Intermodal Solutions for Freight Flows in Southwest U.S.

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Project Partners: Oak Ridge National Lab and Southwest Supply Chain Coalition

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16. Abstract

The U.S. logistics sector continues to grapple with congested highways, extended transportation times, elevated costs, workforce shortage, and increased greenhouse gas emissions from the transportation sector. California's San Pedro Port Complex (SPPC), the nation's busiest, is significantly impacted by these challenges. This study proposes an intermodal transportation solution to address logistical challenges in the U.S. Southwest region, focusing on the inbound freight supply chain network originating from the SPPC. The proposed system expands the container classification process to potential logistics centers in California, Utah, Arizona, and Nevada, rather than exclusively at port areas. By utilizing inland facilities for classification, the system enables rails to be cost-efficient for shorter-distance hauls, reducing the number of trucks on highways, mitigating environmental impact, lowering transportation costs, and promoting resource balance in port complex areas. We developed a two-stage mixed-integer stochastic programming model to optimize overall distribution costs through a modified intermodal transportation system. We evaluated the proposed system's performance in terms of cost, freight throughput, and environmental impact. To address uncertainties in demand. The total transportation cost is reduced by 0.3519%, equivalent to $716 million over 10 years, with an additional $19.3 million to $21.7 million saved in environmental impact due to the switch from trucks to rail, representing a 4.2% reduction.

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Executive Summary

The U.S. logistics sector continues to grapple with congested highways, extended transportation times, elevated costs, workforce shortage, and increased greenhouse gas emissions from the transportation sector. California's San Pedro Port Complex (SPPC), the nation's busiest, is significantly impacted by these challenges. This study proposes an intermodal transportation solution to address logistical challenges in the U.S. Southwest region, focusing on the inbound freight supply chain network originating from the SPPC. The proposed system expands the container classification process to potential logistics centers in California, Utah, Arizona, and Nevada, rather than exclusively at port areas. By utilizing inland facilities for classification, the system enables rails to be cost-efficient for shorter-distance hauls, reducing the number of trucks on highways, mitigating environmental impact, lowering transportation costs, and promoting resource balance in port complex areas.

This study developed a two-stage mixed-integer stochastic programming model to optimize overall distribution costs through a modified intermodal transportation system. We evaluated the proposed system's performance in terms of cost, freight throughput, and environmental impact. To address uncertainties in demand. The total transportation cost is reduced by 0.3519%, equivalent to $716 million over 10 years, with an additional $19.3 million to $21.7 million saved in environmental impact due to the switch from trucks to rail, representing a 4.2% reduction.

The project results suggest railroads may consider businesses connecting ports and logistic centers with distances shorter than $500. Our study shows that such a business could be economically feasible due to no classification effort and possible unit trains. Some infrastructure investment to improve railway network accessibility for existing logistic centers could be economically viable. The proposed intermodal network needs a public-private partnership among port authorities, state DOTs, state economic councils, railroads, and logistic companies.

Problem Description

Intermodal transportation includes coordinating multiple transport modes—from trucks and trains to ships and occasionally planes—to facilitate the shipment of goods, typically in standardized containers. Compared to using highways alone, integrating intermodal rail can reduce costs by 10% to 40% [1]. Additional benefits of intermodal transportation include enhanced flexibility, improved throughput, and minimized environmental and social impacts. For ground transportation, rail offers these benefits prominently. However, trucks remain the dominant mode of transportation in the United States. A significant area that relies on the performance of inland intermodal transportation is port operations, particularly major ports such as the San Pedro Port Complex (SPPC). Comprising the Port of Los Angeles (POLA) and the Port of Long Beach (POLB), SPPC managed 29% of all U.S. containerized international waterborne trade in 2021 [2], including 75% of such trade on the West Coast (**Figure 1)** [3]. As the leading U.S. container port since 2000, the port faces significant issues, including severe shortages of port operators, truck drivers, and chassis, leading to prolonged waiting times. On January 19, 2022, about 100 container vessels experienced delays of 17.6 to 28 days before [4]. Some vessels were rerouted to other ports, requiring additional transportation to return the freight [5]. A critical issue is the scarcity of truck drivers, with 81,258 driver shortages in 2021, potentially increasing to 160,000 by 2031 [6]. Labor problems have exacerbated container congestion, causing Union Pacific to suspend service at all inland rail ramps serving the complex in June 2023 to encourage shippers to use alternate ports [7]. Trucks were also denied access to the terminal due to low productivity. Additional factors contributing to transportation bottlenecks include e-commerce trends, globalized supply chains, pandemic impacts, congested highways in California, aging infrastructure, environmental concerns, regulations, and limited public-private collaboration. Other ports in the U.S. face similar issues. In response to these challenges, researchers actively strive to comprehend and enhance port operations and associated transportation systems, aiming to facilitate smoother international trade.

Figure. 1: Highway traffic in southwest U.S. [3]

While existing literature extensively covers port operations and associated transportation systems, our research offers a fresh perspective by exploring the expansion of inland locations for the classification process (see Literature Review section). To solve the current disruptions and congestion in California and build a sustainable and resilient supply chain in the U.S., we propose a new intermodal transportation solution that moves containers, without classification, directly from California ports by rail to logistics centers away from the ports. In recent years, new warehouses and distribution centers have been built across Nevada, Arizona, Utah, and the Inland Empire around the cities of Riverside and San Bernardino. The proposed solution addresses the current supply chain disruption, attacks its root causes, and brings social and environmental benefits to Southwest U.S. and the whole nation. In this scenario, containers are transferred directly by cranes from ocean ships to trains no matter what their final destinations are. This will improve the efficiency and space utilization at and around ports. Containers or items in containers will be sorted and shipped to final destinations by either rail or trucks. A 100-railcar train, operated by two crew members, has an equivalent carrying capacity of about 300 to 400 trucks [8]. The proposed solutions to move traffic from highways to railroads will also make our transportation system more environmentally friendly by reducing energy consumption and carbon emissions because highways consume about 10 times as much energy as railways per ton-mile [9].

However, there are several barriers to implementing new intermodal solutions, including capital for new freight infrastructure investment, limited attention from railroads, and a lack of coordination among stakeholders. Most distribution centers in Nevada, Arizona, and Utah do not use rail [10]. For the State of Nevada, there is only one active sidetrack serving warehouses or distribution centers in the state, while there have been 6.4 million square feet of warehouse space built next to Union Pacific (UP) right-of-way in Region 1 (Las Vegas) with no rail sidetracks at all. In Region 6 (Reno/Sparks/Stead), there are 37 warehouses and distribution centers served by rail, in total five million square feet of space, and none of their sidetracks are being used. There are also 53 facilities located adjacent to the UP right-of-way that ship or receive in truckload lots, but none have built a sidetrack. Thirty-six of those 53 facilities are warehouses with another 5+ million square feet of space. **Figure 2** shows a large distribution center in North Las Vegas, NV across a street from a branch railroad but not using rail. All distribution centers in Nevada are currently served by trucks and 70% of all trucks in the State travel to or from California. To implement the new intermodal solution, new sidetracks may be built or activated, which involves capital investment. We need to select investment projects and decide on the funding models. The solution needs support from ports and railroads. Even though the team has received positive responses from port authorities, the Class-I freight-hauling railroads in the Western and Midwestern U.S. require further enrollment and support toward these new approaches as have previously emphasized long haul moves in their operating plans.

