating (at capacity conditions) in the considered case study route between Houston and Satellite (15 miles) is 80 gondolas (see chapter 3). As the total number of both routes is the same per day, the shorter route needs to circle 16.7 times more than the longer one from Houston to Dallas to complete the unloading process. The required time for completing each circle as the following calculations shows is estimated for about 86 minute for each circle.

Required time for unloading gondolas (short route): 1,334 / 80 = 16.7 times

Time for each circle of containers (min): (1,440 min/day/16.7) = 86 min

The annual expected numbers of containers need to take care of shipments for the UFT terminal has been calculated as 486,910.

4.9.3 Multiple Cycle Time for Loading/Unloading Handler for each Primary Model

The element of the terminal loading/unloading handler for examination of the simulation model is considered as a multiple cycle type machine with triangle distribution. Three cycle time limitations have been established for the Houston-Dallas UFT terminal handler: 1) a lower limit, the mode limit, and 3) an upper limit. Unloading the cargo at each platform by using a handler is estimated to take about 90 seconds for a UFT terminal. Therefore, three cycle time limits for base-model are counted as 60, 90, and 120 seconds for the lower, mode and upper limit, respectively. The cycle time applied for the optimized-model is considered 30 seconds lower than base-model cycle time, which is equal to 30 seconds for the lower limit, 60 seconds for the mode limit, and 90 seconds for the upper limit. The triangle distribution is an appropriate statistic option for this modeling, since the lower limit <= mode <= upper limit.

Table 4-3 summarizes the additional operational parameters for the Houston Distribution Center to and from the Dallas Satellite.

Table 4-2 Summary of Operational Parameters
(Modified Table from Chapter 3)

Route	Houston to Satellite
Cargo Type	Shipping Container
Route Length, mile (ft)	15 (79,200)
Gondola Length (ft)	49
Speed in the Route and in Terminal Entrance, mph (ft/sec)	45 and 5 (66 and 7.4)
Vehicles (Gondolas) Circulating (at capacity conditions) between Houston and Satellite (15 miles)	80
Required times for unloading 1,334 Containers per Day (1,334/80)	16.7
Time for each Circle of Containers (min) (1440 min/day / 16.7)	86
Cycle Time for Handler (min) for Base-Model	(min=1, ava=1.5, max=2)
Cycle Time for Handler (min) for Optimized-Model	(min=0.5, ava=1, max=1.5)
Gondola Inter Arriving Time (min/sec)	0.5/ 30
Annual Expected Number of Shipped Items for UFT Terminal	486,910

4.9.4 Speed, Headway, and Minimum Allowable Distance (Gap)

The minimum headway is different between consecutive vehicles at each of the three parts of the route. The speed of the vehicle at Route Part 1 and Route Part 3 wherein the approaching the terminal entrance is considered to require a speed decrease from 45 mph to 5 mph with an average speed of 25 mph. In turn, the minimum headway could be as low as 30 seconds for Route Part 2 with an incoming speed of 45 mph (see Figure 4-3).

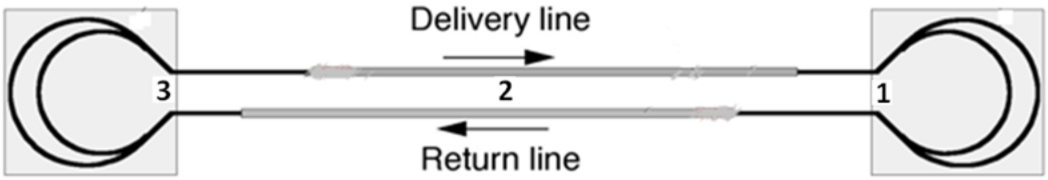


Figure 4-3 Three Parts of the Route with Two Ended Terminals

Table 4-3 Speed, Min Headway, and Min Allowable Distance (Gap)

Speed, mph (ft/sec)	Min Headway (sec)	Min Allowable Gap (ft)
45 (66)	30	1,980
30 (44)	20	880
25 (36.7)	15	551
15 (22)	10	220
10 (14.7)	8	117
5 (7.4)	5	37

The minimum headway and minimum allowable gap—using Equation 3-1—varies from 30 seconds and 1,980 ft in Route Part 2 to about 5 seconds and 37 ft for the containers that pass the terminal entrance in Route Part 1 and Route Part 3 with the speed of 5 mph to stop at the unloading and loading platforms.

Table 4-4 illustrates details of the minimum headway for the route. As this table shows, the minimum headway for the average speed of 25 mph in this route could be as low as 15 seconds which is equal to 551 ft (minimum allowable distance). Figures 4-4 to 4-6 illustrate the speed, minimum headway, and minimum allowable gap relationships based on the speed change from 45 mph (66 ft/sec) to the minimum speed of 5 mph (7.4 ft/sec).

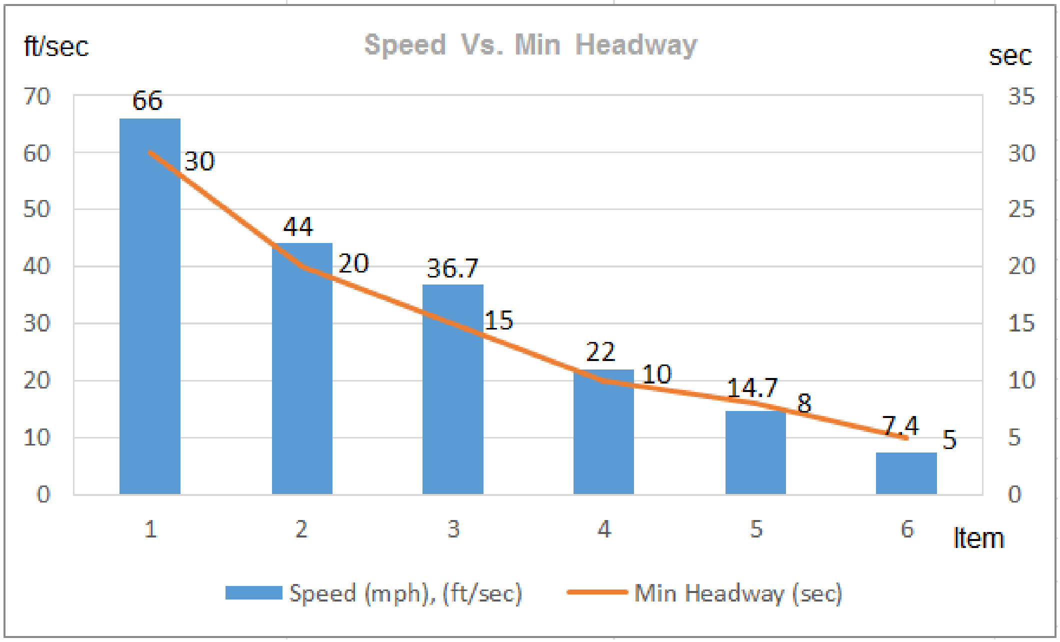


Figure 4-4 Speed Vs. Min Headway

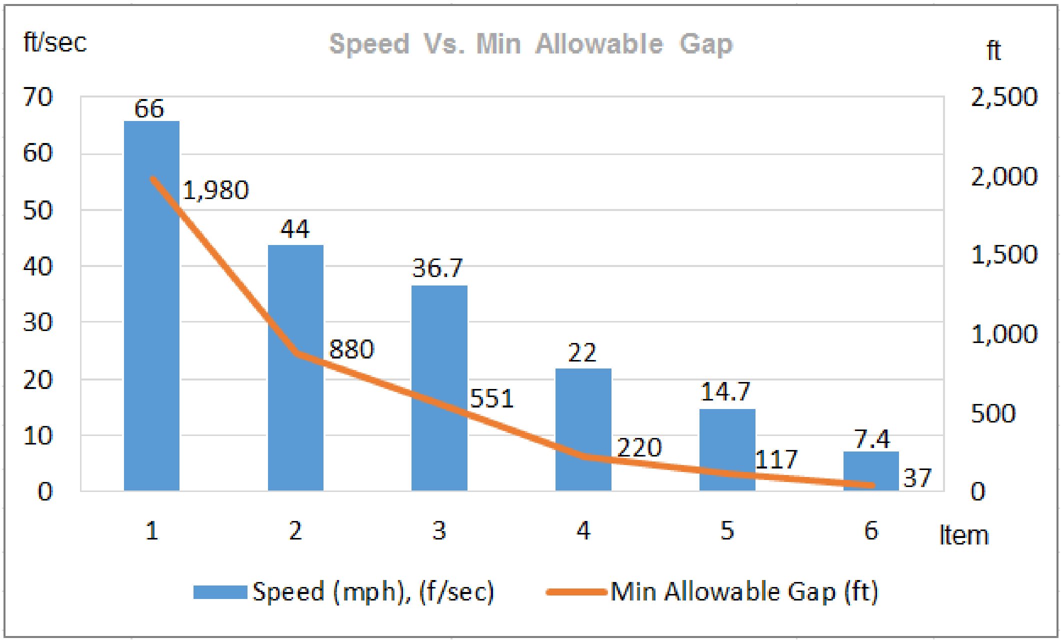


Figure 4-5 Speed Vs. Min Allowable Gap

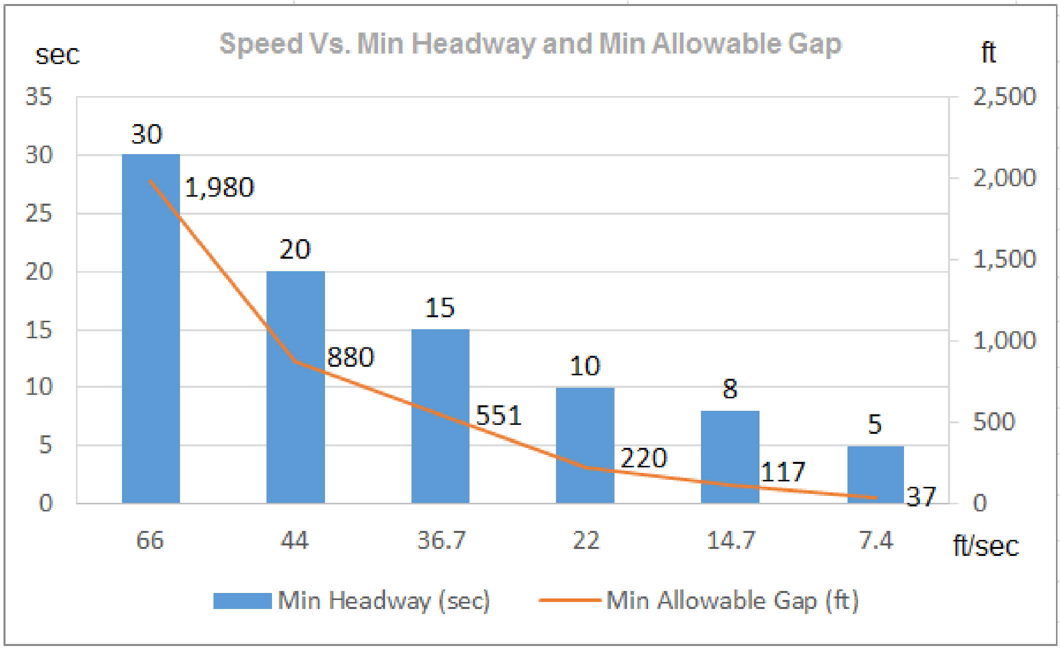


Figure 4-6 Speed Vs. Min Headway and Min Allowable Gap

4.9.5 Braking Distance at the Terminal Entrance

In order to unload gondolas in the terminal, the vehicle speed must be decreased from 45 mph when it gets close to the terminal entrance to a gradually achieved lower speed. According to Figure 4-6, the vehicle speed decreases to 5 mph from 45 mph at the entrance of the terminal to facilitate the loading/unloading processes inside the terminal. For this change, a gondola needs to travel an approximate distance to stop or to decrease the speed after the brakes are applied in a vehicle moving at a specific speed. Therefore, it is required to calculate the braking distance in order to find the maximum number of gondolas at each part (1, 2, and 3) as Figure 4-6 shows.

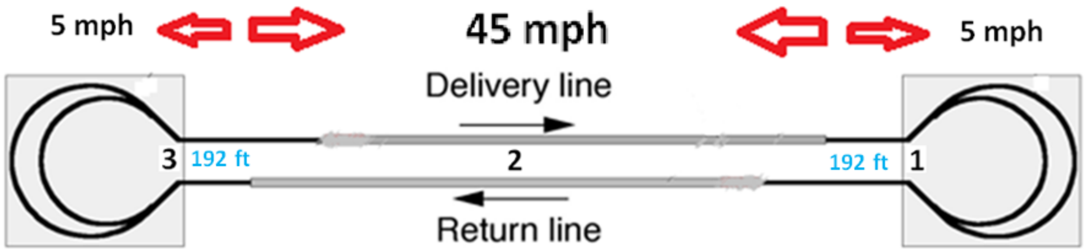


Figure 4-7 Speed Changes into Three Parts and
Braking Distance in the Terminal Entrance

The braking distance is calculated by using the Equation 4-1 (AASHTO, 2011). It shows the minimum stopping distance is equal to 192 ft for each end.

$$X_{br} = (V_i^2 - V_f^2) * (1.47)^2 / 2a \qquad \text{Equation 4-1}$$

Where:

X_{br} = braking distance of a vehicle,

V_i = initial speed (mph),

V_f = final speed (mph), and

a = acceleration rate, AASHTO recommended value= 11.2 (ft/sec^2).

The coefficient 1.47 is for converting the speed from mph to ft/s.

X_{br}= 0.096 * (5^2 - 45^2)

X_{br}= 192ft = 0.036 mile

$X_{br\ total}$ = 384 ft

4.9.6 Cycle Time and Number of Gondolas

Models are built in WITNESS^{TM} (Lanner Group, 2016) simulation by details including the timing and routing of entities as they move through the model. Each element type has its own characteristics such as machine cycle time or vehicle speed.

Speed inside the terminal is calculated as 5 mph (7.4 ft/sec), which means that the required time to travel each 7.4 ft. is one second. Based on this 1-second travel time for each 7.4 ft., the required cycle time for Route Part 1 and Route Part 3 is between the terminal entrance and its loading dock 192 ft away. This affects travel, which shows the distance to be achievable in 0.273 min. The 192 ft calculated as the minimum braking distance in order to speed up from 5 mph to 45 mph and also slow down from 45 mph to 5 mph. At these parts with an average speed of 25 mph, the gondola capacity is one.

Following the same process, the gondola capacity for the middle part of the route with the 78,000 ft, length shows 38 gondolas and the required total cycle time is 19.7 min. Table 4-5 and the formula illustrates the detailed data.

Part 1 and 3 (192 ft):

V_{ava}. = 25 mph = 2,200 ft/min

X_{br}= 192 ft

$L_{\ total}$= $L_{gondola}$ + $L_{\ min\ allowable\ distance}$

$L_{\ total}$= 49 ft + 551 ft, $L_{\ total}$= 600 ft

Where:

V_{ava} = average speed (mph),

L_{total}= required length in a line for passing one gondola

Line Capacity in part 1 and 3: 1 gondola

Cycle time: 600 ft / 2,200 ft/min = 0.273 min (speed up/slow down)

Part 2:

V= 45 mph = 3,960 ft/min

$X_2 = X - 2X_{br}$= 78,816 ft

$L_{total} = L_{gondola} + L_{\text{min allowable distance}}$

L_{total}= 49 ft + 1,980 ft, L_{total}= 2,029 ft

Line Capacity in Route Part 1 and Route Part 3: 38 gondola

(1 Machine, 37 Buffer)

Cycle time: 78,000 ft / 2,200 ft/min = 19.7min (speed up/slow down machine)

2,029 ft/ 3,960 ft/min = 0.5 min

19.7 – 0.512= 19.2 min (Buffer time)

Table 4-4 Route Parts, Speed, Length, Line Capacity (Gondola), and Cycle Time

Route Parts	Speed (mph)	Length (ft)	Line Capacity (Gondola)	Cycle Time (min)
Part 1- Terminal entrance to 192 ft away	5 - 45	192	1	0.273
Part 2- Middle part of route= 78 k, and 192 ft. away from terminal entrance at each end	45 - 45	78,000	38 38 = 1 Machine + 37 Buffer	19.7 0.5, 19.2
Part 3- Terminal entrance to 192 ft away	45 - 5	192	1	0.273

4.9.7 Number and Length of Distance Measurements in UFT Terminal, Capacity of Gondola at Each Measured Distance, and Cycle Time

The length between joint a (the point where the sections of a structure such as terminal tracks are linked), and joint b is measured is D_{ab}. The number of distance measurements for the selected UFT terminal is counted as 30 (Figures 4-8 and 4-9). The joint is illustrated as a point where structural sections (such as terminal tracks) are linked.

For each distance measurement, the gondola capacity is estimated. Cycle time for distance numbers 1 to 30 (D_1 to D_{30}), which is based on the speed, is also calculated (Table 4-6). These data are required inputs for the model.

To determine the number of gondola at each distance, the total required length for each gondola (L_{total}) is the sum of gondola length ($L_{gondola}$) and the minimum allowable gap ($L_{min\ allowable\ gap}$). The total length (L_{total}) for distance 1 (D_1) is 86 ft which can define the capacity of 1 gondola with D_{ab} as distance number 1 (Figure 4-10). The calculations for distance numbers 1, 10 and 30 are presented as an example. Table 4-6 illustrates the gondola capacity for all defined distance measurements from D_1 to D_{30}.

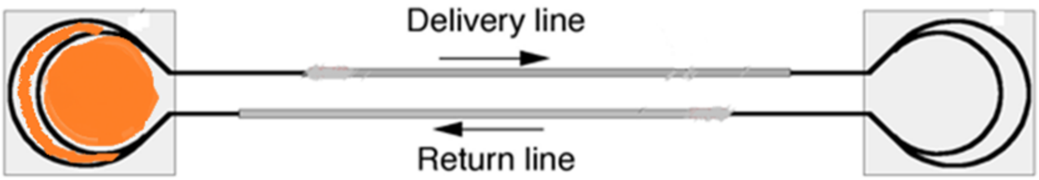


Figure 4-8 Terminal Location

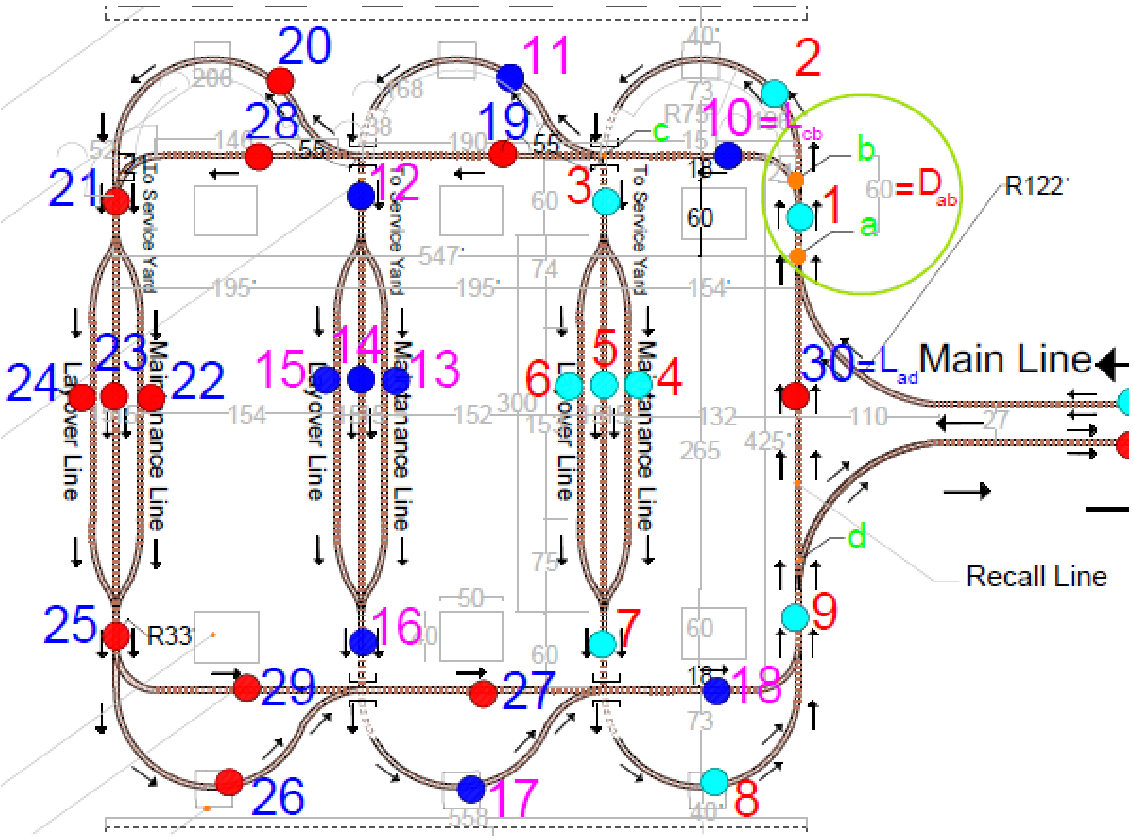


Figure 4-9 Number and Length of Distance Measurements in Intermodal UFT Terminal

As mentioned above, the cycle time at each distance is also a part of the required input data for this research simulation modeling. It is estimated that the time needed to pass the first distance of 60 ft will be 8.1 sec, equaling 1.135 minutes. This is the cycle time for Distance No.1.

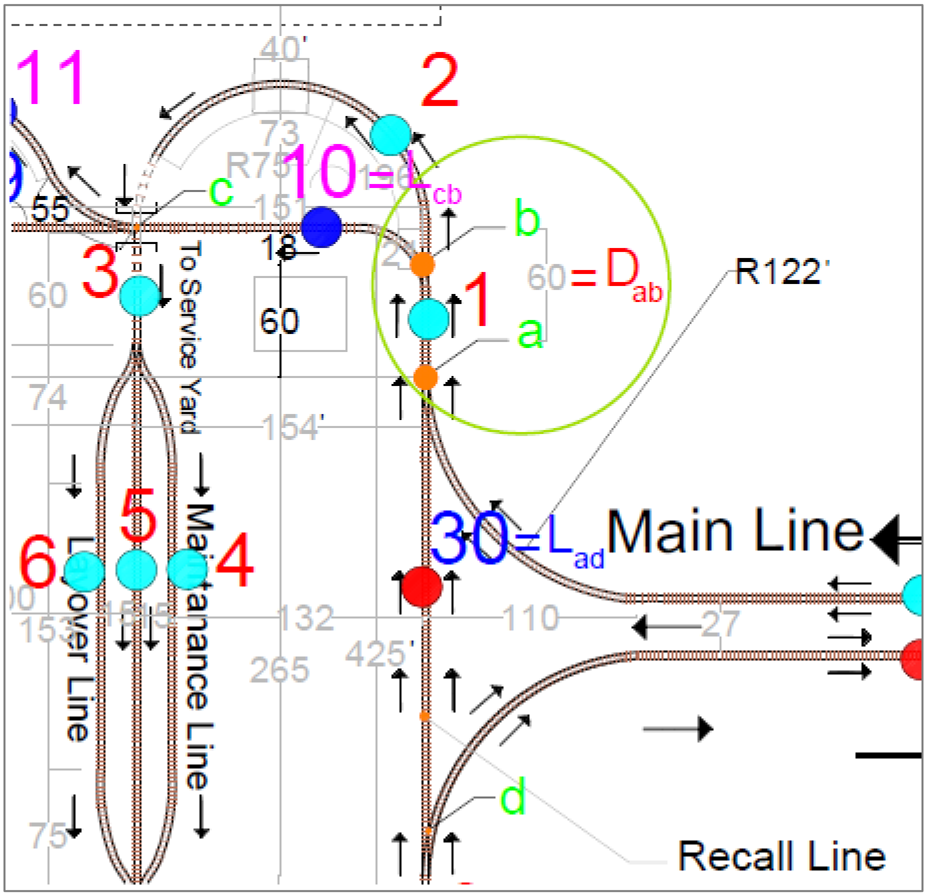


Figure 4-10 Detailed Distance for D_{ab} in Intermodal UFT Terminal

The detailed calculation for three distance measurements as an example is elaborated below.

Line Capacity and Cycle Time in Distances No. 1, 10, and 30:

Distance No. 1 (Joint a- Joint b)

Distance 1 (D_1) = D_{ab}

D_{ab} = 60 ft

V= 5 mph/ 7.4 ft/sec

$L_{total} = L_{gondola} + L_{min\ allowable\ gap}$

Where:

L_{total} = total length

$L_{gondola}$ = length of gondola

$L_{min\ allowable\ gap}$ = minimum allowable gap

L_{total}= 49 ft + 37 ft L_{total}= 86 ft

Line Capacity in Distance No. 1: 1 gondola

Cycle Time$_1$ = 8.1 sec = 0.135 min

Distance No. 10 (Joint b- Joint c)

Distance No.10 (D_{10}) = D_{bc}

D_{bc} = 151 ft

V= 5 mph/ 7.4 ft/sec

L_{total}= 86 ft

Line Capacity in Distance No. 10: 1 gondola

Cycle Time$_{10}$ = 20 sec = 0.34 min

Distance No. 30 (Joint a- Joint d)

Distance No. 30 (D_{30}) = D_{ad}

D_{ad} = 265 ft

V= 5 mph/ 7.4 ft/sec

L_{total}= 86 ft

Line Capacity in Distance No. 30: 3 gondolas

Cycle $Time_{30}$ = 35.8 sec = 0.60 min

Table 4-5 Number and Length of Distance Measurements in UFT Terminal, Capacity of Gondola at Each Measured Distance, and Cycle Time

Number of Distance Measurements (D_1- D_{30})	Length (ft)	Arrow Capacity (Gondola)	Cycle Time (min)
D_1: Joint 1 to Joint 2	60	1	0.135
D_2: Joint 2 to Joint 3	88	1	0.20
D_3: Joint 3 to Joint 4	148	1	0.34
D_4: Joint 4 to Joint 5	309	3	0.50, 0.20
D_5: Joint 5 to Joint 6	300	3	0.48, 0.20
D_6: Joint 6 to Joint 7	309	3	0.50, 0.20
D_7: Joint 7 to Joint 8	148	1	0.34
D_8: Joint 8 to Joint 9	88	1	0.20
D_9: Joint 9 to Joint 10	60	1	0.135
D_{10}: Joint 10 to Joint 11	151	1	0.34
D_{11}: Joint 11 to Joint 12	106	1	0.24
D_{12}: Joint 12 to Joint 13	166	1	0.37
D_{13}: Joint 13 to Joint 14	309	3	0.50, 0.20
D_{14}: Joint 14 to Joint 15	300	3	0.48, 0.20
D_{15}: Joint 15 to Joint 16	309	3	0.50, 0.20
D_{16}: Joint 16 to Joint 17	148	1	0.30
D_{17}: Joint 17 to Joint 18	106	1	0.156
D_{18}: Joint 18 to Joint 19	151	1	0.34
D_{19}: Joint 19 to Joint 20	190	2	0.43
D_{20}: Joint 20 to Joint 21	116.5	1	0.26
D_{21}: Joint 21 to Joint 22	176.5	2	0.40
D_{22}: Joint 22 to Joint 23	309	3	0.50, 0.20
D_{23}: Joint 23 to Joint 24	300	3	0.48, 0.20
D_{24}: Joint 24 to Joint 25	309	3	0.50, 0.20
D_{25}: Joint 25 to Joint 26	148	1	0.30
D_{26}: Joint 26 to Joint 27	116.5	1	0.26
D_{27}: Joint 27 to Joint 28	190	2	0.43
D_{28}: Joint 28 to Joint 29	198	2	0.45
D_{29}: Joint 29 to Joint 30	198	2	0.45
D_{30}: Joint 30 to Joint 31	265	3	0.60

4.9.8 Number of Crew Members (Laborers)

The total number of handlers needed in each terminal is twice the number of loading/unloading platform pairs. Hence, a total of 12 handlers are needed in each terminal based on the container size system; then, the total number of crew members for three 8-hour shifts as shown in Table 4-6 will be 36 for terminal operation. It is considered that each labor during 8-hour has 1-hour for rest and break time. So every laborer will work 7 hours or 420 min/day (Table 4-7).

Table 4-6 Number of Required Crew

Crew Members	Number
Two Handler Operators at each platform	2*6= 12
Crew Number for a 24-hour Terminal Operation	12*3= 36

Table 4-7 Shift Data

Monday- Sunday		
8:00 – 16:00	Break (60 min)	Working hours = 420 min
16:00 – 12:00	Break (60 min)	Working hours = 420 min
12:00 – 8:00	Break (60 min)	Working hours = 420 min

4.10 Simulation Model Building Process for Intermodal UFT Terminal Operations

4.10.1 Model Building Process

4.10.1.1 Definitions of main elements

The main elements for building a simulation model are defined below.

Part/ Entity: Flow-through model. The parts in our model represent three physical components including the gondola, unloading container, and container.

Buffer/Queue: Places where parts are held. People in a line or queue are the usual example. Two buffer types are considered. The first type is a simple buffer for forklift and handler, which is a place where forklift and handler wait until they can load and unload a container. The second type is a machine time buffer. This simulated element can hold multiple simulation entities for a specific amount of time. In this research, the minimum-time buffers are used to represent track sections, which can hold multiple gondolas. The minimum delay time represents the minimum amount of time it takes a gondola to move through the section of track if not blocked by another gondola.

Figure 4-11 Main Elements: Part, Buffers, Machine, and Labor.
Created with WITNESS^{TM} (Lanner Group, 2008) software

Machine/Activity: Machines (M) are a simulation modeling construct used to represent activities within a simulated system. In this research, the machine construct is used in two ways. Machines are used to represent the gondola loading and unloading stations in our model. Machines are also used to represent track sections (TSs) that are only long enough to hold a single gondola. The simulated cycle time of the machine element is used to present the time it will take for the activity task to be completed. In our model, this might be the time needed to unload a container from a gondola or the time it takes for a gondola to move through a section of track.

Our simulation model for an UFT intermodal terminal, buffers and machines represents 30 section tracks.

Labor Resource: The number of crew members needed for each shift is detailed below. Main elements are shown in Figure 4-11.

Running the Model: Experimentation is defined as the process of running the model and collecting the required statistical output to fulfill the needs of the experimental design (Huff, 2018). Models can be run for specified lengths of time or until all parts have been processed.

The basic principles of building the model in WITNESS^{TM} (Lanner Group, 2008) are simple but for constructing complicated models, WITNESS^{TM} (Lanner Group, 2016) provides sufficient facilities for model optimization. The model process can be observed in a different frame time (short or long) which is not simple to observe in real-world day-to-day manual accounting due to so many constraints.

4.10.2 Time Frame

The intermodal UFT terminal operates 24-hour/day with three 8-hour shifts. The total run length is 525,600 minutes per year.

- Hours of operation: 24-hour/day
- Total hours per year: 8,760-hour/ year
- Total run length: 525,600 minutes

4.10.3 Simplified Model Listing

4.10.3.1 Resources

Model resources name and type will be defined below. Three main Parts namely, Gondola, Unload Container, and Container is examined. The number of 17 Buffers, 61 Machines, 12 Labors, and 1 Shift for this modeling are defined (see Appendix B for more details).

4.10.3.2 Details of the Model

The details for building the simulated model for intermodal UFT terminal are defined to examine the model. The detailed process for at-least one element of each type including Part, Buffer, Machine, Labor, and Shift is elaborated below.

4.10.3.2.1 Detail Part

The Gondola detail is explained below. According to Appendix Figure B-1, the name of Part is defined in the first step. Maximum gondola arrivals in the circle for 80 units and inter arrival time of 30 secs, based on the mathematical calculation from the data generation task—is considered. Output rule is set to direct gondola to the process of model building.

.10.3.2.2 Detail Buffer

For the next step, Buffer detail is described as Buffer S1_78kft_45mph. As stated by the Figure B-2 (Appendix B), the capacity based on the previous calculations is defined as 38 gondolas. Delay mode is considered as the minimum delay and it is calculated for 19.2 minutes (see Table 4-5). Detailed process is explained in Appendix B.

4.10.3.2.3 Detail Machine

Machine detail refers to anything that takes a part, processes it and sends them on to their next destination. This is explained for two single- and one multiple-cycle time machine as an example. These examples of machines are referred to as Machine006 and MPH45_1 for single type and Unload_01 for multiple-cycle time machines.

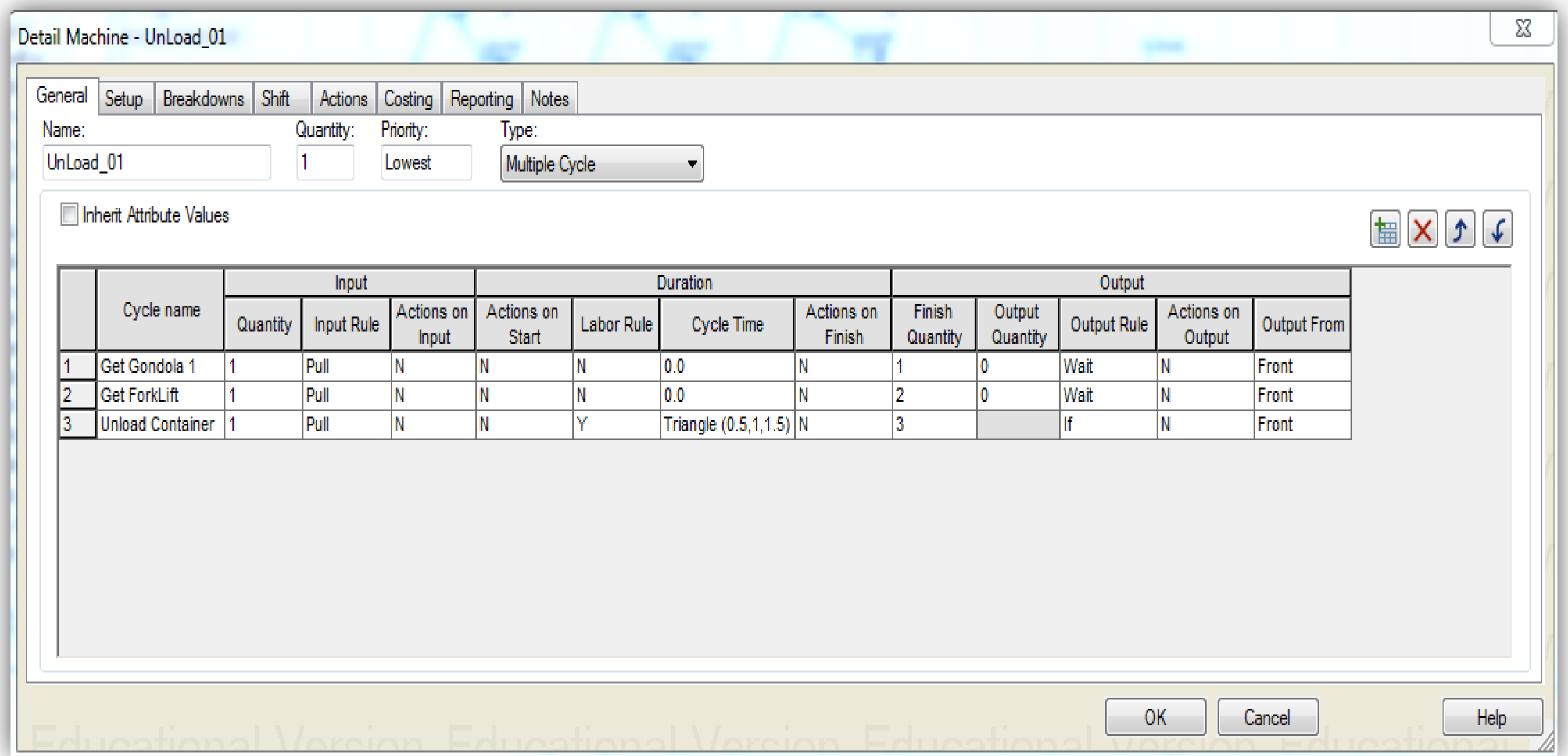
Figures B-3 to B-10 in Appendix B show the details for these three machines based on the calculated data. Explanations for each machine by defining input and output rule for each one is elaborated in Appendix B as well.

Machine type for machine Unload_01 is a multiple cycle (Figure 4-12). The cycle time distribution for this machine is defined as a triangle distribution. In statistics and probability, the triangle distribution is a continuous probability with three different limits.

For this unloading container process, there is a three-cycle time limitation: For the optimized model, the lower limit is expressed as a= 30 sec., the upper limit b= 90 sec., and the mode limit c = 60 sec. The three most practical cycle times for a handler (based on direct contact with company) are 30, 60, and 90 sec. The triangle distribution is an appropriate statistic option for modeling, since a= 30 < b= 90 and a= 30<= c= 60 <= b= 90.

