Consolidation for Import Distribution Optimization

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Abstract

With the rapid growth of the e-commerce and the increasing awareness of environmental protection, retailers are facing new challenges to make product delivery fast and green while maintaining their profit margin. A balance between service level and cost to serve is required on both strategic and operational level. Transactional transportation decisions are usually made with transportation cost minimization as a target, due to the inefficiency of information flow in the organization. In this capstone project, we introduced a practical model to perform transactional route and load planning through quantifying the business implication of shipment delay. Export container consolidation for DC by-pass in import distribution was the use case, and analysis was performed on the historical shipment data from a global sports brand. Mixed Integer Linear Programming was used to model the problem based on the routes in the existing network. Total cost minimization was the objective. Carbon emissions for line-haul movements and delivery performance were included as planning effectiveness indicators. 30% total cost reduction and 13% improvement on delivery performance were seen with the sample data. The model is very efficient for transactional planning purpose, with 80% of the runs executed within 1 second. It is also scalable to simulate various business scenarios. We expect the findings provide directions to drive product and solution development.

Capstone Advisor: Mehdi Farahani
Title: Postdoctoral Associate

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Huisi Wu

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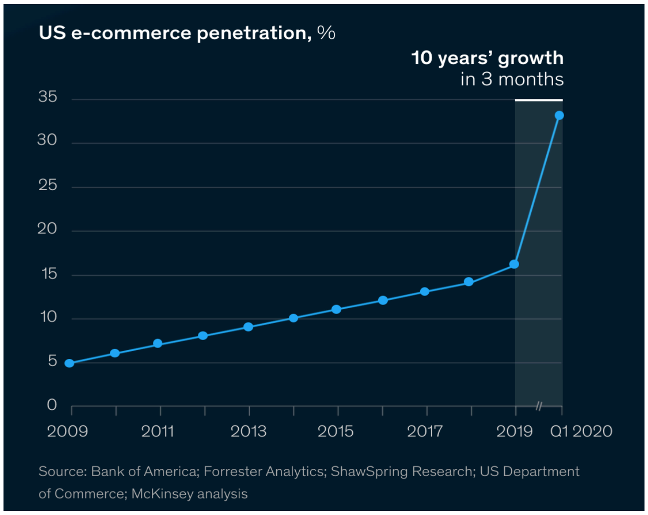
1 Introduction

1.1 New Challenges for Retailers

E-commerce growth over the past decade presented new challenges to the supply chain of the retail industry. Omnichannel fulfillment strategy was introduced and adopted by major retailers to cope with the change brought by e-commerce. It enabled consumers to purchase on-line and off-line, and to receive the products at the brick-and-mortar stores or at their doorway. Delivery with speed in smaller units is becoming the new norm (Ayers & Odegaard, 2018a). COVID-19 accelerated the growth of e-commerce. More and more people do their daily purchases on-line rather than in the physical stores only. The majority of the retail products are highly substitutional, so retailers are likely to lose the sales to their competitors if they are not meeting the customer expectation, or they are penalized for a delayed order. Figure 1 shows a steady growth of e-commerce from 2009 to 2019 in the U.S. and a spike in 2020 since the outbreak of Covid-19.

Figure 1

Increase in On-line Spend due to COVID-19 in the U.S.



Source: Bank of America; Forrester Analytics; ShawSpring Research; US Department of Commerce; McKinsey analysis

Customers are looking for product delivery with speed and on time, multiple pickup and return options, which requires flexibility in the supply chain. Flexibility leads to operating cost increase in the logistics network, so retailers are keen to review their existing supply chain strategy to stay competitive. Retailers in general tend to have a lower net margin than other sectors, ranging from 2.0% - 5.0%. (Ross, 2020). Traditionally they adopt the efficient supply chain strategy based on a high-volume procurement strategy, given the fact that both demand and supply uncertainty are relatively low. Cost optimization is the key objective in the supply chain strategy setting (Ayers, 2006). The increased focus on flexibility and the need to be cost efficient become a common challenge for retailers to stay competitive in the market.

Under these circumstances, the transportation cost is one of the important elements in the whole retail supply chain to drive the cost down. The supply chain processes are connected through transportation, and it brings in elasticity by increasing or decreasing lead time through different transportation modes based on the existing network, so that customer demand can be fulfilled properly. This brings up the question in which situations cargo should be moved by a transportation mode with a shorter transit time that costs more in general. There are debates between sales and transportation departments whether shipments should be delivered earlier with higher transportation cost to increase revenue, or they should be delivered with lower transportation cost. And there are debates on service performance between the logistics departments and the logistics service providers (LSPs) when LSPs are not providing solutions proactively but simply following standard operating procedures (SOP) without consideration to business impact. One important reason is that the whole business process is divided into sub-processes, along with split responsibilities and objectives across functional departments (Ayers & Odegaard, 2018a). This split causes a lack of common business outcome and an inefficiency of information flow. Another reason is a lack of proper tools to support daily operational decisions efficiently. Instead, transport planning including route and load planning is executed by following pre-defined decision matrices which do not necessarily optimize the business objective.

Apart from the transportation cost, the increasing awareness of the environmental protection and the reinforcement of the authorities (Pan et al., 2013a) has pushed the retailers, who heavily rely on road transportation, to take the reduction of carbon emissions into consideration.

In conclusion, cost efficiency is the key supply chain objective for retailers, while on-time delivery compliance and carbon emissions reduction are also key indicators for their supply chain effectiveness.

1.2 Motivation for Upgrading Consolidation Services

Freight consolidation has been introduced and offered as a common service by logistics service providers. Retailers utilized this service heavily to reduce their unit transportation cost from overseas. Instead of moving the underutilized containers from factories in exporting countries to the importing countries, retailers contract with LSPs who offer various freight consolidation services to collect shipments from multiple shippers. These shipments are too small in cubic meter (CBM) to require a full container to ship. LSPs consolidate the shipments into containers, then ship the containers to the importing countries, where deconsolidation takes place and deliveries are made to the final customer markets.

Consolidation has been successful in reducing the ocean freight cost per unit significantly compared to shipping underutilized containers from exporting countries. Ocean freight cost is the key consideration. Haulage cost and rehandling cost at regional distribution centers (RDC) are not considered in the daily operation for the consolidation plan in exporting countries. However, they are key cost drivers for import distribution. In addition, shipment delays are treated as an exception handling process.

In this project, we work with Maersk Logistics and Services (Maersk LNS). They are one of the top service providers in the logistics industry, and often develop new products and solutions to help their customers address business challenges.

One of the freight consolidation services offered by Maersk LNS is called CFS service–container freight station (CFS). Maersk LNS consolidates shipments from multiple shippers into containers for single customer/consignee distribution centers (DC). In general, for retailers, the containers will be delivered into RDCs after discharging at importing countries. Then shipments will be reconsolidated with containers coming from exporting countries and distributed to area distribution centers (ADC) closer to the consumer markets.

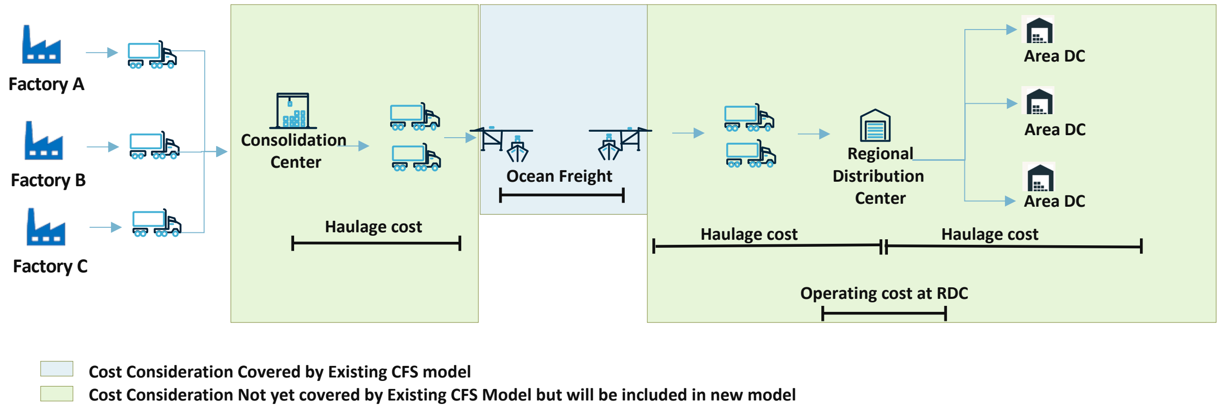
Maersk LNS relies on a transactional shipment planning tool to plan its CFS operations. Planning is conducted based on the SOPs jointly created with customers, who are the retailers in this case. The planning includes shipping schedule assignments to meet the expected delivery date specified in the purchase order, and container loading plans based on a container minimum utilization matrix, calculated with ocean freight cost as a key cost reference. The minimum utilization matrix is reviewed periodically, based on the historical shipment data. Figure 2 illustrates the cost elements being included and excluded in the current CFS service model according to Maersk LNS.

Cost pressures and changing customer expectations require a more effective way to manage the consolidation planning, taking into consideration the cost of shipment delays and the dynamic change of freight costs throughout the transportation process.

This has motivated Maersk LNS to offer the retailers a better consolidation planning service, optimizing the end-to-end transportation cost with reference to sales impact, not just the ocean cost component. In addition, the service should be efficient to execute on Maersk LNS' side, without significant increase in staff cost and system running cost.

Figure 2

Cost Elements Included and Excluded in the Current CFS Model



1.3 Problem Statement

This project is to establish a practical and scalable route and load optimization model for transactional transportation planning. The objective of the model is to optimize total cost, including transportation cost and cost of delay which is defined as a quantified factor for late deliveries. The use case is export consolidation for DC by-pass decision in import distribution for retailers. Furthermore, comparison of the results is conducted between current practice and the new model in terms of total cost, delivery performance and carbon emissions.

We will validate the business hypotheses on how cost, delivery performance and carbon emissions are interacting, and made suggestions in the actual business applications. We expect the findings provide directions to drive product and solution development.

The transportation cost includes haulage cost from CFS to port of loading (POL) in exporting countries, ocean freight from POL to port of discharge (POD) at importing countries, and the haulage cost from POD to RDC and ADC. Cost of delay is incorporated in the total transportation cost as a quantified factor in the customer service level requirement. Cost of split is introduced to reflect the additional documentation cost in the case of one shipment being split into multiple containers.

The problem will be approached in four phases:

1. Identify the possible routes and conduct cost simulation: In this phase, the relevant physical routes are the combination of CFS, POL, POD, RDC and ADC in the physical network. For one shipment, there would be two possible physical routes in the setting of this project. One is CFS-POL-POD-RDC-ADC, and the other is CFS-POL-POD-ADC. On top of the defined physical routes, a mathematical model is built with reference to four container sizes, given that ocean freight cost and container capacity differ per size. Thus, eight routes for each shipment are identified in the mathematical model. In addition, cost simulation will be done with cost reference data from Maersk LNS, based on one-year historical shipment data for the three customer markets of a global sports brand who handles all European import shipments through an RDC.

2. Model the problem: In this phase, the problem is formulated using Mixed Integer Linear Programming (MILP). The objective of the model is to minimize the total transportation cost. Assumptions are made to simplify the model as a proof of concept for the actual business practice. Constraints will be defined to make the model configurable to ensure the scalability and adaptability to apply to different transportation modes and cost structures. Input from Maersk LNS is required on the cost, the lead time for each arc in the existing network, and the cost of delay.

3. Cost Simulation and Comparison: In this phase, with the cost from the simulated historical plan, a comparison on the results will be done between current practice and the new model. Cost, on-time delivery compliance ratio, and carbon emissions for the line-haul trucking movement are the key dimensions. Till this end, the following questions will be answered with the result of the sampled customers:

Q1: Does by-passing RDCs reduce the total cost?

Q2: Does by-passing RDCs improve on-time delivery compliance?

Q3: Does by-passing RDCs reduce the distance and carbon emissions for line-haul movements?

4. Sensitivity testing: In this phase, sensitivity testing will be done to evaluate the total cost by tuning the cost parameters. The purpose is to identify a potential removal of cost elements in the end-to-end transportation network, to minimize the efforts in maintaining cost in a real business environment. In addition, sensitivity testing will be done by altering cost of delay to reflect the sales impacts for different product types in case of late deliveries. An analysis will be done to reflect the behavior of the model to help concluding the business indications.

In the following chapters, we will go through the literature review, the methodology applied, mathematical modeling, results, and the recommendations.

2 Literature Review

This study proposes a transactional consolidation model based on a multi-echelon distribution network. The model intends to support the total cost optimization from CFS at exporting countries into ADC by-passing RDC as a routing option. Carbon emissions will be key indicator based on the output of model. This literature review will cover general freight consolidation methods, the current modeling approach, and techniques for solving the problem. By reviewing the related topics, it helps to enhance the knowledge in this field, improve the methodology and better contextualize the findings in the capstone project.

2.1 Freight Consolidation

Consolidation is the process of combining shipment of small volume into certain transportation unit. The shipments can then be located, produced, and finally distributed in different locations. According to Hall (1987), there were three types of consolidation: inventory consolidation, vehicle consolidation and terminal consolidation.

