Developing a Sustainable Intermodal Transportation System to Enhance the Efficiency of Port's Activities

by

Tareq ABU AISHA

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Mr. Yvan Beauregard, President of the Board of Examiners
Department of mechanical Engineering at École de technologie supérieure

Mr. Amin Chaabane, Member of the jury
Department of systems engineering at École de technologie supérieure

Mr. Ali Gharbi, Member of the jury
Department of systems engineering at École de technologie supérieure

Ms. Anjali Awasthi, External Evaluator
Concordia Institute for Information Systems Engineering, Concordia University

THIS THESIS WAS PRESENTED AND DEFENDED

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Développer un système de transport intermodal durable pour améliorer l'efficacité des activités

Tareq ABU AISHA

RÉSUMÉ

Transiter chaque année des millions de conteneurs à travers les ports maritimes tout en garantissant des coûts et des émissions de manutention minimaux constitue un défi majeur pour les terminaux à conteneurs. Aujourd'hui, le terminal à conteneurs intermodal est considéré comme le cœur pour la plupart des systèmes de transport intermodal. Le terminal à conteneurs intermodal du port maritime est un système complexe qui nécessite une planification minutieuse afin d'exécuter efficacement les opérations de fonctionnement. En effet, un fonctionnement inefficace du terminal peut ralentir le flux des conteneurs vers leur destination et augmenter le temps de séjour du navire dans le port. Cela entraîne généralement une augmentation du coût total et affecte la durabilité. Par conséquent, il existe un besoin de nouvelles méthodologies et technologies qui garantissent l'amélioration des performances des terminaux, augmentent la capacité et atténuent les impacts négatifs sur l'environnement. Dans un grand nombre de cas, les ports maritimes sont généralement entourés de grandes villes. Par conséquent, l'amélioration de la configuration du terminal à conteneurs conduira à un transfert plus rapide, moins coûteux et plus efficace des conteneurs de leur origine à leur destination de manière durable. Dans ce travail, le port de Montréal est utilisé comme étude de cas pour valider l'aménagement proposé et les expériences.

Dans le premier article, intitulé "développement de l'aménagement du terminal à conteneurs du port maritime pour accroître l'efficacité du système de transport intermodal et des opérations portuaires - cas du port de Montréal", nous avons développé un nouvel aménagement de terminal à conteneurs. Un aménagement efficace du terminal à conteneurs peut être obtenu en réduisant la distance et la disposition entre le quai et les voies ferrées. Nous proposons un nouvel aménagement pour réduire les coûts et accélérer le flux des conteneurs, améliorant ainsi l'efficacité du système de manutention. Nous développons un modèle MILP pour estimer et analyser les performances en tenant compte de la congestion des arcs pour l'aménagement existant et notre proposition. Nous présentons un cas d'étude portant sur le port de Montréal pour valider la solution. Les résultats montrent que l'aménagement proposé réduit le coût total et le temps de transport des conteneurs du port à leur destination.

Malgré ses avantages, le transport intermodal a encore des effets indésirables liés à la congestion et aux émissions. Dans le deuxième article, intitulé "optimisation de l'aménagement des terminaux à conteneurs dans le port maritime - cas du port de Montréal", nous abordons le système de transport intermodal et ses effets sur l'efficacité portuaire. Cet article étudie le rôle de l'aménagement proposé dans la réduction des coûts de transport des conteneurs du navire à la destination finale et des émissions générées par ces opérations. L'aménagement proposé peut améliorer la durabilité des activités portuaires en diminuant la distance entre le poste d'amarrage et les points d'échange tout en évitant la double manutention. Le problème étudié est formulé sous forme d'un modèle d'optimisation multiobjectif et nous utilisons la méthode ε-contrainte pour le résoudre. Les résultats montrent que l'aménagement proposé génère une réduction considérable à la fois du coût et des émissions associés transport des conteneurs jusqu'à leur destination finale.

Étant donné que différents modes et ressources relatives au transport interagissent et fonctionnent de façon conjointe, le système devient assez complexe pour comprendre son comportement et prédire l'effet de la modification de certains paramètres. À cet égard, nous avons développé un modèle de simulation dans le troisième article intitulé "une approche de simulation pour comparer différentes configurations de terminaux à conteneurs". Un modèle de simulation discret est développé en utilisant le langage de simulation SIMAN puis implémenté via le logiciel ARENA. Ce travail vise à améliorer les performances et la capacité de traitement du terminal en recommandant une nouvel aménagement plus efficace. Des expériences de simulation ont été menées pour évaluer et comparer les performances de l'aménagement proposé avec celles de l'existant à l'aide des données recueillies au port de Montréal. Les résultats indiquent que le plan de l'aménagement du terminal a un impact significatif sur la performance du terminal dans la configuration des différents modes de transport.

Mots-clés: Terminaux à conteneurs, transport maritime, transport intermodal, durabilité, plan d'aménagement.

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ABSTRACT

Transporting millions of containers through the container terminal at the seaport per year while ensuring minimum handling operations cost and emission is challenging for the container terminals. Today, the intermodal container terminal is considered as a hearth for most intermodal transportation systems. The intermodal container terminal in the seaport is a complex system that requires careful planning in order to perform operations efficiently. Thus, inefficiently operating the terminal can slow down the flow of containers to their destination as well as increase the dwell time of the ship in the port, which leads to an increase in the total cost and affects sustainability. Consequently, there is a need for new methodologies and technologies that guarantee enhancements of terminal performance, increase capacity, and mitigate negative impacts on the environment. In a large number of cases, the seaports are usually surrounded by big cities. Hence, improving new layouts for the container terminal will lead to the faster, cheaper, and more efficient transfer of containers from their origin to the destination in a sustainable way. In this study, the Port of Montreal is used as a case study to validate the proposed layout and experiments.

In my first article, titled *"Developing the Seaport Container Terminal Layout to Enhance Efficiency of the Intermodal Transportation System and Port Operations - Case of the Port of Montreal,"* we developed a new container terminal layout. An efficient layout of the container terminal can be achieved by reducing the distance and disposition between the quay and rail tracks. We propose a novel layout to reduce the cost and accelerate container flow, thus improving the handling system's effectiveness. We develop a MILP model to estimate and analyze the performance considering the arcs congestion for the current layouts and the new proposed layout. We present a study case on The Port of Montreal to validate the suggested solution. We found that the projected layout reduces the total cost and time for transporting containers from the port to their destination.

Despite the advantages of intermodal transportation, it still has undesirable effects connected with congestion and emission. In the second article, titled *"Optimization of Container Terminal Layouts in the Seaport - Case of Port of Montreal,"* the intermodal transportation system and its effect on port efficiency were addressed. The article investigates the role of the proposed layout in minimizing the cost of transport containers from the ship to the final destination and emissions generated from these operations. The proposed layout can improve the sustainability of port activities by decreasing the distance between the berth and interface points as well as avoiding double handling. The model was formulated as multi-objective optimization, and we use the ε-constraint method to solve the problem. The results illustrate that the proposed layout resulted in a considerable reduction in both the total cost of transport containers to their final destination and emission associated with these operations.

Since different modes of transportation and resources interact and function together, the system is becoming quite complex to understand its behaviour and predict the effect of changing in some parameters. In this regard, we developed a simulation model in the third paper titled *"A Simulation Approach to Compare Different Container Terminal Layouts."* A discrete simulation model is developed using the SIMAN simulation language and then implemented through the Arena software application. This study aims to improve the performance and handling capacity of the terminal by recommending a new layout. Computational experiments were conducted to evaluate and compare both layouts' performance using data collected from the Port of Montreal. The results indicate that terminal layout design has a significant impact on terminal performance under the configuration of different transportation modes.

Keywords: Container terminals, maritime transportation, intermodal transportation, sustainability, layout.

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LIST OF ABREVIATIONS

GDP	gross domestic product
IMO	International Maritime Organization
TEU	20-foot equivalent unit
UNCTAD	United Nations Conference on Trade and Development
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
KPIs	Key performance indicators
ft	feet
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour
kg	Kilogram
BPR	Bureau of Public Records
QC	Quay crane
YC	Yard crane

INTRODUCTION

Due to the extensive increase in international trade carried through maritime transportation in recent decades, the minimization of cost and soaring of the container's flow are at the center of interest to scholars, Governments, and private parties. According to the International Maritime Organization (IMO), marine transportation contributes more than 90% of world trade. The prediction of the United Nations Conference on Trade and Development (UNCTAD) states that the average rate of expanding the international maritime trade in the period from 2019 to 2024 is 3.5 percent (United 2019). North American Ports are no exception. The importance of maritime transport can be seen as stated by the American Association of Port Authorities (AAPA), ports of the US currently transport about 99% of the merchandise by weight and 65% by value. The importance can also be seen as the US ports responsible for transporting value of $3.8 billion of the cargo of the whole US merchandise daily (Walker, 2016).

The continuous increase of international container traffic and the stringent rules for the environment in the recent decade had forced the involved parties to pay more attention to the negative influence on their operational activities. In the transportation industry, attention must be paid to the terminals in the seaports to fulfill the maritime operations requirements. Recently, considerable attention has been paid to the sea-rail intermodal container transportation sector because of its cost and environmental advantages. Many container ports worldwide are trying to enhance the connectivity between railway transportation and the shipping area by investing in a rail terminal situated at seaports. One of the significant problems that must be concentrated on is finding an efficient way to accelerate container transfers between container ships and trains (Yan, Zhu, Lee, Jin, & Wang, 2020). Intermodal transportation system provides an opportunity to decrease shipping costs and helping to override congestion by keeping the low carbon emissions. The motivation to shift transportation systems from road to rail and sea is an excellent way to eliminate congestion on the roads and decrease GHG emissions. Nowadays, there is a widespread consciousness about increased negative environmental effects, which is generated by various transportation modes. Researchers are working in different domains consider that the existing general model is not environment-friendly (unsustainable). There should be possible procedures to decrease GHG emissions and encourage sustainability in the transportation sector (López-Navarro, 2014). Ports represent a link between maritime and land transportation. It is an essential element in the intermodal transportation system. Therefore, there is an urgent need to optimize container terminal operations (Arango, Cortes, Escudero, & Onieva, 2013).

Due to the increase in the container ships' size, the container terminals had become a bottleneck in the intermodal transportation system; thus, any delay and inefficiency of operations in the terminal affect the supply chain (Amir Gharehgozli, 2019).

As an increased competition between the ports, it has become necessary to improve their service quality and reduce service costs. To satisfy stakeholders' demands at ports, it is needed to minimize the ship's dwell time and containers in the terminals. It will lead to a reduction in the cost and helps in minimization of the negative impacts arose due to port operations (Böse, 2011). Container terminals at seaports are used as temporary storage points for containers, which aids in exchanging transportation modes to reach its final destination (Böse, 2011). Therefore, minimizing the time that containers spend at a terminal's yard is one of the key challenges at seaport terminals (Ng & Talley, 2020).

Various countries around the world are planning to mitigate congestion and environmental effects. Rotterdam Port has planned to reduce 20% congestion at peak periods, and the port of New York in the United States has gradually moved the real port away from the city while keeping administrative function in the first port (Fan, Liang, Hu, & Li, 2020). Minimizing the ship dwell time at the terminal helps the port authorities and decision makers improve port operations. The improvement of port operations includes accelerating loading and unloading operations, which can be obtained through the right channel of investment in infrastructure and superstructures of the terminal. A short time spent in a port is regarded as a positive indicator of port efficiency and the competitiveness it holds (United Nations, 2019).

Although the most common way for containers to leave the port is by truck, terminal operators and port authorities realize a need for an urgent shift for the flow of containers from road to rail transportation due to the negative effects of road transportation (Ng & Talley, 2020). Nowadays, congestion on the roads has been a serious problem, particularly in metropolitan regions across the world, due to delays in the transportation of merchandise and passengers (Selmoune, Cheng, Wang, & Liu, 2020). Therefore rail transportation is considered a sustainable mode of container transportation, especially in congested terminals, to handle the increasing number of containers in the ports (Ng & Talley, 2020).

In the present era, environmental concerns have become the main concern for international maritime transportation. The effect of environmentally driven regulations on the maritime transportation sector has become quite clear. According to the UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT, the most significant issues for 2018 were fuel economy and environmental sustainability (United Nations, 2019). In the transportation sector, the shipping operations are one of the largest, and it is quite difficult to control and regulate pollution being generated in the maritime sector. Seaports are significant economic and logistic centers; whereby, they also have a negative effect on the environment (Sislian, Jaegler, & Cariou, 2016).

In the case of Canadian ports, Canada's seaports are key to moving goods via a complex logistic supply chain, which extends to other seaports spread around more than 160 countries throughout the world (Association of port authorities, 2020). The volume of cargo currently handled in Canada's ports had significantly shown record growth. Therefore, the Canadian ports respond with major expansions and far-reaching transformation of their facilities (Zatylny, 2020). The plan of Transport Canada in 2019-2020 is to continue work on the Ports Modernization Review with a view to optimize their current and future role in the transportation domain as an innovative system, which supports inclusive growth and trade. In addition, to minimize environmental effects and adopt new technologies to improve Canadians' lives by implementing measures to reduce greenhouse gas emissions arising from inward and outward transportation (Marc Garneau, 2019).

Thus, awareness of sustainable design is growing. However, it will take a couple of years in realization to truly develop a sustainable design solution and integrate it into a network design strategy for the proper facilitation of container terminals (Böse, 2011). The current understanding of sustainable terminal design is targeted primarily at eco-friendly machinery, easy facilitation of design, and the service. Designing and operating an efficient container terminal is a challenging mission that requires to deal with the conflicting objectives, such as cost reduction of operations while at the same time augmentation of service quality and effectiveness of operations (Brinkmann, 2011).

Intermodal transportation system

The term intermodal and multimodal are frequently used in the literature and the industry; they are different in perspectives. There is a slight uncertainty in utilization between these two terms. The intermodal is a specific kind of multimodal transportation. In intermodal, the cargo is transported between the origin and destination in the same unit (e.g., a container), without handling the cargo itself during the operations of transferring. Multimodal transportation is a process of using two or more modes to transport cargo sequentially. It requires handling the cargo itself and reconsolidate the cargo in each terminal (SteadieSeifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014). Intermodal transportation plays a significant function in the industry of freight transportation as it holds benefits in terms of cost, GHG emission, and congestion. Intermodal transportation is a viable system used for transporting cargo for a long distance and worldwide. This system includes different modes of transportation, such as maritime, land, and air transportation.

The fundamental principle of intermodal transportation system is the consolidation of shipments for long-distance transportation efficiently using rail or large ocean vessels while taking advantage of trucking flexibility for local delivery operations. Intermodal transportation's primary purpose is to transport the shipments from origin to their destination in the same unit of transportation. Nevertheless, the cargo itself is not handled during the transfer activity from one transportation mode to another (C.-Y. Lee, 2015).

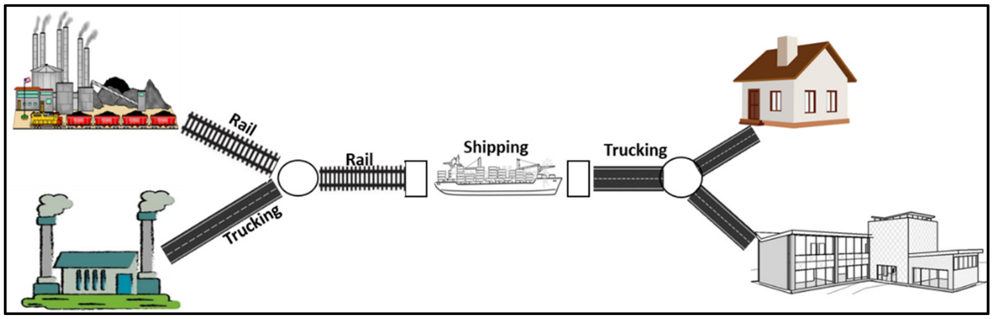

Figure 0.1 Intermodal transportation system

Figure 0.1 illustrates the concept of the intermodal transport chain. In this figure, the containers leave the shipping yard using the trucks, which is then moved towards the rail yard. In this rail yard, the containers are consolidated into the train to send them to another rail yard. From the second rail yard, the truck is used to carry containers to the sea container terminal (the port). After which the containers are transported to another port by ship. Due to the enormous features of using road transportation, such as high frequency and flexibility, the market share of road transportation is increased worldwide. As per enormous popularity, we have seen huge truck flows and congestion on public roads and cities in adjoining the ports. Additionally, it causes a high level of emissions. Avoiding congestion and unplanned delays are some of the primary objectives of intermodal terminal operations. The performance of intermodal transportation is connected with every component of the chain's performance individually, and the efficient integration between them regarding operations, information, and decisions. However, intermodal transportation is a good way to reduce shipping costs and carbon emissions (Bektas & Crainic, 2007).

Intermodal Container terminal

Nowadays, approximately 100% of the international trade between countries is carried out in containers (Branch, 2007). Using containers in transporting goods allows an intermodal transportation system that provides an optimal combination of road, rail, and shipping (Steenken, VoB, & Stahlbock, 2004). The container terminal is a complicated system that cannot function efficiently until its layout is designed to enhance the flow of containers smoothly (Brinkmann, 2011). The container terminal is an expensive capital asset that fundamentally contains the infrastructure of the terminal and different equipment for handling the containers. Designing and operating an efficient container terminal is a complicated and challenging mission with the goal of decreasing the cost of operation at the same time while increasing service quality as well as the effectiveness of the operation (Brinkmann, 2011). The intermodal seaport container terminal, as shown in figure 0.2, consists of four different areas:

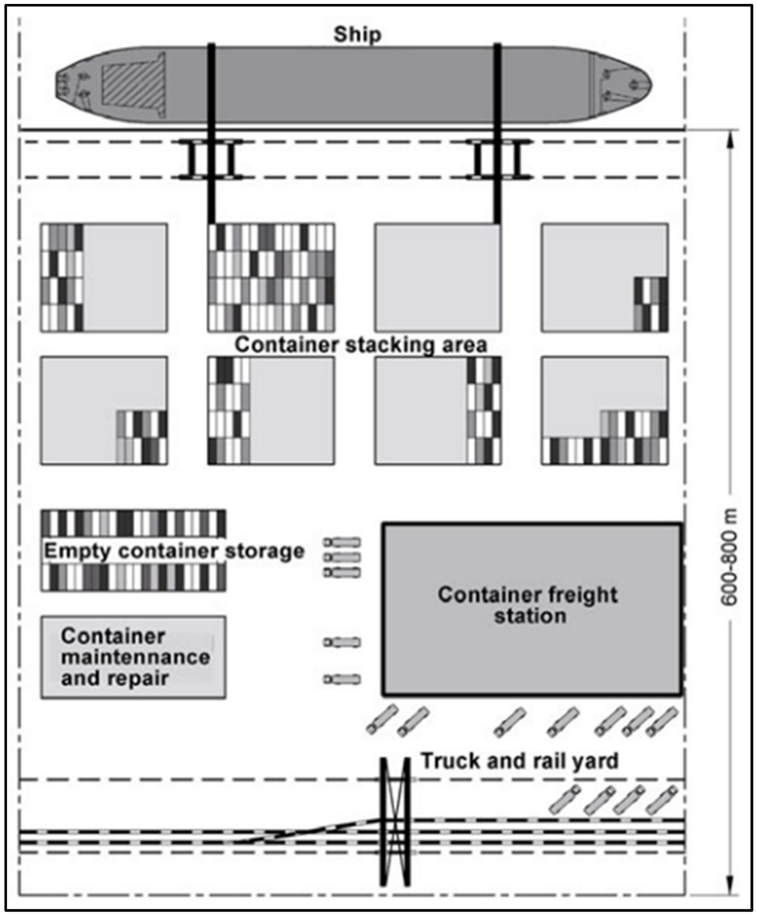

Figure 0.2 Container terminal operations
Taken from Brinkmann (2011)

- The Berth Area: the operation of loading and unloading containers onto or from the berthed ship is carried out in this area using shore cranes. After this, the containers are moved to the storage area.
- The Main Storage Area: in this area, containers are stored for a short period of time while they are waiting to be transported by truck or trains form of inland transportation.
- The Rail Intermodal Terminal (RAIT): this area is usually situated at the end of the terminal. It is where the containers are unloaded and, after that, loaded onto trains to the next destinations.

- The Road Intermodal Terminal (ROIT): this area is usually adjacent to the storage area. The operations of loading and unloading of the trucks are carried out in this area.

The containers flow between these above-defined areas starts from the berthed ship to the berth area and from the berth area to the storage area. The containers will then be transported to either rail intermodal terminal or road intermodal terminal to transport them to the inland area. The processes of Scheduling many synchronized activities and operations with different transportation modes despite handling equipment for the containers is a complex process. The description of container export operations has been discussed as follows: After bringing the container to the container terminal by truck or train. The processes of checking container will be started to, identify, classify, and register with basic details: next destination, cargo, shipping lines, and the name of the ship if the container has to be shipped to another port. The handling equipment is used to pick up the containers and deliver it to the determined place in the yard (block, row, and bay). Finally, after the ship arrives, the container is discharged from its place in the storage yard block, after which it will be carried towards the quay, whereas berth cranes pick it up and load it onto the ship destined for it. The container's import operations are executed in the reverse order (Günther & Kim, 2006). Figure 0.3 shows the processes of discharging and loading containers at container terminals. Designing and running a container terminal in an efficient way is a challenge and a complicated task that has the goal of reducing cost while simultaneously increasing operational effectiveness.

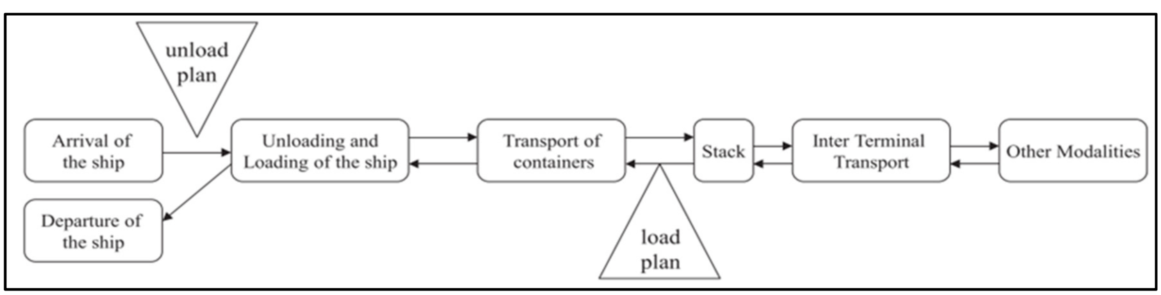

Figure 0.3 Unloading and loading processes at container terminals

Taken from Carlo, Vis, and Roodbergen (2014)

The other challenge for the container terminal is the scarcity of land (Brinkmann, 2011). The overall terminal design awareness with a sustainable design for terminal handling systems has seen growth only in the last decade. In general, there are considerable directives to reach a sustainable container terminal design by minimizing (or even avoiding) transportation, both horizontally (travelling) and vertically (hoisting/lowering), as well as minimizing high-valued resources such as land area (Brinkmann, 2011). The environmental concern, aside from being assessed based on factors and measures that aim to decrease pollution, depends on the modal shift. In this situation, it is usually associated with economic factors, as maritime transportation became attractive to cargo transportation, and though, now it is the most preferred mode of transportation. However, many ports problem is the ability to adapt efficiently to meet the industry's changing and developing needs (Panteia, July 2013).

Sustainability

The concept of sustainability has been steadily increased in salient and urgent societal discourses and the strategies of various public and private sectors (Binder, Wyss, & Massaro, 2020). However, some references defined sustainability as "a wise balance among economic development, environmental stewardship, and social equity" (Jorat & Manousiouthakis, 2019). According to this modern definition, the description of sustainability includes three essential components: economic, environmental, and social. These three components are often indicated as the three pillars of sustainability. Firstly, an economic perspective includes an efficient way to use the port area, return on investment, and all facilities to maximize their performance. Secondly, a social perspective represents a relationship between port and city. The port's contribution to the city affects the employment in port companies and helps to generate indirect employment. Thus, it provides participation in development and education and the possibility of life in the area surrounding the port. Thirdly, the environmental performance perspective includes air quality, noise pollution, digging operations in the port, and disposal of dredging waste (Sislian et al., 2016).

Research Problem

The operations of transport containers from the container ship at the port to the final destination are achieved using different numbers and handling equipment types. The increase in the container ship size requires a sufficient storage yard to absorb this a huge number of containers (Steenken et al., 2004). As a result of growing global trade volume, countries like- China and India had begun to construct dry ports and connect them directly with the respective seaports by rail tracks (Yangyang Xie, Liang, Ma, & Yan, 2017). The increase in the number and types of equipment used in handling operations generates a lot of congestion and emissions in the terminal. Also, the dependence on trucks in transport (Tao, Wu, & Zhu, 2017). However, although some studies attempt to optimize transportation time, economic, and environmental concerns, most studies consider individual factors; besides, most of them do not consider the intermodal transportation system as a whole system (López-Navarro, 2014). The best way of dealing with intermodal transportation problems is by considering more than one factor in real-life situations. Thus, it forms a basis for using multi-objective optimization to solve these kinds of problems (Resat & Turkay, 2015). Traditional intermodal transportation models have motivated by optimizing operational transportation costs. However, considering the wider objectives and issues, especially GHG emissions, leads to new models (Qu, Bektaş, & Bennell, 2014). The current research area still needs a comprehensive methodology to deal with conflicting objectives in the container terminal in the seaports to achieve sustainability. To overcome the above-discussed obstacles and difficulties, this study investigates the impact of transfer the location of rail tracks from its current location to a proposed new location close to the berth. Consequently, the dependence on the train to transport the bigger percentage of containers to destinations helps reduce the number of handling equipment, the number of trucks, and which is proportionally dependent on reducing GHG emissions (Comer, 2009). To develop a sustainable intermodal transportation system in a seaport container terminal requires a comprehensive operations planning and utilization of the available resources efficiently to enhance the performances of the port. The long-distance between the rail terminal and marshalling area affects the container terminal efficiency. It needs more horizontal transport equipment to transport containers from the marshalling area to the rail terminal. Cranes are also used to hoist the containers from the trucks and load them on the rail wagon or rail terminal storage yard and vice versa. Thus, the congestion will be higher. Consequently, fuel consumption will be higher, as a result, it increases GHG emissions followed by using trucks as multimodal transport could raise congestion at the container terminal and obstruct throughput of the terminal. These factors affects terminal productivity and minimize the container terminal efficiency. Port of Montreal (as a case study) is facing increased of both congestion and GHG emissions due to:

- At the peak period, truck traffic causes congestion due to 2500 trucks passing the port daily (Port of Montreal, 2015).
- Terminal design review in the port of Montreal shows a considerable influence on the terminal efficiency.
- Double containers handling contributes to inefficiency.
- The long-distance between the intermodal terminal and the berth and storage area causes a rise in the amount of equipment used in the operations and increases the movement of trucks and equipment, thus increasing CO2 emissions from this equipment and trucks. Figures 0.4 and 0.5 demonstrate these issues.

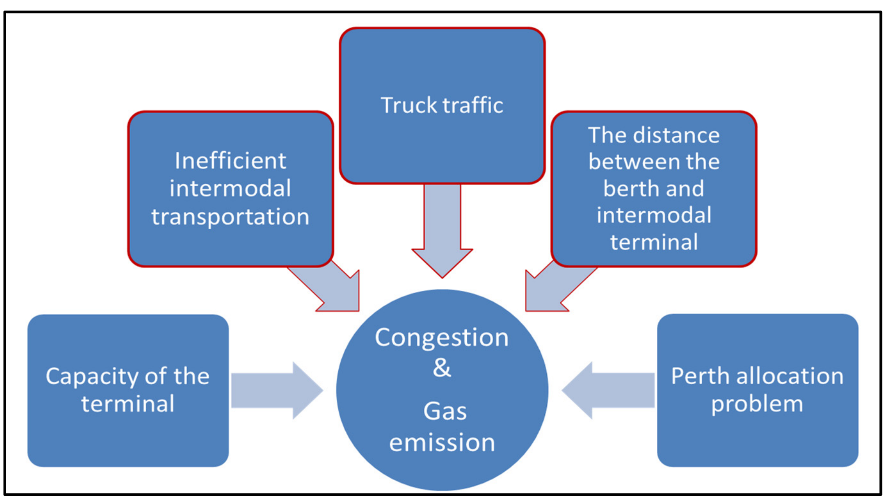

Figure 0.4 Problems in the ports

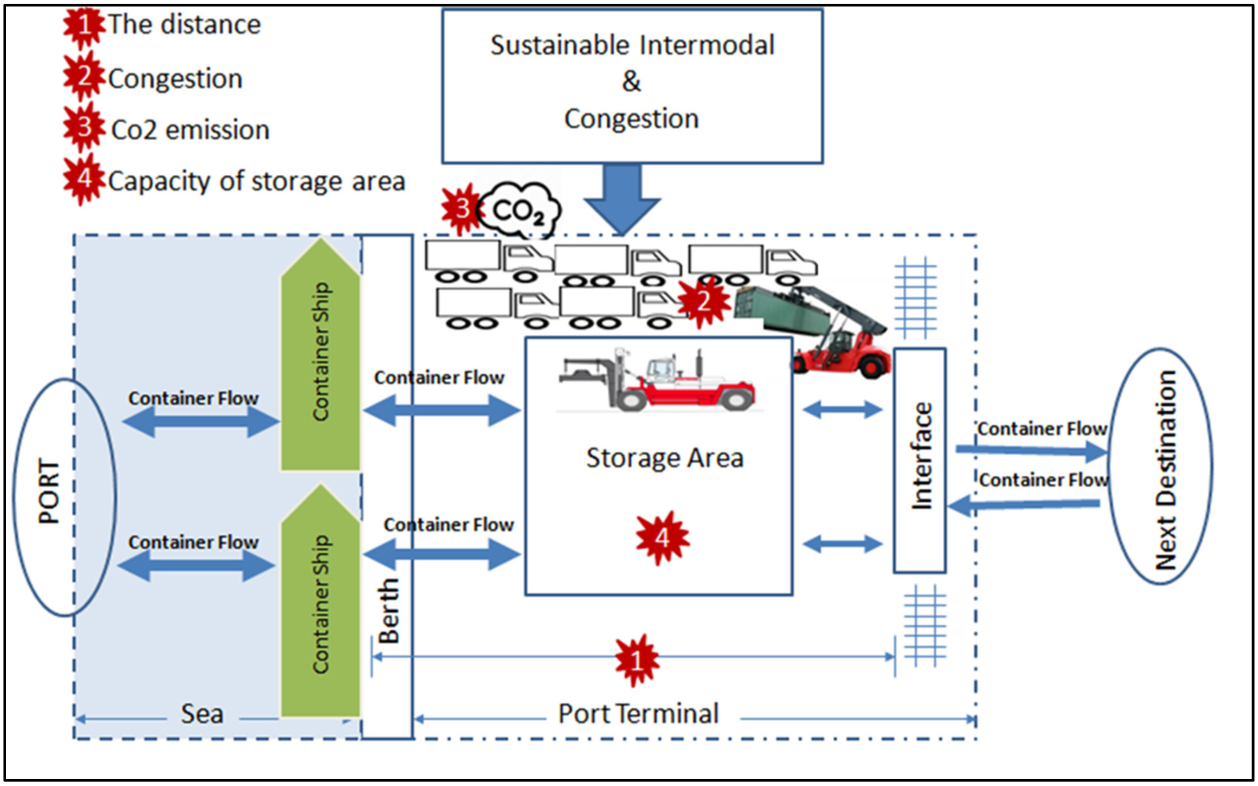

Figure 0.5 Research problem

Thesis objectives

This thesis's main objective is to propose and develop a new sustainable layout for port terminals that enhances port activity efficiency. The key points of this thesis are summarized as follows:

- Design a new sustainable layout that maximizes the efficiency of port operations and port performance.
- Apply and validate the proposed layout for the port of Montreal as a case study.
- Develop a model to calculate GHG emissions from different modes of transportation in the intermodal transportation system.
- Propose a new innovative model for handling containers in port container terminals efficiently.

