Assessing Feasibility of an Inland Container Terminal in the Pacific Northwest

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There has been a persistent challenge amongst small to mid-size agricultural shippers in the Pacific Northwest accessing available empty containers for outbound, export shipments. The challenges led to an earlier study with the USDA (Pacific Northwest Container Availability Study) which utilized a combination of historical manifest data and interviews with participants involved throughout the supply chain to investigate and illuminate those challenges to remedy or mitigate future container availability problems. This study follows upon the information and insights developed from that earlier study. While the full study results have yet to be published, the overall findings are synthesized here to provide context for a natural progression of research implementation.

There are many facets, participants and nuances to the container market, particularly in the Pacific Northwest, that contribute in different ways to containers being available for outbound exports. One major factor involves demand for inbound containers, primarily loaded with consumer durables, a significant proportion of which is loaded directly on rail and shipped to inland markets such as Chicago, IL. Unlike the ports of Los Angeles / Long Beach, CA with a nearby population exceeding 24 million residents, the population density around the Northwest Seaport Alliance (Ports of Seattle and Tacoma, WA) comprises about 13 million people, if you include all of Washington, Oregon and Idaho. Thus, in total, there is significantly less demand for import containers that stay in the local market as compared to those in Southern California. Inbound containers that end up in Chicago, IL involve increased repositioning costs in order to make them available for Pacific Northwest (PNW) agricultural export shippers.

Ocean shipping lines own the containers and are interested in maximizing profits and thus seek opportunities to increase equipment utilization, lower transportation costs and improve margins, all of which has led to consolidation of services, increased vessel sizes and reduced ports of call. Given that domestic demand for inbound freight has been significantly greater than export freight, ocean container lines must continue to reposition empties back to Asia. Opportunities exist for some of that empty container repositioning to be captured and utilized by high value agricultural exports in the PNW, but it involves significant participation and coordination by several parties. Primarily, it involves participation by the ocean shipping lines, Class I railroads (e.g. BNSF and UP) and the shippers.

The Class I railroads are interested in providing transportation services, including moving empty containers if it fits with their overall business model and doesn't compete with higher margin freight. Currently, the demand for their services is strong and thus their interest in creating new business opportunities may not be as strong as when overall rail freight demand is lagging. However, they are interested in is moving unit or shuttle trains, long distances and on a consistent basis. Coordination of equipment, labor and services is far more difficult and costly with peak demand during concentrated time windows and then long periods of low volumes.

The agricultural shippers in the Pacific Northwest are many and diverse. The largest of these companies which move large volumes of exports via containers rarely complain about difficulty obtaining containers. The ocean shipping lines provide these firms with excellent service, including repositioning empties for their use, because they represent a sizeable business to the shipping lines, but the PNW is comprised of many small to mid-size shippers across multiple commodities, including hay, potatoes, onions, apples, cherries, peas, lentils, garbanzo beans and more. Many of the firms have interest and currently strive to obtain containers for export moves, but because they are divided across many different commodities with different seasonal needs and each moving relatively small volumes, they don’t reach the threshold of volume
that makes the shipping lines respond by providing empties. However, collectively, they represent a very sizeable business.

There are also the PNW ports, or the Northwest Seaport Alliance, which oversees the ports of Tacoma and Seattle. These ports are currently involved in significant infrastructure investments aimed at being competitive as a deep-water west coast port, including larger cranes, channel deepening and port expansions to accommodate larger container vessels. This is all occurring on a relatively constrained geography, given the real estate market in the Puget Sound and the development of retail and residential properties surrounding the ports. It is also occurring at a time when highway congestion to and from the ports is becoming extremely costly for trucks seeking to access port terminals. Given the constrained geography, there simply isn’t available space on port property to accommodate containers coming off those largest vessels, or to facilitate repositioning empties on port property. This has led to the Northwest Seaport Alliance attempting to develop an inland port at Richland, WA, some 200 miles east of Seattle, WA. This has been attempted several times in the PNW, once at the Port of Quincy and at the Port of Moses Lake, WA. The concept is that container freight would concentrate at the inland port and be loaded on rail for export moves, instead of traveling by truck to port terminals and then inbound container freight could be moved to the inland terminal quickly by rail and away from the port. This would alleviate highway congestion in the Puget Sound/I-5 corridor and accommodate quick load/unload of the larger container vessels. The challenge has always been that the Class I rail line (in this case BNSF at Richland, WA) isn’t interested in setting a rate and offering service unless they have a relatively firm commitment of what the volume will be. The shippers are likewise reluctant to commit volumes without a rate and service agreement. On the east bound move, the Class I railroad is also not so interested in loading a unit train at the port and then stopping that train again only 200 miles east of the port. They would prefer to load the train and not stop until Chicago, IL. On the west bound move from the inland terminal, they would be interested in providing a shuttle service, but only if the volumes are large enough and consistent throughout the year.

The underlying issue is scale, or volume. With adequate and consistent volumes, the ocean container lines would provide adequate service/rates, as would the Class I railroads. This research effort seeks to address this by developing a model of container freight demand at an inland terminal in the PNW. This model would include all agricultural commodities currently seeking containers and provide critical information related to scale efficiencies. More directly, it would provide greater certainty to the ocean shipping lines and Class I rail regarding potential container volumes at different rates. But mostly it could be an avenue for agricultural shippers to improve export opportunities, as it would illustrate how a shared commitment on volumes across many different commodities would be beneficial to all shippers.

II. PROBLEM STATEMENT

Agriculture shippers in the Pacific Northwest strive to access export markets for their products. They depend upon access to containers and service to access these markets. Due to the diverse and varied nature of the many different commodities produced in the PNW, the shipping demands are likewise fragmented and seasonal and thus not large enough volume within any product or commodity type to warrant competitive rates and service from the shipping lines and Class I railroads. This is particularly true for an inland container terminal. Development of an optimization model that incorporates container volumes across all commodities would illuminate the tradeoffs associated with scale efficiencies and inform stakeholders of the opportunities from collective participation.
III. STUDY OBJECTIVES

The primary objective of this study is to develop an optimization model to evaluate site specific attributes and viability for inland container terminals.

The specific objectives of the study are to:

- Obtain detailed information related to volumes of containers moved by commodity type in order to develop container demand functions in the PNW.
- Develop an optimization model of container exports from the PNW, evaluating existing conditions with limited container availability / service and with trucks accessing the ports versus an inland terminal concept with improved service / rates and increased volumes.
- Evaluate the impact on shippers (transportation cost savings, increased market access) and impact upon public infrastructure (highway congestion, pavement impacts, energy consumption, emissions).
- Apply our model to various scenarios related to port developments and ocean carrier service schedules into the future.

IV. LITERATURE REVIEW OF CONTAINER TERMINAL MODELS

With the expanse of containerized exports, and container repositioning, inland container terminals have been extensively studied in freight transportation literature (Francesco et al., 2009; Chen et al., 2016; Choong et al., 2002; Clott et al., 2015). Container repositioning is a crucial element in freight shipping industry and closely linked to the inland container terminal concept as the inland terminals facilitate container repositioning by consolidating container shipping within a region and improving transport services and logistics of inland freight transport. The container repositioning problem has been studied together with the container inventory and storage problem, and intermodal transportation network.

Kuzmicz and Pesch (2017) provided a summary of studies on empty container repositioning. They define the empty container problem and identify pre-requisites and elements of empty container modeling. Trade imbalance is a major factor causing the need for empty container repositioning. With substantial outsourcing of manufacturing activities to Asia, and to China in particular, many ports globally face an imbalance of inbound and outbound container flow and thus, need to repositioning empty containers back to Asian export origination ports (Fransoo & Lee, 2013). In addition, repositioning costs, container manufacturing and leasing costs, and the shipping lines’ preferences to use containers as branding tools are additional causes of an empty container problem (Notteboom & Rodrigue, 2007).

