TRANSPORTATION OPTIMIZATION MODELING FOR WASHINGTON STATE
HAY SHIPMENTS: MODE AND COST IMPLICATIONS DUE TO LOSS
OF CONTAINER SERVICES AT THE PORT OF PORTLAND

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Abstract

        A recent issue impacting hay shipments in Washington State involves the reduction of container services at the Port of Portland, Oregon. Prior to this change, containers filled with hay were shipped almost exclusively via barge on the Columbia River to the Port of Portland. After reaching Portland, the containers were then loaded onto one of three steamship lines: Hyundai, K-Line, or Hanjin and destined to markets in Japan and China. As of September 2004, Hanjin is the only carrier that calls on the Port of Portland.

        This research effort collected firm level data on the production, transportation and marketing of hay in Washington and utilizes this information to develop an optimization model of regional hay movements. One alternative evaluated in this study is determining industry shifts in transportation usage and modal choice in reaction to the transportation changes after September 2004.

        The results indicate that after all barge and hay shipments were eliminated into Portland, total transportation costs decrease initially overall, while some producers experience shipping cost increase. Both rail and truck volumes increase substantially in the absence of container shipments on barge. The total industry impact is a $6.3 million increase in transportation costs from the Base Scenario to Scenario 3. Also, once trucks rates are allowed to increase due to the shortage of trucks and the increased demand for truck services, the total transportation cost increased by $8.7 million.

Introduction

A recent change in the regional transportation landscape in the Pacific Northwest involves the reduction of container services at the Port of Portland, Oregon. As a result, the Port of Seattle and Tacoma have experienced a considerable increase in hay shipments since September of 2004. Prior to this date, containers filled with hay were shipped almost exclusively via barge on the Columbia River to the Port of Portland. After reaching Portland, the containers were then loaded onto one of three steamship lines: Hyundai, K-Line, or Hanjin. As of September 2004, Hanjin is the only carrier that calls on the Port of Portland. As a result, barge shipments of containers out of the Port of Pasco decreased 75 percent, while rail shipments to the Port of Tacoma and Seattle grew from 40 containers per month to 600 containers per month. Rail shipments are expected to increase even further to 1000 containers per month in early 2005 (Port of Pasco). Transportation costs will undoubtedly increase for shippers from the Port of Pasco's barge terminal who are unable to secure space on remaining Portland cargo ships

Shippers of hay and other agricultural commodities will adjust to this change by shifting from barge to rail and truck. Eastern Washington agricultural exporters save an estimated $500 per container in shipping costs due to the fact that large numbers of "empties" are passing through on their way back to Asia (Pascall).

Data and Information

In addition to the industry information collected by hay producer and processor surveys, the Port of Pasco, Portland, Seattle and Tacoma were all contacted by phone to obtain additional information on volume of hay shipments through port facilities. Information on feedlot operations in Washington State was also obtained from the Licensed Certified Feedlots, Washington State Department of Agriculture (WSDA, 2004).

Trucking rates were obtained by phone interviews with processors and selected producers.   Container rail rates were provided by Northwest Containers, Inc. and barge rates were the posted published rates from local barge service providers.

Transportation Optimization Model

A transportation optimization model is developed to realistically represent hay shipments throughout Washington's multi-modal transportation network. A cost minimization model is developed for hay shipments out of Washington that is then used to investigate impacts to hay producers, brokers and ports.

The collection of allowable origin and destination combinations of hay shipments in Washington State are displayed in Figure 3.1. There are three categories: Producers, Intermediate Destinations which include brokers and ports (Pasco and Portland) and Final Destinations which include final export ports (Portland, Seattle and Tacoma) and feedlots. The hay producers serve as the source of hay shipments originating throughout the state and the final

destinations serve as the ending demand points. Each producer has the option of transporting their hay by truck to brokers, intermediate ports, final export ports and/or feedlots. Producers also can ship hay directly to the final destinations or to intermediate destinations and from there it will be shipped to the final destinations. The intermediate destinations act as temporary collection/processing points from which hay is then allocated to final destinations. The total amount of hay produced in the state (3.6 million tons) will eventually move from producers to final destinations.