Figure 2: A warehouse with a rail track across a street [10]

The study of inland port locations, operational improvements, and related transportation enhancements to boost port efficiency has a long history. Operational optimization typically focuses on equipment, inventory levels, facility relocation, and resource scheduling within a port or its immediate vicinity. Molnar et al. examined the selection of a warehouse and its storage capacity to facilitate material transport through a reloading terminal and the seaport [11]. Jula and Leachman developed a mixed-integer non-linear programming model to optimize the supply chains for importers of waterborne containerized goods from Asia to the United States [12]. They aimed to minimize handling and inventory costs by determining the most suitable ports for inbound freight and selecting the appropriate land transportation modes. Chen et al. concentrated on regional empty container inventory management at inland freight stations [13]. Cao et al. developed a mixed-integer linear program (MILP) to analyze the impact of inland container depots on the efficiency of Yangshan Port, considering inter-terminal connections from the offshore port to satellite terminals [14]. This research also focused on optimizing truck drayage operations within the port area.

The inland facility location problem, an important component of our study, has been studied using various approaches and focuses. Rahimi et al. studied the inland port for intermodal freight movement, particularly for the Ports of Los Angeles and Long Beach, with location choices restricted to five counties within 100 miles of the ports [15]. Our study went well beyond California and considered possible new infrastructure investment. Halim et al. used a multi-objective, multi-actor optimization approach to simultaneously optimize total logistics costs and client regions for European port-hinterland freight distribution networks [16]. They formulated the problem as a Network Design Problem to optimize the location of distribution centers and demand allocation, restricting each demand region to be served by only one DC facility. Osorio-Mora et al. proposed a MILP model for capacitated multimodal, multi-commodity hub location problems that allow direct shipments between origins and destinations [17]. Their model, however, does not account for uncertainties or externalities such as pollution and social costs. Shang et al. advanced the field by developing a stochastic multi-modal hub location problem that incorporates multiple capacity levels and mode-specific hubs within a hybrid hub and-spoke (H&S) model, including direct links between spokes [18]. However, their study limited each spoke to being served by a single, mode-specific hub, unlike ports where hubs can serve multiple modes and routes.

Sarmadi developed a stochastic programming approach to handle uncertain container demands, focusing on both strategic decisions (number and location of dry ports) and operational decisions (intermodal transportation of laden and empty containers, empty container repositioning, leasing, and inventory planning) [19]. They studied a hypothetical dry port network design in North Carolina, assuming equal capacity for all destinations and constant unit transportation costs between location pairs. Zhang et al. addressed the stochastic incomplete multimodal hub location problem with multiple assignments and delivery-time restrictions [20]. Their work considers mode-specific hubs and links, incomplete interhub connectivity, multiple assignment patterns for demand nodes, and two types of uncertainties. They conducted numerical experiments based on the Turkish network and AP dataset, evaluating both transportation costs and travel times, though the model does not include direct links between spokes.

In our research, we employed a two-stage stochastic program to address uncertain demand scenarios and focus on the value proposition of intermodal transportation solutions in the Southwest U.S. Our study makes contributions in two main areas. Firstly, from a modeling perspective, we integrated several elements that are typically considered separately. We considered multiple warehouse locations with two transportation mode choices for multiple demand allocations at each destination. This allows multiple warehouses to serve each destination, rather than restricting each destination to be supplied by only one intermediate warehouse. In other words, we investigated the possibility of shipping containers without sorting from the port to intermodal logistics centers, which can significantly reduce the operational cost and time at the port and possibly attract support from railroads. Additionally, we allow direct flow from the source to destinations. The stochastic aspect of our problem captures the uncertainty of demand. We extend the existing models in the literature by situating container sorting warehouses in hinterland regions to obtain a new network design solution. Second, regarding model implications, we offer insights into the design of inbound intermodal systems, using a real-world case study of the SPPC that utilizes more distant inland ports. We perform sensitivity analysis to compare various installation costs and probabilities of demand scenarios. Our cost considerations encompass a broad spectrum, including drayage, transloading, demurrage, storage at ports and warehouses, operating and administrative costs, and variable shipping costs. Additionally, we evaluate the performance of our proposed system by considering the impacts on greenhouse gas (GHG) emissions, alongside the financial aspects related to operations and transportation. This contributes to the field of sustainable supply chain and logistics, which requires more attention in the context of intermodal and marine transportation. Adopting our proposed system can reduce total costs, make rail transport profitable for shorter distances, and lower GHG emissions.

Approach

We chose the San Pedro Port Complex (SPPC) as our target area, aiming to minimize the transportation impacts and costs of the inbound freight distribution system through an intermodal solution. Our strategy involves installing intermodal capability at potential locations to reduce dependence on the port's classification yard, decrease highway congestion, and minimize train assembly time at the port. To address fluctuating demands, we develop a two-stage stochastic model. The process begins when containers arrive at the SPPC, from where they are dispatched by rail or trucks to their final destinations or intermediate nodes such as rail terminals, near-dock terminals, logistics centers, distribution centers, warehouses, and rail yards located in California and neighboring states, including Nevada, Utah, and Arizona. Traveling through multiple intermediate facilities by train is allowed, as depicted in Figure 3. Solid lines indicate connectivity by rail, while dashed lines signify connectivity by trucks. Orange nodes represent ports, logistics centers, and destinations with intermodal facilities, while grey nodes denote logistics centers and destinations without such facilities. Clear nodes represent final consumer destinations, which may or may not be equipped with intermodal facilities and could be aggregated (e.g., by states). The dimly drawn lines and nodes form complete networks that extend beyond the scope of our decision problems.

