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PORTALLITE TOWNS: INVESTIGATING THE VIABILITY AND IMPACT OF DISTRIBUTED SMALL PORTS NETWORK IN ENHANCING ACCESSIBILITY AND SUSTAINABILITY

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ABSTRACT

This study delves into the feasibility and efficiency of the PortalLite system, an innovative maritime logistics concept designed to enhance accessibility to remote regions, reduce environmental impact, and alleviate urban congestion through the use of a small distributed ports network. Through a combination of simulation and mathematical modeling, the system's economic viability, operational efficiency, and environmental benefits are evaluated under various scenarios. The findings indicate that the PortalLite system can reduce overall logistical costs in urban areas with existing waterways under certain conditions. Furthermore, the analysis reveals that despite initial investment costs, the PortalLite system's long-term economic benefits can be significant, with a return on investment achievable within a relatively short period under optimal conditions. This research highlights the potential of the PortalLite system to provide sustainable, cost-efficient, and accessible transportation solutions, especially in areas currently underserved by traditional logistics models.

1 INTRODUCTION

Within geographical regions, the size of cities or metropolitan areas, ports operate in a centralized model where shipping containers arrive at a central port and are then distributed within that region via road and rail networks. Chicago serves as a prime example, where containers arriving at the city's main port are subsequently dispatched across the metropolitan area primarily through truck transportation. This method will henceforth be referred to as *"Direct Trucking"* systems. While Direct Trucking Systems are a staple of traditional logistics practices and serve as the backbone for the movement of goods in urban settings, they are not without drawbacks. This approach incurs significant transportation costs, carbon emission, and increases road congestion. Moreover, it becomes impractical or even impossible in regions lacking direct road connectivity, such as the smaller islands of Alaska or various archipelagos. The reliance on Direct Trucking Systems not only hinders access to essential goods and services, but also contributes to large areas remaining uninhabited or underdeveloped. This limits their potential for economic growth and community development, presenting a clear need for innovative logistics solutions.

This research delves into the transformative potential of *"PortalLite Towns"*, featuring a network of *"PortalLite ports"* – compact, strategically situated ports within geographical regions the size of cities or metropolitan areas that aim to expand and enhance the efficiency of maritime logistics. These ports are designed to receive containers from primary ports via small vessels, thereby bringing goods closer to end users while minimizing the reliance on road transportation. The initiative aims to utilize existing waterways to provide an environmentally cleaner and more economical way of transporting shipping containers in regions with existing Direct Trucking Systems, as well as to make previously uninhabitable areas viable for human settlement and economic activity.

As illustrated in Figure 1, the Direct Trucking System relies on a single primary port and distributes containers to customers directly via trucks. In contrast, Figure 2 depicts the PortalLite Town, which features

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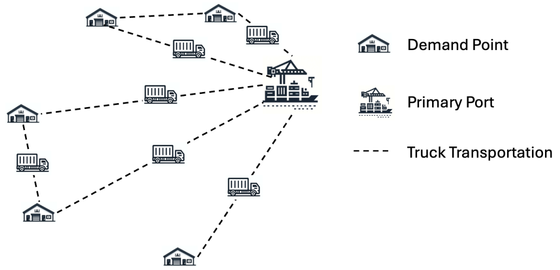

Figure 1: Direct Trucking System schematic.

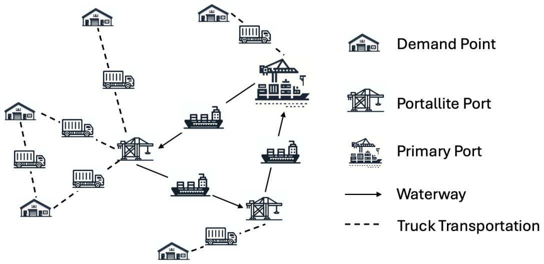

Figure 2: PortalLite Town schematic.

a network of PortalLite ports and ships that utilize waterways to bring containers closer to the end customer prior to using truck transportation.

The fuel efficiency of both land and waterway transport is improving. Vessels such as the Yara Birkeland, Ammonia, and Azane and trucks like the Tesla Semi and Volvo FM Electric indicate that the future of zero-emission transportation could be possible for both means of transport. To provide a fair and currently accurate assessment of the feasibility and environmental impact of a PortalLite system, recent historical data on the fuel efficiency and costs of land and waterway transportation have been used. This approach ensures that the analysis is grounded on real-world data, avoiding speculation about future advancements.

This study delves into the feasibility of the PortalLite Town concept in comparison to the conventional Direct Trucking System, utilizing two distinct modeling approaches: a simulation model and a mathematical model. The dual-model approach is strategically chosen to capture the dynamics of both systems under various operational scenarios. The simulation model is designed to reflect the stochastic nature of maritime logistics, including variability in demand and operational uncertainties, offering insights into the system's behavior under real-world conditions. Conversely, the mathematical model provides a deterministic framework, allowing for the precise calculation of costs, benefits, and efficiencies associated with both the Direct Trucking and PortalLite systems under the assumed conditions. The aim of utilizing these models is to explore the specific conditions under which PortalLite Town becomes a viable and efficient alternative to Direct Trucking.