Since the intermediate destinations (nodes 2 and 3 in Figure 3.1) are the only transshipping locations, they each act both as a potential destination and as a potential source. The number of movements transshipped through each location is included as an option for both the demand for the locations as a destination and the supply for that location as a source (Hillier and Lieberman, 1974). Brokers transport all processed hay by truck to final export ports, river ports and feedlots. After hay has been processed by a broker its primary destination is to foreign markets. Ninety-one percent of processed hay is exported to foreign markets while 9 percent is distributed domestically. Intermediate ports have the option of transporting by barge, rail or truck. The Columbia River is an inexpensive alternative to shipping hay by barge from the Port of Pasco to the Port of Portland. These two intermediate ports transport hay exclusively to final export ports.

Figure 3.1. Transshipment Possibilities for Model
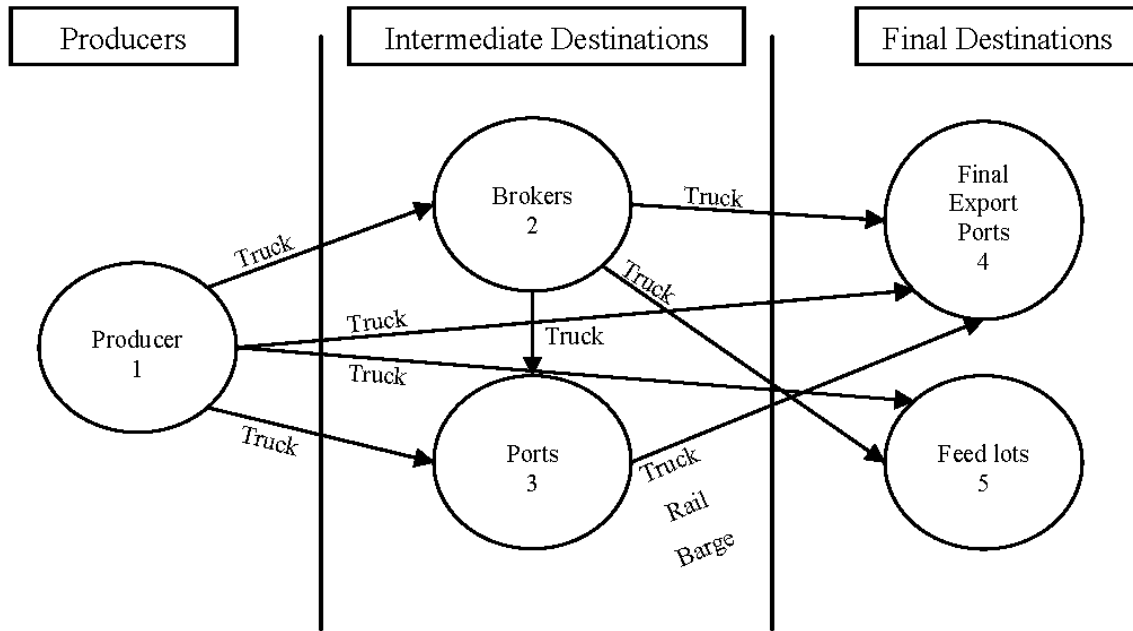
The transportation optimization model allocates shipments in order to minimize total transportation costs, as defined by the objective function (1). The cost per unit (c_{ijkl}) for shipments between origin i, intermediate destination j and final destination k via mode l ($/ton) is multiplied by the amount of hay (x_{ijkl}) that is shipped from origin i to intermediate destination j to final destination k via mode l (tons). Thus, the objective is to minimize total cost subject to five separate supply and demand constraints which add realism to the model. The objective function can be specifically stated as follows:

(1) Minimize $\sum_i \sum_j \sum_k \sum_l c_{ijkl} \, x_{ijkl}$

    i = origin
    j = intermediate destination
    k = final destination
    l = mode

s_i = supply of hay at origins (in tons)
d_k = demand for hay at destinations (in tons)
c_{ijkl} = cost per unit shipment between origin i, intermediate
destination j and final destination k on mode l ($/ton)

The decision variables for this model are the elements X_{ijkl} under control for the model and their values determine the optimal solution of the model. The decision variables X_{ijkl} in function (2) is equal to the amount of hay that is shipped from origin (i) to intermediate destination (j) to final destination (k) on mode (l) (tons). The transportation model only allows positive shipments between each origin and destination point.