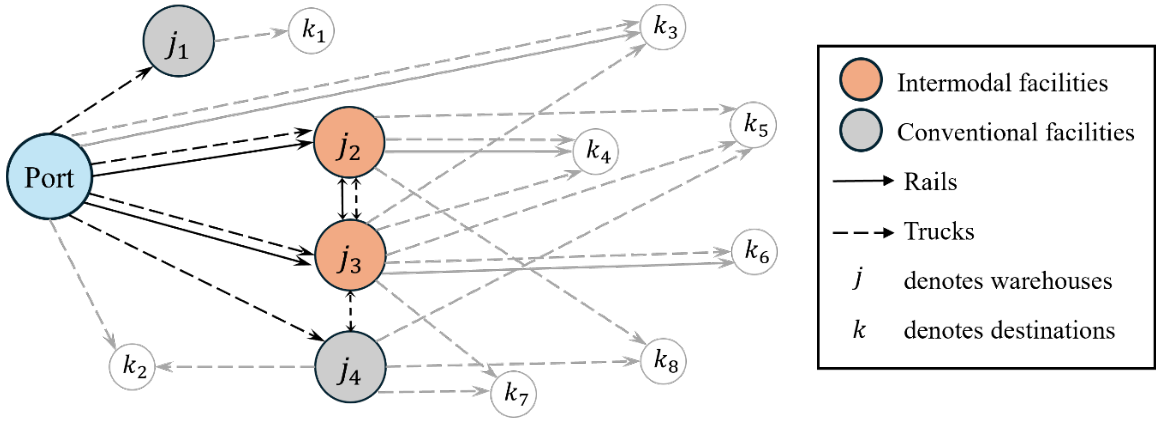

Figure 3 Proposed intermodal network

To manage inbound containerized shipment flow and mitigate congestion, containers are loaded onto trucks or unsorted full-length trains at port areas. These trains are subsequently expedited to available warehouses regardless of their final destinations. Once sorted at those warehouses, containers are transported to their destinations by trucks for shorter distances and railroads for longer distances. We make the following set of assumptions:

1. The classification process may be carried out at intermodal logistics centers. This approach relocates portions of the classification process that require significant time and space to less congested areas, thereby reducing congestion around the port. This arrangement reduces traditional high fixed costs associated with railroads because the loading process at ports to trains no longer requires extra steps, such as unloading from ships and storing goods in container yards for extended periods until they can be grouped with others destined for the same location. In addition, the steps of loading sorted containers onto railcars and sorting railcars to form a train are eliminated. Consequently, the process is

expected to be faster and more cost-effective as shown in Figure 4. The red line represents the cost structure of trucking regarding travel distance while the green lines are the cost structures of the railway. When the fixed cost for the railway goes down from $124 to $92 per ton, the breakeven point between the two modes drops from 545 miles to 381 miles. It illustrated that railroads could be more interested in serving demands with shorter distances when their fixed costs go down. In our proposed intermodal solution, containers, no matter what their destinations, are directly transferred from a ship to a train so the loading operations are much simpler and faster.

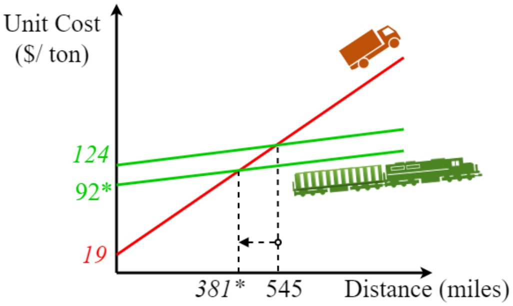

Figure 4 Rail and truck transportation costs

2. Exclusively assembling full trains for transportation, while trucks manage both full truckload (FTL) and less-than-truckload (LTL) shipments. FTL shipments fill an entire truck, whereas LTL shipments combine smaller shipments from various customers into a single truck.
3. In the first stage of decision-making, at the strategic level, the selection of warehouses to be equipped with intermodal capabilities will be made annually, which involves large capital investment. Once installed, these capabilities will remain in place until the end of our 10-year analysis horizon. The second stage involves annual flow allocation. All parameters associated with the decision variables, including costs, capacity, and demand, are calculated on a per-year basis. This stage does not reflect operational behaviors but is intended to provide a strategic overview.
4. As mentioned previously, the connections between warehouses and destinations are not within our decision-making scope. Therefore, the mode of transportation and the percentage of freight sent to each destination are predefined. For distances over 500 miles, transportation will be designated to rail, while for distances less than 500 miles, trucks will be used.

Methodology

In the proposed two-stage stochastic program, the first stage deals with long-term strategies to identify the optimal locations for logistics centers to be equipped with intermodal facilities over a ten-year period that would enhance accessibility to railroad systems. The subproblem (i.e., second-stage) stage is formulated as a network flow problem, addressing annual transportation operations. It determines the most efficient routing and allocating the appropriate quantities of goods to be transported via railroads and trucks to each location. These decisions are associated with various factors, including total cost, budget constraints, warehouse availability, and capacity, as well as the potential impacts on the community and environment. Notations and definitions are described in **Tables 1- 3** for set and indices, parameters, and decision variables, respectively.

TABLE 1 Definition of Sets and Indicies

Sets	Definitions	Indices	Definitions
I	set of the port complex	i	index for the port complex $i \in I$
J	set of candidate logistic centers	j	index for logistic warehouse $j \in J$
K	set of destinations	k	index for destination $k \in K$
T	number of planning horizon periods	t	index for time $t \in \{1,2,\dots,T\}$
S	set of demand scenarios	s	index for scenario $s \in S$
		m	index for modes m =0 for rucks and m =1 for rails

TABLE 2 Definition of Parameters

Parameters	Definitions
c_j	one-time fixed cost of intermodal capability installation at warehouse $j \in J$
u_j^m	variable costs per ton for mode $m \in \{0,1\}$ from the port to warehouse $j \in J$
γ_{jb}^m	variable costs per ton for mode $m \in \{0,1\}$ from warehouse $j \in J$ to warehouse $b \in J - \{j\}$
δ_{jk}	variable costs per ton for the most cost-effective mode from warehouse $j \in J$ to destination $k \in K$
σ_k	variable costs per ton for the most cost-effective mode from the port to destination $k \in K$
e_j	capacity of warehouse $j \in J$
d_{kts}	annual demand at destination $k \in K$ at time $t \in T$ under scenario $s \in S$
B_t	budget for intermodal capability installation at time
$a_{j1} \in \{0,1\}$	indicator for whether warehouse $j \in J$ initially has intermodal capability
$\alpha_{kt} \in [0,1]$	percentages of containers shipped to destination $k \in K$ at time $t \in \{1,2,\dots,T\}$
ρ_s	probability of the occurrence of scenario $s \in S$