4.10.3.2.4 Detail Labor

Labor detail (referring to records on laborers) is described for as UnloadGondForkLift_001 presented by Figure B-11 in Appendix B, the quantity computed is for one laborer, and one shift for a 24-hour-day. The captured image shows a spread sheet set up with tabs that lead to all of the information that can be collected on one UFT-employed forklift operator.



Name: UnLoad_01

Quantity: 1

Priority: Lowest

Type: Multiple Cycle

☐ Inherit Attribute Values

	Cycle name	Input			Duration				Output				
		Quantity	Input Rule	Actions on Input	Actions on Start	Labor Rule	Cycle Time	Actions on Finish	Finish Quantity	Output Quantity	Output Rule	Actions on Output	Output From
1	Get Gondola 1	1	Pull	N	N	N	0.0	N	1	0	Wait	N	Front
2	Get ForkLift	1	Pull	N	N	N	0.0	N	2	0	Wait	N	Front
3	Unload Container	1	Pull	N	N	Y	Triangle (0.5,1,1.5)	N	3		If	N	Front

Figure 4-12 Detail Machine- Unload_01, Simulated Base-Model for UFT Terminal

4.10.4 Model Network Structure

The actual presence of the simulated model in WITNESS^{TM} (Lanner Group, 2008) depends on the identification of the network elements (part, buffer, machine, and labor) together with the correlated queue distances, and logical relationships. However, the model network structure depends mostly on the way a work task sequence is modeled (Halpin and Riggs, 1992). The various model tasks are logically interconnected according to the technology of the transportation process and the work plan. The work plan in a simulated model defines the order in which the resources are made available to the terminal operators, so they can carry out the different tasks. Figures 4-13 to 4-15 show the development of an operational structure through schematic diagrams.

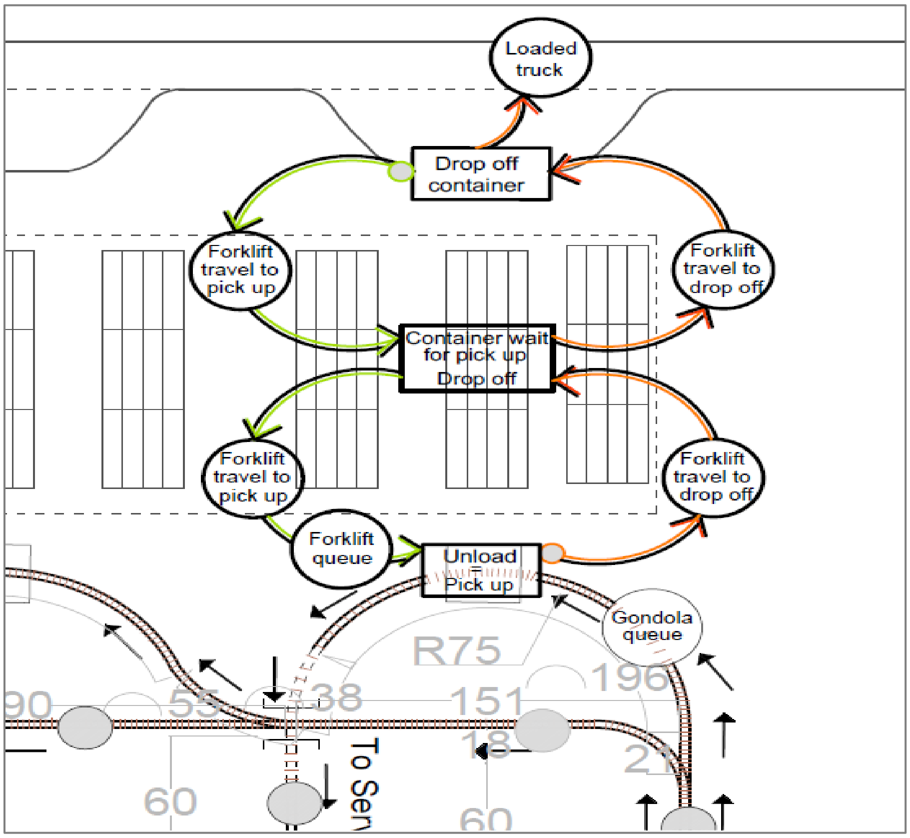


Figure 4-13 Development of Operational Structure, Schematic Diagram

According to the Figures 4-13, the loaded gondola stops at the first platform approached after departure from the main line to unload the container. As the schematic diagram shows, containers wait for forklift/handler to pick up. Then, the loaded forklift travels to drop off the container in the stack yard. From that point, the stack-yard, container will wait for pick up by another forklift—circulating in this operation circle—to be dropped off in the land-side truck service area. This circle is completed as loaded truck departs to continue his route to the next unloading terminal or customer dock.

The development of the operational structure for loading/unloading processes for one section out of three sections is shown in Figures 4-14. Here, the gondola comes from the mail line to stop at the first platform for unloading. Then the empty gondola travels to the other side of the terminal to be loaded with the new container. In this way and before reaching the next platform, the gondola passes the service yard where maintenance and layover lines are placed for repair needs. Finally, the loaded gondola will leave the platform loaded and ready to pass the last track section in the UFT terminal to go back to the main line to unload container in the port of Houston and load gondola from port.

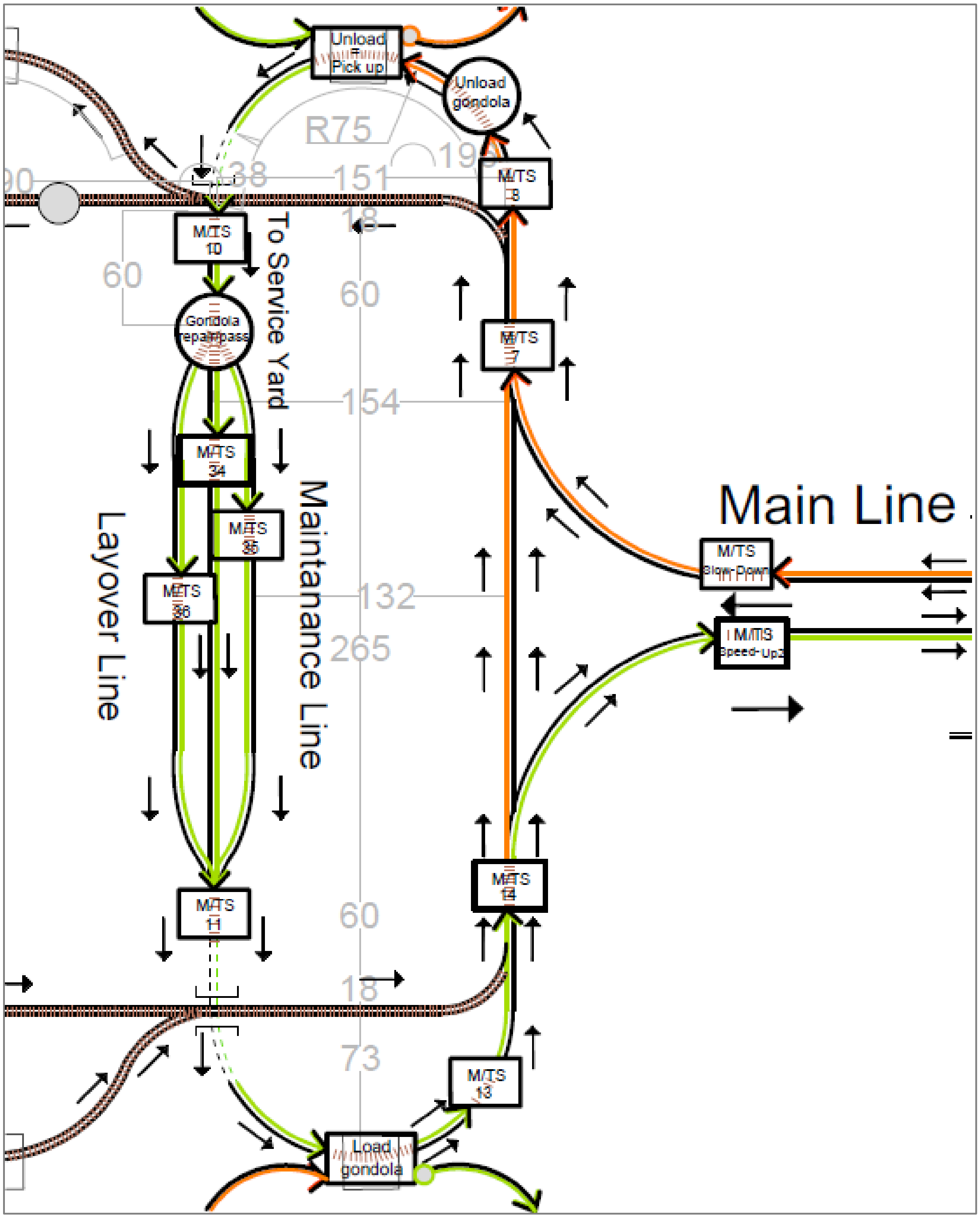


Figure 4-14 Development of Operational Structure, Schematic Diagram

Figure 4-15 shows the loading area where the empty gondola stops at the platform for loading. Whenever the loading process in this circle is completed, the loaded gondola will go back to the main line and will travel to the Port of Houston where their containers will be shipped to another destination.

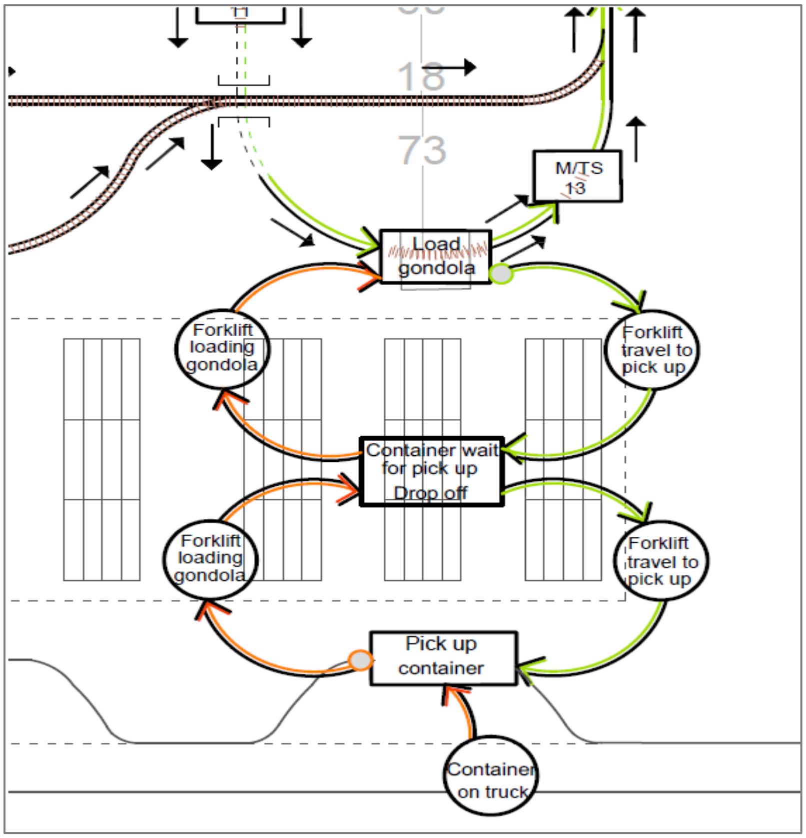


Figure 4-15 Development of Operational Structure, Schematic Diagram

Following the steps explained above, the completed simulated model for the whole process of building the model for intermodal UFT terminal is illustrated in Figure 4-13 to 4-15.

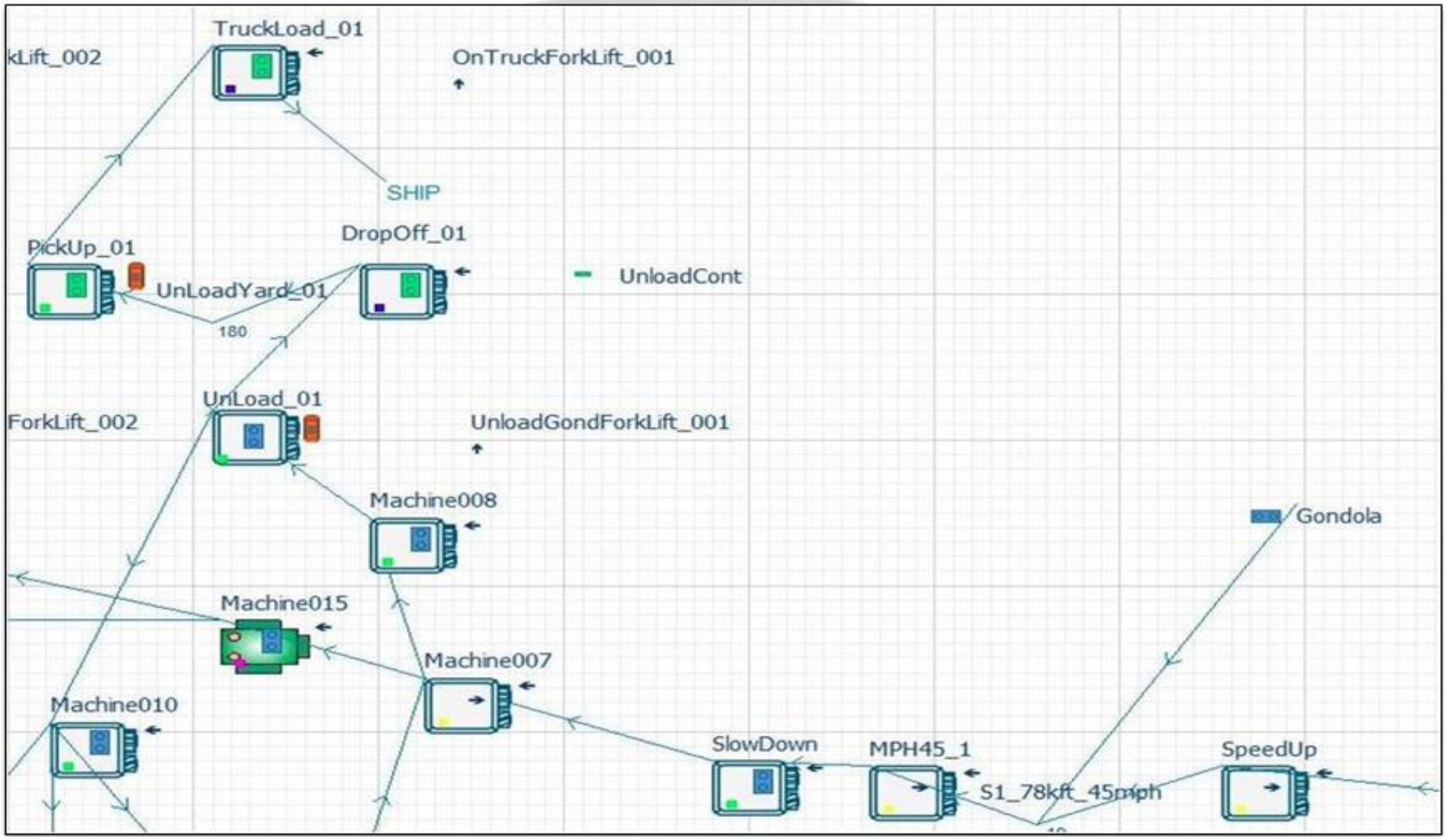


Figure 4-16 Simulated Model for Intermodal UFT Terminal in WITNESS^{TM} (Lanner Group, 2008)

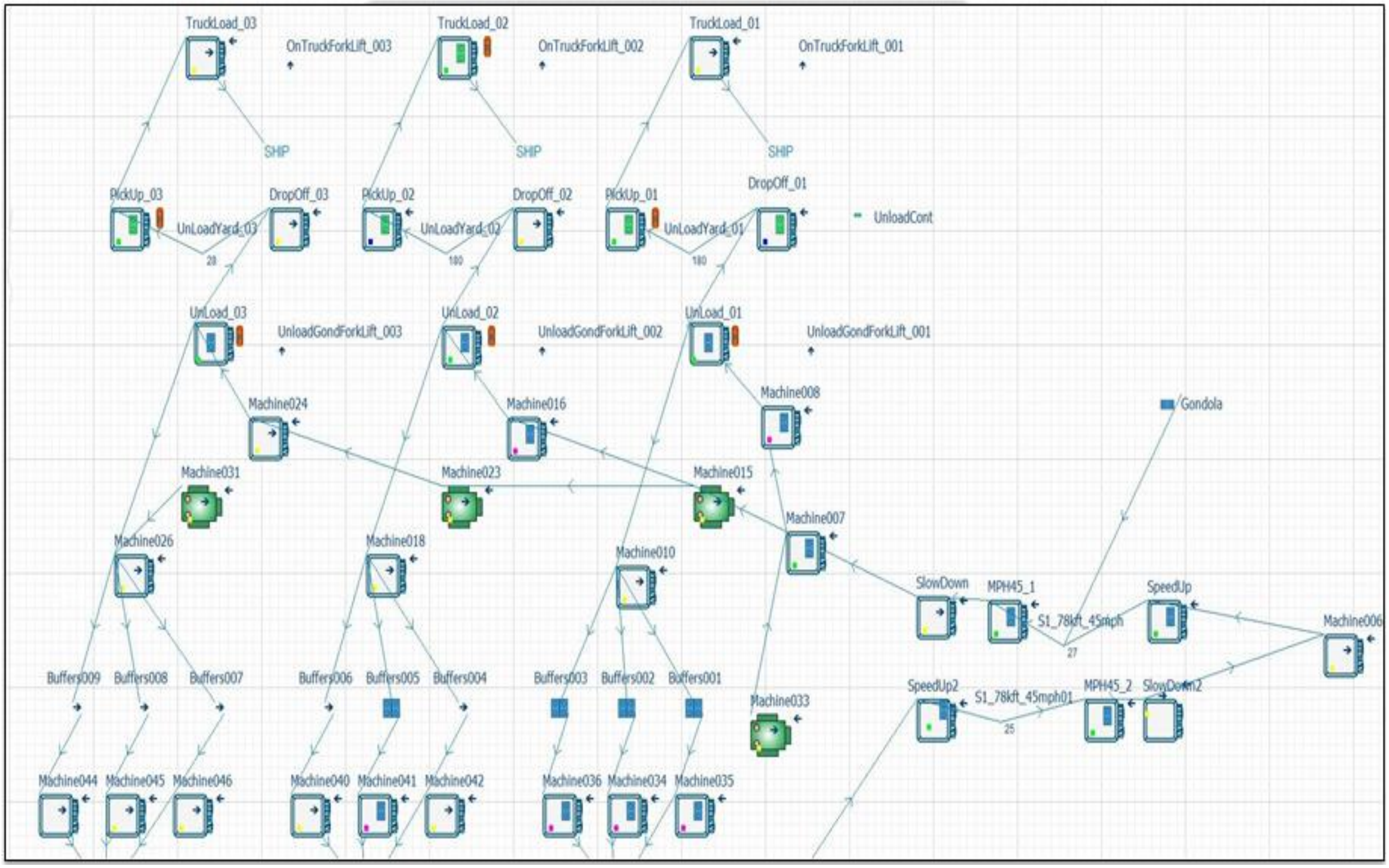


Figure 4-17 Simulated Model for Intermodal UFT Terminal in WITNESS^{TM} (Lanner Group, 2008)

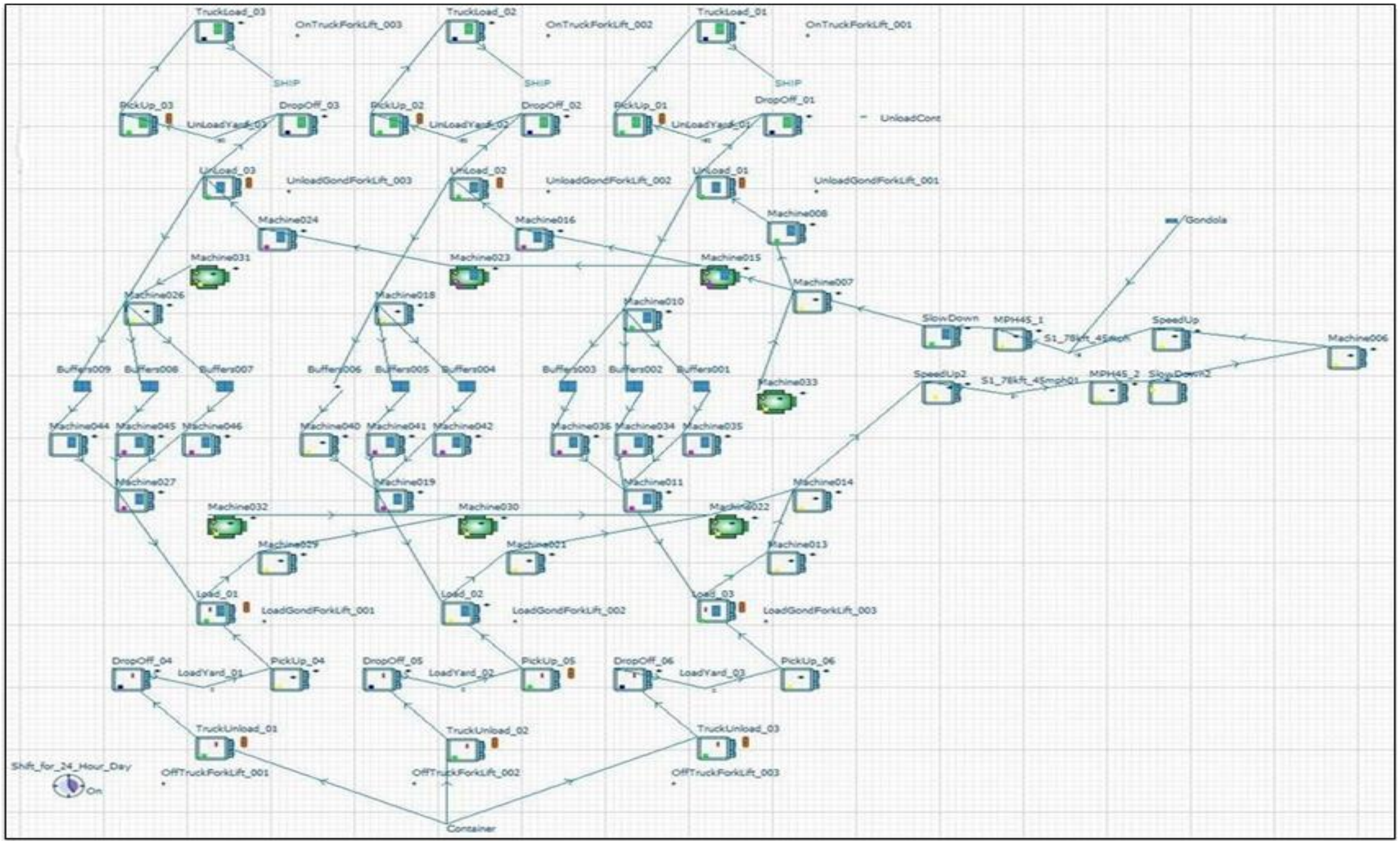


Figure 4-18 Simulated Model for Intermodal UFT Terminal

4.11 Benefits of Simulation Modeling and Analysis

- As reported by professionals in the area of simulation modeling (Maria, 1997), simulation is most commonly used in operation research analysis. This type of modeling can:
- Test system hypotheses for feasibility
- Acquire a better system understanding through expanding mathematical models and scrutinizing system's operational behavior over longer durations of time.
- Extend time to monitor a complicated event comprehensively or compress time to study determined phenomenon over long terms.
- Investigate the impacts of specific informational, environmental and organizational changes as well as policy changes on system operations by changing the system's model. This approach can be done without disturbing the day-to-day system progress, thereby decreasing the risk of experimenting.
- Determine the "driving" variables, which are performance assessed and the most sensitive to those factors and the interdependence among them.
- Apply the system technique to problem solving (Maria, 1997).
- Recognizing bottlenecks in the parts flow (people, containers, material, etc.) or information.

4.12 Chapter Summary

This chapter discussed the simulation model, which is the methodology of this dissertation for optimizing intermodal UFT terminal operations. It started with defining discrete event simulation and optimization, and continues with modeling framework. The basic simulation model procedure was presented in four major parts, followed by simulation model development steps, the decision process for simulation modeling and the use of the WITNESS^{TM} software ((Lanner Group, 2008 and 2016). Moreover, a description was provided of the additional generated intermodal UFT terminal operation data for simulation modeling inputs including but not limited to cycle time for the loading/unloading handler for each primary model (base-model and optimized-model), speed, headway, and minimum allowable gap, braking distance, number of arrows, capacity and cycle time for each distance (d_1 to d_{30}), number of laborers, and shift data. Simulation model building processes for intermodal UFT terminal operations were described by defining the main elements, as well as the simplified and explained model resources. An example was given of a detailed program by showcasing some important elements for building the base-model of this research. The final contribution was a simulated model of an intermodal UFT terminal.

Chapter 5 Implementation of Model, Results and Discussions

5.1 Introduction

The previous chapter supported this effort to develop the dissertation model and detailed model processes for the intermodal UFT terminal by using simulation-optimization tools in WITNESS^{TM} software (Lanner Group, 2008 and 2016). This chapter describes the model implementation results in two sections. The base-model results for the intermodal UFT terminal operations is elaborated in Section 1 (in 5.7.1), and the results of the optimized base-model are discussed in Section 2 (5.7.2) by defining and comparing two scenarios. Chapter 5 begins with two primary modeling section explanations and continues with result comparisons, validation and discussion.

5.2 Section 1: Base-Model Simulation for Intermodal UFT Terminal Operations

To meet the primary objectives of this chapter, an integrative simulation model is developed to simulate a base-model for intermodal UFT terminal operations in Section 1. The generated data considered as model input includes line capacity, number of handlers, minimum number of crew members (36 laborers or12 per shift), and operation shift time. The development of the WITNESS^{TM} (Lanner Group, 2016) simulation-optimization framework focused on the impacts of terminal system operations on the annual number of shipped items.

5.4.1 Analysis and Interpretation of Reports

In this section, simulation outputs are studied. The impact of varying various system parameters within the model is determined. The model output analysis allows the modeler to draw inferences about the performance of various system configurations.

Tables 5-8 to 5-12 illustrate the results for our simulated model. The modeling elements provide the building blocks for illustrating the physical and logical components of the system being modeled. Physical elements of the system such as parts, laborers, buffers, machines, or resources may be referenced either graphically or by name. The simulation model’s listed results are in the form of tabulated reports on parts, machines, buffers, labor and shift statistics.

5.4.1.1 Parts

Parts or entities as mentioned in the previous chapter refer to the items being processed in the system. These include containers, materials, loads, and work in progress (WIP), finished products, etc. This table is a determinative table in analysis of results as it shows the parameters of shipped containers for terminal and can be compared with the UFT output to define the best approach for model optimization. The results of applying a simulation model on an intermodal UFT terminal operation in Table 5-1 shows the annual number of 448,957 containers for the base-model for a running length of 525,600 minutes.

Table 5-1 Intermodal UFT Terminal Part Statistics
for Base-Model Report on Shift Time

Part Statistics Report by On-Shift Time					
Name	**No. Entered**	**No. Containers Shipped**	**W.I.P.**	**Avg W.I.P.**	**Avg Time (min)**
Gondola	80	0	80	80	525,575.34
Unload Container	449,506	448,957.0	549	542.92	634.83
Container	449,484.0	0	9	7.94	9.28

Annual Number of Shipped Items for base-model shows 448,957 Containers.

5.4.1.2 Shift/ Work Schedule

A powerful characteristic of the simulated model is the ability to define work and break schedules through the WITNESS^{TM} shifting of module capability (Lanner Group, 2016). Work and break schedules are defined graphically by the percentage of on-shift and off-shift times of year (Figure 5-1). Resources or locations are then assigned to a specific shift schedule. The base-model works on eight-hour shifts for 24-hour operation work days and it has a one-hour break time for each eight hours.

Table 5-2 reports 87.5% for on-shift time and 12.5% for off-shift time over a total of 365 work days each year.

Table 5-2 Intermodal UFT Terminal Shift Statistics for Base-Model

Shift Statistics Report by On Shift Time			
Name	**% On-Shift**	**% Off-Shift**	**Completed Shifts**
Shift_for_24_Hour_Day	87.5	12.5	365

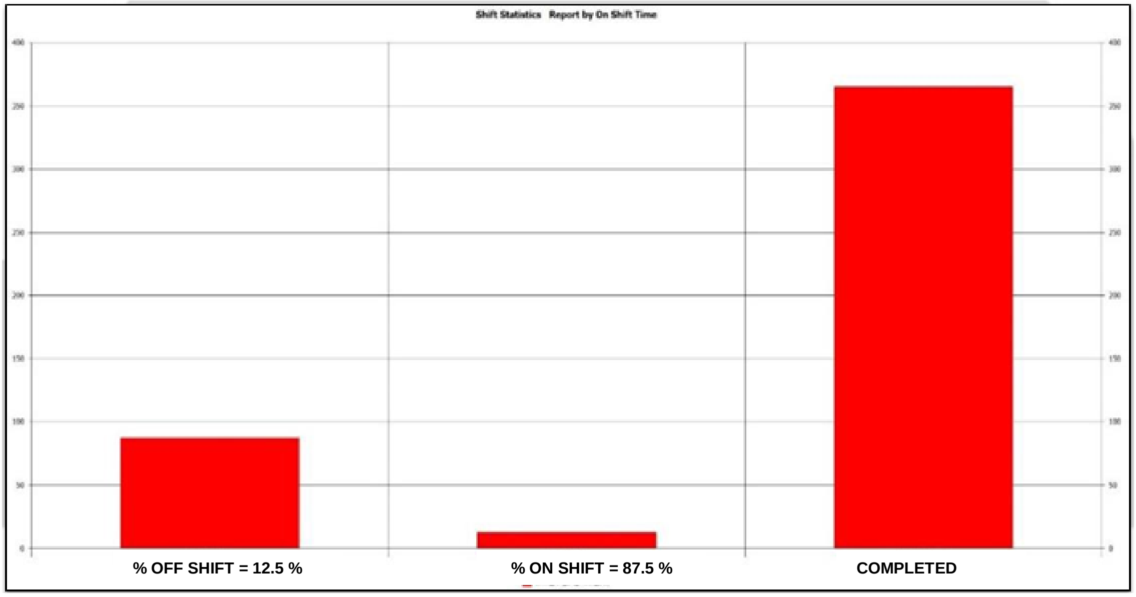


Figure 5-1 Intermodal UFT Terminal Shift Statistics for Base-Model

5.7.1.3 Labor

The minimum size of the crew in a terminal for the base-model is estimated as needing a total of 12 laborers. All 12 laborers in each shift go to break for one hour at the same time.

A terminal for the standard shipping container would need to have three loading and three unloading platforms. Two handler cranes must be assigned to each platform, resulting in 12 operating handlers per terminal. For each eight-hour shift, it is estimated that a total of 12 crew members will be needed at single terminal. These include two handler and forklift operators at each platform, one for loading and unloading of gondolas and the other for loading and unloading trucks. This will yield a total of 12 crew members for a terminal with six platforms.

The table of labor statistics report for Scenario 1 is in Table 5-3 and show a stack-yard and cycle time varying from 1 to 2 minutes for each handler. This report shows detailed outcomes for each laborer separately. Based on Table 5-3, the average job time and average cycle time is 1.5 for this base-model.

The percentage of busy and idle time for each forklift/ handler was calculated between 100% for the maximum amount and 95.33% for the minimum busy time and this amount changes from 4.67% to 0.00% for the idle time in this simulated model (Table 5-3).

Table 5-3 Intermodal UFT Terminal Labor Statistics for Base-Model, Report by On Shift Time

Labor Statistics Report by On Shift Time						
Name	**% Busy**	**% Idle**	**Quantity**	**No. Of Jobs Started**	**No. Of Jobs Ended**	**Avg Job Time (min)**
OffTruckForkLift_002	100	0	1	308,408	308,407	1.49
LoadGondForkLift_002	95.47	4.53	1	293,755	293,754	1.49
OnTruckForkLift_001	100	0	1	308,562	308,561	1.49
OffTruckForkLift_003	100	0	1	308,349	308,348	1.49
LoadGondForkLift_003	95.46	4.54	1	293,715	293,714	1.49
OnTruckForkLift_002	99.99	0.01	1	308,448	308,447	1.49
OffTruckForkLift_001	100	0	1	308,426	308,425	1.49
LoadGondForkLift_001	95.47	4.53	1	293,846	293,845	1.49
OnTruckForkLift_003	99.99	0.01	1	308,538	308,537	1.49
UnloadGondForkLift_001	95.33	4.67	1	293,628	293,627	1.49
UnloadGondForkLift_002	95.35	4.65	1	293,769	293,768	1.49
UnloadGondForkLift_003	95.33	4.67	1	293,727	293,726	1.49

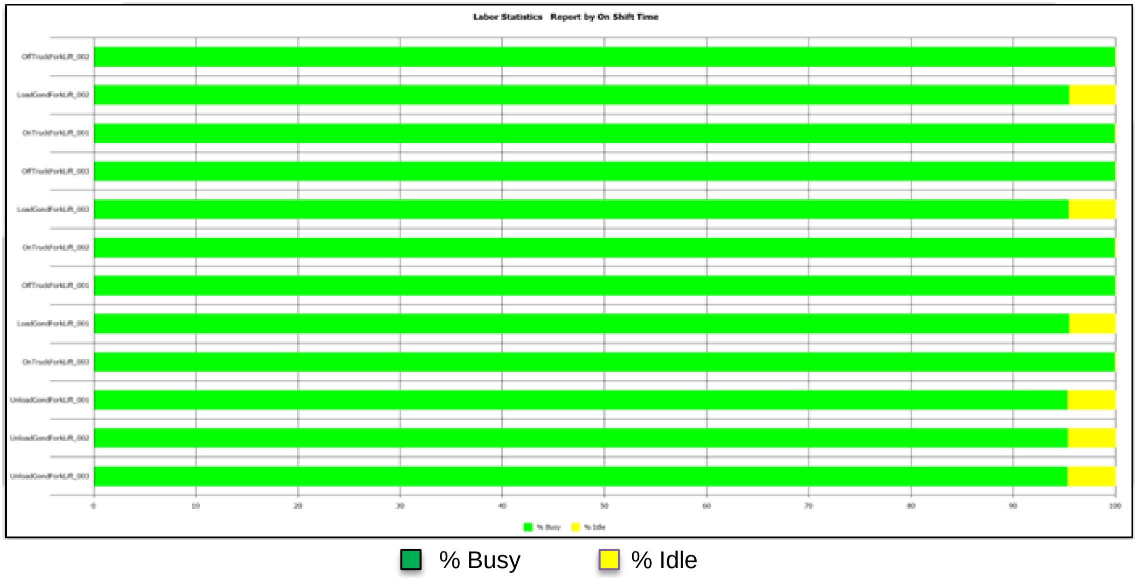


Figure 5-2 Intermodal UFT Terminal Labor Statistics for Base-Model

The location of the busiest forklift handlers namely OffTruckForkLift_002, OnTruckForkLift_001, OffTruckForkLift_003, OffTruckForkLift_001, OnTruckForkLift_002, and OnTruckForkLift_003 are shown in Figures 5-2 to 5-4.