(2) x_{ijkl} = amount of hay to ship from origin i to intermediate destination j to final destination k on mode l (tons)

with $x_{ijkl} \geq 0$, for all i, j, k and l

The optimization model includes basic supply and demand constraints for realism. The supply constraint limits total shipments from each origin (i) that is available from each supply point, defined by S_i (3). Thus, the sum of all shipments from each producer cannot exceed the available production of each producer. The demand constraint in function (4) observes that the sum of all shipments from origin (i) and/or intermediate destination (j) has to be greater than or equal to the demand of each final destination (k), defined by D_k.

Observe supply limit at producer (i):

(3) $\sum_{jk} x_{ijk} \le S_i$, for all i

        Satisfy demand at market (k):
(4) $\sum_{ij} x_{ijk} \ge D_k$, for all k

        Function (5) displays the rail constraints for hay shipments within

Washington State. The rail constraints observes that the sum of mode (l) (rail)

for the amount of hay from origin (i) to final destination (j) has to be less than or

equal to the rail capacity for all final destination (k).

(5) $\sum_l x_{ik} \le R_k$

        The barge constraint assures that the sum of mode (l) (barge) for

the amount of hay from origin (i) to final destination (j) has to be less than or

equal to the barge capacity for all final destination (k).

(6) $\sum_l x_{ik} \le B_k$

Constraints are needed in model to find the least-cost optimal solution that would

identify flows and modes that best satisfy the objective function. Without some

reality constraints on the amount of shipments leaving each origin point by truck,

rail or barge, all hay shipments from origin points would be entirely shipped

directly to final destinations; never passing through an intermediate destination.

Though, this would be the least-cost optimum it is not realistic of hay shipments

out of Washington State. The rail and barge constraints are added to accurately

reflect reality and better estimate the impacts of increased rail usage since

September 2004.

There are 40 hay production locations serving as origin points which represent the majority (by volume) of hay tonnage by area in the state of Washington. The quantity of supply from each origin point enters the linear program model as a constant (perfectly inelastic). Given the nature of hay production, this particular assumption related to price and quantity responses in the hay supply market are not unjustifiably limiting. Production decisions within the hay industry require long-term financial commitments in capital, land and equipment. The price elasticity of supply is certainly inelastic, approaching perfectly inelastic, as illustrated in Figure 3.2.

This transportation optimization model includes 4 processors, 2 ports and 9 destination markets (k) within Washington State. The quantity of hay demanded at each destination market is also treated as a constant. The true demand function for hay is downward sloping to the right instead of perfectly inelastic (Figure 3.2) due to the fact that most consumers are sensitive to price fluctuations.

Figure 3.2 graphically presents the implications from treating demand as a fixed constant instead of a downward sloping demand function. The financial impact from an increase in price from P_1 to P_2 is equal to the area a, d, e, b without an associated quantity response to changing prices. This corresponds to the reduction in consumer surplus due to a price increase. Realistically, as prices increase from P_1 to P_2, consumers will adjust their quantity consumed by substituting away from Washington hay to markets elsewhere. As a result, the true loss in consumer surplus will be the smaller area defined as a, c, e, b. The

difference between the two estimation measures is represented in Figure 3.2

shaded area. The loss is consumer surplus is overstated by treating demand as

fixed; this amount is also represented in the shaded area. However, in order to

estimate unique supply and demand schedules for each market an overwhelming

amount of firm level data would be required through time. This information isn't

available and therefore this transportation optimization model approximates

demand with the aforementioned limitations.