TABLE 3 Definition of Decision Variables

Variable	Definitions
$X_{jt} \in \{0,1\}$	1, if intermodal capability is installed at warehouse $j \in J$ at year $t \in \{1,2,\dots,T\}$; 0, otherwise
$a_{jt} \in \{0,1\}$	1, if warehouse $j \in J$ has intermodal capability at the beginning of year $t \in \{2,3,\dots,T\}$; 0, otherwise
$Y_{jts}^m \in \mathbb{R}^+$	annual amount of freight shipped from the port to facility $j \in J$ by transportation mode $m \in \{0,1\}$ at time $t \in \{1,2,\dots,T\}$ under scenario $s \in S$
$W_{jbts}^m \in \mathbb{R}^+$	annual amount of freight shipped from facility warehouse $j \in J$ to facility $b \in J - \{j\}$ by transportation mode $m \in \{0,1\}$ at time $t \in \{1,2,\dots,T\}$ for scenario $s \in S$
$V_{jkts} \in \mathbb{R}^+$	annual amount of freight shipped from warehouse $j \in J$ to destination $k \in K$ by the most efficient transportation mode at time $t \in \{1,2,\dots,T\}$ under scenario $s \in S$
$Z_{kts} \in \mathbb{R}^+$	annual amount of freight shipped directly from the port to destination $k \in K$ by the most efficient transportation mode at time $t \in \{1,2,\dots,T\}$ under scenario $s \in S$

The optimization problem is formed as a two-stage stochastic problem. The first-stage problem determines long-term strategies for network design, including which logistics centers should have intermodal facilities to improve accessibility to railroad systems. The **objective function (1)** minimizes the overall costs associated with utilizing existing logistic centers or upgrading them to intermodal facilities, and the expected of the second-stage network flow problem. **Constrain set (2)** imposes a restriction that the intermodal installation investment cost must be less than the budget available in year t.

$$\min \sum_{j\in J}\sum_{t\in T} c_j X_{jt} + \sum_{s\in S} \rho_s Q(X,S) \tag{1}$$

$$\text{s.t.} \sum_{j\in J} c_j\, X_{jt} \leq B_t, \quad t \in \{1,\dots,T\} \tag{2}$$

$$X_{jt} \in \{0,1\}$$

$$\begin{aligned}\min \sum_{j\in J}\sum_{m\in\{0,1\}}\sum_{t\in T}\sum_{s\in S} \mu_j^m Y_{jts}^m + \sum_{j\in J}\sum_{b\in J-\{j\}}\sum_{m\in\{0,1\}}\sum_{t\in T}\sum_{s\in S} \gamma_{jb}^m W_{jbts}^m + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T}\sum_{s\in S} \delta_{jk} V_{jkts} \\ + \sum_{k\in K}\sum_{t\in T}\sum_{s\in S} \sigma_k Z_{kts}\end{aligned} \tag{3}$$

$$\text{s.t.} \sum_{m\in\{0,1\}} Y_{jts}^m - \sum_{b\in J-\{j\}}\sum_{m\in\{0,1\}} W_{jbts}^m + \sum_{b\in J-\{j\}}\sum_{m\in\{0,1\}} W_{bjts}^m \leq e_j \qquad \forall j \in J, \forall t \in \{1,\dots,T\}, \forall s \in S \tag{4}$$

$$Y_{jts}^1 + \sum_{b\in J-\{j\}} W_{jbts}^1 + \sum_{b\in J-\{j\}} W_{bjts}^1 \leq e_j \cdot a_{jt} \qquad j \in J, \forall t \in \{1,\dots,T\}, \forall s \in S \tag{5}$$

$$X_{jt} + a_{jt} = a_{j,t+1} \qquad \forall j \in J, \forall t \in \{1,\dots,T\} \tag{6}$$

$$Z_{kts} + \sum_{j\in J} V_{jkts} = d_{kts} \qquad \forall k \in K, \forall t \in \{1,\dots,T\}, \forall s \in S \tag{7}$$

$$\begin{aligned}\alpha_{kt}\left(\sum_{m\in\{0,1\}} Y_{jts}^m - \sum_{b\in J-\{j\}}\sum_{m\in\{0,1\}} W_{jbts} + \sum_{b\in J-\{j\}}\sum_{m\in\{0,1\}} W_{bjts}\right) \\ = \sum_{m\in\{0,1\}} V_{jkts}\end{aligned} \qquad \begin{aligned}&\forall j \in J, \forall k \in K, \forall t \in \{1,2,\dots,T\}, \\ &\forall s \in S\end{aligned} \tag{8}$$

$$a_{jt} \in \{0,1\}, Y_{jts}^m \geq 0, W_{jbts}^m \geq 0, Z_{kts} \geq 0, V_{jkts} \geq 0.$$

The second-stage model determines the cost related to freight distribution over 10-year periods. The **objective function (3)** is the sum of the following transportation costs: from SPPC to warehouses, between warehouses, from warehouses to destinations, and from SPPC to destinations. The distribution costs include fixed costs at each location associated with transportation mode m such as L&UL costs, and variable costsbetween locations based on miles. **Constraint set (4)** represents the warehouse capacity constraint, stating that the total amount of freight shipped from the port to a warehouse, minus the freight that passes through without being handled at the warehouse, plus the freight shipped from other warehouses, should not exceed the capacity of the warehouse in each period. **Constraint set (5)** restricts the flow of goods in and out of a warehouse by rail, allowing such movement only when the warehouse has intermodal capability. **Constraint set (6)** updates warehouse j intermodal capability at the start of time period t. **Constraint set (7)** represents the demand constraint, ensuring that all containers transported to destination k at time t under scenario s, whether they go directly from the port or pass through warehouses first, must equal the demand at destination k. **Constraint set (8)** represents the flow constraint, ensuring that all remaining freight at warehouse j must be sent out to destination k by the end of time t, with the specified ratio α_{kt}.

Findings

Data documentation

The data (or called parameters for the optimization model) used in this study include annual demand, logistics centers' capacity, intermodal capability installation costs, transportation costs, and the costs of environmental and social impacts. The predicted commodity data and flow for U.S. freight are based on the Freight Analysis Framework Version 5.6 (FAF5) dataset [21]. We filtered this dataset to include only waterway imports to the U.S. through California and their distribution to all states. FAF5.6 provides forecasts up to 2050, with data available every five years (e.g., 2025, 2030, ...). To obtain annual data from 2025 to 2034 for low, medium, and high-demand scenarios, we used linear interpolation to obtain annual demand, the tonnage received by the continental states and Washington, DC. We then computed the corresponding percentages of the flow for each destination k at time t, which are later referenced in the model as α_{kt}. The percentage captures the model's dynamic behaviors and facilitates the unclassified operations at the port to form a train to an intermodal logistic center. α_{kt} will be the same for each transfer train, no matter which intermodal logistic center that train serves.