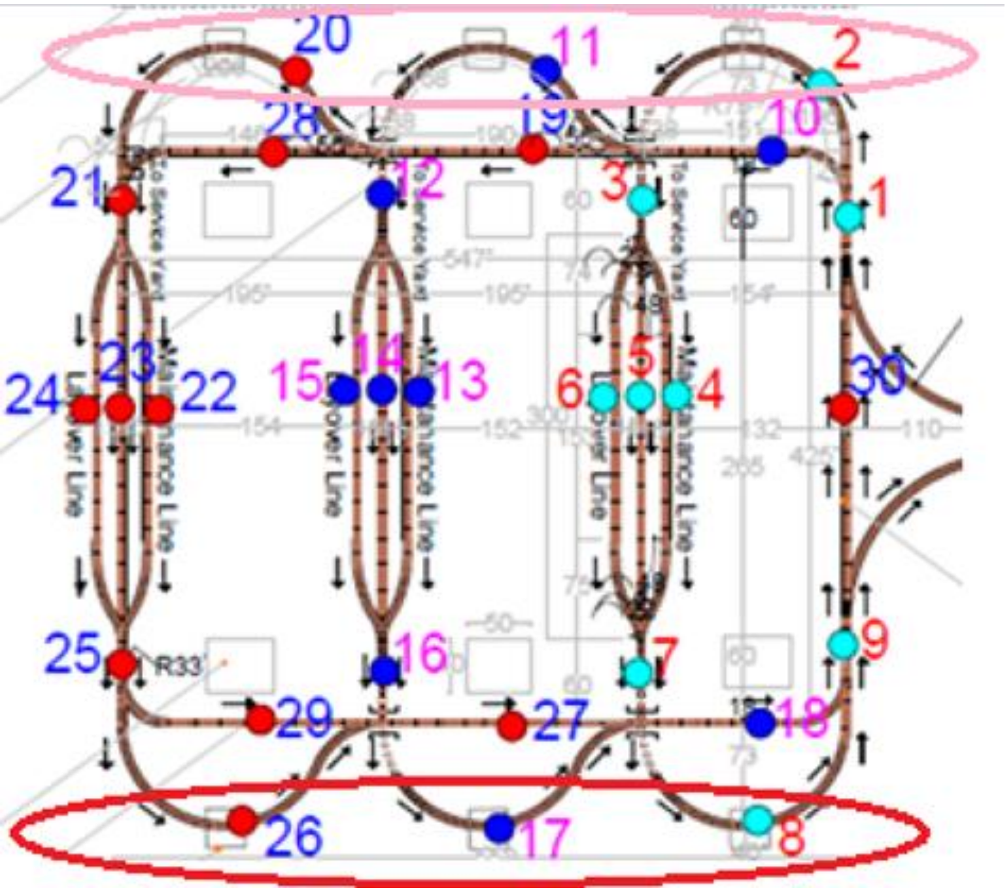


Figure 5-3 Intermodal UFT Terminal Loading/Unloading Platforms

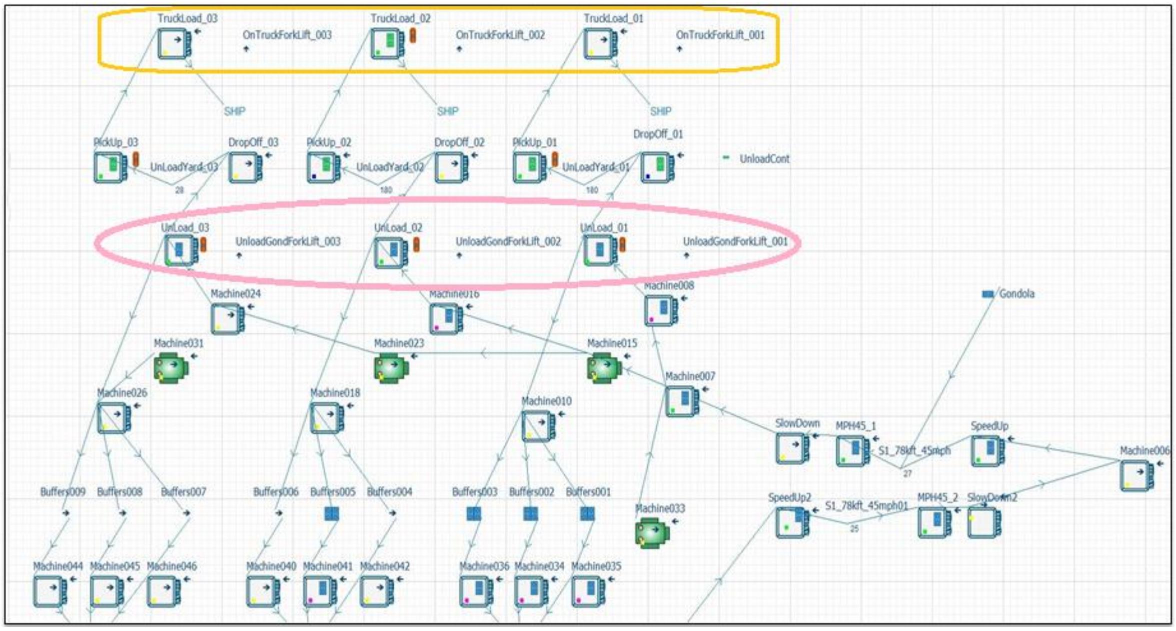


Figure 5-4 Intermodal UFT Terminal Labor Statistics for Base-Model

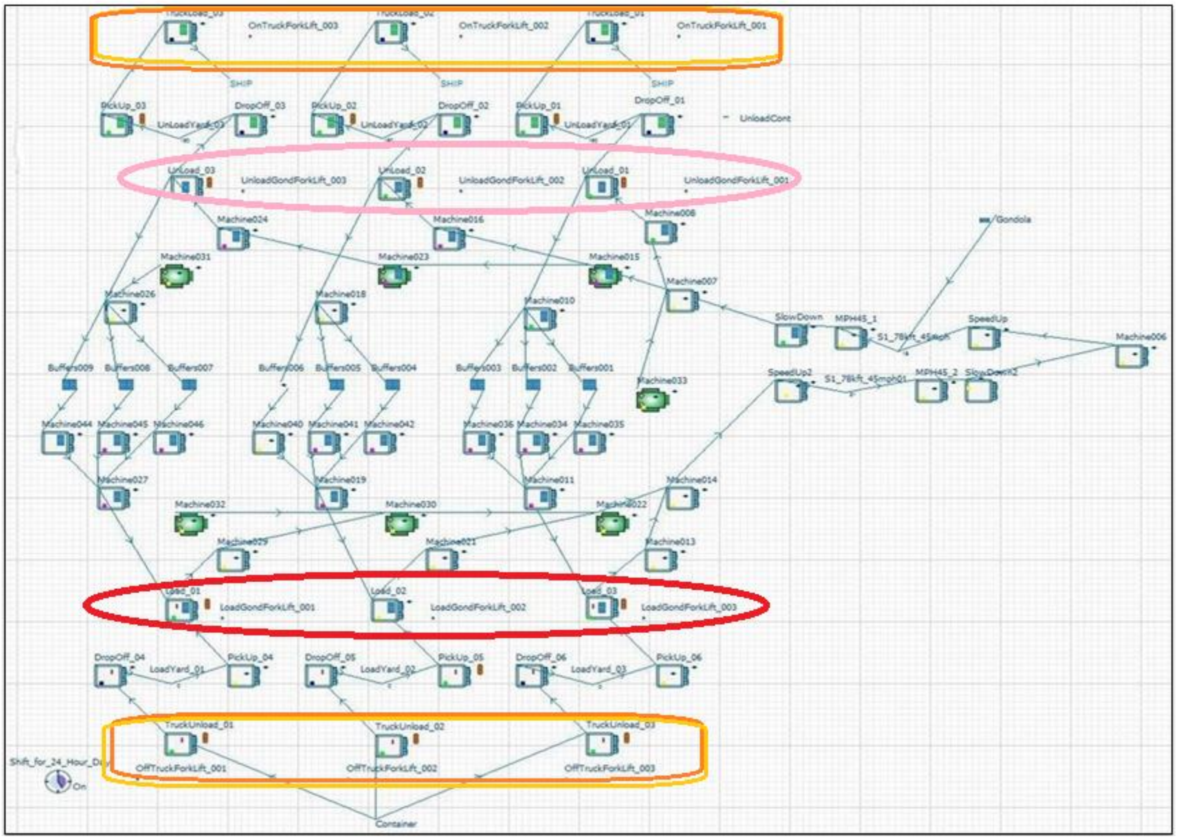


Figure 5-5 Intermodal UFT Terminal Labor Statistics for Base-Model

5.7.1.4 Buffer

Detailed results for buffer as one of the simulation modeling elements in the process of analysis of input data for expected outcomes have been shown in Table 5-4. The maximum number of containers is 180 at stack-yards. Stack-yards capacity in each platform is 180 for 36 spots. Considering our defined operation performance (handler/forklift), each spot has the capacity of five stacks and a total of 180 containers (36*5=180). Buffers, namely UnLoadYard_01, UnLoadYard_02, UnLoadYard_03, shows the maximum capacity for 180 gondolas.

Table 5-4 Intermodal Terminal Buffer Statistics Base-Model, Report by On Shift Time

Buffer Statistics Report by On Shift Time

Name	Total In	Total Out	Max	Min	Min Time (min)	Max Time (min)
S1_78kft_45mph01	449,475	449,454	23	0	19.2	78.03
S1_78kft_45mph	449,534	449,515	38	0	19.2	100.56
UnLoadYard_01	149,815	149,635	180	0	0	686.18
UnLoadYard_02	149,832	149,652	180	0	0	685.38
UnLoadYard_03	149,856	149,676	180	0	0	688.08
Buffers001	48,478	48,476	2	0	0.5	81.5
Buffers002	64,007	64,005	2	0	0.48	82.24
Buffers003	37,330	37,328	2	0	0.5	82.54
LoadYard_01	149,847	149,847	8	0	0	60.48
LoadYard_02	149,826	149,826	7	0	0	18.41
LoadYard_03	149,805	149,805	6	0	0	16.86
Buffers004	51,351	51,349	2	0	0.5	81.78
Buffers005	64,130	64,128	2	0	0.48	81.56
Buffers006	34,352	34,352	2	0	0.5	81.29
Buffers007	48,096	48,094	2	0	0.5	81.8
Buffers008	65,933	65,931	2	0	0.48	82.05
Buffers009	35,828	35,826	2	0	0.5	82.64

5.7.1.5 Machine

5.7.1.5.1 Identifying Bottlenecks in the Flow of Containers for Base-Model

The highest utilization—flow rate/capacity (always between 0% and 100%)—indicates the bottleneck (the Point of Greatest Congestion) process step. The system performance reduction and the corresponding decrease of the number of shipped containers in a terminal are often due to the increase of cargo flow and subsequent bottlenecks in chains.

Table 5-5 The Highest Bottleneck Points in Intermodal UFT Terminal
Machine Statistics Report for Base-Model

Name	**% Idle**	**% Busy**	**% Blocked**
Machine041	1.68	2.44	95.88
Machine034	3.31	2.44	94.26
Machine045	3.36	2.51	94.14
Machine008	3.44	5.7	90.86
Machine019	0.61	8.55	90.84
Machine027	1.33	8.55	90.12

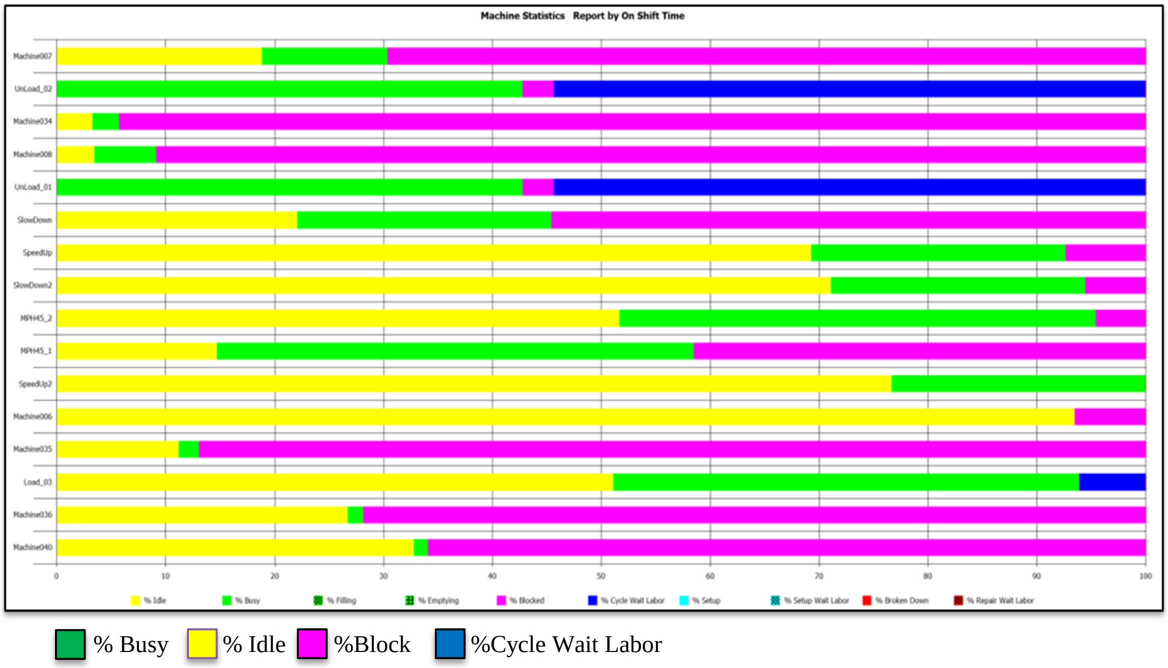


Figure 5-6 Intermodal UFT Terminal Machine Statistics for Base-Model

Table 5-5's machine statistics report for a base-model shows the detailed outcomes for each machine separately. According to this table, the percentage of busy and idle time for each machine is between 43.79% for the maximum amount (MPH45_1 and MPH45_2) and 0.00% for the minimum amount of busy time. Moreover, this amount changes from 92.59% (Machine029) to 0.00% for the idle time in this simulated model (see Appendix C). The other important factor, which has been considered in these simulated model calculations is the percentage of the blocked times for each machine. This factor is very important as it determines the bottlenecks over the whole system of terminal machines. The more bottlenecks occur, the more cargo flow happens and the number of shipped containers will decrease consequently.

The results based on Table 5-5, and Figure 5-5 shows that highest rate of blocked times are 95.88%, 94.26%, and 94.14% for this base-model. Also, a total number of 18 machines are involved in the highest blocked times for more than 60%. Figure 5-6 shows the most critical bottlenecks in the flow of containers for this model.

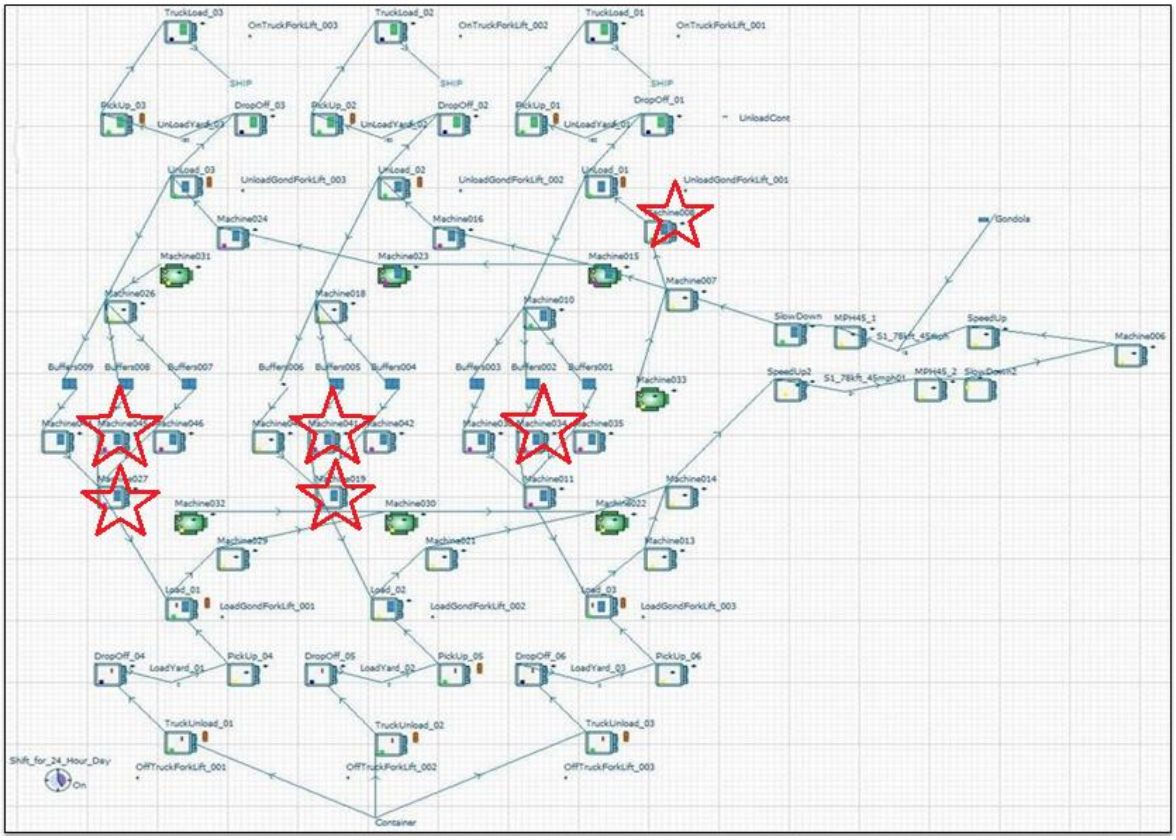


Figure 5-7 Bottlenecks in the Flow of Container for Base-Model

5.5 Section Summary

An integrative simulation-optimization framework was developed in this section to Simulate a Base-Model for UFT intermodal terminal operations in the first section of Chapter 5. The generated data, including line capacity, number of handlers, minimum number of crew members (i.e., 36 laborers with 12 per shift), and operation shift time were considered as model input. The development of the WITNESS^{TM} simulation-optimization framework (Lanner Group, 2008 and 2016) focused on the impacts of terminal system operations on the number of shipped items.

Results indicate that the developed simulated base model can produce optimal solutions efficiently for intermodal freight terminal networks. These research findings show that the total number of shipped items is 459,470 based on the input data for 525,600 minutes in 365 days over a year. This number of shipped items is 8.5% less than the expected shipped items, which are estimated at around 486,910 per year.

The report results for forklift handlers with an average cycle time of 1.5 min at the loading and unloading platforms show, the forklift handlers in this part are almost 100% busy. Analysis of the machine statistic report presents the maximum number of blocked machines among the total number of 33 machines. According to this report, the maximum block happened for machin024, 016, and 027 with 92.20%, 92.08%, and 86.24% blocked, respectively. On-shift time report presents 87.50%, and off-shift time is 12.5% for a 24-hour work day (three 8-hour shifts).

5.6 Section 2: Optimizing Intermodal Terminal Operations Base-Model through Simulation Modeling in Witness

The simulation module provides a realistic reproduction of the activities and flows that occur inside the terminal. It allows engineers to experiment and compare different policies and techniques before their application. It also provides a graphical interface in order to have easy access to the current state-of-the-simulated terminal and to simulate specific events. This section optimizes the simulated base model in the previous section. Summary of operational parameters with a modified cycle time (0.1, 1, 1.5) is presented in Table 5-13.

5.7 Different Settings: Simulated Scenarios

To improve the knowledge of the potential of the base-model and to optimize intermodal UFT terminal container unloading/loading and handling operations, two types of scenarios are simulated to provide what-if scenarios for model experimentation:

5.7.1 Scenario No. 1: *Intermodal container terminal with stack-yard operations for unloading/loading gondolas (Figure 5-8).*

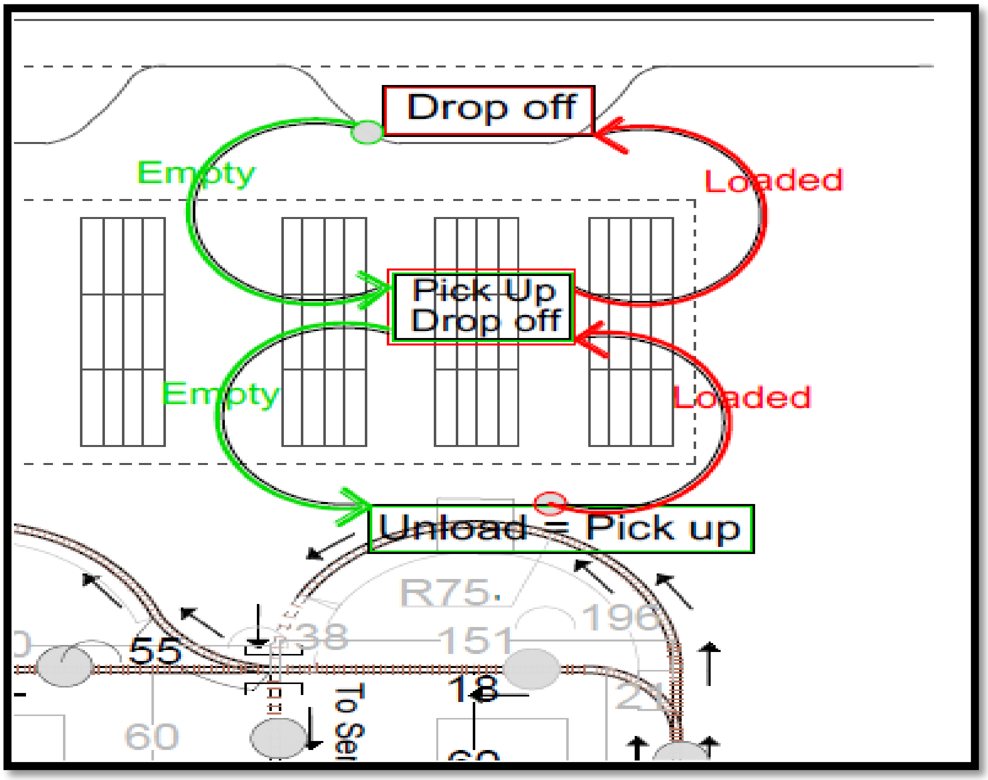


Figure 5-8 Scenario No. 1: Intermodal container terminal with stack-yard

5.7.2 Scenario No. 2: Intermodal container terminal without stack-yard operations for unloading/loading gondolas (non-stop cargo transfer from platforms to trucks) (Figure 5-9).

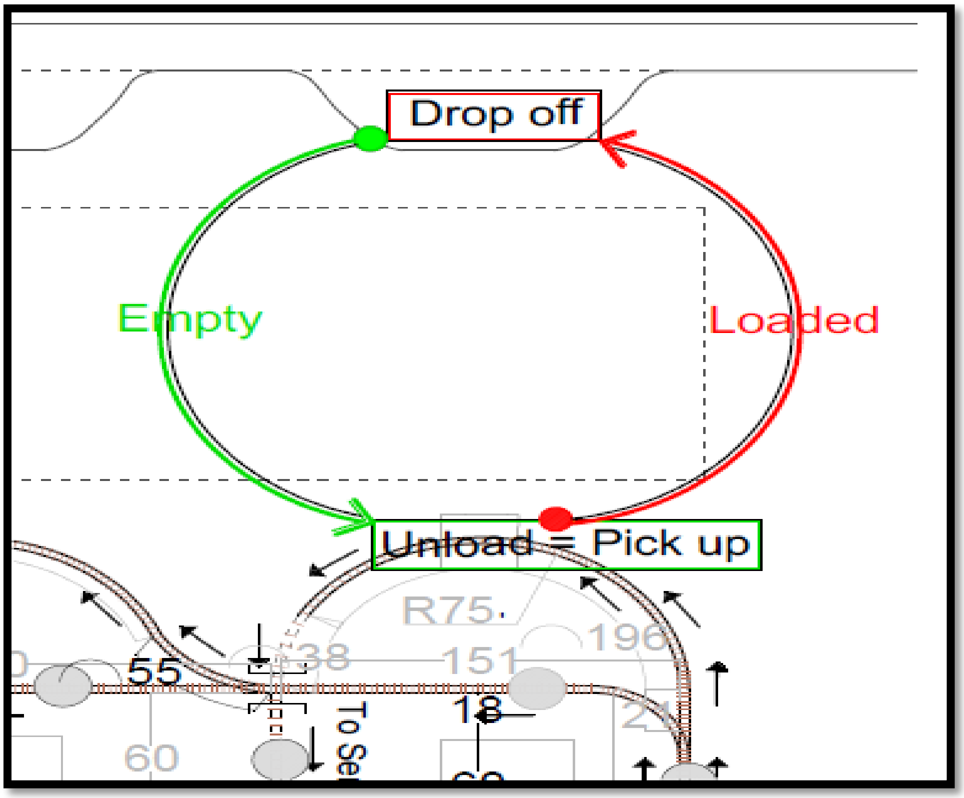


Figure 5-9 Scenario No. 2: intermodal container terminal without stack-yard

These two scenarios were created with the simulation-optimization tools in WITNESS^{TM} (Lanner Group, 2016) and developed to describe and evaluate day-by-day loading and unloading operations. Moreover, for each scenario, it was assumed that the truck is always available in both loading and unloading container sides. Additionally, this study does not model container sorting, and it was assumed that the handler always picks the right containers up and put them down in the available trucks and that the trucks send the right containers to the right customer destination.

5.7.3 Simulation Modeling Results

The goal of using simulation modeling for this research for two scenarios is to calculate the total number of containers shipped over the run for a year, which equals 525,600 minutes, considering the average waiting time in each platform for unload/loading trucks and gondolas. Utilization of system operations (proportion of busy times) will also be measured as an output performance by using simulation tools in WITNESS^{TM} (Lanner Group, 2016). For both scenarios, the intermodal container terminal operates 24 hours a day, 7 days a week, 365 days a year.

5.7.4 Table of Results for Scenario No. 1

5.7.4.1 Part

The results of Scenario No. 1 for the number of the shipped items (unload container) is shown in Table 5-16—with part statistics report by on shift time. This table shows the number of unloaded containers for intermodal terminal with stack-yard is 654,247 containers for 525,600 minutes for 365 days in a year. This table's content is the most important table in our analysis, because it is based on the number of shipped containers as a system output and helps define which scenario is more practical. The Scenario No. 1 results for the optimized UFT simulated terminal model follows:

Table 5-6 Intermodal UFT Terminal Part Statistics for
Scenario No. 1 Report by On Shift Time

Part Statistics Report by On Shift Time					
Name	**No. Entered**	**No. Shipped**	**W.I.P.**	**Avg W.I.P.**	**Avg Time (min)**
Gondola	80	0	80	80	525,579.81
Unload Container	654,667	654,274	393	509.8	409.29
Container	654,708	0	58	18.13	14.56

5.7.4.2 Shift/ Work Schedule

The model in Scenario No. 1 works for eight-hour shifts for 24-hour work days and it has one-hour off for break time for each eight-hour. The minimum size of the crew in terminal for this model in Scenario No. 1 with stack yard is estimated at 12 laborers. All 12 laborers in each shift go to break for one- hour at the same time. Table 5-6 shows 87.5% on-shift and 12.5% off-shift for a total of 365 work days in a year.

Table 5-7 Shift Statistics Report by On Shift Time

Shift Statistics Report by On Shift Time			
Name	**% On-Shift**	**% Off-Shift**	**Completed Shifts**
Shift_for_24_Hour_Day	87.5	12.5	365

5.7.4.3 Laborers

Like the base-model, for each eight-hour shift, it is estimated that a total of 12 crew members will be needed at the terminal. The table of laborer statistics reports Scenario No. 1 with a stack-yard and the cycle time variation to range from 0.5 to 1.5 minutes for each handler showing the detailed outcomes for each laborer separately. Based on this table, the average job and average cycle time is 1.0.

The percentage of busy and idle times for each forklift handler was calculated between 100% for the maximum amount and 84.99% for the minimum busy time and this amount differs from 15.01% to 0.00% for the idle time in this simulated model (see Table 5-16 for more details).

Table 5-8 Intermodal UFT Terminal Labor Statistics for
Scenario No. 1 Report by On-Shift Times

Labor Statistics Report by On Shift Time						
Name	**% Busy**	**% Idle**	**Quantity**	**No. Of Jobs Started**	**No. Of Jobs Ended**	**Avg Job Time (min)**
OffTruckForkLift_002	100	0	1	461,440	461,439	1
LoadGondForkLift_002	92.27	7.73	1	425,386	425,385	1
OnTruckForkLift_001	100	0	1	461,898	461,897	1
OffTruckForkLift_003	100	0	1	461,633	461,632	1
LoadGondForkLift_003	92.25	7.75	1	425,469	425,468	1
OnTruckForkLift_002	100	0	1	461,607	461,606	1
OffTruckForkLift_001	99.9	0.1	1	461,280	461,279	1
LoadGondForkLift_001	84.99	15.01	1	392,105	392,104	1
OnTruckForkLift_003	99.6	0.4	1	460,016	460,015	1
UnloadGondForkLift_001	92.17	7.83	1	425,260	425,259	1
UnloadGondForkLift_002	92.16	7.84	1	425,234	425,233	1
UnloadGondForkLift_003	85.24	14.76	1	393,250	393,249	1

Figure 5-10 Intermodal UFT Terminal Labor Statistics for Scenario No. 1

The location of the busiest laborers, namely OffTruckForkLift_002, OnTruckForkLift_001, OffTruckForkLift_003, OnTruckForkLift_002, OffTruckForkLift_001, and OnTruckForkLift_003 has is shown in Figures 5-10 and 5-11.

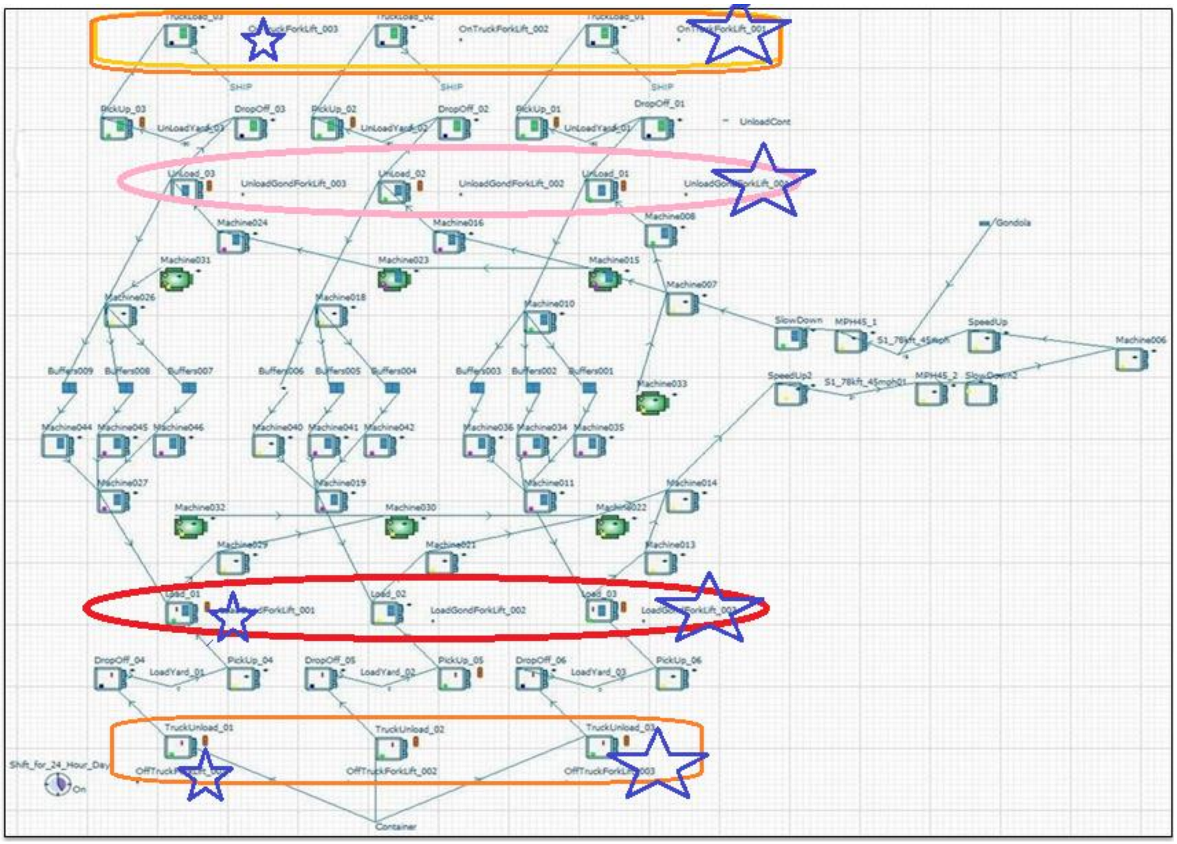


Figure 5-11 Intermodal UFT Terminal Labor Statistics for Scenario No. 1

5.7.4.4 Buffer

Table 5-8 shows the maximum number of containers for 180 at the stack-yards. Stack-yard capacity in each platform is also mentioned in Section 5.1 for 36 spots or 180. Buffers, namely UnLoadYard_01, UnLoadYard_02, UnLoadYard_03, and LoadYard_01 keep the maximum capacity for 180 gondolas.

Table 5-9 Buffer Statistics Report by On Shift Time

Buffer Statistics Report by On Shift Time						
Name	**Total In**	**Total Out**	**Max**	**Min**	**Min Time (min)**	**Max Time (min)**
S1_78kft_45mph01	654,648	654,623	33	0	19.2	75.8
S1_78kft_45mph	654,701	654,674	38	0	19.2	84.73
UnLoadYard_01	221,071	220,891	180	0	0	446.42
UnLoadYard_02	221,001	220,821	180	0	0	447.32
UnLoadYard_03	212,594	212,566	180	0	0	457.87
Buffers001	61,074	61,072	2	0	0.5	74.87
Buffers002	130,873	130,871	2	0	0.48	74.97
Buffers003	29,125	29,123	2	0	0.5	74.69
LoadYard_01	212,643	212,595	180	0	0	734.36
LoadYard_02	220,997	220,997	11	0	0	60.32
LoadYard_03	221,062	221,062	10	0	0	60.65
Buffers004	52,613	52,613	2	0	0.5	74.61
Buffers005	149,640	149,638	2	0	0.48	75.5
Buffers006	18,748	18,748	2	0	0.5	74.62
Buffers007	12,863	12,863	2	0	0.5	73.31
Buffers008	196,874	196,874	2	0	0.48	73.19
Buffers009	2,857	2,857	2	0	0.5	73.62

5.7.4.5 Machine

5.7.4.5.1 Identifying Bottlenecks in the Flow of Container for Scenario No. 1

Table 5-10 represents the machine statistics report for Scenario No. 1 and shows the detailed outcomes for each machine separately. According to this Table, the percentage of busy and idle time for each machine was calculated between 63.77% for the maximum amount (MPH45_1 and MPH45_2) and 0.00% for the minimum busy time and this amount changes from 100% (Machine031, Machine032, Machine033) to 0.00% for the idle time in this simulated model (see Appendix C). The other important factor is the percentage of blocked times for each machine. This factor as mentioned in Section 5.1 is very important as it determines the bottlenecks over the whole system machines in terminal. The more bottlenecks occur the more cargo flow happens and the number of shipped containers will decrease accordingly. The results based in Table 5-10, and Figure 5-11 shows that highest rate of blocked times as 83.75%, 80%, and 78.93% for this simulated model for scenario number one with stack-yard. Also, a total number of seven machines are involved in the highest blocked times for more than 50%. Figure 5-12 shows the most critical bottlenecks in the flow of container for this model.