Inventory consolidation is optimizing the utilization of the transportation unit by combining items produced at different times. The service level is maintained through a certain level of on-hand inventory. There is a trade-off between inventory cost and transportation cost.

Vehicle consolidation is optimizing the utilization of the transportation unit by combining shipments in different locations, usually before line haul transportation. This implies longer total travel distance and higher cost in the pick-up process, and there is a trade-off between pick-up cost and line-haul transportation cost.

Terminal consolidation is optimizing the utilization of the transport unit by gathering shipments in a facility. In the facility, shipments are sorted and put into the transportation unit. There is a trade-off between fixed and variable operating cost at the facility and the line-haul transportation cost.

The focus of our capstone is a combined method, both inventory consolidation and terminal consolidation. Shipments are delivered into a consolidation center (CFS), from where they are sorted by a set of rules and containerized based on certain objectives and constraints.

2.2 Transportation Modeling Approach

Transportation modeling can be applied to different objectives. The objective could be to optimize the supply chain network or to minimize the ocean freight cost. The modeling is also subject to different constraints like consolidation, network planning, routing, time limits, capacities, etc. The combination of the objective and constraints determines the modeling approach and the algorithm being deployed. We reviewed the papers related to this subject, which are summarized in Figure 3.

Tsiakis et al. (2001) proposed a network optimization model with the objective to minimize the annual transportation and distribution cost in a multi-echelon supply chain network. MILP was used to formulate the problem. Consolidation and distribution centers are the nodes and binary variables to determine the best routings in the overall network design.

Nguyen et al.(2014) proposed a stochastic dynamic programming approach to minimize line-haul transportation costs from a consolidation location into multiple destinations. It was using a transactional model that considers line-haul trucking cost to the single delivery point in a particular destination, meaning a single-echelon distribution network.

Tiwari et al. (2021) intended to minimize the total cost of import shipments in a multi-echelon distribution network. The model includes ocean transportation cost, the trucking cost from POD to RDC and the trucking cost from RDC into retail stores. This model did not include fixed and variable cost of the RDC. It did not consider the routing option to by-pass the RDC. Environmental factors were introduced to balance transportation cost and carbon emissions.

Hanbazazah et al.(2019) modeled the target delivery window of the shipments into the consolidation strategy. Shipments are delivered to a consolidation center separately by various factories and must be delivered to the ADCs at destination. Table 1 illustrates the relations and differences in terms of objectives and modeling approach to the research topic. A MILP model is applied in majority of the papers to model the consolidation problems.

Table 1

Summary of Modeling Approaches of Existing Research and Differences Compared to the Capstone Project Scope

Authors		**1.Nguyen et al. (2014)**	**2. Tsiakis et al. (2001)**	**3. Tiwari et al. (2021)**	**4. Hanbazazah et al., (2019)**
Objective		Transactionally minimize long-haul transportation costs from a consolidation location into multiple destinations	Network Optimization - Cost effectiveness	Transactionally minimizes the total cost of import shipment in a multi-echelon distribution network, balancing carbon emission	Transactionally minimize the transportation cost from supplier locations to single area DC through multiple gateway
Modeling Approach		Stochastic dynamic programming	MILP	MILP	MILP
Input to the model					
1	Production Cost	Not included	Included	Not included	Not included
2	Inventory Cost	Not included	Included	Not Included	Not Included
3	Transportation cost from supplier to consolidation center	Not included	Included	Not Included	Included
4	Long-haul transportation cost	Included (FTL/LTL/Courier Cost)	Included	Included (Ocean transportation cost)	Included
5	Cost from discharge port to RDC	Not included	Included	Included	Included
6	Cost from RDC to Area DC/retail stores	Not included	Included	Included	Included
7	Fixed and Variable operating cost in RDC	Not included	Included	Not Included	Not Included
8	Gateway	Single gateway to customer location	Single gateway to customer location	Single gateway to customer location	Multiple gateway to customer location
9	Carbon emission	Not included	Not included	Included	Not Included
Relation to Thesis		Consolidation of shipment from multiple shippers	Multi-echelon distribution network	Multi-echelon distribution network	Single-echelon distribution network with multiple gateway
		Stochastic demand - transactional model		Transitional model	Hard delivery time constraints
Difference to the Thesis		Single echelon in distribution network	Network optimization model	Fixed and Variable cost in RDC is not included	A single customer with multi-period horizon

2.3 Carbon Emissions Modeling

For our study, the objective is to minimize the total cost. To further evaluate the effectiveness of the route and load plan, carbon emissions and on-time delivery compliance are introduced as indicators. On-time delivery compliance indicates the compliance ratio that a delivery is made to meet the customer delivery expectation. Carbon emissions give good indication on the sustainability of the solution. There are two popular approaches to evaluate carbon emissions:

1) Use Pareto Efficiency and Multi Objective Optimization to find the efficient frontier of logistics cost and environmental emissions. This methodology is discussed in detail by Frota Neto et al.(2008). This approach was used in the study by Pan et al.(2013a), and it contrasted tons of equivalent CO_2 on one axis, vs. transportation cost on the other.
2) The carbon tax approach used by Tiwari et al.(2021) when planning freight consolidation between two ports as a conversion of emissions into a currency cost value, and adds the value to a single objective function along with transportation cost to be minimized.

2.4 Carbon Emission Conversion

A survey of road transport emissions calculation methodologies shows three categories of emission models: macroscopic, microscopic, and factor models (Demir et al., 2014).

One model was used in France to study retail shipment consolidation emissions for electric trains and road transport (Pan et al., 2013b). The France-focused study identified the efficient frontier of cost/emissions trade-off when emissions are optimized, but also added intermodal transportation (electric trains) into the equation. Indeed, consolidating shipments results in reduced loads, thus reduced the sum of kilometers/miles to drive. This study also emphasized the detrimental impact of the large, fixed cost associated with each truck/train trip. Thus, reducing the number of loads through better consolidation always yields significant cost and emissions reductions.

In the case of ocean shipping, the paper by Tiwari et al.(2021) considered the model by Leonardi & Browne(2010) for calculating maritime emissions. It also considered the paper by Brander(2012) to calculate equivalent CO_2 emissions for truck transports.

2.5 Solution Process and Techniques

The solution method varied between commercial solvers in the papers by Pan et al., (2013a) and Tiwari et al., (2021), however, the papers by Cóccola et al., (2015), Geoffrion & Graves, (1974), Hanbazazah et al., (2019) and Nguyen et al.,(2014) used custom heuristics. The choice of either method depends on the efficiency; commercial solvers are easier to implement and use but could underperform in efficiency. Heuristics could solve the problem much faster, but require programming knowledge, and their solutions are not exact. For our case, efficiency is key. MILP will be applied to model the problem and Open Solver that uses COIN-OR CBC optimization engine will be used to solve the problem.

2.6 Conclusion on Literature Review

The literature review covers the modeling of optimization problems including network optimization and transportation cost optimization. Cost elements included in each paper are slightly different based on the objective. MILP in general is being applied as the modeling approach.

In addition, the literature review covers the modeling of carbon emission optimization. In discussions with Maersk LNS, they confirmed our view that the conversion of carbon emissions into a currency cost value used by Tiwari et al. (2021) is more suitable for the operational weekly decision making we are researching. Thus, the carbon emission conversion methods will also be covered.

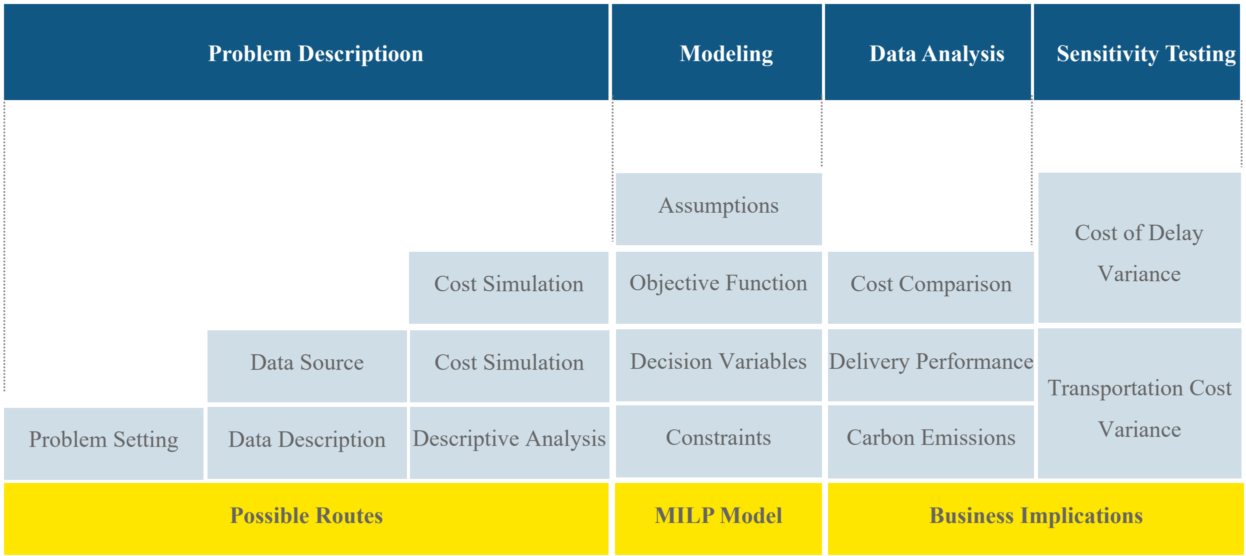
In conclusion, our study will apply MILP to model the problem and will use similar models and techniques to the carbon tax approach to formulate and calculate CO_2 emission with difference in terms of the input elements, the constraints and objective. The conversion method of carbon emission and the technique to solve the problem are discussed in the methodology section.

3 Methodology

Our methodology is shown in Figure 3. Initially, we examined and understood the problem context and research setting, then did the modeling and ran the analysis. We discussed the problem context, the physical network, data availability, data fields and their business meanings, the business partners' need for analysis and how they intend to use the models, the indicators, and the optimization business objective. Based on these, the possible routes were identified, and cost simulation of the historical plan was performed. Then the technical modeling approach was discussed, including the objective function, the constraints, and the input parameters. Finally, the model was tested with historical data and the results were analyzed. The modeling results will be discussed in chapter 4.

Figure 3

Summary of Modeling Approaches of Existing Research and Differences Compared to the Capstone Project Scope



3.1 Problem Description

3.1.1 Problem Setting

The problem was set at a logistics service provider, Maersk LNS, in an ocean shipping operation of standard containers. The process starts at a CFS in exporting country where shipments are consolidated in containers. The containers are trucked to POL and shipped by ocean to the POD in the importing country, then further into RDCs and ADCs in the importing country by truck. Historical shipment data is available for all customers' shipments, however, we decided to pick one of the largest and most well-known retail brands with established operating procedures for cargo consolidation, to properly model their existing consolidation and import distribution policies, and to compare them against our proposed model. We focused on shipments from one port of loading into three European markets.

The selected customer is a global sports brand. The customer consolidates cargo from Shenzhen, China, and delivers to the RDC in Belgium. The only PODs involved are Antwerp and Rotterdam. They are alternative ports, depending on the carrier routing. For simplicity, Rotterdam was used as POD in this study. Shipments are sent directly to the stores in European countries. The shipments for customer market Italy, Russia and Germany were selected in this study. They were representative in terms of distance to the RDC – Germany is close to Belgium, while Russia and Italy are relatively far away. We expect to see how the results of the model look like for each market, given the difference in lead time and distance between the route through RDC and by-passing RDC. There was no ADC setup during the time in scope of this project. The distribution centers of Maersk LNS in Italy, Russia and Germany were taken as ADCs to simulate the multi-echelon distribution network for the customer.

3.1.2 Data Source

Maersk LNS was the primary data source for the data used in this study. The data provided the information for the existing operation network of the two sample retailers, the selected routes for each historical shipment, and the cost for each arc in the network. With these data, total transportation cost, total lead time and carbon emissions could be simulated to be compared with the outcome of the optimization model. Table 2 provides an overview of list of data and the sources.

Table 2

Data Sources Overview

Data Type	Source
Historical Shipment Record	Maersk Logistics and Service Reporting Tools Data Range 1. Vessel Departure 01-01-2019 - 12-31-2019 2. Port of Loading : Shenzhen, China 3. Final importing countries: Italy, Russia, Germany
Customer DC List	Maersk Logistics and Services DCs in Europe
Trucking Cost (CFS - POL)	Maersk Standard Trucking Rates
Ocean Freight	Maersk Standard Ocean Rates
Trucking Cost (POD - RDC, RDC - ADC, POD - ADC)	Maersk Standard Trucking Rates
Distance between nodes (ports, DCs)	Google Maps

3.1.3 Data Description

3.1.3.1 Historical Shipment Data and DC list

Historical shipments data is contained in table 4 with the associated explanation.

Table 3 contains the information on the existing network of the customer.