Obtaining warehouse capacity data and locations was a challenge. We gathered real-world GIS data to capture the capacity and functionality of 249 locations, including warehouses, distribution centers, logistic centers, and rail terminals across the four states: California, Nevada, Arizona, and Utah. Given that this data is not publicly accessible, we justified our estimates by considering various factors, such as warehouse space, number of rail doors, storage capacity, and annual lift. In cases where details were unavailable, we assumed the warehouse was relatively small with a space of 10,000 sq. ft and an estimated annual capacity of 45,590 tons. In addition, for all warehouse capacity data, we assumed that only 70% of each warehouse's capacity would be used to handle the inbound freight, leaving the remaining 30% for other activities such as serving domestic shipments or engaging in other value-added activities. Since some of the intermediate warehouses lack direct railroad access, we categorized installation costs into three levels: low ($100,000 - $500,000), medium ($500,000 - $1,000,000), and high ($1,000,000 - $1,500,000). These installation costs may include building new sidetracks, activating unused tracks, or acquiring intermodal handling equipment such as cranes or container handlers.

To evaluate the total cost, we included the following operational costs per ton-mile: $0.2225 for trucks and $0.0302 for rails, based on the data generated from the research conducted by Rattanakunuprakarn et al. [22]. These numbers are presented in 2020 dollars per ton-mile, encompassing costs solely related to operating metrics, such as energy, labor and administration, maintenance of transportation assets, end-of-life asset value, transport equipment, and maintenance of transport equipment. For tonnage and vehicle capacity parameters, we assumed 16 tons per TEU, which was calculated based on data published by the Port of Long Beach [23] including the total tonnage of containerized commodity, number of loaded TEU, and number of empty TEU. Additionally, for Class-I railroads, we considered an average ton loaded per railcar of 52.9 tons per railcar [22].

In the current transportation system, freight is primarily transported to on-dock or near-dock rail terminals via drayage trucks. Demurrage or storage (D/S) costs at the port were set at $1.552 per ton, calculated based on an average dwell time of 4.3 days [24]. Notably, the initial four days do not incur charges [25], but any fraction of a day is treated as a full day, resulting in a charge of $24.83 per container per day [26]. Given that one TEU averages 16 tons, the resulting cost per ton is $1.552. Containers assigned to warehouses via truck transport incur no D/S costs due to their shorter average dwell time of 3.2 days [24]. However, exceptions exist for truck-assigned containers transported directly from the port to final destinations, which are subject to D/S costs due to container sorting and waiting time for truck pickup. For containers sorted at the port and assigned to rail for final destinations, loading and unloading (L&UL) costs are incurred in addition to D/S costs, amounting to $17.01 per ton. This number was derived from L&UL costs of $900 per railcar divided by 52.9 tons per railcar. The assumption of rail fixed costs, i.e., L&UL, at $900 per railcar is based on railcar equipment costs, indicating that using rail or multi-modal transit adds about $900 per railcar shipment [27]. Regarding D/S costs at rail terminals, the cost for railcars at Barstow, CA BNSF terminals was estimated at $ 9.375 per ton. This figure is based on an average dwell time at rail terminals of 42.3 hours [28], with the charge for one day calculated from the difference between the free time of 24 hours [29] and the dwell time of 42.3 hours, amounting to $150 per container. When divided by 16 tons, the resulting cost is $9.375 per ton. For inbound containers initially handled by trucks, we have assumed that D/S costs at rail terminals are not applicable. This assumption is based on the understanding that the processing time of trucks is relatively short compared to rail operations. Therefore, we assume that the dwell time for trucks at warehouses and rail terminals will be less than the free time of 24 hours, only slightly shorter compared to the average rail dwell time of all rail terminals at 28.1 hours [28]. Warehouses accumulate operating and administrative (O&A) expenses averaging $2.62 per ton. This calculation is derived from the combined O&A costs across all warehouses, divided by their annual freight-handling capacity. The total O&A costs for all warehouses are estimated based on the square footage allocated to inbound freight in our system. The average annual cost to rent warehouse space is $7.96 per square foot, with additional operating expenses ranging from $2 to $5 per square foot [30]. These operating expenses include electricity, janitorial services, water, internet, taxes, and insurance. For the 122 warehouses with unknown capacity, we assumed a standard size of 10,000 square feet. Furthermore, warehouse L&UL costs are estimated to be $17.01 per ton, based on the same cost assumptions used for L&UL at the port. These costs were applied to the first and second warehouses where cargo is processed. Additionally, warehouse operating costs encompass D/S costs, adopting the same cost as D/S at rail terminals, which is $9.375 per ton for warehouses in proximity to the port area. For warehouses farther away, we assume a cost of $0.3776 per ton. This figure was calculated using data from the BNSF 2020 R-1 report in Schedule 410 [31]. BNSF recorded an operating income of $193,279,000 from demurrage charges associated with freight-related revenue and expenses. We divided this D/S cost by the total tons handled, 511,801,000 in 2020, as per the R-1 report in Schedule 755. Consequently, on average, demurrage costs at rail facilities amounted to $0.3776 per ton.

In the proposed intermodal system, with a presumed reduction of 6.98% in dwell time for containers assigned to rail at the port, the average dwell time falls below 4 days. This effectively eliminates D/S costs at the port associated with rail transportation. Additionally, D/S costs at the port remain at zero for trucks, assuming the new system does not change dwell times for containers designated for truck transportation. However, if both trucks and rails are assigned to pick up cargo destined for the final destinations, they must wait for the sorting process at the port, thus incurring D/S costs at the port as per the current practice ($1.552 per ton for trucks and $17.01 per ton for rails). The main difference in the proposed intermodal system is the allowance of cargo transloading from vessels to trains at the port without considering the final destinations in the train forming process. Consequently, the L&UL cost for rails at the port is reduced to $3.78 per ton (from $200 divided by 52.9 tons). This eliminates the need for transloading from trucks to rails at the warehouse, resulting in no L&UL cost from transloading at warehouses. Only D/S costs remain at warehouses.

For trucking, the shipping cost per ton is competitive for short hauls up to approximately 500 miles, priced at $0.2225 per ton-mile, based on the operating metric in the research by Rattanakunuprakarn et al. [22], with an additional initial cost of $19.268 per ton, estimated by Fayek [32], where a comparison graph between rail and truck transportation indicates that the total cost at a distance of 0 for a TEU container is approximately $180 for trucks. To convert this cost per TEU to cost per ton, we used data from the Port of Houston, as this study collected data based on a case study of the port. In 2023, the port handled 50,323,264 tons of all kinds of commodities [33], with 71% being containerized cargo [34], equivalent to 35,729,517.44 tons. Dividing this number by the 3,824,600 TEUs handled that year [35] gives an average of 9.342 tons per TEU. Therefore, dividing $180 per TEU by 9.342 tons per TEU yields an initial cost of $19.268 per ton for using trucks.