Table 5-10 The Highest Bottleneck Points in Intermodal UFT Terminal
Machine Statistics Report for Scenario No. 1

Name	% Idle	% Busy	% Blocked
Machine034	11.27	4.98	83.75
Machine011	5.42	14.3	80.28
Machine019	8.45	12.61	78.93
Machine041	16.87	5.69	77.44
Machine008	14.64	8.41	76.94
Machine035	33.46	2.32	64.21

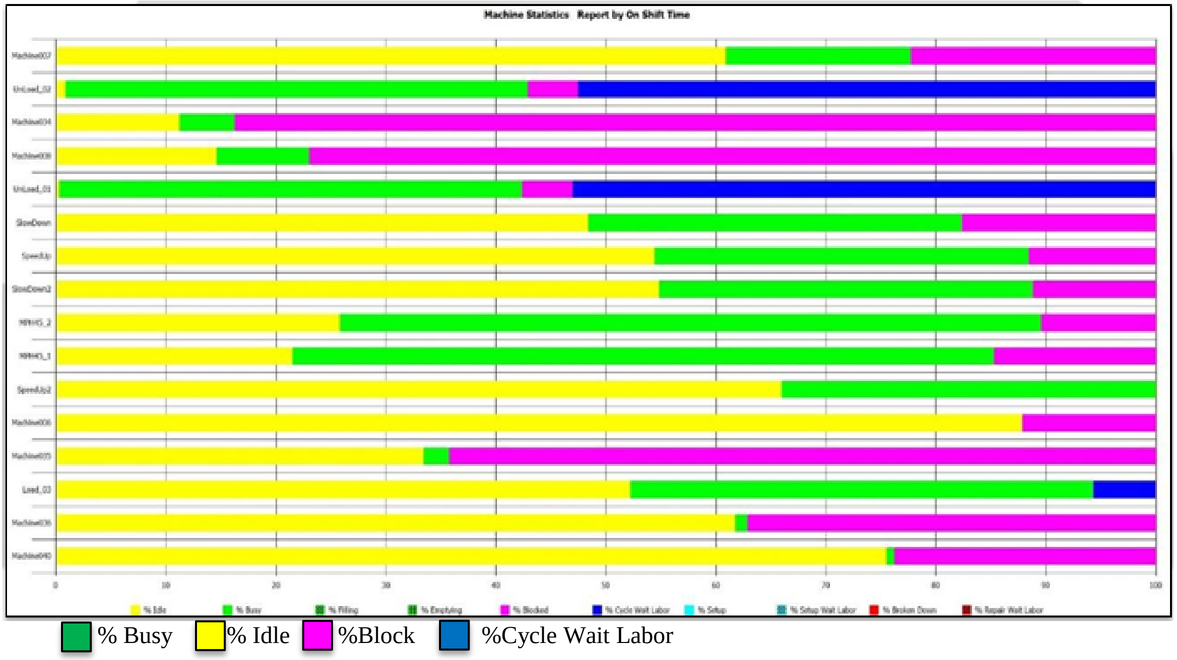


Figure 5-12 Intermodal UFT Terminal Machine Statistics for Scenario No. 1

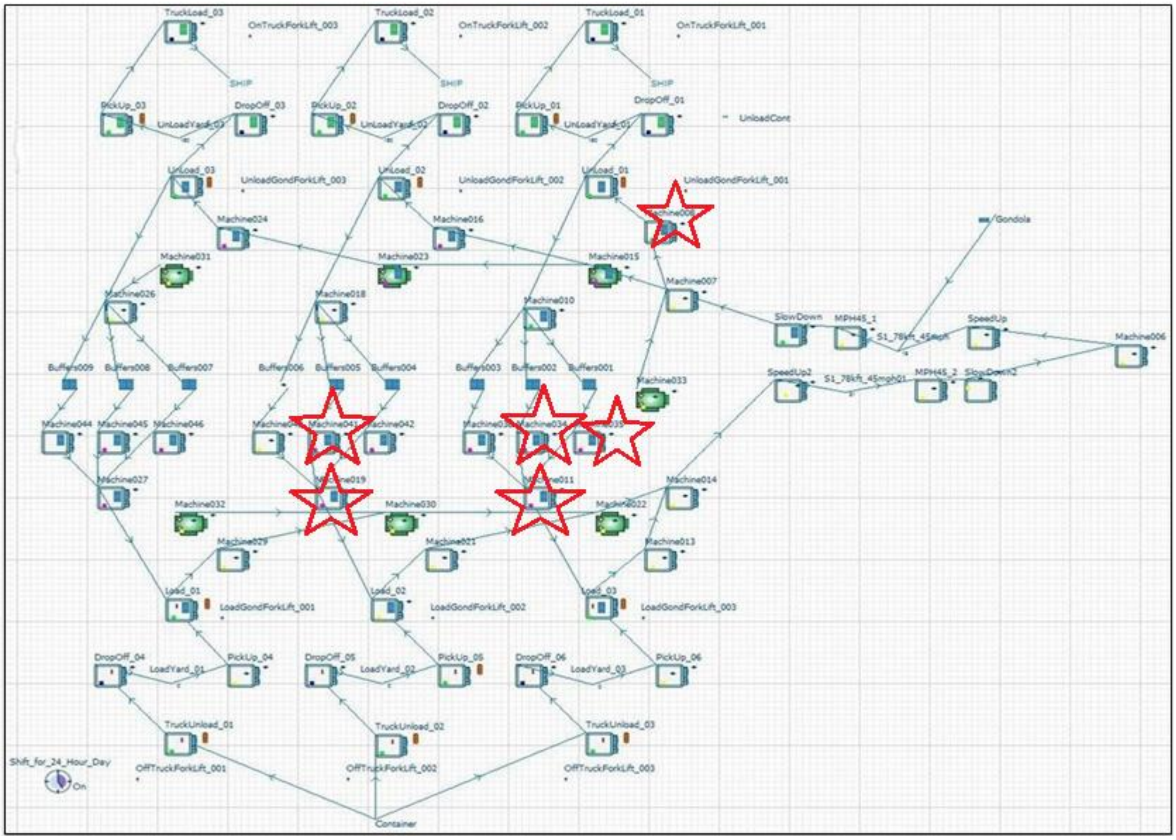


Figure 5-13 Bottlenecks in the Flow of Container for Scenario No. 1

5.7.5 Table of Results for Scenario No. 2: Results for the UFT Terminal, Optimized Model

5.7.5.1 Part

According to the Table 5-11, the number of unloaded containers for intermodal terminal without stack-yard is 775,936 items for 525,600 minutes for 365 days in a year. This shows that the number of shipped containers as a system output for Scenario No. 2 is significantly more than Scenario No. 1 with stack-yards, and it was calculated at 654,272 containers per year. The result of this simulated model illustrates that Scenario No. 2 is more practical.

Table 5-5 Intermodal UFT Terminal Part Statistics
for Scenario No. 2 Report by On Shift Time

Part Statistics Report by On Shift Time					
Name	**No. Entered**	**No. Shipped**	**W.I.P.**	**Avg W.I.P.**	**Avg Time (min)**
Gondola	80	0	80	80	525,579.88
Unload Container	775,942	775,936	6	7.17	4.86
Container	775,942	0	2	2.05	1.39
ForkLift005	2	0	2	2	525599.75
Forklift_001	2	0	2	2	525599.75
ForkLift004	2	0	2	2	525599.75
ForkLift006	2	0	2	2	525599.75
Forklift_002	2	0	2	2	525599.75
Forklift_003	2	0	2	2	525599.75

5.7.5.2 Shift/ Work Schedule

The minimum size of the crew in each terminal for this model in Scenario No. 2 without stack-yard is the same as Scenario No. 1 with a stack yard and it equals to a total number of 12 laborers. All 12 laborers in each shift go to break for one-hour at the same time. Table 5-20 illustrates the simulation modeling results for 87.5% on-shift and 12.5% off-shift for a total of 365 work days in a year for Scenario No. 2 and it is the same as Scenario No. 1.

Table 5-6 Intermodal UFT Terminal Shift Statistics Report by On-Shift Time

Shift Statistics Report by On Shift Time			
Name	**% On-Shift**	**% Off-Shift**	**Completed Shifts**
Shift_for_24_Hour_Day	87.5	12.5	365

5.7.5.3 Labor

A total of 12 crew members are required for a terminal with six platforms. The table of labor statistics report for Scenario No. 2 without a stack yard and the cycle time variation from 0.5 to 1.5 minutes for each handler show the detailed outcomes for each laborer separately. Based on Table 5-13, the average job time/ average cycle time varies slightly from 0.0 to 1.2 minutes.

The percentage of busy and idle time for each operator was calculated between 89.87% for the maximum amount and 0.0% for the minimum busy time, and this amount fluctuates from 100% to 10.13% for the idle time in this simulated model (as shown in Table 5-13).

Table 5-7 Intermodal UFT Terminal Labor Statistics Report for Scenario No. 2 Report by on Shift Time

Labor Statistics Report by On Shift Time						
Name	**% Busy**	**% Idle**	**Quantity**	**No. Of Jobs Started**	**No. Of Jobs Ended**	**Avg Job Time (min)**
OffTruckForkLift_002	49.17	50.83	1	188,898	188,898	1.2
LoadGondForkLift_002	49.16	50.84	1	188,871	188,870	1.2
OnTruckForkLift_001	89.02	10.98	1	342,990	342,990	1.19
OffTruckForkLift_001	89.43	10.57	1	343,789	343,788	1.2
LoadGondForkLift_001	89.44	10.56	1	343,782	343,781	1.2
OnTruckForkLift_002	0.15	99.85	1	1,106	1,106	0.63
OffTruckForkLift_003	63.88	36.12	1	245,660	245,659	1.2
LoadGondForkLift_003	63.84	36.16	1	245,651	245,650	1.2
OnTruckForkLift_003	63.86	36.14	1	245,640	245,639	1.2
UnloadGondForkLift_001	89.87	10.13	1	346,487	346,486	1.19
UnloadGondForkLift_002	48.97	51.03	1	376,642	376,642	0.6
UnloadGondForkLift_003	0	100	1	244,826	244,826	0

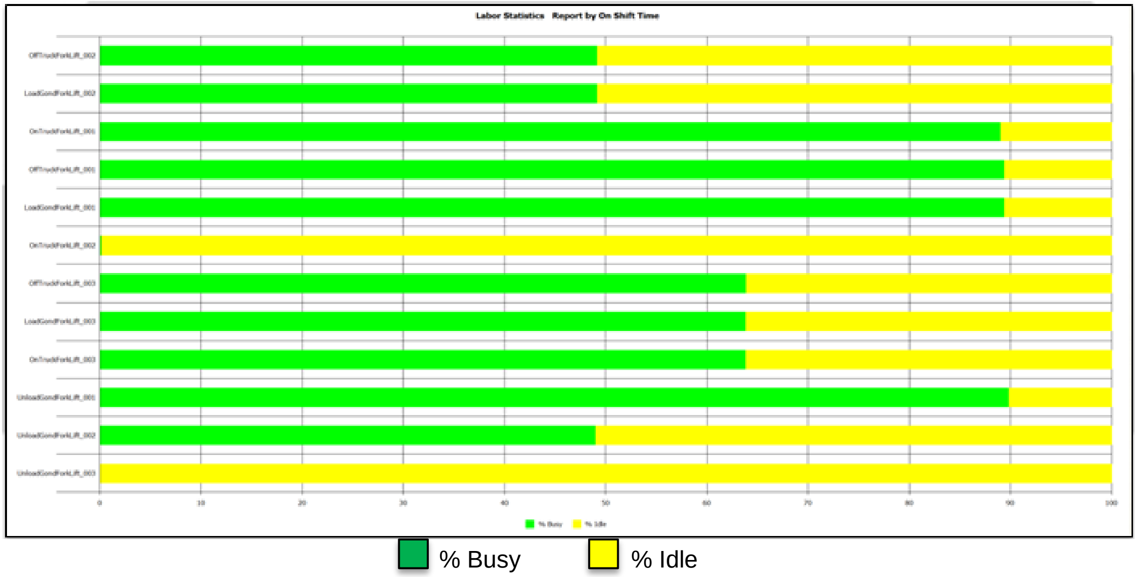


Figure 5-14 Intermodal UFT Terminal Labor Statistics for Scenario No. 2

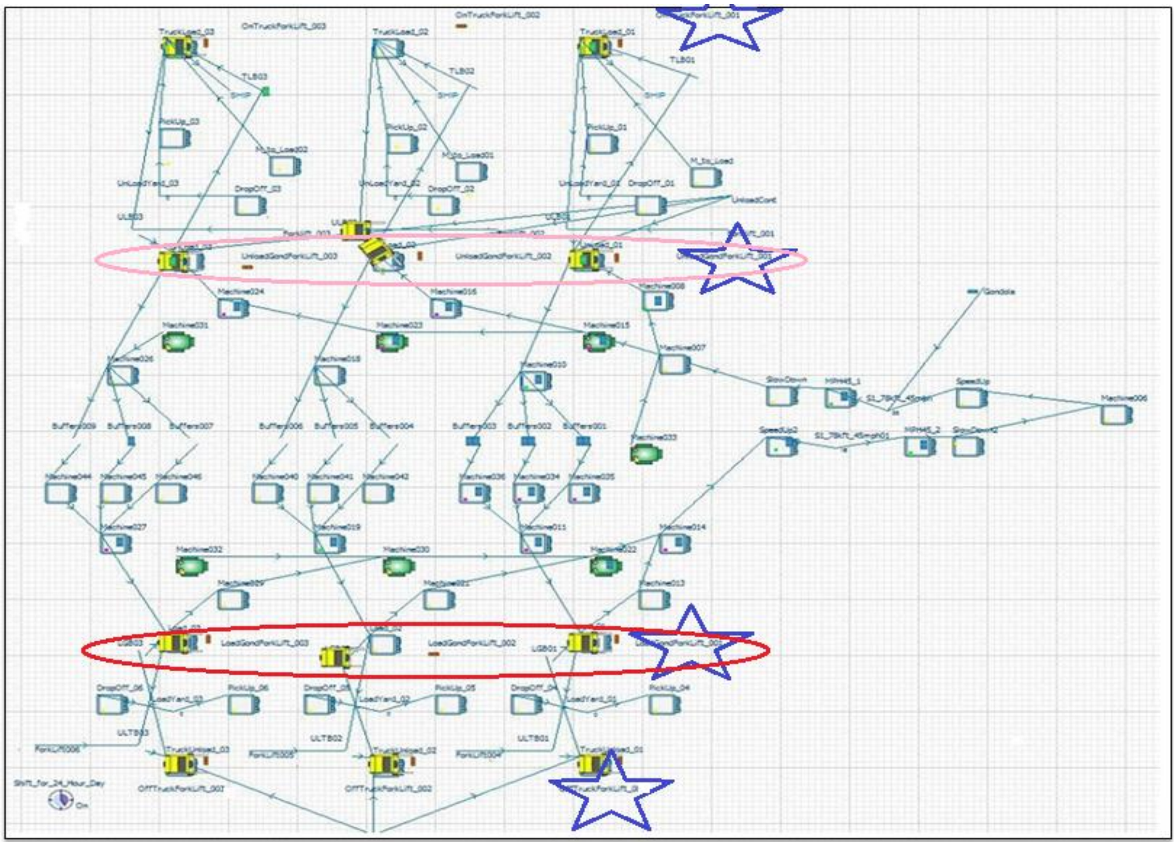


Figure 5-15 Intermodal UFT Terminal Optimized Model for Scenario No. 2

5.7.5.4 Buffer

Table 5-14 shows the detailed results for Scenario No. 2 without a stack yard for the element of buffer. The maximum number of gondolas is 38 at the terminal entrance gate.

Table 5-8 Buffer Statistics Report by On Shift Time

Buffer Statistics Report by On Shift Time						
Name	**Total In**	**Total Out**	**Max**	**Min**	**Min Time (min)**	**Max Time (min)**
S1_78kft_45mph01	775,934	775,905	38	0	19.2	73.01
S1_78kft_45mph	775,984	775,950	38	0	19.2	78.42
UnLoadYard_01	0	0	0	0	0	0
UnLoadYard_02	0	0	0	0	0	0
UnLoadYard_03	0	0	0	0	0	0
Buffers001	13,196	13,196	2	0	0.5	68.25
Buffers002	328,949	328,948	2	0	0.48	68.04
Buffers003	648	648	2	0	0.5	68.06
LoadYard_03	0	0	0	0	0	0
LoadYard_02	0	0	0	0	0	0
LoadYard_01	0	0	0	0	0	0
Buffers004	0	0	0	0	0	0
Buffers005	188,323	188,323	2	0	0.48	0.48
Buffers006	0	0	0	0	0	0
Buffers007	0	0	0	0	0	0
Buffers008	244,827	244,826	2	0	0.48	59.92
Buffers009	0	0	0	0	0	0
ULTB03	244,827	244,827	1	0	0	60.61
ULB01	342,793	342,792	2	0	0	60.85
TLB01	685,583	685,583	2	0	0	61.69
ULB02	188,323	188,322	2	0	0	62.97
TLB02	376,643	376,643	2	0	0	61.69
TLB03	489,651	489,650	2	0	0	61.67
ULB03	244,826	244,825	2	0	0	64.77
ULTB02	188,324	188,324	1	0	0	60.15
LGB03	244,826	244,826	2	0	0	65.09
ULTB01	342,791	342,791	1	0	0	60.76
LGB02	188,324	188,323	2	0	0	63.45
LGB01	342,790	342,790	2	0	0	61.16

5.7.5.5 Machine

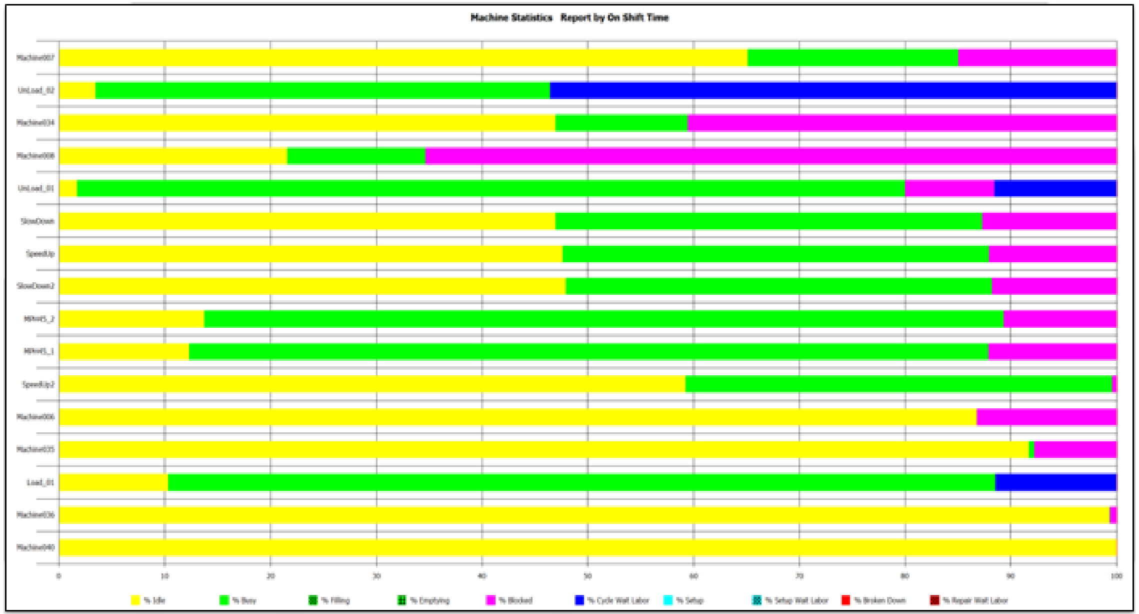
5.7.5.5.1 Identifying Bottlenecks in the Flow of Container for Scenario No. 2

The table of machine statistics reported for Scenario No. 2 without a stack yard shows the detailed outputs for each machine.

Table 5-9 The Highest Bottleneck Points in Intermodal UFT Terminal
Machine Statistics Report for Scenario No. 2

Name	% Idle	% Busy	% Blocked
Machine016	25.64	8.6	65.76
Machine008	21.59	13.04	65.36
Machine011	20.52	22.17	57.30
Machine034	46.95	12.52	40.54
Machine024	57.03	12.11	30.85
Machine027	66.78	13.97	19.25

Results in Chart for Machine Statistics for Scenario No. 2:



🟩 % Busy 🟨 % Idle 🟪 %Block 🟦 %Cycle Wait Labor

Figure 5-16 Intermodal UFT Terminal Machine Statistics for Scenario No. 2

The percentage of busy and idle time for each machine based on the Table 5-15 and Figure 5-15 was calculated between 78.27% for the maximum amount (UnLoad_01 ,and Load_01) and 0.00% for the minimum busy time and the amount for the idle time differs from 100% for 21 machines (Machine040, Machine042, Machine044, Machine046, DropOff_01, DropOff_02, DropOff_03, DropOff_06, DropOff_04, PickUp_01, PickUp_02, PickUp_03, PickUp_06, PickUp_05, PickUp_04, Machine031, Machine032, M_to_Load01, Machine033, M_to_Load , M_to_Load02) to 1.73% (UnLoad_01) (see Appendix B).

The results for the percentage of blocked times, based on the Table 5-15, and Figure 5-16 show that the highest rate of blocked times are 65.75%, 65.36%, and 78.93% for scenario No. 2 l without a stack yard. In this case, the total number of machines, which are involved in the highest blocked percentage (more than 50%) is three machines. Figure 5-17 shows the most critical bottlenecks in the flow of containers for Scenario No. 2

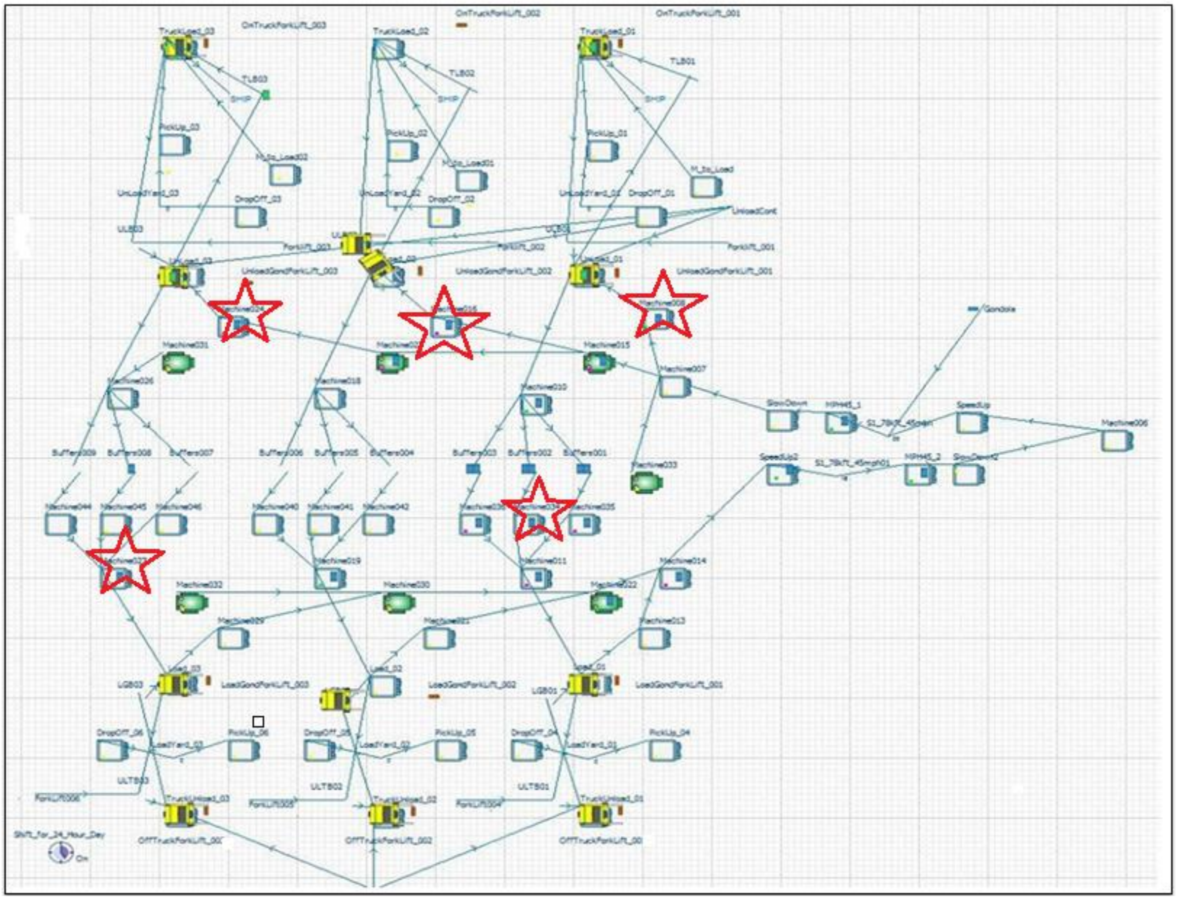


Figure 5-17 Bottlenecks in the Flow of Containers for Scenario No. 2

5.8 Results and Comparison

Each simulation model was performed for 365 days or 525,600 minutes. Section 5.1 results indicate that the total number of shipped items for the base model is 448,957 containers at the end of 525,600 min or 365 days. The calculated total number of shipped cargo in Section 5.1 is about 7.8% less than the expected shipped items for UFT terminal which was estimated for 486,910 containers per year.

The results of this study as noted in Section 5.2 show that the total number of shipped items (unloaded containers) for intermodal terminal for Scenario No. 2 without a stack yard is 775,936 items for 525,600 minutes for 365 days in a year. This output is about 60% more than the annual expected shipped items equal to 486,910 and 73% more than the number of shipped items in the base-model which is estimated around 448,957. This shows that the number of shipped containers as system output for Scenario No. 2 is significantly more than Scenario No. 1 with a stack yard which was calculated for 654,247 containers per year. The result of Scenario No. 1 is respectively 34% and 46% more than the annual expected shipped items for the UFT terminal (486,910), and the calculated number of shipped items for the base-model (448,957). See Tables 5-16 and 5-17 for model results and comparisons.

Table 5-10 Model Results and Comparison to the Annual Expected Shipped Items for a UFT Terminal

Name	**No. Shipped**	**Difference (Compared to the UFT Terminal)**
Unload Gondola for the UFT Terminal	486,910	_
Unload Gondola for the UFT Base-Model	448,957	-7.8%
Unload Gondola for the UFT Optimized-Model, Scenario No. 1	654,274	34%
Unload Gondola for the UFT Optimized-Model, Scenario No. 2	775,936	59%

The results of this simulated model compared to the base model illustrates that Scenario No. 2 is a type of intermodal container terminal without a stack yard with 27% difference in the annual number of shipped containers is more applicable than in Scenario No. 1.

Table 5-11 Model Results and Comparison to the UFT Base-Model

Name	No. Shipped	Difference (Compared to the UFT Base-Model)
Unload Gondola for the UFT Base-Model	448,957	_
Unload Gondola for the UFT Optimized-Model, Scenario No. 1	654,274	46%
Unload Gondola for the UFT Optimized-Model, Scenario No. 2	775,936	73%

5.9 Testing the Model: Verification and Validation

Verification of the simulated model was tested during the modeling process. For instance, any labor used to build a model as an accurate element was examined to be in the correct priority order. Another example of the simulated model verification in this research was checking that the model parts were moving in the right direction on the line between model elements. Validation is the next step of simulation in the modeling process, which follows verification. Validation analyzes the accuracy of the model compared with the real world. Validation for our model explores the model outputs which is the number of shipped items for this research.

As mentioned previously, the development of the WITNESS^{TM} simulation-optimization framework (Lanner Group, 2016) in this chapter focused on the impacts of the intermodal UFT terminal system operations on the number of shipped items. The results indicate that the total number of shipped items for the base model is 448,957 containers for 525,600 minutes in 365 days. The calculated total number of shipped cargo in Section 5.1 is about 7.8% less than the expected shipped items for the UFT terminal, which was mathematically estimated at 486,910 containers per year. The base-model results show only a 7.8% difference compared to the calculated annual expected number of shipped items, and these results validate the accuracy of the model. Additionally the output of model experimentation through what-if scenarios shows that the number of annual shipped containers for Scenario No. 1 and Scenario No. 2 in Section 5.2 (optimized-model) are respectively 34% and 59% more than the expected results for the UFT terminal.

5.10 Chapter Summary

This chapter presents the development of a simulation optimization model, which can cope with fluctuation in demands and increase the number of daily shipped items and enhance the intermodal freight terminal operations. Because the major goal is optimizing an intermodal terminal operation, which can increase the terminal's capacity for the rapidly changing freight industry. The DES model was applied by using WITNESS^{TM} (Lanner Group, 2008 and 2016) to optimize intermodal terminals operations and to identify the best layout for expedited freight movement. To examine the model, a case study was selected on the Inland Satellite Dist. Center Terminal in Baytown in Texas, which is about 15 miles from the Port of Houston.

This chapter provided the details of the model implementation results in operation performances in two sections and presented comparison of results in terms of the total number of shipped items in intermodal terminals. Chapter 5 described the model implementation results in two sections. The base model for UFT was presented in this chapter's first section for intermodal terminal operations. The generated data including line capacity, number of handlers, minimum crew member, and operation shift time was considered as a model input. As mentioned, the development of the WITNESS^{TM} (Lanner Group, 2008 and 2016) simulation-optimization framework focused on the impacts of the terminal system operations on the number of shipped items. The Section 1 results from the viewpoint of operational performance indicate that the total number of shipped items for a base model is 448,957 containers for 525,600 min in 365 days. The calculated total number of shipped cargo in Section 1 is about 7.8% less than the expected shipped items for UFT terminal which was estimated for 486,910 containers per year.

The results for Section 2 of this chapter show that the total number of shipped items (unloaded containers) for the intermodal terminal for Scenario No. 2 without a stack-yard is 775,936 items for 525,600 minutes or 365 days a year and it is about 59% more than the annual expected shipped items equal to 486,910 and 73% more than the number of shipped items in the base-model which is estimated around 448,957. This shows that the number of shipped containers as a system output for Scenario No. 2 is significantly more than Scenario No. 1 with a stack yard which was calculated as handling 654,247 containers per year. This result of Scenario No. 1 is respectively 34% and 46% more than the annual expected shipped items for UFT terminal and the calculated number of shipped items for the base-model. This research's model works for eight-hour shifts for 24-hour operations work day which is equal to 87.5% for on-shift and 12.5% for off-shift based on the simulated model table. The minimum size of the crew is calculated for 12 labors for both scenarios.

The percentage of busy and idle time for each operator for Scenario No. 1 and Scenario No. 2 was calculated between 100% and 89.87% for the maximum amount and 84.99% and 0.00% for the minimum busy time and this amount differs from 15.01% to 0.00% a 100% to 10.13% for the idle time in Scenario No. 1 and Scenario No. 2, respectively. The analysis of machine results in the simulation model illustrates that there is a higher blocked rate for Scenario No. 1 in comparison with the other scenario. It shows the highest rate of blocked times for 83.75% for the first scenario and 65.79% for the second one. Also, the number of machines involved in the highest blocked times in Scenario No. 1 is much more than the scenario without a stack-yard. It is obvious that the more bottlenecks occur, the more cargo flow happens and the less number of containers will be shipped.

Considering all of l the above, the result of this simulated model compared to the base-model illustrates that the Scenario No. 2—intermodal container terminal without stack-yard— with about 121,662 annual extra shipped items and 27% difference in the annual number of shipped containers is more applicable than Scenario No. 1.

Chapter 6 Conclusions, Limitations, and Recommendations for Future Research

The main contribution of this research is the development of a new integrative simulation-optimization framework for intermodal underground freight terminals systems. This analysis can be used to assess the performance of intermodal terminal operations. The developed framework in this dissertation is based on the simulation-optimization modeling in WITNESS^{TM} (Lanner Group, 2016), where discrete-event variables describing the model change at instantaneous discrete points in time (event times) for the number of containers in queue and server status (busy, idle, down). This simulation model used in this dissertation is uniquely capable of assessing real-world system complexity. This dissertation attempted to improve the base-model to upgrade it to efficiently increase the number of shipped items and handle the increasing volume demands placed on them. This increasing-volume challenge is made even more difficult by the fact that many ports and terminals will need to handle this increased volume without increasing available physical space. Therefore, upgrading operations and technologies applied constantly across the entire intermodal system can offer significant opportunities to increase existing system capacity. Improved terminal designs, advanced computer modeling and simulation systems, and advanced technologies for moving cargo and information, operating in collaboration with focused logistics can be applied to accelerate the movement of freight through intermodal terminals.

Chapter 3 reviewed planning and design process for the UFT system terminals for TxDOT and explained the operational parameters for UFT terminals. Three schematic terminal designs were presented- one for each type of load, namely for standard shipping containers, crates, and pallets. Given the needed 250-mile UFT line between Houston and Dallas, it showed a line capacity of 2,880 containers/day/direction which required 1,334 vehicles circulating in the line at 30- second headways.

An integrative simulation-optimization model framework to simulate an intermodal terminal operation is presented in Chapter 4. To evaluate intermodal terminal operations performance, a simulation base-model using WITNESS^{TM} (Lanner Group, 2008 and 2016) software was developed. The development of the WITNESS^{TM} simulation-optimization framework focused on the impacts of terminal system operations on the number of shipped items in the long term, where loading/unloading processes play an important role. The concept of optimization, however, embodies, not only aspects of cargo flow, but also includes system speed, terminal capacity and operation management.

Chapter 5 supported the effort to develop an optimal option for intermodal underground freight terminals as a key component of any transportation system by using simulation-optimization tools in WITNESS^{TM} (Lanner Group, 2008 and 2016). This chapter provided the details of the model implementation results in operation's performance in two sections and presented comparison of results in terms of the total number of shipped items in intermodal terminals. Chapter 5 described the model implementation results in two sections. The base-model for the UFT developed in the first section for intermodal terminal operations and optimizing the base-model is discussed in the second section of this chapter. The generated data including line capacity, number of handlers, minimum crew member, and operation shift time was considered as a model input. As mentioned, the development of the WITNESS^{TM} (Lanner Group, 2008 and 2016) simulation-optimization framework focused on the impacts of the terminal system operations on the number of shipped items. Section 5.1 results indicate that:

- The total number of shipped items for the base-model is 448,957 containers for 525,600 min or 365 days.
- The calculated total number of shipped cargo in Section 5.1 is about 7.8% less than the expected shipped items for the UFT terminal which was estimated to receive 486,910 containers per year.
- The base-model result with the only 7.8% difference in the number of shipped containers compared to the calculated annual expected number of shipped items validates the accuracy of the base-model.

Section 5.2 improved the previous base-model into two different scenarios to upgrade it and to efficiently increase the number of shipped items in the terminals and handle the increasing volume demands placed on them. This impending overflow challenge was made even more difficult by the fact that many ports will need to handle this increased volume without increasing available physical space. This study was carried out to assess the potential of an optimization-based simulation in increasing intermodal terminal capacity from the operational perspective.

For this purpose, an optimization-based simulation was named the WITNESS Simulator, which focuses on building simulation models in highly productive ways. This WITNESS Simulator was used to test different terminal layouts. After running the model with input datasets, the report results were analyzed to evaluate the effectiveness of each scenario layout on system operational performance and subsequently the number of shipped items from the Port of Houston to intermodal inland terminal.

The results in Section 5.2 indicate that from the viewpoint of operational performance:

- Model results show that the total number of shipped items (unloaded containers) for an intermodal terminal designed for Scenario No. 2 without a stack-yard is 775,936 items for 525,600 minutes or 365 days a year.
- The estimated total number of shipped cargo in Section 5.2 is 34%–59% more than the annual expected shipped items equal to 486,910.
- The calculated total number of shipped items in Section 5.2 had a lower average cycle time (60 seconds), which is 46%–73% more than the number of shipped items in the base-model in Section 5.1 which is estimated at around 448,957.
- The number of shipped containers as a system output for scenario two (without stack-yard, nonstop cargo transfer from platforms to trucks) in Section 5.2 is significantly more than Scenario No. 1 with a stack yard which is equal to 654,247 containers per year.

- The number of shipped containers as a system output for both scenarios in Section 5.2 is significantly more than in Section 5.1 (base-model) with the higher average cycle time of 90 seconds.
- The number of shipped items in Scenario No. 2 for the optimized model in Section 5.2 (without stack-yard) is 59% more than the annual expected shipped items.
- The number of shipped containers in Scenario No. 2 is 46% more than the calculated number of shipped items per year for the base-model in Section 5.1.
- The results of both models (base-model and optimized-model) signify that an increasing trend in the annual number of shipped items is more affected by the average cycle time.
- Comparing Scenario No. 1 and Scenario No. 2 shows that the stack-yard effect is considerable in increasing the annual number of shipped items.
- The number of shipped containers in Scenario No. 2 in Section 5.2—the intermodal container terminal without stack-yard—is significantly more than Scenario No. 1 with stack-yard.
- Model results show that the parameter of a stack-yard is a sensitive factor in the UFT terminal operations performance. Additionally, model results are very sensitive to the parameter of cycle time, speed and headway.

Considering all of the above, the results of this simulated model illustrate that Scenario No. 2—the intermodal container terminal without a stack-yard—is more practical than Scenario No. 1 with a stack-yard for containers between platforms and available trucks.

This type of descriptive simulation results could allow us to investigate and look at things like time-based availability of resources, crew break time, alternative scheduling strategies or prioritizing performance, and its impact on operations.

6.1 Limitations of this Research

Based on a conceptual case study, this research developed a simulation-optimization method to improve the performance of the UFT intermodal terminal operations and increase the number of annual shipped containers. Reviewing literature in the area of intermodal terminal optimization did not show any comprehensive research for operation optimization of the underground freight transportation terminals as an innovative technology in transferring freight. Most of the available studies are connected to railroad transportation and truck companies. The biggest limiting factor for expanding research goals and implementing modeling task was inadequate available data sources. However the investigation of the impact of incorporating different real-world operational parameters was the goal of this dissertation even though real-world data has simply not been available.

6.2 Recommendations for Future Research

The development of the simulation-optimization framework opens many possibilities for future research in the intermodal terminal field, related potentially to future work based on this study's analysis and results. Some recommendations are posed as follows.

- First, consideration of the crews' break time for lunch at two different times.

There is a potential for increasing the intermodal terminal's performance if we schedule our laborers' lunch time at two different hours for two different groups of crew members, and define it as two shifts for our simulation model. Our crews work 8-hour shifts and can choose from three schedules in the 24-hour work day. Future researchers can further investigate this type of scheduling for crews and could use simulation tools to measure the labor performance and productivity and compare it with the regular schedules what were studied in current research.

- Second, consideration of the constraints in this research such as track availability.