In order to fulfill these objectives, we aim to answer the following research questions:

1. How does the new proposed sustainable intermodal terminal design layout can improve port efficiency?
2. To what extent can the new proposed layout decrease GHG emissions and congestion in the terminal and surrounded the area?
3. To what extent the new proposed layout contributes to decreasing the cost of transportation handling?

This research question can be conducted by measuring the port terminal's current layout performance with the proposed layout and identifying the economic, environmental, and social factors. To measure the port terminal performance, there is a prerequisite to determine proper indicators, which gives the full overview to measure all operations and activities at the terminals, thus measuring and evaluating the terminals' performance. It is also required to figure out the relationship between environmental and social dimensions from one side and the proposed layout from another side to decrease GHG emissions in the port and surrounding area. A new sustainable layout will be designed to answer the research questions. The proposed layout considers the operations and the port activities, which will help in investigating the influence of changing the rail track location at the time-container handling, the total cost of transportation, and GHG emissions.

Proposed methodology

This thesis is developed under the pattern of a case study, which is the Port of Montreal. The case study provides researchers with tools to study complex phenomena within their contexts, particularly investigating how and why questions (Voss, Tsikriktsis, & Frohlich, 2002). To achieve the thesis's objectives and answer the research questions, the methodology framework was proposed. A quantitative approach is used in this research to evaluate the overall terminal layout performance in terms of cost and environment (sustainability).

- Step 1. Problem identification: the purpose of this step is to obtain a concrete understanding of sustainability in intermodal transportation, terminal operations, the relationship between terminal layout and terminal performance. In addition, reviewing the previous related studies helped us gain insight into sustainable intermodal transportation to improve efficiency and decrease emissions. An overview of relevant literature is provided in Chapter 1. As a result of the detailed literature review, the research gap can be determined based on the previous studies' weaknesses and challenges. Thus, we will have a good understanding of the problem dimensions and the techniques applied to solve this kind of problem.

- Step 2. Modelling the problem: the study is intended to minimize the overall cost of transportation, GHG emissions, and congestion. A mathematical model has been proposed to evaluate and optimize both the current layout and proposed layout. We divide this step into two sections, single objective function optimization and multi-objective function optimization. We will use a single objective function optimization in chapter 2 to optimize the total cost. In chapter 3, since the objective is minimizing the total cost of transporting containers from the container ship to their final destination and GHG emissions, and they are conflicted objectives, we will use a multi-objective function approach. In this case, there is no single optimal solution, but there is the most preferred solution. However, the concept of the optimal solution is substituted with the Pareto optimality concept. Generally, the widest generation methods are used in the literature are the $\in$-constraint method and weighting method. According to (Resat & Turkay, 2015), it is not obligatory to rely on only one factor in real life when considering intermodal transportation activities. Therefore optimization the intermodal transportation can be efficiently applied to a multi-objective optimization problem, and it can be more realistic (Resat & Turkay, 2015). The IBM ILOG CPLEX solver will be used to solve the mathematical model in chapters 2 and 3.

- Step 3. The simulation model: simulation is one of the most widely used techniques in the field of container terminal operations. The simulation will be used for analyzing the impact of the terminal layout of overall terminal performance. This model's objective is to compare the port of Montreal layout performance (common layout) with the performance of the proposed layout to determine to what extent the proposed layout can decrease the cost and the emissions from the container terminal operations.

Thesis outline

Terminology and background related to container terminals were presented in the earlier section, along with an introduction. The rest of this thesis is structured as follows.

- The first chapter presents the literature review of the intermodal transportation system. The specific focus is on the container terminal in the seaport and the sustainability associated with the container terminals. The research gap is identified, and the methods with techniques are proposed to fill the gaps.
- The second chapter shows the impact of rail track location is proportional to the cost of transporting containers from a container ship in the port to their destinations. This problem has been formulated by using integer linear programming. This chapter aims to compare the current layout being used in the port of Montreal and the proposed layout in terms of container cost and container flow. In this chapter, it has been proposed that changing the location of the rail track significantly reduces the cost of operations.
- The Third Chapter is an extension of the work is done by finding the reduced cost due to change in the rail track location. In addition, we have investigated the impact of changing the rail track on reducing transport containers' cost with terminal emissions. In this chapter, we have proposed multi-objective optimization using the ε-constraint method to solve the problem. The model was tested through a case study of the Port of Montreal in Canada. The findings reveal that the proposed layout resulted in considerable emissions and cost reduction.
- Chapter 4 is presented by proposing a simulation model to investigate the behaviour of the port of Montreal layout and proposed layout. Whereby the proposed simulation model was used to evaluate the operational performance of both layouts. It is proposed and studies in order to reduce the cost and emission in both layouts.

- Finally, the conclusion is presented, which gives the guidelines for future research potential.

Research contributions

This thesis pursues to narrow the research gap and develop a sustainable intermodal transportation system to enhance port activities' efficiency, which is one of our important contributions to this work. Besides, the first article (chapter 2) compares between the common layout of the container terminal and the proposed layout in terms of the time and cost of transporting containers. Considering the congestion on the public roads in the model is an additional contribution. Furthermore, evaluating and analyzing the various combinations of export and import containers and investigate the impact of these changes on the cost of transportation and travel time has been investigated. See table 0.1.

Table 0.1 Research contribution in the first contribution

Chapter 2 Developing the Seaport Container Terminal Layout to Enhance Efficiency of the Intermodal Transportation System and Port Operations – Case of the Port of Montreal	
Problem	• The vast distance between the marshalling space and rail terminal affects the container terminal performance, slow down the flow of containers, and increase the cost of transportation.
Hypothesis	• It is possible to further improve the efficiency by changing the layout of the terminal.
Methodology	• A mathematical model is developed to evaluate both layouts' performance considering congestion between nodes throughout the network. • Comparing the results of the proposed layout and the layout of the Port of Montreal.
Contribution	• We believe this is the first work to address the impacts of rail track location changes in the container terminal. • Considering congestion as an essential factor in the problem of container transportation operations. • Analyzing the optimization of container terminal problems with different modes of transportation by using the principle of cost and time minimization. • Publish the paper in Maritime Policy&Management.

In the second article (chapter 3), promoting the sustainability and efficiency of terminal operation is pivotal to enhance maritime shipping reliability, which we had done in chapter 3 by proposing the novel layout to mitigate the emission from the operations of handling and transporting containers. The current layout of the Port of Montreal has some defects due to the flow of trade changes and can be improved by implementing our proposed layout. The major contribution of the paper is proposing the novel model, which simultaneously minimizes the cost of transport containers and emissions generated from these operations in the environment. Hence, we tried to find a sustainable layout for reducing the ever-increasing emissions from the port operations. See table 0.2.

Table 0.2 Research contribution to the second contribution

Chapter 3 Optimization of Container Terminal Layouts in the Seaport—Case of Port of Montréal	
Problem	• Greenhouse Gas (GHG) emission is highly associated with the handling and transportation of containers. • To simultaneously consider multiple objectives and achieve sustainability in the container terminal.
Hypothesis	• Changing the container terminal layout can achieve sustainability in the container terminal. • Multi-objective optimization provides a more balanced solution in terms of conflicting objectives compared to single-objective models.
Methodology	• Collecting related data from the case study. • The constraint method is used to solve the multi-objective problem . • Comparing the results of both layouts.
Contribution	• Develop a bi-objective mixed integer programming model to simultaneously consider two objectives (cost and emission). • Proposing a new container terminal layout. • The paper published in the Journal of Sustainbility.

The contribution of the third article (chapter 4) is twofold: firstly, developing an overall framework using simulation technique to investigate and analyze the impact of shifting the location of the rail track on the performance and sustainability at the terminal. Secondly, we studied and investigated a specific topic that, being relevant to decision makers and operators in container terminals, has not been studied enough in the academic literature and deserves further research. See table 0.3.

Table 0.3 Research contribution to the third contribution

Chapter 4 A simulation approach towards a sustainable and efficient container terminal layout design	
Problem	• Investigating the behaviour and to assess the performance of the container terminal, which is characterized by complex interrelated relationships between its components. • Minimizing transportation cost while dealing with the effect of terminal operations on the environment.
Hypothesis	• Simulation technique is considered as a powerful tool to effectively imitate such a complex system (container terminal).
Methodology	• Collecting related data from the case study. • Simulation-based optimization approach used to optimize key parameters which minimize the total cost.
Contribution	• Develop a simulation model to evaluate and compare the performance of proposed layout and port of Montreal layout. • Apply the model to port of Montreal. • Submit the paper to the Journal of Maritime Economics & Logistics.

Three peer-reviewed journal articles were written from this work. These articles were presented in detail in chapters 2, 3, and 4. Chapter 2 published in Maritime Policy and Management Journal, chapter 3 published in the Journal of Sustainability, and chapter 4 submitted to the Journal of Maritime Economics & Logistics.

CHAPTER 1

LITERATURE REVIEW

1.1 Fundamental of the intermodal transportation system

This chapter will present a theoretical background on the intermodal transportation system while focusing on the container terminal operations. Though this extensive review does not claim to be comprehensive, the objective is to provide a standard overview of the previous studies and the models that address terminal container issues. Although the first part of this section addresses the general intermodal transportation system problem, the second section will concentrate more on the container terminal problems in terms of efficiency, affecting terminal performance, which can be related to the layout. In the third section, associated studies with emissions from container terminals are discussed. The last part of this analysis emphasizes the sea-rail connectivity in order to improve the terminal performance. Finally, we conclude this review by identifying the research gaps which are tried to be filed.

1.2 Intermodal transportation problems

In the last few years, there has been increasing interest in the intermodal transportation system, which is evident from various good publications related to this domain. Bektas and Crainic (2007) provided a comprehensive review of the intermodal transport system. This research examined intermodal transport from both carriers and suppliers' perspectives. The study shows major challenges and difficulties in planning, designing, and operating intermodal transport networks. This study is based on the modelling approach and operational research role in the intermodal transportation system (Tolga Bektas, 2007). Another overview covering the intermodal transportation system was done by SteadieSeifiet al. (2013). The performance of the intermodal transportation system depends on the performance of every element of the individual chain, such as ports, shipping companies, motor carriers, and rail, as well as the efficient integration of them in terms of operations, making decisions, and information. Several publications have appeared in recent years investigating about the intermodal mode of transportation problems from different aspects (Ishfaq & Sox, 2010), (Ishfaq & Sox, 2011), (Meng & Wang, 2011), (Hanssen, Mathisen, & Jørgensen, 2012), (Winebrake et al., 2012), (Craig, Blanco, & Sheffi, 2013), (Lam & Gu, 2013), (Resat & Turkay, 2015), (Othman, Jeevan, & Rizal, 2016), (Mostert, Caris, & Limbourg, 2017), (Yan et al., 2020).

Most research in the field of intermodal transportation has focused mainly on reducing operating cost as a single measure (Ghane-Ezabadi & Vergara, 2016), (Hanssen et al., 2012), (Ishfaq & Sox, 2011), (Chen, Govindan, & Golias, 2013). Additionally, some other work on the intermodal transportation network aims at evaluating the optimum position of the intermodal terminal in order to ensure the intermodal transport system performance (Violeta Roso, 2015), (Regmi & Hanaoka, 2013). The European Commission has highlighted the need to use effective intermodal transportation rather than unimodal road transportation, considering that the latter contributes significantly towards increased CO_2 emissions (López-Navarro, 2014).

Intermodal Transportation helps to reduce congestion as well as accidents, which usually occurs in deep seaports. It is recognized for its higher environmental performance, congestion avoidance, thereby causing unplanned delays. Hence, environmental benefits are the objectives for the intermodal transportation (Tolga Bektas, 2007), (Dekker, Bloemhof, & Mallidis, 2012), (Craig et al., 2013),(Bouchery & Fransoo, 2015).

Due to the enormous features of transportation by using trucks, such as high-frequency and flexibility (Bouchery, Woxenius, & Fransoo, 2020), the market share of the mode of transportation by truck is growing by many folds around the world (Hanssen et al., 2012). As a result of this trend, massive truck flows and congestion on public roads in and around the cities became one of the port cities' characteristics. Therefore, providing an appropriate integrated rail network with an accurate schedule and proper organization for the train to face the demand enhances container transport operations and reduces transport costs. Also, it allows shipping firms to offer trustworthy service at a competitive rate. Regarding all these concerns, a study conducted by P. T. Aditjandra, Thomas H. Zunder, Dewan Md Zahurul Islam, and

Roberto Palacin (2016) investigated the advantages of using rail transportation. In a recent paper by Ng and Talley (2020), the seaport container terminal's intermodal rail problem was addressed to utilize the train efficiently. Also, the study of Yan et al. (2020) investigated the direct transshipment of containers to the train instead of storing all imported containers in the storage yard before loading them onto the train. However, developed network designs through real-world data assure that the applicable plans help decision-maker benefit from utilizing distribution network designs.

As per the economic and environmental benefits of using sea-rail intermodal transportation to transport containers, this topic has attracted more attention from researchers (Yan et al., 2020). In order to use the intermodal transportation system, most of the countries are shifting from road to rail for mitigating the congestion and other negative impacts associated with it, whereas Canada is not an exception. Several studies in the related literature have revealed the environmental and economic advantages of shifting shipment transport from road to rail transportation (Frémont & Franc, 2010), (Demir, Huang, Scholts, & Van Woensel, 2015), (Bickford et al., 2014), (Song, Zhang, Zeng, Liu, & Fang, 2016), and (P. T. Aditjandra, 2018). Rail transport is a sustainable and effective mode of container transportation for avoiding congestion in container terminals (Ng & Talley, 2020). Much of the research on utilizing the space of the train has been done in order to achieve cost savings (Bruns & Knust, 2010), and (Ambrosino, Caballini, & Siri, 2013).

1.3 Container terminal problems

The container terminal is a complex system; therefore, it has integrated issues, storage space allocation problems, crane assignment, truck assignment, and sustainable challenges. The problems associated with the logistics planning at container terminals in seaport are divided into three levels: terminal design level, operative planning level, and real-time control levels. In chapter 2, this division will be explained in more detail, and we will define every level's relationship with different terminal equipment types.

As intermodal container transport by sea rail is gaining attention due to the cost and environmental benefits it holds, the container terminal in seaports is considered as an essential node for the intermodal transport network (Zhuo, Lee, Chew, & Tan, 2012). Therefore, planning and improving container terminal operations' efficiency is widely considered an open topic for academic research worldwide. Container terminals play a crucial role in the intermodal transportation system, as it links different modes of container transportation for exchanging the containers. A comprehensive description of container terminal operations can be found in the study conducted by Stahlbock et al.(2004), Kap Hwan Kim (2007b), and Stahlbock et al. (2007).

A growing body of literature has evaluated the operating performance of the container terminals to improve terminal efficiency. In this regard, Osman Kulak (2011) conducted a study to improve the terminal's performance in Turkey. Similarly, Yen-Chun Jim Wua and Mark Goh (2010) had conducted a comparative study to examine the efficiency of port operations in emerging and advanced markets. The study has concluded that there is no standard model in developed markets as each port has its characteristics.

In another study, Ha, Yang, and Lam (2019) have discussed port performance in the context of container transport logistics. Bichou (2013) had investigated the operating environment and port efficiency relationship deeply. The proposed model inputs are the port draft, berth length, the terminal area, storage yard, the number of lanes in the gate, the number of rail tracks, and the quay crane index. It has concluded that terminal efficiency is significantly influenced by its operating conditions.

Much of the work on terminal problems at the operational level has been carried out, such as berth and quay crane allocation problems (Imai, Chen, Nishimura, & Papadimitriou, 2008), (Zhang, Zheng, Zhang, Shi, & Armstrong, 2010), (Yang, Wang, & Li, 2012), (Jin, Lee, & Hu, 2015) for improving port efficiency. Storage yard planning and its control is another factor that determines terminal efficiency (Caserta, Schwarze, & Voß, 2011), (Minghua Zhu, 2010), (Y. Lee & Lee, 2010).

A simplified approach to evaluate the container terminal performance is by following a simulation technique. Simulation techniques are precious tools used for decision support in the container terminal problems. Thus, enormous research has been conducted to evaluate the performance of the container terminal by building a simulation model, as done by Osman Kulak (2011), Kotachi, Rabadi, and Obeid (2013), and Zhuo et al. (2012). Similarly, Zhuo et al. (2012) created a simulation model for evaluating a seaport container terminal's operational capability and efficiency. Simulation models are significantly different in terms of its objectives and in detail to model the real system. The integrating of simulation and optimization is becoming more and more popular in recent literature. In this manner, Zhou et al. (2021) conducted a literature review on the integration of simulation and optimization in maritime logistics studies. Dragović et al. (2012) have presented an approach that combines the advantages of simulation models and an optimization method for evaluating the container terminal's performance.

Organizing the container terminal layout in the seaport is another field of research for improving container terminal efficiency. As reported by Kim, Phan, and Woo (2012), many factors are needed to be adopted to design the terminal layout. These factors include cost, environment, flexibility, and technological feasibility. Taner, Kulak, and Koyuncuog (2014) investigated the effect of different layout formats on terminal performance. The difference between layouts is of the storage yards, perpendicular or parallel to the major berth. In another study, four different automated container terminal concepts were experimentally investigated by C.-I. Liu, Jula, & Ioannou (2002). These concepts are an overhead grid rail system (GR), linear motor conveyance system (LMCS), and a high-rise automated storage and retrieval structure (AS/RS). The focus of recent research has an impact on the parallel and perpendicular layouts of container yard to the berth on terminal performance (Kemme, 2011), (Zhou, Chew, Lee, & Liu, 2015), (B. K. Lee, Lee, & Chew, 2018). Taner, Kulak, & Koyuncuog (2014), C.-I. Liu et al. (2002), Kemme (2011), Zhou et al. (2015), B. K. Lee et al. (2018) analyzed and compared various layouts for the storage yard.

Nevertheless, there are still some interesting and relevant problems which have to be addressed. The research to date has tended to focus on optimizing the existing design of container terminals rather than changing the design of the container terminal layout (Amir Gharehgozli, 2019). Even though much work on the terminal layout has been carried out to optimize the container storage yard, as mentioned before, there are still some critical issues that need to be addressed.

1.4 Evaluating the environmental effect of container terminal operations

Despite the enormous importance of seaport container terminals in the global supply chain, they negatively impact the environment. This negative impact is generally generated by handling operations in the terminals (Hossain, Adams, & Walker, 2019). Therefore, reducing the negative impact and sustainably improving container terminals' performance is crucial (Ilaria Vacca, 2010).

For several years, a great effort has been devoted to the study of sustainability at ports. So, there is quite a considerable amount of literature signifying the importance of sustainability in ports (Ashrafi, Acciaro, Walker, Magnan, & Adams, 2019); (Dinwoodie, Tuck, Knowles, Benhin, & Sansom, 2012); (Di Vaio & Varriale, 2018); (Sihyun Kim, 2014); (Acciaro, 2015); (Roh, Thai, & Wong, 2016); (Sislian et al., 2016); (Kang & Kim, 2017); (Langenus & Dooms, 2018), (Oh, Lee, & Seo, 2018).

In order to mitigate the emissions from the container terminal, it is imperative to evaluate emissions from container terminals in the seaports as a primary step. However, making a comprehensive approximation of the overall emissions generated at the terminal is not an easy task (Sim, 2018). Although several studies have carried out to assess the environmental performance of different transportation modes, most of this research focuses on investigating the environmental impact of each mode of transportation individually; for example, H. Liu, Wang, F., Zhang, Z. (2011) investigated the emissions generated from the gantry crane. D. Liu and Ge (2018) studied the emissions from shore crane in the terminal. The emissions from the trucks were studied by Berechman and Tseng (2012), while the emission generated from a yard tractor in the port has been analyzed by Yu et al. (2017). Since the trucks are not owned by terminal operators, it is not easy for port operators to control the emissions from trucks and do not have direct dominance to reduce emissions from the trucks. In some terminals that do not have sufficient environmental regulations, the emissions from trucks account for a considerable share of emissions in the terminal. Thus, the only viable solution to reduce emissions is optimizing truck flow to minimize idling time for trucks in the port (Ari Hirvonen, 2016a).

Several publications have been appeared to estimate the emissions from shipments transportation through calculating fuel consumption of transportation modes. Emrah, Tolga, & Gilbert (2011) compared different models that have appeared to estimate greenhouse gas (GHG) emissions based on fuel consumption associated with road freight transportation. The results of this study demonstrated some differences in the results of the models that use large realistic assumptions. However, in reality, the findings compatible with their expectancies in terms of fuel consumption depend on the speed and the size of the vehicle and road track gradient. One of the most significant current discussions is to evaluate the emission from the container terminal by finding a proper methodology as the first step for policymakers because it is fundamental in evaluating the quantity of CO2 emissions from terminals (Duin & Geerlings, 2011). Some scholars focus on calculating and analyzing emissions generated from handling equipment located in the terminal (Chen et al., 2013); (Geerlings & van Duin, 2011).

By keeping the above viewpoint, J.H.R. Van Duin (2011) provided an approach to estimate CO2 emissions produced from the container terminal situated in the port. The study used different case studies (sea and inland container terminals in the Netherlands) to validate the model. The study considered the fuel consumption and travelled distance for each equipment in the terminal but did not consider congestion, which is usually responsible for generating a significant amount of emissions. Similarly, Sim (2018) proposed a model to evaluate the container terminal's overall emission in South Korea.

In the context of sustainability at Canadian ports, the Canadian ports strive to improve their environmental performance to meet social and economic requirements. The related provincial and Federal Governments and Organizations like the Association of Canadian Port Authorities (ACPA) and Green Marine (GM) should do their part to help Canadian ports in achieving sustainability (Hossain et al., 2019). Some of the research has paid attention to the assessment of the present situation of sustainability in ports of Canada by investigating their KPIs and strategies to achieve sustainability (Hossain et al., 2019), (Ashrafi et al., 2019). Despite the number of studies that have been achieved on sustainability in ports of Canada, to the best of our knowledge, no single research sufficiently investigates the impact of changing the container terminal layout in the port on the cost of transportation and emissions.

1.5 Sea – rail intermodal problems

The rail connectivity with the seaport container terminal is an essential part of the efficient container flow, which is significant for the port operations. Port operations efficiency is considered as an indicator of economic growth in respective countries. As it holds, around 85% of international trade in the world is carried by ship and through seaports (Chung-Yee Lee, 2015).

In previous studies, several theories have been proposed to explain sea-rail intermodal problems. Woodburn (2013) analysis a practical case of a rail network improvement measure designed to switch from road transportation to rail to transport freight for medium- to long-distance in the United Kingdom (UK). The result obtained by this study is that the rail connectivity is an essential component for efficient container flow (Woodburn, 2013).

Similarly, Kozan (2006) studied the optimum capacity of the intermodal for the container terminal, which is a separate terminal away from the maritime container terminal. Thereby, a simulation model was proposed to investigate the train delays under different configurations of service. These results reveal that the number of equipment on the terminal has more influence on delay than the train's throughput time. Another example of implementing the concept of the dry port and how connect it with the port has been presented in the study of

Roso (2007). The study was performed in the Scandinavian region. It found that the implementation of the dry port in the hinterland increases the efficiency of using the train, thereby reducing congestion and environmental effects.

Schönemann (2010) has investigated the transport process between the container ship and railways in German ports, which motivated to propose a model for information flow to decrease the buffer time by enabling better communication between agencies of the transshipment process.

Another study in a Northern Europe seaport was conducted by Ying Xie and Song (2018) to investigate container prestaging problems at a rail terminal in the port. Prestaging means transferring containers from storage yards to the rail terminal buffer in advance. The study concluded that the port could use prestaging to reduce the cost of transport. One example of investigating rail-seaport intermodal issues in Canadian Port is studied by Gillen and Hasheminia (2018), which has demonstrated that enhancing train services and increasing train frequency is the best way to minimize dwell time in ports of Canada and enhance port performance.

1.6 Research gap

The literature review mentioned above shows that previous works have realized the significance of the intermodal transportation system in decreasing the cost and emissions during transport operations. Despite much of the work of the intermodal transportation system, especially on the container terminal, has been carried out; however, there are still some critical issues that require imminent attention. Moreover, most of the studies are tended to focus on improving performance by the operational level in the container terminal. Also Lam & Gu (2013) conducted a literature review study and have arrived at the conclusion that there is a considerable gap regarding sustainability in intermodal container flow.

Although several studies have carried out to solve the problems related container terminals and the environmental impacts of port operations, most of these studies consider the environmental effects of every transportation mode as an individual. A key problem with most of the literature regarding container terminal performance and cost minimization is that the previous studies did not explore the impact of rail track location in the terminal on the cost and environmental performance. Previous studies are limited to address the effect of the container terminal layout on the performance. Thus, none of these studies have taken into account the changing of the rail track location. In other words, they did not investigate the impact of distance between the rail interface and the berth on cost reduction and the efficiency of port activities. Therefore, it is constructive for the analyses by considering sustainable intermodal transportation issues into the terminal layout with respect to environmental aspects. It has not yet been established whether changing the rail track location in the terminal can positively affect sustainability. To the best of our knowledge, no study has been conducted or published comparing different container terminal layouts at the seaport. In other words, there is an urgent need to focus upon the proposed novel terminal layout for the terminal efficiency.

CHAPTER 2

DEVELOPING THE SEAPORT CONTAINER TERMINAL LAYOUT TO ENHANCE EFFICIENCY OF THE INTERMODAL TRANSPORTATION SYSTEM AND PORT OPERATIONS – CASE OF THE PORT OF MONTREAL

Tareq Abu Aisha[a], Mustapha Ouhimmou[b], Marc Paquet[c] , and Julio Montecinos[d]

[a, b, c, d] Department of Systems Engineering, École de Technologie Supérieure, 1100 Rue Notre-Dame Ouest, Montreal, QC H3C 1K3, Canada

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Abstract

The intermodal container terminal is considered the heart of intermodal transportation systems, where different modes of transportation meet to exchange containers. Using intermodal transportation efficiently reduces the handling procedures and relieves congestion at every transfer site. The efficient container terminal operations play a significant role in enhancing container flows at the container terminal. One way to enhance port operations efficiency and facilitate smooth container flow is to improve the intermodal container terminal layout. An efficient container terminal layout can be achieved through a reduction in the distance between the quay and rail tracks. We propose a novel layout to reduce the cost and accelerate container flow, thus improving the effectiveness of the container terminal. A novel new layout is analyzed as a new solution that could reduce the cost and accelerate container flow, thus increase the intermodal transportation system's efficiency. A mathematical model is developed to evaluate both layouts' performance considering congestion between nodes throughout the network. The Port of Montreal is used as a case study to validate the proposed layout and the experiments conducted. It has been found that the proposed layout resulted in significant reductions in cost and time. Comparative results between the proposed layout and that of the Port of Montreal demonstrates a reduction of 10% and 8% respectively to the total cost and time of transport containers from the port to their final destination.

Keywords: Container terminals, maritime transportation, intermodal transportation, new layout.