Empty container repositioning requires efficient inventory management which involves choosing optimal location of warehouses, transportation mode and container allocation strategies (Jula, 2006; Francesco et al., 2009; Li et al., 2007). Furthermore, container repositioning often offers opportunities to meet secondary container demands, which are not met under regular pricing conditions. Chen et al. (2016) model optimal pricing strategy for containerized waste shipments under different market competition, which represents a secondary container demand not satisfied under regular pricing. Their model shows that catering to the surplus demand through repositioning can be profitable and sustainable under general conditions. Surplus empty containers in the Midwestern ports offer a similar context for the shipping lines and the PNW agricultural shippers. While Chen et al. (2016) assumed a linear demand function for the secondary
container market, we derive the demand for these surplus containers in the PNW region from the model solution.

Dry ports or inland container terminals are defined as inland freight terminals directly connected to one or more seaports with high capacity and often intermodal transport network, where customers can drop off and pick up their shipping equipment as if directly at a seaport (Crainic et al., 2014). Inland terminals make container repositioning easier and cost effective (Clott et al., 2015; Crainic et al., 2014). It also offers flexible shipping by offering a choice of transport modes and access to a larger port network. With increasing need to enable inland freight transport, inland terminals are becoming a widely studied concept. Lattila et al. (2013) provided a summary of the literature on inland container terminals.

Transport cost reduction is one of the major benefits of inland terminals. Estimating costs under an intermodal transport network and comparing them with that of a unimodal transport network is difficult. Kim and Van Wee (2011) use a break-even distance approach to determine choice of specific freight transport and identify the relative importance of the cost components. They argue that rather than geometric factors and terminal handling costs, relative cost of trucking and rail transport play a significant role in this decision. Access to rail transport via inland ports also reduces highway congestion (Bryan et al., 2007).

Another stream of literature investigates issues regarding location choice of an inland terminal. Rahimi et al. (2008) propose a model to choose terminal locations by minimizing daily vehicle-miles. With increasing number of inland terminals, vehicle-miles decrease resulting in reduced congestion and air pollution. Ka (2011) identifies factors influencing dry port location and presents a case study on finding optimal dry port location in China using a fuzzy analytical hierarchy process (AHP).

Feasibility analysis of an inland container terminal is context specific and relies heavily on the objective. There are many case studies assessing feasibility of inland ports (Dadvar et al., 2011; Idris et al., 2017). Cullinane and Wilmsmeier (2011) identifies main factors determining a successful implementation of inland terminals. They are transportation cost, location and distance of the site from the seaport, the demography of the area under study, competitiveness of the intermodal transport, overcoming traffic congestion, and overcoming and expansion of ports’ capacity limitations.

Given the central role of the shipping lines owning the containers in managing container inventory and choosing efficient intermodal freight transport system, most studies have investigated container repositioning and inland container terminals from the shipping lines’ perspective while assuming a given demand for containers and intermodal freight services. However, we aim to understand the demand for containers at inland terminals among the agricultural shippers in the PNW region. Therefore, we developed a model to evaluate the feasibility of an inland container terminal that determines the demand for containers at the inland terminal and allows assessing the outcomes to find the optimal proposed location.

V. METHODOLOGY / STUDY APPROACH

To illustrate the impacts of developing a multi-modal inland port, the research team constructs an optimization model of agricultural shippers in the PNW. It accounts for transportation services provided by the Class I railroads and ocean shipping liners and incorporates the issues in empty container availability and relevant logistics.
Before proceeding to the mathematical formulation, Figure 1 is presented first for better understanding the modelling framework. The solid lines show the loaded container movement and the dashed lines show the empty container movement, while the arrows show the direction of the movement. It also indicates the mode of transportation available/used: O for ocean vessel, R for rail, and T for truck.

In general, there are two scenarios in the framework. The only difference in them is whether an inland port is involved in the outbound container movement. In both cases, loaded inbound containers shipped from foreign markets arrive at the Seattle/Tacoma seaport. A portion of them are immediately emptied at the seaport while the rest are shipped to the Midwest (e.g., Chicago) by rail and emptied there. Agricultural shippers in the PNW can only get empty containers in the PNW from shipping lines, carry them to agricultural distribution centers, load export commodities into empty containers, and send the loaded outbound containers back to the Seattle/Tacoma seaport, all by truck. From the seaport, the loaded outbound containers are then shipped to foreign destinations by ocean vessel. Meanwhile, the empty containers in the Midwest are directly shipped back to foreign destinations via the Seattle/Tacoma seaport. This scenario, without any involvement of an inland port, is considered as the baseline that reflects the current circumstance.

In contrast, if an inland port exists in the PNW, the Class I rail can send available empty containers in the Midwest to the inland port. Therefore, local agricultural shippers can obtain additional empty containers from the inland port by truck. Moreover, once those empty containers are loaded in agricultural distribution centers, agricultural shippers can also send the loaded outbound containers to
the Seattle/Tacoma seaport via the inland port. The main question is whether and how much the proposed inland port improves container availability and container transport services in the PNW.

To answer the question, the rest of this section shows a formal optimization model illustrating shipping cost minimization problem of the PNW agricultural shippers under certain constraints on mode choice, container availability and a proposed inland container terminal. The following table summarizes all variables, parameters, subscripts and superscripts.

Table 1: Model notations

<table>
<thead>
<tr>
<th>Subscripts and Superscripts</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>Agricultural commodity or agricultural shipper</td>
</tr>
<tr>
<td>$i$</td>
<td>Agricultural shippers’ distribution center</td>
</tr>
<tr>
<td>$j$</td>
<td>Intermediate container terminal: inland port ($l$) or Seattle/Tacoma Seaport ($s$)</td>
</tr>
<tr>
<td>$c$</td>
<td>Container type</td>
</tr>
<tr>
<td>$p$</td>
<td>Domestic origination of empty containers: Seattle/Tacoma Seaport ($s$) or Midwestern rail facilities ($q$)</td>
</tr>
<tr>
<td>$k$</td>
<td>Foreign destination</td>
</tr>
<tr>
<td>$E$</td>
<td>Empty container</td>
</tr>
<tr>
<td>$L$</td>
<td>Loaded container</td>
</tr>
<tr>
<td>$t$</td>
<td>Truck as mode of transport</td>
</tr>
<tr>
<td>$r$</td>
<td>Rail as mode of transport</td>
</tr>
<tr>
<td>$o$</td>
<td>Ocean vessel as mode of transport or ocean shipping liners</td>
</tr>
<tr>
<td>$v$</td>
<td>Ocean vessel type</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{ij}^{Et}$</td>
<td>Empty container truck rate from $j$ to $i$ ($$ per container$)</td>
</tr>
<tr>
<td>$T_{ij}^{Er}$</td>
<td>Empty container rail rate from $q$ to $l$ ($$ per container$)</td>
</tr>
<tr>
<td>$T_{qs}^{Er}$</td>
<td>Empty container rail rate from $q$ to $s$ ($$ per container$)</td>
</tr>
<tr>
<td>$T_{ij}^{Lt}$</td>
<td>Loaded container truck rate from $i$ to $j$ ($$ per container$)</td>
</tr>
<tr>
<td>$T_{ls}^{Lr}$</td>
<td>Loaded container rail rate from $l$ to $s$ ($$ per container$)</td>
</tr>
<tr>
<td>$T_{c}^{Lo}$</td>
<td>Loaded container ocean rate by container type ($$ per container$)</td>
</tr>
<tr>
<td>$p_{ac}$</td>
<td>Penalty cost of delay ($$ per container$)</td>
</tr>
<tr>
<td>$\sigma_{is}^{C}$</td>
<td>Percentage of delayed containers on truck route from $i$ to $s$</td>
</tr>
</tbody>
</table>
\( \sigma_{il} \) Percentage of delayed containers on truck route from \( i \) to \( l \)