Table 3

Shipment Report Fields Description

Shipment Report Field Name	Explanation
Booking Number/Purchase Order	The entity includes purchase orders to be delivered as smallest unit. Shipment number
Actual Measurement	CBM (Cubic Metres) of the shipment
Actual Weight	Weight of the shipment
Actual Receipt Date	1) The date when the shipment is being delivered to the consolidation center 2) ETD should not be earlier than this date
Expected Delivery Date	The date when the cargo is expected to be delivered into ADC
Equipment Number	Container number
Equipment Size	Container size
Equipment Type	Container type
Container Size and Type	Container size and type
Origin Service	Consolidation method at exporting country, e.g. factory load (CY) or consolidation of shipment from multiple shippers (CFS)
Destination Service	If this column = CFS, then it is LCL (the shipment was consolidated with cargo from other customers)
ETD	Vessel departure from port of loading
ETA	Vessel arrival from port of discharge
Origin Port of Loading	Port of loading at exporting country
Port Of Discharge	Port of discharge at importing country
Place Of Delivery	Place of delivery (inland location) by carrier
Last Ocean Vessel	Vessel name
Last Ocean Voyage	Voyage name
Final Destination	Customer market - Country

Table 4

Customer POD and DC Locations

Customer Market	RDC	POD	ADC	POD (bypassing RDC)
Italy	Belgium	Antwerp/Rotterdam	Vado	Genoa
Russia	Belgium	Antwerp/Rotterdam	St.Petersburg	St. Petersburg
Germany	Belgium	Antwerp/Rotterdam	Bremen	Bremerhaven

3.1.3.2 Physical Network and Routes

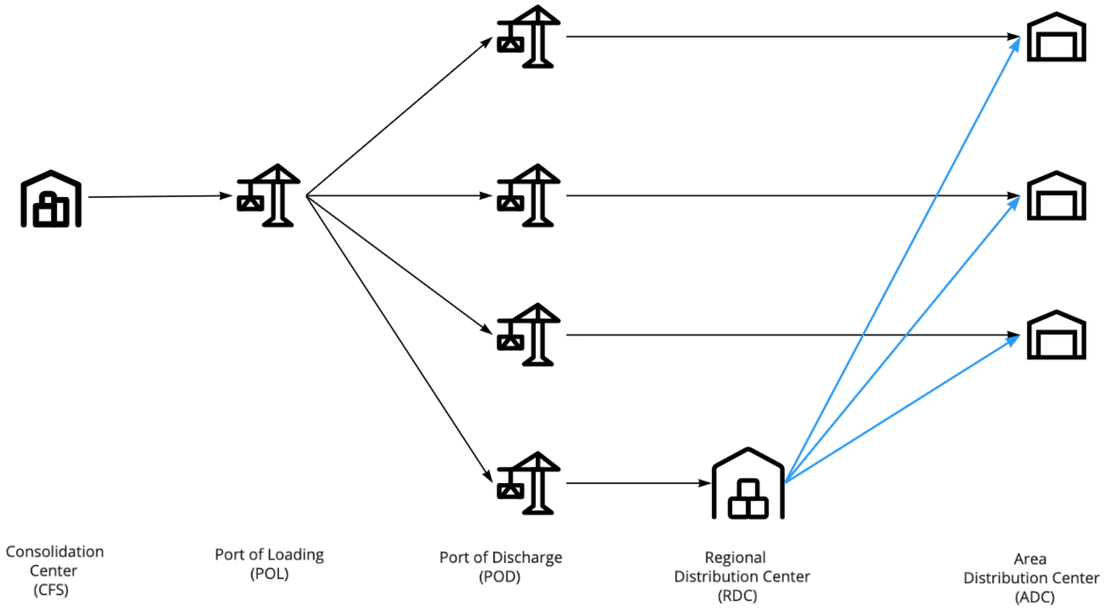
The physical distribution network was built with nodes and arcs. The nodes included CFS, POL, POD, RDC and ADC. Each arc was built with two nodes. With the nodes and arcs in the existing network, a route was built to cover the end-to-end physical cargo flow from CFS in the exporting country to ADC in the importing country. For each shipment, there were two possible physical routes in the setting of this project. One was CFS-POL-POD-RDC-ADC, the other was CFS-POL-POD-ADC. Figure 4 illustrates the physical network model with the nodes and arcs.

The customer was using 4 types of containers for ocean transportation, these were 20-ft. dry, 40-ft. dry, 40-ft. high-cube and 45-ft. high-cube. Each shipment would potentially be consolidated in any container size during the planning cycle, thus on top of the physical network, container sizes were taken into consideration for the route definition in the mathematical model.

For the selected customer, the network in the research scope included 10 nodes and 12 arcs that built up a physical network of 6 physical routes into customer markets Italy, Russia and Germany. With consideration of the 4 container sizes, 24 routes in total were identified for the mathematic model.

Figure 4

Physical Network Model



3.1.3.3 Transportation Costs and Distance for the Routes

Based on the exiting network, as input to the model, the transportation cost parameter was built based on the two defined routes. One was CFS-POL-POD-RDC-ADC, the other was CFS-POL-POD-ADC. Similarly, the total transportation lead time and the total distance travelled were built per route.

1) The transportation cost for the route CFS-POL-POD-RDC-ADC was composed of two parts. The first part was container-level cost from CFS, POL, POD to RDC. The second part was from RDC to ADC on CBM level. The first part of the cost was the sum of trucking cost to CFS, the ocean freight from POL to POD, and the trucking cost from POD to RDC. The second part of the cost was on CBM level, because the container would be deconsolidated and reconsolidated in the RDC into different ADCs. The CBM-level cost included the rehandling cost at RDC and the

trucking cost from the RDC to each ADC. The rehandling mainly refers to labor cost which takes up at least 70% of the total operating cost according to Maersk LNS. And the assumption of the rehandling cost was made with one employee operating for 10 hours to finish the task per container. For the trucking cost from the RDC to each ADC, the assumption was made that an outbound trailer has a capacity of 91 CBM in Europe and each trailer was fully utilized.

2) The transportation cost for the route CFS-POL-POD-ADC, meaning the containers were shipped from CFS directly to ADCs by-passing RDC, without deconsolidation and reconsolidation activities in between. The end-to-end transportation cost included trucking cost from CFS to POL, ocean freight from POL to POD, and the trucking cost from POD to ADCs. All the cost elements remained on container level. Table 5 and Table 6 shows the cost elements included in the cost parameters for the route CFS-POL-POD-RDC-ADC and the route CFS-POL-POD-ADC respectively.

Similarly, the distance for the routes was built by adding up the distance of the arcs shown in Table 7 below. However, given that the carbon emissions in line-haul movements in the importing country was the focus of this study, the routes started from POD. Therefore, there were two routes for each shipment, one was POD-RDC-ADC, the other was POD-ADC. Table 8 shows the distance for the routes that built upon the related arcs.

Table 5

Cost Parameter Composition for the Route CFS-POL-POD-RDC-ADC

Cost Parameters	Cost Elements
Container-Level Transportation Cost	**Trucking cost** From : CFS To : POL
	Ocean freight cost From: POL To: POD
	Trucking cost From : POD To : RDC
CBM-level Cost	Trucking cost From : RDC To: ADC
	Operating cost In : RDC

Table 6

Cost Parameter Composition for the Route CFS-POL-POD-ADC

Cost Parameters	Cost Elements
Container-Level Transportation Cost	**Trucking cost** From : CFS To : POL
	Ocean freight cost From: POL To: POD
	Trucking cost From : POD To : ADC

Table 7

Distance between the Nodes in the Physical Network

From	To	Kilometers
RDC	Italy ADC	1102
RDC	Germany ADC	437
RDC	Russia ADC	2405
Rotterdam Port (POD)	RDC	144
Genoa Port (POD)	Italy ADC	52.6
St. Petersburg Port (POD)	Russia ADC	23
Bremerhaven Port (POD)	Germany ADC	81

Table 8

Distance per the Routes for Import Distribution

Customer Market	POD-RDC-ADC (Kilometers)	POD-ADC (Kilometers)
Italy	1246	52.6
Russia	2549	23
Germany	225	81

3.1.3.4 Cost of Delay

Cost of delay was modeled to reflect the potential sales loss for late delivery. It was a key input parameter to the proposed model and was highly related to the profit margin of the products.

The profit margin of the customer, a global sport brand, was around 13%. Based on the historical shipment data, there were approximately 155 pieces of product per CBM, and the revenue was assumed as $50 per piece. The profit loss would be $813 per CBM. The average lead time from Shenzhen, China to the customer market Italy, Russia and Germany was 32 days. Cost of delay was calculated as $25 / CBM/ day, meaning $25 extra cost occurred for each CBM shipped if the arrival date was one day later than expected delivery date.

3.1.3.5 Cost of Split

Cost of split was introduced to reflect the additional documentation cost in the case when one shipment was split into multiple containers. Whenever one shipment was split into two, additional custom clearance cost would occur, for both import and export clearance. In this study, the standard Maersk LNS rate was applied. The export clearance cost was the tariff rate for Shenzhen port, while the import clearance was the average tariff rate of Italy, Russia, Germany, and Belgium for the customer.

3.1.4 Cost Simulation of Historical Load Plan

In this study, we focused on three customer markets, Italy, Russia, and Germany. Replanning the containers based on the existing policies was required for the shipments for the three customer markets to make sure that the container sizes were assigned to reflect the reduced volume, so the transportation cost was reasonably allocated. The purpose of doing this simulation was to enable a fair comparison between current practice and the solution proposed by the new model in terms of cost, on-time delivery compliance, and carbon emissions for the line-haul trucking movement at import distribution, based on the assumption that the same transportation mode by ocean and by truck was applied.

3.1 5 Descriptive Analysis

The annual CFS volume for Italy, Russia and Germany totals 6661 CBM for 2019 after data clearance. Germany took up 65%. Italy and Russia took up 17% and 18% respectively. Figure 5 shows the volume in CBM and the share for each customer market.

All the shipments are consolidated at the CFS and delivered into the RDC before reconsolidation and delivery into each ADC as per the existing policies. Thus, the container count and utilization refereed to the containers for the RDC. Around 55% of the volume was moved in 20-ft.dry, and close to 41% was moved with 40-ft.dry. Only 4% of bigger-size containers were used. When it comes to container utilization, the average cbm per container was 14.93, 41.90, 62.70 and 74.11 respectively for each container size. Figure 6 shows the container count per container size. Figure 7 shows the average utilization per container size.

Figure 5

Volume (CBM) and Share (%) for the Three Customer Markets

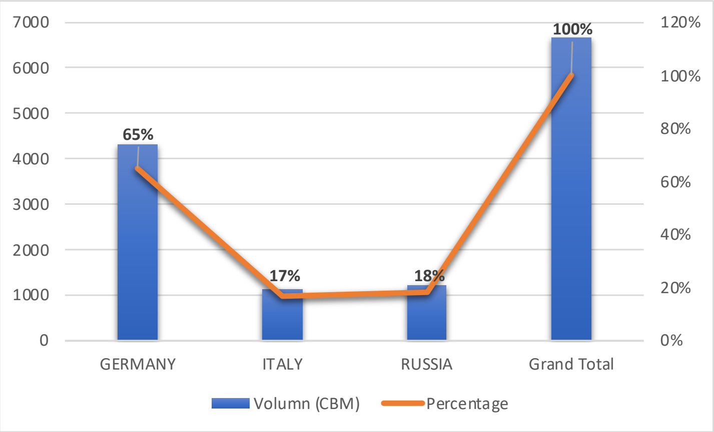


Figure 6

Container Count per Container Size

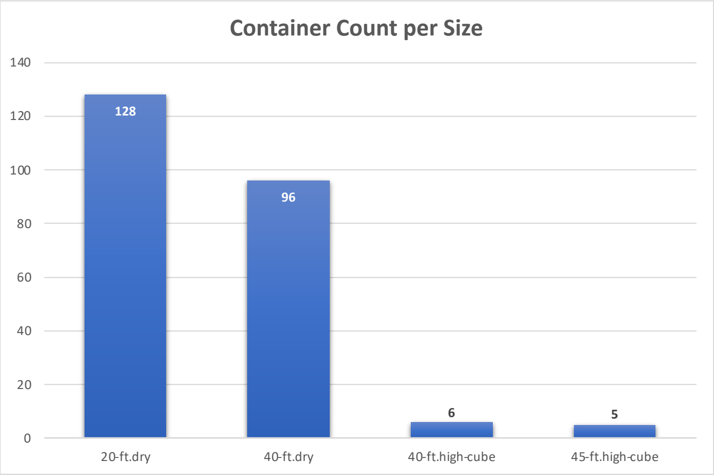
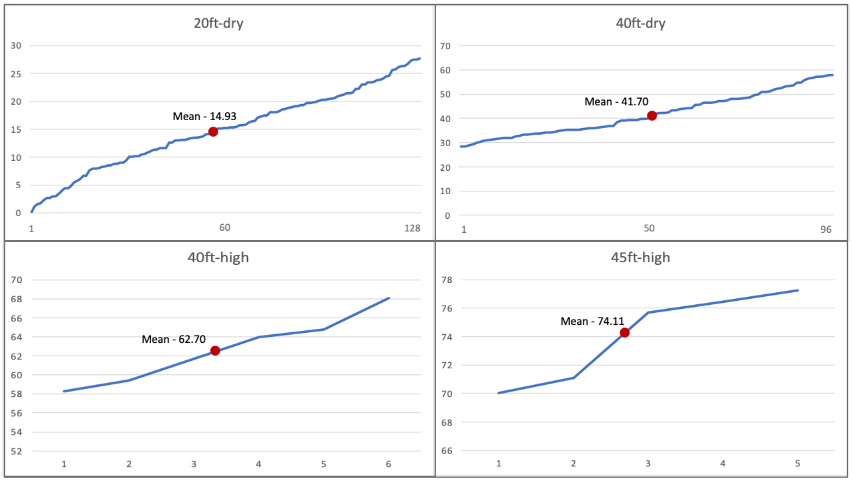


Figure 7

Average Container Utilization per Container Size and Type



3.1.6 Research questions

To this end, we have in place the required input to the proposed model, including possible routes in the existing network, cost parameters, distance between nodes and the simulated cost of historical shipment, the purpose is to answer the following questions by developing an optimization model, and comparing results to the simulated result of the existing policy :

Q1: Does by-passing regional distribution center reduce the total cost?