Figure 3.2. Supply and Demand Market Relationships
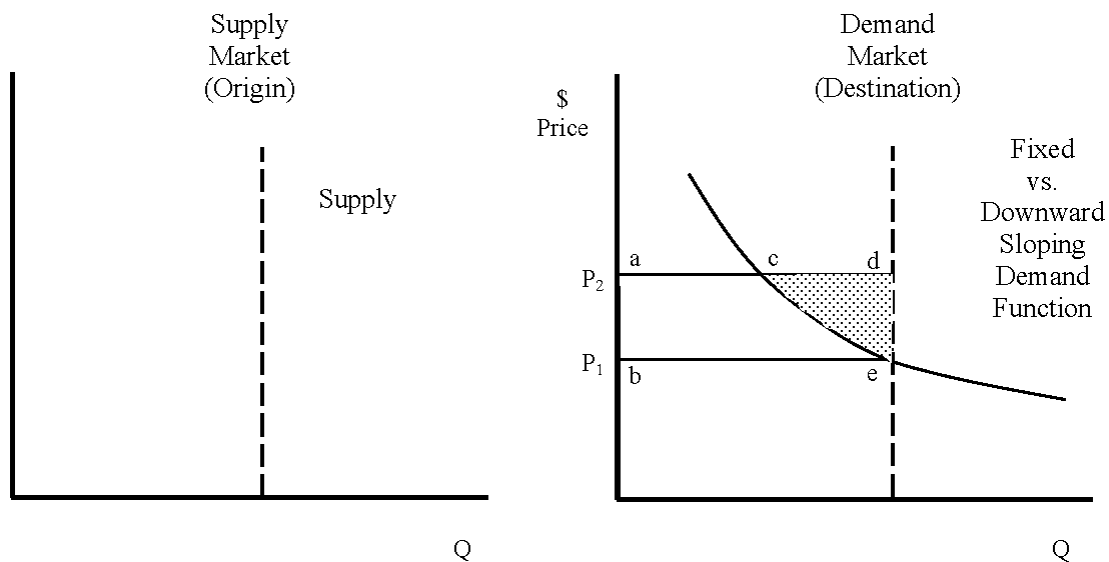
Scenarios

      Three separate scenarios are analyzed in this study in order to

estimate the cost and volume implications resulting from loss of container

services at the Port of Portland.

      The optimal base scenario transportation flows reveal the comparative

advantages of each mode and aims to depict flows prior to loss of container

services at the Port of Portland. The second scenario utilizes a similar model but

eliminates all barge activity and relaxes the volume constraint on rail. Portland's hay demand is then set to zero; meaning all hay that was shipped to Portland is now redistributed to Seattle (25 percent) and Tacoma (75 percent). The Port of Pasco will continue to handle the same volume but now distributed between truck and rail. This model represents the hay flows after September 2004 when two of the three main steamship lines pulled out of the Port of Portland and now call on the Port of Seattle and Port of Tacoma. The final scenario maintains all assumptions as Scenario 2 but introduces a 25 percent increase in trucking rates due to truck shortages brought about by increased demand and limited supply. Scenario 3 is designed to provide a realistic representation of hay movements once market conditions have responded to the reduction in container services at the Port of Portland. This scenario reflects the new transportation costs, volumes by mode and also the shadow prices that will occur due to the shift in the model.

This 25 percent increase in truck rates is the result of several contributing factors. The major issue being the loss of container services at Port of Portland due to two of the three oceanic steam ship lines pulling out. The containers that were once barged down the Snake/Columbia River now have to be redistributed to truck and rail leading to increased demand for truck services. The second issue that affects the increase in truck rates is the recent changes to the federal guidelines controlling truck drivers' hours of service. The new rule states that truck drivers and operators may drive 11 hours after 10 hours of being off-duty but cannot exceed 14 hours of driving after the same 10 hour break. Trucking firms will need additional drivers and equipment to compensate for

lower hours of operation and productivity per driver. This change is expected to increase costs of operation.

Results

Scenario I

The optimal base scenario outlines transportation flows of each mode. All hay movements were shipped via truck from producers and the large majority of shipments from producers go directly to feedlots within the state, accounting for 57 percent of all producer shipments (Table 4.1). The next largest destination for hay shipments from producers is hay brokers, to be processed and then reallocated for further final destinations. A total of 880,573 tons of hay is shipped from producers to brokers, primarily from producers within close geographical proximity to their facility. Producers ship 24 percent of their total production to brokers. Of the 880,573 tons of hay shipped from producers to brokers, 22 percent is then transported via truck to the Port of Pasco for a total of 193,726 tons. These hay shipments are from the two brokers located near the Port of Pasco which rely upon efficient barge access. Twenty-eight percent of hay shipments leaving brokers go directly to Tacoma via truck and 50 percent is shipped to Portland also using truck.