In order to apply the simulation model in a case study for an intermodal underground freight terminal in chapter 5, two scenarios were defined. Both case scenarios for terminal with stack-yard and terminal without stack-yard, truck availability was always an option as an assumption in order to focus on stack-yard components in setting our simulated model. This underlining assumption for the availability of trucks on both sides (loading and unloading) to pick the container up and go back to deliver it to customers does not happen in the real world due to so many constraints. It can be a good potential for future research to consider these constraints in their studies. Major constraints to be considered include trucks breaking down, which must be towed to a truck repair shop and drivers having to be called in due to the incoming driver has reached or almost reached the required number of hours he or she can drive before being made to stop since their driving time is up.

- Third, consideration of the sorting process for containers in a terminal.

Picking the right container, putting it in the right truck, and sending to the right customer through an intermodal terminal requires a container sorting process that current research did not consider. Future research should look at Qualcomm or alternative means of interaction with the trucking companies, truckers and terminal operators so the best routes can be planned ahead and the terminal can know ahead of time how many trucks are incoming and their estimated time of arrival.

- Fourth, consideration of using innovative technologies in the terminal yard and at terminal platforms or docks.

Innovative technology is the most logical and labor-saving way to survive increasing worldwide shipping traffic. New innovations including artificial intelligence and robots can contribute to intermodal terminals to make a difference. Robots can largely perform tasks such as lifting and stacking containers in a terminal stack-yard in an organized way and at the specific required time. Some robotic (machines) handlers will pick a container up—no human operators required—and load it onto a waiting truck with better organization than humans. Automating activities once handled by human operators improves terminal productivity by reducing wait time. Robots also do not need weekends, breaks, or health insurance.

However, even though this dissertation’s goal was to investigate the impact of incorporating different real-world operational parameters, real-world data is simply not available. The case study results are not generalized based upon this research data set for the final design; thus, different data may result in other outcomes. When operating an intermodal facility, there are capacity issues that impact costs and level of service capabilities. Simulation models that were used in this study are valuable tools created to benefit designers and operators when analyzing complicated intermodal systems and their capability to calculate or validate estimated demand volumes. Simulation is a tool that has a broad applicability for these problems, and it can assist in the promotion of a project idea to funding organizations. In this case, it is refined concepts during the early design phase and during the continued operation of a surviving facility.

Appendix A

Freight Transportation Modes and Terminal Layout

Table A-1 Top U.S. Foreign Trade Freight Gateways by Value of Shipments (2015- 2016 $ billions), (USDOC, 2017)

Gateway	Type	2016				2015			
		Rank	Exports	Imports	Total	Rank	Exports	Imports	Total
Los Angeles, CA	Water	1	33.8	176.0	209.8	2	31.4	166.9	198.4
Laredo, TX	Water	2	88.3	104.9	193.2	3	91.2	106.1	197.2
New York, NY	Land	3	42.5	144.7	187.3	1	46.9	155.8	202.6
John F. Kennedy International Airport, NY	Air	4	87.7	96.1	183.9	4	90.4	95.0	185.5
Long Beach, CA	Water	5	31.2	119.0	150.2	5	31.0	123.3	154.2
Chicago, IL	Air	6	44.8	98.7	143.5	6	45.7	96.0	141.8
Detroit, MI	Water	7	69.8	60.3	130.1	8	70.0	58.9	128.9
Houston, TX	Land	8	62.6	49.2	111.8	7	75.9	58.7	134.6
Los Angeles International Airport, CA	Air	9	50.5	50.7	101.2	9	49.0	50.9	99.9
Savannah, GA	Water	10	23.5	59.2	82.7	10	25.8	61.5	87.3
Port Huron, MI	Land	11	36.5	41.3	77.8	11	36.9	40.9	77.9
Buffalo-Niagara Falls, NY	Land	12	41.6	34.7	76.3	12	41.6	36.0	77.6
Norfolk, VA	Water	13	27.8	44.3	72.1	14	30.8	43.0	73.8
New Orleans, LA	Water	14	30.1	40.1	70.3	15	30.1	37.9	68.0
Charleston, SC	Air	15	25.5	44.2	69.7	13	27.6	47.9	75.6
El Paso, TX	Land	16	30.4	38.5	68.9	16	30.3	37.2	67.5
Miami International Airport, FL	Air	17	31.6	25.6	57.1	18	32.1	20.7	52.8
San Francisco International Airport, CA	Air	18	26.8	27.7	54.5	17	25.3	27.6	52.9
Tacoma, WA	Air	19	9.0	45.4	54.4	21	9.0	42.4	51.3
Anchorage, AK	Air	20	13.7	38.1	51.8	20	13.6	38.6	52.2
Dallas-Fort Worth, TX	Water	21	21.3	29.6	51.0	19	20.6	32.1	52.7
Baltimore, MD	Water	22	14.0	35.8	49.8	22	15.4	35.8	51.2
Cleveland, OH	Air	23	28.1	20.6	48.7	23	25.2	23.3	48.5
Oakland, CA	Water	24	18.4	27.8	46.2	24	17.6	26.3	43.9
Otay Mesa, CA	Land	25	15.0	27.0	42.0	25	14.4	28.1	42.5
Atlanta, GA	Air	26	14.6	24.7	39.3	26	13.5	23.0	36.4
New Orleans, LA	Water	27	19.9	12.6	32.5	27	19.2	13.8	33.0
Hidalgo, TX	Land	28	10.3	19.0	29.3	28	10.6	18.4	29.0
Eagle Pass, TX	Land	29	8.1	21.0	29.1	30	8.0	18.1	26.1
Nogales, AZ	Land	30	10.1	16.0	26.2	29	11.4	15.8	27.2
Miami, FL	Water	31	9.3	14.3	23.6	32	10.1	14.7	24.8
Jacksonville, FL	Water	32	6.1	17.5	23.6	33	8.2	15.7	23.9
Santa Teresa, NM	Water	33	10.7	11.8	22.4	35	10.1	11.7	21.8
Port Everglades, FL	Land	34	11.8	10.4	22.3	31	13.4	12.0	25.4
Champlain-Rouses Point, NY	Land	35	8.2	12.9	21.1	36	8.2	13.3	21.5
Pembina, ND	Land	36	12.1	8.6	20.7	34	13.8	9.1	22.9
Seattle, WA	Water	37	7.6	12.5	20.1	37	7.1	13.8	20.9
Blaine, WA	Water	38	10.8	8.5	19.4	39	11.5	8.3	19.7
Newark, NJ	Land	39	4.6	14.2	18.9	42	4.3	13.6	17.9
Seattle-Tacoma International Airport, WA	Water	40	8.8	9.2	18.0	47	8.9	7.4	16.4
Brunswick, GA	Water	41	6.0	12.0	18.0	38	5.8	14.5	20.3
Gramercy, LA	Air	42	13.1	3.8	16.9	40	14.2	4.5	18.7
Philadelphia, PA	Water	43	2.8	13.5	16.4	41	3.4	15.0	18.4
Logan Airport, MA	Air	44	6.2	9.6	15.8	46	6.0	11.1	17.0
Logan Airport, MA	Land	45	4.9	10.8	15.7	51	4.9	10.5	15.4
Corpus Christi, TX	Air	46	10.2	5.4	15.5	43	10.5	7.1	17.6
Calexico-East - California	Air	47	6.1	9.4	15.5	48	6.5	9.7	16.2
San Juan International Airport, PR	Land	48	8.6	6.2	14.8	44	10.5	6.9	17.4
Chicago, IL	Land	49	0.0	14.4	14.4	45	0.0	17.3	17.3
Houston Intercontinental Airport, TX	Water	50	8.6	5.6	14.2	52	9.2	5.9	15.1
Total top 50 gateways[a]			**1,124.2**	**1,783.7**	**2,907.9**		**1,158.9**	**1,800.9**	**2,959.9**

Table A-2 Total Domestic, Export, and Import Goods Movements by Different Modes of Freight Transportation in U.S. from 2012 to 2045 (USDOC, 2017)

	2012	2012	2012	2012	2015	2015	2015	2015	2045	2045	2045	2045
Millions of tons	Total	Domestic	Exports1	Imports1	Total	Domestic	Exports1	Imports1	Total	Domestic	Exports1	Imports1
Total	16,953	14,953	864	1,136	18,056	16,045	912	1,099	25,345	20,914	2,190	2,241
Truck	10,166	9,970	107	89	10,859	10,649	110	100	14,866	14,270	291	305
Rail	1,613	1,487	52	74	1,607	1,458	54	85	1,921	1,597	108	216
Water	933	506	68	359	936	553	94	289	1,158	614	189	355
Air, air & truck	10	2	4	4	11	2	4	5	38	4	16	18
Multiple modes	1,320	311	596	413	1,353	327	613	412	2,971	434	1,519	1,018
Pipeline	2,870	2,641	36	194	3,258	3,017	37	204	4,361	3,978	63	319
Other	41	37	1	3	33	29	1	3	31	16	4	11

Table A-3 Value of Monthly U.S.-Canada Freight Flows in millions of 2017-2018 dollars (BTS, 2018)

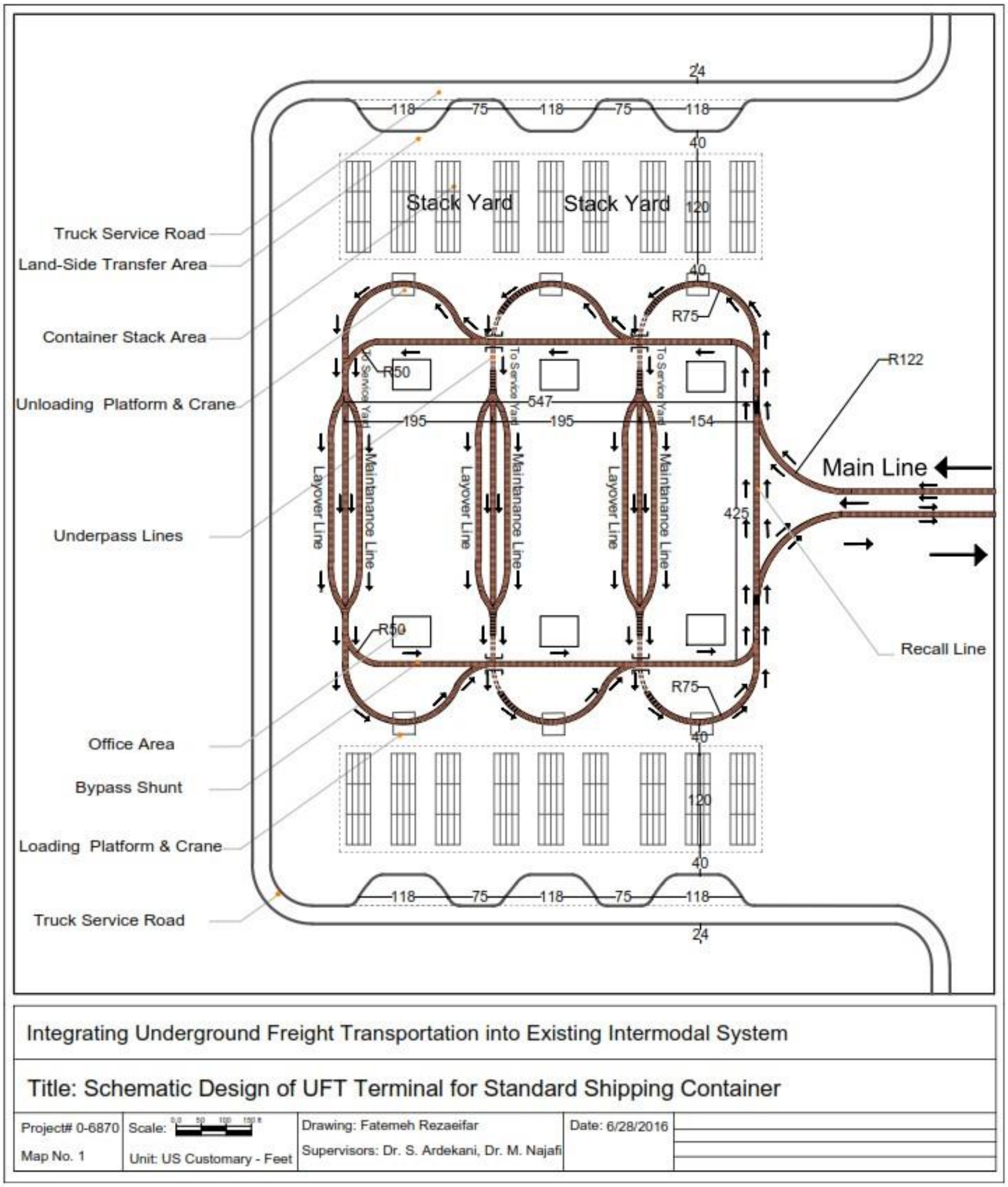
Mode		March 2017	March 2018	Percent Change March 2017-2018
All Modes	Imports	26,293	26,798	1.9
	Exports	24,920	27,104	8.8
	Total	51,213	53,902	5.3
All Surface Modes	Imports	23,388	23,618	1.0
	Exports	20,449	22,030	7.7
	Total	43,837	45,647	4.1
Truck	Imports	13,166	13,287	0.9
	Exports	16,767	17,781	6.0
	Total	29,934	31,068	3.8
Rail	Imports	5,451	5,824	6.8
	Exports	2,830	3,365	18.9
	Total	8,281	9,188	11.0
Pipeline	Imports	4,770	4,507	-5.5
	Exports	852	884	3.8
	Total	5,622	5,391	-4.1
Vessel	Imports	1,105	1,225	10.8
	Exports	390	751	92.3
	Total	1,496	1,976	32.1
Air	Imports	1,002	1,089	8.7
	Exports	1,481	1,597	7.9
	Total	2,483	2,686	8.2

Table A-4 Value of Monthly U.S.-Mexico Freight Flows by Mode of Transportation in millions of 2017-2018 dollars (BTS, 2018)

Mode		February 2017	February 2018	Percent Change February 2017-2018
All Modes	Imports	28,054	29,959	6.8
	Exports	21,022	21,906	4.2
	Total	49,076	51,865	5.7
All Surface Modes	Imports	24,466	25,454	4.0
	Exports	17,315	17,307	0.0
	Total	41,780	42,762	2.3
Truck	Imports	19,443	20,848	7.2
	Exports	14,531	14,627	0.7
	Total	33,974	35,475	4.4
Rail	Imports	5,006	4,595	-8.2
	Exports	2,530	2,341	-7.5
	Total	7,536	6,936	-8.0
Pipeline	Imports	16	11	-32.0
	Exports	254	340	34.0
	Total	270	351	30.0
Vessel	Imports	2,060	2,864	39.0
	Exports	2,031	3,106	52.9
	Total	4,092	5,970	45.9
Air	Imports	652	737	12.9
	Exports	980	793	-19.1
	Total	1,632	1,529	-6.3

Table A-5 Flow of Goods Through States on the U.S.-Mexico Border by All Modes of Transportation Ranked by 2017 Value, (millions of current dollars) (BTS, 2018)

State	2016		2017		Percent Change 2016 - 2017
	Value	Rank	Value	Rank	
Texas	364,798	1	390,137	1	6.9
California	63,365	2	66,157	2	4.4
Arizona	30,221	3	27,949	3	-7.5
New Mexico	22,861	4	22,277	4	-2.6



Integrating Underground Freight Transportation into Existing Intermodal System

Title: Schematic Design of UFT Terminal for Standard Shipping Container

Project# 0-6870	Scale:	Drawing: Fatemeh Rezaeifar	Date: 6/28/2016	
Map No. 1	Unit: US Customary - Feet	Supervisors: Dr. S. Ardekani, Dr. M. Najafi		

Figure A-1 Terminal Layout and Dimensions for Vehicles (Gondolas) Carrying Standard Shipping Containers (Najafi et al., 2016).

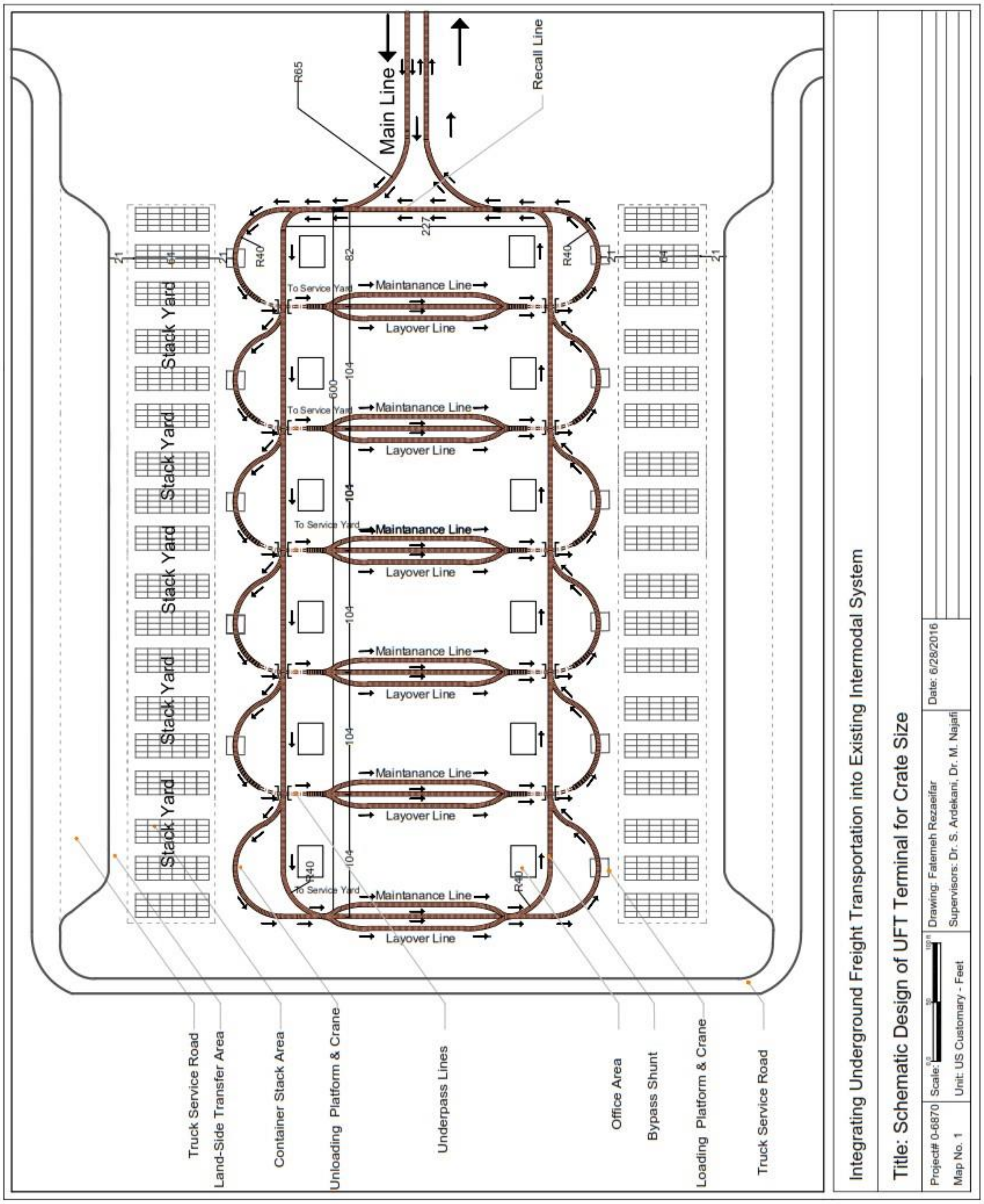


Figure A-2 Terminal Layout and Dimensions for Capsules Carrying Crates (Najafi et al., 2016).

Appendix B

Model Development Tables and Resources

Model Development Tables

Table B-1 Define Part

Define Part Elements for Model		
Gondola	Unload Container	Container

Table B-2 Define Buffer

Define Buffer Elements for Model				
S1_78kft_45mph01	UnLoadYard_03	LoadYard_01	Buffers005	Buffers009
S1_78kft_45mph	Buffers001	LoadYard_02	Buffers006	
UnLoadYard_01	Buffers002	LoadYard_03	Buffers007	
UnLoadYard_02	Buffers003	Buffers004	Buffers008	

Table B-3 Define Labor

Define Labor Elements for Model		
OffTruckForkLift_002	LoadGondForkLift_003	OnTruckForkLift_003
LoadGondForkLift_002	OnTruckForkLift_002	UnloadGondForkLift_001
OnTruckForkLift_001	OffTruckForkLift_001	UnloadGondForkLift_002
OffTruckForkLift_003	LoadGondForkLift_001	UnloadGondForkLift_003

Table B-4 Define Machine

Define Machine Elements for Model				
Machine006	Machine036	Machine014	DropOff_03	PickUp_06
Machine007	Machine040	Load_02	DropOff_04	Machine027
UnLoad_02	Machine041	Machine015	Load_01	Machine029
Machine034	Machine042	TruckUnload_02	PickUp_01	Machine022
Machine008	UnLoad_03	Machine016	Machine021	Machine023
UnLoad_01	Machine044	Load_01	DropOff_05	Machine030
Slow Down	Machine010	TruckUnload_03	Machine024	Machine031
Speed Up	Machine045	TruckLoad_02	DropOff_06	Machine032
SlowDown2	Machine011	Machine018	PickUp_02	Machine033
MPH45_2	TruckLoad_01	TruckLoad_03	PickUp_03	
MPH45_1	Machine046	DropOff_01	Machine026	
Machine035	Machine013	DropOff_02	PickUp_04	
Load_03	TruckUnload_01	Machine019	PickUp_05	

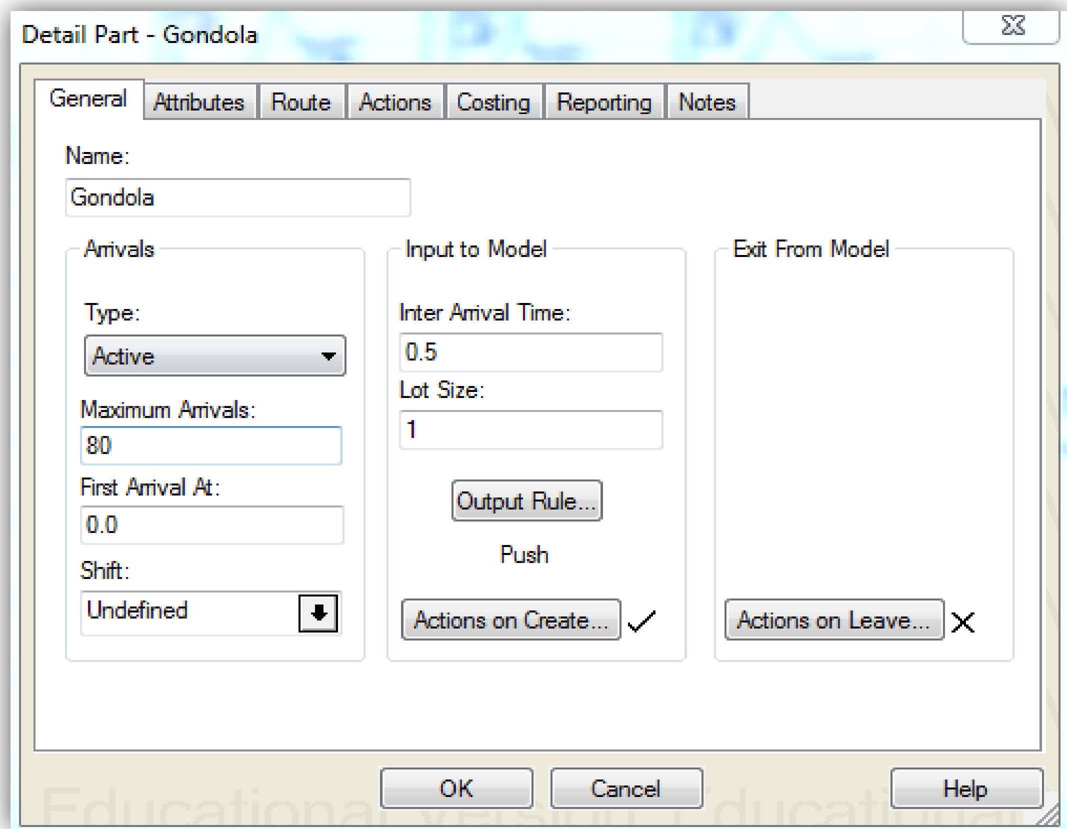
Table B-5 Define Shift

Define Shift Element for Model
Shift_for_24_Hour_Day

- Detail Part

  NAME OF PART: Gondola;

  OUTPUT RULE: PUSH to S1_78kft_45mph;



Detail Part - Gondola

Name: Gondola

Arrivals

Type: Active

Maximum Arrivals: 80

First Arrival At: 0.0

Shift: Undefined

Input to Model

Inter Arrival Time: 0.5

Lot Size: 1

Output Rule... Push

Actions on Create... ✓

Exit From Model

Actions on Leave... ✗

Figure B-1 Detail Part

- Detail Buffer

NAME OF BUFFER: S1_78kft_45mph;

QUANTITY: 1;

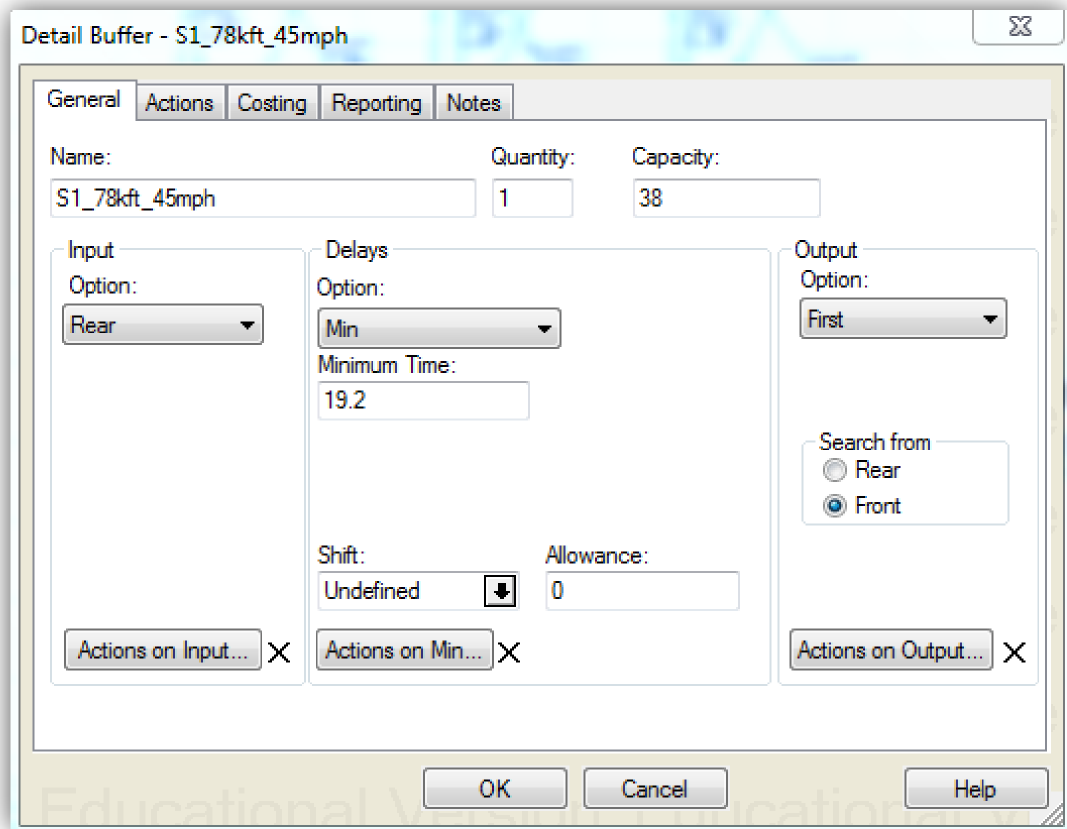
CAPACITY: 38;

DELAY MODE : Min;

Minimum Time : 19.2;

INPUT POSITION: Rear;

OUTPUT POSITION: First;



Detail Buffer - S1_78kft_45mph

Name: S1_78kft_45mph

Quantity: 1

Capacity: 38

Input

Option: Rear

Delays

Option: Min

Minimum Time: 19.2

Shift: Undefined

Allowance: 0

Output

Option: First

Search from

○ Rear

● Front

Figure B-2 Detail Buffer

- Detail Machine

NAME OF MACHINE: Machine006

QUANTITY: 1;

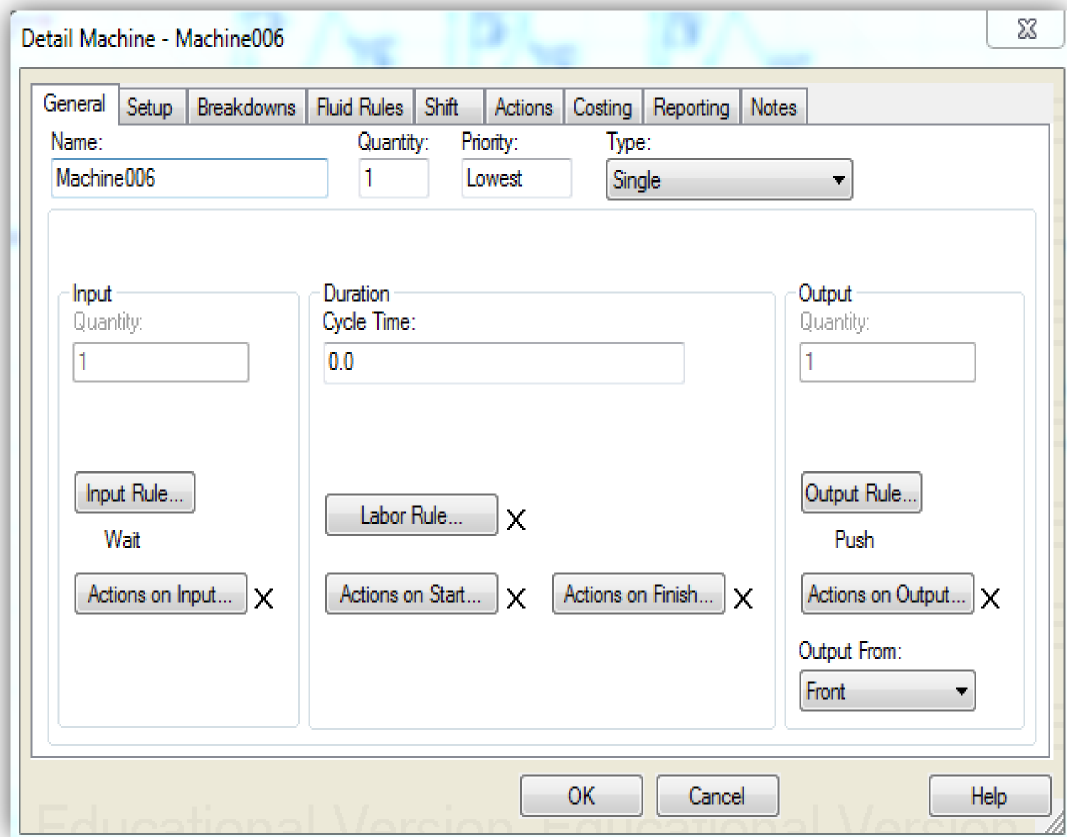
PRIORITY: Lowest;

TYPE: Single;

INPUT QUANTITY: 1;

INPUT RULE: Wait;

OUTPUT RULE: PUSH to Speed Up(1);


Detail Machine - Machine006

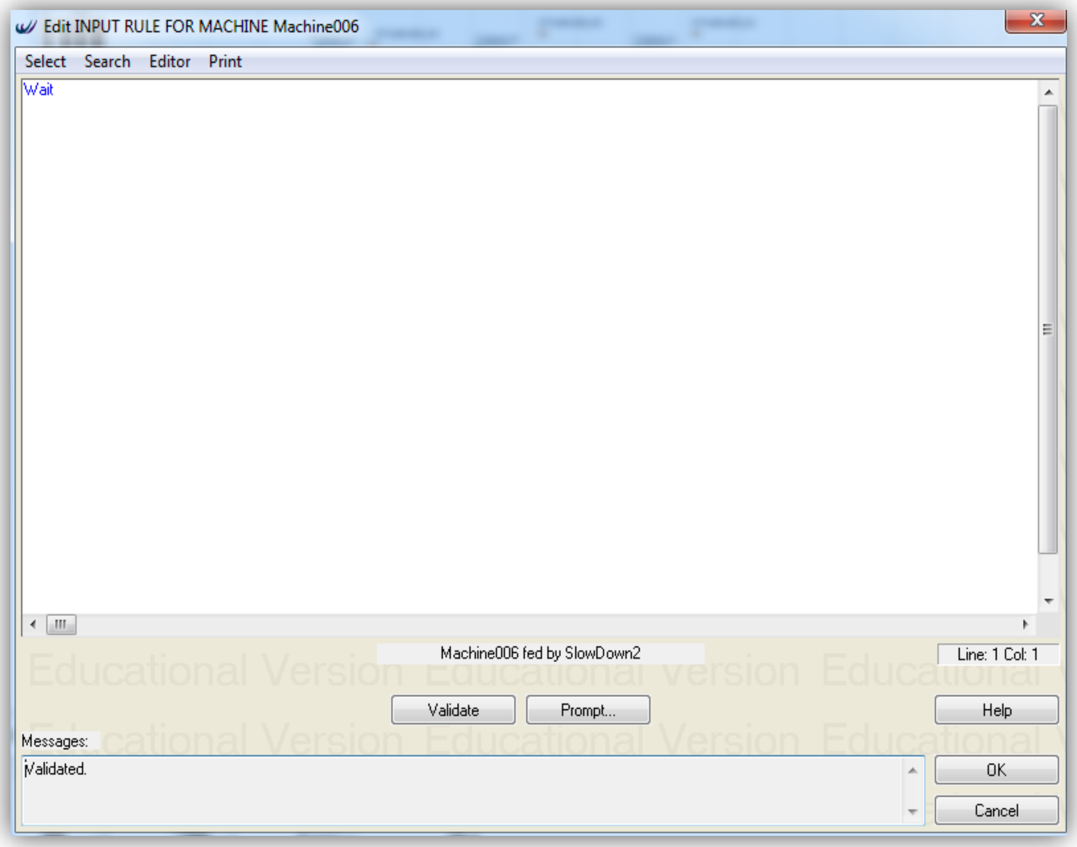
Name: Machine006
Quantity: 1
Priority: Lowest
Type: Single

Input
Quantity: 1
Wait

Duration
Cycle Time: 0.0

Output
Quantity: 1
Push
Output From: Front

Figure B-3 Detail Machine006



```
Wait
```

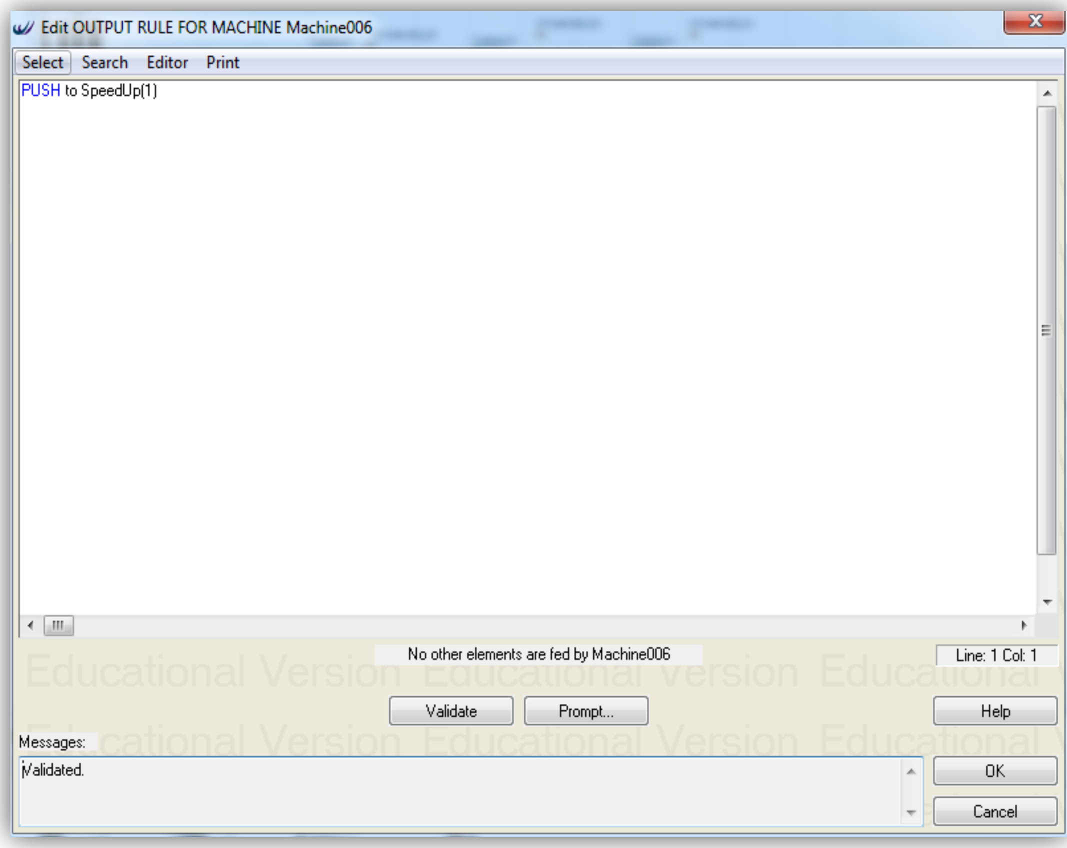
Machine006 fed by SlowDown2

Line: 1 Col: 1

Messages:

Validated.