Q2: Does by-passing regional distribution center improve on-time delivery compliance?

Q3: Does by-passing regional distribution centers reduce the distance and carbon emissions for line-haul movements at import distribution?

3.2 Modeling

After identifying the routes in the existing network and conducting the cost simulation of the historical shipment plan in phase 1, we went through the modeling process. This modeling section covers the assumptions, the objective function, the constraints of the model and two performance indicators – on-time delivery compliance and carbon emissions.

3.2.1 Assumptions

To ensure the research questions are accurately modeled and analyzed, certain assumptions are made as below:

1) Shipments in scope have been delivered into the CFS. This means any cost occurred before cargo delivery into CFS is not considered in the model.
2) Shipments consolidated in same container in the historical plan is considered as one planning run.
3) Carrier space availability is not a constraint, so unlimited number of containers of any size are available on a single vessel sailing.
4) The choice of POD impacts the distance, lead time, and haulage cost. To limit data processing to a reasonable scale and to focus on the analysis of the real-life problems, logistics domain knowledge is applied to set up POD for RDC and ADC. Thus, each DC is assigned a specific POD.
5) Lead time between each node is deterministic and derived from vessel schedule published on carrier's website, same for the haulage lead time.
6) Distance between each node is known and derived through Google Maps based on the address of each node. Approximation is applied when converting the distance.
7) Vessels with different PODs depart from Shenzhen on the same day of the week. This is to eliminate the impact of different departure dates offsetting the difference of lead time on different carrier routes.

8) The carbon emission in ocean transportation is not considered, because the main objective is to test the impact of carbon emission generated through road transportation going through or bypassing RDC, and the ocean emissions are too small to make a marginal difference between European ports for the volumes in question.

3.2.2 Total Cost Equation

According to Maersk LNS, cost efficiency is the most relevant objective for retailers. On-time delivery compliance and the reduction of carbon emissions serve as indicators when evaluating the execution performance.

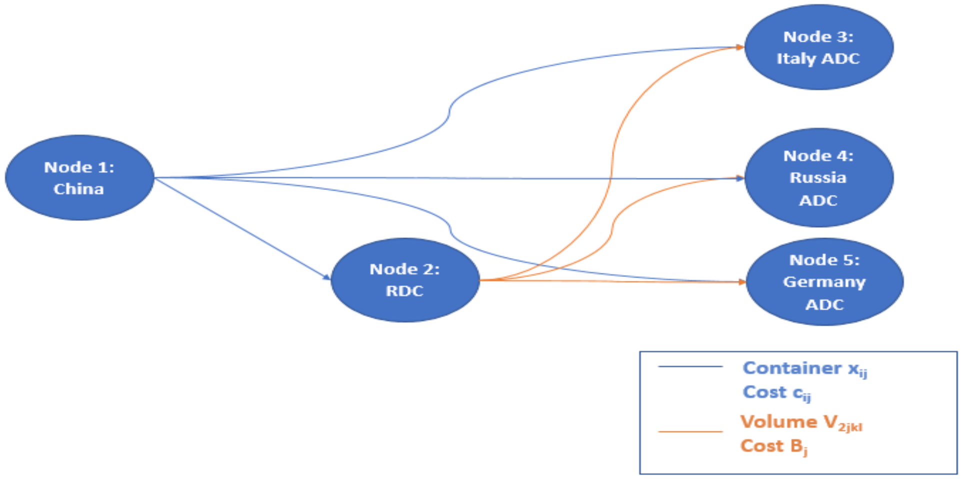
The total cost in scope was comprised of transportation cost and cost of delay. The transportation cost included trucking cost from CFS to POL, ocean freight from POL to POD, the trucking cost from POD to ADCs through RDC or bypassing RDC, and cost of split if one shipment being split into multiple containers. Cost of delay was a quantified cost parameter as penalty for late delivery. Based on the routes defined in chapter 3.1.3.3, and the cost parameters in Table 5 and Table 6, the total cost per run in the optimization was defined as

Total cost = Container-level transportation cost for Route CFS-POL-POD-ADC
+ Container-level transportation cost for Route CFS-POL-POD-RCD-ADC
+ CBM-level cost for Route CFS-POL-POD-RCD-ADC
+ Cost of split
+ Cost of delay

Figure 8 shows the possible routes defined in phase 1 and node numbering. Legend notation was explained in section 3.2.3. This was not a physical network, but a conceptual representation of how arcs and nodes are used in the mathematical model developed. Each node was a point at which a decision was made to for the shipment to proceed to further nodes on CBM level. On top, container sizes were included in this conceptual framework, meaning the conceptual route was a combination of physical nodes and container sizes. Till this end, MILP was applied in modeling the flow of shipment for the lowest total cost as defined by the total cost equation.

Figure 8

Conceptual Network Routes



3.2.3 Notation

The model inputs are divided into two categories: decision variables and parameters, as shown in Table 9 below.

Table 9

Notation

Notation	Classification	Description	Unit
V_{ijkl}	Decision Variable	Volume leaving China node to node i with final destination node j as part of shipment k on container type l.	CBM

x_{il}	Decision Variable	number of type l containers going to destination i (i ∈ {2,3,4,5})	NA
N_{ikl}	Decision Variable	0-1 Binary indicating 1 piece of shipment k shipped from node 0 to node i on container type l ∈ {2,3,4,5}	NA
Node #	Parameter	Node 1: China. Node 2: RDC. Node 3: Italy. Node 4: Germany. Node 5: Russia	NA
Index i	Parameter	i is the destination node of arcs starting at Node 1 (China) i ∈ {2,3,4,5}	NA
Index j	Parameter	j is the final destination node where product demand is required j ∈ {3,4,5}	NA
Index k	Parameter	k is a shipment made up of Cubic Meters (CBMs) of products. k ∈ $\{each\ week\ bookings\}$	NA
Index l	Parameter	l is the ocean container type corresponding to 20 Dry, 40 Dry, 40 High, 45 High. l ∈ {1,2,3,4}	NA
c_{il}	Parameter	Cost per container going from China to destination i on container type l. i ∈ {2,3,4,5}	Relevant currency
B_j	Parameter	Cost to handle and ship 1 CBM from node 2 (RDC) to node j (trucking from RDC to ADC j, and handling per CBM at RDC)	Relevant currency
P_l	Parameter	Capacity of container l ∈ {1,2,3,4}. Corresponds to (26, 56, 66, 76) (varies from one product group to another based on product packaging characteristics (pallets, cartons, etc.), so each customer model varies.	CBM

W_l	Parameter	Weight capacity of container $l \in \{1,2,3,4\}$. Equals 26 metric tons for any container $l \in \{1,2,3,4\}$.	Metric tons
L_{ijk}	Parameter	Cost of delay per CBM from Node 1 (China) to node i and final node j per shipment k. ($i \in \{2,3,4,5\}, j \in \{3,4,5\}$)	Relevant currency
S	Parameter	Cost of splitting k shipment across routes per single split (universal across all k shipments)	Relevant currency
M	Parameter	Any big number larger than or equal to the sum of V_{ijkl}	CBM
Q	Parameter	Number of shipments in one planning run	NA
Z	Objective Function	Total Cost	NA
F	Objective Function	Number of shilpment	NA

3.2.4 Objective function in mathematical form

With the conceptual routes defined as per Figure 8, the objective function in mathematical form is built as below

$$\boldsymbol{min\ Z} = \sum_{i=2}^{5}\sum_{l=1}^{4} \boldsymbol{x_{il}c_{il}} +$$

1) Origin container shipping cost

(Trucking cost CFS-POL,

Ocean freight POL-POD,

Trucking cost POL- RDC/ADC)

$$\sum_{j=3}^{5} \boldsymbol{B_j} \sum_{k=1}^{Q}\sum_{l=1}^{4} \boldsymbol{V_{2jkl}} +$$

2) Cost of shipped volume RDC-ADC

$$\sum_{j=2}^{4}\Big(\sum_{k=1}^{Z}\sum_{i=2}^{5} \boldsymbol{L_{ijk}} \sum_{l=1}^{4} \boldsymbol{V_{ijkl}}$$

3) Cost of shipped volume CFS-POD

$$\sum_{i=1}^{4}\sum_{k=1}^{Z}\sum_{l=1}^{4} \boldsymbol{N_{ikl}} - \boldsymbol{K}\Big)$$

4) Cost of split

3.2.5 Decision Variables

The outcome of the transactional optimization model will determine the number and type of containers going through each i routing, the volume of each booking k going through each container type l on each i route, and the splitting of each booking on each route, with the objective of total relevant cost optimization.

Decision Variables: $V_{ijkl}, x_{il}, N_{ikl}$

3.2.6 Constraints

Following are the constraints, based on discussion with sponsor and observations in modeling:

1) A demand constraint is needed to ensure all volumes go to the correct demand destinations

$$\sum_{i=2}^{5}\sum_{l=1}^{4}\sum_{k=1}^{F} V_{ijkl} \geq \sum_{k=1}^{k=\mathrm{F}} D_{jk} \qquad \text{for all j } \in \{1,2,3\}$$

2) Container capacity must be limited to the physical CBMs:

$$\sum_{i=2}^{5} P_l\, x_{il} \geq \sum_{i=2}^{5}\sum_{j=3}^{5}\sum_{k=1}^{F} V_{ijkl} \qquad for\ all\ l\ \in \{1,2,3,4\}$$

3) Containers weight constraints must be limited to regulated container limits:

$$\sum_{i=2}^{5} W_l\, x_{ij} \geq \sum_{i=2}^{5}\sum_{l=1}^{4}\sum_{k=1}^{F} V_{ijkl} \qquad \text{for all l } \in \{1,2,3,4\}$$

4) Each and every shipment demand must be satisfied:

$$\sum_{i=2}^{5}\sum_{l=1}^{4}\sum_{j=3}^{5} V_{ijkl} \geq \sum_{k=1}^{k=\mathrm{F}} D_k \qquad \text{for all k } \in \{1,2,3\}$$

5) Cost of split linking constraint

   Big M Constraint. Big M should not be less than maximum shipment k volume. N is a binary indicating a shipment CBM goes through node i

$$\sum_{l=1}^{4}\sum_{j=3}^{5} V_{ijkl} \geq \mathrm{M}\, N_{ikl} \qquad \text{for all i, k, l}$$

$x_{il} \in Integer\ \{0,1,2,3,\ldots\}$ $N_{ikl} \in Binary\ \{0,1\}$

3.3 Carbon Emissions

Carbon emissions are measured using the unit of kilograms of CO2 (CO2 KGs). Each mode of transport kilometer is converted to CO2 KGs using a different equation as per Pan et al. (2013b). In our case, we ignored ocean shipping emissions, and decided to focus on trucking emissions, as per the modeling assumptions in section 3.2.1. Trucking in Europe is done using an HDV (Heavy Duty Vehicle) with capacity for 25 tons of cargo, as described by Pan et al. (2013), and the emissions equation assumed 1.096 CO2 KGs per kilometer (km) of a fully loaded HDV; fully loaded means a weight loading of maximum 25 tons, with no volume limits, since we also assumed the HDV can handle the size of any ocean container we are using in our optimization model. A few assumptions were also made in the paper by Pan et al., as follows:

1) An empty truck is assumed to emit 0.772 CO2 KGs per km.
2) The gradient of the road is not considered
3) The truck average speed is 80 km/h.

The model calculated the number of CO2 KGs per km using the following equations:

1) Truck from port of discharge to RDC/ADC destination:

$$CO2\ KGs\ per\ KM = \left(\varepsilon_{vf} - \varepsilon_{ve}\right)\left(\frac{x}{c}\right) + \varepsilon_{ve}\left\lceil\frac{x}{c}\right\rceil$$

2) Truck from RDC to ADC:

$$CO2\ KGs\ per\ KM = \left(\varepsilon_{vf} - \varepsilon_{ve}\right)\left(\frac{x}{c}\right) + \varepsilon_{ve}\left(\frac{x}{c}\right)$$

Where x is the weight in tons of the container cargo, and c is the maximum capacity of the HDV (25 tons).The only difference between the two equations is we do not round up the second term x/c in the second equation, because we assume there are other volumes in the truck utilizing the 25 tons maximum capacity, so the empty truck emissions are allocated fairly across all tonnage.