On the other hand, rail shipping costs are relatively low at $0.03 per ton-mile [22]. Nevertheless, there are three additional initial costs associated with rail transportation even before a rail journey commences. These include 1) Drayage costs at origin and destination, totaling $71.334 per ton; 2) Transloading costs, amounting to $17.01 per ton each time, for loading and unloading railcars at both origin and destination; 3) D/S costs at rail terminals, totaling $9.375 per ton each time. The drayage cost of $71.334 per ton was derived from a drayage cost of $666.4 per TEU based on the research by Fayek [32], which indicates that the total cost at a distance of 0 for a TEU container is approximately $680 for rail. According to the research, drayage accounts for 98% of this cost, resulting in $666.4 per TEU. To determine the drayage cost per ton, we use the same method as for trucks, dividing by the average of 9.342 tons per TEU based on Port of Houston data [35]. Therefore, the drayage cost of $666.4 per TEU translates to $71.334 per ton. The transloading costs of $17.01 per ton and D/S costs at rail terminals of $9.375 per ton were previously explained in the Current Practice Assumptions and Parameters section.

The cumulative sum of these three costs is $124.104. The interplay between these expenses indicates that rail transportation becomes cost-competitive at distances exceeding 645.367 to 545.169 miles. This distance is consistent with the general ranges established by researchers [36, 37]. The initial cost of the proposed system $92.218 comes from 71.334 /2 + 17.01×2 + 3.781 + 9.375×2. According to Fayek [32], a 15 percent reduction in drayage costs would make rail intermodal competitive with trucks for hauls over 400 miles. With a 25 percent reduction, rail intermodal could be feasible even for distances under 400 miles. Furthermore, if issues related to drayage, terminal capacity, location, and configuration can be addressed, rail intermodal could compete with trucking over distances as short as 150 miles.

The archived data are enclosed as follows:

- Input data: traffic demand data in “FAF5.6_State_HiLoForecasts_CAonly.xml”and the location/capacity data of logistics centers in “Location List_4_refined.xlsx”.
- Program file: “Intermodal Project_codes.zip”.
- Output data: “results.docx”.

Analyses performed

The model (1-8) was solved by Gurobi 11.0.2 with the collected data for the SPCC. An assessment was conducted to compare the current practice under medium-level demand against our proposed system under the stochastic situation with low, medium, and high costs of installing intermodal capacity.

Results

Table 4 presents a comparative assessment of the current practice against our proposed system under medium-level demand. We compare the base case of the current practice, which incurs a total cost of $203.461 billion, with three cases of the proposed system. For the proposed system, the total cost is $202.745 billion with low intermodal installation costs, $202.746 billion with medium intermodal installation costs, and approximately $202.746 billion with high intermodal installation costs. In all three cases of the proposed system, we can save about $716 million in overall transportation costs compared to the current practice under medium-level demand. As mentioned in Parameter Justification section, installation costs are defined in three categories: low ($100,000 - $500,000), medium ($500,000 - $1,000,000), and high ($1,000,000 - $1,500,000).

In all cases, the direct flow from the port to all destinations, without passing through any intermediate warehouse, remains constant at 661,092,153 tons via trucks and 3,127,086,289 tons via rail for all three demand scenarios combined. This consistency is likely due to the lower cost of direct transportation compared to using intermediate facilities. Consequently, the system utilizes all available capacity at the on-dock terminal, and any excess flow is directed through intermediate warehouses.

For the sensitivity analysis of intermodal installation costs, we observe that the first three rows of the table with low installation costs favor installing intermodal capabilities at the highest number of locations ranging from four to six warehouses. In the highest demand scenario, the need for intermodal facilities is the greatest to manage the extra flow. With medium intermodal installation costs, the number of locations follows the same trend: more installations occur with higher demand, and the model selects locations with higher capacity or lower costs compared to alternatives. For high intermodal installation costs, the model does not consider adding any intermodal capacity in the low-demand case. In this scenario, the model relies predominantly on trucks, with the least rail usage among all proposed systems. This is because the installation cost exceeding $1 million per facility does not justify the cost savings from shifting from truck to rail transportation in our inbound freight transportation system.

For the change in 10-year tonnage flow sent by truck, the current practice involves a total of 1,602,255,354 tons sent. This figure is the sum of 800,990,901, 140,172,300, and 661,092,153 tons, which represent all the connection links in the system that use trucks. Averaging the tonnage across all nine cases of the proposed system, the total tonnage sent by trucks in the proposed system is 1,537,857,444 tons. Although the difference between 1,602,255,354 tons and 1,537,857,444 tons is only 4.2%, this translates to a difference of 64,397,910 tons, or approximately 4,024,869 fewer trucks over a 10-year period.

Next, in **Table 5**, we calculated the ton-miles for trucks and rails over a 10-year analysis period. We observed that truck ton-miles are reduced by approximately 13% to 14%. Unsurprisingly, the scenario with high installation costs and low demand, which has the least freight shifted from trucks to rails, shows the smallest percentage reduction in truck ton-miles. For rail ton-miles, the usage increases by around 0.4% to 0.55%. The shift from trucks to rails results in a significant reduction in truck ton-miles compared to the rise in rail ton-miles due to the higher capacity of rail transport.

We also calculated the environmental impact costs, which include greenhouse gas emissions, criteria pollutants, and toxic releases as defined in the BCA study by the author (Rattanakunuprakarn et al., 2024). The cost in 2020 dollars per ton-mile is $0.3216 for trucks and $0.0145 for rails. By multiplying these costs with the ton-miles for each mode, we compared the environmental impact of the proposed system with the current system. The proposed system shows savings of around $19.3 million to $21.7 million.

The stochastic programming model shows varying effectiveness across different installation cost scenarios. For low installation costs, the Value of Stochastic Solution (VSS) is -$1,664,505 and the Expected Value of Perfect Information (EVPI) is -$965,403, indicating limited improvement over deterministic solutions. As installation costs rise, the VSS improves to -$450,935 and -$123,029 for medium and high costs, respectively, while the EVPI increases to -$1,206,874 and -$828,858. This trend suggests that the model performs better under higher installation costs, with increasing benefits from reduced uncertainty. Overall, the model effectively optimizes transportation costs under demand uncertainty, showing enhanced performance with higher costs.