Figure B-4 Input Rule for Machine 006



```
PUSH to SpeedUp(1)
```

No other elements are fed by Machine006

Validated.

Figure B-5 Output Rule for Machine006

- Detail Machine

NAME OF MACHINE: MPH45_1

QUANTITY: 1;

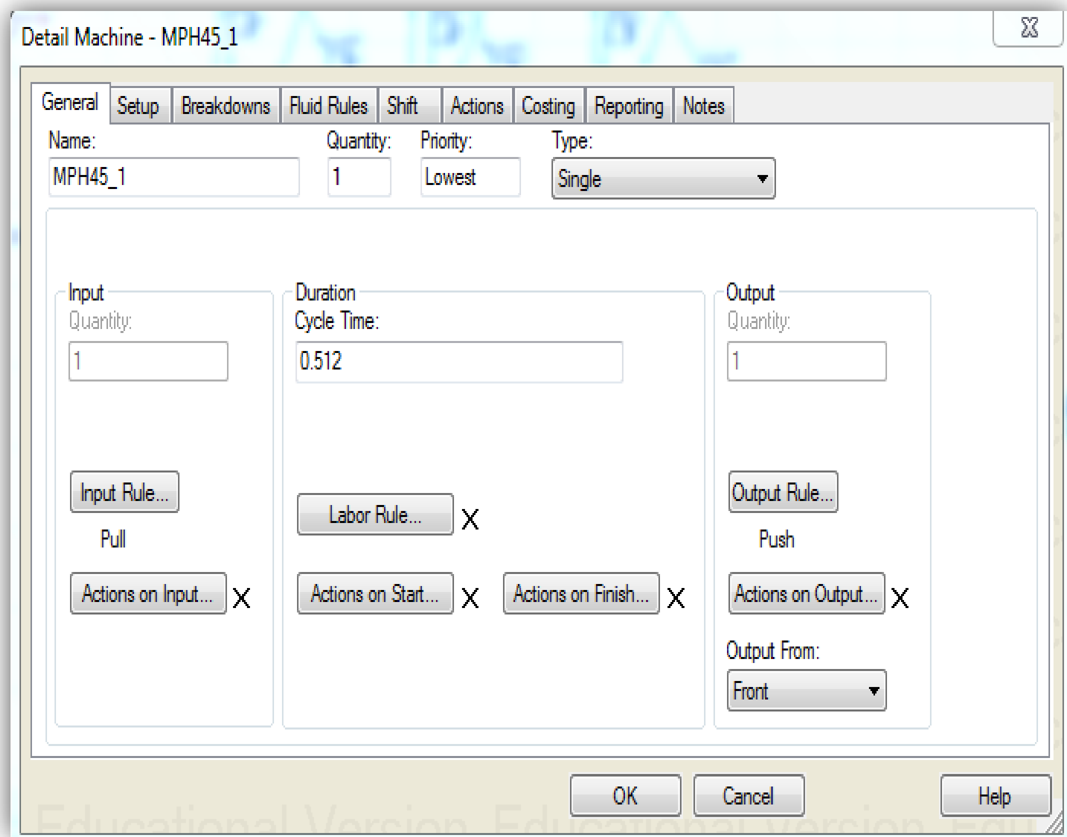
PRIORITY: Lowest;

TYPE: Single;

INPUT QUANTITY: 1;

INPUT RULE: PULL from S1_78kft_45mph;

OUTPUT RULE: PUSH to Speed Down;



Detail Machine - MPH45_1

Name: MPH45_1

Quantity: 1

Priority: Lowest

Type: Single

Input

Quantity: 1

Pull

Duration

Cycle Time: 0.512

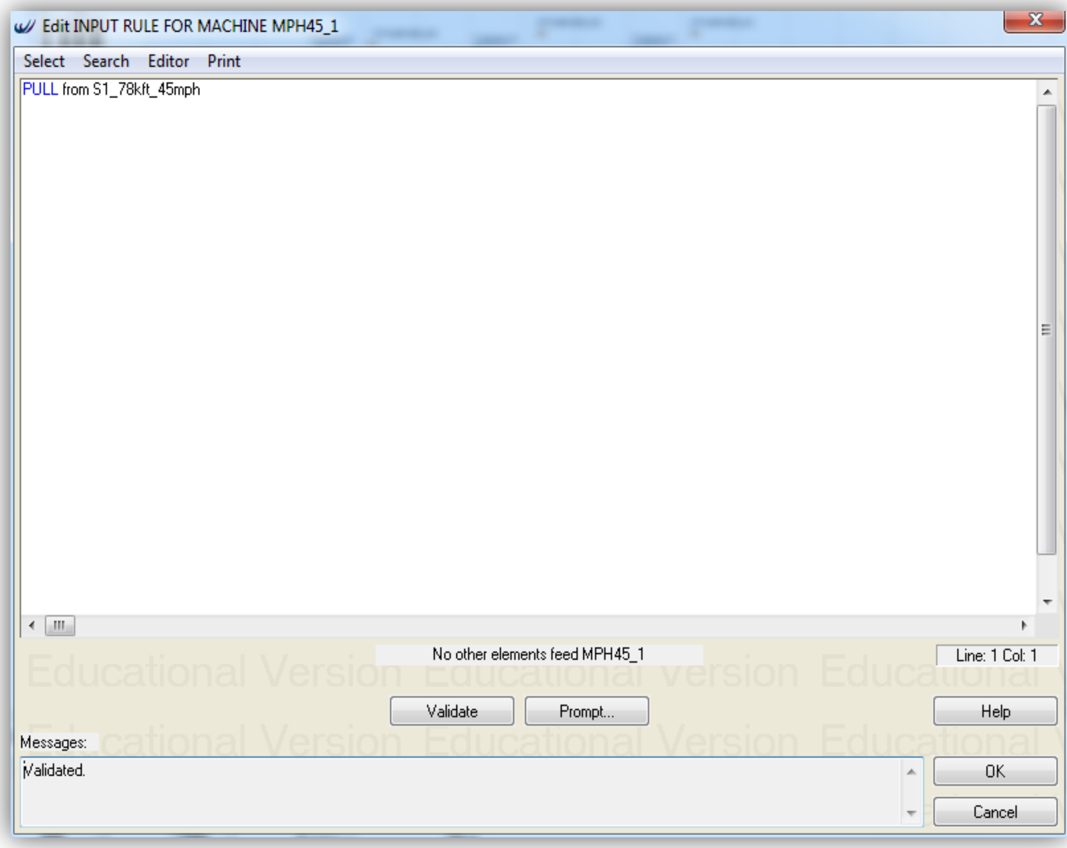
Output

Quantity: 1

Push

Output From: Front

Figure B-6 Detail Machine MPH45_1



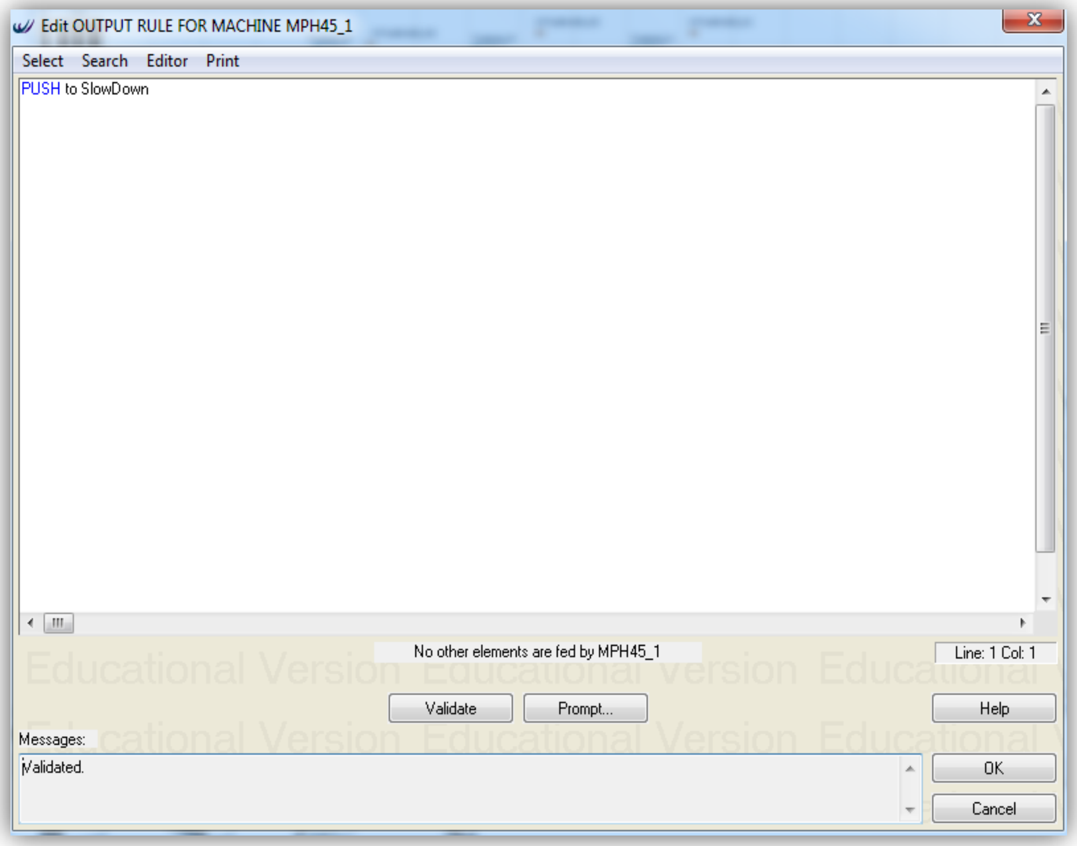
```
PULL from S1_78kft_45mph
```

No other elements feed MPH45_1

Line: 1 Col: 1

Validated.

Figure B-7 Input Rule for Machine MPH45_1



```
PUSH to SlowDown
```

No other elements are fed by MPH45_1

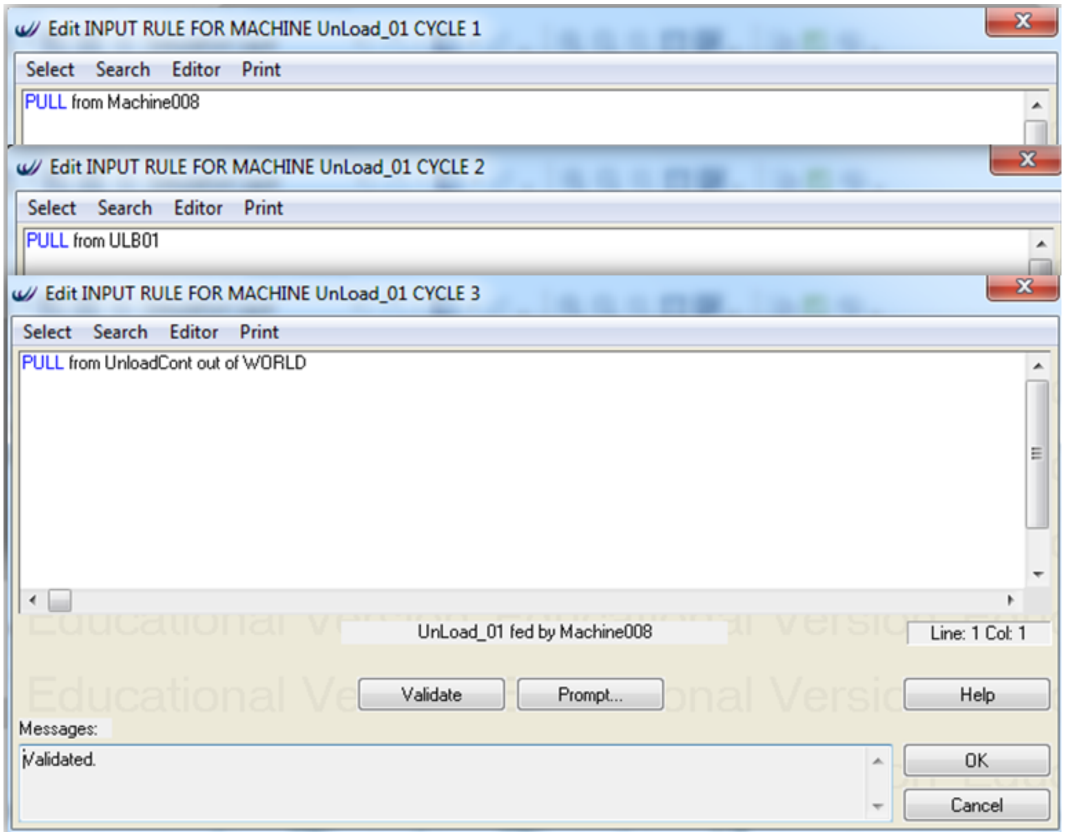
Messages:

Validated.

Figure B-8 Output Rule for Machine MPH45_1

- Detail Machine

```
NAME OF MACHINE: Unload_01
QUANTITY: 1;
PRIORITY: Lowest;
TYPE: Multiple Cycle;
INPUT QUANTITY: 1;
INPUT RULE FOR CYCLE 1: PULL from Machine008;
INPUT RULE FOR CYCLE 2: PULL from ULB01;
INPUT RULE FOR CYCLE 3: PULL from Unload Container out
of WORLD;
OUTPUT RULE FOR CYCLE 1: Wait;
OUTPUT RULE FOR CYCLE 2: Wait;
OUTPUT RULE FOR CYCLE 3: !PUSH to Gondola to
Machine010,UnloadCont to DropOff_01;
!
IF TYPE = Gondola
PUSH to Machine010
ELSEIF NParts [TLB01] <= 1
PUSH to TLB01
ELSE
Wait
ENDIF
```



PULL from Machine008

PULL from ULB01

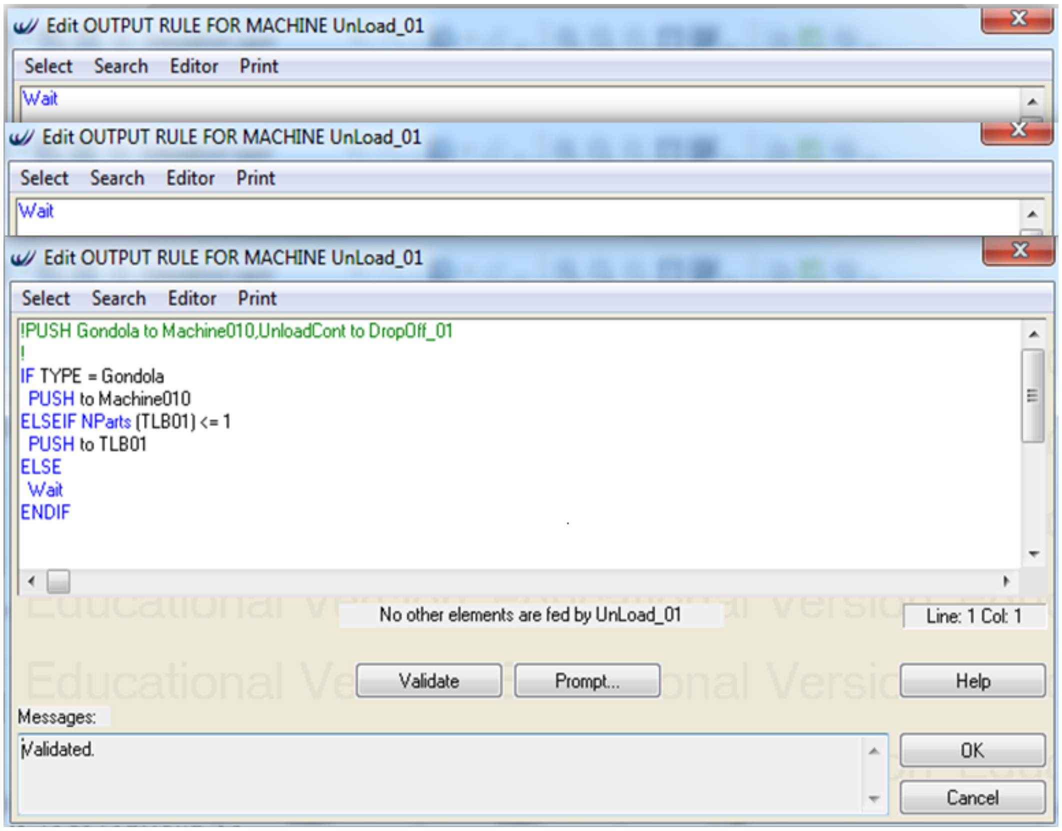
PULL from UnloadCont out of WORLD

UnLoad_01 fed by Machine008

Line: 1 Col: 1

Validated.

Figure B-9 Input Rule for Multiple Cycle Machine Unload_01



```
Wait
```

```
Wait
```

```
!PUSH Gondola to Machine010,UnloadCont to DropOff_01
!
IF TYPE = Gondola
 PUSH to Machine010
ELSEIF NParts (TLB01) <= 1
 PUSH to TLB01
ELSE
 Wait
ENDIF
```

No other elements are fed by UnLoad_01

Line: 1 Col: 1

Messages:

Validated.

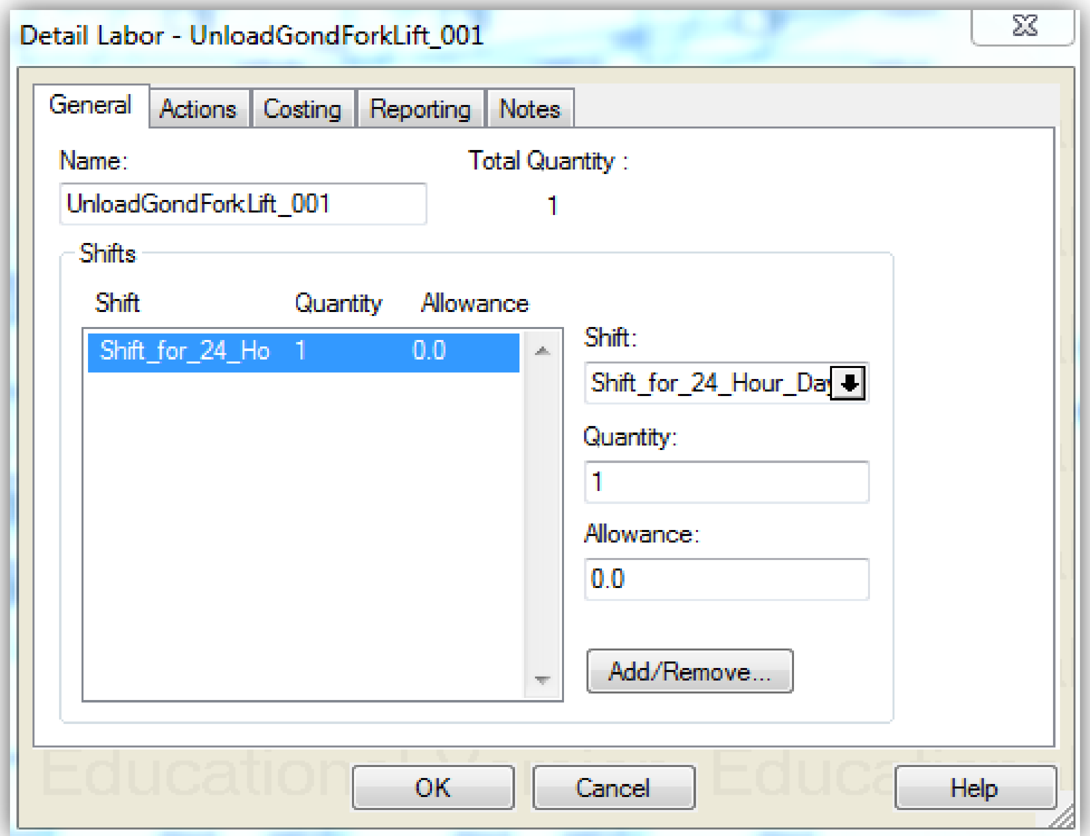
Figure B-10 Output Rule for Multiple Cycle Machine Unload_01

- Detail Labor

NAME OF LABOR: UnloadGondForkLift_001

Quantity: 1

SHIFT: Shift_for_24_Hour_Day



Name: UnloadGondForkLift_001

Total Quantity : 1

Shifts

Shift	Quantity	Allowance
Shift_for_24_Ho	1	0.0

Shift: Shift_for_24_Hour_Day

Quantity: 1

Allowance: 0.0

Figure B-11 Detail Labor. This spread sheet set up shows all of the information that can be collected on an underground transportation freight terminal-employed forklift operator.

Appendix C

Results Table and Graphical Illustrations Charts Simulation Results Analysis in WITNESS^{TM}

(Lanner Group, 2016)

Statistics Results Tables for Base-Model

Table C-1 Intermodal UFT Terminal Machine Statistics for Base-Model

Machine Statistics Report by On Shift Time					
Name	**% Idle**	**% Busy**	**% Blocked**	**% Cycle Wait Labor**	**No. Of Operations**
Machine007	18.86	11.55	69.6	0	449,514
UnLoad_02	0.02	42.76	2.85	54.37	149,833
Machine034	3.31	2.44	94.26	0	64,005
Machine008	3.44	5.7	90.86	0	149,817
UnLoad_01	0.01	42.76	2.9	54.33	149,816
Slow Down	22.1	23.35	54.55	0	449,514
Speed Up	69.31	23.34	7.34	0	449,454
SlowDown2	71.12	23.34	5.54	0	449,454
MPH45_2	51.66	43.78	4.56	0	449,454
MPH45_1	14.71	43.79	41.5	0	449,515
SpeedUp2	76.65	23.35	0	0	449,475
Machine006	93.47	0	6.53	0	449,454
Machine035	11.23	1.84	86.93	0	48,476
Load_03	51.14	42.76	0	6.1	149,804
Machine036	26.74	1.42	71.84	0	37,328
Machine040	32.81	1.31	65.89	0	34,352
Machine041	1.68	2.44	95.88	0	64,128
Machine042	10.08	1.95	87.97	0	51,349
UnLoad_03	0.62	42.75	2.76	53.87	149,857
Machine044	29.58	1.36	69.06	0	35,826
Machine010	75.28	9.69	15.03	0	149,815
Machine045	3.36	2.51	94.14	0	65,931
Machine011	1.39	9.69	88.92	0	149,806
TruckLoad_01	48.21	42.69	0	9.1	149,633
Machine046	12.93	1.83	85.24	0	48,094
Machine013	94.13	5.7	0.17	0	149,804
TruckUnload_01	0	42.76	0.15	57.09	149,848
Machine014	87.3	11.54	1.16	0	449,475
Load_02	50.98	42.76	0	6.25	149,825
Machine015	11.11	19.39	69.5	0	299,696
TruckUnload_02	0	42.77	0.16	57.08	149,827
Machine016	3.72	6.84	89.44	0	149,835
Load_01	51.2	42.75	0	6.05	149,846
TruckUnload_03	0	42.77	0.15	57.08	149,806
TruckLoad_02	48.42	42.7	0	8.88	149,650
Machine018	76.63	10.55	12.82	0	149,833

TruckLoad_03	48.79	42.69	0	8.52	149,674
DropOff_01	17.06	42.77	33.42	6.76	149,815
DropOff_02	16.83	42.75	34.11	6.31	149,832
Machine019	0.61	8.55	90.84	0	149,827
DropOff_03	17.45	42.75	33.71	6.09	149,856
DropOff_04	49	42.77	0	8.24	149,847
PickUp_01	0	42.69	0.17	57.14	149,634
Machine021	95	4.45	0.56	0	149,825
DropOff_05	48.45	42.76	0	8.79	149,826
Machine024	3.08	7.41	89.5	0	149,859
DropOff_06	48.48	42.76	0	8.76	149,805
PickUp_02	0	42.72	0.15	57.13	149,651
PickUp_03	0.01	42.71	0.15	57.13	149,675
Machine026	75.13	11.4	13.47	0	149,857
PickUp_04	35.84	42.76	0.03	21.38	149,847
PickUp_05	36.03	42.75	0.03	21.2	149,825
PickUp_06	36	42.75	0.03	21.22	149,805
Machine027	1.33	8.55	90.12	0	149,848
Machine029	92.59	7.41	0	0	149,846
Machine022	80.4	19.39	0.21	0	299,671
Machine023	7.29	12.26	80.45	0	149,860
Machine030	87.18	12.26	0.56	0	149,846
Machine031	100	0	0	0	0
Machine032	100	0	0	0	0
Machine033	100	0	0	0	0

Table C-2 Intermodal UFT Terminal Machine Statistics for Scenario Number One Report by On Shift Time

Machine Statistics Report by On Shift Time

Name	% Idle	% Busy	% Blocked	% Cycle Wait Labor	No. Of Operations
Machine007	60.95	16.82	22.24	0	654,672
UnLoad_02	0.88	42.04	4.56	52.51	221,001
Machine034	11.27	4.98	83.75	0	130,871
Machine008	14.64	8.41	76.94	0	221,074
UnLoad_01	0.35	42.06	4.58	53	221,072
Slow Down	48.42	34	17.58	0	654,673
Speed Up	54.47	34	11.53	0	654,621
SlowDown2	54.86	34	11.13	0	654,622
MPH45_2	25.84	63.77	10.39	0	654,622
MPH45_1	21.52	63.77	14.71	0	654,673
SpeedUp2	66	34	0	0	654,648
Machine006	87.87	0	12.13	0	654,622
Machine035	33.46	2.32	64.21	0	61,072
Load_03	52.27	42.06	0	5.68	221,061
Machine036	61.8	1.11	37.1	0	29,123
Machine040	75.55	0.71	23.74	0	18,748
Machine041	16.87	5.69	77.44	0	149,638
Machine042	46.09	2	51.91	0	52,613
UnLoad_03	21.44	40.44	1.41	36.71	212,594
Machine044	96.42	0.11	3.47	0	2,857
Machine010	80.31	14.3	5.39	0	221,072
Machine045	62.98	7.49	29.52	0	196,874
Machine011	5.42	14.3	80.28	0	221,063
TruckLoad_01	47.94	42	0	10.05	220,890
Machine046	87.97	0.49	11.54	0	12,863
Machine013	91.23	8.41	0.36	0	221,061
TruckUnload_01	0	40.46	0.19	59.35	212,644
Machine014	80.67	16.81	2.51	0	654,649
Load_02	51.82	42.07	0	6.11	220,996
Machine015	49.05	28.05	22.9	0	433,598
TruckUnload_02	0	42.08	0.1	57.81	220,998
Machine016	22.78	10.09	67.13	0	221,003
Load_01	52.97	40.43	0	6.6	212,593
TruckUnload_03	0	42.07	0.11	57.83	221,063
TruckLoad_02	47.6	42.01	0	10.39	220,819
Machine018	81.96	15.56	2.48	0	221,001
TruckLoad_03	46.55	40.42	0	13.03	212,565
DropOff_01	16.89	42.06	34.5	6.55	221,071
DropOff_02	17.31	42.05	34.34	6.3	221,001
Machine019	8.45	12.61	78.93	0	220,998
DropOff_03	44.15	40.45	9.97	5.44	212,594
DropOff_04	45.86	40.43	0.13	13.58	212,643
PickUp_01	0	42.02	0.1	57.87	220,890
Machine021	92.3	6.56	1.14	0	220,996
DropOff_05	47.89	42.06	0	10.06	220,997
Machine024	48.14	10.52	41.35	0	212,595
DropOff_06	47.9	42.06	0	10.03	221,062
PickUp_02	0	42.03	0.11	57.85	220,820
PickUp_03	0.83	40.43	0.1	58.63	212,565
Machine026	83.57	16.18	0.25	0	212,594
PickUp_04	24.32	40.45	6.96	28.26	212,594

PickUp_05	37.07	42.03	0.24	20.66	220,996
PickUp_06	37.01	42.03	0.16	20.79	221,062
Machine027	46.65	12.13	41.21	0	212,594
Machine029	89.48	10.52	0	0	212,593
Machine022	71.48	28.05	0.47	0	433,588
Machine023	54.07	17.39	28.54	0	212,595
Machine030	81.44	17.39	1.17	0	212,593
Machine031	100	0	0	0	0
Machine032	100	0	0	0	0
Machine033	100	0	0	0	0

Table C-3 Intermodal UFT Terminal Machine Statistics for Scenario Number Two Report by On Shift Time

Machine Statistics Report by On Shift Time

Name	% Idle	% Busy	% Blocked	% Cycle Wait Labor	No. Of Operations
Machine007	65.11	19.93	14.96	0	775,949
UnLoad_02	3.45	42.99	0	53.56	188,322
Machine034	46.95	12.52	40.54	0	328,948
Machine008	21.59	13.04	65.36	0	342,795
UnLoad_01	1.73	78.27	8.48	11.53	342,792
Slow Down	46.98	40.3	12.72	0	775,949
Speed Up	47.62	40.3	12.08	0	775,904
SlowDown2	47.9	40.3	11.79	0	775,904
MPH45_2	13.72	75.58	10.7	0	775,904
MPH45_1	12.3	75.59	12.11	0	775,949
SpeedUp2	59.25	40.3	0.44	0	775,934
Machine006	86.8	0	13.2	0	775,904
Machine035	91.7	0.5	7.79	0	13,196
Load_01	10.32	78.26	0	11.43	342,789
Machine036	99.35	0.02	0.62	0	648
Machine040	100	0	0	0	0
Machine041	92.82	7.17	0.01	0	188,323
Machine042	100	0	0	0	0
UnLoad_03	28.12	55.87	11.03	4.98	244,826
Machine044	100	0	0	0	0
Machine010	77.82	22.17	0.01	0	342,793
Machine045	83.48	9.32	7.2	0	244,826
Machine011	20.52	22.17	57.3	0	342,791
TruckLoad_01	10.53	78.26	0	11.21	342,791
Machine046	100	0	0	0	0
Machine013	86.37	13.04	0.59	0	342,789
TruckUnload_03	34.59	55.9	0	9.51	244,826
Machine014	75.94	19.93	4.13	0	775,935
Load_02	44.57	43.01	0	12.42	188,322
Machine015	55.85	28.02	16.13	0	433,153
TruckUnload_02	50.43	43.02	0	6.55	188,324
Machine016	25.64	8.6	65.76	0	188,325
Load_03	32.2	55.86	0	11.93	244,825
TruckUnload_01	10.35	78.26	0	11.39	342,790
TruckLoad_02	44.58	42.98	0	12.44	188,321
Machine018	86.74	13.26	0	0	188,323
TruckLoad_03	32.1	55.88	0	12.03	244,824
DropOff_01	100	0	0	0	0

DropOff_02	100	0	0	0	0
Machine019	82.38	10.75	6.87	0	188,323
DropOff_03	100	0	0	0	0
DropOff_06	100	0	0	0	0
PickUp_01	100	0	0	0	0
Machine021	93.21	5.59	1.2	0	188,322
DropOff_05	100	0	0	0	0
Machine024	57.03	12.11	30.85	0	244,827
DropOff_04	100	0	0	0	0
PickUp_02	100	0	0	0	0
PickUp_03	100	0	0	0	0
Machine026	81.37	18.63	0	0	244,827
PickUp_06	100	0	0	0	0
PickUp_05	100	0	0	0	0
PickUp_04	100	0	0	0	0
Machine027	66.78	13.97	19.25	0	244,826
Machine029	87.89	12.11	0	0	244,825
Machine022	71.21	28.02	0.77	0	433,146
Machine023	61.84	20.03	18.13	0	244,827
Machine030	78.84	20.03	1.13	0	244,824
Machine031	100	0	0	0	0
Machine032	100	0	0	0	0
M_to_Load01	100	0	0	0	0
Machine033	100	0	0	0	0
M_ to_ Load	100	0	0	0	0
M_to_Load02	100	0	0	0	0