In the first term, since our CBM is absorbing the empty truck emissions completely, we have to round up to 1.

We calculate CO2 KGs on the simulated historical plan and the plan from the new model. Comparison of emissions per 1 transported CBM is shown in the section 4.3. The driving distance in kilometers between the nodes is obtained from Google Maps, as shown in Table 7.

4 Results and Discussions

In this chapter, the comparison between the cost of simulated historical plan and the cost from the new model will be discussed. A brief overview and analysis of the on-time delivery compliance and carbon emissions will be provided as a key indicator of the effectiveness of the new model. Then, the three hypotheses will be revisited and the related conclusion will be presented.

The sensitivity testing results discussion will follow with the identification of the binding variables. The findings will provide recommendations on cost maintenance to improve the practicality of the model application in the day-to-day operation. In addition, we will examine behavior of the model by altering the cost of delay as a parameter, which helped to simulate the profit loss in different industries and to see how the cost of delay impacted the transportation decision.

Lastly, post-hoc research suggestion will be included in this section.

4.1 Cost Comparison and Analysis on Based Model

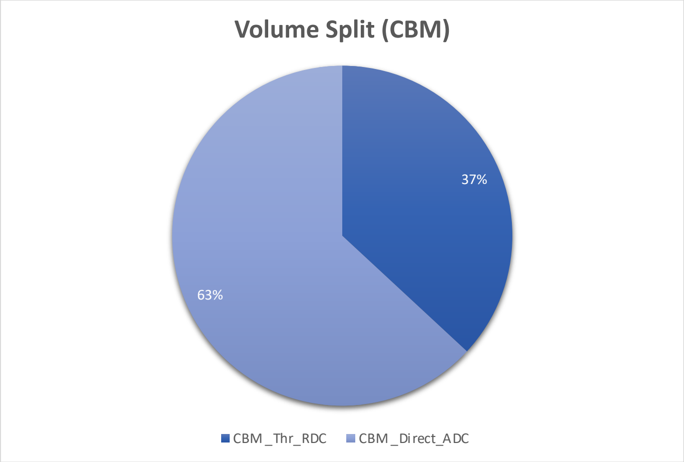
In the section, we will review the results from the new model. We will go through the cost comparison between the historical plan and the new model. Then we will discuss each cost component and the cost drivers.

4.1.1 Load Plan Result from the New Model

The result from the new model showed 63% of the volume routed directly into ADC when by-passing the RDC was an option in the network in the new model. Figure 9 shows the percentage of volume moving through RDC or bypassing RDC.

Figure 9

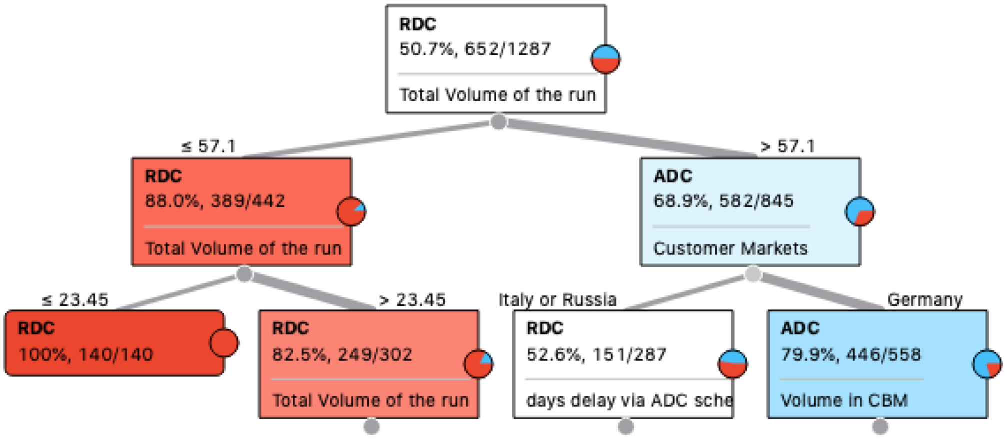
Volume Split – Volume through RDC vs Volume By-passing RDC



It was observed that when the total volume of the shipments per run was less than or equal to 57.1 CBM, 88% of the shipments, regardless of customer markets, were assigned to the route CFS-POL-POD-RDC-ADC, meaning they were not by-passing RDC. When the total volume per run was higher than 57.1 cbm, 68.9% of the shipment were assigned to the route CFS-POL-POD-ADC, meaning they were by-passing RDC. And shipments bound for Germany were more likely, 79.9%, to be routed by-passing RDC than the other two customer markets. Figure 10 is a snapshot of the results from the classification model, providing an overview of the route decision on shipment count.

Figure 10

Classification Tree for Shipment Route Allocation



4.1.2 Cost comparison and analysis

The total cost included haulage cost from CFS to POL in exporting country, the ocean freight cost from POL to POD, the haulage cost from POD to RDC and to ADC in the importing country. The cost of delay and the cost of split were also included.

The total cost from the new model was 31.50% lower than the simulated historical plan. Figure 11 shows the comparison between the simulated cost of the historical plan and the cost from the new model. Figure 12 shows the contribution of the reduction for each cost component.

The transportation cost from POD to ADC and the cost of delay contributed the biggest share of the total reduction. The cost of split was the only increase, because a single shipment was allowed to split into different containers in the new model while the split was not allowed in the current model. Different cost drivers were seen for each cost element.

Figure 11

Contribution of Reduction for Each Cost Component

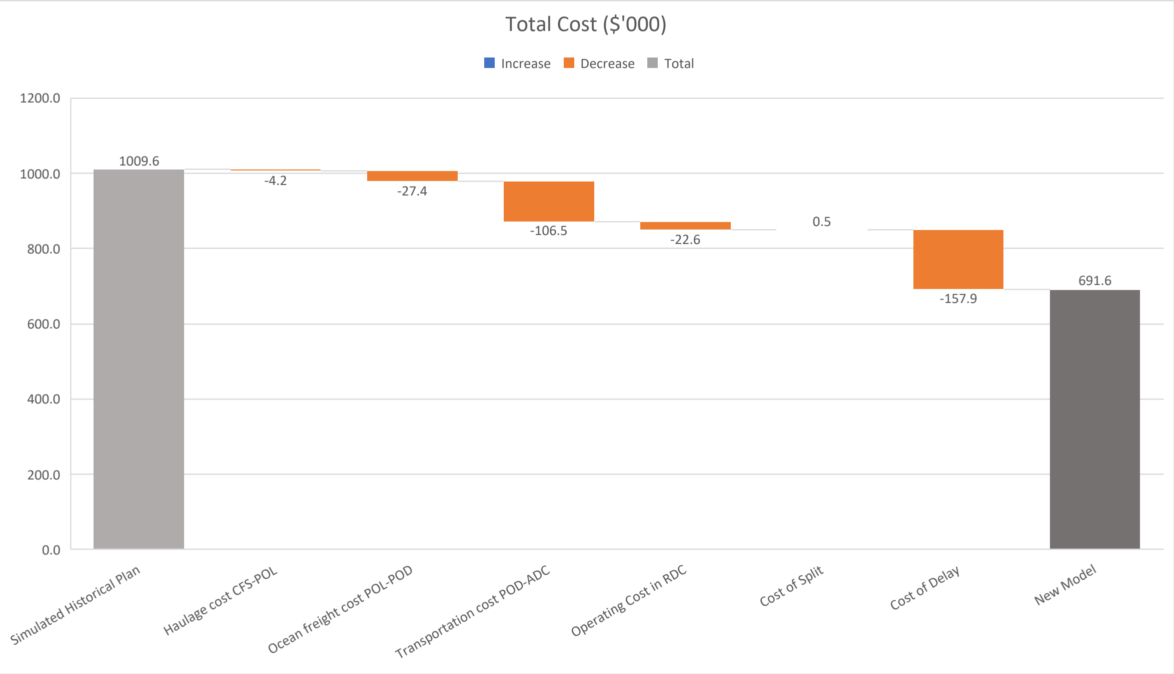
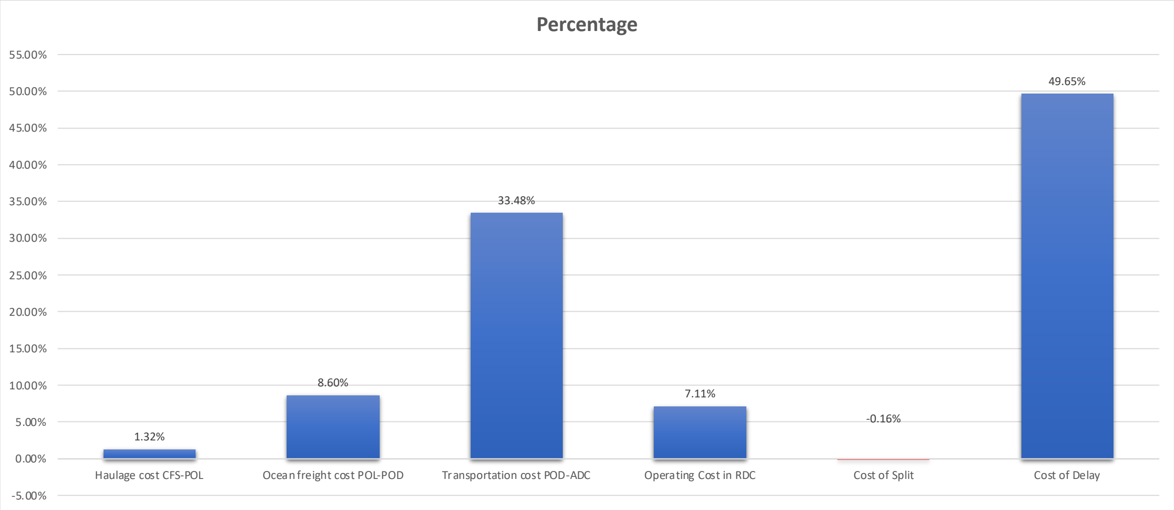


Figure 12

Contribution of Reduction for Each Cost Component



4.1.2.1 Transportation Cost from POD to ADC

The transportation cost from POD to ADC contributed 33.48% of the total reduction. The key driver was the distance reduction between POD and ADC for cargo routed by-passing RDC. Over 50% cost reduction was seen for shipments into both Russia and Germany. The absolute reduction of cumulated distance travelled from POD to ADC directly was the key driver for shipment to Russia while for it was the combined effect of volume shift and reduction of cumulated distance travelled by-passing RDC for Germany.

Figure 13 shows the percentage volume converted to routes by-passing RDC per customer markets. This explained the significant impact of shipment volume shifting to the route by-passing RDC for Germany. Table 10 shows the distance from POD to each ADC both through RDC and by-passing RDC, and the reduction in kilometers and expressed as a percentage.

Figure 13

Percentage per Country (CBM) Contributed to the Volume Converted to Routes By-passing RDC

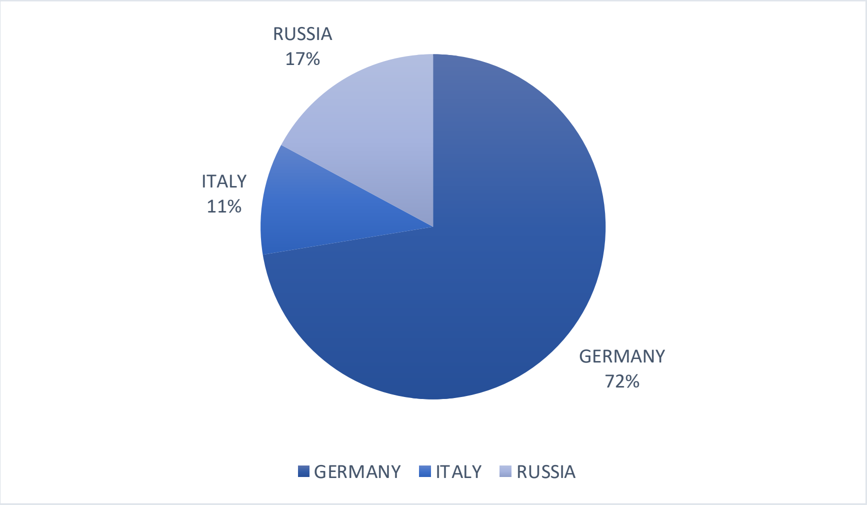


Table 10

Distance from POD to ADC through RDC and By-passing RDC

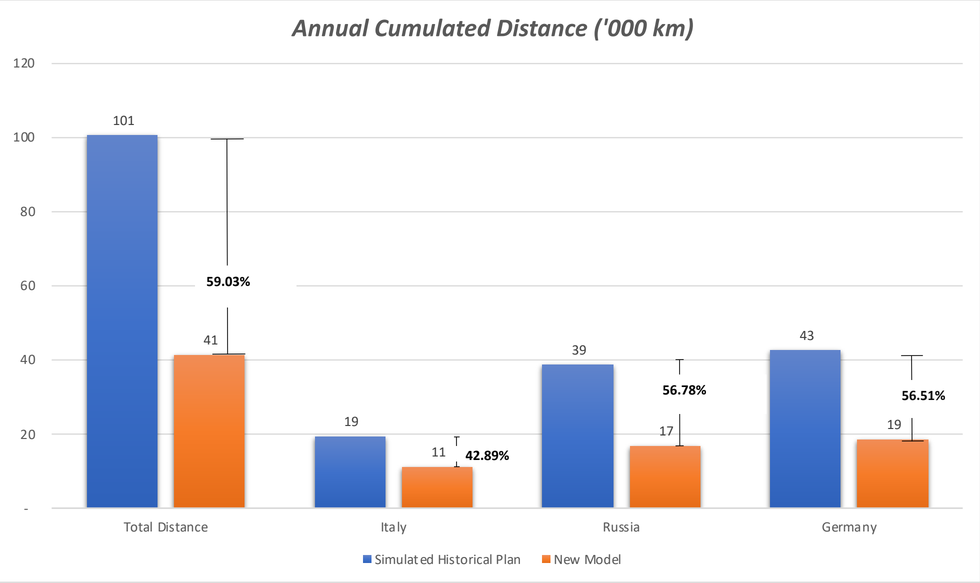
Distance Travel (KM)	Italy	Russia	Germany
Distance from POD to ADC through RDC (KM)	1246	2549	581
Distance from POD to ADC bypassing RDC (KM)	52.6	23	81
Reduction in distance (KM)	1193	2526	500
Reduction in distance (%)	95.78%	99.10%	86.06%

Figure 14 shows the total annual cumulated distance travelled from POD to ADC in each customer market and the respective reduction. The distance was calculated with the following logic:

1) From POD to ADC, the distance was fully allocated to the country in the respective column.
2) Distance from POD to RDC was calculated proportionally to each customer market based on the total weight split.
3) Distance from RDC to ADC was derived based on the percentage of weight of the assumed utilization of an outbound trailer (91 CBM).