The feasibility of the PortalLite system has been assessed in a large metropolitan area with existing waterways, specifically the city of Chicago. Using an analytical approach, the optimal number and locations for the required PortalLite ports have been identified and the investment payback period calculated. The goal is to equip government officials with a comprehensive framework to evaluate the feasibility and environmental impact of implementing a PortalLite system in their own regions.

2 LITERATURE REVIEW

2.1 Location Routing Problem

Zanjirani Farahani and Hekmatfar (2009) provide a summary of the location routing problem (LRP), which is an extension of the classical vehicle routing problem. LRP has been noticed and studied for a long history by a large amount of researchers (Von Boventer 1961; Webb 1968; Higgins 1972). The intricacy of LRP as a combined problem is not taken into account in these primary studies. In the late 1970s and early 1980s, LRP is introduced and expanded upon as a combined problem and widely studied in the fields of transportation and supply chains (Laporte and Nobert 1981). However, its application research in the field of shipping is rarely seen. The location routing problem of maritime emergency materials distribution is the only example using the name LRP in maritime research (Peng et al. 2022). There are also some instances focusing on the hub location and routing problem, which are very similar to the assumptions of this research. Gelareh and Pisinger (2011) use mixed integer linear programming to decide the design of the network, the location of the hub port, and the fleet deployment of a liner service. Bütün et al. (2021)

study the impact of congestion and hub location on network design by introducing a directed cycle hub location. Wang et al. (2023) propose an island supply chain network design model integrating a maritime inventory routing problem.

2.2 Intermodal Transportation

Intermodal transportation is first noticed in inland transportation, such as rail-truck or barge-truck. However, intermodal transportation for both inland and maritime is rarely analyzed (Liu et al. 2014; Archetti et al. 2022), especially the combination of barge and truck. Although some research has focused on the intermodal transshipment from barge to truck, most of them put more attention on the design, characteristics, and effects of the new mode (Li et al. 2015; Corman et al. 2017; Grobarcikova and Sosedova 2016). As Bu and Nachtmann (2021) summarize, there are three main methodologies mainly applied: simulation, case study analysis, and network optimization. Riessen et al. (2015) develop intermodal transportation between the seaport terminal and a hinterland terminal, which is a mixed-integer linear programming problem. Zhao et al. (2018) illustrates stochastic intermodal service network design in a sea-rail network by using a two-stage chance-constrained programming model. Bilegan et al. (2022) integrate revenue management considerations into service network design models using mixed-integer linear programming, where barge intermodal transportation is applied.To the authors' knowledge, only a few studies tried to combine simulation and integer programming, as far as we know. Zehendner and Feillet (2014) explore the best method to distribute truck and straddle carries for internal container movement between the yard and different transportation modes (train or barge) in order to minimize the overall delay time at an intermodal container terminal, by combining simulation with a mixed-integer programming model.

2.3 Research Gap and Contribution

While investigating the impact of decentralizing transportation networks is not new, the approach of this paper is novel in combining mixed integer programming and agent-based simulation to assess the feasibility of the novel PortalLite town system. This innovative methodology is the primary contribution to this field of research.

3 SIMULATION MODEL

This simulation is developed in `AnyLogic`. Figure 3 depicts the simulation process map for the PortalLite system. The city of Chicago, selected for its existing waterway system and urban setting, serves as the simulation's backdrop.

The simulation model incorporates six agents: `demandPoints`, `orders`, `largePort`, `smallPort`, `smallShips`, and `trucks`. `demandPoints` agents are intended to represent customers. To define the `demandPoints` locations, the 500 zip codes nearest to the existing Chicago Port are clustered into ten `demandPoints` using K-means clustering as depicted in Figure 4. `demandPoints` are assigned their constituent zip code average population and location. Details on these agents can be found in the GitHub supplementary materials page.

`Orders`, emanating from `demandPoints`, follow a Poisson distribution with mean $q_i = dp_i$ reflective of the `demandPoints`'s population. The adoption of Poisson arrivals for `Orders` in the model is based on the assumption that, although large vessels offload containers in substantial batches, the processing and dispatch of these containers at the port occur with independent interarrival times. These orders are mapped to their originating `demandPoints` and nearest `smallPort`. The `smallPort` agents, embodying the PortalLite ports, function as predefined nodes within a GIS network (Figure 5). Each `smallPort` is equipped to handle single-order ship unloading and truck loading operations. In the Direct Trucking System scenario, `truck` agents facilitate the delivery of orders from the primary `largePort` to their final destinations. Conversely, the PortalLite scenario introduces an intermediary step where orders are