2.1 Introduction

Maritime transportation is responsible for 80% of international trade, and its cost depends upon the transportation modes' use. Thus, supply chain managers must carefully consider the transportation costs, as it can affect the trade (Chopra & Meindl, 2013). The increase in container ship sizes causes the congestion of transportation containers and trucks in the port's surrounding area, which usually slows down container flow. This increased congestion results in added travel time and fuel consumption (Park & Suh, 2019). Specifically, roughly 65% of maritime transportation sector delay is due to port congestion (Chung-Yee Lee 2015). However, the increased prospect of involving trains and vessels in shipping logistics can help mitigate serious congestion problems and accelerate the cargo flow (Panagakos, 2015).

Since roads' primary function is to carry passengers, most developed countries seek to increase their share of rail and sea use for transportation and shipping (Resat & Turkay, 2015). For instance, the target of Virginia (USA) port is to increase its rail transportation share by more than 40% by the year 2020. Conversely, the Port of New York-New Jersey seeks to raise its share of train use by 20% (Ng & Talley, 2020). This trend is similar in Canada, which is the second-largest nation on the globe. Typically, there is a wide distance separating the locations of production, consumption, and maritime gates. Therefore, the maritime shipping sector plays a vital role in forming Canada's economy. This relationship means that the sector's success relies extensively on the infrastructure of Canadian ports and their facilities. These ports are considered the main gates of Canadian trade with the world (Hossain et al., 2019), because they link the domestic inland with Canadian coastlines and the US markets (Canada, 2018).

Currently, the intermodal transportation system represents the backbone of the world trade chain. The aim of intermodal transportation is to integrate various modes of transportation to increase the efficiency of the whole transport operations (Bektas & Crainic, 2007). The intermodal transportation system means the movement of loading units containing goods without handling the commodities themselves while in transport between transportation types (Lin & Lin, 2016). The seaports' container terminals are one of the most significant components of the intermodal transportation system (Hanssen et al., 2012). These intermodal container terminals at seaports serve as links connecting the operations between the seaside, where the charging and discharging operations of containers are executed, and landside operations, where containers are loaded and unloaded to other transportation modes. Since the handling equipment operates in unique layouts (i.e., each layout has its own characteristics), therefore, a more robust layout will enhance operations' performance in the terminal (B. K. Lee et al., 2018).

Because of the scarcity of land to expand the seaport terminals and accommodate the increased number of containers, port authorities and terminal operators are obliged more than before to improve the current layouts and overcome these challenges. The essential factors for consideration when adopting a layout include the performance to be achieved, investment expenses, and potential social and ecological benefits (Gharehgozli, Zaerpour, & de Koster, 2019). Since carrier companies seek to take advantage of economies of scale by increasing container ship sizes, container terminals must be adopted that can handle these larger ships in both minimum time and cost. Due to both the trend of increasing container sizes handled by seaports, and scarcity of land to expand the terminal at the ports, many ports have used the concept of dry ports. Dry ports are container terminals located in the hinterland to accommodate the higher number of containers. However, even with the use of a dry port, a change of layout is unavoidable.

Taner et al. (2014) demonstrated that the performance of the container terminal in the seaport is significantly impacted by the terminal's layout. Conversely Fan et al. (2020) conducted an interesting study to both accelerate container flow and mitigate the congestion at ports and adjacent areas caused by container transport. The study introduced a new concept, which is the underground logistics system. The study also depicts the port convergence-station floor area and its interior layout. Therefore, it is essential to analyze how the distance between the interface points in the seaport container terminal layout impacts the Port of Montreal's efficiency.

Improving container transportation operations' efficiency through seaport container terminals requires paying more attention to the layout and container handling systems (Gharehgozli et al., 2019). In the current layouts of container terminals, the containers are usually tentatively stored in the terminal, awaiting transport to the next destination, either by trains, trucks, or ships. The current layout shape usually has a rectangular structure. Typically, in this structure, rail tracks are situated at the terminal's end, parallel to the berth, and the storage yard is located between the berth and rail tracks.

Hence, this paper's objective is to minimize container transportation costs from the origin port to its destination and accelerate container flow by proposing a new container terminal layout. Nevertheless, this paper compares the common container terminal layouts with a novel proposed layout. Specifically, this study compares transportation costs and time using various equipment and modes of transportation. The proposed layout offers many advantages to shipping, including the potential for significant port expansion cost savings by, for instance, avoiding the problem of land scarcity and the high costs of land reclamation (if found). Saving on the costs of handling operations and transportation, mitigating congestion, and accelerating container flow are also advantages of the proposed layout. While accurate and robust scheduling between the ship and the train can be a drawback of this layout, it is an opportunity for future research.

The present model has been solved using the integer linear programming approach. The Port of Montreal was used as a case study to test the proposed approach. The present work has seven sections, including: Section 2.1, which introduces the paper; section 2.2 presents a brief overview of the extant related studies; and section 2.3 outlines the problem definition. Next, section 2.4 is a case study and section 2.5 provides the modelling framework. Finally, section 2.6 is the computational results, which followed by section 2.7, which provides the study's conclusions and limitations.

2.2 Problem definition

Due to innovations in the maritime transportation sector, container ships capacity has been increased, benefiting economies to scale and increasing the efficiency of transport operations. Connecting maritime transportation with that of land, especially by rail, provides the advantage of intermodal transportation that facilitates the flow of containers. Even though the efficiency of the container terminal in the seaport has been improved in recent years, most improvements have been achieved by solving many problems such as; Berth assignments, vehicle routing, selection of terminal equipment, scheduling, and yard storage issues. Meanwhile, container terminals suffer from a storage space scarcity, usually in ports surrounded by cities, as reported by (PwC, 2013). Moreover, the rail track's location at the end of the container terminal in the common layouts requires using additional horizontal transportation. Horizontal transportation is used to move the containers between the rail track and the marshalling area. Consequently, transportation time and transportation costs are higher.

Nonetheless, it is possible to further improve the efficiency by changing the layout of the terminal. For this goal, the current work seeks to investigate the effect of the distance between the berth and rail track on terminal performance. However, from the literature, several studies have investigated different factors to improve container terminal efficiency, but none have investigated the effect of the layout on terminal efficiency.

In addition, dependence on road transportation more than rail transportation in container terminals to transport the containers causes congestion in the port's terminal and city. Specifically, at peak traffic periods in the Port of Montreal, there are increased truck traffic and congestion (Montreal, 2015).

Moreover, the vast distance between the marshalling space and rail terminal requires more equipment to handle the containers and horizontal transportation equipment to transfer the containers from the ship to the rail track. These challenges and obstacles affect the container terminal performance, slow down the flow of containers, and increase the cost of transportation. In response to these challenges, a new design figure 2.1 for container terminals is needed to reduce the cost of transportation and improve the efficiency of the container terminal. Based on the above problem description, the present paper seeks to answer the following questions:

- How can the new proposed layout design for the intermodal terminal enhance the port's efficiency?
- To what extent does the new proposed layout decrease the transportation cost of containers?
- To answer the questions above with the concerns mentioned previously into account, a new layout for the terminal is proposed, as seen in Figure 2.1.

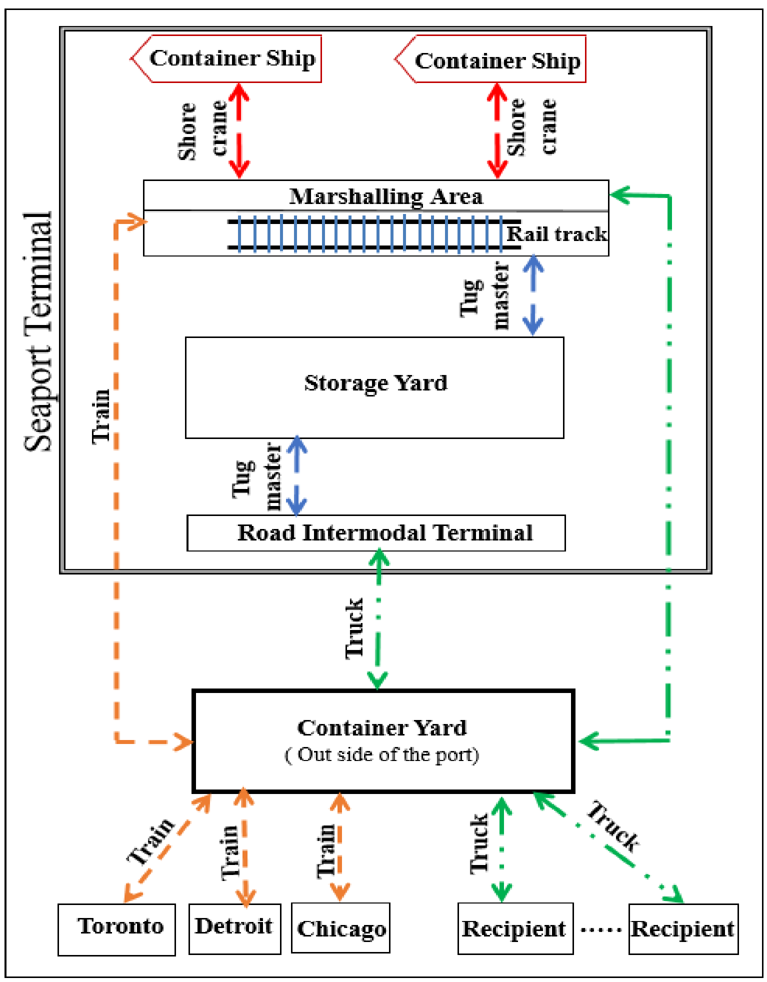

Figure 2.1 The proposed layout.

In the proposed layout Figure 2.1, to minimize the operations of moving containers from ship to rail tracks, the rail track location is moved from the terminal's end to a location between the marshalling area and the storage yard. The proposed layout can improve the efficiency of the container terminal at the seaport by avoiding double handling of containers and reducing the use of equipment in the terminal. The dry port was implemented in this layout by introducing a container yard outside of the port, thereby overcoming the lack of storage space in the port. Regardless of the container storage service in the container yard, other services could be available at the container yard such as storage of empty containers, consolidation, maintenance of the containers, and all value-added activities. The use of trains to transfer containers between the container yard and container terminal at seaports has the advantage of preventing congestion, thus decreasing container delivery time resulting in minimizing transport cost and accelerating the flow of containers. Therefore, distributing containers through this point could achieve different benefits. Since industrial firms are usually located outside of the city, and the movement of the trucks in the city is restricted by specific hours and specific roads and bridges, these restrictions lead to increased transportation time and cost. The social benefits are additional potential advantages from the proposed layout, since delivering containers from the container yard helps to mitigate the congestion and reduce accidents caused by truck. The accident caused by truck usually block the streets for long hours. In addition, store containers of dangerous goods outside the port and far from the ships and inhabited areas are considered another benefit of the proposed layout. However, the function of the intermodal road terminal in the proposed layout is to deliver containers with domestic destinations. Also, since scheduling trucks is more flexible than scheduling trains, some of the containers are transported between the port and the container yard by road transportation.

2.3 Literature review

The transportation system shift from road to rail and sea can lower shipping cost and mitigate road congestion. The primary objective of intermodal transportation is to improve container flow and distribution process efficiency (Bektas & Crainic, 2007). The most interesting study in this regard is an overview of the intermodal transportation system done by Bektas and Crainic (2007). The study demonstrated the significance and challenges of designing, planning, and operating intermodal transportation networks. A similar review of intermodal transportation was studied by SteadieSeifi et al. (2013). The containers flow in the context of the intermodal transportation system is another concern mentioned by scholars (Meng & Wang, 2011). For instance, to improve port efficiency, Meng & Wang (2011) developed an approach to solve intermodal hub-and-spoke network design problems. A similar article by Ishfaq and Charles (2011) investigated the effect of using intermodal shipments in the context of a hub logistics network.

The container terminal in the seaports is considered as a significant node of the intermodal transportation system (Sun, Lee, Chew, & Tan, 2012). Therefore, studying and optimizing of container terminal operations is an increasingly popular subject for scholars. However, a container terminal in the seaports is an essential element for the intermodal transportation system. The terminal connects different transportation modes to exchange the containers. A more comprehensive description can be found in the study of Stahlbock et al. (2004) and Stahlbock and Voß (2007). These studies discussed many problems in container terminals, such as trucks and stacker cranes, scheduling of berths, Quay Crane (QC), Automated Guided Vehicle (AGV), and Straddles Carriers (SC). Finally, this study also described the mechanism of container port operations.

The market share of road transportation is rising worldwide (Hanssen et al., 2012) because of the advantages of the flexibility and high frequency of road transportation (Bouchery et al., 2020). Consequently, these advantages have led to massive truck flows resulting in congestion in cities and on public roads. Therefore, providing a rail network that is integrated enough and that has excellent organization of train schedules helps container traffic processes and reduces costs of transport. Regarding all these concerns P. T. Aditjandra, Thomas H. Zunder, Dewan Md Zahurul Islam, and Roberto Palacin (2016) investigated the advantages of using rail transportation. Moreover, Ng and Talley (2020) recently studied intermodal rail problems at the seaport container terminal to utilize the train more efficiently. Also, Yan et al. (2020) investigated direct-transshipment containers going to the train instead of being stored in the storage yard before loading them on the train. Similarly, Woodburn (2013) examines the rail transportation effect in the United Kingdom on the efficiency of the port and container flow by using a before and after a survey of the container train's capacity and loading factors. This study demonstrates the importance of rail connectivity for containers flows efficiency, resulting in improved efficiency of the port (Woodburn, 2013).

Rail connectivity is crucial for increased containers flow efficiency that significantly helps with port operations efficiency. Port operations efficiency is considered an indicator of a country's economic development (Chung-Yee Lee, 2015). In recent years, research focused on operations efficiency in seaport container terminals has become quite popular. Indeed, there is a vast amount of literature on performance and operations efficiency. For example, Yen-Chun, Jim Wua, and Mark Goh (2010) conducted a comparative study to investigate port operations efficiency in rising and advanced markets. The study concludes that there are no ports in the developed markets that are standard models in this field because each port has its own characteristics (Wu & Goh, 2010). Kulak et al. (2011) also conducted a study to enhance terminal performance in Turkey. This study applied the simulation approach and found that the terminal layout has an impact on applying some allocation strategies in the terminal. Conversely, Kozan (2006) studied the optimum capacity of the Pinter model for the container terminal, which is a separate terminal away from the maritime container terminal. A simulation approach was also developed to assess the train delays under different service configurations. The results reveal that the equipment amount on site impacts delays. Additionally, Min-Ho et al. (2019) assess the performance of ports regarding logistics of container transportation. Conversely, Bichou (2013) investigate the relationship between the operating environment and port efficiency. The model inputs include the port draft, berth length, terminal capacity, storage yard, number of gate lanes, number of rail tracks, and the QC index. Ultimately, Bichou (2013) concluded that operating conditions significantly influence terminal efficiency.

Various studies investigate the factors influencing the container terminals' operating performance to improve the efficiency of the terminal. Most of the extant studies address problems at the operational level; for example, the berth and QC assigning problems improving port efficiency (Imai et al., 2008); (Zhang et al., 2010); (Yang et al., 2012). Storage yard planning is another factor that affects terminal efficiency (Caserta et al., 2011); (Minghua Zhu, 2010); (Y. Lee & Lee, 2010). Finally, minimizing operation costs of the intermodal transportation system is another concern (Hanssen et al., 2012); (Chen et al., 2013); (López-Navarro, 2014).

The increased pressure on ports with the common layouts to accommodate the increased number of containers reinforces the need for port expansion. However, in most cases, the ability of these ports to expand is extremely limited due to the scarcity of land, and the fact that land in traditional port cities is costly. Moreover, in some cases, extending in the ports is politically contested and expanding the ports can result in increased congestion (Flämig & Hesse, 2011). Therefore, terminal decision makers are increasingly compelled to develop new layouts to meet the aforementioned challenges (Gharehgozli et al., 2019).The shape of common layouts takes one of two designs. In the first design, containers stack perpendicular to the berth, which is a prevalent design for export and import terminals. In the second design, containers stack parallel to the berth, which is a common design to transshipment terminals (Amir Gharehgozli, 2019). Though investments in container terminals and their infrastructure expansions are costly, using transportation technology is a continuous trend in the advancement of port container terminals (Kap Hwan Kim, 2007a). One of the first examples regarding the performance of different systems in the container terminal is presented in (C.-I. Liu et al., 2002). These authors designed, analyzed, and evaluated different concepts of automated container terminals (ACT). These concepts include an overhead grid rail system (GR), an automated high-rise storage and retrieval structure (AS/RS), and a linear motor conveyance system (LMCS). To compare these four systems, the authors designed the general layout for their studies. Additionally, Taner, Kulak, and Koyuncuoğlu (2014) carried out another study on the container terminal layout, comparing the effects of different layout formats on terminal performance. Specifically, the difference between layouts is that the storage yards are either parallel or perpendicular to the main berth (Taner, Kulak, & Koyuncuoğlu, 2014). However, the above studies do not investigate the location of the rail track in the container terminal. They do, nevertheless, investigate the container terminal layout in terms of the storage yard’s shape in the container terminal of the seaport.

Importantly, to the best of the authors' knowledge, very few publications exist in the literature on the layout of container terminals. Although much work on the potential of the intermodal transportation system (especially on the container terminal) has been carried out, there are still some critical issues requiring investigation. A key problem with much of the literature regarding container terminal performance and cost minimization is that they do not explore the impacts of terminal rail track location on the costs and performance. Moreover, despite the works of C.-I. Liu et al., (2002) and Taner, Kulak, & Koyuncuoğlu (2014) that addressed the container terminal layout impacts on performance, none of these studies considered changing the rail track location. In other words, they did not analyze the impacts of distance between the rail interface and the berth on cost reduction and port activity efficiency. Therefore, the present study is designed to fill these gaps in the literature on the impacts of the layout of container terminal performance. To address these gaps, we develop a model to examine the impacts of distance between the rail interface and the berth determining the efficiency of port activities. The proposed layout will be a suitable solution for container ports that suffer from land scarcity to expand in the city and its surroundings. The problem is modelled as an integer optimization problem that considers time and congestion dependent on the speed of the vehicles. This paper’s primary contribution to the literature is to investigate how the new container terminal design affects the terminal performance and reduces container transportation costs. We believe this is the first work to address the impacts of rail track location changes in the container terminal. In addition, this work analyzes the optimization of container terminal problems with different modes of transportation and equipment by using the principle of cost and time minimization. Our paper presents an innovative approach by considering congestion as an essential factor in the problem of container transportation operations. Since the Bureau of Public Roads (BPR) function is widely used in North America to formulate traffic congestion, in this paper, the BPR function was applied to estimate the travel time delay on the network. This function addresses the relationship between the volume of traffic and capacity (Bahrami & Roorda, 2020).

2.3.1 Level of problems in container terminals

Some related studies describe container terminals as an open cargo flow system between two points. The quayside is the first interface point in which the operations of ship loading and unloading take place. Conversely, the landside is the second interface point, where the operations of loading and unloading containers onto trucks or trains take place, moving them to the final destination (Voß et al., 2004). A description of containers import and export operations steps can be found in (Kap Hwan Kim, 2007a). Typically, the location of the rail track in the common layout of port container terminals is at the end of the terminal after the storage yard and intermodal road location, which is far from the berth and in the parallel direction. Therefore, to move the containers from ship to train, containers need to go to the storage yard and then to the train, requiring the use of different types of equipment. Figure 2.2 represents the common layout of container terminals.

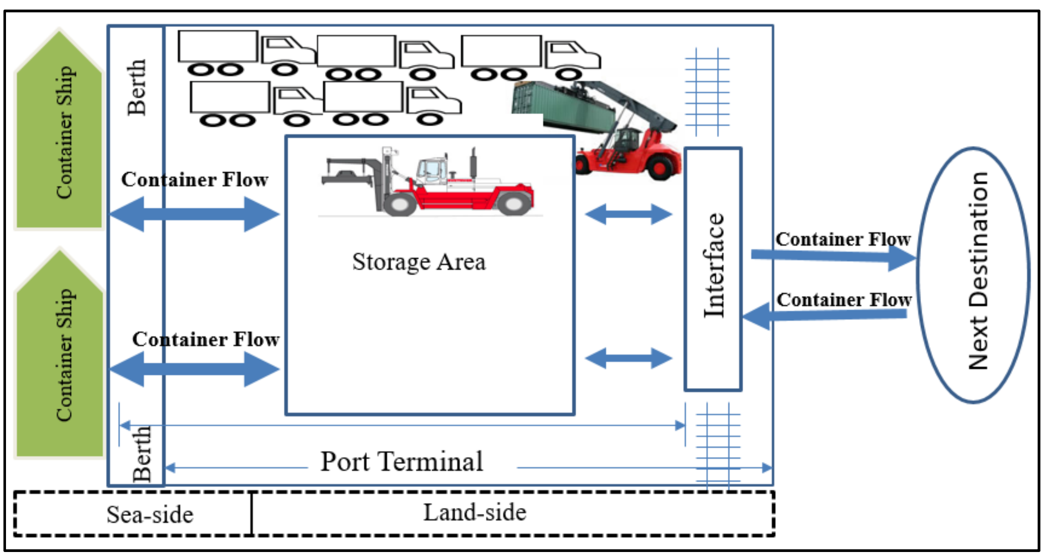

Figure 2.2 The layout of the common container terminal.

The container terminal problems can be divided into three levels, as illustrated in Figure 2.3, including: Terminal design problems, operative planning problems, and real-time planning problems. The terminal design problems include multimodal interfaces, the layout of the terminal, selection of equipment, capacity of the berth, and IT systems. Since these problems are associated with linking the terminal with different modes of transportation and equipment selection, the issues at this level significantly affect the terminal layout. However, the problems at this level have to be investigated from performance, economic, and technical perspectives (Kap Hwan Kim, 2007a).

The problems in the operative planning level contain berth allocation, crane assignment, stowage planning and stacking policies. The problems at this level got more attention from scholars, as aforementioned in the literature review section. Real-time planning problems include issues related to scheduling landside transportation, allocation storage spot to containers, and operations of the quay and stacking cranes.

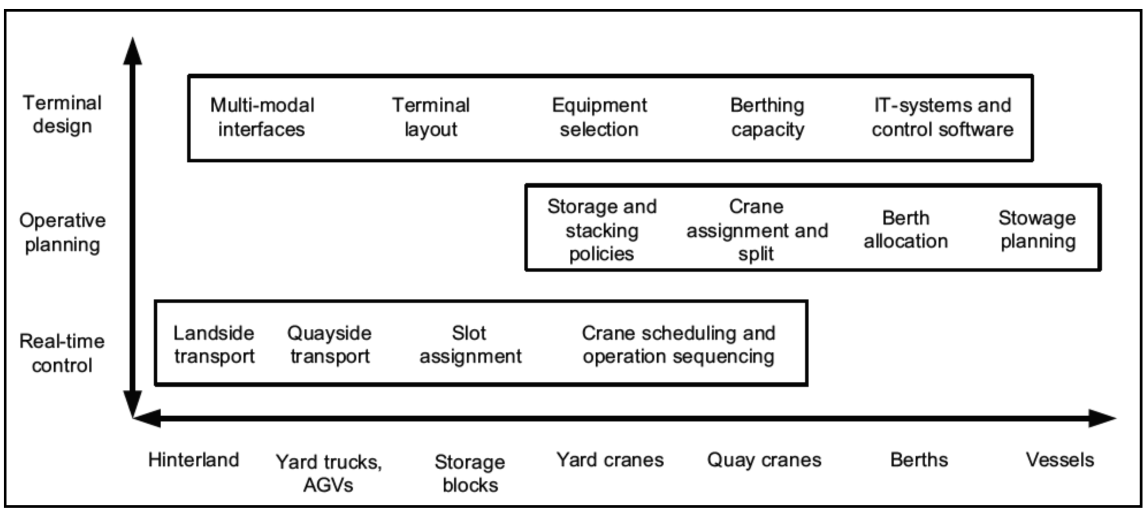

Figure 2.3 Levels of problems in container terminals
Taken from Kap Hwan Kim (2007)

2.4 The case study of the Port of Montreal

The Port of Montreal is Canada's second-largest container port. This port serves the provinces of Quebec and Ontario. About 98% of imported and exported cargo is shipped through this port. Additionally, the port handles more than 1.4 million TEUs annually, and its activity translates to $2.1 billion in benefits to Canada's economy. According to Port statistics, the port receives more than 2,000 vessels per year, up to 2,500 trucks pick up or deliver containers and goods every day, and receives between 60 and 80 trains per week (PortofMontreal, 2015). The Port of Montreal's layout is the same common layout mentioned above, in which the position of the rail track is located at the terminal's end. The trains transport containers to Chicago, Detroit, and Toronto while the trucks transport containers with domestic destinations. At the peak period, about 2,500 trucks enter the port daily that cause increased truck congestion (Montreal, 2015). Therefore, this congestion affects the port efficiency and has a negative impact on the city. In addition, the distance between the three locations (i.e., the berth, the rail intermodal terminal, and the storage area) results in a rise in truck and equipment movement in the terminal, thus, increasing the congestion. The Port of Montreal's layout contains three storage yards; one of exported containers, another for imported containers with domestic destinations, and finally, a third for imported containers destined for Chicago, Detroit, and Toronto. The nodes represent regions, and Arcs connect the nodes. On each arc, containers move from its origin to the final destination using particular modes of transportation. Presents the transfer of the containers from its origin to its destination by using a specific transportation mode. The trucks are used to transport containers with domestic destinations; however, the trains are used to delivers containers to Chicago, Detroit, and Toronto. The sketch in figure 2.4 of the Port of Montreal was drawn based on multiple port visits and meetings with a port representative.

To examine the behaviour of the methodology and compare the results of two layouts, a realistic case study was applied. We visited the Port of Montreal several times and met with managers to see the sequence of charging and discharging container operations, and transporting them to their destinations. During these visits, we collected data related to the amount of equipment and the locations of the interface points. The sketch of the Montreal port was drawn up based on these visits. The present paper, then, discusses the operations of transport containers from the berthed ship at the port to their destination, and vice versa. There are two different modes of transportation to deliver containers to their destinations; the trains are used to transport containers to Toronto, Detroit, and Chicago, and the trucks transport containers to domestic destinations, as shown in figure 2.4.

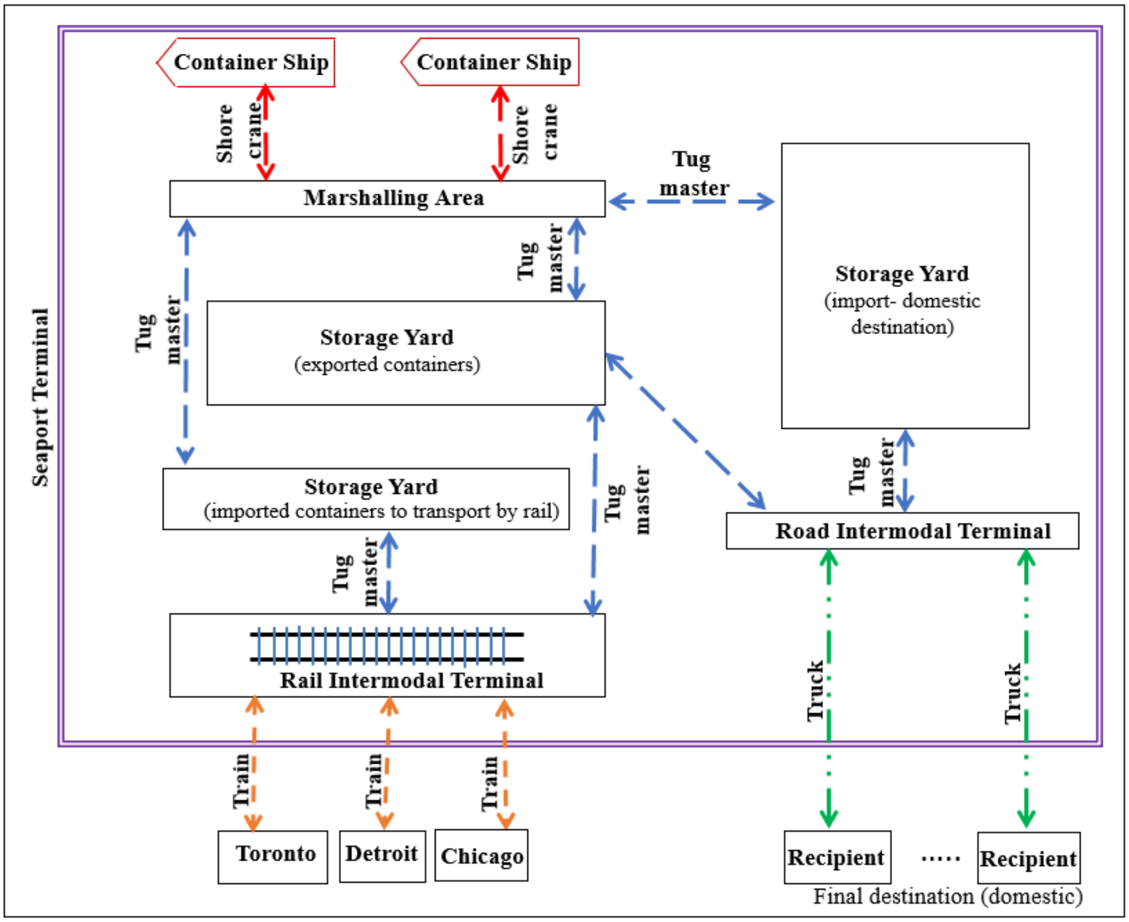

Figure 2.4 Current layout of the Port of Montreal

2.5 Modelling framework

For each layout, a flow network is designed to model the problem. The network of the Port of Montreal's layout is represented in figure 2.5, while a flow network for the proposed layout is represented in figure 2.6. The current layout includes sixteen nodes with four different modes of transportation, while the proposed layout is composed of fifteen nodes with the same modes of transportation. The nodes in both networks represent different locations in the container terminal, such as the rail track, storage yard, and marshalling area. The nodes in both networks are connected with arcs. The containers move between the nodes of the arcs. Regarding transportation modes, shore crane is for loading and unloading the containers between different interface points in the terminal. Tag master transfers containers between the interface point in the terminal. Conversely, trucks are used in transporting containers from the intermodal road terminal, which is inside the port, to the final destination, while the trains are used to move containers to Toronto, Detroit, and Chicago.