\( \sigma_{ls} \) Percentage of delayed containers on rail route from \( l \) to \( s \)

\( Y_{ai} \) Total production of commodity at \( i \) (ton)

\( w_c^l \) One-unit loaded container’s weight by container type (ton per container)

\( w_c^e \) One-unit empty container’s weight by container type (ton)

\( D_{ak} \) Total commodity demand in foreign market \( k \)

\( cont_{cp} \) Empty container availability at \( p \) by container type

\( TEU_c \) One-unit container’s TEU by container type (TEU)

\( cap_j \) Container handling capacity at \( j \) (TEU)

\( \rho \) Percentage of empty space in any vessel

\( n_{vk} \) Number of vessel type \( v \) to foreign market \( k \)

\( Z_{vk} \) Carrying capacity of vessel type \( v \) to foreign market \( k \) (TEU)

\( W_{vk} \) Carrying capacity of vessel type \( v \) to foreign market \( k \) (ton)

\( n_{iql} \) Number of trains from \( q \) to \( l \)

\( n_{isl} \) Number of trains from \( l \) to \( s \)

\( cap_{iq} \) Carrying capacity of any train serving between \( q \) to \( l \) (TEU)

\( cap_{ls} \) Carrying capacity of any train serving between \( l \) to \( s \) (TEU)

<table>
<thead>
<tr>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>( TC^a ) Total cost of transportation and delay for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{aEt} ) Truck transportation cost of moving empty containers for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{aEr} ) Rail transportation cost of moving empty containers for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{aLt} ) Truck transportation cost of moving loaded outbound containers for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{aLr} ) Rail transportation cost of moving loaded outbound containers for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{Lo} ) Ocean transportation cost of moving loaded outbound containers for agricultural shipper</td>
</tr>
<tr>
<td>( DC^a ) Delay cost due to congestion for agricultural shipper</td>
</tr>
<tr>
<td>( TC^{oEt} ) Rail transportation cost of moving empty containers for shipping liners</td>
</tr>
<tr>
<td>( X_{aijcp}^E ) Number of empty containers moving from ( p ) to ( i ) via ( j )</td>
</tr>
<tr>
<td>( X_{aijck}^L ) Number of loaded outbound containers moving from ( i ) to ( k ) via ( j )</td>
</tr>
</tbody>
</table>
The total cost consists of seven components and are modeled by the following equations:

1. Truck transportation cost of moving empty containers to agricultural shipper’s distribution:

\[ TC^{aE} = \sum_i \sum_j \sum_c \sum_p T_{ij}^{Et} \cdot X_{aijcp} \]  

(1)

It includes the truck movement of obtaining empty containers to agricultural shipper’s distribution center \( i \), from both the Seattle/Tacoma seaport \( s \) (corresponding to (I) in Figure 1) and Midwest \( q \) via inland port \( l \) (corresponding to the truck part of (III) in Figure 1). Particularly, \( X_{aiqc} \) indicates the truck movement of empty containers from the Seattle/Tacoma seaport \( s \) to agricultural shipper’s distribution center \( i \) directly. Notice that there are two scenarios in our model are not allowed. First, based on our knowledge, the Class I rail will not offer an inbound shuttle service from the Seattle/Tacoma seaport \( s \) to inland port \( l \). As a result, there is no empty container movement through inland port \( l \) that originates from Seattle/Tacoma, i.e. \( X_{aiqc} = 0 \). Second, any empty container moved from the Midwest \( q \) to the Seattle/Tacoma seaport \( s \) is directly loaded on vessels to a foreign country. Therefore, any empty container moved to Seattle/Tacoma from the Midwest is not accessible to the PNW shippers anymore, i.e. \( X_{aiqc} = 0 \). The empty container truck rate, represented by \( T_{ij}^{Et} \), is defined as a function of weight and distance and involves a round trip. Thus, \( T_{ij}^{Et} = m_{cij}^{Et} \cdot w_c^{Et} \cdot 2 \cdot d_{ij} \), where \( m_{cij}^{Et} \) is the marginal ton-mile trucking rate of empty containers and \( d_{ij} \) denotes the distance between \( i \) and \( j \).

2. Rail transportation cost of moving empty containers to agricultural shipper’s distribution center:

\[ TC^{aEr} = \sum_i \sum_c \sum_q T_{iq}^{Er} \cdot X_{aiqc} \]  

(2)

It is related to the rail movement of obtaining empty containers from the Midwest \( q \) to inland port \( l \) (corresponding to the rail part of (III) in Figure 1). The empty containers arriving at the inland port are to be further trucked to agricultural shipper’s distribution center \( i \), which is included in equation (I). The empty container rail rate for moving a container from the Midwest to the inland port is defined as: \( T_{iq}^{Er} = m_{cqi}^{Er} \cdot w_c^{Er} \cdot d_{qi} + \pi \), where \( m_{cqi}^{Er} \) is the ton-mile rail cost of empty containers, \( \pi \) is the profit margin and \( d_{qi} \) denotes the distance between \( q \) and \( l \).

3. Truck transportation cost of moving loaded outbound containers to the Seattle/Tacoma seaport:

\[ TC^{al} = \sum_i \sum_j \sum_c \sum_k T_{ij}^{Lt} \cdot X_{aijck} \]  

(3)

It includes the movement of trucking loaded outbound containers from agricultural shipper’s distribution center \( i \) directly to the Seattle/Tacoma seaport \( s \) (corresponding to (I) in Figure 1) and to inland port \( l \) (corresponding to the truck part of (II) in Figure 1). The latter requires a rail service to reach the Seattle/Tacoma seaport \( s \), which is contained in Equation (4). \( T_{ij}^{Lt} = m_{cij}^{Lt} \cdot w_c^{Lt} \cdot 2 \cdot d_{ij} \), where \( m_{cij}^{Lt} \) is the marginal ton-mile trucking rate of loaded containers and \( d_{ij} \) denotes the distance between \( i \) and \( j \).
4. Rail transportation cost of moving loaded outbound containers to the Seattle/Tacoma seaport:

\[ TC^{alr} = \sum_i \sum_c \sum_k T^r_{ls} \cdot \left(1 - \sigma^r_{is}\right) \cdot X^L_{aitck} \quad (4) \]

It is related to the rail movement of sending loaded outbound containers from the inland port \(l\) to the Seattle/Tacoma seaport \(s\) (corresponding to the rail part of (II) in Figure 1). The containers are trucked to the inland port, as shown in Equation (3). Due to road congestion, a portion of containers \(\sigma^r_{is}\) fail to arrive at the inland port on time and therefore miss the scheduled train. As a result, only the rest of containers \((1 - \sigma^r_{is}) \cdot X^L_{aitck}\) are shipped by rail. Notice that the delay parameter \(\sigma\) in the model refers to the proportion of containers failing to reach a destination on a given route, but it could be for a variety of reasons including road congestion, scheduling issues, labor strikes etc. 

\[ T^r_{ls} = m c_L^r \cdot w_c^r \cdot d_{ls} + \pi, \]

where \(m c_L^r\) is ton-mile rail cost for loaded containers, \(\pi\) is the profit margin and \(d_{ls}\) denotes the distance between \(l\) and \(s\).