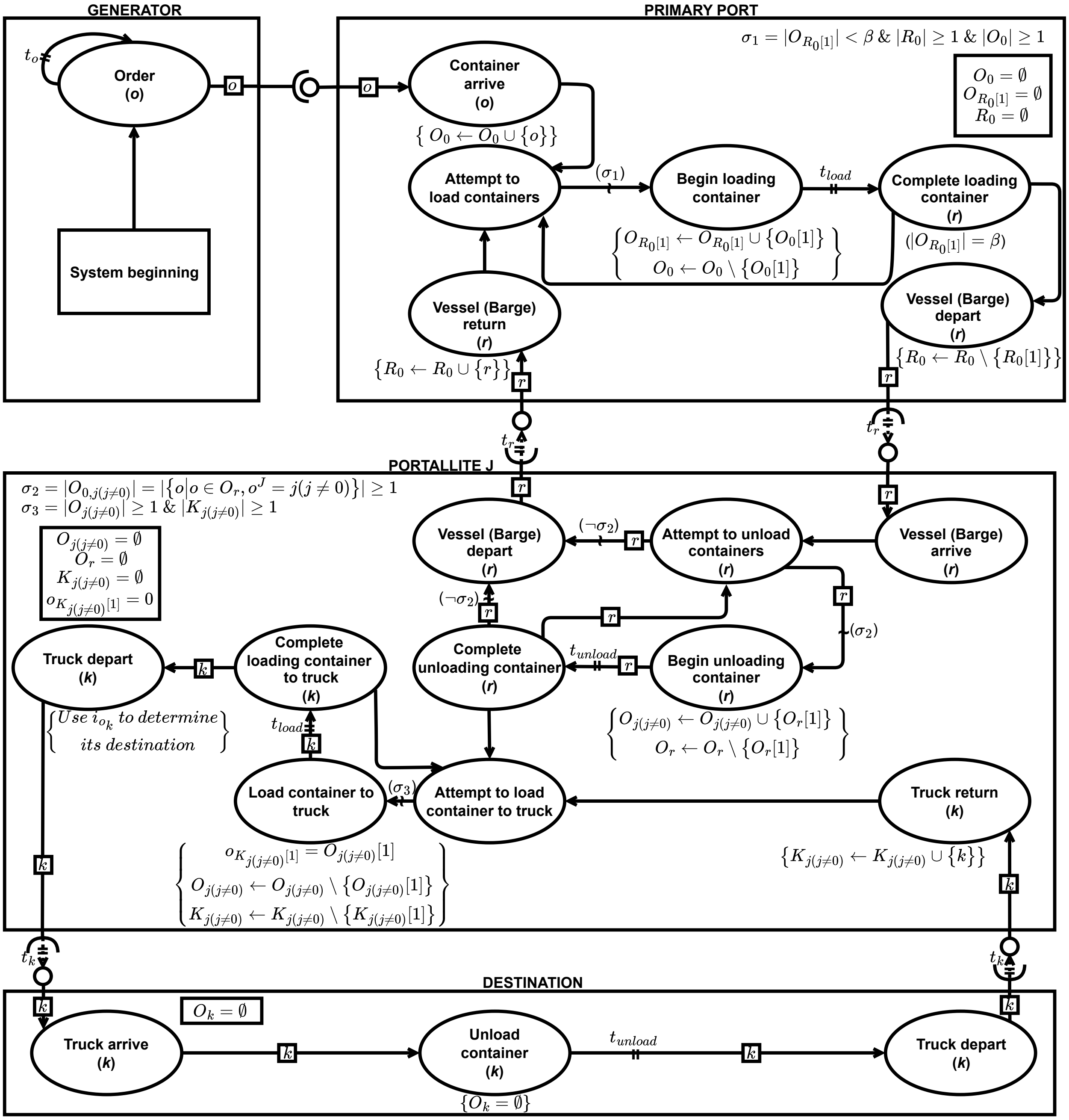

Figure 3: Simulation process map.
The diagram depicts the flow of orders ($o \in O$) through the simulation for the PortalLite system.

transported to their designated `smallPort` via `smallShips`, before being dispatched to their final destinations by truck.

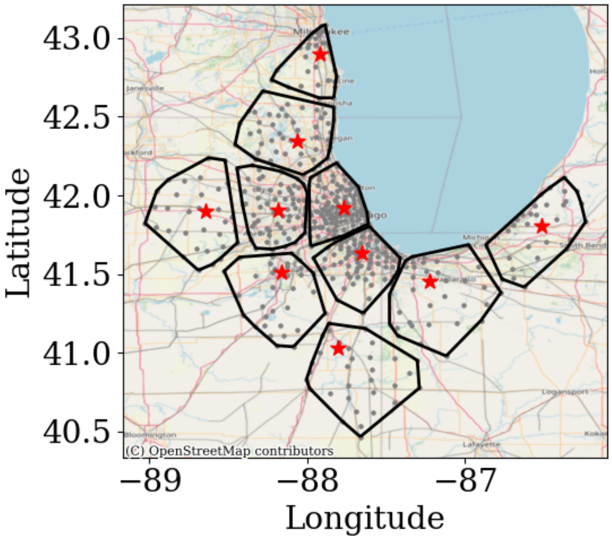

Figure 4: Zip code clustering.
The plot shows how zipcodes are clustered into nine `demandPoints`*.*