TABLE 4 Computational Results of the Current and Proposed System with Sensitivity Analysis

Case	Objective of Stochastic ($)	Objective of Deterministic ($)	Installed Warehouse	Installation Cost ($)	Port to Rail Terminal/ WHS (tons)		WHS to Destination (tons)	
					By Trucks	By Rails	By Trucks	By Rails
Current	2.03461e+11	-	not allowed	-	800,990,901	1,013,507	140,172,300	656,816,415
Proposed System – low installation cost	2.02745e+11		[47, 125, 126, 148, 168, 171, 186]	1465612				
		low: 1.94963e+11	-	-	202,223,851	10,255,629	36,848,854	174,301,791
		avg: 1.97981e+11	-	-	223,510,860	10,255,629	40,540,513	191,764,012
		high: 2.15287e+11	[47, 83, 125, 126, 148, 168, 171, 184, 186, 210]	2,512,997	310,369,942	45,388,497	61,739,517	291,794,027
Proposed System – medium installation cost	2.02746e+11		[186]	830,343				
		low: 1.94963e+11	-	-	202,223,851	10,255,629	36,848,854	174,301,791
		avg: 1.97981e+11	-	-	223,510,860	10,255,629	40,540,513	191,764,012
		high: 2.1529e+11	[47, 125, 184, 186, 209]	3,298,128	312,233,295	43,525,143	61,760,584	291,772,960
Proposed System – high installation cost	2.02746e+11		[186]	1,158,249				
		low: 1.94963e+11	-	-	202,223,851	10,255,629	36,848,854	174,301,791
		avg: 1.97981e+1	-	-	223,510,860	10,255,629	40,540,513	191,764,012
		high: 2.15292e+11	[47, 186, 209]	3,842,823	312,971,782	42,786,657	61,765,372	291,768,172

TABLE 5 Environmental Impacts of the Current and Proposed System

Case	**Annual Ton-Miles**				**Emission cost ($)**		
	By Trucks	**Change (%)**	**By Rails**	**Change (%)**	**By Trucks**	**By Rails**	**Saving**
Current	8.78966E+09	0	2.54537E+11	0	2.82646E+08	3.68104E+09	0
PP low IIC	7.57545E+09	-13.9845	2.55823E+11	0.5489	2.43735E+08	3.69969E+09	1.93223e+7
PP med IIC	7.59882E+09	-13.5482	2.55824E+11	0.5057	2.43120E+08	3.70124E+09	1.96779e+7
PP high IIC	7.59882E+09	-13.5482	2.55824E+11	0.5057	2.43396E+08	3.69970E+09	1.96779e+7

*IIC: Intermodal Installation Cost

TABLE 6 Comparison between the Current and Proposed System

	Installation Cost ($)	**Total Cost ($)**	**Installation Cost ($)**	**Number of Installation**	**Total Annual Tons-Miles By Trucks**	**By Rails**
Current Practice		2.03461E+11	0	0	8.78966E+09	2.54537E+11
Proposed System	Low	2.02745E+11	1.46561E+06	7	7.57545E+09	2.55823E+11
	Medium	2.02746E+11	8.30343E+05	1	7.59882E+09	2.55824E+11
	High	2.02746E+11	1.15825E+06	1	7.59882E+09	2.55824E+11

Technical Transfer and Commercialization

Presentations & Publications

- A poster presentation at the first FERSC Annual Conference, College State, TX, April 26, 2024.
- An oral presentation titled "Stochastic Optimization of Intermodal Freight Transportation: A Case Study of the U.S. Southwest Supply Chain", Montreal, Canada, May 20, 2024.
- The paper was submitted to Transportation Research on August 1st, 2024.
- A Poster presentation at the Summit of Future Transportation, Washington, DC, August 13, 2024.

Community Engagement

- The research was introduced to Southwest Supply Chain Coalition.

Other relevant efforts

- none

Conclusions

In this project, we proposed an intermodal solution to alleviate the trucking volume out of the SPPC by extending the process of container sorting to inland warehouses located far from the SPPC, in contrast to the current operational practices. The network design and flow problem was modeled by a two-stage stochastic program to examine the proposed container inbound system, which

The computational findings demonstrate that our proposed system reduces the total transportation costs, the number of trucks out of the ports, and trucking ton-miles. The results demonstrate the cost-effectiveness of using rail transportation for shorter distances in the proposed solution, which may help to persuade railroads to work with the state governments to implement such a proposed intermodal solution. Moreover, we anticipate additional advantages of the proposed intermodal system, including the alleviation of traffic congestion in and around port areas and local neighborhoods, the mitigation of bottlenecks, the promotion of a more balanced distribution of transportation resources, the reduced environmental impacts, the reduced needs of truck drivers, and the enhancement of overall freight throughput efficiency in the inbound supply chain to the United States. These benefits warrant further investigation and exploration.

However, our proposed system faces challenges, such as the limited hinterland connections of rail due to the absence of intermodal capability at all logistics centers. Additionally, transitioning to this system requires a shift in shipping modes, as the current setup heavily relies on trucking. Furthermore, the proposed system redefines the role of distribution centers, shifting from primarily transferring cargo into domestic containers to facilitating transloading and providing value-added services, and assuming a greater role as an intermediary for rail access and sorting railcars. This transition necessitates increased cooperation from various stakeholders, including private entities such as warehouses and railroads, as well as public entities like port authorities and state departments of highways. A thorough examination of their goals and policies is required to encourage engagement, raise awareness, and facilitate alignment.

Recommendations

- Railroads may consider businesses connecting ports and logistic centers with distances shorter than $500 because our study shows that such a business could be economically feasible due to no classification effort and possible unit trains. Some infrastructure investment to improve railway network accessibility for existing logistic centers could be economically viable.
- The proposed intermodal network needs a public-private partnership among port authorities, state DOTs, state economic councils, railroads, and logistic companies.

Appendix

References

1. CSX. Intermodal 101, 2023. https://www.intermodal.com/index.cfm/resource-center/information-kits/intermodal-101-part-two-the-benefits-of-intermodal-rail-shipping/. Accessed March 11, 2024.

2. POLA. Facts and Figures, 2022. https://www.portoflosangeles.org/business/statistics/facts-and-figures. Accessed February 1, 2024.

3. Southern California Association of Governments, 2022. Goods Movement, access at https://scag.ca.gov/post/goods-movement on April 29, 2022.

4. Western Overseas Corporation. Weekly Vessels Anchored and at Terminals as of 1/21/2022, 2022. https://www.westernoverseas.com/port-congestion-update-1-21-22/. Accessed February 8, 2024.

5. McKenzie, L. Understanding Port Operations and Logistics, 2023. https://www.supplychainflow.com/port-operations-and-logistics/#mcetoc_1fe90qhhe1bq. Accessed February 2, 2024.

6. American Trucking Associations. Driver Shortage Update 2022, 2022. https://ata.msgfocus.com/files/amf_highroad_solution/project_2358/ATA_Driver_Shortage_Report_2022_Executive_Summary.October22.pdf. Accessed November 24, 2023.

7. LaRocco, L. A. West Coast Port Labor Issues Continue as Some Los Angeles, Long Beach Rail Shipments Get Temporarily Paused, 2023. https://www.cnbc.com/2023/06/06/west-coast-port-labor-issues-continue-as-some-los-angeles-bound-rail-shipments-get-paused. Html. Accessed February 7, 2024.