In the proposed layout, a new container yard is introduced. The location of this new container yard is far from the port, and out of the city. It is connected with the port by road and rail track. In the figure 2.6, the containers at node (2) have two options; the first option is to go to node (4), which is the storage yard. The second option is to go to the intermodal rail terminal and then to the container yard outside. In the case of export containers, if they arrive at the terminal before the due time of the ship, the containers can also be stored in the storage yard (node (4)). Because containers will arrive at node (3), the containers will then be unloaded at node (2) (the marshalling area), and then they can be sent to node (4); the storage yard.

The BPR equation, which was developed by Horowitz (BPR, 1964), was used to calculate transportation times of the road transportation taking into account road congestion. Moreover, the equipment transportation times inside the seaport terminal and train are assumed to be constant and the average speed used equation (2.2) to calculate time. Time used for the transportation mode was then utilized to calculate the cost. For the computational analysis, the current layout was optimized to compare it with the proposed one.

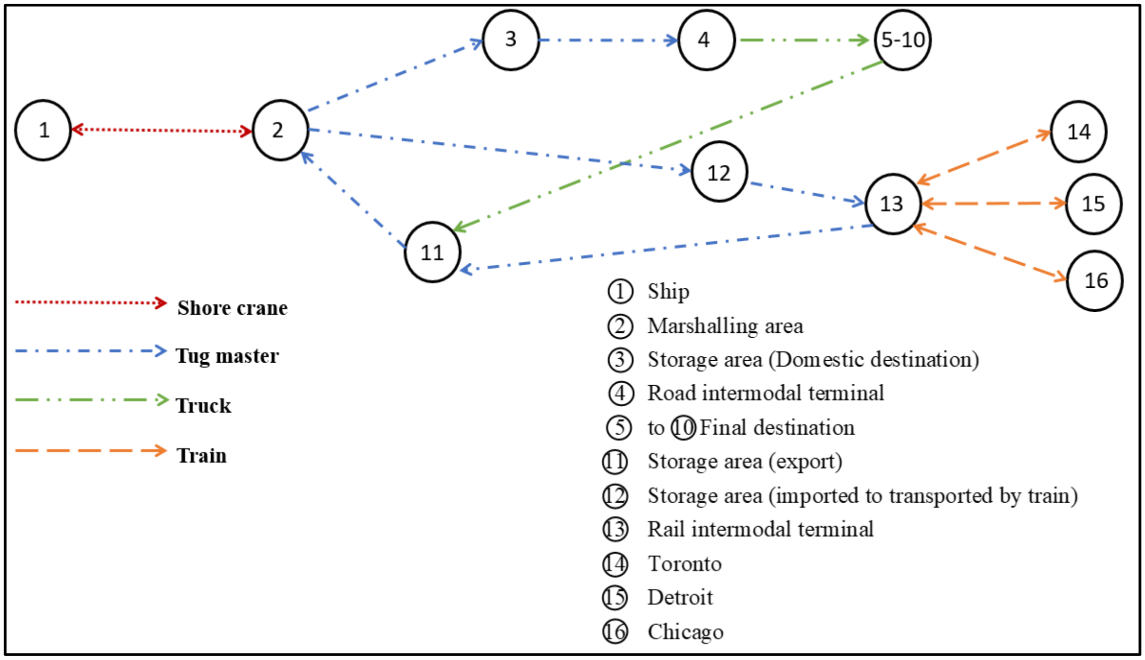

Figure 2.5 A flow network of the Port of Montreal's layout

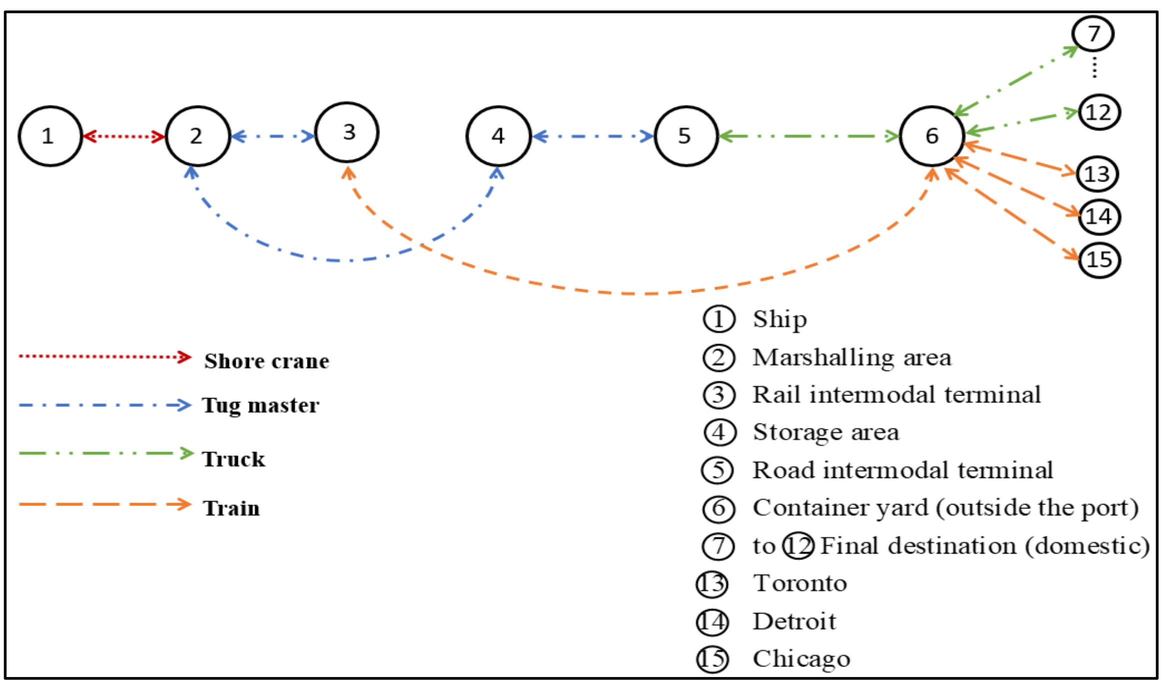

Figure 2.6 A flow network for the proposed layout

The graph G = (N, A) presents the container terminal network and the container yard (outside the seaport). N represents a set of nodes, in which each node $n \in N$ is a particular zone or equipment in the terminal. For instance, the node could be a ship, intermodal rail terminal, intermodal road terminal, storage yard, marshalling area, or container yard.

Conversely, A represents a set of Arcs in graph G, in which, for each Arc $a \in A$, (j, i, k) ∈A, and a = (m, n, k) is a link from node m to node n using mode of transportation k, in which $n, m \in N, a \in A$ and $k \in K$. Below is the definition of the sets, parameters, decision variables, objective function, and the constraints needed to model the problem as an integer linear programming model.

K : Modes of transportation set.

U : Container types set $\{import, export\}$.

S_n^+ : Set of arcs with origin node n.

S_n^- : Set of arcs with destination node n.

A_k : Set of arc uses transportation mode k

2.5.1 Scalar

α : BPR equation constant.

β : BPR equation exponent.

2.5.2 Parameters

D_n^u : A number of containers type u, which already exists at node n.

P_n^s : Represents the storage capacity of node n.

C_{ua}^T : Cost of transportation per container type u on arc a.

T_a^u : Time of transportation for container type u on arc a.

P_k^t : Total available time for transportation mode k.

P_u^s : Unit storage space for container type u.

H_n^u : Unit cost of storage for container type u in node n.

L_a : Arc a length.

V_k : The velocity limit of types of equipment k for free-flow transportation.

v_a : Total volume of traffic for the arc a.

V_e : Equipment speed in the terminal.

Cap_a : Total vehicle capacity of the link between the node i and j for mode of transportation k.

2.5.3 Variables

y_{un} :The number of containers type u stowed in node n, where $y_{un} \in Z$ for $u \in U$ and $n \in N$.

x_{ua} :The number of containers type u transported on arc a,where X_ua ∈ Z for all u ∈ U and a ∈ A.

2.5.4 Objective function

The objective function of this model is to minimize the total transportation cost, Eq. (2.1), from the origin node to the node of destination. Time management plays a crucial role in the problems of intermodal transportation systems, which is also considered the main factor of the cost of intermodal transportation. Therefore, the transportation equipment cost was defined based on each type's hourly cost. Therefore, minimizing the total cost can be expressed as:

$$min\, f = \sum_{u \in U} \sum_{a \in A} C_{u,(m,n,k)}^{T}\, x_{u,(m,n,k)} + \sum_{u \in U} \sum_{n \in N} H_n^u\, y_{un} \tag{2.1}$$

Eq. (2.2) is used to calculate the travelling time for equipment k from its origin node to its destination node for the equipment in the terminal.

$$T_a^u = \frac{L_a}{V_e} \tag{2.2}$$

BPR function, which was developed by Horowitz (BPR, 1964), is widely used in North America to formulate the traffic congestion. This function addresses the relationship between the volume of traffic and capacity (Bahrami & Roorda, 2020). In this paper, the BPR function was applied (Eq. 2.3) to estimate the delay in travel time on the network.

$$T_a^u = \frac{L_a}{V_k} \times \left[1 + \alpha \left[\frac{v_a}{Cap_a}\right]^\beta \right] \tag{2.3}$$

2.5.5 Constraints

There are three constraint conditions to this model. The flow constraint is the first, the capacity of each node is the second, and the final constraint is the equipment capacity. The remaining constraints assure the model variable's non-negativity.

Constraints to ensure the flow of containers:

$$\sum_{a \in S_n^-} x_{u,(m,n,k)} - \sum_{a \in S_n^+} x_{u,(m,n,k)} = D_n^u + y_{un} \quad \forall\, n \in N\,,\ \forall\, u \in U \tag{2.4}$$

The space constraints for each node n:

$$\sum_{u \in U} P_u^s\, y_{un} \leq P_n^s \qquad \forall\, n \in N \tag{2.5}$$

The following constraints are to confirm the time for using equipment k does not exceed the total available time for the terminal.

$$\sum_{a \in A_k} \sum_{u \in U} T_{(m,n,k)}^u\, x_{u,(m,n,k)} \leq P_k^t \qquad \forall\, k \in K \tag{2.6}$$

2.6 Computational results

The data was gathered based on several visits to the Port of Montreal (the case study) and meetings with Port officials to monitor the transport containers' operations. The data collection occurred between March and October 2017. Some of the collected data was manipulated to calculate their average, such as the equipment speed. The model's data are comprised of the distances between interface points in the port, unit of transfer costs and times, modes of transportation, average speeds for transportation modes and equipment that are used in handling and moving containers, and storage costs in the seaport. This data was collected and organized in excel sheet files. The depiction of the Port of Montreal's layout and dimensions are based on the Port's actual layout and functioning. This depiction was achieved via the meetings with the Operations Manager and respective authorities, as well as the numerous visits to the Port of Montreal. The distance measurements of the Port were taken from the Port's map and measurements between the other nodes were taken by Google Earth. After defining the transportation modes that are used in the operation of transferring containers in the terminal and all-determining nodes in the network, the data related to transportation modes are collected from the equipment operation manuals. The equipment amount is the real number used by the Port of Montreal. The manufacturer's manual was used get the speed and time of the equipment movement. Transportation cost is calculated through multiplying the time of transportation on the arc, obtained from eq.2.2 and 2.3, by transportation cost rates. Handling capacity is based on the available resources at the port. Therefore, total available hours of transportation mode k equal to the number of the resources of transportation mode k multiplied by the total working time of the planning horizon. The IBM ILOG OPL Studio modelling environment was used to write the model and solved using IBM ILOG CPLEX 12.1. The mathematical model presented in the present study is implemented in the Port of Montreal using a network including four different modes of transportation (road, rail, tug master, and shore crane). The operation type and characteristic of each transportation mode determines which mode will be used on each arc. Figures 2.5 and 2.6 illustrate the type of transportation mode used on each arc in the network of both layouts. The layout of the Port of Montreal's container terminal demonstrates the common layout found in many terminals in which the rail track location and truck terminal are at the terminal's end (figure 2.4). The Port of Montreal's layout was optimized to obtain the optimal solution. However, the rail track's location in the proposed layout is moved to a location beside the berth. The distance between the berth and rail track was reduced by designing a new layout, as illustrated in figure 2.1. The proposed layout is represented by the network in figure 2.6 to optimize and compare its results with those of the current layout's optimization. Table 2.1 shows the total cost of transportation and time related to both the current and new layouts. The comparison of the total transportation cost and time of container transportation between the current optimized layout of the Port of Montreal to the proposed layout demonstrated a significant cost and time reduction by 10% and 8%, respectively. Furthermore, the reduction of total transportation time resulted in smoother container flow.

Table 2.1 The comparison between the cost and time of the layouts.

	Current layout	Proposed layout
Total cost of transportation (in million $)	13,147	11,831
Total transportation time (hours)	28,592	26,280

Table 2.2 illustrates the time usage of different equipment used for the entire transportation operations in the current and proposed layouts. The time of using the shore crane was constant because the shore crane is the only way to load and unload the containers from the ship. The tag master, truck, and train usage time have reduced by 38.7%, 10.7%, and 6%, respectively. Ultimately, the new proposed layout saved 2,312 hours of the total usage time for the equipment in the terminal. In other words, proposed a new layout decreased 8.09% of the total usage time.

Table 2.2 Time comparison of different modes.

Mode of Transportation	Current layout Time (hours)	Proposed layout Time (hours)
Shore crane	333.3	333.3
Tug master	758.3	465.0
Truck	7,900.8	7,055.0
Train	19,600.0	18,426.6
Total	28,592.4	26,279.9

To investigate the impact of the imported and exported container number on the cost of transportation and transportation time of containers on the same ship, five possible scenarios were studied for the proportions of exported containers through the proposed layout (0%, 20%, 40%, 50%, and 60%). Figure 2.7 illustrates the changes in the transportation cost while changing the proportions of exported containers for current and proposed layouts.

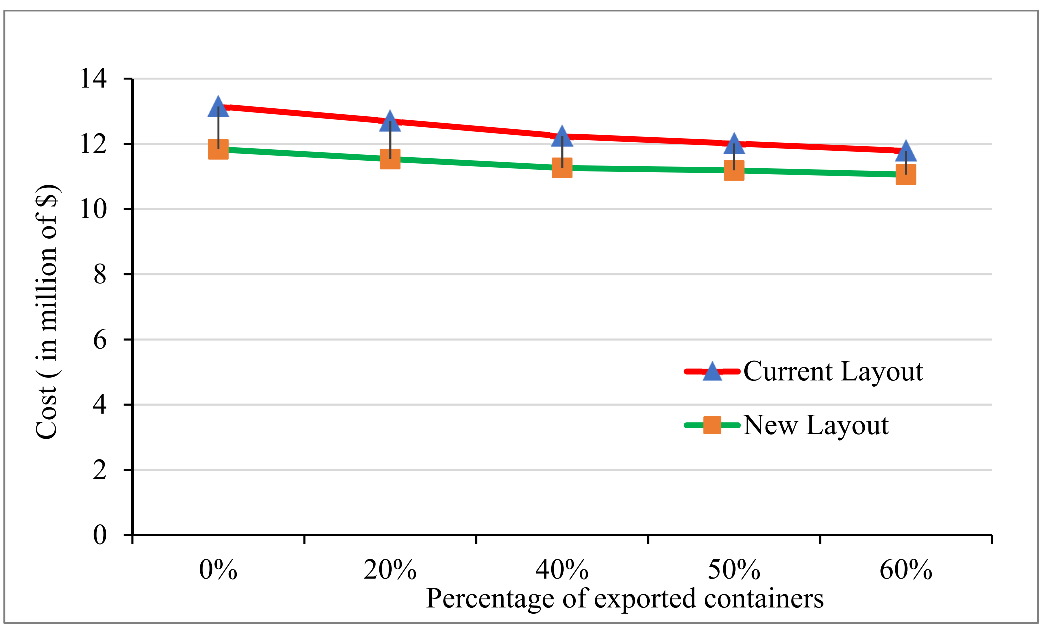

Figure 2.7 The comparison of the effect of proportion of exported containers on transportation cost for the current and proposed layouts.

The comparison shows that the new layout always provides lower transportation costs and, consequently, transportation time is lower because the transportation cost is calculated based on the equipment usage time.

Figures 2.8 and 2.9 illustrate the sensitivity analysis that corresponds to the number of transferred containers and transportation costs using trucks and trains, respectively. Figure 2.8 represents the effect of truck costs on the number of containers transferred between node 3 (rail intermodal terminal) and node 6, which is a container yard located outside the Port (blue line), and between node 5 (road intermodal terminal) and node 6, as well as in the network of the new layout (red line).

The truck cost has changed between \$2 and \$5, and the number of transported containers using trucks from node 5 to 6 decreased from 1,157 containers to no containers. While transporting containers by train from node 3 to node 6 increased from 1,157 to 1,343 containers. Based on our results, the optimal price for transportation by truck and train are \$3 and \$8, respectively with the objective value of \$10,984,970.

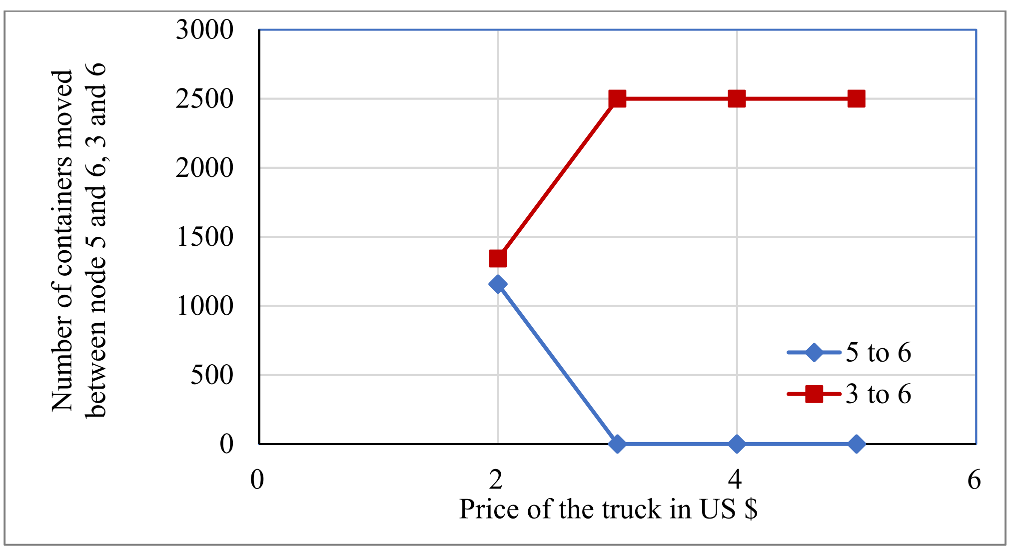

Figure 2.8 Effect of transportation cost by route (trucks)

Different values of train cost have been implemented from $7 to $15. Figure 2.9 represents the optimal number of transferred containers using trains. To mitigate the congestion in the terminal and its surrounding areas, the proposed new layout maximizes the number of transferred containers by train. The results show that the price range from $7 to $10 provides the maximum container transportation number by train.

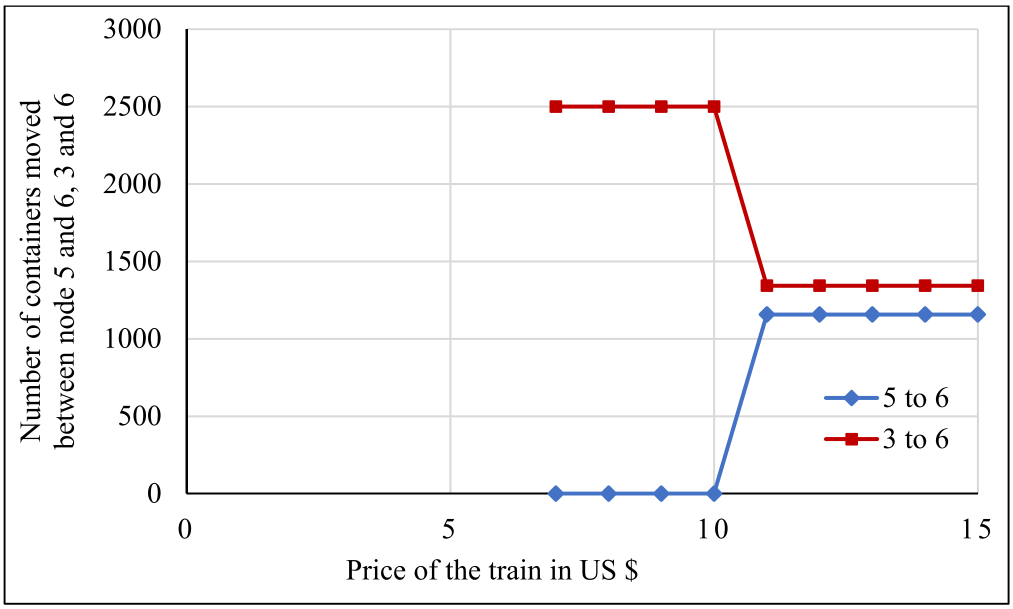

Figure 2.9 Effect of transportation cost by rail (train)

In the proposed layout, the container yard functions as a dry port and most of the containers will be moved between the container terminal and the container yard. Therefore, the container yard location may affect the container terminal performance. In this respect, the impact of changing the distance between the container terminal and container yard on the total cost was investigated. As shown in figure 2.10, the distance between the container terminal and container yard was increased by 15%, 30%, and 45%, and was decreased by -15%, -30%, and -45% from the base case.

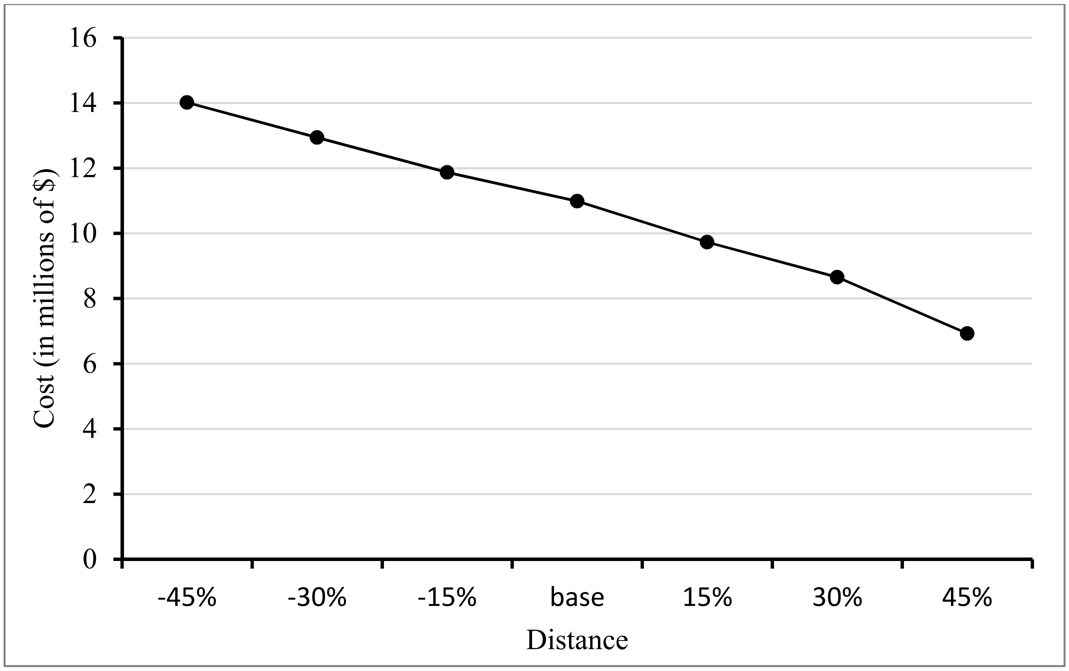

Figure 2.10. Effect the distance on the total cost

The results reveal that total cost of container transportation is decreased when the distance increased from -45% to 45%. Since the container yard became far from the terminal and close to the customers, the train used longer than before, while the trucks used less to transport containers to the final destination.

2.7 Conclusion

Although seaport container terminal problems are well investigated. Improving the efficiency of terminal operations is a crucial way to enhance maritime transportation performance, while, at the same time, minimize the negative impacts associated with increased container ship sizes. The present paper solves the intermodal transportation problem in consideration of the different modes of transportation to minimize cost and time. Moreover, this paper also considers congestion as a key factor because traffic congestion significantly influences the time and, consequently, the transportation cost. To calculate speed flow and predict the delay in intermodal transportation, the equation introduced by BPR was used. Both layout's solutions were compared regarding the transportation cost and time, which shows that the proposed layout's transportation cost and time are always less than the current layout for all cases. Furthermore, the current study's results help to gain more effective solutions for intermodal transportation problems considering the congestion, thereby, maximizing the benefits of the intermodal transportation system. Our findings will also help terminal operators to manage and improve intermodal transportation.

Since most of the ports are surrounded by cities and land for port expansion is scarce, the present study can assist seaport industry decision makers evaluate investment decisions in intermodal container terminals by comparing the total cost of the new layout with the current layout, taking into account other factors, such as transfer time, container flow, congestion, and port performance evaluation. Conversely, in terms of social and environmental contributions, the proposed layout can reduce the pressure on roads and decrease the road accident rate. Moreover, it can also improve the urban environment by dependence on trains more than trucks. Scientifically, the present proposed model is intended to fill the current literature gaps, however, it still has limitations. The intermodal container terminal is a complex integrated system that includes operations of mooring the ship, container inspection, preparing the ship for unloading, and so on. This paper considers operations of unloading and loading containers from vessels and operations of transport containers to their destinations. Future research should consider GHG emissions because of the role of congestion in this effect. Another potential future work is including new objectives and constraints into the current model.

CHAPTER 3

OPTIMIZATION OF CONTAINER TERMINAL LAYOUTS IN THE SEAPORT- CASE OF PORT OF MONTRÉAL

Tareq Abu Aisha[a], Mustapha Ouhimmou[b] ,and Marc Paquet[c]

[a, b, c] Department of Systems Engineering, École de Technologie Supérieure,
1100 Rue Notre-Dame Ouest, Montreal, QC H3C 1K3, Canada

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Abstract

The intermodal transportation system plays a pivotal role in a global supply chain. Despite the benefits of intermodal transportation, it still has negative impacts, which are associated with congestion and emission. Greenhouse Gas (GHG) emission is highly associated with the transportation industry, and the share of the transportation sector is growing at a rapid pace. This paper discusses intermodal transportation and its effects on port efficiency. We proposed a new layout for the container terminal in the seaport in order to decrease cost as well as emission generated by the port operations. The proposed layout can improve the sustainability of port activities by decreasing the distance between the berth and interface points as well as avoiding double handling. We propose multi-objective optimization using the ε-constraint method to solve this problem. The model was tested through a case study of the Port of Montreal in Canada. The findings reveal that the proposed layout resulted in considerable emissions and cost reduction. Compared with the current layout of Port of Montreal, the proposed layout achieved a reduction of 46.5% of the total transportation cost of the containers to their final destination, as well as 21.6% in the emission.

Keywords: maritime transportation; intermodal transportation; container terminals; sustainable terminals.

3.1 Introduction

It is worth noting that a massive amount of global trade flows between the countries through seaports. These seaports, in the past, acted as a point to change the mode of transportation only. However, currently, the ports exceeded this traditional concept and became logistic centers and intermodal terminals. The intermodal transportation term indicates to transport cargo from the origin destination to the final destination in the same loading unit without handling merchandise themselves during the exchange between transportation modes (Lin and Lin 2016). As a result of the increase in the size of container ships, advantages of economy of scale, and global competition, the ports are suffering from a lot of obstacles and challenges limiting their ability to survive and grow. The increase in the size of ships causes congestion in the ports and the area surrounding the port, and usually slows down the flow of containers. The studies show that about 65% of delay in maritime transportation is because of congestion in the ports (Chung-Yee Lee 2015).

In most cases, long distances separate the source of raw material (production site) from the consumption location, and usually, these locations are separated by oceans. Therefore, transportation, especially maritime transportation and the container terminal, is considered as the most significant component of the cost structure of the global supply chain (Qu, Bektaş, and Bennell 2014). Consequently, seaports have been enforced to meet the increased needs of global supply chains and flow of commodities. In order to meet the increased demands, intermodal transportation is being used. The use of efficient intermodal transportation has significantly reduced handling operations and congestion at ports and all other transfer points, thus increasing the efficiency of the ports (Othman, Jeevan, and Rizal 2016). Intermodal transportation is also playing a significant role in the industry of freight transportation because of its benefits regarding minimization of cost, greenhouse gas emissions (GHG), and congestion (Demir et al. 2016). Trans-shipment operations in intermodal transportation systems in the container terminal also release GHG emissions. The emissions from these operations in a particular terminal depend on the type of equipment used for handling the containers and infrastructure and layout of the terminal (Demir et al. 2016). However, greenhouse gas emission is a significant threat to the human and environment (Qu, Bektaş, and Bennell 2014).

Globally, in 2016, the transportation sector represents one quarter of overall emissions at about 8 GtCO2, which is a level 71% higher than what it was in the year of 1990. Road transportation constituted the highest percentage. Overall, the share of air and water transport remained unchanged while road transport emissions increased by two percentage points to 74% (IEA 2019).