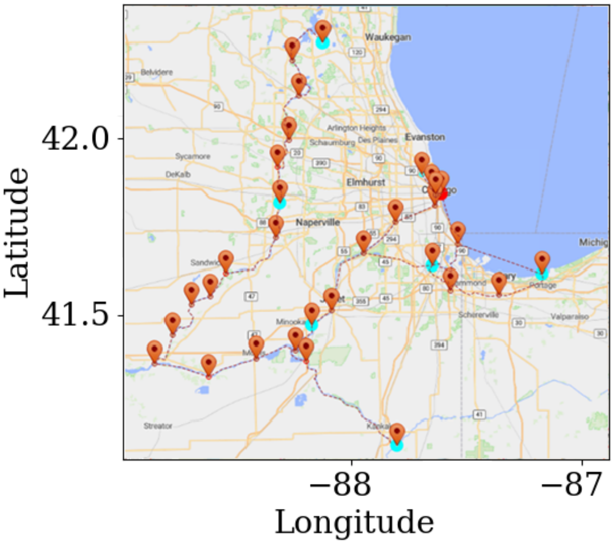

Figure 5: GIS waterway network map.
The PortalLite ports are nodes located on a GIS map of the cities existing waterway system.

4 MATHEMATICAL MODEL

4.1 General Assumptions

In this section, two mathematical models are developed: one for the Direct Trucking System a second one for the PortalLite Town system, using the same customer and port locations as for the simulation model.

4.2 Direct Trucking System

The Direct Trucking System mathematical model contains only a single binary decision variable – x_{ijk} representing truck routes. Similar to the simulation model, the demand is proportional to the cluster population, but no longer stochastic. Table 1 lists the variables used, and Table 2 details the sets and parameters.

$$\text{Minimize} \quad (1-\gamma^{\theta})\Big(\sum_{(i,j)\in E}\sum_{k\in K}(\rho+\psi\kappa)c_{ij}x_{ijk}\Big)/(1-\gamma) \tag{1}$$

$$\text{subject to} \quad \sum_{j\in U:j\neq i}\sum_{k\in K} x_{ijk} \geq 1 \qquad \forall i\in I : i\neq j \tag{2}$$

$$\sum_{j\in U} x_{ijk} \leq 1 \qquad \forall i\in U, k\in K \tag{3}$$

$$\sum_{j_1\in U} x_{ij_1k} = \sum_{j_2\in U} x_{j_2ik} \qquad \forall i\in U, k\in K \tag{4}$$

$$u_{ik} - u_{jk} - r_{jk} + \alpha(1-x_{ijk}) \neq 0 \qquad \forall i\in U, j\in I, k\in K \tag{5}$$

$$\alpha\sum_{i\in U} x_{ijk} \geq r_{jk} \qquad \forall j\in I, k\in K \tag{6}$$

$$\sum_{k\in K} r_{ik} \geq q_i \qquad \forall i\in I \tag{7}$$

Table 1: Variables for the Direct Trucking system model.

Variable	**Definition**	**Type**
x_{ijk}	Whether truck k travels from node i to node j	Binary
u_{ik}	The load of truck k after visiting node i	Continuous
r_{ik}	The weight of unload items of truck k in node i	Continuous

Table 2: Notations for sets and parameters in the paper.

Set	**Definition**	**Model**
O	The set of orders generated by customers, where O_* represents the set of orders stored/loaded in port/vehicle $*$, $O_*[1]$ represents the first order conveyed to port $*$, $O_{*_x[1]}$ represents the first order transported by the first vehicle (k or r) departed from the port x	Sim.
V	The set of all nodes including customers and all ports, where v=0 represents the main port	MIP
U	The set of all customers and the main port, where u=0 represents the main port	MIP
I	The set of all customers	Sim. / MIP
J	The set of all potential ports, where $j = 0$ represents the main port	Sim. / MIP
K	The set of available trucks in each port, where $K_{j(j \neq 0)}$ means the set of all trucks at port j	Sim. / MIP
R	The set of all ships, where R_0 represents the set of all ships in the main port, $R_0[1]$ represents the first vessel departed from the main port	Sim. / MIP
Parameter		
α	The capacity of each truck	MIP
κ	The unit carbon emission tax of each truck (per mile).	Sim. / MIP
p_i	The population at node i	Sim. / MIP
d	The demand rate per resident	Sim. / MIP
q_i	The demand of node i	Sim. / MIP
$c_{i_1 i_2}$	The grounded transportation cost from node i_1 to node i_2	MIP
β	The capacity of each ship	Sim. / MIP
ζ	The unit carbon emission tax of each ship (per mile)	Sim. / MIP
$C_{j_1 j_2}$	The waterway transportation cost from port j_1 to port j_2	MIP
γ	The discount factor of the operation cost over years	MIP
ψ	The factor of carbon emission tax	Sim. / MIP
ρ	The factor of transportation cost	Sim. / MIP
ω_j	The fixed cost of PortalLite port j	MIP
θ	The number of years	MIP
σ	The condition of loading or unloading a container	Sim.
t	The time of loading or unloading a container, or transiting it to a barge or truck	Sim.
h	The ratio of truck to waterway total shipping costs per distance travelled	Sim.