5. Ocean transportation cost of moving loaded outbound containers to foreign destinations:

\[ TC^{alo} = \sum_i \sum_c \sum_k T^o_{ci} \cdot \left((1 - \sigma^o_{is}) \cdot X^L_{aisck} + (1 - \sigma^o_{is})(1 - \sigma^r_{is}) \cdot X^L_{aitck}\right) \quad (5) \]

It involves the ocean vessel movement of loaded outbound containers from the Seattle/Tacoma seaport \(s\) to foreign destination \(k\) (corresponding to (IV) in Figure 1). The containers arrive at the seaport either by truck only or by a combination of truck and rail. If by truck only, due to road congestion, only a portion of containers \((1 - \sigma^o_{is})\) can reach the seaport and thus catch the scheduled vessel on time. If sent by a combination of truck and rail, the number of on-time containers is \((1 - \sigma^o_{is})(1 - \sigma^r_{is}) \cdot X^L_{aitck}\).

6. Delay cost in transporting commodity from agricultural shipper’s distribution center to the Seattle-Tacoma seaport by truck only or by a combination of truck and rail:

\[ DC^a = \sum_i \sum_c \sum_k P^a_{ac} \cdot (\sigma^o_{is} \cdot X^L_{aisck} + (\sigma^o_{is} + (1 - \sigma^o_{is}) \sigma^r_{is}) \cdot X^L_{aitck}) \quad (6) \]

It reflects the issue of congestion and is discussed in the last component. When the promised amount of a commodity fails to reach foreign importers, agricultural shippers suffer a penalty on the delayed amount. The delayed amount is equal to \((\sigma^o_{is} \cdot X^L_{aisck} + (\sigma^o_{is} + (1 - \sigma^o_{is}) \sigma^r_{is}) \cdot X^L_{aitck})\).

7. Rail transportation cost of moving empty containers from the Midwest to the Seattle-Tacoma seaport:

\[ TC^{aoEr} = \sum_i \sum_c \sum_q T^r_{qs} \cdot X^E_{aitcq} \quad (7) \]

It is associated with the rail movement of available Midwestern empty containers from the Midwest \(q\) to the Seattle-Tacoma seaport \(s\) (corresponding to (V) in Figure 1). In this situation, these empty containers are directly shipped to foreign countries from the seaport and therefore unavailable to the PNW. It should be noted that this cost is taken by ocean shipping lines.
All rail freight transport in the model includes repositioning containers from the Midwest to the inland hub and that repositioning cost is paid by the shipping liners owning the containers. Therefore, we define: repositioning cost = equation (2) + equation (4) - equation (7), where equation (2) and (4) are costs incurred due to repositioning while equation (7) denotes the cost saving from redirecting the containers to the inland hub. We assume that shipping liners make zero profit from the repositioning and charge a premium over the regular ocean shipping rates equal to the repositioning cost. Thus, we include them in the agricultural shipper’s cost function, or in other words in the $T^0_T$ term of equation (5).

By combining the seven cost components above, the objective function of each agricultural shipper is specified as following:

$$
\min_{X^E_{aijcp},X^L_{aijck}} \quad TC^a = TC^{aEt} + TC^{aEr} + TC^{aLt} + TC^{aLr} + TC^{aLo} + DC^a - TC^{aEr}
$$

It essentially adds Equation (1) through (6) and subtracts Equation (7).

Each agricultural shipper’s decision is constrained by:

1. Commodity supply constraint at origin:

$$
Y_{ai} \geq \sum_j \sum_c \sum_k (w^L_c - w^E_c) \cdot X^L_{aijck}
$$

2. Commodity demand constraint at destination:

$$
D_{ak} = \sum_i \sum_c (w^L_c - w^E_c)((1 - \sigma^L_{il}) \cdot X^L_{aitck} + (1 - \sigma^L_{il})(1 - \sigma^E_{il}) \sum_j X^E_{aitck})
$$

3. Empty container availability at each port by container type:

$$
\sum_a \sum_i \sum_j X^E_{aijcp} \leq cont_{cp}
$$

4. Loaded and empty container balance at origin:

$$
\sum_k X^L_{aijck} = \sum_p X^E_{aijcp}
$$

5. Loaded container handling capacity at each intermediate port:

$$
\sum_a \sum_i \sum_c \sum_k (1 - \sigma^L_{il}) \cdot TEU_c \cdot X^L_{aitck} \leq cap_i/2
$$

6. Loaded container handling capacity at Seattle/Tacoma ports:

$$
\sum_a \sum_i \sum_c \sum_k (1 - \sigma^L_{is}) \cdot TEU_c \cdot X^L_{aisck} + (1 - \sigma^L_{is})(1 - \sigma^E_{is}) \cdot TEU_c \cdot \sum_j X^E_{aitck}) \leq cap_s/2
$$

7. Empty container handling capacity at each intermediate ports and Seattle/Tacoma ports:

$$
\sum_a \sum_i \sum_c \sum_p TEU_c \cdot X^E_{aijcp} \leq cap_j/2
$$
8. Total vessel capacity available for outbound flow, limits the number of loaded containers that can be shipped:

$$\sum_{a} \sum_{l} \sum_{c} \left( (1 - \sigma_{is}^{t}) \cdot TEU \cdot X_{alck}^{L} + (1 - \sigma_{is}^{r}) \cdot TEU \cdot \sum_{i} X_{alck}^{L} \right) \leq \sum_{v} \rho \cdot n_{vk} \cdot Z_{vk} \quad (15)$$

9. Total deadweight tonnage (DWT) of the vessel, limits the number of loaded containers that can be shipped:

$$\sum_{a} \sum_{l} \sum_{c} \left( (1 - \sigma_{is}^{t}) \cdot TEU \cdot X_{alck}^{L} + (1 - \sigma_{is}^{r}) \cdot TEU \cdot \sum_{i} X_{alck}^{L} \right) \leq \sum_{v} \rho \cdot n_{vk} \cdot W_{vk} \quad (16)$$

10. Empty container repositioning services are bounded by railroad capacity for empty containers in each intermediate facility:

$$\sum_{a} \sum_{l} \sum_{c} TEU \cdot X_{alck}^{E} \leq n_{lq} \cdot cap_{lq} \quad (17)$$

11. Loaded container transport services are bounded by railroad capacity for loaded containers in each intermediate facility:

$$\sum_{a} \sum_{l} \sum_{c} \sum_{k} TEU \cdot X_{alck}^{L} \leq n_{ls} \cdot cap_{ls} \quad (18)$$

Overall, the model describes that each agricultural shipper decides the flow of each container movement to minimize the total cost related to transportation and delay while accounting for various capacity, shipping, and production constraints. By solving this system, the optimal shipping volume of each movement is used to compare the baseline scenario with the inland port scenario. The demand functions for rail transportation services can be further derived. In addition, the optimal inland port location can be investigated through a spatial analysis. The next section shows the details on data used to solve the model.

VI. DATA DESCRIPTION

Study Area

Our study concerns five agricultural commodity shippers across three states in the PNW region: Washington (WA), Idaho (ID) and Oregon (OR). The commodities are apples, cherries, potatoes, hay, and grains. All these commodities except grains are almost always exported using containers (Figure 2). Although only 2% of all grain exports considered in this study use containers, they are still a considerable volume.

