A simulation approach towards a sustainable and efficient container terminal layout design

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ABSTRACT

Seaports are considered gateways for international maritime trade. The flow of trade and the size of containerships have been growing exponentially in the last two decades, and as a result, the exchange of containers has increased dramatically. In consequence, adapting container terminal designs 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 seaport terminals by taking into consideration both costs and emissions. A new design of a container terminal located in the Port of Montreal is proposed and compared with the current layout. A discrete event-based simulation approach is adopted to investigate the impact of terminal layout on economic and environmental performance. This study aims to improve the performance and handling capacity of a 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.

INTRODUCTION

An intermodal system implies that the transportation of cargo is done in the same container unit without handling the cargo itself during the change of transport modes. Intermodal transportation is a preferred approach, as it is known to be environmentally friendly and to reduce congestion (Lin and 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, and González-Laxe 2019). Also, the Nations, United (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 serve various modes of transportation such as rail, trucks, and ships that meet at the terminal to exchange containers. Since different modes of transportation and resources interact and function together, the system is quite complex to understand and predict. Also, the behavior of the system is a complicated process, often requiring the use of simulation (Kotachi, Rabadi, and Obeid 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 trucks and railways (Government of Canada 2018). Statistics report that maritime transportation in Canada attributes to shipping about 20% (in dollar values) of Canadian trade. Therefore, improvement in the environmental performance of Canadian ports is required to meet sustainability demands (Hossain, Adams, and Walker 2019).

The Port of Montréal, serving the provinces of Quebec, Ontario, and some regions in the United States, is the second-largest container port in Canada. In 2018, more than 38.9 million tonnes of cargo were handled at the port (Government 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, Lee, and Seo 2018).

Furthermore, ports are often a concern to the cities where they are located, due to emissions from their operations and port activities that are rapidly growing. Seaports are seeking to understand and evaluate 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 2016). 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 (CO₂) (European Commission 2020). Thus, companies are seeking alternative options in order to reduce the negative effects of road transport and develop distribution systems in a sustainable way (Demir et al. 2015). In order to meet sustainability demands and growing trade, 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, Lee, and Seo 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 and 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, Jeevan, and Rizal 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 Ghareghozi 2019). These trends will eventually demand that container terminals redesign their layouts to satisfy such standards and requirements. Container terminal layout influences the performance of the terminal and the amount of equipment used in it (Taner, Kulak, and Koyuncuoğ 2014). Thus, closer attention to layouts and handling systems used to move containers is the key (Amir Ghareghozi 2019).

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

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, through a sustainable new layout. The proposed layout might help accelerate containers flow to their final destination, as a response to increased demand and increasing number of containerships. Simulation is used to investigate the behavior of the system and compare the performance of the Port of Montreal between the old and the 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 2. In Section 3, we present two container terminal layouts. The simulation model of the container terminal layouts is presented in Section 4. Mathematical formulations that are used to calculate GHG emissions are explained in Section 5. Results and sensitivity analysis are presented in Section 6. Finally, concluding remarks and future research directions are presented in Section 7.

**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 and Sox 2011) (Meng and Wang 2011) (Resat and Turkay 2015) (Alumur, Kara, and Karasan 2012) (Wang and Meng 2017) (Mostert, Caris, and Limbourg 2017). Another popular area of study in intermodal transportation is the minimization of the total cost of operations (Hanssen, Mathisen, and Jørgensen 2012) (Lupi et al. 2019). Also, a stream of research consists of optimizing the load of trains at intermodal terminals (Ng and Talley 2020) (Bruns and 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, Rabadi, and Obeid (2013), Osman Kulak (2011) and 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 modeling the real system (Osman Kulak 2011).

In this manner, Park et al. (2012) have 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 cargohandling (Hossain, Adams, and Walker 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, Thai, and Wong 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 practices 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 and Kim (2017) addressed sustainability practices in port operations in the major ports in Northeast Asia, using 203 samples collected to analyze multi-measurement items that are used to evaluate sustainability practice in port operations. Oh, Lee, and Seo (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, Govindan, and Golas (2013). Because of advantages of using the train to connect 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 (Aditjandra 2016) (Woodburn 2013).

Redesign container terminal layout in seaports is another field of research. Taner, Kulak, and 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 amount 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 traveled 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 dynamics 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, Adams, and Walker 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 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.