The objective function (1) aims to minimize the total costs in the operation process, which includes the transportation costs and carbon emission tax of all trucks in the coming θ years with an increasing discount factor γ to show the maintenance costs. Constraint (2) enforces that every destination should be visited. Combined with Constraint (7), the demand of each destination can be fully met. All trucks must have at most one complete round route in each trip, which is ensured by Constraint (3). Constraint (4) ensures all trips are round trips. The load of a truck changing during the trip is used as the MTZ formulation (Miller et al. 1960) in Constraint (5) to eliminate subtours in each trip. Constraint (6) guarantees each unloaded container cannot exceed the capacity of the truck.

4.3 PortalLite Town System

The PortalLite system model utilizes the same assumptions as that of the Direct Trucking System, with the exception of allowing for an intermediary ship transportation step. Additionally, ships must return to the main port prior to loading new orders. Ships also have distinct traveling, carbon footprint costs and capacity.

Again, Table 2 depicts sets and parameters used. In order to estimate the potential return on investment of the PortalLite system, an additional discount factor is added to represent the annual maintenance costs. Table 3 shows variables used in the model.

Table 3: Variables for the PortalLite system model.

Variable	**Definition**	**Type**
$x_{i_1 i_2 j k_j}$	Whether truck k_j from port j travels from node i_1 to node i_2	Binary
$y_{j_1 j_2 r}$	Whether ship r travels from node j_1 to node j_2	Binary
z_j	Whether port j is selected	Binary
u_{ijk_j}	The load of truck k_j from port j trip after visiting node i	Continuous
δ_{ijk_j}	The weight of unload items of truck k_j from port j in node i	Continuous
v_{jr}	The load of ship r after visiting port j	Continuous
w_{jr}	The weight of unload items of ship r trip in port j	Continuous

$$
\begin{aligned}
\text{Minimize} \quad & (1-\gamma^{\theta})\Big(\sum_{i_1 \in V}\sum_{i_2 \in V}\sum_{j \in J}\sum_{k \in K}(\rho+\psi\kappa)c_{i_1 i_2}x_{i_1 i_2 j k_j} \\
& +\sum_{j_1 \in J}\sum_{j_2 \in J}\sum_{r \in R}(\rho+\psi\zeta)C_{j_1 j_2}y_{j_1 j_2 r}\Big)/(1-\gamma)+\omega_j z_j && (8)\\
\text{subject to} \quad & \sum_{j \in J}\sum_{k \in K}\delta_{ijk} \geq q_i && \forall i \in I \quad (9)\\
& \sum_{i_2 \in V} x_{i_2 i_1 j k_j} = \sum_{i_2 \in V} x_{i_1 i_2 j k_j} && \forall i_1 \in V, j \in J, k \in K \quad (10)\\
& x_{i_1 i_2 j k_j} = 0 && \forall i_1 \in V, i_2 \in J : i_2 \neq j, j \in J, k \in K \quad (11)\\
& x_{i_2 i_1 j k_j} = 0 && \forall i_1 \in V, i_2 \in J : i_2 \neq j, j \in J, k \in K \quad (12)\\
& u_{i_1 j k_j} - u_{i_2 j k_j} + \alpha(1 - x_{i_1 i_2 j k_j}) - \delta_{i_2 j k_j} \geq 0 && \forall i_1 \in V, i_2 \in I, j \in J, k \in K \quad (13)\\
& \sum_{i \in I}\sum_{k \in K}\delta_{ijk_j} \leq \sum_{r \in R} w_{jr} && \forall j \in J : j \neq 0 \quad (14)\\
& \delta_{i_1 j k_j} \leq \sum_{i_2 \in V}\alpha * x_{i_2 i_1 jk} && \forall i_1 \in I, j \in J, k \in K \quad (15)\\
& z_{j_1} \geq y_{j_2 j_1 r} && \forall j_1, j_2 \in J : j_1 \neq 0, r \in R \quad (16)\\
& z_j \geq x_{i_1 i_2 j k_j} && \forall i_1 \in V, i_2 \in V, j \in J : j \neq 0, k \in K \quad (17)\\
& \sum_{j_2 \in J} y_{j_1 j_2 r} = \sum_{j_2 \in J} y_{j_2 j_1 r} && \forall j_1 \in J, r \in R \quad (18)\\
& w_{j_1,r} \leq \sum_{j_2 \in J}\beta y_{j_2 j_1 r} && \forall j_1 \in J : j_1 \neq 0, r \in R \quad (19)\\
& v_{j_1 r} - v_{j_2 r} + \beta(1 - y_{j_1 j_2 r}) - w_{j_2 r} \geq 0 && \forall j_1 \in J, j_2 \in J, r \in R \quad (20)
\end{aligned}
$$

To incorporate inflation associated with increasing annual maintenance costs, a multiplier factor is used in the operation costs to estimate the operation costs in θ years. The objective function (8) minimizes the total system costs. Similar to the previous model, Constraints (9) – (15) ensure the feasibility of each truck's trip and guarantee that the demand of each destination is met by the trucks. Additionally, trucks in this system can only transport containers that have already been delivered to a PortalLite Port. Constraints (11) and (12) ensure that each truck returns to its originating port. Constraint (14) ensures that the outflow of PortalLite port i is not greater than its inflow. Constraints (16) and (17) ensure that there can be no outflow from a PortalLite port that has not been built. Constraints (18) – (20) ensure that ships take round sequential trips with no sub-tours.