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1 Grains commonly contain a wide range of crops. In our study we consider wheat, barley and garbanzo beans only.
The shares of containerized exports of the five commodities considered in the study are shown in Figure 3. As the figure shows, hay exports dominate the containerized agricultural commodity exports in the PNW.

Three USDA proposed locations have been assessed for feasibility as an inland container terminal. They are Spokane, WA; Richland, WA; and Millersburg, OR.
Containers

There are many types of containers. Given the commodities considered here, we limit our analysis to four types of containers: 20-foot dry, 20-foot reefer, 40-foot dry, and 40-foot reefer. In twenty-foot-equivalent unit (TEU) measure, one 20-foot container is one TEU and one 40-foot container is two TEUs. Given the commodity characteristics, we further constrain grain shippers to only use dry containers and hay shippers to only use 40-foot dry containers while reefer containers are for apple, cherry, and potato. We use historical container availability reported by the USDA’s Ocean Shipping Container Availability Report (OSCAR) from 2012 to 2017 to estimate average container availability per month at different Midwestern and Seattle/Tacoma ports. Then using the BNSF website, we identify seven intermodal facilities near those ports: four in Chicago, IL and one each in Denver, CO, Minneapolis, MN, and Kansas City, MO and select them as the origin of container repositioning from the Midwest.

Production and Exports

For each commodity, we collect the list of producers and exporters from their regional/state commissions and use commission directory and individual firm’s website to collect the location for distribution centers. The USDA NASS database provides annual production at the state/county level. We equally divide annual production into 12 months and assign an equal share of the state production to each distribution center located within the state.

As the main trade destinations for the selected commodities, we select five foreign destinations: China, Hong Kong, Japan, South Korea, and Taiwan. Commodity exports by each state is used to proxy export demand at foreign countries. The monthly export data by commodity by foreign destination is collected from the USA Trade Online reported by the U.S. Census Bureau.

Truck Shipping Parameters

As a part of total transportation cost, trucking cost plays a vital role in determining agricultural shipper’s optimal choice. We obtain trucking rate data from the BioSAT trucking cost model adapted from Berwick and Farooq (2003). Depending on the origin and destination pairs (O-D pairs) and loading status, we collect data on total cost of trucking on a given route and estimate per container and per ton-mile marginal costs. An empty container weighs between 2.3 and 4.4 tons, and the highway weight limit is 22 tons for total payload. With these values, we can also divide the rates by payload and distance to obtain the ton-mile rate for further analysis.

The model accounts for road congestion that results in a portion of loaded outbound containers delayed by truck. Although such data is unavailable, it is reasonable to adopt a higher delay rate on the way to Seattle/Tacoma ports than that to the proposed inland port. In practice, we set the former at 5% and latter at 2%. As agricultural commodities are perishable, we assume that there is a 20% price drop for those delayed goods.

Rail Shipping Parameters

The rail rate data is obtained from the Uniform Rail Costing System (URCS). A typical intermodal rail shuttle can haul more than 400 TEUs. Assuming a rail car can carry four TEUs, we conservatively choose 100 cars as a train’s carrying capacity. For each car, we set a weight of 66 tons while carrying loaded containers and 10 tons while carrying empties. With these parameters, we collect total cost of a rail shipment between two locations and estimate the marginal cost per ton-mile. The model also accounts
for rail congestion that results in a portion of loaded outbound containers delayed by rail. Given that this is less likely than that by truck, we set 1% delay rate on the route to Seattle/Tacoma ports from the inland hubs.

A rail service is limited by capacities of various rail facilities. The frequency data of rail service between the Midwest and a proposed inland port are unavailable. We assume only one rail shuttle per origin per month. Consequently, there are seven trains between the Midwest and a proposed inland port and seven trains between the inland port and seaport. Based on a BNSF report, we estimate that intermodal rail facilities handle about 12,000 TEUs per month on average. This number is used for the handling capacity of the proposed inland terminals. Like rail schedule data, data for rail rates are also unavailable. We assume that Class I rail bids a price markup above their marginal cost. Thus, we use a range of profit margin in our analysis.

**Ocean Shipping Parameters**

Using the vessel schedule for Seattle/Tacoma ports, we collect information regarding ocean vessels typically moving through these ports. We classify them into three categories: low-capacity (below 7,000 TEU), medium-capacity (7,000-9,000 TEU), and high-capacity (9,000-11,000 TEU) vessels. The capacity of the vessels is set by the upper-bound value of each group. That is, the low-capacity vessel can carry 7,000-TEU containers with 78,716 DWT; the medium-capacity vessel can carry 9,000-TEU containers with 114,175 DWT; the high-capacity vessel can carry 11,000-TEU containers with 131,097 DWT. From the rotation schedule of the Northwest Seaport Alliance, we calculate each vessel type's frequency by foreign destination. It varies from 1 to 4 each month. A vessel usually arrives at a seaport with only a portion of empty space for loading. Such data is unavailable for the Seattle-Tacoma seaport. In our analysis, we use 50% empty vessel space on arrival at Seattle/Tacoma. We also try different values for a sensitivity test.

The ocean shipping rates are obtained from the World Freight Rates website by commodity, destination, and container type. The ocean freight rates are very similar across destinations as suggested by Jones et al. (2011). Thus, we average across destinations. Depending on container type, the rate varies from $470 to $1,192 per container. Jones et al. (2011) also provides the total capacity of the Seattle-Tacoma seaport at 160,300 TEUs per week, which we convert into a monthly capacity estimate.

A list of parameters and their sources are provided in the appendix. In the following section, we describe our approach for solving the model and present the results.

**VII. RESULTS**

We solve the model described above using relaxed mixed integer programming (RMIP) method in GAMS. Due to a lack of data on individual firm's production and export, we optimize the model for all commodities at the aggregate level and observe the shipment flow through different routes (via highway vs an inland terminal). We consider four different scenarios: a baseline that reflects the current container movement in the PNW and three alternative scenarios involving each of the proposed locations of inland container terminals in place. To capture seasonal variation in containerized shipping, we solve the model
on a monthly basis. Furthermore, we solve the model over a range of rail rates\(^2\) representing different levels of profit and present the findings below for three rail rates. Low, medium, and high denoting zero profit, 50% and 100% markup over the marginal cost, respectively. Table 2 summarizes rail rates per container from each inland terminal to Seattle/Tacoma ports.

<table>
<thead>
<tr>
<th>Rail rate</th>
<th>Millersburg</th>
<th>Richland</th>
<th>Spokane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (zero profit)</td>
<td>397</td>
<td>311</td>
<td>196</td>
</tr>
<tr>
<td>Medium (50% profit)</td>
<td>577</td>
<td>452</td>
<td>296</td>
</tr>
<tr>
<td>High (100% profit)</td>
<td>758</td>
<td>594</td>
<td>396</td>
</tr>
</tbody>
</table>

There are several determinants of the feasibility of an inland container terminal in the PNW. Changes in container traffic and transportation costs due to an inland container terminal and the geographic population that the terminal services are among the few factors that need to be considered while evaluating the viability of an inland terminal and the optimal location for it. Sustainability under changing demand conditions is also an important factor. In the following sections, we assess the feasibility of an inland container terminal in the PNW by evaluating three aspects: 1) container demand at the inland terminal, 2) changes in inland freight transportation cost, and 3) changes in composition of container traffic via road and rail. We also evaluate the long-term viability using changing export demand conditions. Finally, we present a sensitivity analysis of our findings to model parameters used.