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 and Meisel 2010). Usually, most of the container terminals have a square or rectangular layout where containers are stored temporarily for further transportation by truck, train, or vessel. 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.

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 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 10 interface points, where the location of the container is changed or changing at transportation mode. These interface points are shown in Figure 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 marshaling 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 terminal or trucks depending upon the destination. Train is used as a transportation mode for the containers to be transported to Toronto, Detroit, and Chicago.

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 are complex systems, consisting of many subsystems and different overlapping operations, which undoubtedly impact outputs, a platform that simulates precisely such a system could provide a significant analytical benefit. To implement and validate the developed framework, a complex large-scale discrete event-based simulation model was developed, following which the model was used as a testing platform for the proposed layout.

After a full understanding of the real system of the Port of Montreal and its integrated operations, a conceptual model was created. The entities which move through the simulation model are ships, containers, trucks, and trains. Resources include a berth, a shore crane to load/unload the ship, a tugmaster to move containers in order to load/unload trucks and trains, and storage areas in the terminal. The processes are created to represent port operations 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 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, as well as types and amount of equipment. Other data, like equipment speed, were obtained from manufacturers’ manuals. The distances used to calculate the traveling time of equipment and modes of transportation are obtained using the port map and Google Earth.

However, some assumptions have been made, in order to focus on aspects of main interest and exclude others of minor relevance. 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.

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 closer to the berth. The proposed layout, shown in Figure 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, situated outside the city. Both container yards are connected to the rail track and through road transportation (trucks). The rail track location inside the container terminal is located at the end of the marshaling 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 marshaling area; then, from the marshaling area there are three options which are as follows: First, from the marshaling area towards the train, then to the container yard situated outside the port. Second, from the marshaling area towards the storage yard in the port. Thirdly, from the marshaling 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.

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 as accurately as possible. The simulation model investigates both layouts 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.

In Figure 4, the operations in the layout start with the ship arriving at berth. The operations of unloading the containers take place after the ship is berthed at berth. After unloading containers to the marshaling area, containers have two options to reach their destination. Containers are transported either by truck or train. Containers that will reach their final destination directly from the port are sent to the storage yard in the port, to be loaded on trucks. Containers whose destination is
the container yard (outside the port) are loaded on trains. From the container yard, some of the containers are transported to their final destination by trucks. The rest of the containers are transported by train to Toronto, Detroit, and Chicago.

**Simulation model**

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's 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. These 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 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.5, (see Figure 2. The flow chart of the operations in the Port of Montreal layout.)
Section 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 5.

**Calculating GHG emissions**

Emissions from container terminal are a direct consequence of energy consumption related to equipment and transportation modes and use fuel and electricity. Equipment that uses fuel energy such as tug master, trucks, and trains causes 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. (1). The indirect and direct emissions for each mode of transportation can be calculated according to Yun et al. (2018), based on energy consumption and emission coefficient of the energy as follows in Eq. (1)

\[ E = G \cdot C_{\text{energy}} \] (1)
Figure 4. The flow chart of the operations in the proposed layout.

Figure 5. Diagram of the simulation model.
Where \( E \) denotes the emission; \( G \) represents the equipment energy consumption, diesel (kg) or electricity (kWh); \( C_{\text{energy}} \) denotes energy emission coefficient, which is obtained from (Intergovernmental Panel on Climate Change, IPCC 2006).

### Energy consumption of shore crane

Energy consumption of quay crane (QC) is given in Eq. (2):

\[
G_{j}^{QC} = C_{a}^{QC} \cdot y_{j}^{QC}
\]

Where \( G_{j}^{QC} \) denotes the energy consumption of quay crane \( j \) in kWh; \( C_{a}^{QC} \) represents the handling capacity of \( QCj \) in TEU; \( y_{j}^{QC} \) denotes the power consumption rate of \( QCj, \text{kWh/TEU} \).

### Energy consumption of equipment

Equipment energy consumption is given in Eq. (3):

\[
G_{k}^{VC} = C_{a}^{VC} \cdot y_{k}^{VC}
\]

Where \( G_{k}^{VC} \) represents the diesel consumption of equipment \( k \) in kg; \( C_{a}^{VC} \) represents the handling capacity of \( YCs \) in TEU of containers; \( y_{k}^{VC} \) denotes the power consumption rate of \( QCj, \text{kWh/TEU} \).