Figure 14

Total Annual Cumulated Distance for Shipments to Each Customer Market



4.1.2.2 Operating Cost in RDC

The operation cost in RDC only occurred when volume was consolidated into RDC before deconsolidated and delivered to ADCs. As it shows in Figure 9, 63% of the volume routed directly into ADC. The switch of the volume directly resulted in the reduction of the operating cost in RDC, contributing 7.11% of the total cost reduction.

4.1.2.3 Cost of Delay

Cost of delay reduction contributed 49.65%. The key driver was the shift of volume by-passing RDC that improved the overall delivery compliance. Figure 15 shows the cost of delay comparison between simulated historical plan and output from new model.

However, we saw 11.97% of the volume was allocated to a delayed schedule, and 79.27% of the volume was allocated to a schedule that improved the on-time delivery compliance. Among the shipments with the same arrival date, 62.14% of the volume was allocated to a new route. Figure 16 shows the share of volume with new schedule allocated and the indication of delivery performance.

Figure 15

Cost of Delay Comparison - Simulated Historical Plan vs. Output from New Model

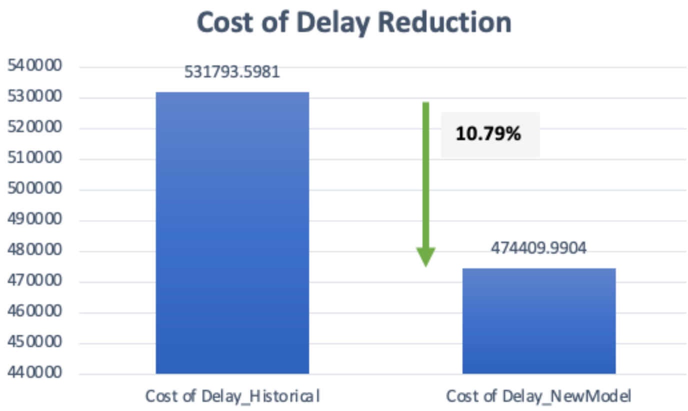
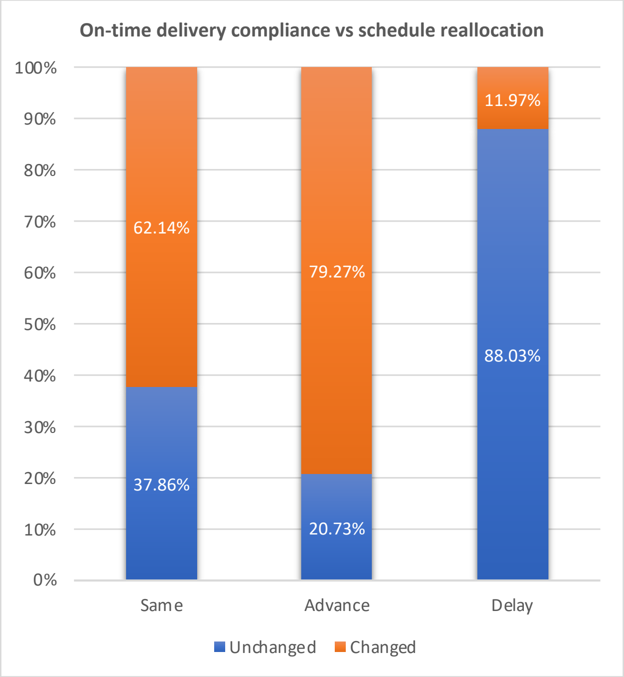


Figure 16

On-time Delivery Compliance vs. Schedule Reallocation

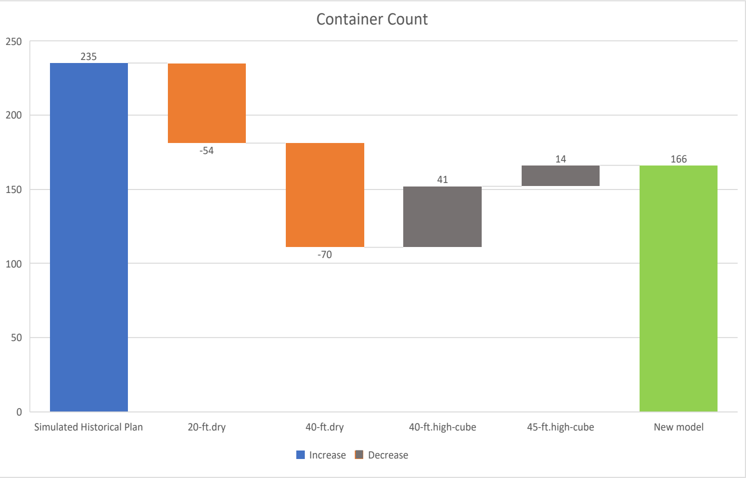


4.1.2.4 Trucking Cost from CFS to POL and Ocean Freight Cost from POL to POD

The trucking cost reduction from CFS to POL and the ocean freight cost reduction from POL to POD contributed 1.32% and 8.60% to the overall reduction. The reduction was mainly due to reduction in container counts. Figure 17 illustrates the increase and decrease of container counts per container size. 29.36% reduction in total container counts was observed. A 42.19% reduction for 20ft.-dry and a 71.88% reduction for 40ft.-dry were seen, while 666.67% and 280.00% increase of container count respectively for 40ft.-high and 45ft.-high since the counts were low in absolute amount in the simulated historical plan. An increased number of larger containers were used as the result of the new model.

Figure 17

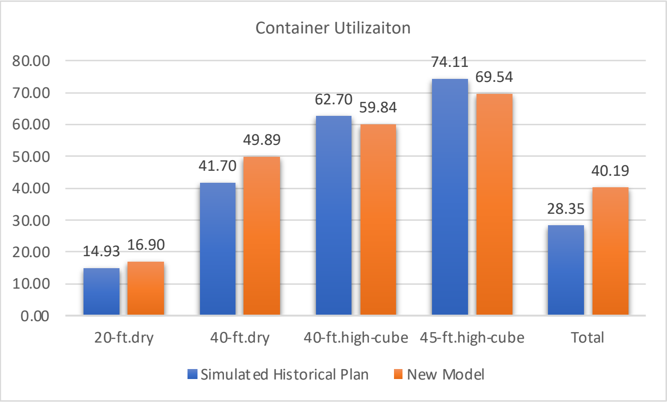
Container Counst for Simulated Historical Plan and New Model



It was also interesting to see a different trend for container utilization. The utilization of 40ft.-high and 45ft.-high containers dropped by 4.56% and 6.17% respectively, despite the container counts going up. Reverse trend was seen for 20ft.-dry and 40ft.-dry with 13.19% and 19.64% increase, respectively. In addition, the weighted average container utilization increased from 28.35 cbm/container to 40.19 cbm/container. This also explains the 29.36% reduction in total container counts. Figure 18 shows the container utilization for each container size.

Figure 18

Container Utilization Comparison



4.2 Sensitivity Analysis and Binding Constraints

Since business scenarios are dynamic and fast changing, we decided to do a sensitivity analysis to study the impact of changing business inputs on some unique shipping characteristics. Following are the unique shipping characteristics we decided to investigate:

1) Cost of delay variation

Since cost of delay varies depending on the profit margin, we decided to study two upper and lower values by adding/subtracting 30% to the current value of $25/CBM/Day, resulting in 2 scenarios where cost of delay is $40/CBM/Day and $10/CBM/Day.

2) Zero RDC operating cost and trucking cost CFS-POL

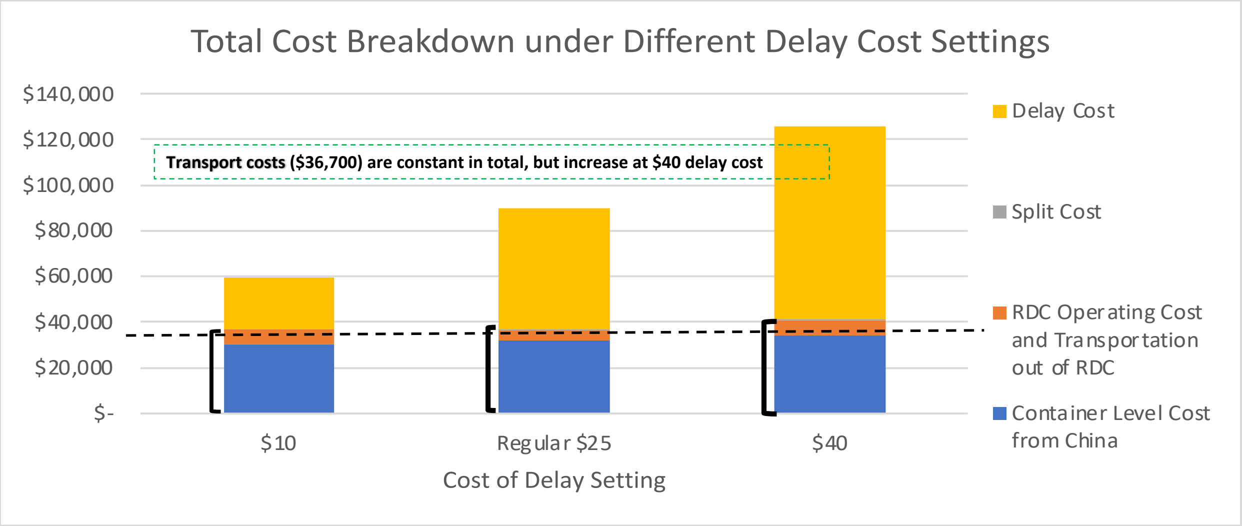
Based on the cost analysis results in Figure 11, we noticed that the haulage cost from CFS to POL, and the operating cost at RDC are very small (1.32% and 2.11% respectively of total cost), so we decided to study the impact of eliminating both costs from the input variables, thus making the data collection process more efficient in real business environment.

4.2.1 Cost of Delay Variation

We reran 10 previous runs for this sensitivity test, choosing runs that reflect a variety of routing decisions, to expose underlying patterns in behavior with respect to the test we are conducting. In this case, it was observed that transportation costs are the same for $10/CBM/Day cost of delay and $25/CBM/Day. Transportation costs started to increase when we increased the cost of delay to $40, suggesting the optimization engine can find alternative routes while keeping transportation costs low to a minimum until the $25 threshold, but there was no better routes combination to choose after the $25 threshold unless we spent more on transportation. This exercise can be replicated for each customer to understand the impact of their business margins (modelled as the cost of delay) on their transportation spend.

Figure 19

Total Cost Breakdown under Different Cost of Delay Settings



We also observed a clear distinction between Germany and Italy on one side, and Russia on the other side as the cost of delay changed. For Germany and Italy, we noticed that volumes shift from RDC to bypass as the cost of delay increases. This was due to the fact bypass routes have shorter lead time, resulting in lower cost of delay when a shipment was late. But for Russia, bypass was selected when cost of delay was at its lowest value anyway and continued to be so as the delay cost increased, since the lead time was longer by-passing RDC than through RDC. The behaviors for the three markets were similar. When cost of delay increases, the model tends to pick the route with shorter lead time.

Figure 19, Figure 20 and Figure 21 show the comparison for cost of delay for each customer market when unit cost of delay is at different level.