5 RESULTS

5.1 Data

Based on the case mentioned in Section 3, to enhance the applicability of the achieved results, cost ratios are used instead of exact figures due to the significant variation in operational and construction costs by region and transportation fuel type. The assumption is that both the unit transportation cost and the unit carbon emission tax for ships are half compared to trucks, based on the average values from a case study by Yin et al. (2021). Additionally, the assumptions by Elhedhli and Merrick (2012) to estimate the ratios of fixed costs to transportation costs for ω are adopted. The default parameters used in both simulation and mathematical models are: $\alpha = 1, \beta = 20, c = 10, C = 5, \kappa = 0.2, \zeta = 0.1, \psi = 1, \rho = 1, \gamma = 1.02, \theta = 10, \omega = 150$. Additionally, as of June 2024, available river-side lots in the greater Chicago area listed on Zillow cost an average of \$1.85M with an average lot size of 10 acres. To be conservative, these lots are estimated to cost between \$1M and \$5M in the near future. Considering the additional infrastructure costs required, default PortalLite Port costs of \$5M are assumed.

5.2 Simulation Model Analysis

A pilot study consisting of 30 one-month-long runs is conducted to determine the number of replications needed for future experiments. The pilot indicates that the coefficient of variation for the PortalLite system is slightly higher (4.7 %) than that of the Direct Trucking System. To ensure a more conservative estimate, the mean and standard deviation of the PortalLite system are used instead of those from the Direct Trucking System. Given a mean of \$0.3448/order, a confidence level of 98 %, and a desired margin of error of 2 % of the mean value, the number of replications is calculated as $n_{exp} = \left(\frac{Z_{\alpha=0.02}\cdot s_{pilot}}{E_{pilot}}\right)^2 = \left(\frac{2.326\cdot 0.0114899}{0.02\cdot 0.3448}\right)^2 = 15$.

Figure 6 shows that the costs per order significantly decrease when six or more PortalLite ports are opened. This finding is corroborated by the findings of the MIP model. Figure 7 indicates that, due to the additional travel distance required for the PortalLite system, the PortalLite system only reduces emission if the ratio of truck to ship emissions exceeds three. Figure 8 demonstrates that the PortalLite system reduces the costs per order at truck to ship cost-per-mile ratio greater than three. This finding provides similar intuition as the MIP model finding in Figure 10 in the subsequent section.

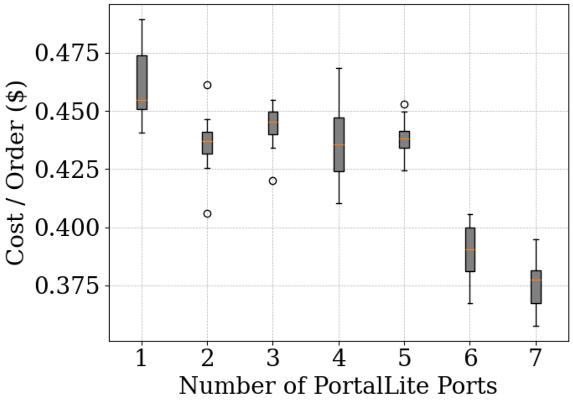

Figure 6: System cost by port quantity.
Adding PortalLite ports reduces costs, with the largest reduction going from 5 to 6 ports.

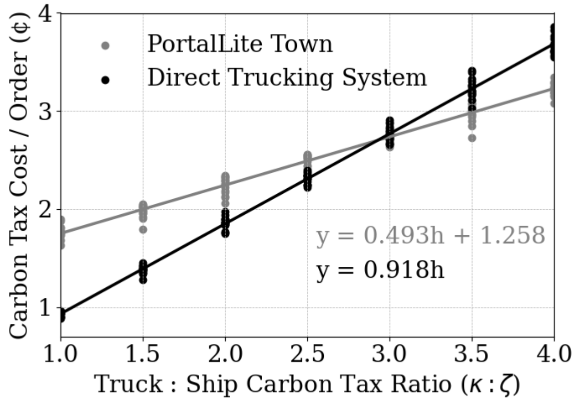

Figure 7: Emission ratio on carbon tax cost.
The PortalLite systems reduces system emissions at κ/ζ ratios of greater than 3.

While the PortalLite system shows potential cost savings, its effectiveness declines under high demand. Figure 9 illustrates the impact of demand (d) on order fulfillment. Up to a certain demand rate, the PortalLite system performs similarly to the conventional state. However, beyond this threshold, the system's capacity to meet increasing demand diminishes, eventually plateauing at its maximum throughput capacity.