In Canada, approximately 20% (by dollar value) of Canadian imports and exports are transported by maritime transportation. Canadian ports are in need of a move forward in environmental performance, concurrently, to meet the sustainability demands (Hossain, Adams, and Walker 2019). Though, as our research is concentrated upon reduction of GHG and cost at Canadian Ports, it has been seen that in 2017, the total greenhouse gas (GHG) emissions in Canada reached 716 megatons of carbon dioxide equivalent or CO2 eq; the second-largest GHG emitter in Canada was the transportation sector with 174 Mt CO2 eq, meaning 24% of total emissions, closely followed by the largest emitter in Canada, the oil and gas sector that emitted 195 Mt CO2 eq, and representing 27% of total emissions. The increase in GHG emissions was mostly due to growth in the transportation and oil-gas sectors. Regarding transportation emissions, from 1990 to 2017, GHG emissions from the transportation sector increased by 43%. This increase was due to freight trucks, whereas it increased by 122% between 1990 and 2017 (Canada 2019). The number of transportation emissions depends on the amount of fuel used (Demir et al. 2016). Generally, fuel consumption can be calculated by taking into account many factors such as road types, loading factors, and speed. So, we assume the value of 3.24 kilograms CO2 emissions per ton as the emissions factor used for diesel (Demir et al. 2016). The energy consumption of the equipment that is used in handling containers relies on the travelled distances between the different sub-processes. However, the consumption of energy can be calculated, taking into account these distances by type of equipment, per modality (Van Duin and Geerlings 2011). In order to overcome these challenges, seaports need particular attention to deliver their service to their stakeholders in an efficient and productive way (ElSayed 2012).

The transportation sector represents 30% of the overall cost of logistics operations (S. Chopra 2013). The growth in demand for container transport has many undesirable effects (congestion, emissions, noise, etc.). Unfortunately, it generates a conflict with the port city as it has to endure the undesirable effects of the port operations. In this regard, sustainable solutions are essential for the development of both ports and surrounding urban areas (Urbanyi-Popiołek and Klopott 2016). One major trade-off between the transportation systems is its effect on the environment. Thus, calculating the emissions from all transportation systems is the main step in the performance measurement for the transportation system (Wang 2004).

The minimization of transportation costs is the key objective of traditional logistics models. However, taking into account wider objectives and problems such as changes in the layout of container terminals, reduction of GHG emissions, and a decrease of congestion will lead to new models and solutions. These models and solutions can be used to define efficient intermodal transportation (Qu, Bektaş, and Bennell 2014). In this paper, the above-defined intermodal problems have been considered. In the case of the container terminals, in which every container terminal has a particular design and layout with distinctive dimensions between interface points, we use the concept of the dry port as one of the ways to increase the use of rail transportation instead of trucks (Othman, Jeevan, and Rizal 2016). The current study uses the concept of the dry port by introducing a new container terminal far from the seaport in the proposed layout model. Thus, the result of solving such problems and overcoming the challenges will be the increase in terminal productivity. Moreover, it will minimize transportation time, cost, and emissions (sustainability), followed by an increase in the capability of the container terminal to meet the recent high demand for containerization. However, this paper makes a comparison between the common layouts of the container terminal with a new proposed developed layout. This comparison is in terms of cost and emission generated by different equipment and modes of transportation used in transferring containers from the container ship to their final destination. The multi-objective optimization approach has been used to optimize the model. In this paper, we took the case of Port of Montreal to validate the proposed model.

The remainder of the paper is organized as follows: In Section 3.2, a comprehensive review of previous research relevant to the current study will be discussed. Section 3.3 presents a real case study. Sections 3.4 and 3.5 are devoted to the problem definition and problem formulation. Section 3.6 analyzes computational results. The conclusion is reported in Section 3.7.

3.2 Literature Review

The basic concept of intermodal transportation is consolidating shipments for efficient long-distance transportation such as by large ocean vessels or rail, at the same time, taking advantage of the efficiency of local delivery and truck pick-up operations. The definition of Intermodal Transportation is transporting cargo from origin to its final destination in the same transportation unit (Mostert, Caris, and Limbourg 2017). The cargo itself is not handled during the transferring activity from one mode of transportation to another (Chung-Yee Lee 2015). Due to the advantages of trucking transportation, such as flexibility and high frequency, the market share of trucking transportation is increasing around the world (Hanssen, Mathisen, and Jørgensen 2012). All these have caused huge truck flows and congestion on public roads and in cities. In addition to that, it produces a high level of emissions. In Canada, based on The Railway Association of Canada, 2006, the number of intermodal carloads increased by 77.5% in the last decade; this demonstrates 26.3% of the overall growth in carload industry appearing during this period. Avoiding congestion and unplanned delays are one of the primary objects in intermodal terminals' operations. Intermodal transportation performance is associated with the performance of every component of the chain individually, ports, maritime line companies, motor carriers and rail, also the efficient integration between them regarding operations, decisions, and information (Tolga Bektas 2007). In this respect, the authors (Tolga Bektas 2007) provided an overview of the intermodal transportation system. This study presented intermodal transportation from the perspective of both carriers and suppliers; as well, the study showed significant problems and difficulties in planning, designing, and operating networks of intermodal transportation. The study focused on the modelling approach, and it paid attention to the role of operations research in the intermodal transportation domain (Tolga Bektas 2007). Most studies in the field of intermodal transportation have only focused on minimizing operation costs as a single objective (Hanssen, Mathisen, and Jørgensen 2012), (López-Navarro 2014), and (Chen, Govindan, and Golias 2013). For ensuring the intermodal transportation system efficiency, some research on the intermodal transportation system is focused on analyzing the optimal location of the intermodal terminal itself (López-Navarro 2014), and (Chen, Govindan, and Golias 2013). The European Commission has pointed out that it is necessary to use efficient intermodal transport instead of using unimodal road transport, in light of the evidence that the latter contributes significantly to increasing CO2 emissions (López-Navarro 2014).

The container's flow from the port to the next destination has become a challenge for many container terminals in the ports. Although using trucks offers door-to-door service that cannot be provided by the train service, using this option is impeded due to congestion and emissions. The use of trains has the advantage of preventing congestion, thus decreasing container delivery time resulting in minimizing transport cost and accelerating containers' flow (Chen, Govindan, and Golias 2013). European Commission aims to shift 30% of transported freight more than 300 km by truck to rail or maritime transportation by 2030, with more than 50% by 2050 (EuropeanCommission 2011). A comprehensive study by P.T. Aditjandra et al. in 2016, investigated the advantages of rail transportation to enhance sustainable transportation (Aditjandra 2016). A large number of existing studies in the broader literature have investigated the economic and environmental benefits of shifting freight transport from road to rail transportation (Woodburn 2013), and (Chen et al. 2019). Regarding all these concerns, Woodburn (2013) investigated the effect of rail track transportation on container flow and port efficiency in the United Kingdom by using a 'before and after' survey of the capacity of the container trains supply and loading factors. The author found that rail connectivity is essential for efficient container flow, which means better port efficiency (Woodburn 2013). Similarly, the author (Bichou 2013) investigated the relationship between the operating environment and port efficiency. The study took 420 container terminals as a sample to study the operating conditions and the market. The terminal efficiency is significantly influenced by operating condition changes (Bichou 2013). Another study shows how the amount of equipment on the site has an impact on delay more than it does on the throughput time of the train (Kozan 2006). Providing a sufficient and integrated rail network and excellent organization for train schedules to meet the demand helps containers in traffic processes and minimizes transport costs. In addition, it enables shipping companies to offer reliable services at a competitive cost. However, developed network designs by using real-world data guarantee the applicable plans that assist decision makers in utilizing advantages of distribution network designs. Such research seeks to improve port operations' efficiency. Due to increased pressure on industries and governments to come forward with initiatives to reduce GHG emissions, the reduction of GHG emissions has become a priority for these organizations (Geerlings and van Duin 2011). Chen et al. used Interpretative Structural Modelling (ISM) to analyze relationships between different structural factors, and they propose governance policies and specific countermeasures to construct green and smart ports (Chen et al. 2019). Gibbs et al. conducted a study to evaluate the role of seaports in the chain of maritime transport emissions. Port operations and transportation activities from the port to hinterland generate a large number of emissions (Gibbs et al. 2014).

Some publications have appeared in recent years documenting the assessment of the current state of sustainability in Canadian ports by analyzing their strategy and KPIs to meet sustainability goals such as (Hossain, Adams, and Walker 2019), and (Sim 2018). Although some research has been carried out on sustainability in Canadian ports, to our knowledge, no single study exists, which adequately covers the effect of changing the layout of the container terminal in the port on the transportation cost and emission.

It is not easy to make a comprehensive estimation of the total emissions generated in the seaport (Sim 2018). Although there is intensive research to calculate the environmental performance of modes of transportation, most of them investigate the negative effect on the environment for each mode of transportation individually. Some of these studies investigated the emissions generated from shore crane (Liu and Ge 2018). Liu et al. studied the emissions from gantry crane in the terminal (Liu 2011). The emissions from the yard tractor in the terminal have been investigated by Yu, Ge, Chen et al. (2017), while the emissions from the trucks were investigated by Berechman and Tseng (2012). Since the terminal operators do not own these trucks, thus terminal operators do not have direct control over reducing emissions from these trucks. In some ports with fewer environmental regulations, the trucks are responsible for generating a significant share of emissions in the port. Therefore, optimizing truck flow to reduce idling time for trucks in the terminal is the only action terminal operators can take to reduce the emissions (Ari Hirvonen 2016).

There are different models to calculate fuel consumption and emissions from freight transportation. Demir et al. conducted a study to compare some models that have been deployed to calculate greenhouse gas emissions and fuel consumption related to road freight transportation. The results of this study showed there are some differences in findings in simulations of the models using largely realistic assumptions, but in general, are consistent with their expectations, such as consumption of fuel differs from the size of the vehicle, road track gradient, and speed (Demir, Bektaş, and Laporte 2011). For policymakers, and as a first step, it is essential to understand the quantity of CO2 emissions for different terminals (Van Duin and Geerlings 2011). Some studies focus on analyzing and estimating emissions from handling equipment in the terminal (Chen, Govindan, and Golias 2013), and (Geerlings and van Duin 2011). Duin and Geerlings presented a methodology to calculate emissions of CO2 generated from the container terminal in the seaport (Van Duin and Geerlings 2011). The model was validated through different case studies (sea and inland container terminals) in the Netherlands. The model took into account the travelled distance and fuel consumption for each piece of equipment in the terminal but did not take congestion into account, which often takes place, and generates a significant amount of emissions. This model will be used in our study to calculate the emissions from both layouts of the container terminal with consideration of congestion and changing the layout of the terminal to improve the efficiency and decrease the emissions.

3.2.1 Common Container Terminal Layout

Container terminals are described in some related references as an open system of cargo flow with two interface points (see Figure 3.1). The first interface point is the quayside, where the operations of loading and unloading ships are done. The second interface point is the landside where the operations are of picking up containers by trucks and trains to move them to the next destination and vice versa (Robert Stahlbock 2007). Every terminal has a particular layout and associated dimensions between the different locations of operations in the terminal. The terminal's design determines these distances. Figure 3.1 illustrates the common layout of the container terminal. In the common container terminal layout, the rail track and truck terminal location is at the end of the terminal opposite the berth. This layout involves using different equipment types to transfer containers from the ship operations area to the truck and train operations area. This equipment generates emissions in the terminal. Figure 3.1 demonstrates the sequence of operations in container terminals: After the container is brought to the terminal by train or truck, the container will be checked to identify and register it (e.g., destination, content, shipping lines, and exported ships). Internal equipment for transportation picks up the container and distributes it to its exact position in the yard (bay, row, and tier within the block) by using specific cranes. Finally, after the ship arrives, the container is discharged from its place in the storage yard block; it will then be carried to the quay where berth cranes pick up and load it onto the ship at the exact location, which is pre-defined based on the storage plan. The containers' import operations are executed in reverse order (Voß, Stahlbock, and Steenken 2004). Improving container handling processes and making them more efficient will save energy and decrease emissions of $CO2$ (Demir, Bektaş, and Laporte 2011). The increase in the amount of container cargo results in a high level of demand for the services of container terminals at seaports, container logistics, and technical equipment (Voß, Stahlbock, and Steenken 2004).

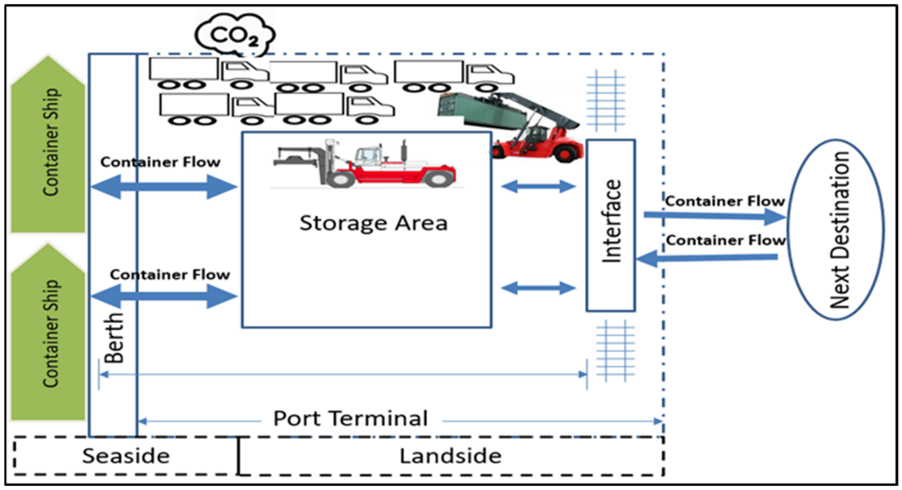

Figure 3.1 Common container terminal layout.

The environmental concern, aside from being assessed based on factors and measures that aim to decrease pollution, depends on the modal shift. In this situation, it is associated with economic factors because maritime transportation is becoming more attractive to transport cargo, and it is preferred to other kinds of transportation (PwC 2013). Scheduling several synchronized operations, activities with various modes of transportation, and handling equipment for containers are very complicated processes. Intermodal Transportation offers an opportunity to lower shipping costs and congestion. Shifting transportation systems from their route to rail and sea is a way to eliminate congestion on the roads, thus GHG emissions.

On the other hand, intermodal transportation systems in container terminals in ports face problems and challenges such as low efficiency, land scarcity, and labour shortage (Chung-Yee Lee 2015). The result of solving such problems and overcoming the challenges will be an increase in terminal productivity and minimizing logistics of time, cost, and emissions (sustainability), thus increasing the capability of the container terminal to meet the recent high demand for containerization.

The literature review shows that prior studies have noticed the importance of the intermodal transportation system in reducing the cost and emissions. Although there are different research in the field of container terminals and environmental effects of these operations, most of the studies that consider the environmental effects dealt with every mode of transportation individually. According to the literature review conducted by Lam et al., there is a big concern about a research gap in intermodal container flow with respect to sustainability (Lam and Gu 2013). Therefore, it is constructive for the analyses by taking into account sustainable intermodal transportation issues into the layout of the terminal with respect to environmental aspects, even though there is still a research gap in the field of sustainable intermodal transportation systems (Sim 2018). To the best of our knowledge, no study has been conducted and published on comparing different layouts of the container terminal in the seaport. In other words, there is an urgent need to focus upon the proposed novel terminal layout for the terminal efficiency. Whereby, this research aims to narrow the research gap and to develop a sustainable intermodal transportation system to enhance the efficiency of port activities, which is the main contribution of this paper. Besides, the comparison of time and cost between two layouts of the terminal, considering the congestion on the public roads, is an additional contribution. Moreover, evaluating the different combinations of import and export containers and testing the influence of these changes on the cost of transportation and travel time is being investigated.

3.3 Case Study of Port of Montreal

In order to examine the methodology's conduct and compare the results of the proposed layout and the Port of Montreal layout, a realistic case study was investigated. This investigation includes trucks, rail, and equipment that are used in the terminal as transportation and handling modes to transfer containers from the container ship to the destination and vice versa. We visited the site of the Port of Montreal several times to observe the operations being conducted over there. We also collected the data from the respective authorities about its layout as well as its functioning. So, we took Port of Montreal as our case study, and it has the same layout as the common layout, where the rail track is located at the end of the terminal. The location of the intermodal road terminal is also at the end of the terminal. The container terminal in the Port of Montreal uses trucks to transfer containers that have a domestic destination. The train is used to transport containers to destinations such as cities like Toronto, Detroit, and Chicago. However, the Port of Montreal has the problem of congestion due to:

- At the peak period, truck traffic is increasingly congested because about 2500 trucks pass through the port daily. (According to the speech of Chief Executive of the Port Authority, March 19, 2015) (Port of Montreal, 2015).
- Inefficient intermodal transportation causes congestion in the port, terminal, and the area surrounding the port.
- The distance between the berth and intermodal terminal and storage area causes an increase in the movement of trucks and equipment, thus increasing the congestion from this equipment and trucks.

The congestion in the terminal generates GHG emissions in the atmosphere and air pollution in the port and surrounding area.

In order to formulate the problem, the sketch for the Montreal Port layout was created, shown in Figure 3.2. The layout of the current case study has three storage yards; firstly, a storage yard for imported containers with a domestic destination; secondly, a storage yard for exported containers; and a storage yard for imported containers that transport to Toronto, Detroit, and Chicago. Each region represents a node. Arcs connect these nodes. Each arc presents a container transfer from its origin to its destination by using a specific transportation mode. In addition to using road transportation to deliver containers to domestic destinations, the train is used to deliver containers to different regions. Transportation by truck is comparatively flexible regarding route and departure time since there is no need to operate the trucks according to fixed schedules in the container terminal. Therefore, every container that arrives can be transported by truck. Travel time was calculated based on the distance between nodes and speed of transportation modes, considering congestion on the road.

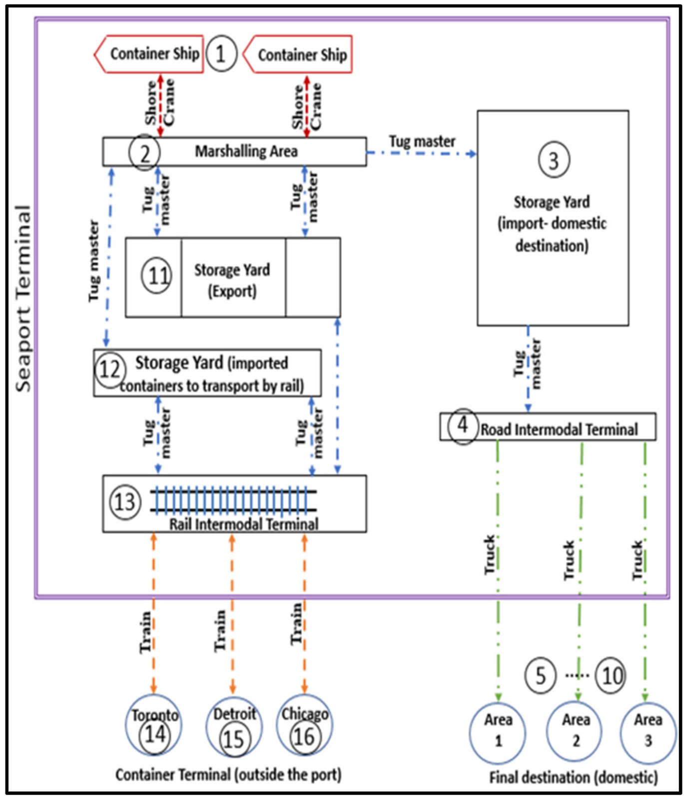

Figure 3.2 The layout of the Port of Montreal

3.4 Problem Definition

Container terminals face many interconnected issues such as storage space allocation problems, crane assignment, truck assignment, and sustainable challenges (Othman, Jeevan, and Rizal 2016). In addition, nowadays, many ports face pressing regulatory and public policy pressures to work toward zero or near-zero emissions technology, which means electrification of most cargo handling equipment and other clean technologies for equipment that cannot run on electricity or batteries (Mongelluzzo 2019). Many ports are not able to serve their customers with the right mix or standard of services because they do not have the right combination of infrastructure.

The long distance between the marshalling area and rail terminal influences the efficiency of the container terminals. It requires more horizontal transport vehicles to move containers between the marshalling area and rail terminal as well as cranes to lift the containers from the trucks and drop them on the real wagon or storage yard of a rail terminal and vice versa. Consequently, congestion will be higher. The amount of fuel consumption determines emissions, which is not the same for all sources of energy: for instance, the burning of a litre of diesel generates about 2.65 kg of CO_2 (Van Duin and Geerlings 2011). Additionally, using trucks as multimodal transport may increase congestion at the terminal and impede terminal throughput. All of these factors influence terminal productivity and reduce container terminal efficiency. Based on the problem definition, the research question is as follows:

- How does the newly proposed sustainable intermodal terminal design layout improve port efficiency?
- To what extent does the new proposed layout contribute to the decrease in the cost of transportation handling and GHG emissions from the operations in the terminal?

Thus, the container terminal and movement of containers between the origins to their destination have become a source of concern for governments, environmental associations, and decision makers. Therefore, studying and facing these challenges have become very necessary to guarantee container flow smoothly and minimize the negative impacts at the same time. So, we try to propose the novel approach by considering all the above concerns and propose the new layout, as seen in Figure 3.3.

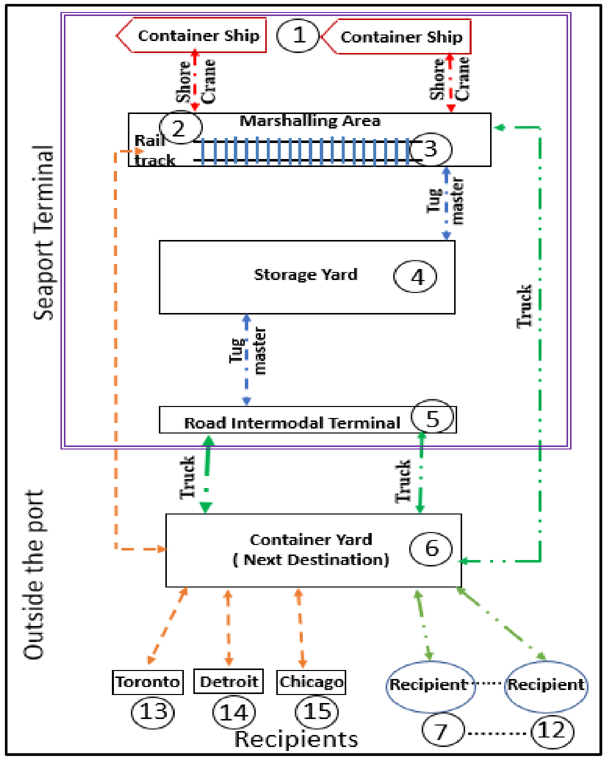

Figure 3.3 The proposed layout.

3.5 Problem Formulation

The Port of Montreal and the proposed layout of the terminal is divided into different locations, such as marshalling area, rail tracks, storage yard, etc., as shown in figures 3.2 and 3.3. These locations are connected by arcs. The containers are transferred between these locations on the arcs by different modes of transportation. The different modes of transportation used in the terminal are as follows: Shore cranes are used to transfer containers between the ship and the seaside; tug master (diesel and electricity) is used to transfer containers between the nodes in the container's terminal in the seaport; trucks are used to carry containers from the intermodal road terminal in the seaport to the destination; the train is used to transfer the containers from the intermodal rail terminal to the destination.

In this study, we propose another type of cargo equipment handling, which is an electric straddle carriers. Therefore, in order to minimize the cost and emissions at the same time, the model will trade-off between the usage of electrical straddle carriers and diesel straddle carriers. In order to formulate the problem, a network representation of flows is designed for each layout. Figure 3.4 represents the network for the Port of Montreal layout, while Figure 3.5 represents a network for the proposed improved the layout for the case of the Port of Montreal. As we have seen in Figure 3.4 (the proposed layout), the nodes are rearranged for the optimization. Port of Montreal has three storage yards, whereas the proposed layout has only two storage yards, which is the difference between the two layouts.

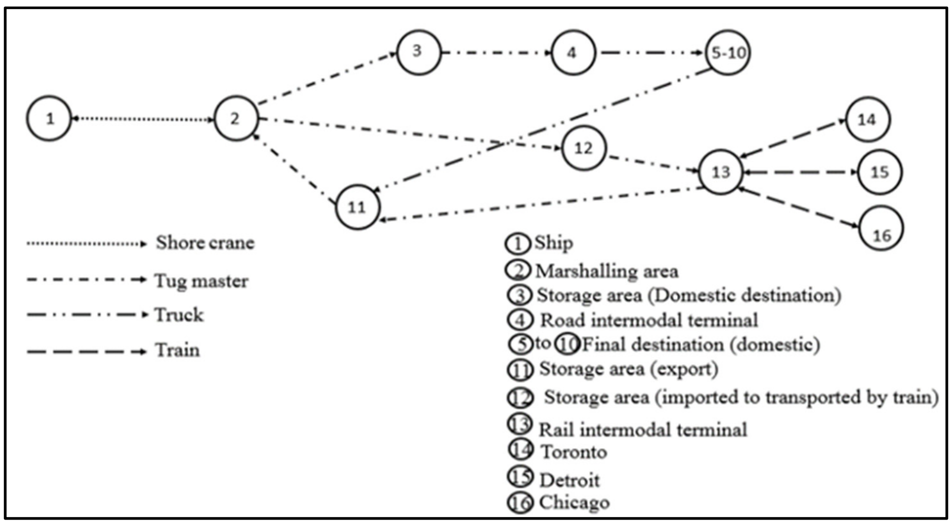

Figure 3.4 A network for the Port of Montreal layout

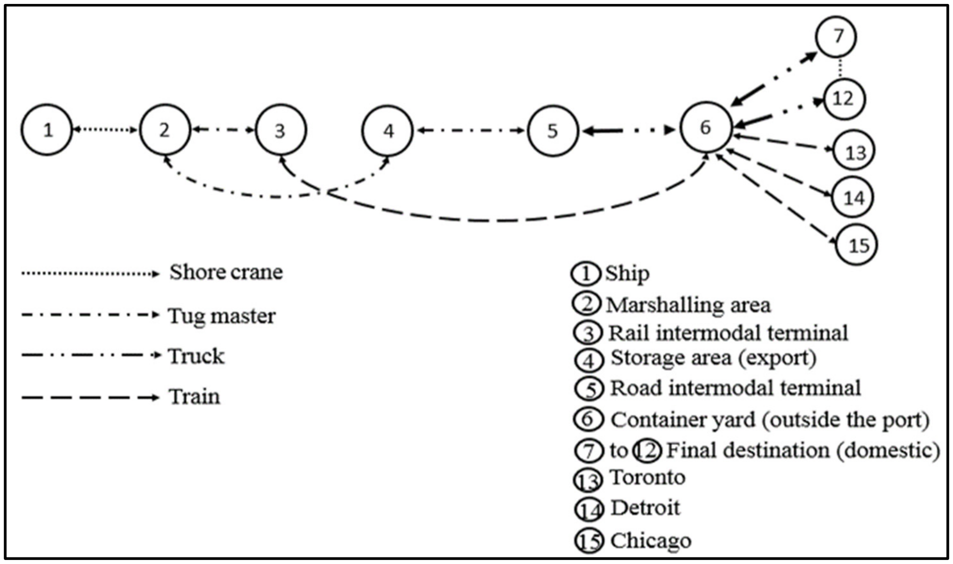

Figure 3.5 A network for the optimized proposed layout

In this research, we solve the intermodal transportation system problem to minimize the cost and GHG emissions considering two objectives functions, considering the congestion on the arcs in the network. The objectives of the study are as follows:

The primary objective function aims to minimize the cost, while the second objective function is to minimize GHG emissions. The proposed model generates different Pareto-optimal solutions for activities of the intermodal transportation system in the Port of Montreal.

The framework of the problem's solution is illustrated in the flow chart Figure 3.6. Since the congestion function is a non-linear function, the approximation method will be used. The primary objective of approximation (Linearization) is to figure out the best representation of the original non-linear objective function of the model. A good expressing of piecewise linear functions has an effective role in minimizing the size of the problem and promoting the efficiency of computation. Generally, a piecewise linear function of a single variable x with $m + 1$ acts as a breakpoint by adding extra m binary variables and $4m$ constraints, which usually raise computational efforts when m becomes large.

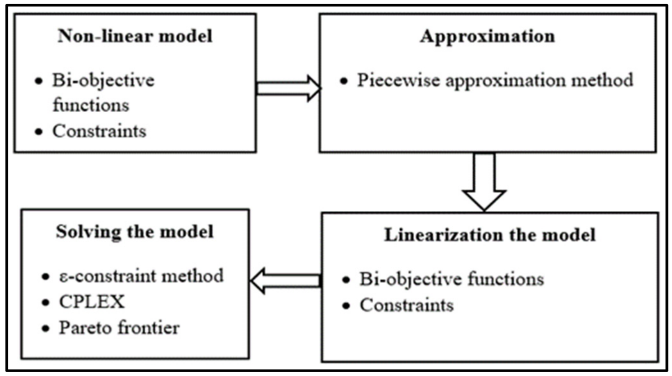

Figure 3.6 The framework of the problem solution

$G = (N, A)$ is a network graph presenting the network of the container terminal and next container terminal, which is located outside the seaport. N is a set of nodes, where every node $n \in N$ represents a specific element in the terminal. For example, a node could represent a ship, marshalling area, storage yard, intermodal road terminal, intermodal rail terminal, or container yard, which is the final distance in this modal.

On the other hand, A is a set of arcs in graph G, where for every arc $a \in A$ and $(j, i, k) \in A$ and $a = (m, n, k)$ represents a link from node m to node n using transportation mode k, where $n, m \in N, a \in A,$ and$k \in K$. The notations, scalars, parameters, and variables are as follows:

K: Set of transportation modes.