Illustrations Charts Simulation Results for Base-Model

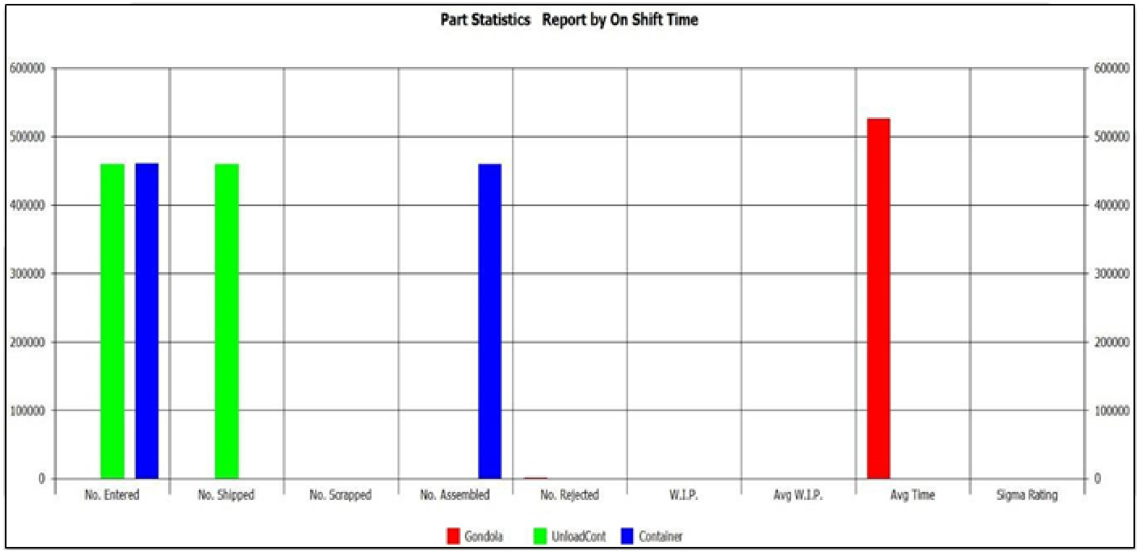


Figure C-1 Intermodal UFT Terminal Part Statistics for Base-Model

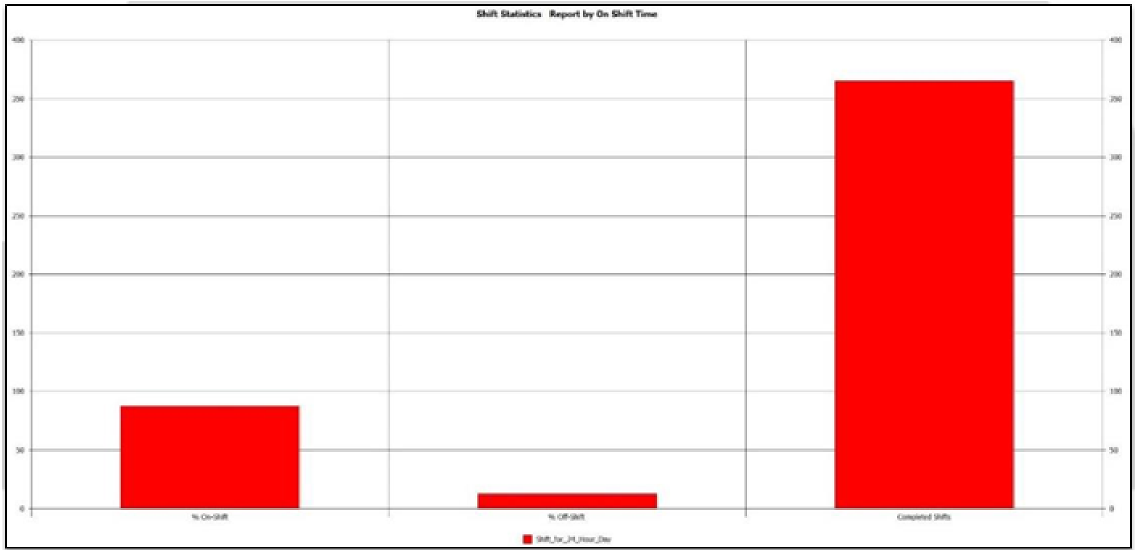


Figure C-2 Intermodal UFT Terminal Shift Statistics for Base-Model

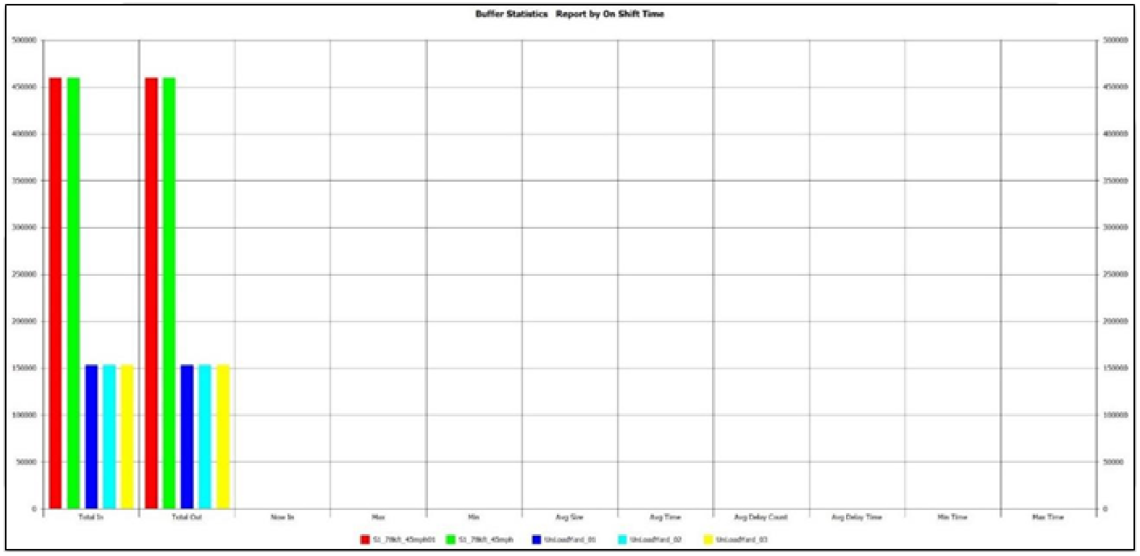


Figure C-3 Intermodal UFT Terminal Part Statistics for Base-Model

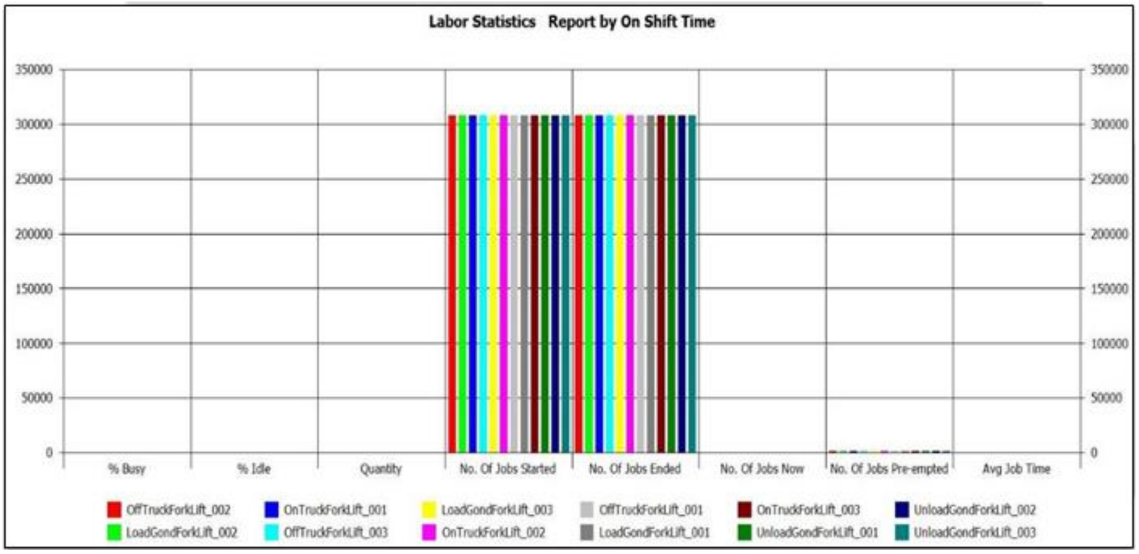


Figure C-4 Intermodal UFT Terminal Labor Statistics for Base-Model

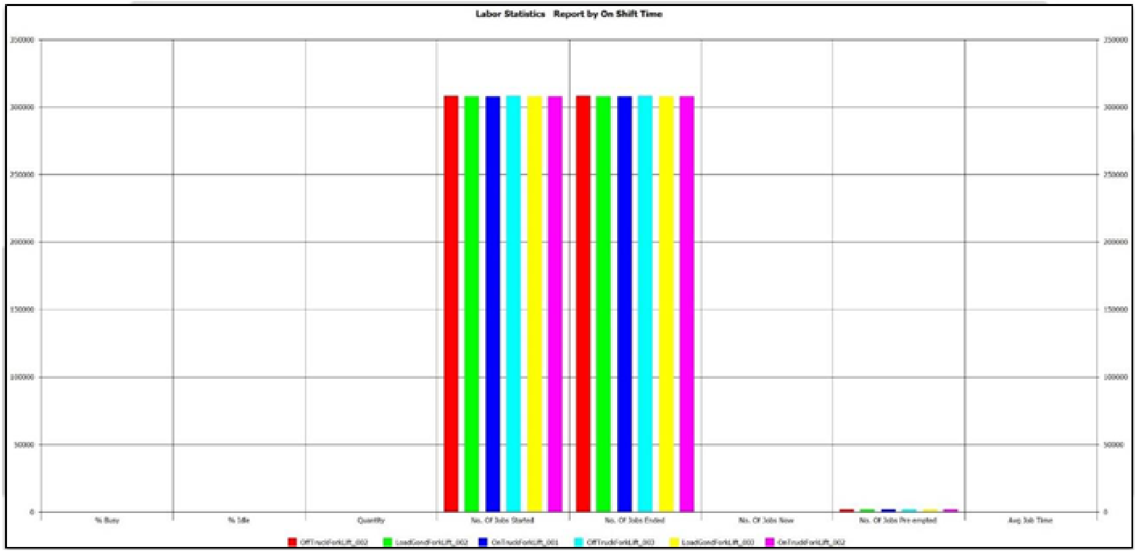
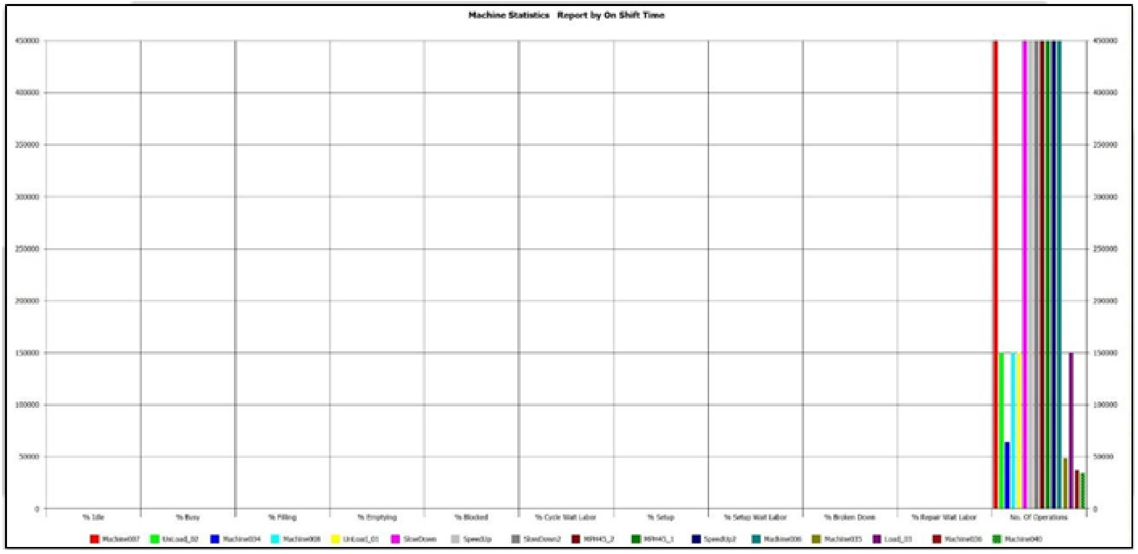


Figure C-5 Intermodal UFT Terminal Labor Statistics for Base-Model



FigureC-6 Intermodal UFT Terminal Machine Statistics for Base-Model

Graphical illustrations of Simulation modeling process in WITNESS^{TM} (Lanner Group, 2008.

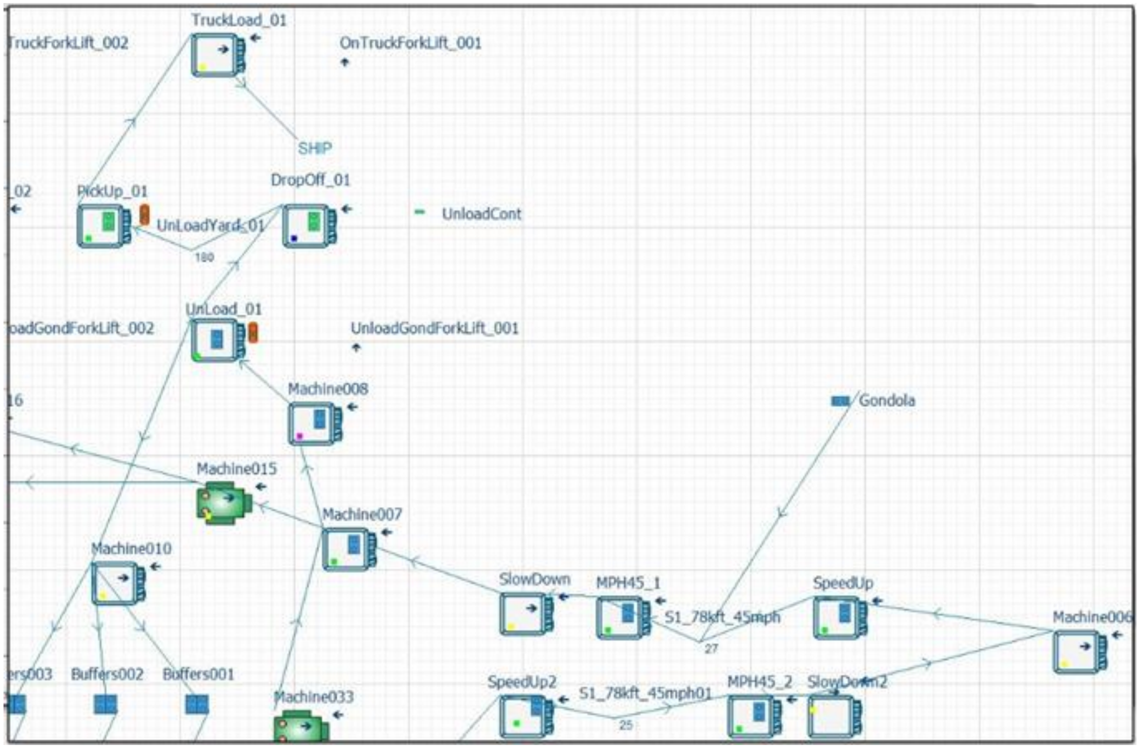


Figure C-7 Simulated Model for Intermodal UFT Terminal in WITNESS^{TM} (Lanner Group, 2008)

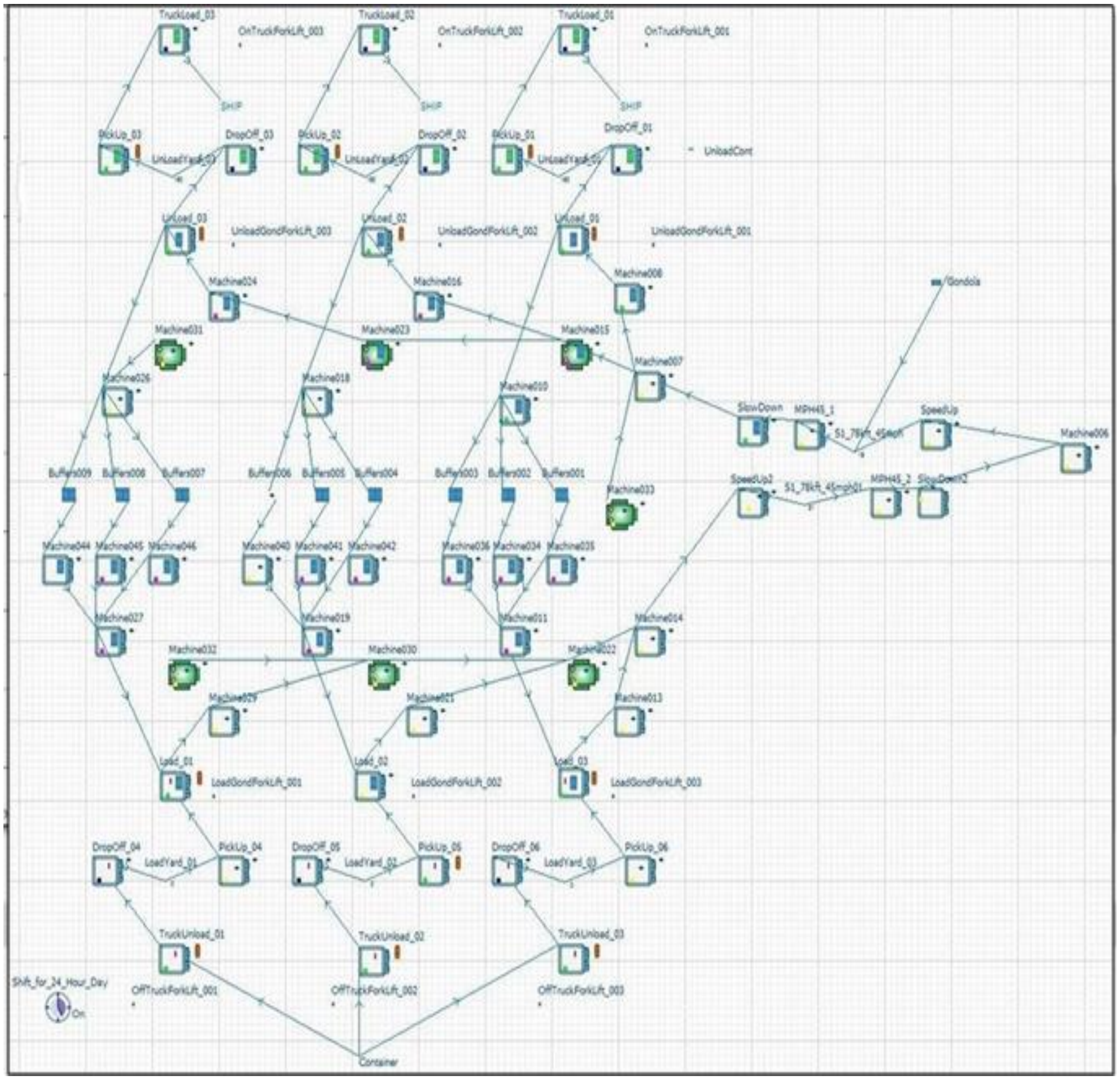


Figure C-8 Simulated Model for Intermodal UFT Terminal in WITNESS^{TM} (Lanner Group, 2008)

Appendix D

Graphical Illustrations Charts Simulation Results Analysis in WITNESS^{TM} (Lanner Group, 2016) for Two Scenarios