CONTAINER DEMAND AT THE INLAND TERMINAL

In solving the model, we hold the total export demand in the PNW region fixed. Thus, the total number of containers being shipped from the Seattle/Tacoma ports are the same across scenarios. At the baseline and all subsequent scenarios, the total number of containers shipped is about 32,400 annually\(^3\). The following figure shows the annual number of containers handled by inland terminals in different scenarios with an inland terminal in place. As shown in Figure 4, Richland site handles the most containers with the Spokane site being a close second at all price levels. Containers handled at Millersburg site is about four times lower than that of the Richland site.

---

\(^2\) The rail rates are changed for the short hauls only, i.e., the rates between the proposed hubs and Sea-Tac port. This is because these short hauls are uncommon and costly for the rail to operate. One objective of the study is to find the rail rate function for these short hauls. Moreover, the determinants of rail profit in the long hauls (regular rail traffic) might be more complex and are outside the scope of this study.  

\(^3\) In the results section, we reported yearly estimates unless specified otherwise.
Figure 4: Container shipping at each inland terminal at different rail rates

Figure 5 shows the percentage of total shipped containers being handled by each site. The Richland site handles between 52%-59% of all containers modeled. The Spokane site handled between 44%-48% and the Millersburg site handles between 13%-15% of all containers shipped at different price levels. This implies that a large number of containers are diverted from the highway and transported via rail when the Richland or Spokane site is used. This shift in mode choice is further discussed later.
The following figure shows annual container freight demand via rail at three proposed locations. As noted earlier, rail rates are defined with a profit margin above the marginal cost while the marginal costs are functions of distance between O-D pairs. As a result, actual rail rates charged at different locations vary. The demand functions here are derived providing rail rates for profit margins ranging from 0% to 150% above the marginal cost for the trip between the inland terminals and Seattle/Tacoma ports. The estimated demand functions shown in Figure 6 can be interpreted as rail rate functions with the lowest rate in the demand curve being the breakeven rate. As the figure shows, for a rail rate between $200 and $300 per container, Spokane is the only viable option due to its proximity to Seattle/Tacoma ports. For a per container rate above $300, both Spokane and Richland sites are operationally viable, while with a rail rate above $400, either of the three locations are viable options. However, it is evident that Richland site draws the most container traffic, while Spokane is a close second. Container traffic at the Millersburg site is significantly lower than the other locations. Moreover, a comparison of the demand curves shows that demand for containers are relatively more elastic at Spokane and Richland sites compared to that of Millersburg site as suggested by Figure 5 above as well.
Seasonality

A major concern in utilizing the proposed inland terminal is the seasonality of agricultural exports. Both shipping liners and Class I rail prefer to have continuous flow of large volumes to move. As Figures 7, 8, and 9 suggest, Millersburg site handles only about 400 containers each month when a low rail rate is offered. With increased rates, the volume decreases even further. However, there is no evidence of seasonal variation for the Millersburg site.
At the Richland and Spokane sites, there is seasonal variation in container shipping (Figure 8 and 9). At the Richland site, container shipping is the highest in the months of May and September to November, while it is the lowest in April and June. Container movement at Spokane site shows a similar pattern. Also, we find that seasonal variation is unaffected by rail rates.
The following two figures show the percentage change in container handling at the Richland and Spokane sites for medium and high rail rates compared to low rail rates. These figures reveal that with rail rates per container being the lowest at the Spokane site, demand at this site is less responsive to rate increases than other sites. For an increase to the medium rate, containers handled differs only slightly for Spokane. This holds true for the peak months of May, September, October, and November. For these same months, similar decreases also occur at Richland for the medium rate. More importantly the decrease in containers remains minimal (below five percent) during all off-season months except July in Spokane, where it is just above 10%, and for June and July in Richland when the decreases are around 7% and 5% respectively. Furthermore, when increased to the high rate, decreasing container handling remains below 5% in seven out of twelve months for Spokane. On the contrary, at the Richland site, there is very large decrease (above 10%) in nine out of the twelve months for the high rates. The results of figures 10 and 11 corroborate inelasticity of the lower portion of the demand functions, for both Spokane and Richland, presented in Figure 6.
TRANSPORTATION COST

Cost is an important factor in evaluating the feasibility of the inland terminal. A comparison between different scenarios reveals that total cost is the lowest at the Richland site with other alternatives also having lower costs than the baseline (Figure 12). Both the Richland and the Spokane sites perform well in lowering the total cost. Richland performs better than Spokane site under low or medium rates while the Spokane site performs better at high rail rates. The costs at Millersburg site are very close to the base...
scenario implying that this site does not perform well in reducing transportation costs. Total transportation costs per container, as shown in Figure 13, show a similar pattern.
Since inland container terminals change the composition of inland freight transportation based on whether a container was transported using the inland terminal or directly sent to Seattle/Tacoma ports, we present per unit analysis by route choice in Figure 14. The figure reveals two interesting features distinguishing the sites in terms of the geographic population each site services.

![Inland Transportation Cost](image)

**Figure 14: Inland transport cost per container**

First, per unit inland transport cost at the baseline is $1,532 per container, which by construction consists only of direct shipping to Seattle/Tacoma ports. Cost per containers directly sent to the ports when an inland terminal is in place differs between the Richland and Spokane sites, and Millersburg site. In the Richland and Spokane scenarios, inland freight cost per container goes down significantly (about $800 compared to $1,532 at the baseline) for containers being directly sent to the ports. It implies that the shippers, who are still using the baseline option of directly sending the containers to the ports, are located closer to the ports than the broader geographic population and require shorter trucking trips. Given the objective of reducing highway congestion near the Seattle/Tacoma ports, results imply that the inland terminals will be effective at producing this outcome. On the contrary, at Millersburg site, the trucking cost of such containers are similar to the baseline or higher. This implies that the Millersburg site is attracting shippers with shorter trucking distances while the shippers located farther from the ports and requiring long trucking hauls are still using highway to transport containers. Although it seems contrary to the purpose of an inland terminal, spatial analysis reveals that this site generally services the shippers using I-5 to access the ports at the baseline and thus might partially meet the objective by reducing congestion on I-5 (discussed further in the next section).

Second, the shippers choose to use the inland terminal if it incurs them lower cost than directly transporting the containers to the ports by construction of the model. Notwithstanding, per unit cost of container transported via Richland or Spokane site are higher than the baseline per unit cost, which implies that these sites are serving the shippers located far from the ports and require long truck hauls such that their per unit cost would have been even higher for direct transport. Thus, these sites perform
well in terms of costs by reducing inland transport costs for a large number of distant agricultural shippers. On the contrary, per unit cost at Millersburg site is significantly lower than the baseline cost reinforcing our conclusion earlier that this site services shippers located closer.

Notice that the per unit costs for the containers handled at the inland terminals include the repositioning cost of empty containers from the Midwestern ports and transporting the loaded containers from the terminals to the ports via rail along with trucking costs of empty and loaded containers to and from the shippers’ distribution centers. All these cost components minus the trucking cost is defined as the repositioning cost in the model. Per unit repositioning cost at the different sites with different rail rates are presented in Figure 15. Similar to rail rate per container (Table 2), repositioning cost per container is the lowest at Spokane and the highest at Millersburg.