Total transportation costs for Scenario I is $41.2 million, with the largest proportion of this cost resulting from shipments from producers to intermediate and final destinations ($22.9 million or 56 percent). It is interesting to note that while 57 percent of total shipments leaving producers go to feedlots, this type of movement only accounts for 38 percent of total cost (Table 4.2).

Table 4.1 Volume of Hay Shipments, by Scenario

	Volume (Tons)								
Type of Movement	% of total hay distribution	Base Scenario 1	% of total hay distribution	Scenario 2	% Δ change from Base Scenario	% of total hay distribution	Scenario 3	% Δ change from Base Scenario	% Δ change from Scenario 2
Producer to Intermediate Destination (Truck):									
Broker	24%	880,573	24%	880,573	0%	24%	880,573	0%	0%
Port	3%	119,980	3%	119,980	0%	3%	119,980	0%	0%
Producer to Final Destination (Truck):									
Seattle	9%	334,578	15%	550,770	65%	15%	550,770	65%	0%
Tacoma	6%	200,777	0.3%	10,001	-95%	0.3%	10,001	-95%	0%
Portland	1%	25,416			-100%			-100%	
Feedlots	57%	2,041,676	57%	2,041,676	0%	57%	2,041,676	0%	0%
Total	100%	3,603,000	100%	3,603,000		100%	3,603,000		
Broker to Final Destination (Truck):									
Port of Pasco Feedlot	22%	193,726			-100%	4%	35,223	-82%	100%
Port of Seattle			11%	93,566	100%	11%	93,566	100%	0%
Port of Tacoma	28%	249,422	89%	787,007	216%	85%	751,784	201%	-4%
Port of Portland	50%	437,425			-100%				
Total	100%	880,573	100%	880,573		100%	880,573		
Port to Final Destination:									
Port of Seattle									
Truck									
Rail									
Port of Tacoma									
Truck									
Rail			100%	119,980	100%	100%	155,203	100%	29%
Port of Portland									
Truck									
Rail	48%	149,697			-100%				
Barge	52%	164,009			-100%				
Total	100%	313,706	100%	119,980		100%	155,203		

Table 4.2 Transportation Costs, by Scenario

	Transportation Costs								
Type of Movement	% total transportation cost distribution	Base Scenerio 1	% total transportation cost distribution	Scenario 2	% Δ change from Base Scenario	% total transportation cost distribution	Scenario 3	% Δ change from Base Scenario 1	% Δ change from Scenario 2
Producer to Intermediate Destination (Truck):									
Broker	26%	$6,061,830	25%	$5,522,549	-9%	26%	$7,167,078	18%	30%
Port	1%	$236,218	3%	$719,880	205%	3%	$776,558	229%	8%
Producer to Final Destination (Truck):									
Seattle	18%	$4,241,413	32%	$7,160,684	69%	32%	$8,950,948	111%	25%
Tacoma	15%	$3,439,315	1%	$124,720	-96%	1%	$155,882	-95%	25%
Portland	2%	$379,735			-100%			-100%	
Feedlots	38%	$8,628,285	39%	$8,595,495	-0.4%	38%	$10,604,292	23%	23%
Total	56%	$22,986,797	57%	$22,123,328		58%	$27,654,760		
Broker to Final Destination (Truck):									
Port of Pasco Feedlot	0.1%	$7,555			-100%	0.1%	$9,158	21%	
Port of Seattle			16%	$2,230,617	100%	8%	$1,320,218		-41%
Port of Tacoma	24%	$3,185,115	84%	$11,307,084	255%	92%	$14,485,382	355%	28%
Port of Portland	76%	$10,200,758			-100%			-100%	
Total	32%	$13,393,428	35%	$13,537,701		33%	$15,814,759		
Port to Final Destination:									
Port of Seattle									
Truck									
Rail									
Port of Tacoma									
Truck			100%	$3,084,686	100%	100%	$3,990,269		29%
Rail									
Port of Portland									
Truck									
Rail	68%	$3,327,764			-100%				
Barge	32%	$1,540,045			-100%				
Total	12%	$4,867,809	8%	$3,084,686		8%	$3,990,269		
Total Costs		$41,248,034		$38,745,715			$47,459,788		

Shipments which arrive at brokers represents nearly 24 percent of total hay tonnage, but outbound shipments from the brokers represents 32 percent of the total transportation costs. The largest component of this cost is attributed to truck shipments to Portland (76 percent), accounting for $10.2 of the $13.4 million transportation cost for outbound broker shipments. Broker shipments to Tacoma on truck account for the remaining 24 percent.