Illustrations Charts Simulation Results for Scenario No. 1 with Stack-Yard

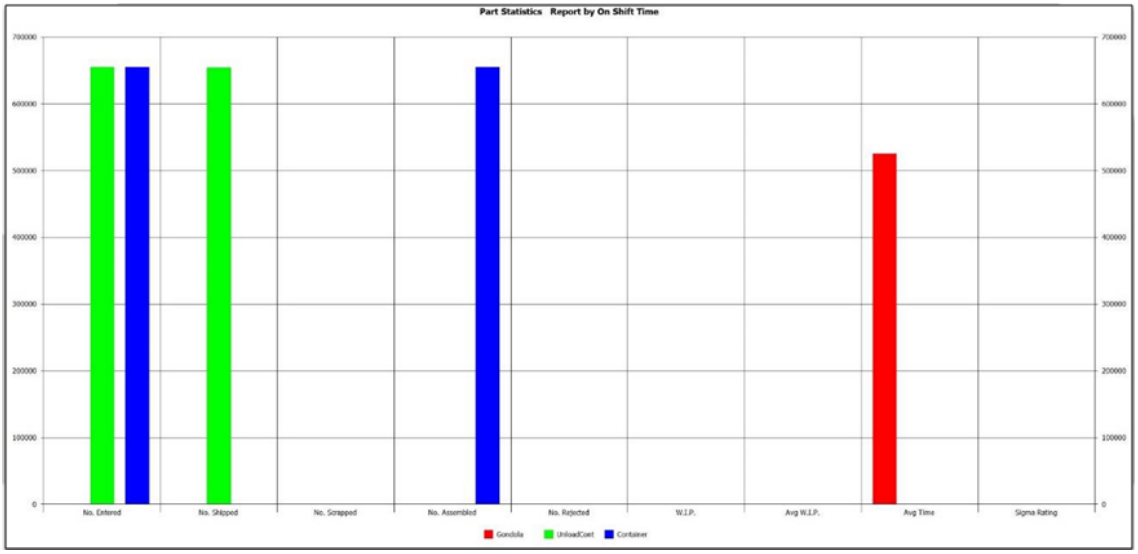


Figure D-1 Intermodal UFT Terminal Part Statistics for Scenario No. 1

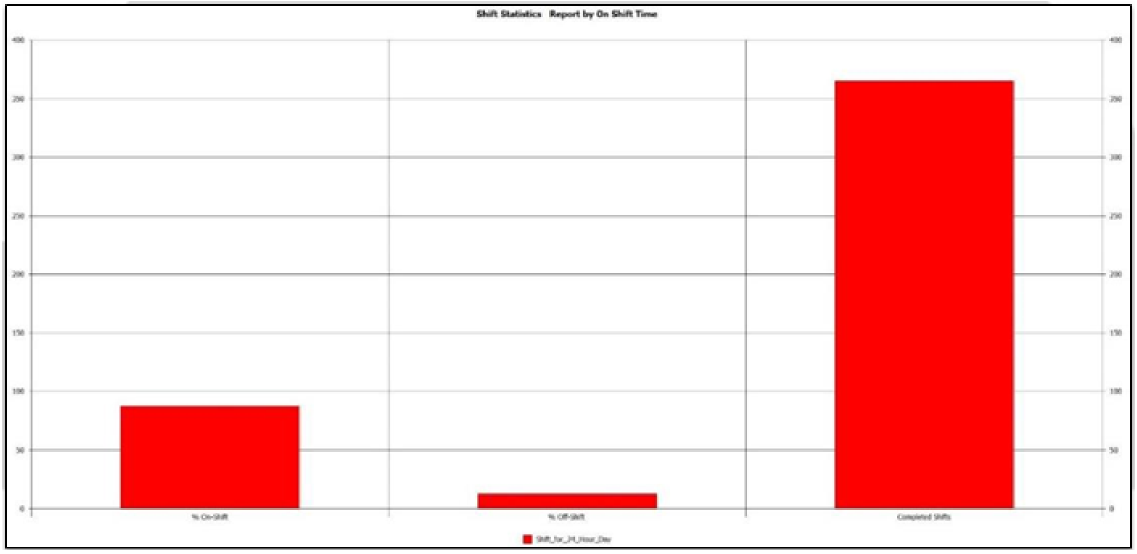


Figure D-2 Intermodal UFT Terminal Shift Statistics for Scenario No. 1

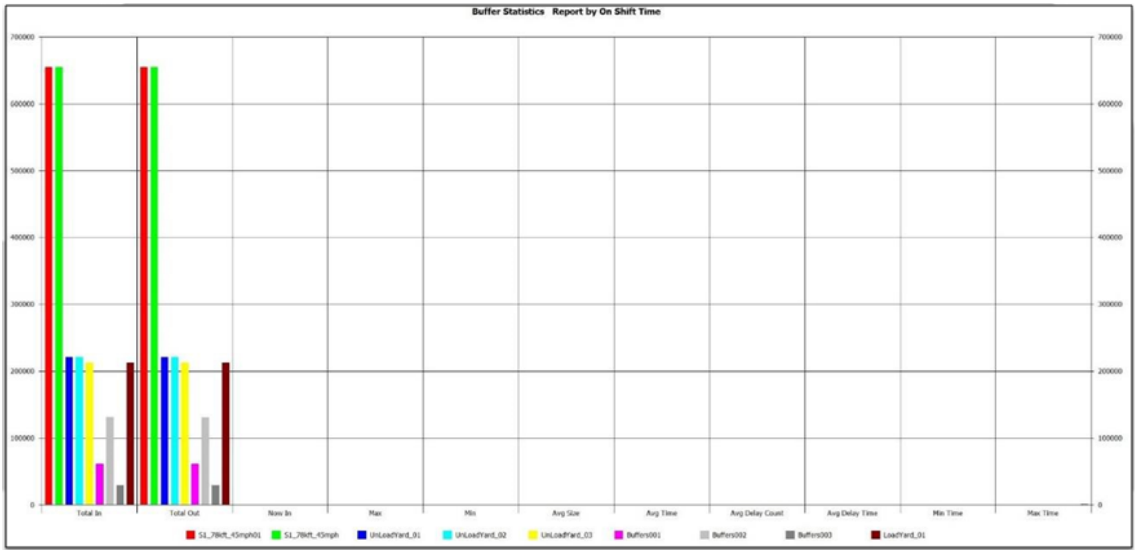


Figure D-3 Intermodal UFT Terminal Buffer Statistics for Scenario No. 1

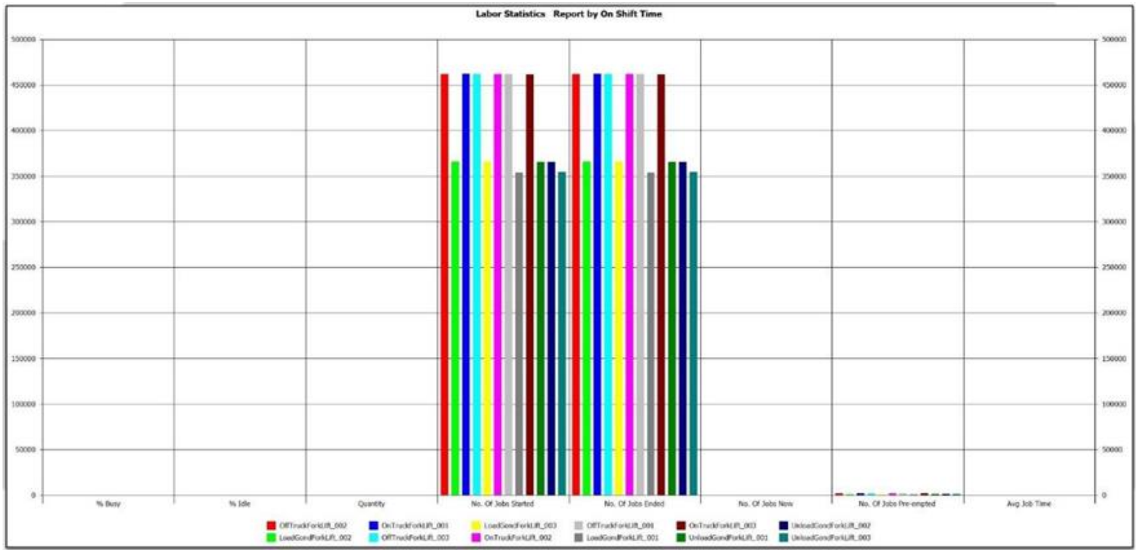


Figure D-4 Intermodal UFT Terminal Labor Statistics for Scenario No. 1

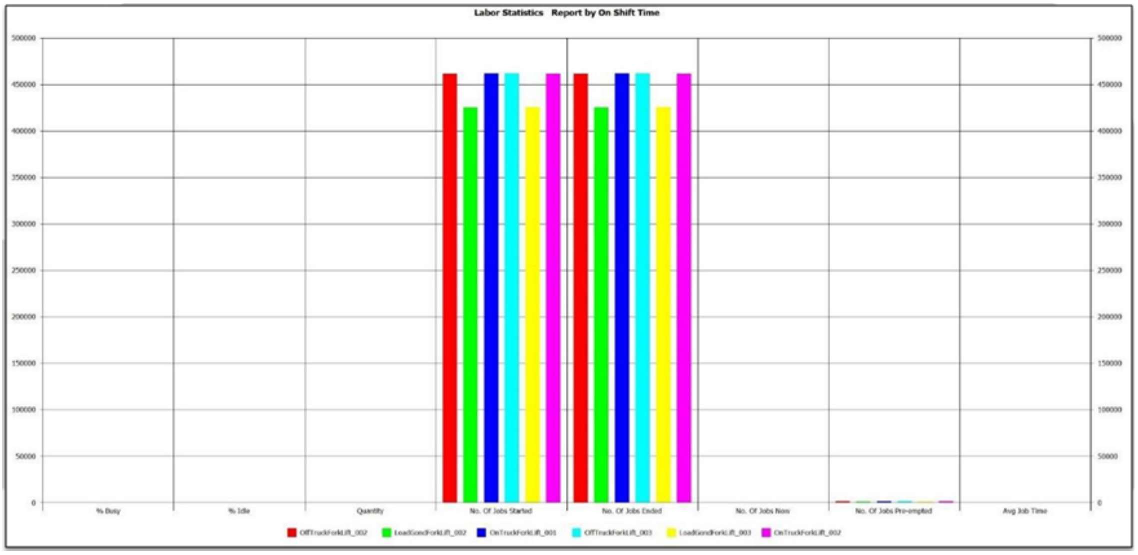


Figure D-5 Intermodal UFT Terminal Labor Statistics for Scenario No. 1

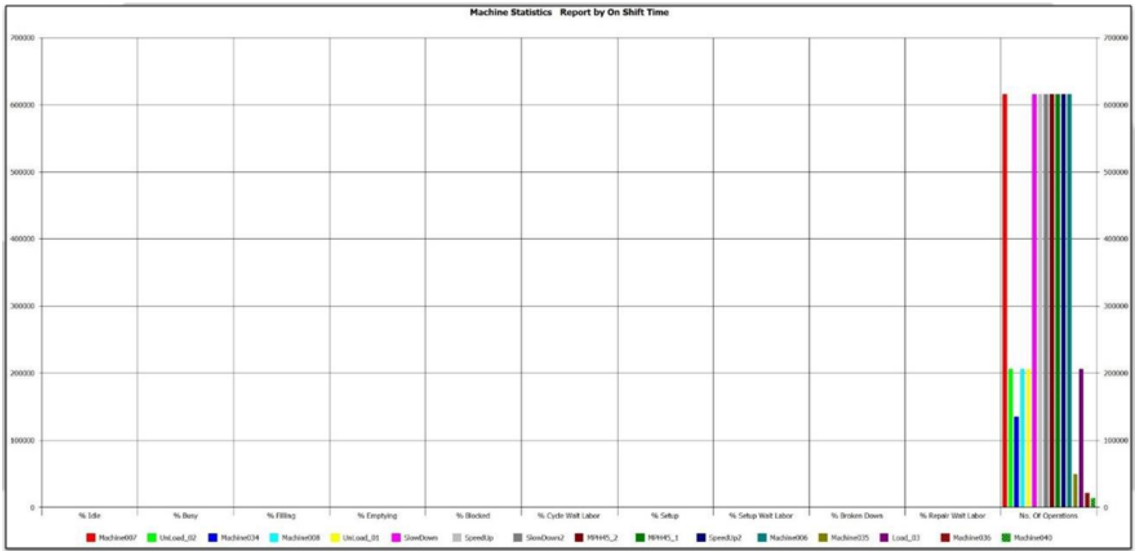


Figure D-6 Intermodal UFT Terminal Machine Statistics for Scenario No. 2

Illustrations Charts Simulation Results for Scenario No. 2 without Stack-Yard

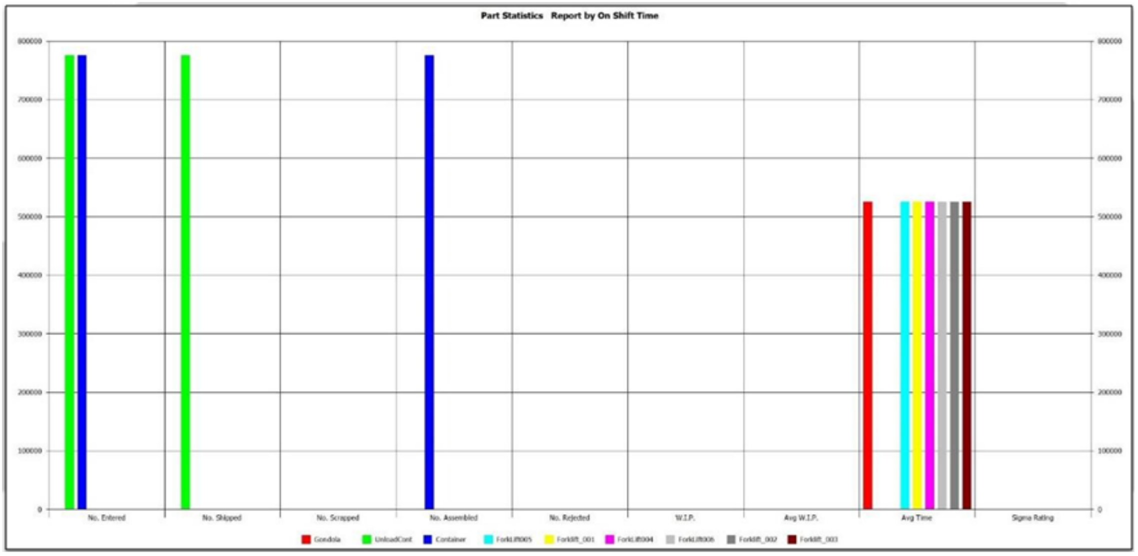


Figure D-7 Intermodal UFT Terminal Part Statistics for Scenario No. 2

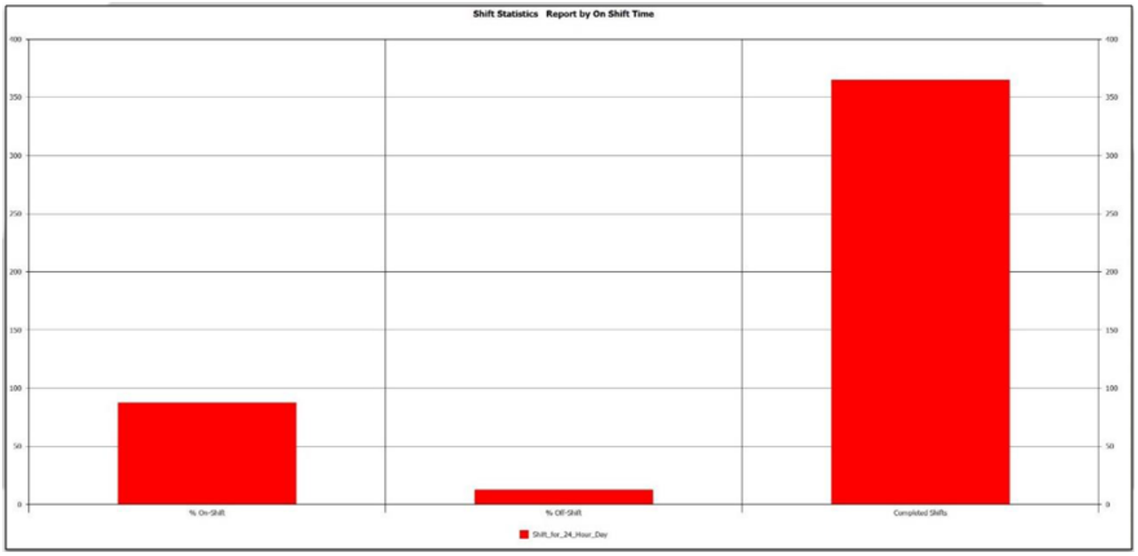


Figure D-8 Intermodal UFT Terminal Shift Statistics for Scenario No. 1

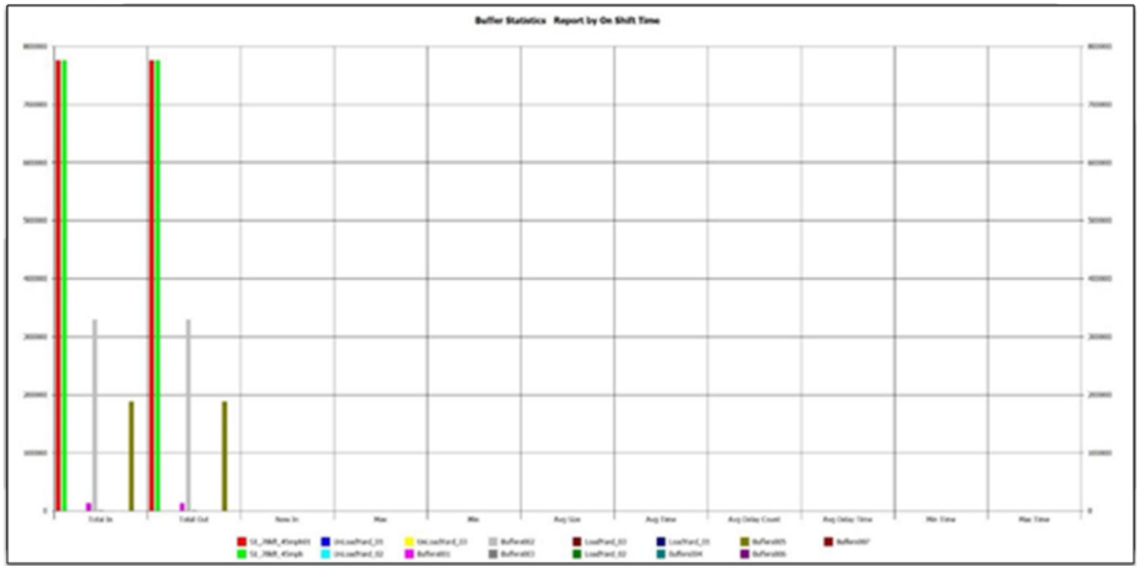


Figure D-9 Intermodal UFT Terminal Buffer Statistics for Scenario No. 2

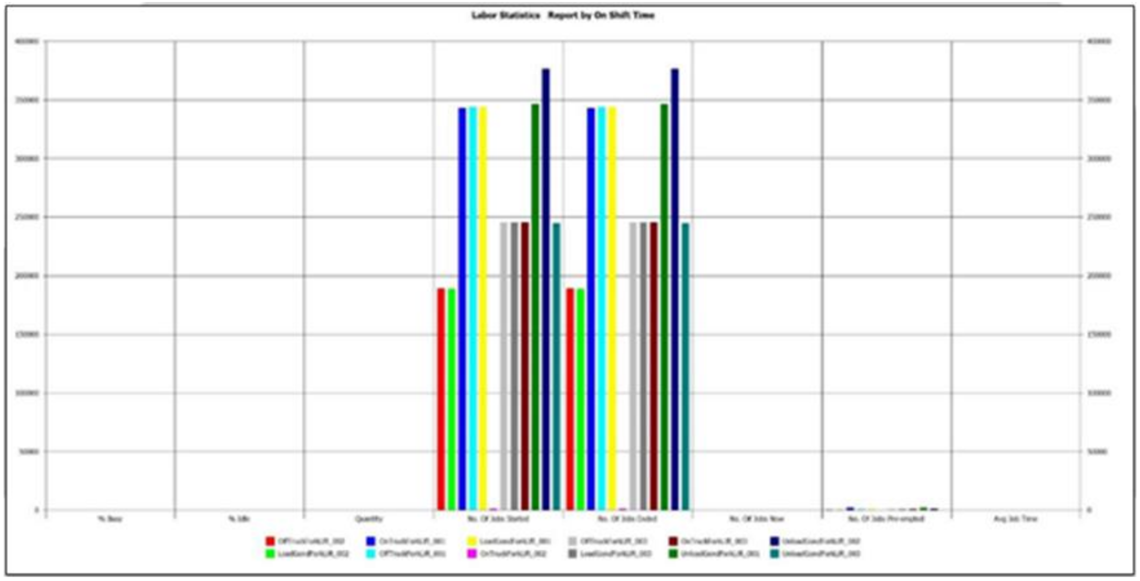


Figure D-10 Intermodal UFT Terminal Labor Statistics for Scenario No. 2

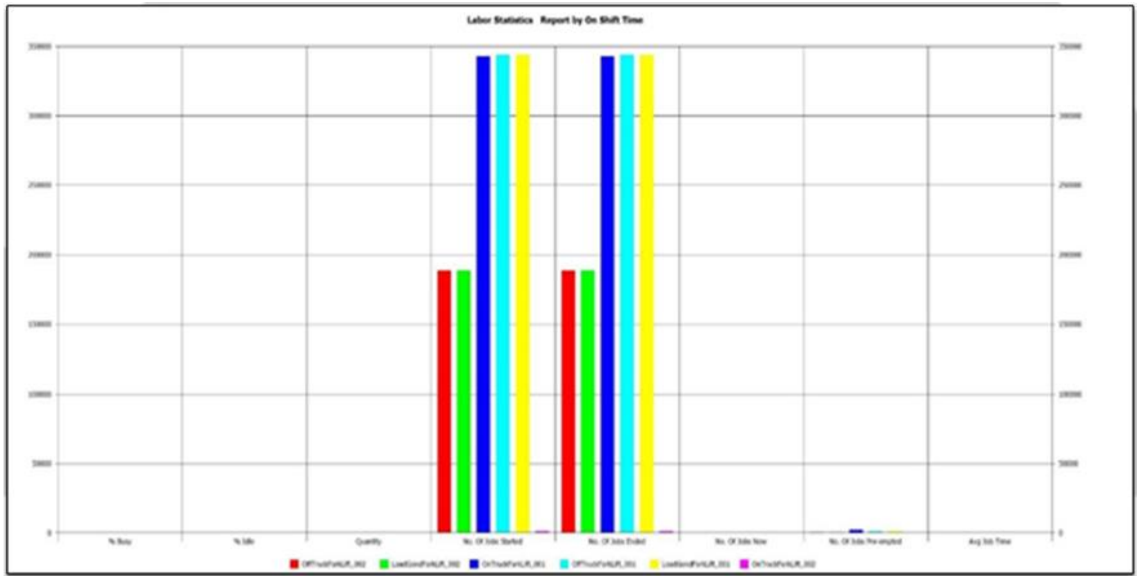


Figure D-11 Intermodal UFT Terminal Labor Statistics for Scenario No. 2

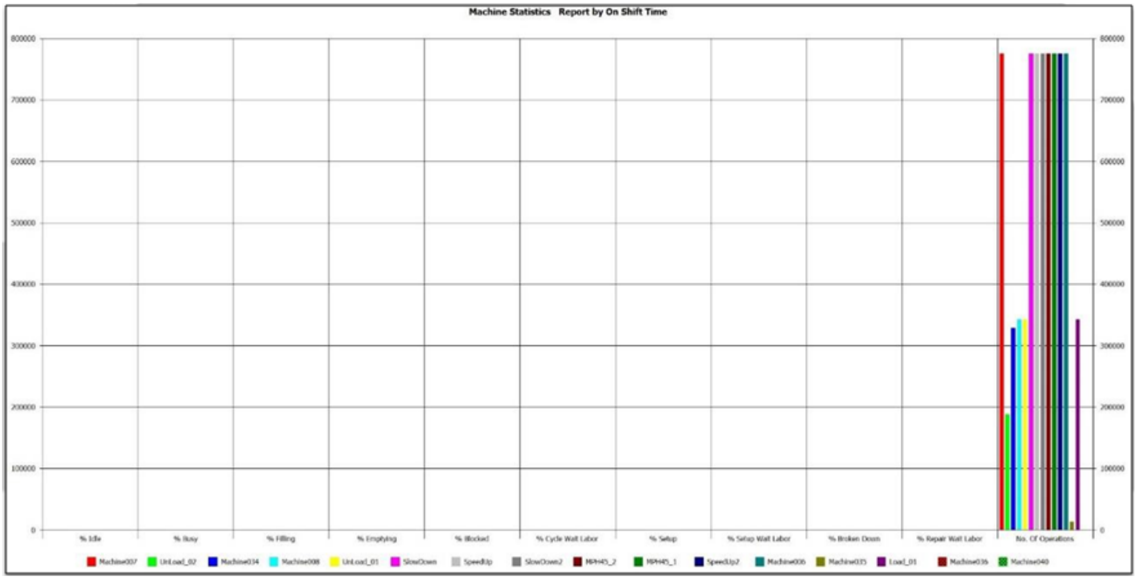


Figure D-12 Intermodal UFT Terminal Machine Statistics for Scenario No. 2

Graphical Illustrations of Simulation Modeling Process in Witness

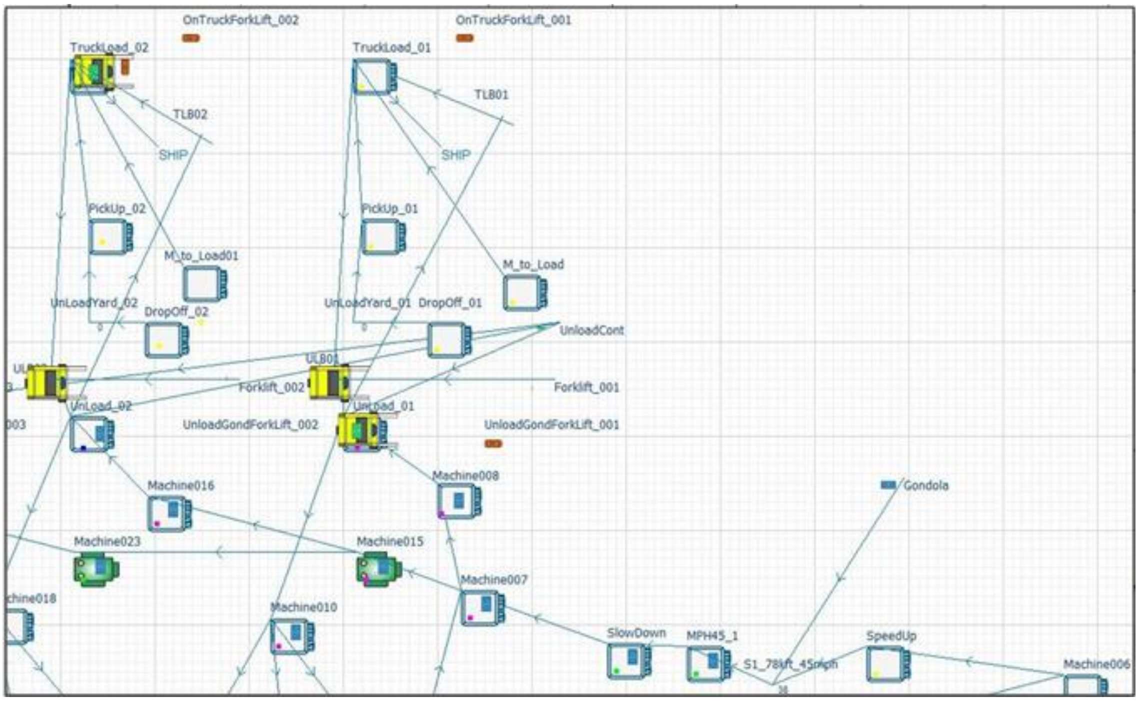


Figure D-13 Simulated Model for Intermodal UFT Terminal

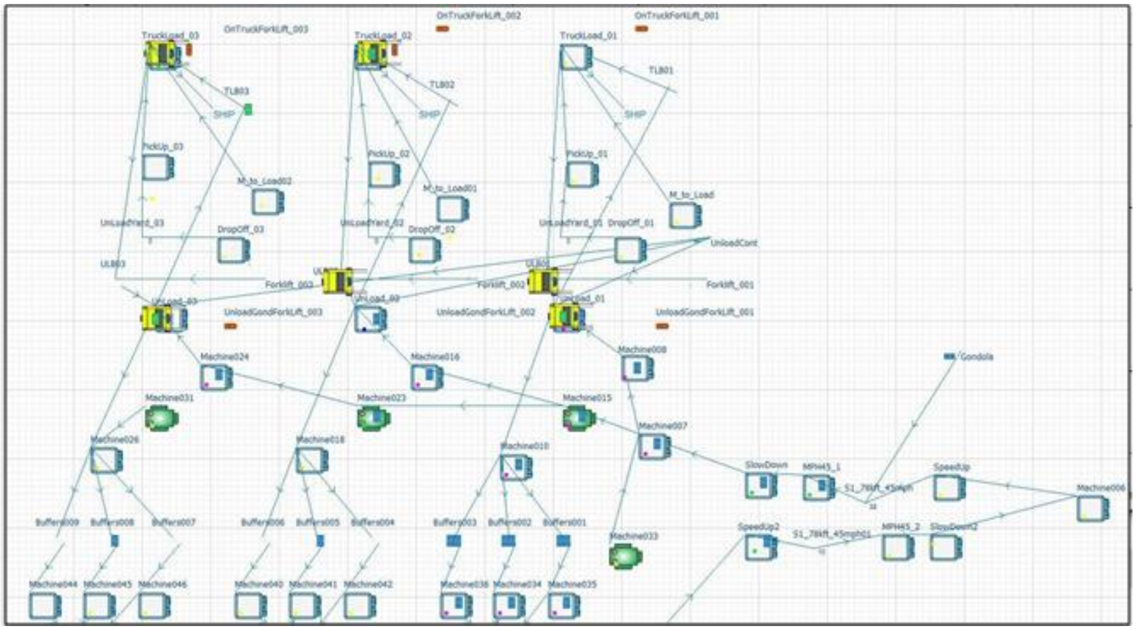


Figure D-14 Simulated Model for Intermodal UFT Terminal

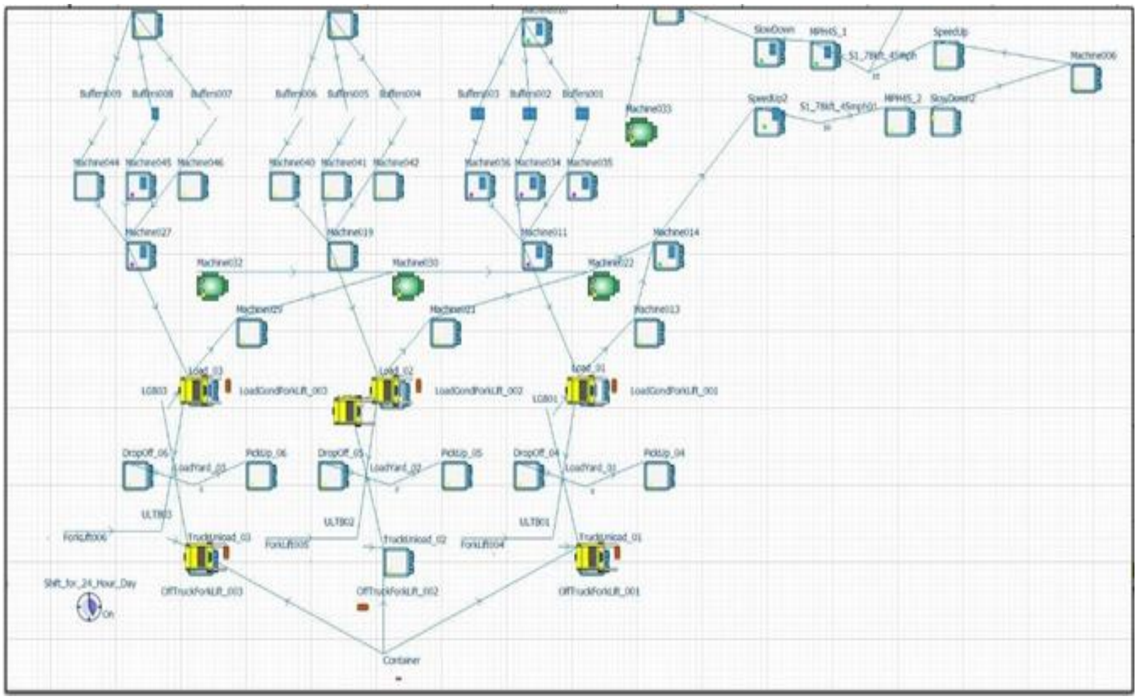


Figure D-15 Simulated Model for Intermodal UFT Terminal

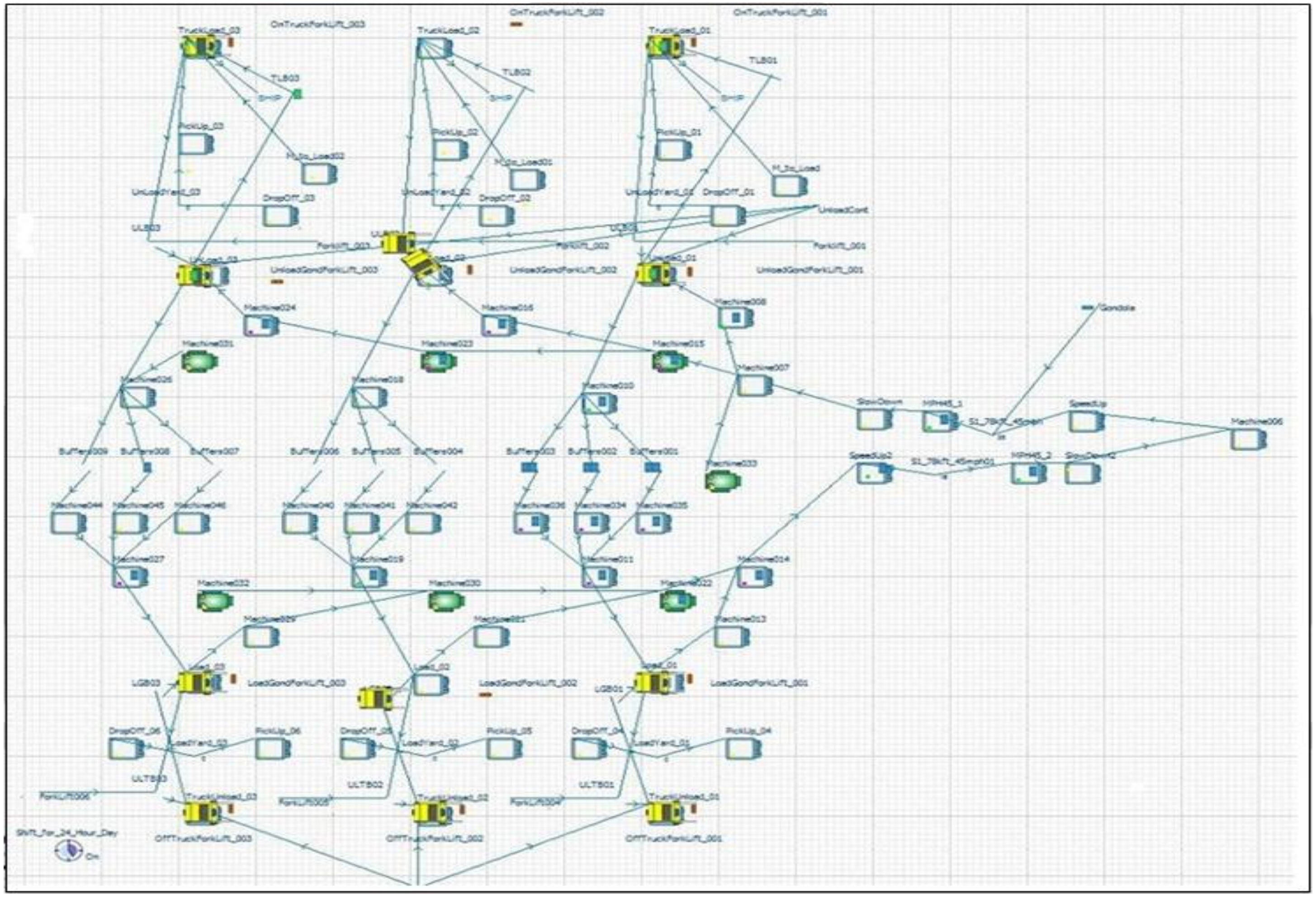


Figure D-16 Simulated Model for Intermodal UFT Terminal

List of Acronyms

ft/s^2	Acceleration of Gravity
AAR	Association of American Railroads
ATA	American Trucking Association
AASHTO	American Association of State Highway and Transportation Officials
BTS	Bureau of Transportation Statistics
DES	Discrete Event Simulation
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
ft	Feet
ft^2	Square Feet
hr.	Hour
ICTs	Information Communication Technologies
IH	Interstate Highway
IH-45	Interstate Highway 45
L	Length
LIM	Linear Induction Motor
mph	Mile per Hour
M	Machine
NAFTA	North American Free Trade Agreement
NASEM	National Academies of Sciences, Engineering, and Medicine
No.	Number
OECD	Organization for Economic Co-operation and Development
s^2	Square Second

sec.	Second
SH	*State Highway*
sq. yds.	Square Yards
TEU	*Twenty-Foot Equivalent Unit*
TS	Track Section
TRB	Transportation Research Board
TX	Texas
TxDOT	Texas Department of Transportation
UFT	Underground Freight Transportation
U.S.	United States
U.S. DOT	United States Department of Transportation
UTA	University of Texas at Arlington
Vehs.	Vehicles
v	Operating Speed

List of Definitions

Bypass Shunt: A short lane for diverting the vehicles to the platforms for loading/unloading.

Buffer/Queue: Places where Entities are held. People in a line or queue are a usual example.

Capacity: The capacity of a UFT system in terms of containers flow per day should be sufficiently high to justify the construction and operation of the system.

Discrete Event Simulation (DES): Models the operation of a system as a discrete sequence of events in time. Each event consists of a distinct change in the system's state at a specific point in time.

Distance: Distance is determined as the amount measured between two points.

Fleet Size: The number of vehicles in use when the system is operating at capacity.

Flow: Is defined as the number of freight containers transported in a day.

Forklifts: Forklifts are used for loading/ unloading the crates and pallets to trucks and UFT vehicles.

Handlers: Handlers are used for loading/ unloading the shipping containers to trucks and UFT vehicles.

Headway: The time gap between launching two successive UFT vehicles.

Joint: A point at which sections of a structure such as terminal tracks are linked.

Labor Resource: Required crew to work in system. the quantity of labor for each shift is detailed.

Linear Induction Motors (LIM): A linear induction motor (LIM) is an alternating current (AC), asynchronous linear motor that works by the same general principles as other induction motors but is typically designed to directly produce motion in a straight line.

Machine/Activity: Elements that are applied to illustrate anything that takes part from somewhere, processes them and sends them on to their next destination.

Operating Speed: The average speed of the vehicles in UFT system excluding stops in terminals.

Platform: The area in UFT terminals which vehicles stop for loading/unloading the freight.

Part/ Entity: Flow through the model. Parts can represent physical components through a large organization, telephone calls, or even people moving through a supermarket.

Running the Model: Experimentation is defined as the process of running the model and collecting the required statistical output to fulfill the needs of the experimental design. Models can be run for specified lengths of time or until all parts have been processed.

Single Track: A UFT system which accommodates only one line in the tunnel.

Traffic Congestion: Traffic congestion is a condition on transport networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queueing. The most common example is the physical use of roads by vehicles.

Underground Freight Transportation (UFT): An unmanned, automated, and intermodal form of freight transportation utilizing pipelines and tunnels to transport container, crate and pallet freight between terminals. An automated technology to carry individual freight capsules through underground pipelines with minimum impact on the surface. This system can be built on available right-of-way (row) or under the highways.

Vehicle: Equipment used for carrying the freight including but not limited to: Capsule, gondola and flatbed trailer.

REFERENCES

AAR. (2014). Association of American Rail roads, Average weekly U.S. rail intermodal traffic, <http://www.calculatedriskblog.com/2014/01/aar-record-intermodal-rail traffic-in.html>, Accessed on Oct.12, 2017.

ATA. (2014). American Trucking Associations, Freight Transportation Forecast 2017 to 2028, report in book (ATA, Arlington, VA) and downloadable PDF formats for purchase. Report not printable from PDF. <https://www.atabusinesssolutions.com/ATAStore/ProductDetails/productId/3614937>, Accessed on March. 19, 2018.

AASHTO. (2011). American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highway and Streets, Washington, DC.

Banks, J., Carson, J., Nelson, B.L., and Nicol, D. (2004). Discrete-Event System Simulation, Pearson Prentice Hall, Upper Saddle River, N.J.

Bektas, T. and Crainic, T. (2007). A Brief Overview of Intermodal Transportation, Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), University of Montreal, Canada.

Bontekoning, Y. M., Macharis, C. and Trip. J. J. (2004). “Is a new Applied Transportation Research Field Emerging? – A Review of Intermodal Rail-Truck Freight Transport Literature.” Transportation Research Part A: Policy and Practice 38:1– 34.

BTS. (2012). Bureau of Transportation Statistics, Freight Transportation, < https://www.bts.gov/topics/freight-transportation>, Accessed on Dec. 4, 2017.

BTS. (2017a). Bureau of Transportation Statistics, Freight Facts & Figures 2017- Chapter 3: The Freight Transportation System, <https://www.bts.gov/bts-publications/freight-facts-and-figures/freight-facts-figures-2017-chapter-3-freight >, Accessed on Apr. 25, 2018.

BTS. (2017b). Bureau of Transportation Statistics, Freight Facts & Figures 2017- Chapter 5: Economic Characteristics of the Freight Transportation Industry, < https://www.bts.gov/bts-publications/freight-facts-and-figures/freight-facts-figures-2017-chapter-5-economic >, Accessed on Apr. 25, 2018.

BTS. (2017c). Bureau of Transportation Statistics, North American Freight Numbers, < https://www.bts.gov/newsroom/2017-north-american-freight-numbers>, Accessed on Apr. 1, 2018.

BTS. (2018). Bureau of Transportation Statistics, Trans Border Freight Data, < https://www.bts.gov/transborder >, Accessed on May. 2, 2018.

Business Dictionary (2017). “Optimization Definition,” <http://www.businessdictionary.com/definition/optimization.html >, Accessed on Nov. 20 1, 2017.

Caris A., Macharis, C. and Janssens. G. K. (2008). “Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects.” Transportation Planning and Technology 31:277–302.

Caris A., Macharis, C. and Janssens. G. K. (2013). “Decision Support in Intermodal Transportation: A new Research Agenda.” Computers in Industry 64:105–112.

Crainic, T. G., and Laporte. G. (1997). “Planning Models for Freight Transportation.” European Journal of Operational Research 97:409–438.

Designing Cargo Terminals. (2015). <http://www.districon.com/practices/cargo-logistics/designing cargo-terminals>, Accessed on Dec. 4, 2015.

Edmonds, J. (2017). The Freight Essentials: Getting Your Products Across The Ocean, < https://go.indiegogo.com/blog/2017/03/freight-essentials.html>, Accessed on Aug. 11, 2017.

Evans, G. M., and Furlong, J. C. (2003). *Environmental biotechnology: Theory and applications*, Wiley, Chi Chester, U.K.

Feghhi, J. (2015). UFT Project email correspondence on Nov. 18, 2015, USA.

FHWA. (1993). Federal Highway Administration, National Transportation Statistics, Annual Report, Historical Compendium 1960-1992, Bureau of Transportation Statistics, U.S. Department of Transportation.

Fiars, R. (2009). “The Virtual Sea Port: Sydney Freight Circle.” Proc. of the 8th International Conference of Associated research Centers for the Urban Underground Space (ACUUS). Shenzhen, China.

Gallamore, R. E. (1998). State of the art of intermodal freight transport in the United States. In: Intermodal Freight Transport in Europe and the United States. Eno Transportation Foundation, Inc., Lansdowne, VA.

Gudelj, A., Krum, M., Twrdy, E. (2010). Models and methods for operations in port container terminals Traffic & Transportation, Vol. 22, No. 1: 43-51.

Guo, D. J., Yu, M. J. and Chen, Z. L. (2008). “The Preliminary Study on Underground Container Transportation System (UCTC) for Yangshan Port in Shanghai.” Proc. of the 5th International Symposium on Underground Freight Transportation (ISUFT). Arlington, TX.

Haefner, L., Bieschke, M. (1998). “Intelligent transportation systems (ITS) Opportunities in Port Operations,” National Transportation Library, < https://rosap.ntl.bts.gov/>, Accessed on Jan. 4, 2018.

Hall, J. D., Bowden, R. O. (1998). “A unified strategy for simulation optimization research and development,” In Proceedings of 7th Industrial Engineering Research Conference, Alberta, Canada.

Halpin, D., Riggs, L. (1992). Planning and Analysis of Construction Operations, John Wiley & Sons, Inc., Toronto, Canada.

Horvat, U., Twrdy, E. (2008). The impact of introducing sea motorways on increase of container transshipment in the Port of Koper, 11th International Conference on Traffic Science – ICTS 2008, Proceedings CD, Portorož, Slovenia.

Holmgren, J., Davidsson, P., Persson, J. A. and Ramstedt. L. (2012). “TAPAS: A Multi-agent-based Model for Simulation of Transport Chains.” Simulation Modeling Practice and Theory 23:1–18.

Huff, B. (2018), Introduction to Simulation, Simulation class handout, Slides adapted from LearningSimio_Chapter_01_Introduction to Simulation by Sturrock D., 2010-2012 Simio LLC.

IANA. (2011). Intermodal Association of North America, Rail Intermodal Terminal Directory, < http://www.intermodal.org/skedz/index.php>, Accessed on Aug. 25, 2017.

Kalmar Co. (2016). Rough Terrain Handlers, <https://www.kalmarglobal.com>, Accessed on April. 1, 2016.

Kelton, W., Smith, J., Sturrock, D. (2013). “Simio and Simulation: Modeling, Analysis, Applications,” Third Edition, Published by Simio LLC, www.simio.com, Accessed on Feb. 12, 2018.

Kosugi, S. (1999). “Pneumatic Capsule Pipelines in Japan and Future Developments.” Proc. of the 1st International Symposium on Underground Freight Transportation, Columbia, Missouri, PP. 61-73.

Lai, Y.C., Barkan, C.P.L., Drapa, J., Ahuja, N., Hart, J.M., Narayanan, P. J., Jawahar, C.V. Kumar, A., Milhon, L.R. and Stehly. M.P. (2007). Machine vision analysis of the energy efficiency of intermodal freight trains. Proceedings of the Institute of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 22: 356-364.

Lai, Y.C., Barkan, C.P.L. and Onal, H. (2007). Optimizing the energy efficiency of intermodal freight trains. Transportation Research Part E 44: 820-834.

Lanner Group. (2008). Predicting Simulation Modeling and Software and Analytical Services, <https://www.lanner.com/en-us/technology/witness-simulation-software.html >, Accessed on April. 1, 2018.

Lanner Group. (2016). Predicting Simulation Modeling and Software and Analytical Services, <https://www.lanner.com/en-us/technology/witness-simulation-software.html >, Accessed on March. 11, 2018.

Lewandowski, K. (2016). Growth in the Size of Unit Loads and Shipping Containers from Antique to WWI, Packaging Technology and Science. 29 (8-9): 451–478. ISSN 1099-1522.

Lin, CH., Chiang, Y., and Lin, Sh. W. (2014). Efficient model and heuristic for the intermodal terminal location problem. Computers and Operations Research, 51, 41–51.

Liu H. (2006). Transporting freight containers by pneumatic capsule pipeline (PCP): port security and other issues. In Invited presentation at Summer Meeting of US Transportation Research Board (TRB) LaJolla, California.

Liu, H., and Lenau, C. W. (2005). “An Electromagnetic Pneumo Capsule System for Conveying Minerals and Mine Wastes.” Final Report, U.S. Department of Energy Project No. DEFG26-03NT41928.

Macharis, C., Caris, A., Jourquin, B., and Pekin, E. (2011). A decision support framework for intermodal transport policy. European Transport Research Review, 3(4), 167-178.

Macharis, C., and Bontekoning. Y. M. (2004). “Opportunities for OR in Intermodal Freight Transport Research: A Review.” European Journal of Operational Research 153:400–416.

Macomber, J. H. (Revised by Turner, M.C.) (2018). “Simulation,” Reference for Business, Encyclopedia of Small Business, Advameg, Inc., Hinsdale, IL., <http://www.referenceforbusiness.com/management/Sc-Str/Simulation.html#ixzz5K4oBf6sJ>, Accessed on Nov. 15, 2017.

Maria, A. (1997). Introduction to Modeling and Simulation, Proceeding of the 1997 Winter Simulation Conference. <http://acqnotes.com/Attachments/White%20Paper%20Introduction%20to%20Modeling%20and%20Simulation%20by%20Anu%20Maria.pdf>, Accessed on Dec. 15, 2017.

Matloff, N. (2008). "Introduction to Discrete-Event Simulation and the SimPy Language," Retrieved 24 January 2013, <http://heather.cs.ucdavis.edu/~matloff/156/PLN/DESimIntro.pdf>, Accessed on Nov. 25, 2017.

Munford C. (1980). Buenos Aires – congestion and the dry port solution. Cargo Systems International: The Journal of ICHCA. 1980;7(10):26-27.

Najafi, M. (2013). “Trenchless technology: Planning, equipment, and methods.” McGraw Hill, New York, USA.

Najafi, M., Ardekani, S., Shahandasti, M. (2016). “Integrating underground freight transportation into existing intermodal systems.”<http://library.ctr.utexas.edu/Presto/content/Detail.aspx?q=MC02ODcw&ctID=M2UxNzg5YmEtYzMyZS00ZjBlLWIyODctYzljMzQ3ZmVmOWFl&rID=MzU1&qcf=&p h=VHJ1ZQ==&bckToL=VHJ1ZQ==&>, Accessed on Aug. 10, 2017.

NASEM. (2011). National Academies of Sciences, Engineering, and Medicine, Impacts of Public Policy on Freight Transportation System, <https://www.nap.edu/read/14453/chapter/4>, Accessed on Oct. 4, 2017.

NetworkRail Co. (2015). “Move my Freight by Rail,” <www.networkrail.co.uk/aspx/10442.aspx>, Accessed on Dec. 1, 2015.

OECD. (2018). Freight transport (indicator), <https://data.oecd.org/transport/freight-transport.htm> doi: 10.1787/708eda32-en, Accessed on June. 8, 2018.

Olafsson, S., Kim, J. (2002). “Simulation Optimization,” In proceedings of the 2002 Winter Simulation Conference, San Diego, pp 79-84.

Pohlen, T. (2015). Intermodal Transportation and the North Texas Region, Center for Logistics Education and Research, University of North Texas Region.

Puppala, A. J., Bheemasetti, T. V., and Shafikhani, A. (2017). Pilot Implementation Using Geofoam for Repair of Bridge Approach Slabs and Adjoining Roadway. Arlington.

Rezaeifar, F., Najafi, M., Ardekani, S., Shahoei, S., (2017). “Optimized Terminal Design for UFT Systems in Integrated Subterranean Pipeline Infrastructure,” ASCE Pipeline Conference, Phoenix, Arizona, August 2017: 528-539.

Rezaeifar, F., Najafi, M., Ardekani, S. (2018). “Optimized Terminal Design for UFT Systems in Integrated Subterranean Pipeline Infrastructure,” Transportation Research Board (TRB) Conference, Presentation for the Utility Committee, National Academy of Sciences Transportation Research Board, Washington D.C., VA.

Rezaeifar, F., Pourjafar, M.R., Taghvaea, A.A. (2012). “The Role of Social Security Spaces of Traditional Iranian Cities in Urban Crimes Reduction: With Emphasis on CPTED Approach,” International Journal of Humanities, Vol. 19 (1): (51-68).

Rickett, T. (2013). Intermodal Train Loading Methods and Their Effect on Intermodal Terminal Operations. Thesis, University of Illinois.

Rizzoli, A. E., Fornara, N. and Gambardella, L. M. (2002). “A Simulation Tool for Combined Rail/Road Transport in Intermodal Terminals.” Mathematics and Computers in Simulation 59:57–71.

Rodrigue JP. (2008). Terminals and Logistics: The Terminalization Thesis, < https://slideplayer.com/slide/7268684/>, Accessed on July.9, 2017.

Rodrigue JP. (2011). Intermodal Terminals, Mega Ports and Mega Logistics. In: Brunn S. (eds) Engineering Earth. Springer, Dordrecht.

Sadowski, D., Sadowski, R., and Kelton, D. (1998). Simulation with Arena; Simulation Steps and Criteria, McGrawHill, <http://www.uh.edu/~lcr3600/simulation/steps.html>, Accessed on Nov. 20, 2017.

Salucci, V. M. (2006). “Intermodal Freight Terminals, In search of efficiency to support intermodality growth.” European Communities, <http://www.transportresearch.info/sites/default/files/brochure/20060831_100031_82868_intermodal_freight.pdf>, Accessed on Nov. 1, 2017.

Shafikhani, A., Bheemasetti, T. V., and Puppala, A. J. (2018). “Performance Evaluation of a Bridge Superstructure Using Terrestrial Laser Scanning Technology.” Geotechnical testing journal, In Press.

Shafikhani, A., Bheemasetti, T. V, and Puppala, A. J. (2017). “Effect of Seasonal Changes on a Hybrid Soil–Geofoam Embankment System.” International Journal of Geosynthetics and Ground Engineering, Springer, 3(4), 39.

Shiri, S. and Huynh, N. (2016). Optimization of drayage operations with time-window constraints. International Journal of Production Economics, 176, pp.7-20.

Shiri, S. and Huynh, N. (2017). Assessment of US chassis supply models on drayage productivity and air emissions. Transportation Research Part D: Transport and Environment, 61, pp.174-203.

Shiri, S., Ng, M. and Huynh, N. (2018). Integrated drayage scheduling problem with stochastic container packing and unpacking times. Journal of the Operational Research Society, pp.1-14.

Shiri, S., Smith, D., Huynh, N. and Harder, F. (2018). Emergence and Impacts of Second-Tier Container Port Facilities, No. 18-04837.

Simulation Steps and Criteria. (2013). <http://www.uh.edu/~lcr3600/simulation/steps.html>, Accessed on Nov. 20, 2017.

Steadieseifi, M., Dellaert, N. P., Nuijten, W., Woensel, T. and Raoufi, R. (2014). "Multimodal Freight Transportation Planning: A Literature Review." European Journal of Operational Research 233:1–15.

Steenken, D., Voß S., Stahlbock R. (2004). Container terminal operation and operations research - A classification and literature review, OR Spectrum, Vol. 26, No. 1, pp. 3-49.

Robinson, S. (2004). Simulation – The practice of model development and use. Wiley.

Tran System, (2009), "IIPOD Competitive Assessment and Opportunities Study," Office of Economic Development City of Dallas.

Terminal Operations. (2017). Container Intermodal Terminals, <https://www.metrans.eu/terminal-operations/rail-hub-terminal-prague-uhrineves-cz/>, Accessed on Aug. 9, 2017.

TRB. (1992). Transportation Research Board, Intermodal marine container transportation: impediments and opportunities, TRB Special Report 236. National Academy of Sciences Transportation Research Board, Washington D.C., VA.

TT-News (2015). <http://www.ttnews.com/articles/basetemplate.aspx?storyid=38987>, Accessed on Nov. 7, 2015.

Turnbull, K., (2014). “The Role of Freight Transportation in Economic Competitiveness,” Supported by University Transportation Centers Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation, Organized by Research Board (TRB) Conference, Washington D.C.

TxDOT. (2015). Texas Department of Transportation, <http://www.txdot.gov/apps/statewide_mapping/StatewidePlanningMap.html>, Accessed on Nov. 11, 2015. “What is intermodal,” Union Pacific, <https://www.up.com/customers/intermodal/what/index.htm>, Accessed on Sep. 1, 2017.

TxDOT. (2007). Texas Department of Transportation, “Texas NAFTA Study Update,” Cambridge Systematics, Inc.

USDOT. (2015), U.S. Department of Transportation, Freight Transportation, < https://www.freight.dot.gov/freight_bookshelf.cfm>, Accessed on Mar. 7, 2018.

USDOT. (2017), U.S. Department of Transportation, U.S. Census Bureau, Foreign Trade Division, < https://usatrade.census.gov/>, Accessed on May. 5, 2018.

Zahed, E., Najafi, M., Shahandashti, M., (2017). “Investment Valuation of an Underground Freight Transportation (UFT) System in Texas,” ASCE Pipeline Conference, Phoenix, Arizona, August 2017.

Biographical Information

Fatemeh Rezaeifar received her B.S. Degree in Architectural Engineering from the Tehran University of Art and a Master of Science in Urban and Regional Planning from Tarbiat Modares University, in Tehran, Iran. She completed her Ph.D. Degree in Civil Engineering with a focus in Construction Engineering and Management at the University of Texas at Arlington (UTA).

During her time at UTA, she contributed to numerous research projects, including a project for the Texas Department of Transportation (TxDOT) on the feasibility of integrating Underground Freight Transportation (UFT) into an existing intermodal system. During her Ph.D. studies, she worked as a graduate research assistant and teaching assistant for different construction engineering and management courses.

She is a student member of the American Society of Civil Engineers (ASCE) and the North American Society for Trenchless Technology (NASTT) UTA Student Chapter. She is also a friend of the following Transportation Research Board (TRB) standing committees: Conduct of Research, Intermodal Freight Terminal Design and Operations, Construction Management, Utilities, and Urban Transportation Data and Information Systems. Her volunteer experiences as a student included the No-Dig Show on trenchless technology, ASCE Pipelines Conferences and for the 2015 and 2016 Annual High School Robot Programming Contests.