Interestingly, even with the lowest per unit repositioning cost at Spokane site, it has higher per unit inland (rail plus truck) transport cost than that of Richland site implying that the shippers using the inland terminal require a longer truck haul when terminal is located at Spokane compared to Richland. It is also evident from Figure 16, which reports per unit trucking cost for containers being handled at the inland terminals. There are two possible explanations: a) Spokane site serves the shippers located farther than the shippers using the Richland site and b) due to the sites’ geographic location, the same shippers need to make longer truck hauls for the Spokane site than the Richland site. A spatial analysis presented in the next section supports the latter.
An analysis of cost by commodities shows that all shipper transport costs go down when an inland terminal is in place (Figure 17). It also shows which location is best for each commodity. For apple, cherry and hay producers, the Richland site provides the lowest cost option. The Spokane site is most preferable to grain shippers while the Richland site is also very cost effective. Except for hay shipping, we do not observe significant cost reduction at the Millersburg site compared to the baseline.
CONTAINER MOVEMENT: TRUCK VS RAIL

With high retail and residential development around the Seattle/Tacoma ports area, highway congestion is a major issue in accessing the ports. An inland terminal can reduce port-bound highway traffic by diverting some of these trucks to the inland terminal which accesses the ports via rail. Figure 18 shows the effectiveness of different sites at achieving that objective. Coupled with Figure 5, this figure shows that both Richland and Spokane site effectively reduces about 50% of the currently port bound traffic by processing them at the inland hubs while Millersburg site reduces only a small portion (about 15%) of the port bound traffic.

To illustrate the geographic impact of an inland terminal under different proposed locations, Figures 19-25 provides a spatial distribution of highway traffic and comparison with the baseline. There are four major routes in our analysis:

1) I-5: Western Washington and Oregon shippers use this highway to access the ports
2) I-90: For most of Washington and all Idaho shippers, this highway is the access route to the ports. Shippers from northwestern Idaho access Spokane site through this highway as well.
3) I-82: Northern Oregon and Southern Washington shippers use this highway to connect to I-90 that leads to the ports.
4) I-84: For most Idaho shippers, trucking to the ports involve a long drive on I-84. It is also the main route for accessing Richland site by the Idaho shippers.
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Under the base scenario, I-90 holds the most traffic (more than 16,000 container trucks per year) consisting of outbound traffic originating anywhere in the PNW east of Yakima (central Washington). Most of these trucks originate in Eastern Washington and Idaho. Thus, trucks through Spokane via I-90 and through Richland via I-82 to Yakima comprise a large share of this traffic (5,000 - 8,700 container trucks per year). High density traffic is also seen on I-5 from Western Oregon shippers accessing the ports (2,650 - 5,000 container trucks per year).

Figure 19: Highway traffic density under baseline scenario

Figure 20 shows that with the Millersburg site, highway port traffic on I-5 may decrease more than fivefold (400-800 container trucks per year compared to the baseline 2,650 – 5,000 container trucks per year). Also, traffic density on I-5 is higher between Portland and the Millersburg site than to the Seattle/Tacoma ports implying that these trucks are rerouted to the inland terminal. However, due to this site’s location, it can cater to only a small number of agricultural shippers in Western Washington and Oregon. Thus, the rest of the highway traffic distribution remains unchanged.
Another distinguishing feature of the Millersburg site is that a large share of the shippers using it are located between the inland port and the Seattle/Tacoma ports. Thus, with a higher rail rate, the cost advantage of the inland terminal is lost to these shippers and they directly ship their containers to the ports (Figure 21). The region indicating high density traffic around the inland terminal site shrinks with a high rail rate. This explains why average trucking cost per repositioned container goes down at this site with increasing rail rate contrary to the other sites as shown in Figure 16.
When the inland terminal is placed at the Richland site, we see many changes to the baseline scenario. Highway traffic density reduces approximately tenfold between Yakima and the Seattle/Tacoma ports on I-90 (Figure 22). Compared to the densest highway traffic route in the baseline (more than 16,000 container trucks per year), this route only holds about 2,650 – 5,000 trucks per year in this scenario. This decrease results from a decrease in two other routes. The traffic density between Spokane and Yakima on I-90 goes down to about 800 trucks per year, so does the traffic between Richland and Yakima on I-82.

The aforementioned decrease in highway traffic on I-90 is achieved by rerouting most of the highway container shipping to the inland terminal. The traffic density between Spokane and Richland increases to about 8,700 – 16,000 container trucks per year compared to a non-existent traffic density on these routes (e.g. WA-395) in the baseline. We also see increased highway traffic to the inland terminal from Central Idaho via I-84 and from Northern Idaho via I-90. Some of the shippers from Northwestern Oregon also choose to use the inland terminal although it does not significantly affect the traffic density on I-5.
The location of the shippers catered to by the inland terminal shows why using the terminal remains attractive to this population even under a high rail rate. Most of the shippers using the inland terminal in this scenario requires a long haul to the inland terminal from their distribution centers but an even longer haul to the ports. As a result, even with a high rail rate, it is cost effective to choose the shorter trucking haul and use the inland terminal (Figure 23). The high rail rate makes the inland terminal cost ineffective for some shippers in the Central Washington region. Thus, we see an increase in traffic density on I-90 between Yakima and the ports, although it is still significantly lower than the baseline traffic. Also, the traffic from Northwestern Oregon reverts to using the direct route.
The resulting traffic density in the Spokane scenario closely matches that of the Richland scenario (Figure 24). There are three areas where this scenario differs from Richland. First, traffic on I-90 originating in central Washington and heading to the ports is higher (5,000 - 8,700 container trucks per year) than in the Richland case (2,650 - 5,000 container trucks per year). Second, the traffic density between Spokane and Richland is lower than that of the Richland case implying that many shippers around Richland now directly ship their containers to the ports. Finally, unlike Richland, the Spokane site cannot draw any container shipping from Oregon shippers.

In our cost analysis, we have shown that trucking cost per repositioned container is higher for the Spokane site than the Richland site. We identified two possible reasons for that. The spatial analysis in Figures 22 and 24 confirm that both sites cater to the same shippers in the region. However, shippers located around Richland and most of Idaho now require a longer trucking trip to reach the Spokane site resulting in higher trucking cost.
Figure 24: Highway traffic density under Spokane scenario (rail rate = low)

Apart from a slightly decreased traffic density toward Spokane from Central Washington and a slightly increased density toward the ports from Yakima, there are no significant changes in traffic density under a higher rail rate in this scenario (Figure 25).
PERFORMANCE UNDER CHANGING EXPORT DEMAND

Containerized exports are rapidly increasing worldwide and an inland terminal is required to meet the demand for containers in the PNW. To evaluate the sustainability of an inland terminal, we test the performance of the inland container terminals under changing export demand conditions. Containerized exports of the five commodities considered in the study grew rapidly over the last two decades. Containerized export of these commodities increased about 42% over the last 10 years (2009-2018) and about 91% since 2002.

Increasing the total export volume by 30% and 50% from the current level of exports we observe several features. First, with both 30% and 50% increases in export demand, only Millersburg site shows a proportional increase in container handling. At the Spokane site, container handling increases by about 20% and 30%, while at Richland site it increases by about 9% and 12% under 30% and 50% demand increase, respectively. This might reflect an already high utilization of the inland terminal capacity at Richland site while capacity at Millersburg site previously remained underutilized (Figure 26).
Second, with proportional increase in container handling at the Millersburg site, the share of total containers transported via this site remained constant at about 15%. With less than proportional increase, Spokane site’s share in total volume decreases by 2%-6% and Richland site’s share decreases by 9%-14% (Figure 27).
Third, although total transport cost increases with increasing container shipping, per unit cost remains constant over different demand conditions (Figure 28).
Fourth, comparison of the inland hubs with the base scenario at the same export demand conditions (current, 30% increase, 50% increase) shows that the baseline can handle up to 35% increase in the export demand only. On the contrary, with inland containers in place, both 30% and 50% increase in export demand can be handled.