U: Set of container types.

S_n^+: Set of arcs that have origin node n.

S_n^-: Set of arcs that have destination node n.

3.5.1 Scalars

α: BPR (Bureau of Public Roads) equation constant.

β: BPR (Bureau of Public Roads) equation exponent.

3.5.2 Parameters

D_n^u: A number of containers type$u$ that already exist at node n.

P_n^s: The storage capacity of node n.

C_{ua}^T: Transportation cost per container of type u on arc a.

T_a^u: Transportation time of container type$u$ on an arc a.

P_k^t: Total time available for transportation mode k.

P_u^s: Unit storage space for container type u.

H_n^u: Unit storage cost container type$u$ in node n.

L_a: Length of arc$a$.

V_k: A speed limit of equipment types k for free-flow transportation.

v_a: The total volume of traffic on the arc.

v_e: Speed of equipment on the port.

Cap_a: The overall capacity of the arc between node i and j for the mode of transportation k.

$E_{u,(m,n,k)}^T$: Total emission to transport container u from node m to node n using equipment$k$.

f_k: The factor of emission for electric equipment = 0.52 (in kg of CO2 emission per kWh), and = 2.65 (in kg of CO2 emission per litre diesel).

F_k: For fixed use, per ride in liters (such as lifting operations).

r_k: Variable usage per km in liters.

d: Travelled Distance for equipment k.

3.5.3 Variables

y_{un} : Number of containers type$u$ stored in node n.

x_{ua} : Number of containers type$u$ moved on arc a.

3.5.4 Objective functions

$$min\, f1 = \sum_{u\in U}\sum_{a\in A} C_{u,a}^{T}\, x_{u,a} + \sum_{u\in U}\sum_{n\in N} H_n^u\, y_{un} \tag{3.1}$$

$$min\, f2 = \sum_{u\in U}\sum_{a\in A} E_{u,a}^{T}\, x_{u,a} \tag{3.2}$$

$$T_a^u = \frac{L_a}{V_e} \tag{3.3}$$

$$T_a^u = \frac{L_a}{V_k} \times \left[1 + \alpha \left[\frac{v_a}{Cap_a}\right]^{\beta}\right] \tag{3.4}$$

$$G_{u,a} = 1 + \alpha_a \left[\frac{x_{u,a}}{Cap_a}\right]^{\beta} \tag{3.5}$$

$$C_{u,a}^{T} = T_a^u . W_a . G_{u,a} \tag{3.6}$$

$$E_{u,a}^{T} = f_k[F_k + r_k * d * G_{ua}] \tag{3.7}$$

3.5.5 Constraints

$$\sum_{a\in S_n^-} x_{u,(m,n,k)} - \sum_{a\in S_n^+} x_{u,(m,n,k)} = D_n^u + y_{un} \qquad \forall\, n \in N, \qquad \forall\, u \in U \tag{3.8}$$

$$\sum_{u\in U} P_u^s\, y_{un} \le P_n^s \qquad \forall\, n \in N \tag{3.9}$$

$$\sum_{a \in A} \sum_{u \in U} T^{u}_{(m,n,k)} \, x_{u,(m,n,k)} \leq \; P^{t}_{k} \qquad\qquad \forall \; k \in K \tag{3.10}$$

The functions (3.1) and (3.2) represent the objective functions. Function (3.1) is the cost objective function and function (3.2) is emissions function. The first expressing of equation (3.1), expresses the total cost of transportation on the network while the second expressing indicates the overall cost of storage containers. In Equation (3.2), the first part shows the overall emissions corresponding to transfer containers from the container vessel to the last destination on the network. Since management of time functions a vital role in intermodal transportation problems, and it describes the main factor of the intermodal transportation cost. The cost of transportation equipment is determined based on the hourly cost of each type. Equation (3.3) is to calculate the travelling time of the equipment in the terminal, while the BPR equation (equation (3.4)) is used to calculate the transportation congestion on the network because the BPR equation relies on the transported volume on the way (BPR 1964). Equation (3.5) is to calculate the congestion factor on arc a for container type u. Equation (3.6) is to calculate unit transportation cost for container type u at arc a. Equation (3.7) is to calculate emissions from the container terminal.

The model has three main constraint conditions. The first is the flow constraint; the second is the capacity of each node; the last one is the capacity of the equipment. The rest of the constraints is to assure the non-negativity of the model variable. The equation (3.8) is a set of constraints to enforce the maintenance of flow between the nodes. By Equation (3.9), we guarantee that the inventory capacity of the nodes that have a storage yard is not violated. The current layout has three storage yards: storage yard for an imported container which has a domestic destination, storage yard for imported containers which will be transported by train, and storage yard for exported containers. In contrast, the proposed layout has two storage yards: storage yard inside the port and container yard in a location outside the port. Equation (3.10) is a set of constraints to ensure that the time of using equipment k does not exceed the total time the company has available for equipment. Equation (3.4) is used to figure out times of transportation of the modes considering the congestion on the road. In addition to road transportation, the times of transportation for equipment inside the seaport terminal and train modes are presumed to be fixed and calculated by using the average speed, equation (3.3). The cost is calculated based on using the time of transportation modes. Based upon the case study, which represents the layout of Port of Montreal, we have described the problem definition, problem formulation, and the computational analysis of the following sections. The following sections will put an insight into the proposed layout, and the comparison has been made thereof.

3.5.6 Approximation

To introduce this method, let us consider a convex function $f(x)$ of a one-variable x; $f(x)$ is a continued function, and x is between the interval $[a_0,a_m]$ (Lin et al. 2013).
Firstly, denote $a_k(k = 0, 1, ... m)$ as the breakpoints of $f(x)$, $a_0 < a_1 < \ldots < a_m$, and Figure 3.7 presents the linearization of $f(x)$ using the piecewise method.

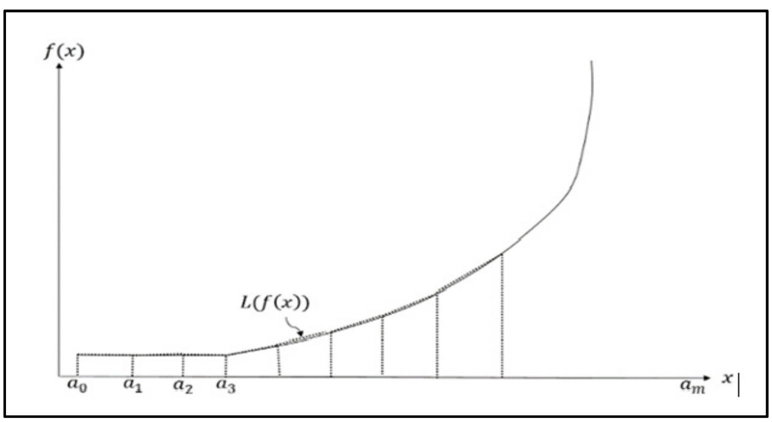

Figure 3.7 Piecewise linearization of (x)
Taken from Lin et al. (2013)

$f\ (x)$ then can be linearized approximately over the interval $[a_0,a_m]$ as:

$$L\big(f(x)\big) = \sum_{k=0}^{m} f(a_k)\, t_k \tag{3.11}$$

Where $x = \sum_{k=0}^{m} a_k\, t_k$, $\sum_{k=0}^{m} t_k$=1,$t_k \geq 0$, in which only two adjacent t_k's are liable to be nonzero. A nonlinear function is then changed into this equation.

$$L\big(f(x)\big) = \sum_{k=1}^{m} f(a_k)\, t_k, \tag{3.12}$$

$$x = \sum_{k=1}^{m} a_k\, t_k, \tag{3.13}$$

$$\sum_{k=0}^{m} t_k = 1, \tag{3.14}$$

This method is used to linearization the proposed model functions for both cost and emission as following:

$$\min f1 = \sum_{u\in U}\sum_{a\in A}\sum_{b\in B} \hat{C}_{u,a}^{T(b)}\ \widehat{X}c_{u,a}^{b}\ tc_{u,a}^{b} + \sum_{u\in U}\sum_{n\in N} H_n^u\, y_{un} \tag{3.15}$$

$$\min f2 = \sum_{u\in U}\sum_{a\in A}\sum_{b\in B} \hat{E}_{u,a}^{b}\ \widehat{X}e_{u,a}^{b}\ te_{u,a}^{b} \tag{3.16}$$

Subject to:

$$\sum_{a\in S_n^-} x_{u,(m,n,k)} - \sum_{a\in S_n^+} x_{u,(m,n,k)} = D_n^u + y_{un} \tag{3.17}$$

$$\sum_{u\in U} P_u^s\, y_{un} \leq P_n^s \qquad \forall\, n \in N \tag{3.18}$$

$$\sum_{a\in A}\sum_{u\in U} T_{(m,n,k)}^{u}\, x_{u,(m,n,k)} \leq P_k^t \qquad \forall\, k \in K \tag{3.19}$$

$$\sum_{u\in U} tc_{u,a}^{b} = 1 \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A} \tag{3.20}$$

$$\sum_{u \in U} te^{b}_{u,a} = 1 \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A} \tag{3.21}$$

$$tc^{b}_{u,a} = te^{b}_{u,a} \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A}\,,\; b \in \mathrm{B} \tag{3.22}$$

$$x_{u,a} = \sum_{u \in U} \widehat{\mathrm{X}}c^{b}_{u,a}\, tc^{b}_{u,a} \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A} \tag{3.23}$$

$$x_{u,a} = \sum_{u \in U} \widehat{\mathrm{X}}e^{b}_{u,a}\, te^{b}_{u,a} \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A} \tag{3.24}$$

$$tc^{b}_{u,a} \;\geq 0 \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A}\,,\; b \in \mathrm{B} \tag{3.25}$$

$$te^{b}_{u,a} \;\geq 0 \qquad \forall\, u \in \mathrm{U}, a \in \mathrm{A}\,,\; b \in \mathrm{B} \tag{3.26}$$

After approximation, the equation (3.1) converted to equation (3.15), which is a linear objective function of cost minimization. In a similar manner, equation (3.2) turned into equation (3.16) to represent the emission objective function. Additionally, for approximation, we introduce new terms, which are $\widehat{\mathrm{X}}c^{b}_{u,a}$ to denote to the number of containers at breakpoints (b) on an arc a in cost objective function. $\widehat{\mathrm{X}}e^{b}_{u,a}$ denotes to the number of containers at breakpoints (b) on an arc a in emission objective function, while $tc^{b}_{u,a}$ is a decision variable ∈ [0,1] in cost objective function, and $te^{b}_{u,a}$ is a decision variable ∈ [0,1] in emission objective function. $\hat{C}^{T(b)}_{u,a}$ is the unit transportation cost at breakpoint (b), and $\hat{E}^{b}_{u,a}$ is the unit transportation cost at breakpoint (b). Constraints (3.17),(3.18) and (3.19) have been previously explained. Constraints (3.20), (3.21), (3.25) and (3.26) are devoted to maintaining the values of $tc^{b}_{u,a}$ and $te^{b}_{u,a}$ within [0,1]. Equation (3.22) is linking constraint, to link decision variable $tc^{b}_{u,a}$ in cost objective function with $tc^{b}_{u,a}$ in emission objective function. Constraints (3.23) and (3.24) to link $X_{u,a}$ with $\widehat{\mathrm{X}}c^{b}_{u,a}\; tc^{b}_{u,a}$ and $\widehat{\mathrm{X}}e^{b}_{u,a}\; te^{b}_{u,a}$ in cost objective function and emission objective function, respectively based on the piecewise linearization method.

The epsilon constraint method is applied to find a solution to this problem (Mavrotas 2009). The epsilon constraint method generates non-extreme efficient solutions, and usually, each run generates a different and new efficient solution, so a number of these solutions are beneficial for decision makers. After calculating the lower and upper bounds of the function of the cost and the emission function, respectively, the epsilon constraint method is applied.

3.6 Computational Results

The data used in this model include distances between the nodes in the network, transportation modes, fuel consumption, transfer costs and times, average speeds for transportation modes and equipment that are used in handling and transferring containers, and costs of storage containers in the seaport. This data involves the Port of Montreal as a real case study. There are some restrictions on using transportation modes on the network because every mode of transportation is designed for performing a different task. The data was collected based on the operations in the Port of Montreal.

The collecting data started from March 2017 until October 2017. The Port of Montreal layout and its dimensions were drawn based on real layout through many visits to the Port of Montreal and meetings with the Operations Manager. The measurement of distances were taken between the nodes from the map of the port and measured by Google Earth. The amount of equipment is the real number used by the Port of Montreal. Speed and time of movement of the equipment were taken from the manufacturer's manual. In the computational results, we presented an overview of both layouts and related data used in this model and computed the analysis of the results obtained. The model of this study was written in the IBM ILOG OPL Studio modelling environment. However, the model was solved by using IBM ILOG CPLEX 12.1(IBM 2020). The model is executed on a computer with 2.50 GHz dual-core processor, with Intel Core I5 2520M CPU, and with 4.00 GB of RAM. The mathematical model shown in this paper is applied to the Port of Montreal with a network containing five different transportation modes (shore crane, diesel tug master, electrical tugmaster, road, and rail). Using transportation modes between the nodes differs based on the characteristic of each mode of transportation and type of operation. Figures 3.2 and 3.3 shows feasible links between the nodes for varying modes of transportation in the current and proposed layout, respectively. The layout of the container terminal of Montreal Port shows that the location of the rail track and truck terminal is at the end of the terminal, as shown in Figure 3.2, and this is the common layout in many terminals. In this section, we will solve both Port of Montreal and proposed layout as a bi-objective function problem to minimize the cost function, and GHG emissions function simultaneously. We will also present a comparison between them. In order to use the ε-constraint method for both layouts, the emission function was minimized to find the bounds of the objective function. Then, this value was used as a constraint in addition to constraints, equations (3.13)–(3.22) to minimize the cost function. The right-hand-side value of the emission function changes in each iteration of the ε-constraint method by adding the ε value for the iteration of the lower bound of the emission function. The solution depends on the decision makers' preferences, if the emission has higher priority, they will choose the solution with low emission and high cost, or they can trade-off between the number of emissions and the cost to find an acceptable solution which meets minimization of emissions and cost. In order to derive the solution, we had used the ε-constraint method for the Multi-objective problem, which thereafter generate the Pareto set with varying solutions. So, the problem is reformulated by keeping the cost function as an objective function and transforming the emission function to a constraint. Eventually, the implementation of the ε-constraint for both layouts becomes as follows:

$$\min f1 = \sum_{u\in U}\sum_{a\in A}\sum_{b\in B} C_{u,a}^{T(b)}\ \widehat{\mathrm{X}}c_{u,a}^{b}\ tc_{u,a}^{b} + \sum_{u\in U}\sum_{n\in N} H_n^u\, y_{un} \tag{3.27}$$

Subjected to:

$$\sum_{u\in U}\sum_{a\in A}\sum_{b\in B} E_{u,a}^{b}\ \widehat{\mathrm{X}}e_{u,a}^{b}\ te_{u,a}^{b} \le \varepsilon \tag{3.28}$$

And the rest of the constraints can be seen in (Equations (3.17)–(3.27).

To develop the Pareto set of the Port of Montreal and the proposed layout, we determined the optimal value of the emission function ($f2$) only. Afterward, we considered the obtained value of f2 as the epsilon value of optimized cost function ($f1$). The value of epsilon has been changed multiple times within the imposed range of the upper and lower bounds. Before delving into the Pareto sets, we show the difference between the Cost of Transportation comparisons between Port of Montreal and the proposed layout, which can be seen in Figure 3.8 and Figure 3.9, considering cost and emissions, respectively.

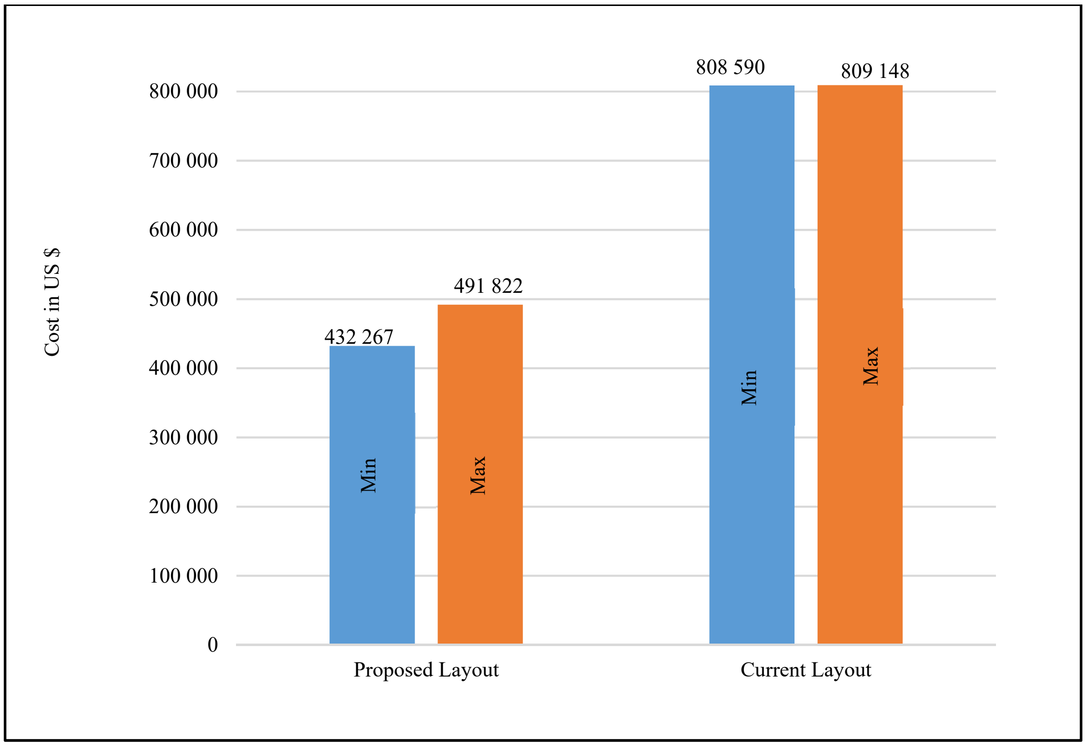

Figure 3.8 Cost of transportation comparison

From Figure 3.8, the proposed layout proposal demonstrated a notable reduction in the overall cost by 46.5% compared to the Port of Montreal layout, while the minimum emissions decreased by 21.6%. Figure 3.9 shows a comparison of the minimum and maximum values of emissions between both layouts. In addition, the flow of containers became smoother, where the congestion was minimized.

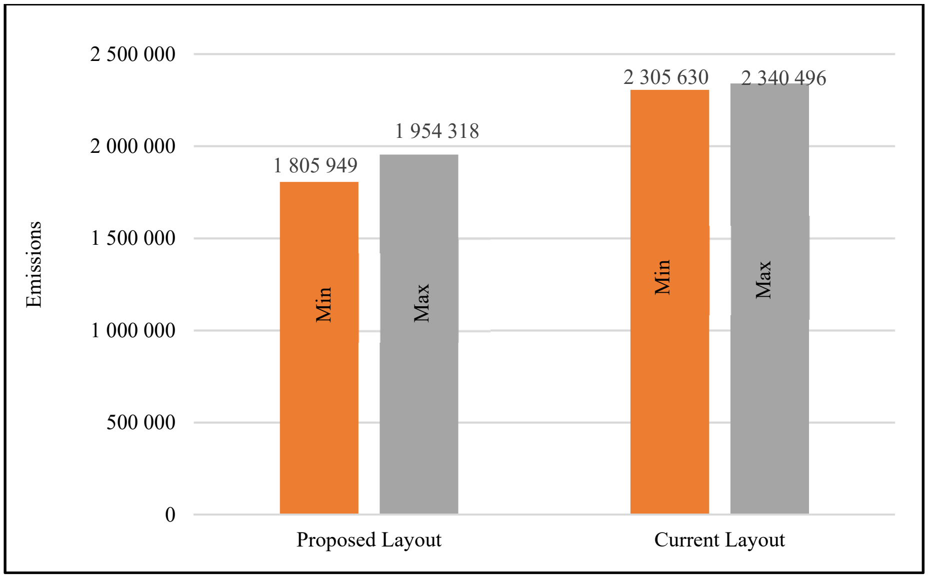

Figure 3.9 Emissions comparison

The main reason behind taking into account the congestion is to reduce emissions and to save the time of transportation of containers from the origin node to the destination, whereby, reducing the cost. The results show the cost of container transportation from the berthed ship to the final destinations. It also shows that the time of the proposed layout is less than the cost and time of transportation of the common layout; Table 3.1 shows this comparison.

Table 3.1 Cost and emissions comparison between the layouts

	Current Layout	Proposed Layout
Minimum total cost (in thousands)	$ 808,590	$ 432,267
Minimum total emission (kg CO2e)	2,305,630	1,805,949
Difference % of the total cost 46.5%		
Difference % in the total emission 21.6%		

It is clear that the proposed layout produces a significantly lower level of CO2. This can be explained while the proposed layout relatively decreased the amount of equipment used in handling and transferring the containers, and in addition, travelled distances.

By using the objective function as discussed above, we had generated the Pareto sets of Port of Montreal and Proposed Layout. The Port of Montreal layout Pareto set, which is represented in Figure 3.10, shows the minimum cost $808,589.80 with emission 2,340,496 kg CO2e, whereas the proposed layout, as represented in Figure 3.11, shows the minimum cost $432,266.60 with emission 1,954,317.7 kg CO2e. By this, we can clearly see, we had significantly optimized cost and emission by using the proposed layout.

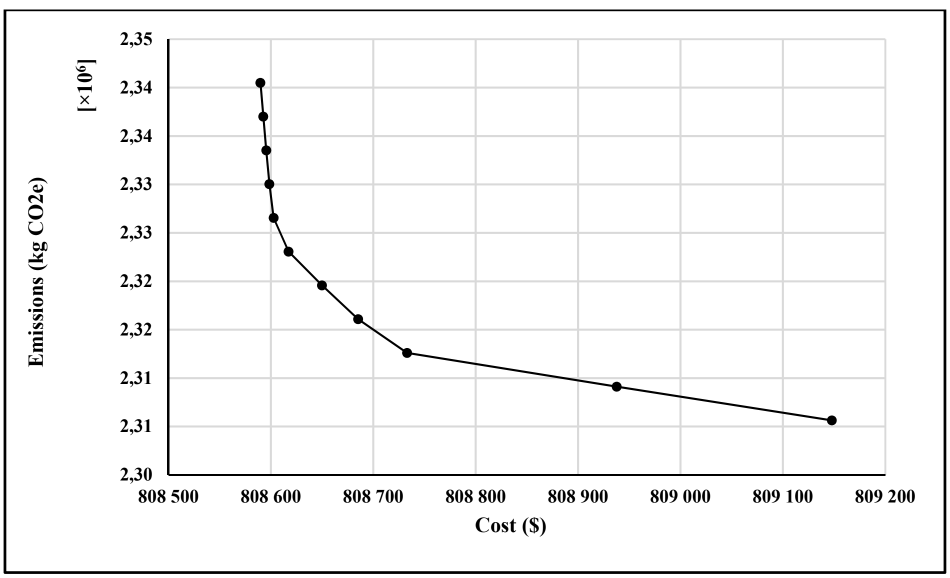

Figure 3.10 Pareto solutions of the Port of Montreal layout

Now, taking into consideration Figure 3.11 (Proposed Layout Pareto set), we had selected three different solutions from Figure 3.11, which represent the minimum, average, and maximum values of the solution. These solutions are indicated on the graph with a red triangle. These solutions were analyzed in Table 3.2.

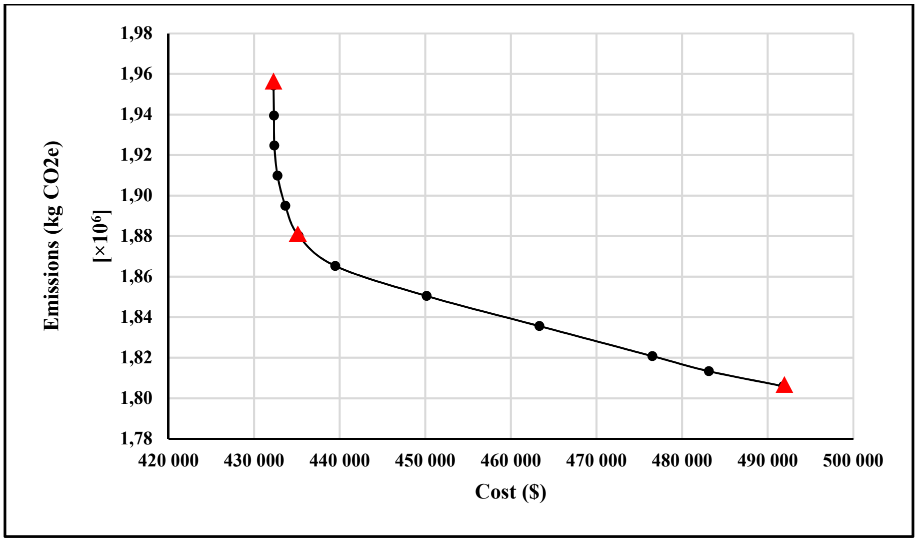

Figure 3.11 Pareto solutions of the proposed layout

Table 3.2 Cost-emission comparison of different solutions in the proposed layout

	Solution I	**Solution II**	**Solution III**
Total cost ($)	491,821.60	439,481.15	432,266.6
Total emissions (kg CO2e)	1,805,949.47	1,865,296.76	1,954,317.7
	Solutions I and II	**Solutions II and III**	
Difference % in the total cost	11.9	1.67	
Difference % in the total emissions	3.3	4.8	

According to the analysis in Table 3.2, while minimizing the cost factor by 11.9%, only 3.3% of additional emissions are incurred on the overall emissions. Furthermore, if the total cost decreases by 1.67%, only 4.8% of extra emissions must be emitted to fulfill that requirement. Since the objective of the proposed layout is minimizing the total cost of transportation containers as well as the amount of equipment and trucks used in transferring containers, the optimal solution depends on the preferences of decision makers. These outcomes may provide strategic management with a valuable guide to reduce the negative impact of the port operations. Based on the results, mitigating the negative impacts of port operations on the environment requires moving the focus of decision makers from financial and operational performance to environmental performances. The port infrastructure should be adopted and upgraded to achieve this goal. These include changing the layout of the terminal and shifting from road transportation to rail tracks, establishing a remote container terminal outside the city, and connecting it with the port depending on rail tracks more than trucks. Moreover, using electric equipment in container handling is a way to lower emissions. This paper analyzes and evaluates the performance of the current terminal layout and the proposed layout in terms of cost, time, and environment. The proposed layout considers all the factors that help in reducing emissions. These factors include using electric equipment, establishing a remote container terminal, and connecting this terminal with the port by rail tracks. However, most ports in the world are surrounded by cities, and they are not able to extend their borders. Thus, the proposed layout takes this issue into account, and it works with a remote container terminal. In the proposed layout, most of the containers will move to the remote container terminal, and the container yard in the port will keep the containers that have a domestic destination. Therefore, there is no need for a spacious storage yard in the port.

3.7 Conclusion

Although problems of container terminals in the ports have been well studied in engineering, economic, and management aspects, numerous significant issues have yet to get the attention that they deserve. Enhancing terminal operations' efficiency is pivotal to improve maritime shipping reliable, which we had done over here by proposing the novel layout. The Port of Montreal Layout has several deficiencies due to the flow trade changes, and can be improved by implementing our proposed layout. The major contribution of the paper is proposing the novel model, which reduces, simultaneously, the cost and emissions in the environment. Hence, we tried to find a sustainable layout for decreasing the ever-increasing emissions from the port industry. Yet, further study can be done for the expense of the implementation of the proposed layout. In this paper, the optimization of the intermodal transportation problem is also studied for different modes of transportation in order to minimize the cost and emissions principle by considering traffic congestion. The results of this research reveal significant managerial insights, such as the advantages of reducing the distance between the berth and rail intermodal terminal and introducing another container yard out of the city. Moreover, there is a dependence on rail transportation to move the containers from the port to the container yard. The study will help decision makers in the seaports industry to evaluate investment decisions in container terminals. In addition, the study could be used by port authorities in evaluating port performance. Moreover, the results of this study will help to obtain more effective solutions for intermodal transportation to create more balance between the conflicting objectives: emissions and costs. The study will help to maximize the benefits of the intermodal transportation system, such as environmental advantages. The implementation of the proposed layout will lead to effective use of the land, which is usually limited and impossible to expand because the ports are usually surrounded by the city. Implementation of this proposed layout depends on the port infrastructure and the accurate configuration between the ship and train regarding the handling operations. Future work in the intermodal transportation system area is using simulation to evaluate the performance of different layouts in the terminal. In addition, research on how to choose geographical locations for inland intermodal terminals is required.

CHAPTER 4

A SIMULATION APPROACH TOWARDS A SUSTAINABLE AND EFFICIENT CONTAINER TERMINAL LAYOUT DESIGN

Tareq Abu Aisha[a], Mustapha Ouhimmou[b] ,and Marc Paquet[c]

[a, b, c] Department of Systems Engineering, École de Technologie Supérieure,
1100 Rue Notre-Dame Ouest, Montreal, QC H3C 1K3, Canada

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Abstract

Seaports are considered gateways for international maritime trade. The flow of trade and the size of container ships have been growing exponentially in the last two decades, and thus the exchange of containers has increased dramatically. In consequence, adapting container terminal design is required in order to confront these new challenges more efficiently and with improved sustainability. This paper studies the effect of changing the layout of container terminals in seaports by taking into consideration both costs and emissions. In this paper, a new design of the container terminal located in the Port of Montreal has been proposed and compared with the current layout. A simulation approach has been adopted to investigate the impact of the terminal layout on economic and environmental performance. This study aims to improve the performance and handling capacity of the terminal by recommending a new layout. Computational experiments were conducted to evaluate and compare the performance of both layouts using data collected from the Port of Montreal. The results indicate that terminal layout design has a significant impact on terminal performance and emission under the configuration of different transportation modes.