8. Ku, C.H. and Smith, M.J. 2010. Organisational factors and scheduling in locomotive engineers and conductors: Effects on fatigue, health and social well-being. Applied ergonomics, 41(1), 62-71.

9. U.S. Department of Transportation, Bureau of Transportation Statistics, 2022. Freight Facts and Figures, https://data.bts.gov/stories/s/Freight-Transportation-Energy-Use-Environmental-Im/f7sr-d4s8/.

10. Nevada Department of Transportation, 2021. Nevada State Rail Plan, https://www.dot.nv.gov/mobility/rail-planning/state-rail-plan.

11. Molnar, V., G. Fedorko, S. Honus, L. Girovska, and J. Lizbetin. Selection and Allocation of a Warehouse Linked to Reloading Terminal and Seaport. Naše more – Znanstveni časopis za more i pomorstvo, 2018. 65(4 Special issue):169–173.

12. Jula, P., and R. C. Leachman. A Supply-Chain Optimization Model of the Allocation Of Containerized Imports From Asia to the United States. Transportation Research Part E: Logistics and Transportation Review, 2011. 47(5):609–622

13. Chen, K., Q. Lu, X. Xin, Z. Yang, L. Zhu, and Q. Xu. Optimization of EmptyContainer Allocation for Inland Freight Stations Considering Stochastic Demand. Ocean & Coastal Management, 2022. 230:106366

14. Cao, P., Y. Zheng, K. F. Yuen, and Y. Ji. Inter-Terminal Transportation for an OffshorePort Integrating an Inland Container Depot. Transportation Research Part E: Logistics and Transportation Review, 2023. 178:103282

15. Rahimi, M., A. Asef-Vaziri, and R. Harrison. Integrating Inland Ports Into the Intermodal Goods Movement System for Ports of Los Angeles and Long Beach. Technical report METRANS 07-01, METRANS Transportation Center (Calif.), 2008.

16. Halim, R. A., J. H. Kwakkel, and L. A. Tavasszy. A strategic model of port-hinterland freight distribution networks. Transportation Research Part E: Logistics and Transportation Review, 2016. 95:368–384.

17. Osorio-Mora, A., F. Núñez-Cerda, G. Gatica, and R. Linfati. Multimodal Capacitated Hub Location Problems With Multi-Commodities: An Application in Freight Transport. Journal of Advanced Transportation, 2020. 2020:1–9.

18. Shang, X., K. Yang, B. Jia, and Z. Gao. The Stochastic Multi-Modal Hub Location Problem With Direct Link Strategy and Multiple Capacity Levels for Cargo Delivery Systems. Transportmetrica A: Transport Science, 2021. 17(4):380–410.

19. Sarmadi, K. Robust Optimisation of Dry Port Network Design in the Container Shipping Industry Under Uncertainty. PhD thesis, Newcastle University, 2021.

20. Zhang, H., K. Yang, Y. Gao, and L. Yang. Accelerating Benders Decomposition for Stochastic Incomplete Multimodal Hub Location Problem in Many-To-Many Transportation and Distribution Systems. International Journal of Production Economics, 2022. 248:108493.

21. Bureau of Transportation Statistics. Freight Analysis Framework, 2022. https://www.bts.gov/Faf. Accessed March 14, 2024.

22. Rattanakunuprakarn, S., M. Jin, M. Sussman, and P. Felix. Comparative evaluation of highways and railroads using life-cycle benefit-cost analysis. Under Review, International Journal of Sustainable Transportation, 2024.

23. Port of Long Beach. Port statistics - tonnage summary, 2024. https://polb.com/business/port-statistics/#tonnage-summary. Accessed Jan 13, 2024.

24. Biggar, K. Dwell Time 'Back to Normal' at San Pedro Ports, 2023. https://splash247.com/dwell-time-back-to-normal-at-san-pedro-ports/. Accessed Jan 16, 2024.

25. POLA. Port of Los Angeles Demurrage & Storage, 2023. https://kentico.portoflosangeles.org/getmedia/9f137578-ff74-41db-ad8e-4da62b3bf343/2024-pola-free-day-calendar. Accessed Jan 16, 2024.

26. Los Angeles Harbor Department. Demurrage Rates Chart, 2023. https://kentico.portoflosangeles.org/getmedia/eb8f0b6d-3dca-46b7-a191-59473e94d9f3/demurrage-rates-chart-2023. Accessed Jan 16, 2024.

27. RSI Logistics. Comparing the Costs of Rail Shipping vs Truck, 2024. https://www.rsilogistics.com/blog/comparing-the-costs-of-rail-shipping-vs-truck/. Accessed May 25, 2024

28. BNSF. Weekly Surface Transportation Board Update, 2024a. https://www.bnsf.com/news-media/customer-notifications/notification.page?notId=weekly-surface-transportation-board-update. Accessed Feb 20, 2024.

29. BNSF. Intermodal Rules and Policies Guide, 2024b. https://www.bnsf.com/ship-with-bnsf/support-services/demurrage-storage-and-extended-services.html. Accessed Feb 13, 2024.

30. Warehouse and Fulfillment. Warehousing Services Costs, Pricing, Rates and Fees, 2024. https://www.warehousingandfulfillment.com/resources/warehousing-services-costs-pricing-rates-and-fees/. Accessed March 8, 2024.

31. Surface Transportation Board. Annual report financial data 2020, 2022. https://www.stb.gov/reports-data/economic-data/annual-report-financial-data/. Accessed May 13, 2022.

32. Fayek, E. K. Vessel-to-Rail Intermodal Connectivity Analysis for the Port of Houston. Master's thesis, Texas Southern University, 2021.

33. American Journal of Transportation. Port Houston Finishes 2023 Strong Biggest December on Record for Loaded Exports, 2024. https://www.ajot.com/news/port-houston-finishes-2023-strong-biggest-december-on-record-for-loaded-exports#:~:text=Total%20tonnage%20at%20all%20of,in%202023%2C%20reaching%2050%2C323%2C264%20tons. Accessed Feb 22, 2022.

34. Port Houston. Port Statistics, 2024a. https://porthouston.com/about/our-port/statistics/. Accessed Feb 5, 2022.

35. Port Houston. Port Houston Finishes 2023 Strong Biggest December on Record for Loaded, 2024b. https://porthouston.com/wp-content/uploads/2024/02/Port-Houston-Finishes-2023-Strong.pdf. Accessed Feb 6, 2022.

36. Hu Y., and X. Zhang. Analysis of the Advantageous Railway Transportation Distance Compared with Truck-Only Transportation. Presented at 2020 4th International Conference on Informatization in Education, Management and Business (IEMB 2020), Suzhou, China, 2020.

37. Rodrigue, J. P. Transportation Modes. In The Geography of Transport Systems (6th ed.), Routledge, NY, 2024.