Finally, spatial analysis shows that in Millersburg scenario, highway traffic density increases proportionally in all major routes except between Portland and the ports on I-5, which remained within the same range as the current demand scenario. It shows the efficacy of the site in reducing highway congestion. In Richland scenario, highway traffic increases in all major routes considered here. Especially, traffic density between central Washington and the ports increased about three times compared to the current demand scenario. We find a similar pattern in Spokane scenario.

**SENSITIVITY ANALYSIS**

There are a few user defined parameters that might affect the outcomes of the model, especially the objective values (e.g. total cost). However, if the container movements, the main objective of the study, are not sensitive to these parameters, our reported results should hold.

**Delay cost**

We defined delay cost as a percentage decrease in the commodity price. The results above are reported with a delay cost of 20% from the original prices. Changing this in a range between 10%-50% did not
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affect the number of containers handled by inland hubs more than 4% for any scenario except Spokane when the delay cost set at 50%. For such an extreme delay cost, Spokane’s outcomes deteriorated by 10%.

**Delay rate**

We defined three delay rates with highest to lowest magnitude as follows: 1) from agricultural shippers distribution point to Sea-Tac by truck, 2) from agricultural shippers’ distribution point to the proposed inland terminals by truck, and 3) from proposed inland terminals to Sea-Tac by rail, with 5%, 2% and 1% delay rates, respectively. We conducted two different sensitivity tests on these rates.

First, we vary the first delay rate only from 5% to 9%. It changes the container movement up to 3% in the Richland scenario and up to 6% in the Millersburg scenario. However, the results from the Spokane site had greater susceptibility to the delay rate. There the outcomes varied about 10%-20% when the delay rate was 7% or higher.

Second, we vary all three delay rates simultaneously. While the first delay rate was varied as before, we set the second rate 2% points lower than the first and the third rate 2% points lower than the second rate at each iteration. The resulting changes were within 5% of the outcomes reported above.

**Loading space in ocean vessels**

An ocean vessel follows a specific route and has multiple ports of call included in our model. Furthermore, cargo ships carry non-agricultural products as well. Thus, it is reasonable to assume that an entire vessel will not be available for loading agricultural shipments from the model. Thus, we defined a parameter that restricts the vessel’s loading capacity. The results are reported with 50% of the vessel being available. However, varying this parameter between 10%-50% does not change the outcomes at all.

**Rail schedule**

We did not find any rail schedule data to estimate potential number of trains that each inland hub might service. The results above are reported assuming one rail shuttle from each of the seven Midwestern port locations, coming to, and leaving from, the proposed inland hubs every month. Each shuttle is available at full capacity. Like the loading space parameter, we observed container movement with varying levels of rail capacity available for loading (between 20% to 100%) for incoming trains, and simultaneously setting the frequency of outgoing trains between one and seven in each decision period. The results show that even with as low as 40% carrying capacity in incoming trains and two outgoing trains per decision period, Millersburg site does not change at all. Outcomes at the Richland and Spokane sites changes significantly with every successive change in rail capacity and frequency, although with a larger magnitude for Richland as opposed to Spokane. This result was not surprising considering that these sites handle almost four times as many containers than the Millersburg site, which implies that their rail capacities would be near full utilization.

**Flexible total export**

In our model, we hold the total export demand of the commodities fixed. Thus, the containers must be shipped no matter the cost. The model then determines the least cost shipping alternative for the shippers. In a slightly modified model specification, we allow for the shippers’ decision to ship each container or not, by comparing the value of the commodities in a container to their shipping cost. Although, this still ignores the production cost of the commodities, the total export volume was
endogenously determined and results from the model solution. However, the model requires additional data on export prices and quantity of demand at the foreign destinations. These data were not readily available. Using domestic commodity price and current export level as proxies for prices and quantity at the foreign destinations, we achieve similar results for all commodities except for hay. To achieve the same results for hay, we needed to increase the hay price by 16%, which might not be surprising given high price volatility of agricultural commodities and use of domestic prices to proxy the export price.
VIII. CONCLUSION

Limited container availability, highway congestion and lack of inexpensive rail freight services pose challenges for the PNW agricultural shippers. Surplus empty containers at Midwestern ports offer a solution to these concerns when an inland container terminal is used to reposition these containers to the PNW region, and they are made available to the PNW shippers at a lower cost. Thus, we evaluate the viability of an inland container terminal in the PNW region using a cost minimization model for the agricultural shippers in this region. In addition, we compare outcomes at three potential sites to determine the optimal location for the inland terminal.

Number of containers shipped, cost effectiveness, impact on highway traffic density and sustainable performance under different demand conditions were analyzed to assess the feasibility of this approach. We find that among the three potential locations for such inland terminal, Richland site performs well in most categories while Spokane site also fares relatively well. Millersburg site performs well in most indicators due to its geographic position. However, its efficacy for reducing highway congestion south of the Seattle/Tacoma ports on I-5 merits consideration.

However, Richland also reduces congestion on this same stretch of I-5 although not to the same degree as Millersburg. In addition, both Richland and Spokane substantially reduce west bound congestion along I-90. Richland not only reduce I-90 traffic but along I-82 and I-84 as well. Unfortunately, the Richland site brings with it increased traffic on routes with very low traffic in the baselines scenario. These include smaller routes such as WA-395. While Spokane's location, further to east, does not increase traffic along those smaller routes it fails to gain the attention of shipper from Northwestern Oregon and north bound traffic on I-5 remains unchanged.

These reductions in congestion are explained by the large portion of containers that both Washington sites are expected to attract. Richland was estimated to handle between 52% and 58% of all containers modeled. Spokane was estimated to handle between 44% and 48% of all containers. Both estimates are substantially higher than Millersburg, which is expected to handle only 13% to 15% of the total number of PNW containers. When exports were increased to 50% the model showed that the Washington sites will handle a larger share of the total containers being shipped while Millersburg's portion remained unchanged leaving the increase in exports to further congest the highways. The ability of Richland and Spokane to attract a greater portion of total containers is also notable since the baseline scenario cannot handle an export increase greater than 35%. The larger share of containers going through Richland and Spokane indicates potential value of these location for shippers of agricultural commodities.

When considering seasonality, the elasticities presented in Figures 10 and 11 indicate that the Spokane site is the least elastic of the three sites and thus would be preferable for Class I railroads since they desire a steady volume for shipments to the Seattle/Tacoma ports. When considering the medium rates alone, Richland's elasticity is like Spokane's, making it a good option as well. Additionally, the medium rate was based on a 50% profit margin, which would allow Class I railroads to list their rates dependent upon the months thereby reducing the variability of volume and still maintain profitability\(^4\).

While these elasticity estimates are promising, due to a lack of data, we can incorporate seasonality with a limited capacity only. In addition, while freight shipping and container repositioning is a dynamic

\(^4\) Different months have different commodities shippers. In this way the monthly rates would allow the railroad to distinguish between shippers.
process, we limit our analysis using a static model due to lack of data and complexity of the problem at hand. Future research might expand on these areas given data availability.
IX. REFERENCES


Kim, Nam Seok, and Bert Van Wee. ‘The relative importance of factors that influence the break-even distance of intermodal freight transport systems.’ Journal of Transport Geography 19, no. 4 (2011): 859-875.

Kuźmicz, Katarzyna Anna, and Erwin Pesch. ‘Prerequisites for the modelling of empty container supply chains.’ Engineering Management in Production and Services 9, no. 3 (2017): 28-36.


**APPENDIX**

**Table 3: List of parameters and their sources**

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<th>Parameter</th>
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