Keywords: maritime transportation; intermodal transportation; container terminals; layout.

4.1 Introduction

The intermodal transportation system states that transport of cargo is done in the same container unit without handling the cargo itself during the change of modes of transportation operations. Intermodal transportation is a preferred approach, as it is known to be environmentally friendly and to reduce congestion (Lin & Lin, 2016). The importance of container terminals in the intermodal system comes from the amount of global trade carried using maritime transportation, which represents 80% of global trade (López-Bermúdez, Freire-Seoane, & González-Laxe, 2019), Also, the United Nations (2019) reported that containerized trade has increased by approximately 2.6% in 2019. Container terminals in seaports are considered as main components of the global supply chain since they consist of various modes of transportation such as rail, trucks, and ships that meet at the container terminal to exchange containers. Since different modes of transportation and resources interact and function together, the system is becoming quite complex to understand and predict. As well, the behaviour of the system will become a complicated task that requires using a simulation approach (Kotachi et al., 2013).

In the Canadian context, seaports are significant hubs; they link inland domestic trade with Canadian coastlines and United States markets where merchandise is transported by truck and railways (Goverment of Canada, 2018). Statistics report that maritime transportation in Canada contributes to shipping about 20% (by dollar value) of Canadian trade. Therefore, improvement in the environmental performance of Canadian ports is required to meet sustainability demands (Hossain et al., 2019). The Port of Montréal, serving the provinces of Quebec, Ontario, and some regions of the United States, is the second-largest container port in Canada. In 2018, more than 38.9 million tonnes of cargo was handled in the Port of Montreal (Goverment of Canada, 2018). Hence, the maritime sector, including seaports and shipping lines, is faced with strict environmental standards, policies and higher expectations in terms of sustainability (Oh et al., 2018).

Furthermore, ports are a serious threat to the cities where they are located, due to emissions from their operations and port activities that are rapidly growing. There is increasing concern about their negative effects. Seaports are seeking to evaluate and understand the volume of their emissions and are trying to find solutions to mitigate the negative impact of port activities on the environment. The expectation of seaports is to sustainably deliver their services with economic and social benefits along with minimal damage to the environment (United Nations, 2019).

Due to complex intensive road transportation networks that enable door-to-door service and flexibility in routing and planning, there is an increased concern of rising road transportation share among other modes of transportation (Ari Hirvonen, 2016b). However, intensive road transportation networks generate congestion on the road network which results in delays with a negative effect on the reliability of transportation services (European Commission, 2012). Moreover, road transportation is one of the main emitters of carbon dioxide equivalent (CO_2) (European Commission, 2020). Thus, companies are seeking alternative options in order to reduce the negative effects of using trucks to minimize and develop distribution systems in a sustainable way (Demir et al., 2015). In order to meet sustainability demands and growing trade, sustainable advanced techniques are required to maintain par with the environmental performance at Canadian ports.

In this context, from the perspective of optimum economic gains, ports usually face pressures to improve efficiency and reduce costs (Oh et al., 2018). The installation of additional intermodal infrastructure in the port is necessary to satisfy the increased demand for containerized cargo. The way intermodal transportation infrastructure is designed to handle freight has an effect on transportation costs and service times significantly (Ghane-Ezabadi & Vergara, 2016). Developing and improving this infrastructure are important elements of the port strategy which help to attract shipping companies (United Nations, 2019).

Since the container terminal is the main component of the intermodal transportation system. The intermodal problems in seaport terminals have been investigated, in which every container terminal has a design and layout with specific characteristics and unique dimensions between interface points in the terminal. One of the strategies to reduce cost and emissions at terminals is to use the dry port concept and connect dry ports to the seaport terminal by railway (Othman et al., 2016). We use this concept to reduce dependence on road transportation between the terminal and the train yard (dry port) that is in a location far from the city.

Although maritime transportation is still considered the most sustainable mode of transportation, new environmental and social standards like green terminals and using green sources of energy, force the transition of this industry to an even more sustainable one (Amir Gharehgozli, 2019). These trends will eventually demand that container terminals redesign their layouts to satisfy these standards and requirements (Amir Gharehgozli, 2019). The container terminal layout influences the performance of the terminal and the amount of equipment used in the terminal (Taner, Kulak, & Koyuncuog, 2014). Thus, closer attention to the layouts and handling systems used to move containers is the key (Amir Gharehgozli, 2019).

Efficiency of the operations of handling containers in the terminal plays a vital role in speeding up the flow of containers at the terminal. As these operations operate in particular terminal layouts, a well-designed layout will enhance the performance of handling container operations (B. K. Lee et al., 2018). A new layout of container terminals needs to consider costs, environment, and flexibility (Amir Gharehgozli, 2019).

However, this study aims to maximize the efficiency of the container terminal and minimize the cost of transporting containers. It also investigates how to mitigate emissions from operations of container transportation by proposing a new sustainable layout. The proposed layout might help accelerate containers flow to their destination as a response to meet the increased demand for containerization and increasing number of container ships. The simulation approach was used to investigate the behaviour of the system and make a comparison between the performance of the Port of Montreal (common layout) and the proposed new layout.

The rest of this paper is organized as follows. A review of previous studies in intermodal transportation, container terminal layouts, and sustainability in seaports is presented in Section

4.2. In Section 4.3, we present two container terminal layouts. The simulation model of the container terminal layouts is presented in Section 4.4. Mathematical formulations that are used to calculate GHG emissions are explained in Section 4.5. Results and sensitivity analysis are presented in Section 4.6. Finally, concluding remarks and future research directions are presented in Section 7.

4.2 Literature review

The container terminal in seaports has been considered as a significant node in the intermodal transportation system network; it is a crucial element in the intermodal transportation system (Zhuo et al. 2012). It connects different modes of transportation in order to exchange the content of the containers. Research in intermodal problems is quite popular, evidenced by the different articles that have been published in this area of research. Most of these articles have studied specific problems such as transshipment operations, storage strategies at the intermodal terminal, scheduling, performance evaluation, and storage yard planning. To our view, the most interesting study in this respect is a comprehensive review of the intermodal transportation system by Tolga Bektas (2007). Similarly, a comprehensive study was done by SteadieSeifi et al. (2013). However, the majority of the extant research focuses on the network design problem (Ishfaq & Sox, 2011), (Meng & Wang, 2011), (Resat & Turkay, 2015), (Alumur, Kara, & Karasan, 2012), (Wang & Meng, 2017), (Mostert et al., 2017). Another popular area of study in intermodal transportation is the minimization of the total cost of operations (Hanssen et al., 2012), (Lupi, Pratelli, Canessa, Lorenzini, & Farina, 2019). Also, a stream of research consists of optimizing the load of trains at intermodal terminals (Ng & Talley, 2020), (Bruns & Knust, 2010).

Simulation is a popular approach for evaluating container terminal performance. Simulation has proven to be a valuable tool for decision support in the container terminal. Thus, research has been conducted for evaluating the container terminal performance by building a simulation model as discussed in (Kotachi et al., 2013); (Osman Kulak 2011); (Zhuo et al., 2012). Zhuo et al. (2012) in particular have developed a simulation model to evaluate the operational capability and efficiency of a seaport container terminal. Simulation models are significantly different in terms of their objectives and their levels of detail in modelling the real system (Osman Kulak 2011). In this manner, Park et al. (2012) has presented an approach that combines the importance of simulation models with an optimization model for evaluating the performance of a container terminal. Although seaport container terminals are important, they have a negative impact on the environment, generated by the process of cargo handling (Hossain et al., 2019). Therefore, developing and improving the performance of the container terminal in a sustainable way has to be taken seriously (Ilaria Vacca, 2010).

Along with an enormous amount of research carried out about sustainability in ports, different factors have been investigated. Investigating the cognizance of decision makers on the concept of port sustainability, policies and strategies, and the impact of other factors such as training programs, sustainability reporting and sustainability awareness, has been analyzed by Ashrafi et al. (2019). Concentration on analyzing and documenting the procedures of environmental management, to enhance planning for more sustainable operations in ports and mitigation of possible risks, has been the focus of research by Dinwoodie et al. (2012).

The main factors, shaping sustainable development in Vietnamese ports, have been investigated through a comprehensive review of related works and interviews with decision makers in seaports, to determine the key factors of sustainable port development from the perspective of port authorities (Roh et al., 2016). Hiranandani (2014) analyzed and compared four ports from four continents in terms of sustainable practices and policies and analyzed the challenges and opportunities they face in achieving sustainable development.

Sihyun Kim (2014) conducted a study at the port of Busan based on interviews to conceptualize the structure of sustainability practises in port operations to encourage seaports to establish sustainability policies and practices in port operations. Corporate social responsibility has been another area of study with regard to sustainability in ports. In this context, a comprehensive review was carried out by Acciaro (2015).

Kang & Kim (2017) addressed sustainability practises in port operations in the major ports in Northeast Asia, using 203 samples collected to analyze multi-measurement items that used to evaluate sustainability practise in port operations. Oh et al. (2018) used the technique of importance-performance analysis (IPA) to determine important standards in evaluating sustainability in South Korean ports. Increased dependence on railways in transporting containers has a positive impact on the transportation cost and environment. In addition, mitigating congestion and increasing the speed of container flow has been studied by Chen et al. (2013). Because of the advantages of using the train to connects the seaport terminal and dry port , we implemented this concept in our model. In this regard and based on the literature review, different research has been conducted to investigate and maximize the advantages of using railways in transporting containers between container terminals (P. T. Aditjandra, Thomas H. Zunder, Dewan Md Zahurul Islam, and Roberto Palacin, 2016), (Woodburn, 2013). Redesign container terminal layout in seaports is another field of research. Taner, Kulak, & Koyuncuog (2014) investigated the effect of different layout formats on terminal performance. The difference between these layouts is that storage yards were perpendicular or parallel to the major berth.

In order to mitigate the number of GHG emissions from a container terminal, one needs to find the proper methodology to calculate the emissions. In this respect, J.H.R. Van Duin (2011) presented such a methodology. Their model was validated through different case studies (sea and inland container terminals) in the Netherlands. Also, the model took into consideration the distances travelled by port handling equipment and their fuel consumption, but failed to take congestion into account. This takes place regularly and generates a considerable amount of emissions. Similarly, Sim (2018) proposed a model using a system dynamic approach to evaluate the overall emissions generated from the container terminal in South Korea, and the results of this study indicated that the container terminal required the annual reduction in order to comply with the South Korean government's emission reduction targets.

In the Canadian context, some researches have appeared in recent years to document the estimate of the present situation of sustainability in Canadian ports by investigating and analyzing their strategies and KPIs (Hossain et al., 2019); (Ashrafi et al., 2019). Despite the fact that some studies have been carried out on sustainability in Canadian ports, to the best of our knowledge no research has been adequately conducted to address the effects of changing the layout of the container terminal on port transportation costs and emissions.

According to the above-mentioned literature review, there are few studies to investigate terminal layout in terms of sustainability (Amir Gharehgozli, 2019). Therefore, we believe that no research has investigated the impact of changing the distance between interface points of the container terminal layout on economic and environmental performance. The effect of container terminal layout performance is still not widely understood. This area of research has often been overlooked, especially when developing intermodal systems in seaports. Doing this in a sustainable way means keeping in mind changes in the layout of the container terminal itself. To date, research has focused on the operational level rather than on the strategic one. To sum up, most studies concentrate on a specific factor when discussing the efficiency of container terminals in terms of sustainability. Nevertheless, the factors influencing container terminal efficiency are diverse, and the influences of different factors are varied and interrelated. As a consequence, this paper aims to develop an overall framework to investigate the impact of shifting the rail track location on performance and sustainability at the terminal.

The main contribution of this paper is twofold: first, developing an overall framework to investigate and evaluate the impact of changing the location of the rail track from its original location at the end of the terminal to a location close to the berth on the transportation cost of containers and environment. Second, we studied and investigated a specific topic that, being relevant to decision makers and operators in container terminals, has not been studied enough in academic literature and, therefore, deserves further research.

4.3 Container terminal layout

In general, the number of containers handled at the container terminals has seen a significant increase in the last years. In order to improve the efficiency of container transportation to their destinations, attention is required to the layout and transportation system of transporting containers. Layout design affects overall terminal decisions (Bierwirth & Meisel, 2010). Usually, most of container terminals have a square or rectangular layout where containers are stored temporarily for further transportation by truck, train, or vessels. Storing a large number of containers requires a large land area, in many cases this is not practical, as many ports are surrounded by cities. In addition, reliance on trucks more than trains to transport containers builds up congestion on roads and the terminal. Furthermore, the location of rail tracks at the end of the terminal, far from the berths requires many different types of equipment to carry out internal terminal movements from berth to rail tracks. These facts contribute to congestion in the terminal and increase costs and emissions, thus affecting the performance of the terminal. For this reason, to meet the discussed challenges, new designs with metrics of better efficiency are required. The future new designs also require a smaller footprint and ensure faster, cheaper, and more efficient ways to transfer containers between the landside and seaside. In this section, we will investigate the layout of the Port of Montreal as an example of a common layout of a container terminal.

4.3.1 The layout of the Port of Montreal

In order to build the model of the Port of Montreal (the current layout), we visited the Port of Montreal several times. The sketch of the layout is shown in Figure 4.1. The layout of the port has three storage yards (storage yard for exported containers, imported containers that will be transported to their destination by train, and imported containers which have to be routed towards domestic destinations), and ten interface points, where the location of the container is changed or changing at transportation modes. These interface points are represented as a number in Figure 4.1. One piece of equipment that has been used in the Port of Montreal layout is a shore crane to load/unload containers from the ship to the marshalling area. Then the containers are shifted to storage yards for temporary storage by tug master, where the containers must wait for transportation to their final destination. From the storage yards, the containers will move by tug master to rail terminals or trucks depending upon the destination. Train is used as a transportation mode for the containers to be transported to Toronto, Detroit, and Chicago.

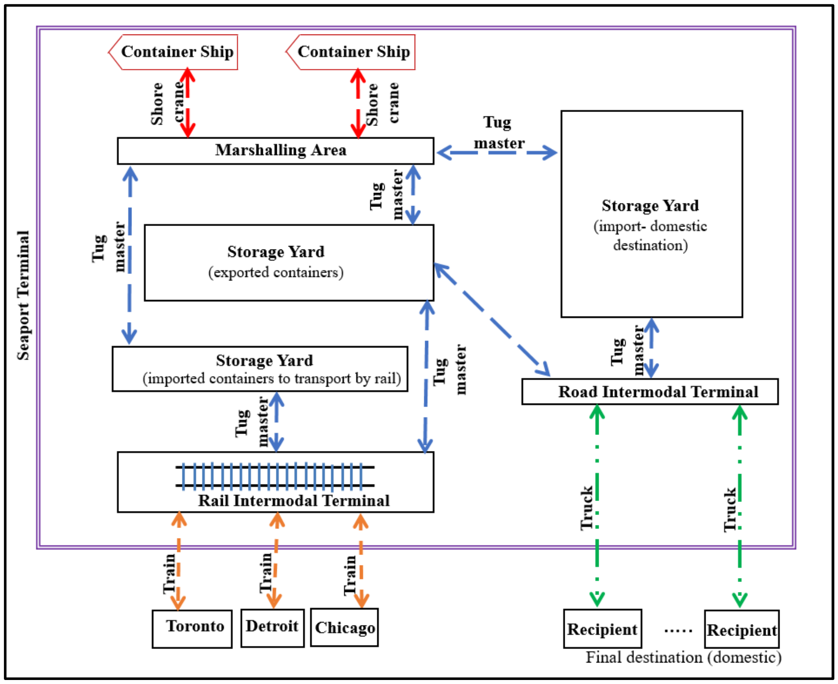

Figure 4.1 The layout of the port of Montreal

4.3.2 Conceptual Model of port of Montreal layout

In this section we model the flow of containers starting from a containership at berth until their arrival at the final destination as shown in figure 1. Since container terminals in seaports are complex systems that consist of many sub-systems and different overlapping operations, which undoubtedly impact the outputs, a platform that precisely simulates such a system could achieve a significant analytical benefit. To implement and validate the developed framework, a large-scale complex container terminal discrete event-based simulation model was developed and validated based on a real system, after which it was used as a testing platform for the proposed layout.

After a full understanding of the real system of the Port of Montreal terminal and all the integrated operations, a conceptual model was created. The entities which move through the simulation model are ships, containers, trucks and trains. The resources include a berth for mooring the ship, a shore crane to load/unload the ship, a tug master to move containers in order to load/unload trucks and trains, and the storage areas in the terminal. The processes are created to represent the operations in the port for transferring containers to their destination by using different equipment and modes of transportation. The flow chart of the operations in the Port of Montreal layout is demonstrated in Figure 4.2.

Data were collected from the Port of Montreal by various visits to the port. This data includes the layout of the Port of Montreal and its associated dimensions, type and amount of equipment. Other data like equipment speed are collected by using the manufacturer's manual for this equipment. The distances that used to calculate the travelling time of equipment and modes of transportation are obtained using the port map and Google Earth.

However, some assumptions have been made to focus upon various aspects which are of main interest and exclude factors of minor relevance. The weather conditions and machine failure are not considered due to the high complexity of our model. The assumptions of our simulation model are as follows:

- The arrival of ships is not scheduled. They are random events.
- Each ship arrives with 5000 TEU (twenty-foot equivalent unit).
- The size of the containers is 20 ft.
- The tug master transports one container at a time.
- Each truck is allowed to carry one container at a time.

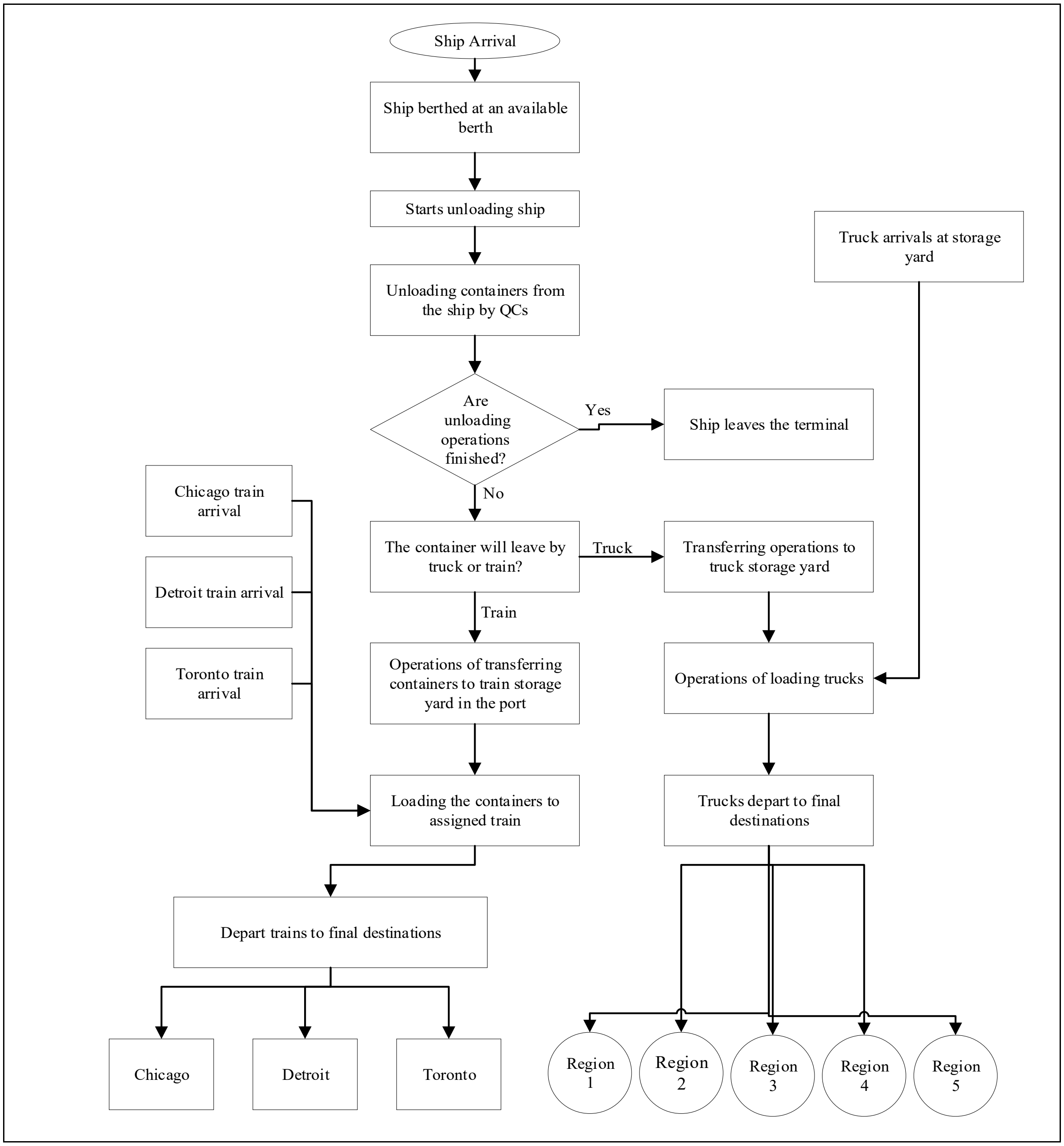

Figure 4.2 The flow chart of the operations in the port of Montreal layout

4.4 The proposed solution

In this section and based on the analyzing of the layout of the Port of Montreal, the new solution was proposed to enhance port efficiency. Since the long distance between the rail track and the berth requires different equipment types and affects terminal performance, the new layout was proposed considering moving the rail track location to a location close to the berth. The proposed layout shown in Figure 4.3 has two storage yards. One of the storage yards is in the port, while the second container storage yard is far from the port and is situated outside the city. Both container yards are connected to the rail track and through road transportation (trucks). The rail track location in the container terminal in the port is located at the end of the marshalling area and is parallel to the berth. So, if the containers are destined outside the city, they should move to the second storage yard. The type of equipment used in the proposed layout is the same (shore crane, tug master, truck, and train). The flow of containers is from the ship to the marshalling area; then, from the marshalling area there are three options which are as follows: First, from the marshalling area towards the train, then to the container yard situated outside the port. Second, from the marshalling area towards the storage yard in the port. Thirdly, from the marshalling area towards the container yard located outside the port. Then, containers in the container yard (outside the port) are transported to their destination by train or truck depending on availability.

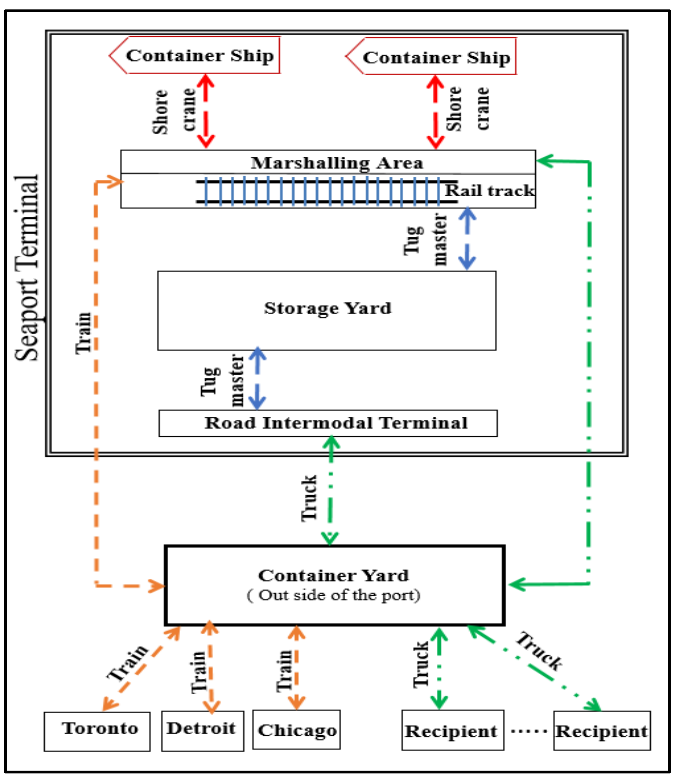

Figure 4.3 The proposed layout

Since our investigation is concerned with comparing the performance of the current layout of the Port of Montreal and the proposed layout, the simulation model aims to represent the real system and system of container transportation the as accurately as possible. The simulation model investigates both layouts, the Port of Montreal and the proposed layout to compare their efficiency in terms of transportation costs and environmental effects. Therefore, the flow chart illustrates the operations implemented by the developed simulation model for the proposed layout, as shown in Figure 4.4.

In Figure 4.4, the operations in the layout started with the ship arriving and berthing at the berth. The operation of unloading the containers take place after the ship is berthed at berth. After unloading containers to the marshalling area, containers have two options to reach their destinations. Containers are transported either by truck or trains to reach their destinations. Containers that will reach their final destination directly from the port are sent to the storage yard in the port, then are loaded on trucks to their final destinations. On the other hand, the containers whose destination is the container yard (outside the port) are loaded from the marshalling area directly on the train to be sent to the container yard. From the container yard, some of the containers are transported to their final destination by truck. The rest of the containers are transported by train to Toronto, Detroit, and Chicago.

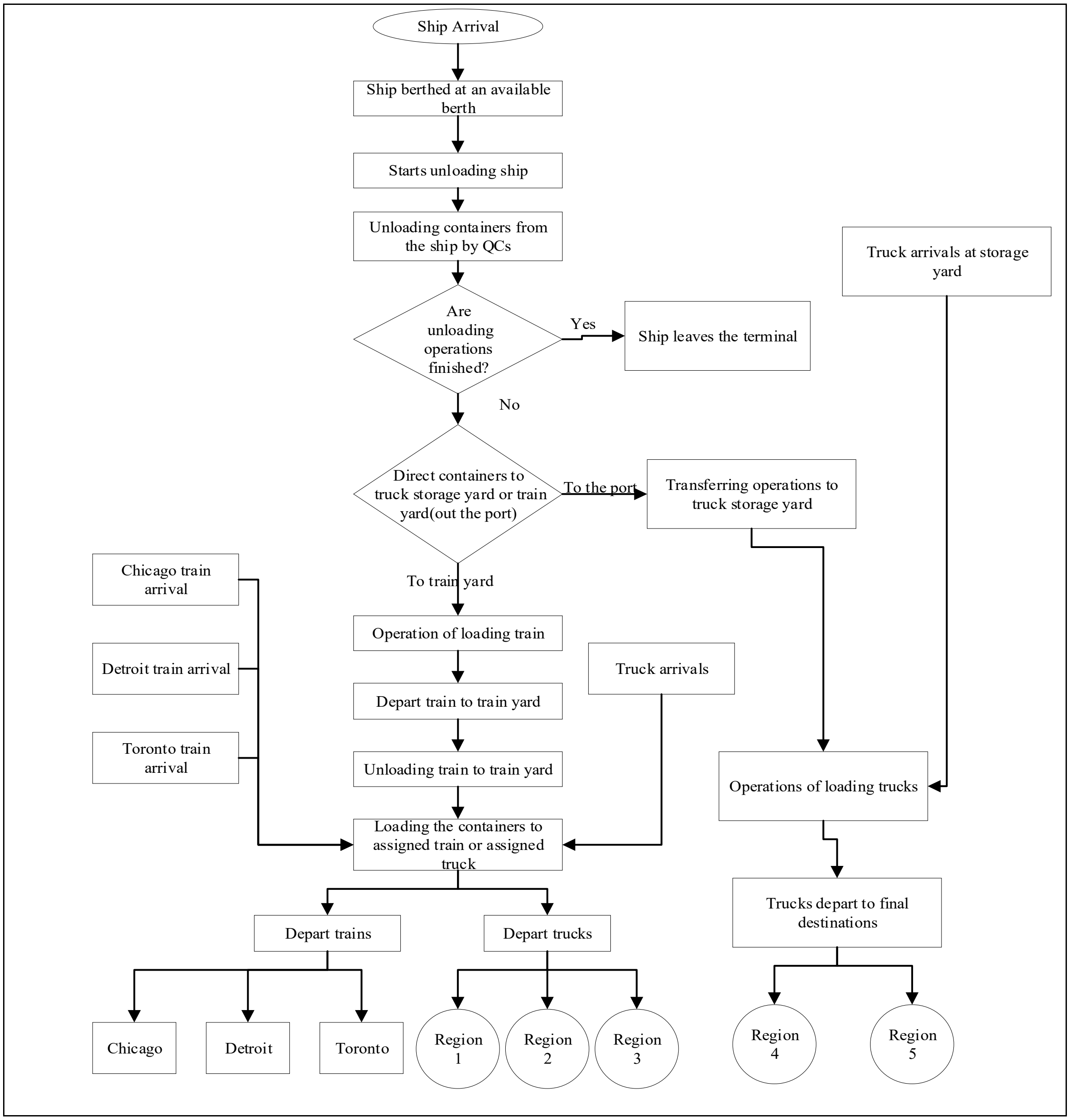

Figure 4.4 The flow chart of the operations in the proposed layout

4.5 Simulation model

The operations in container terminals can be described as non-continuous actions, where all the events happen in a chronological order of events. Each event occurs at a particular instance in time and marks a change of the state in the system.These determinations lead us to use

Discrete-Event Simulation as the methodology for this research problem . Therefore, a discrete simulation model is developed using the SIMAN simulation language and then implemented through the Arena software application. We used Arena software to structure the conceptual and simulation model for both layouts, including terminal resources. The objectives are to reflect the system functioning in both layouts and to assess their performance in terms of cost and emission.