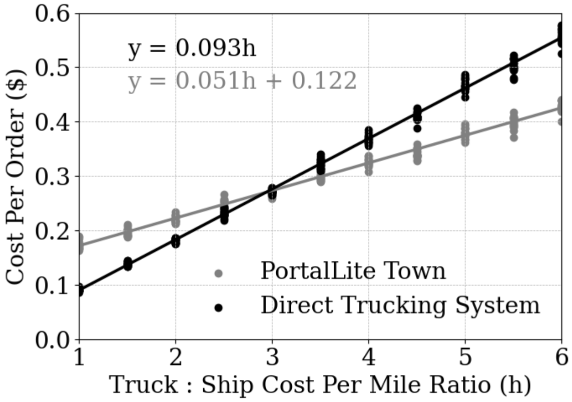

Figure 8: Truck:ship cost ratio on order costs.
Once h is greater than 3, the PortalLite Town begins to exhibit a lower order cost than Direct Trucking.

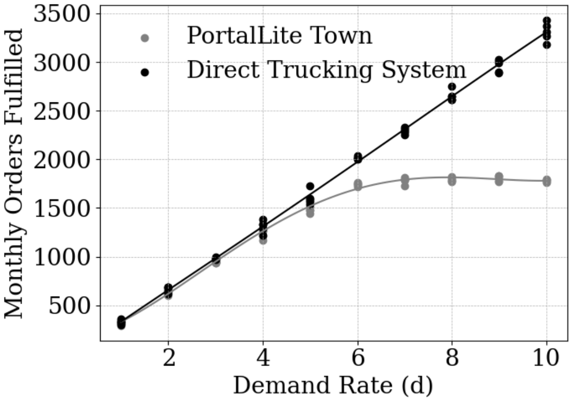

Figure 9: Demand rate (d) on deliveries.
The PortalLite Town demand capacity is limited by the PortalLite ports unlike Direct Trucking.

5.3 Mathematical Model Analysis

In this section, the impact of changing certain parameters on the PortalLite and Direct Trucking Systems mathematical models developed earlier is investigated. Specifically, individual parameters are modified and the two port systems compared to understand how these changes affect decision-making.

In Figure 10, the impact of varying the truck-to-ship transportation cost ratio ($c : C$) from 1:1 to 5:1 is illustrated. The results show that below a 2:1 ratio, both systems generate the same total costs, because below this ratio the PortalLite MIP does not introduce any PortalLite ports, effectively functioning as a Direct Trucking System. However, when the ratio exceeds 2:1, the PortalLite MIP begins to introduce PortalLite ports to reduce the overall system costs. This indicates that when the unit costs of land transportation are more than twice of waterway transportation, the PortalLite system becomes more favorable.

Figure 11 depicts the impact of increasing the PortalLite ports (ω) on the annualized system costs at varying system lifecycles. The figure indicates that above a certain PortalLite cost threshold, the MIP does not introduce any ports, effectively rendering the system into a Direct Trucking System. This threshold varies based on the expected system lifecycle. For a PortalLite system lifecycle of only two years, PortalLite ports fixed costs would need to be \$1.6m. However, these fixed costs can increase to \$4m for a five-year system lifecycle, which means the PortalLite Town will still be better than the Direct Trucking System.

In Figure 12, the total carbon emission tax of these two systems is compared under different expected life cycles. The plot shows that the Direct Trucking System consistently emits more carbon than the PortalLite system. The lines also diverge, indicating that greater lifecycles lead to greater overall emission savings.

In Figure 13, the average costs of the current system are compared to the average costs of the best-designed PortalLite system under the default setting during the years. This plot shows that if the current Direct Trucking System is upgraded to this PortalLite system, it will not provide profit in the first year. However, it benefits after the eighth year, and this revenue keeps increasing. Compared to the Direct Trucking System, it has a lower and lower increasing trend in the average costs due to the usage of the ships and PortalLite ports.

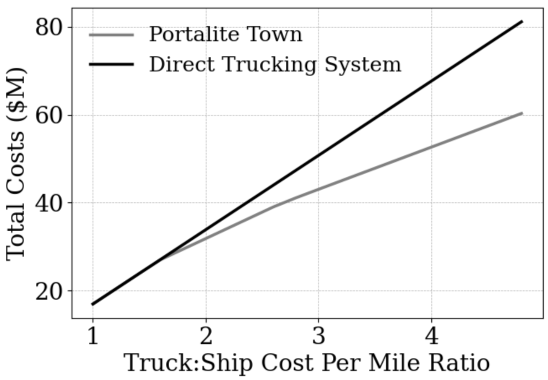

Figure 10: Truck:ship cost ratio on total costs. *PortalLite Town becomes favorable when truck-to-ship cost ratio exceeds 2:1.*

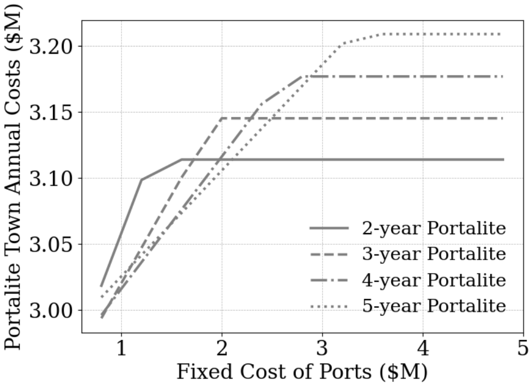

Figure 11: Fixed costs on annual PortalLite costs. *Increasing the PortalLite Town lifecycle reduces annualized costs.*