Figure 20

Cost of Delay for Italy

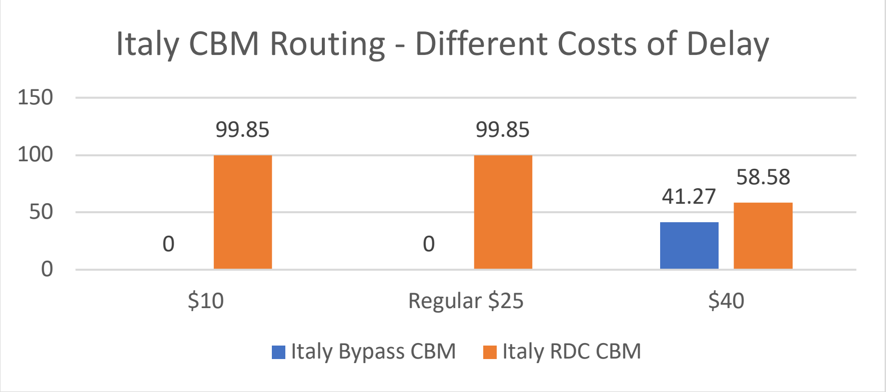


Figure 21

Cost of delay for Germany

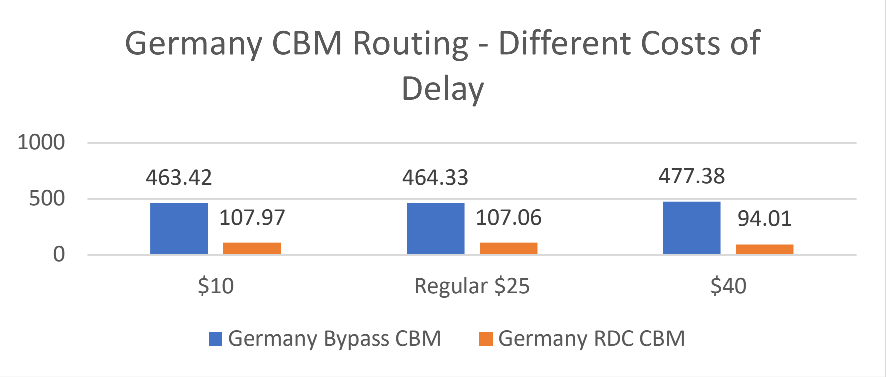
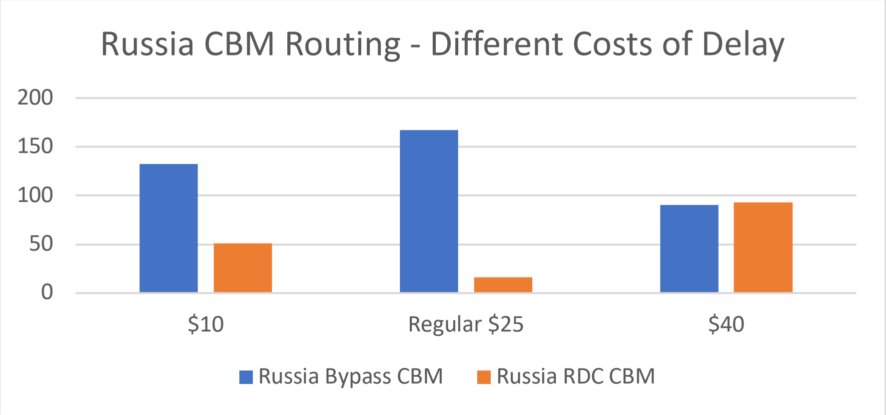


Figure 22

Cost of delay for Russia

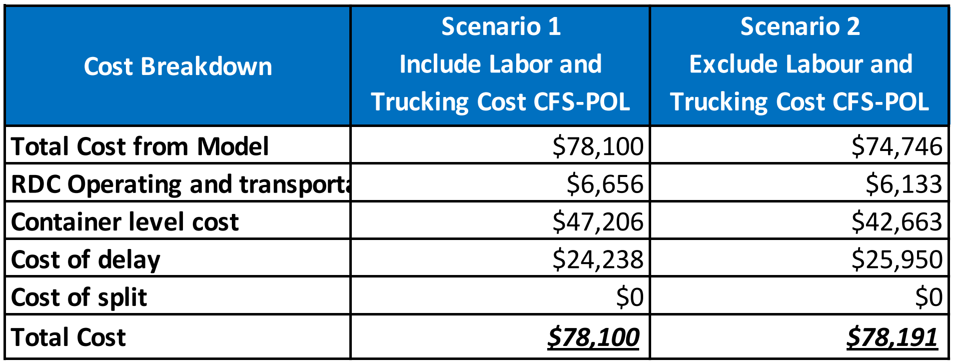


4.2.2 Zero RDC Labor and Trucking Cost CFS-POL

We reran 10 previous runs using this sensitivity test, where the previous runs were picked such that volume was routed mostly by-passing RDC. When looking at the total cost of the sensitivity analysis solution (Scenario 1) vs. the included RDC operating cost solution (Scenario 2), the difference was minor, a mere $91 extra which is 0.12% difference ($78,191 vs. $78,100). This suggests that removing both costs from the optimization equation will not harm the financial results of the model in any meaningful amount, however, the behavior of the model will change, which should be the focus of the analysis to follow. Table 11 shows the simulated total cost comparison when operating cost and trucking cost CFS-POL are included (Scenario 1) or excluded (Scenario 2).

Table 11

Simulated Total Cost Comparison for Scenario 1 and Scenario 2



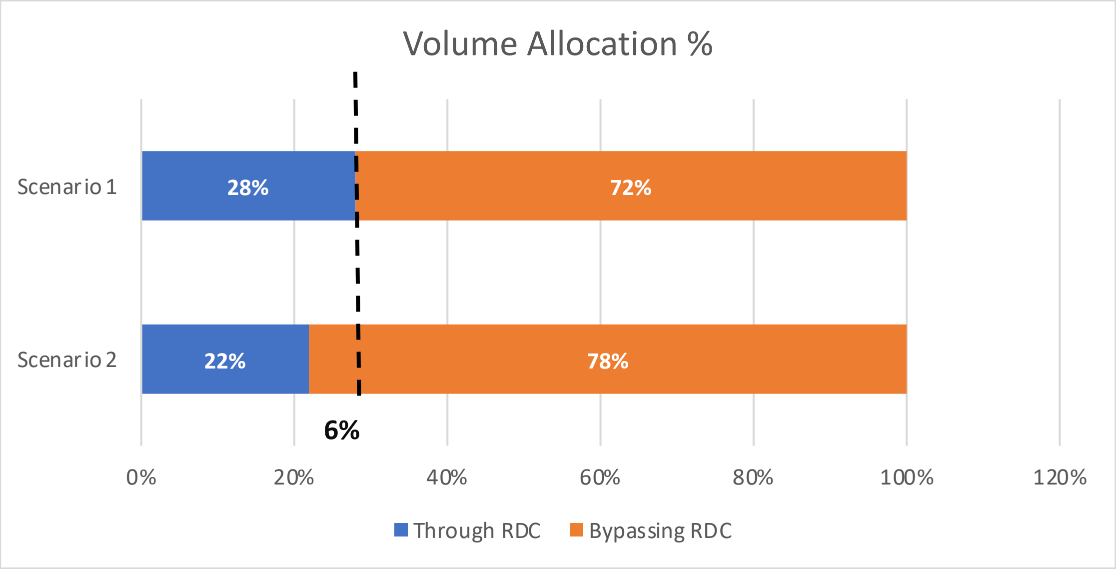
Cost Breakdown	Scenario 1 Include Labor and Trucking Cost CFS-POL	Scenario 2 Exclude Labour and Trucking Cost CFS-POL
Total Cost from Model	$78,100	$74,746
RDC Operating and transport	$6,656	$6,133
Container level cost	$47,206	$42,663
Cost of delay	$24,238	$25,950
Cost of split	$0	$0
Total Cost	***$78,100***	***$78,191***

The impact of making the cost of haulage from CFS to POD zero was not evident, and it did not result in increasing the number of containers. On the contrary, the RDC labor cost elimination incentivized more consolidation, thus further reducing the number of containers. This made us reach the conclusion that eliminating the haulage cost from CFS to POL was not impacting the planning results and could be done in the future by the business to reduce complexity.

We also observed that some volume switched routes to move through RDC instead of bypass in both Germany and Italy in 2 of the 10 runs. Figure 23 shows that 6% of the total volume shifted to RDC. This was due to making the RDC labor cost zero, thus creating more incentive to ship through it. Figure 22 shows the volume routed through or by-passing RDC under scenario 1 and scenario 2.

Figure 23

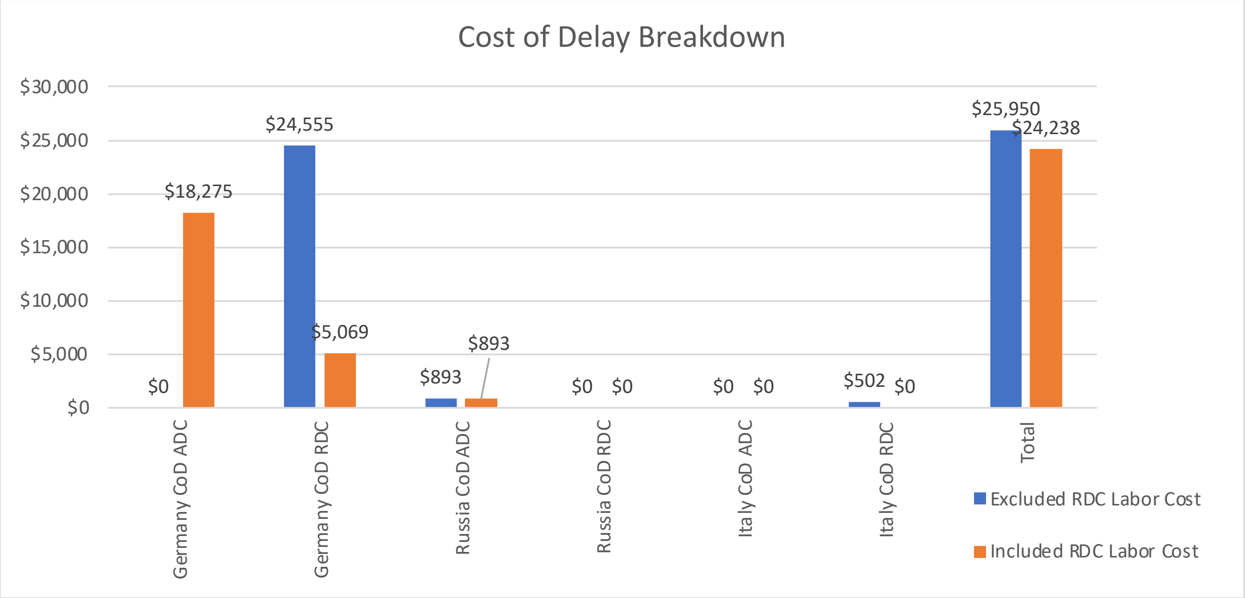
Volume Converted to Routes by-passing RDC – RDC Operating Cost for Scenario 1 and Scenario 2



We also analyzed cost of delay to understand the impact on timeliness, and we noticed that RDC routing did increase delay cost as shown in Figure 24. Some delay cost shifted to RDC from bypass, but also the total cost of delay increased, meaning we were serving more shipments with delayed schedule. There is a tradeoff between transportation cost and cost of delay, and Figure 24 clearly reflects the increase cost of delay and decrease in transportation cost.

Figure 24

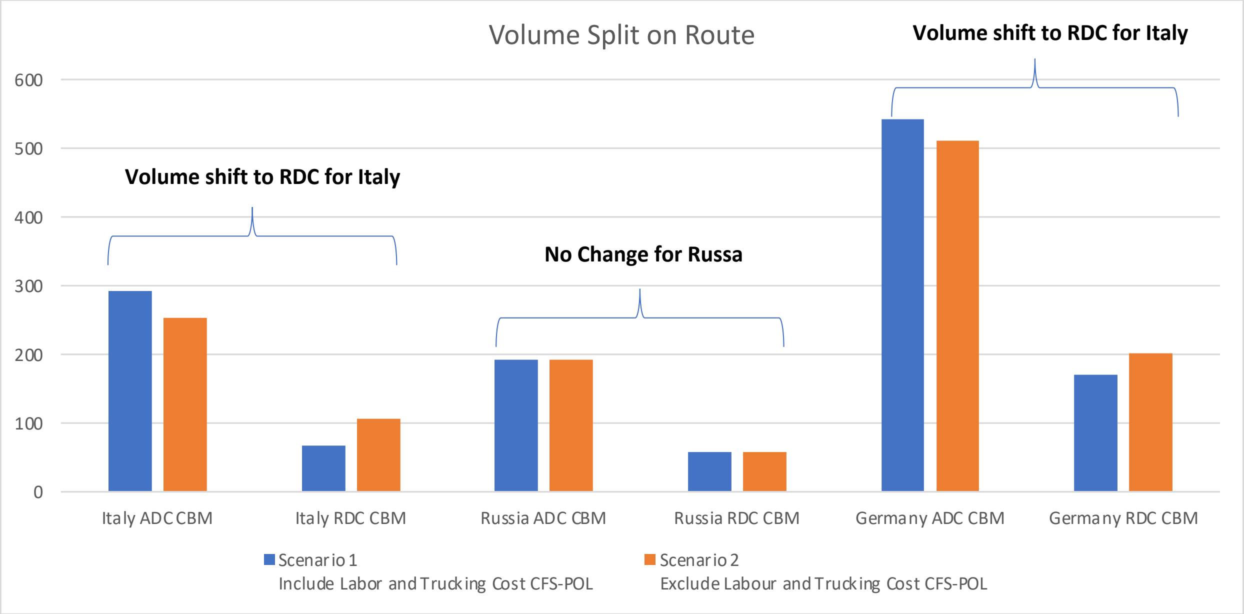
Cost of Delay Breakdown under Scenario 1 and Scenario 2



We also noticed Germany and Italy reduced the volume by-passing RDC as shown in Figure 25, while Russia stayed the same and nothing changed. This was explained by the fact that shipping products directly to Russia ADC was cheaper than through RDC by a wide margin and reducing RDC operating cost was not enough to make the offset and kept volume flowing through RDC. For Italy and Germany, the results did not exhibit a high gap between the route by-passing RDC and the route through RDC. They were more sensitive to RDC operating cost elimination. Figure 25 describes the volume shift for each customer market for both scenarios.