### Energy consumption of trucks

The fuel consumption of truck \( m \) is denoted as Eq. (4):

\[
G_{m}^{truck} = R_{m}^{f} \cdot v_{m}^{s} \cdot t_{m}^{w}
\]

\( G_{m}^{truck} \) represents the diesel consumption of truck \( m \), kg; \( s \) represents the status of a vehicle, is 0 if a vehicle is empty, or 1 if a vehicle is loaded; \( R_{m}^{f} \) represents the diesel consumption efficiency of vehicles at the status of \( s \), kg/km; \( v_{m}^{s} \) is the velocity, km/h and \( t_{m}^{w} \) is the working time, h.

### Energy consumption of train

Emissions from train were calculated according to the new Standard EN 16258 (Schmied et al. 2012). The consumption of energy and emissions based on this method takes into account the gross weight of the load.

\[
G = W[\text{TEU}] \times D[\text{km}] \times e[\text{kWh/TEU} \times \text{km}]
\]

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

### 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 train. The operation of unloading ship follows a triangular distribution with parameters (2,3,4). On the other hand, moving containers from marshaling area to storage yard and the operations of loading and unloading the trains and trucks follow 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 train. The average speed is 100 km/h. The distances from container yard to the cities are 533 km, 894 km, and 1347 km.

The results of simulation showed that the total transportation cost of containers from the container-shipl to the final destinations in the Port of Montreal layout is 1831.2 per unit cost, as shown in Figure 6. From Figure 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.

On the other hand, as illustrated in Figure 6, the total cost of container transport from the container-shipl to the final destinations in the proposed layout is 1363.25 per unit cost. Figure 7(b) shows that the total storage cost accounts for 40% of the total cost, which represents a significantly big percentage. It is followed by trucks, contributing to 25%. The other modes, such as train, 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 containers 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.
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$_2$e, while the total emission from the new layout is 55,491.2 t CO$_2$e. The new layout has seen a reduction of 4.5% in the emissions, see Figure 8. In the current layout, the amount of emission per container to transport to final destinations is 0.196 t CO$_2$e /TEU, while in the proposed layout it is 0.11 t CO$_2$e/TEU.

Based on simulation results and as illustrated in Figure 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$_2$e. 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 accounts for 22,253.67 t CO$_2$e. Also, the emission from the trains which accounts for 32,975.89 t CO$_2$e in the new layout, while the emission from the train in the current layout was 34,106.34 t CO$_2$e, as seen in Figure 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$_2$e which is less than 14.74 t CO$_2$e of emission from the equipment in the current layout, Figure 11. The quay crane uses electrical energy causing indirect emissions, which is in both layouts 0.522 t CO$_2$e, see Figure 12. The emission from shore crane is the same in both layouts because the number of unloaded containers from the ship is the same. Furthermore, the unloading containers 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.

**Sensitivity analysis**

In order to confirm the robustness of the proposed approach and the effectiveness of the proposed layout, a sensitivity analysis was implemented. We tested the impact of different configurations 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 behavior 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 1.

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 tends to increase the utilization of train in transporting containers instead of trucks. This trend has a positive impact on sustainability by reducing emissions and decreasing congestion of the area.

Also, Table 1 shows the number of batch trains (BTD) increased in each scenario from 142 in the base model to 158 in scenario 4. This increment 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
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 in 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.

**Conclusion and future work**

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 modeling 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 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.

**Table 1.** The effect of changing distance on the total cost.

| Scenario No | Distance (km) | Optimal cost ($) | BPT | BTD | EQ1 | EQ2 | EQ3 | EQ4 | Average time between arrival of trucks (min) |
|-------------|---------------|------------------|-----|-----|-----|-----|-----|-----|---------------------------------------------|
| Base model  | 17            | 1363.25          | 97  | 142 | 9   | 8   | 11  | 2   | 3.59                                       |
| Scenario 1  | 28            | 1322.10          | 95  | 146 | 8   | 8   | 8   | 2   | 3.60                                       |
| Scenario 2  | 40            | 1303.50          | 88  | 146 | 8   | 7   | 6   | 2   | 3.60                                       |
| Scenario 3  | 52            | 1297.21          | 88  | 151 | 8   | 8   | 6   | 2   | 3.60                                       |
| Scenario 4  | 63            | 1268.53          | 89  | 158 | 8   | 7   | 6   | 2   | 3.60                                       |

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 point in the layout of the terminal.
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