Scenario II

Transportation flows experience much change in Scenario 2 when barge is eliminated and shipments are then redistributed to Seattle and Tacoma. In Scenario 2 Portland's demand is reduced to zero and shipments from producers to intermediate destinations continue as in Scenario 1. Producers did shift away from trucking hay to Tacoma experiencing a decrease of 95 percent. However, the loss of shipments to Tacoma and Portland from producers was gained in Seattle. The Port of Seattle increased its total volume arrivals by 65 percent (Table 4.1). Volume and transportation costs both increased over 60 percent for shipments from producers to the Port of Seattle via truck.

The distribution of all hay shipments in Scenario 2 into ocean ports has shifted away from Portland and is now weighted toward Tacoma, accounting for 59 percent of the export markets with 916,988 tons. This is followed by the only other export port, Seattle (41 percent or 644,336 tons).

There is a shift in flow resulting from the changing demand. Transportation costs decreased $2.5 million from the base scenario to a total of $38.7 million due to the convenient location of Seattle and Tacoma from its

supply points. There is less distance for producers to transport hay to Seattle and Tacoma versus the lengthy haul to Portland. The largest portion of this cost is still resulting from shipments from producers to intermediate and final destinations ($22 million or 57 percent).

Producer to Seattle truck shipments represent 32 percent of outbound producer costs, a significant increase from the base scenario. However, Seattle only accounts for 15 percent of outbound tonnage to this market (Table 4.1). Approximately 39 percent of the producer to final destinations costs is credited to the hay shipments from producer to feedlots portion at $8.6 million, a minor decrease of 0.4 percent from the base scenario (Table 4.2).

Scenario III

There is a 25 percent increase in truck rates due in Scenario 3, bringing total transportation costs to a total of $47 million. The allocation of hay remained the same as Scenario 2 for the shipments from producer to intermediate and final destinations. However, Brokers did increase their volume to the Port of Pasco (35,223 tons) which resulted in a 4 percent decrease in shipments from brokers to the Port of Tacoma. The 29 percent increase in shipments from the Port of Pasco to the Port of Tacoma reflected the 35,223 tonnage increase that Pasco experienced in this scenario. The increase in volume that occurred at the Port of Pasco also increased transportation costs by 21 percent from the Base Scenario.

Total transportation costs for Scenario 3 increase a total of 23 percent from the second scenario. A large proportion of the total cost is a result of the

shipments from producers to intermediate and final destinations ($27.7 million or 58 percent). Also, the increase of transportation costs in Scenario 3 was the result of the 25 percent increase in trucking rates that was imposed. On the other hand, Ports experienced a drastic increase of 205 percent in transportation costs in the second scenario bringing the total from $236,218 to $719,880 (Table 4.2). Scenario 3 increased as well (8 percent) which was expected with the trucking rate increase.

Hay shipments from broker to final destination represent 24 percent of total hay tonnage, but outbound shipments from brokers represent 33 percent of the total transportation costs. The largest component of this cost is attributed to truck shipments to Tacoma (92 percent), accounting for $14.5 million of the $15.8 million transportation cost for outbound broker shipments. Port of Tacoma's total transportation costs in the second scenario increased 255 percent from the Base Scenario and an additional 28 percent from the second to the third scenario.

Summary and Conclusions

Three different transportation scenarios were presented and evaluated including one which characterized hay shipments prior to September 2004 with Port of Portland assessed in the model as both a port and final destination. The second scenario considers hay movements and flows after September 2004 eliminating barge activity to the Port of Portland as a shipping option. The third scenario was structured the same as the second scenario but also increased trucking rates by 25 percent.

The results indicate that after all barge and hay shipments were eliminated into Portland, total transportation costs decrease initially overall, while some producers experience shipping cost increase. Both rail and truck volumes increase substantially in the absence of container shipments on barge. The total industry impact is a $6.3 million increase in transportation costs from the Base Scenario to Scenario 3. Also, once trucks rates are allowed to increase due to the shortage of trucks and the increased demand for truck services, the total transportation cost increased by $8.7 million.

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