Figure 25

Volume Split on Routes under Scenario 1 and Scenario 2



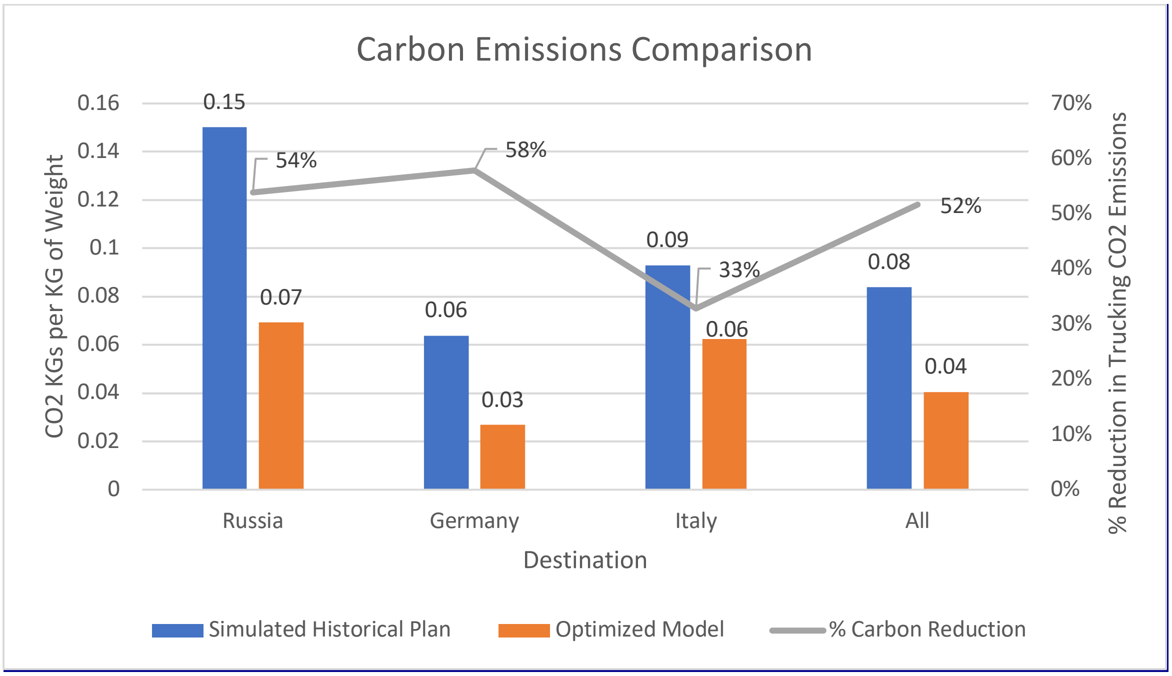
We also noticed the number of containers dropped from 27 to 25 for the 10 runs in total, and when we drilled down, it was found more consolidation through RDC resulted in a smaller number of containers.

4.3 Carbon Emissions vs. Cost

We converted trucking kilometers to kilograms of CO2 based on the modeling equation, then calculated the difference between current planning policies and the new model. We found that Russia destined shipments were by far the largest carbon emitter as expected, due to the longest distance from the RDC (2405 km). However, those emissions were reduced significantly (54%) by introducing the route by-passing RDC. Figure 13 shows the distances, from POD to RDC, from POD to ADC and from RDC to POD. The savings in distance reach over 95 times in the case of Russia with the route by-passing RDC. Overall, we saved 52% of carbon emissions by reducing average kilograms of CO2 per kg of cargo from 0.08 to 0.04. Figure 26 shows the comparison of carbon emissions between the simulated historical plan and the results from the new model.

Figure 26

Carbon Emissions Comparison

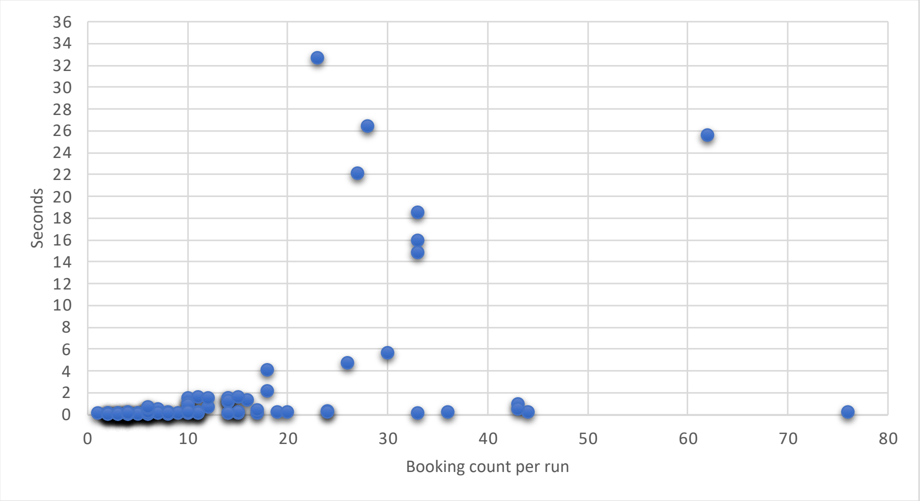


4.4 Run time

Among 101 runs conducted with the optimization model, 79 runs took less than 1 second, and 94 runs took less than 6 seconds. The maximum amount of time taken was 32.7 seconds. From this perspective, the model was very efficient for transactional planning that requires fast response time. All those runs were conducted using COIN-OR CBC linear solver, on an i5 M540 Intel processor in a Windows 10 Pro environment. Gurobi solver was tested on a run which took 25 seconds to reach limit conditions in COIN-OR, and it was solved in 0.48 seconds using Gurobi under the same branch and bound limit conditions (within 1% of optimal). Figure 26 shows the run time of the model and the shipment counts per run.

Figure 27

Run time and Shipment Count per Run



4.5 Managerial Insights

As the results reveal, making DC-bypass as a route option improved the flexibility in the supply chain network. The model was making trade-off between transportation cost and on-time delivery performance. In addition, the results also indicate that decisions in silo does not achieve the optimization of the business outcome. There is trade-off among the cost elements in the supply chain. Furthermore, DC-bypass as a route option shortens the distance travelled at import distribution, thus significantly the route option brings down the figures of carbon emissions. Last but not the least, by tuning the input parameters, the model can be applied widely in business use cases beyond DC-bypass at import distribution. It is practical and scalable.

4.5.1 Container Utilization Maximization vs. Total Cost Optimization

From the cost analysis, we can conclude that decisions in silo does not optimize the business outcome. Figure 18 shows that container utilization of 40ft.-high and 45ft.-high dropped in the result from the new model, though the total cost reduction was significant compared to simulated historical plan. The objective of the existing planning methodology to minimize ocean freight cost per unit, equivalent to container utilization maximization, does not necessarily align with the optimized business outcome. There is a trade-off between profit loss that represented by cost of delay and the transportation cost. Optimization of total cost could be a better alternative in the transactional transportation planning.

The model requires cost of delay as the input parameter to quantify the business impact of late delivery. This requirement facilitates constructive conversation across functional departments to align business target on an operational level and reduce administrative cost for cases where decisions are needed for competing priorities.

4.5.2 Carbon Emissions vs. Cost

Carbon emissions have strong correlation with transportation modes, distance and weight. Trucking cost in general is closely correlated to distance travelled, meaning the longer the distance, the higher the trucking cost given the same required lead time. The cumulated distance from POD to ADC reduced proportionally with the total trucking cost from POD to ADC. Under the condition that no cost of delay occurs, routes with more environmentally friendly transportation modes should be applied.

4.5.3 General application of the model

The new transactional planning model includes major cost elements from CFS in the exporting country to ADCs in importing the country, mirroring the multi-echelon distribution network. By tuning the input parameters and constraints, the model can be applied to different business scenarios. Here are some examples:

1) By assigning zero to cost of delay and at the same time assigning a large number as cost of split, the model prevents splitting a shipment into different container loads. The model simulates the existing CFS service offered by Maersk LNS, a common service from 3PLs, but removes the need to conduct the regular container utilization matrices review.
2) By applying different values for cost of delay, we can simulate the profit loss due to on-time delivery incompliance for different industries. From the sensitivity analysis, we can see the model optimized the planning transactions, trading off higher transportation cost for a lower cost of delay when the cost of delay was high ($40/cbm/day), and the other way round when the cost of delay was low ($10/cbm/day) as shown in Figure 18.
3) By assigning a large number as operating cost in RDC, the multi-echelon network will be turned into a single-echelon network where CFS-POD-ADC becomes the only route for transportation planning.
4) By removing the container capacity constraint and changing the container-level cost parameter (C_{ij}) into CBM level cost, the model simulates the less-than-container-load planning where shipments from different customers are consolidated in the same containers.

4.5.4 Model Maintenance

The best result out of the model would require all cost elements in the model to have the best result possible, but the administrative effort of maintaining the cost elements throughout the network could be substantial. The freight contracts and the operating cost in a global network are maintained by different departments and have different review circles. A balance might be required between the savings out of the model and the cost of achieving the optimal results.

The analysis of section 4.2.2 is an example of how the unbinding variables are identified for the DC-bypass distribution problem. Removing the cost from CFS to POL and operating cost in RDC does not bring significant impact to the total cost describe in Table 11.

5 Future Research and Conclusion

In this chapter, based on the base model, we will make recommendations on the future research, and make conclusion on the study.

5.1 Future Research

In the study, we discussed the cost comparison between the simulated historical plan based on the existing business policy and the transactional optimization model, the indication of on-time compliance performance as well as the carbon emission, by limiting the line-haul mode of transport, which is ocean and inland distribution, which is trucking. We saw value in taking this further by looking into the following business scenarios that have been not been explored but should be supported by the model. These scenarios include multiple transportation modes on the same route, cost of carbon emissions being part of the cost optimization function, and the cost of delay on product item levels.

1) Transportation modes have impact on lead time, with indication of a different cost of delay. The longer the transit time, the higher the cost of delay if the arrival date exceeds the expected delivery date. The optimization model would give a different result and suggested load plans.
2) When carbon emissions cost is part of the cost equation, it is expected to balance the decision between choosing a transportation mode with shorter transit time and higher carbon emissions and a transportation mode with longer transit time and lower carbon emissions.
3) We suggest building the model with cost of delay on product item level instead of product category or shipment level. This is close to a real business scenario when certain products are new launches or promotions that require different shipping options.
4) Opposite to cost of delay which penalizes late delivery, introduction of storage would enable the cost optimization to cover inventory cost. The model is expected to give the route and load result with consideration of customer service level, transportation cost and inventory cost.

5.2 Conclusion

This capstone project builds on the existing research work on freight consolidation, transportation modelling, carbon emissions modelling and conversion.

By introducing the quantified business impact as a cost parameter, the new model enables transactional transportation planning with the objective of maximizing the business outcome. It provides a practical tool for aligning business objective across functional departments in the organization on the operational level. As for the sponsor company, Maersk Logistics and Services and the other 3PLs in the market, this model enables a different service offering to their existing freight consolidation service portfolio that addresses the pain point of their retail customers. The quantified result in cost, delivery performance and carbon emissions from the sample customer provides good supporting details to bring in new concept for implementation.

Furthermore, the scalability, efficiency and adaptability of the models support the application of multiple business scenarios. Retailers and 3PLs could apply the model as a generic tool to manage shipment flow in different parts of their transportation network.

Last but not the least, the model introduced in this capstone could be the base model for future research and business application. Companies could explore the needs to bring in new cost elements that have significant impact on the efficiency and flexibility of their supply chain operation, so the business outcome optimization could be achieved on operational level.

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Appendix

Appendix A

Abbreviations

Abbrevation	Description
CBM	Cubic Meter
LSP	Logistics Service Provider
SOP	Standard Operating Procedures
RDC	Regional Distribution Center
Maersk LNS	Maersk Logistics and Services (Sponsor company)
DC	Distribution Center
POL	Port of Loading
POD	Port of Discharge
ADC	Area Distribution Center
MILP	Mixed Integer Linear Programming
CFS	Consolidation Center in Exporting Country
ARD	Actual receipt date
EDD	Expected Delivery Date
ETA ADC	Estimated arrival date at ADC
CO2 KGs	Kilograms of CO2