In this context four key system parameters were selected based on their significant impacts on the system performance. This key parameters are: (1) the number of containers in each train moved from the port to the container yard. (2) the number of containers in each train moved by train from the container yard to their final destinations. (3) the amount of equipment used to move containers between each interface point in the layout of the terminal. (4) Average time between the arrival of trucks.

The system performance consists of calculating the transportation cost of containers from the ship to their final destination along with the associated emissions. To calculate the total emissions, we need to calculate energy consumption for each mode of transportation as a first step, then calculate the total emissions using Eq.4.5 (see Section 4.6). The module OptQuest of the arena was utilized to find the optimal configuration of selected key system parameters in the terminal with the objective of minimizing the total cost of transport containers to their destination and emissions generated from terminal operations and transporting containers to their destinations. To evaluate and analyze the performance of both layouts of the terminal, simulation tests were performed with the objective of demonstrating the effect of changing the layout of the container terminal. The model is composed of several operations; each performs a specific task or event in the system (loading, unloading, transport, etc.). Because of uncertainties (random delay of trucks, train, ship), separate replications of the simulation model were needed in order to determine the necessary time for the system to reach its steady-state. So, the duration of simulation runs was set to 365 days to ensure the steady-state is reached. Each run takes 15 seconds on average for each run on a computer with a 2.00 GHz CPU. In addition, three replications were used in the OptQuest for each system configuration. Several steps are required to assess and validate the accuracy of the simulation model. They include monitoring the model operation, testing its data, displaying animations and using debug features of the simulation software. Once the simulation run is finished, the total costs and emissions for the given system's configuration are obtained. The block diagram representation of the simulation model is illustrated in Figure 4.5.

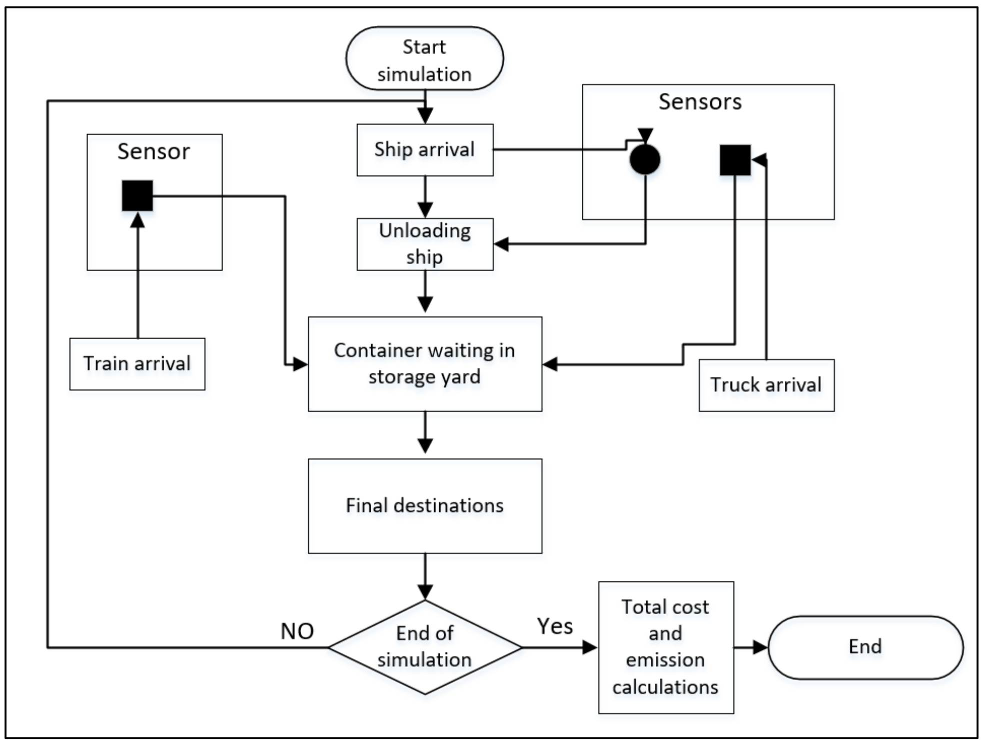

Figure 4.5 Diagram of the simulation model

4.6 Calculating GHG emissions

Emissions from container terminals are a direct consequence of energy consumption related to equipment and transportation modes and uses fuel and electricity. Equipment that uses fuel energy such as tug master, trucks and trains cause direct emissions. In contrast, equipment that uses electrical energy such as shore cranes results in indirect emissions, and both are considered emissions from the container terminal. Therefore, by formulating energy consumption, emissions are obtained, as shown in Eq. (4.1). The indirect and direct emissions for each mode of transportation can be calculated according to Yun, Xiangda, Wenyuan, Ke,

& Chuan (2018), based on energy consumption and emission coefficients of the energy as follows in Eq. (4.1):

$$E = G.C_{energy} \tag{4.1}$$

Where E denotes the emission; G represents the equipment energy consumption, diesel (kg) or electricity (kWh); C_{energy} denotes energy emission coefficients, which is obtained from (Intergovernmental Panel on Climate Change, IPCC, 2006).

4.6.1 Energy consumption of shore crane:

The energy consumption from quay crane (QC) is given in Eq. (4.2):

$$G_j^{QC} = Ca_j^{QC}.y_j^{QC} \tag{4.2}$$

Where G_j^{QC} denotes the energy consumption of quay crane j in kWh; Ca_j^{QC} represents the handling capacity of QCj in TEU of containers; y_j^{QC} denotes the power consumption rate of $QCj, kWh/TEU$.

4.6.2 Energy consumption of equipment

The equipment energy consumption is given in Eq. (4.3):

$$G_k^{YC} = Ca_k^{YC}.y_k^{YC} \tag{4.3}$$

Where G_k^{YC} represents the diesel consumption of equipment k in kg; Ca_k^{YC} represents the handling capacity of YCs in TEU of containers; y_k^{YC} denotes the power consumption rate of $QCj, kWh/TEU$.

4.6.3 Energy consumption of trucks

The fuel consumption of the truck m are denoted as Eq. (4.4):

$$G_m^{truck} = R_m^s . v_m^s . t_m^s \tag{4.4}$$

G_m^{truck} represents the diesel consumption of container truck m, kg; s represents the status of a vehicle, s is 0 if a vehicle is empty, or 1 if a vehicle is loaded; R_m^s represents the diesel consumption efficiency of vehicles at the status of s, kg/km; v_m^s is the velocity, km/h and t_m^s is the working time, h.

4.6.4 Energy consumption of train

Emission from the train was calculated according to the new standard EN 16258 (Schmied, Knörr, Friedl, & Hepburn, 2012). The consumption of energy and emissions based on this method takes into account the gross weight of the load.

$$G = W\ [TEU]\ x\ D\ [km]\ x\ e\ [kWh/TEU - km] \tag{4.5}$$

G represents fuel consumption, W is quantity of containers transported (TEU), D denotes travelling distance (km), and e represents energy consumption rate TEU-km.

4.7 Computational results

The data for this case study was gathered based on several visits to the Port of Montreal and meetings with port officials to monitor transport container operations. Data collection occurred between March and October 2017. Some of the data collected was used to calculate their average, such as equipment speed. Time of transferring containers between transfer points was calculated based on the average speed and distance measurements which were taken by Google Earth, such as the time to reach different destinations in domestic area, and the destinations of Toronto, Chicago, and Detroit. The average time between successive arrivals of trucks is 10 min, and is 1 day for the train. The operation of unloading ship follows a triangular distribution with parameters (2,3,4). On the other hand, moving containers from marshalling area to the storage yard and the operations of loading and unloading the trains and trucks follows a triangular distribution (5, 6, 7). It is assumed that the containers have the same length to simplify the operations of transferring the containers in the model. The average time to transport containers by truck to the five domestic regions in the model is 30, 50, 60, and 80 min, respectively. The time to reach Toronto, Chicago, and Detroit was calculated based on the average speed of the train. The average speed is 100 km/h . The distances from the container yard to the cities are 533 km, 894 km, 1347 km.

The results of simulation showed that total transportation cost of containers from the container ship to the final destinations in the Port of Montreal layout is 1831.2 per unit cost, as shown in Figure 4.6. From Figure 4.7 (a), the most significant part comes from trucks; it represents around 63% of the total cost. The cost of storing containers in the seaport container terminal accounts for 21% of the total cost. In addition, train, handling equipment, and shore crane contribute to 8%, 7%, and 1% respectively of the total cost.

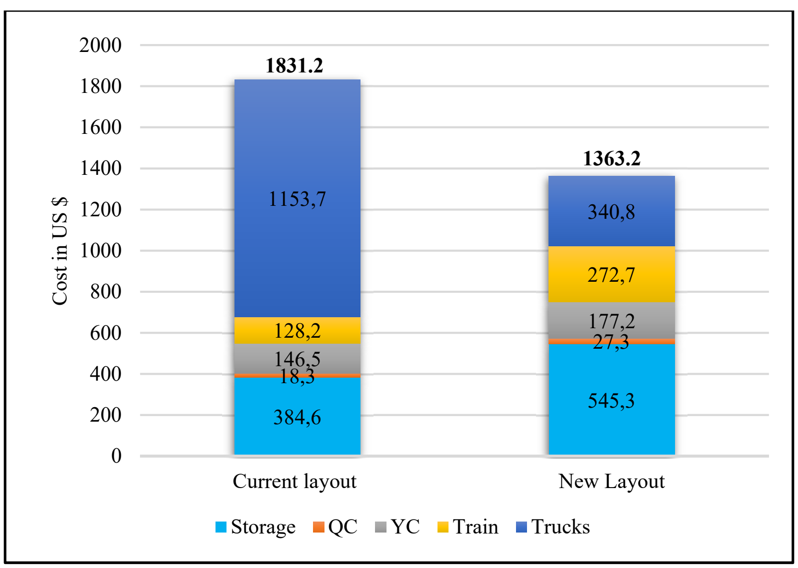

Figure 4.6 Cost comparison of both layouts

On the other hand, as illustrated in Figure 4.6, the total cost of container transport from the container ship to the final destinations in the proposed layout is 1363.25 per unit cost. Figure 4.7 (b) shows that the total storage cost accounts for 40% of the total cost, which represents a significantly large percentage. It is followed by truck, contributing to 25%. The other modes, such as trains, equipment, and shore crane, represent 20%, 13%, 2% of the total cost correspondingly.

The results obtained from simulation models for both layouts show that the container transportation cost to their destination in the proposed layout is less than the cost in the current layout of the Port of Montreal. Overall, the proposed layout resulted in a potential reduction of 18.04% of the total cost.

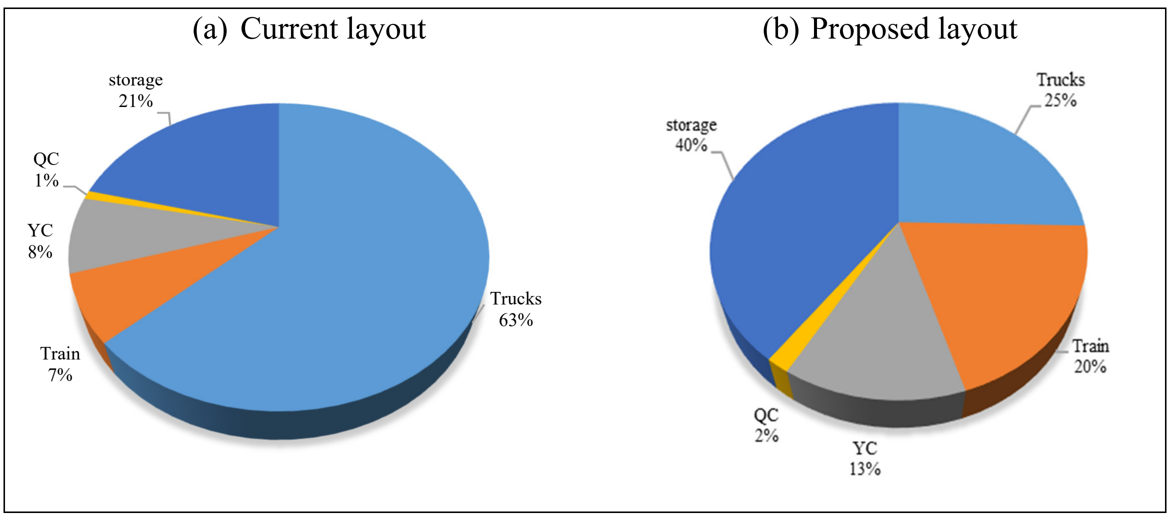

Figure 4.7 Cost comparison

In order to calculate the total emissions generated by the layouts, the amount of equipment and working times were obtained by the simulation. Besides, the fuel consumption rate for the trucks has been set as 0.75 kg/km, the fuel consumption rate of equipment is 3.02 kg/TEU, and the power consumption rate for the quay crane is 5.23 kWh/TEU [49]. The length and the total weight of the train significantly affect the fuel consumption rate. The fuel consumption rate of (0.110) is used to calculate emissions from the train. This rate considers the characteristics of the train, such as the length and the total weight of the train (Schmied et al., 2012). The results of the calculation of emissions show that the total generated emission from the current layout is approximately 58,080.8 t CO_2e , while the total emission from the new layout is 55,491.2 t CO_2e. The new layout has seen a reduction of 4.5 % in the emissions, see Figure 4.8. In the current layout, the amount of emission per container to transport to final destinations is 0.196 t CO_2e /TEU, while in the proposed layout it is 0.11 t CO_2e/TEU.

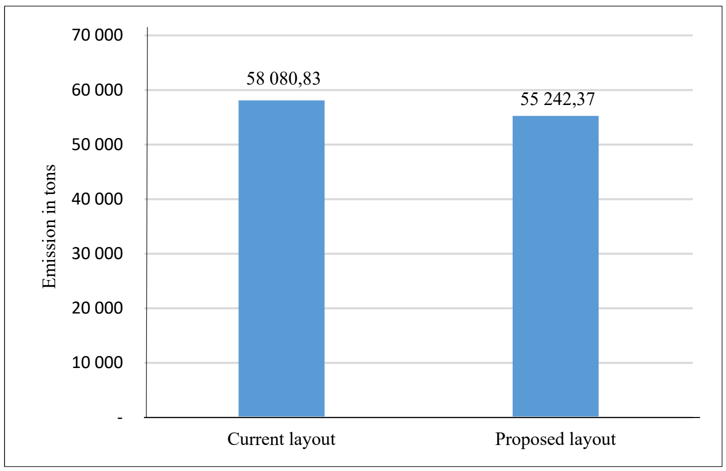

Figure 4.8 Emission comparison

Based on simulation results and as illustrated in Figure 4.9, in the current layout, trucks are used to transport 177,921 TEUs from the Port of Montreal to their final destinations with the emission of 23,959.2 t CO_2e. This amount of emission is higher than emitted emission from trucks to transport the same number of containers to the same destinations in the new layout, which account for 22,253.67 t CO_2e. Also, the emission from the trains which account for 32,975.89 t CO_2e in the new layout, while the emission from the train in the current layout was 34,106.34 t CO_2e, as seen in Figure 4.10. The amount of handling equipment in the new layout has decreased. In consequence, the emission from this equipment in the new layout is around 12.29 t CO_2e which is less than 14.74 t Co_2e of emission from the equipment in the current layout, Figure 4.11. The quay crane uses electrical energy causing indirect emissions, which is in both layouts 0.522 t CO_2e, see Figure 4.12. The emissions from shore crane is the same in both layouts because the number of unloaded containers from the ship is the same. Furthermore, the unloading container operation from the ship to the marshalling area is performed with the same number of shore cranes, and the distance of movements of the shore crane is the same in both layouts.

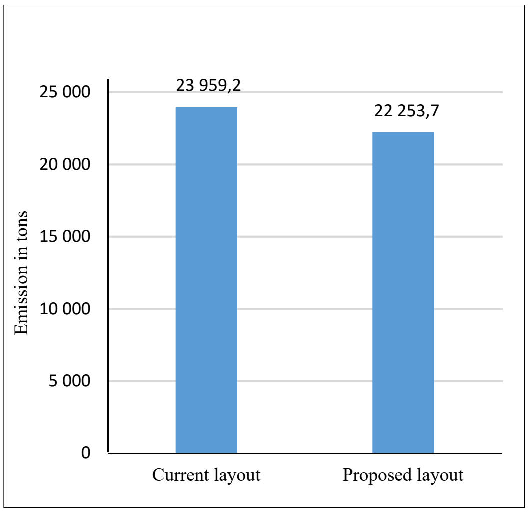

Figure 4.9 Truck emission comparison

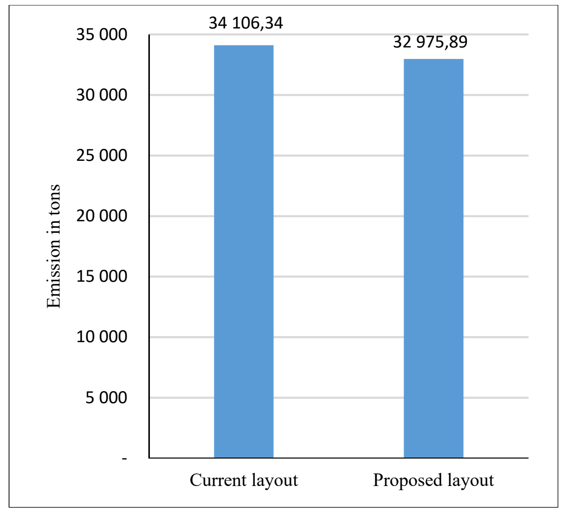

Figure 4.10 Train emission comparison

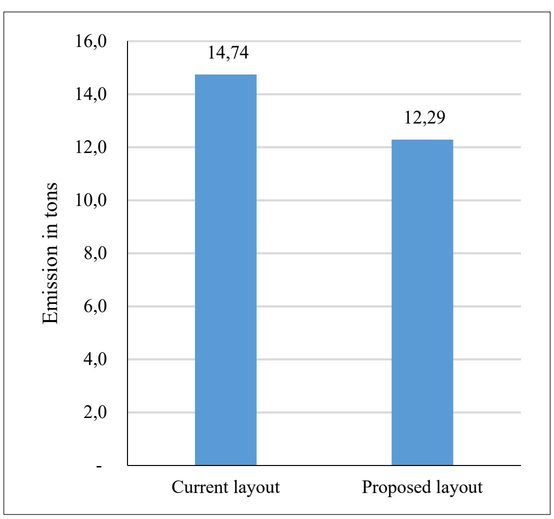

Figure 4.11 Tugmaster emission comparison

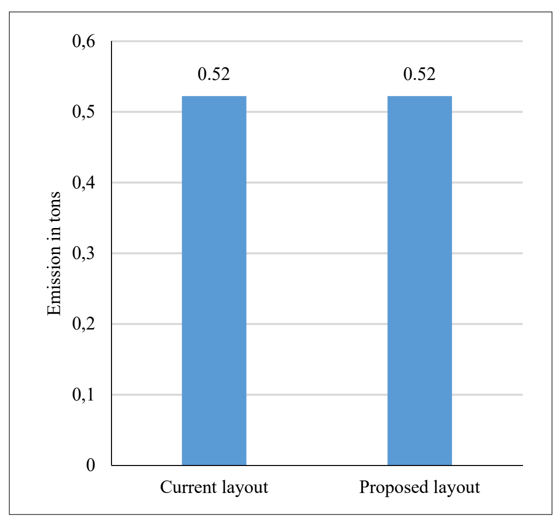

Figure 4.12 Shore crane emission comparison

4.7.1 Sensitivity analysis

In order to confirm the robustness of the proposed approach and effectiveness of the proposed layout, a sensitivity analysis was implemented. We tested the impact of a different configuration of distance parameters on the control parameters and associated total cost of transporting containers to their final destinations. These combinations of parameter distance are evaluated with respect to the basic model in order to understand the behaviour of the system and to what extent the location of the container yard affects the total cost. In this sense, a number of experiments are performed using the Opt Quest tool of Arena software. The objective is to find the optimal cost and optimal equipment configuration. The objective is to investigate the impact of changing the container yard location, which is outside the port, on the total cost. The findings are shown in Table 4.1.

Table 4.1 The effect of changing the distance on the total cost

Scenario No	Distance (km)	Optimal cost	BPT	BTD	EQ1	EQ2	EQ3	EQ4	Average time between arrival of trucks
Base model	17	1363.25	97	142	9	8	11	2	3.599133
Scenario 1	28	1322.10	95	146	8	8	8	2	3.600342
Scenario 2	40	1303.50	88	146	8	7	6	2	3.601441
Scenario 3	52	1297.21	88	151	8	8	6	2	3.602834
Scenario 4	63	1268.53	89	158	8	7	6	2	3.604644

BPT: is the optimal batch value of containers moved by the train from the port to the container yard.
BTD: is the optimal batch value of containers moved by train from the container yard to their final destinations.
EQ1, EQ2, EQ3, EQ4: the optimal amount of equipment used to move containers between each interface.

In the base model, the distance between the port and container yard is 17 km, and the resulting cost is 1363.25 per unit cost. The cost is inversely proportional to the distance between the port and the container yard. The system trends to increase the utilization of the train in transporting containers instead of trucks. This trend has a positive impact on sustainability by reducing emissions and decreasing congestion in the area.

Also, Table 4.1 shows the number of batch trains (BTD) increased in each scenario from 142 in the base model to 158 in scenario 4. This increase directly relates to fewer trains used to transport containers from the train yard to their final destination. As a result of reducing the number of trains, the total cost is increased as well as emissions. If the number of batch trains (BPT) decreases, the system decreases the amount of equipment (EQ3) used to load the train, which goes to the train yard. In addition, the total amount of equipment used to move the containers between the interface points is also decreased, which directly affects the reduction of the total cost and emission.

For instance, in the first scenario, it can be seen that with an increase of the distance from 17 km to 28 km between the port and train yard results in a scenario that gives a reduction of 3.02% of the total cost. The average time between arrivals for the truck is also decreased, which results in less truck waiting time for this particular scenario. Besides, the amount of equipment is also decreased. As a consequence of this reduction in the amount of equipment and number of trucks leads to an emission reduction as well.

In the second scenario, the distance between the port and container yard was increased to 40 km. The cost decreased from 1322.0 to 1303.5, which is around a 1.4% reduction. In scenarios 3 and 4, the reduction of the cost is around 0.48% and 2.26%, respectively. By changing the container yard location from its place in the base scenario to the location of scenario 4, the total cost is reduced up to 6.94%.

It can be seen from sensitivity analysis that the location change in the container yard, which is outside the port, has a significant impact upon the total cost of transferring containers in the proposed layout. The increase of the distance between the port and container yard has a certain effect on the amount of equipment that was used to transfer the containers are decreased as well.

4.8 Conclusion

The container terminal is an expensive capital asset which fundamentally contains the infrastructure of the terminal and different pieces of equipment for handling containers.

Therefore, it is important to use these resources efficiently. Integration between operations and resources in container terminals makes analyzing the system more complex. In this respect, simulation modelling is a very efficient approach to study and evaluate the current situation of the layout of the container terminal in the Port of Montreal. Also, it provides the findings of simulating the proposed layout to compare it with the layout of the Port of Montreal. Unlike other studies on the simulation of the container terminal, including economic and environmental efficiency analysis with respect to improving the efficiency of the terminal in terms of sustainability, this research puts forward proposals for changing the layout of the terminal in order to minimize the cost and emissions.

The results of the proposed layout for container terminals in seaports can mean reductions in the cost of transporting containers to their destination and contribute to developing a greener container terminal, especially in seaports that are surrounded by cities and do not have land for expansion. Presently, this paper investigates the impact of changing the container terminal layout in the seaport, considering emissions from the operations of transporting the containers. Based on the results of this study, port authority and decision makers in port operations will be able to establish policies for investment in the container terminal while satisfying the assigned specific emissions reduction.

CONCLUSION

Container terminals play a vital role in the intermodal transportation network by linking various container transport modes in one location to exchange the containers. Therefore, proper planning and enhancing the efficiency of container terminal operations have attracted much attention from academic research around the world. The operational performance of transshipment container terminals is pivotal not only to the simplification and amplification of the supply chain but also to the country's GDP.

Shipping companies impose additional pressure on container terminals by delivering millions of containers per year to the terminals while ensuring shortened handling times to shipping companies. Hence, terminal operators are now searching for strategies and techniques that can assist them to boost their performance while increasing their capacity and minimize negative impacts of their activities on the social and environmental aspects.

Despite container terminal problems in the ports have received much attention from management, economic, and engineering standpoint, various serious problems have yet to get the interest that they deserve. Promoting efficiency of terminal operations is vital to develop maritime transportation reliability, which we have proposed in this study by addressing the novel layout. The implementation of the proposed layout in this study could help in accelerating the flow of containers.

This thesis studied a new way to mitigate traffic congestion caused by container trucks in the port cities. The rail track location in the container terminal was introduced to the new location; meanwhile, the container terminal in the seaport was connected to a container yard, which is proposed to be located far from the city, with the train. This work studies and signifies the importance of the location of the rail track in the seaport terminal. Instead of stacking all inbound containers in the storage yard, moving the containers from the ship directly by the train is considered in the proposed layout. Meanwhile, all container terminal operations in the terminal are considered. The proposed model optimizes the movements of containers, handling equipment, trucks movement, and hinterland trains in an integrated way. The study analyzes the intermodal transportation system with respect to railways and trucking, which could be beneficial for decision-making purposes by the port authority, terminal operators, and intermodal transportation providers. With an intention for improving operations efficiency in the container terminal, robust optimization models have been established to minimize the total container transportation cost as well as the emissions from these operations. Finally, the effectiveness of the two schemes to reduce the cost, emissions, and congestion are verified by the simulation model. In addition, a comparison has been performed for the performance of both layouts.

Managerial insights

The findings of this study uncover considerable managerial insight, such as the features of decreasing the distance between the rail intermodal terminal and the berth as well as by introducing the concept of dry port, which is another container yard outside of the city. Moreover, increase reliance on rail transportation to transport the containers from the container terminal in the port to the container yard (dry port). The results of this study will aid decision makers in the container terminal industry to assess investment decisions related to container terminals and offer an overall picture to assist operators with strategic developments alongside the improvements. Port authorities could also use the study to evaluate port performance and support them in developing appropriate policies and strategies. These policies with the strategies will help boost the shipping industry, thereby aiding the developmental operations in Canadian ports. Moreover, this study's results will aim achieve more effective solutions for intermodal transportation flaws to make more balance between the contradictory targets: emissions, cost, and congestion. The study also helps to maximize the advantages of using an intermodal transportation system, accompanying environmental benefits.

The study provides shipping lines with overall vision of the terminal performance and service quality in Canadian container terminal. The study will also be useful for shipping companies in making critical decisions related to the criteria for choosing a transshipment container terminal. It will allow them to cut costs and provide better quality service for their customers. At a later stage, the application of the proposed layout will guide to efficient land use, which is usually expensive and restricted or impossible to expand as the city usually surrounds ports. The application of this proposed layout relies on the infrastructure of the port along with the accurate configuration in between the train and ship regarding handling operations.

Future works

Considering what we have mentioned in the research gap (chapter 2), most of the previous studies did not investigate the impact of changing container terminal layout, so investigating and analyzing the terminal's innovative layout designs seems to be a promising academic trend. The proposed models in this study open multiple avenues in terms of research and seaport development. Some of the avenues have been discussed in this research. For future analysis, additional features and factors of the terminal operations can be included in the model.

Since the layout of the storage yard has an effect on the capacity of the terminal and minimizes the resource configuration, one of the features to include in our research is the shape of the storage yard layout. There are two types of storage yard layout based on whether it is parallel or perpendicular to the berth, and each type has two subtypes as following: the parallel layout with double lanes, the parallel layout with single lanes, the perpendicular layout with block access at the ends, and the perpendicular layout with block access at the sides (B. K. Lee et al., 2018). Integrating and evaluating which type of storage yard can achieve a minimum resource configuration and maximum throughput capacity of the storage yard with our model is one of the factors to include in the current model for further analysis and future study. Train schedule is another feature that could be added to this model as a sub-problem making effective coordination between vessels' unloading time and the transshipment plan of inbound containers, where the scheduling of the train affects the performance of the container terminal performance (Yan et al., 2020). The model in chapter 3 considers two objectives (cost and emission); another potential future work is including new objectives and constraints into the current model. However, the scarcity of land is one of the challenges for most ports; adding the objective of minimizing the space of land that used for the operations of the model in chapter 3 will be value-added to the model.

The current models are formulated in a specific environment. It does not consider the uncertain factors in container handling operations and since maritime operations are affected by weather conditions and other uncertain factors. Therefore adding uncertain factors caused by the weather or machine failures could be included in this model.
The distance between the port and container terminal, which is far from the port, was constant in the model. Research in investigating the impact of this distance on the model's performance and how to choose the optimal geographical locations for inland intermodal terminals is required.

This research investigated the emission problem, as we discussed in chapter 3. Minimizing the emissions generates utility to the environment and transportation companies; the research can be extended in future studies using other types of negative externalities to represent the environmental impact. It is very useful for the port community and the port city if the noise pollution is effectively controlled. Further research and attention to strategies and solutions to control noise pollution and promote these benefits are required. Further study can be done for the expense of the implementation of the proposed layout.

Lastly, the research efforts in layout design should not be limited to container terminals only. The layout design is a critical factor that impacts terminals, including bulk storage terminals, chemical tank storage terminals, and even cruise terminals. The research on container terminal automation has become far more nuanced than it once was; implementing automation within this layout and investigating environmental impacts is another topic of research. Another interesting direction is to implement and explore this model with multiple seaports. As it is plausible that a more developed country might be more concerned with green issues while a developing country might only focus on economic issues.

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