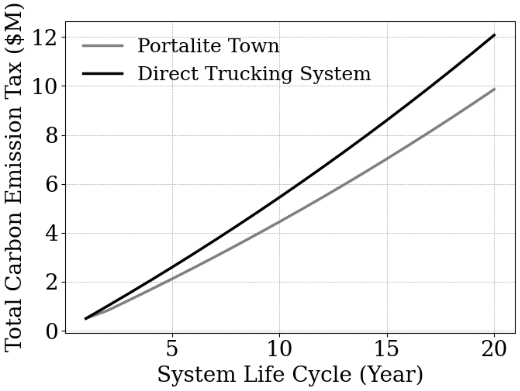

Figure 12: Carbon emission tax costs over time. *PortalLite Town has less and less carbon emission over time when compared to Direct Trucking.*

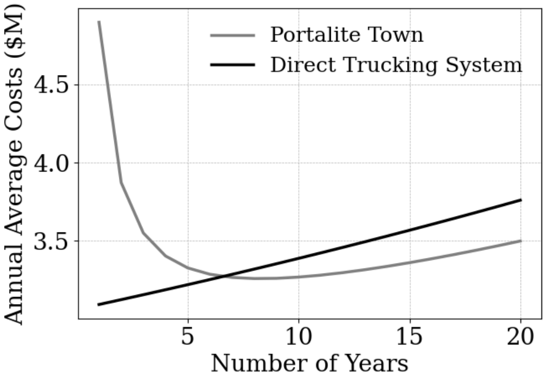

Figure 13: Annual costs of system over years. *Average costs of PortalLite Town lower that Direct Trucking in under eight years.*

6 MODEL LIMITATIONS

Both models focus solely on the import process from the primary port to the end user, omitting the return flow of containers. This simplification overlooks potential complexities and costs associated with reverse logistics. Moreover, the analysis is confined to a single urban center within one country, limiting the findings' generalizability. Differences in trucking and shipping costs, labor rates, and infrastructure quality across various global regions could significantly influence the system's viability elsewhere. Additionally, while the findings indicate potential applicability in urban contexts, extending these results to remote or island regions assumes sufficient future demand to justify PortalLite ports.

Furthermore, the use of a Poisson distribution for order arrivals does not incorporate the Coefficient of Variation (CV) to account for varying levels of demand randomness. Utilizing CV could provide a more precise view of demand variability, enhancing the model's accuracy and applicability by reflecting the relative variability of demand in different scenarios. Additionally, verification of the simulation is not conducted, leading to potential deviations from true system behavior. The impact of rail transportation as another mode of transport in the model has not been considered, too. Incorporating rail transportation could provide additional insights into the cost-effectiveness and feasibility of integrating multiple transportation modes in the overall logistics network.

Another limitation is that although a model of population-correlated demand was described, this is not applicable to many situations such as uninhabited archipelagos. This limitation suggests the need for alternative demand modeling approaches in regions with low population density. Lastly, the model does not include the stochasticity of ship TEUs loaded. It is assumed that ships wait at the port until they are fully loaded to reduce fuel costs. While this approach increases lead times and variability, an alternative model where ships sail at less than full capacity if no more TEUs are available could enhance the understanding of the system.

7 CONCLUSION AND FURTHER RESEARCH

The analysis presented in this study, encompassing both simulation and mathematical modeling, underscores the potential of the PortalLite system as a transformative approach to maritime logistics. The findings from the simulation model reveal that the PortalLite system emerges as an effective solution for costs and environment under specific conditions. However, the system's performance is contingent upon maintaining demand rates below a certain threshold, beyond which its ability to fulfill orders efficiently is compromised.

The mathematical model further elaborates on the financial viability of the PortalLite system, illustrating its relative insensitivity to fluctuations in unit transportation costs compared to traditional Direct Trucking Systems. This resilience is attributed to the utilization of ships, which inherently bear lower transportation costs. Furthermore, the analysis of fixed port costs and their impact on the average costs per life cycle category indicate that the PortalLite system can achieve cost savings over longer life cycles, even in scenarios of relatively high initial investment costs.

A critical takeaway from the study is the PortalLite system's long-term economic advantage. While the initial transition from a Direct Trucking to a PortalLite system may not yield immediate financial benefits, the subsequent years showcase a marked improvement in profitability.

The preliminary findings indicate the environmental and cost-saving potential benefits of PortalLite Town, underscoring the necessity for comprehensive future research to fully realize its transformative potential. Further studies are essential to explore the design, material handling, warehouse management, and operational aspects of PortalLite ports, as these systems do not exist today. Additionally, research should address the gaps identified in the limitations section, including the variability in demand, the impact of rail transportation, the stochasticity of ship TEUs loaded, and the absence of reverse logistics considerations.

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