
Logistics Costs Based Estimation of Freight Transportation Demand
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Logistics Costs Based Estimation of Freight Transportation Demand

Many supply chain and finished goods distribution networks involve intercity freight transportation. Shipping customers secure transportation services by matching their requirements to available service in an effort to minimize their total logistics costs subject to service level constraints. Frequently, shippers' modal decisions are constrained by short-term capacity constraints restricting one of the available options, or gaps in shipper knowledge or carrier marketing programs. As a result, the observed traffic flows may not reflect the potential demand for the mode. Because the potential demand for a mode is not directly measurable, when planning road and rail capacity, governments and railroads cannot make accurate capacity planning decisions based on current traffic flows. The model developed here identifies the potential demand for intercity full truckload and intermodal shipments over the most heavily utilized 75,000 shipment lanes in the western United States by estimating minimum total logistics costs by mode. These flows are compared with actual U.S. freight flows in order to determine the differences between observed flows and the model estimated potential demand. The results indicate potential demand for intermodal transportation is high; considerable freight volumes could be delivered with lower logistics cost by switching from truck to intermodal transportation. This evidence suggests that observed traffic flows and trends may not be a sound basis for planning freight transportation infrastructure in the United States.

by Michael F. Gorman and Daniel G. Conway

Many supply chain and finished goods distribution networks involve intercity freight transportation. Freight shippers secure transportation services by matching their requirements to available service in an effort to minimize their total logistics costs subject to service level constraints. For these supply chains to operate efficiently, the appropriate transportation infrastructure must be in place to support them.

The U.S. government spends more than $95 billion each year on roads, and U.S. Class One railroads invest more than $6 billion each year on their infrastructure to support these distribution networks. In making their capacity expansion decisions, governments and railroads are faced with the difficult task of projecting where traffic growth potential is greatest. This paper focuses on estimating the potential demand for intercity trucking and rail intermodal to plan the U.S. freight infrastructure. Intercity trucking is the largest intercity freight transportation mode. Rail's fastest-growing and most truck-competitive product is intermodal, in which the first and last leg of the shipment is completed by truck, and the middle, long-haul portion of the trip is accomplished by moving the truck trailer on rail flatcar. Projecting capacity expansion needs for intercity trucking and intermodal is particularly challenging because the demands for these products are closely related; yet they utilize different transportation infrastructures whose capacities are planned by different decision-making entities.

Historically, statistical forecasts based on aggregate data such as regional population growth and production indexes have been used to create forecasts of freight shipping patterns. However, the implicit assumption employed is that the observed transportation modal choice will grow proportionally with the freight volumes. In fact, data on shipper modal choice is subject to short-run capacity limitations and may not accurately reflect the long run market potential for capacity expansion because shippers may be under utilizing a mode that is at capacity. Thus, as population and production grows, expansion of modal capacity is as influential as forecasted population and production on freight growth. Unfortunately, governments and individual transportation service providers generally measure the observed modal choice of shippers. Thus, decision makers are not well-positioned to measure the potential (uncapacitated) demand for freight transportation which is subject to infrastructure capacity constraints.

Attention to short-run modal mix may result in a large investment in expanded Interstate highway infrastructure; i.e., extensive Interstate capacity allows for large truck volumes, and these large truck (and passenger) volumes are the justification for expanded Interstate capacity. On the other hand, to earn an effective return on investment for its capital, railroads are careful not to over invest in their rail infrastructure capacity and consequently grow more slowly and under much tighter capacity conditions.

To better understand the optimal mix of freight infrastructure, in this study the unconstrained market potential demand for truck and intermodal shipments is estimated based on a detailed modeling of the individual shipper's modal choice decision which is then applied to the market at large. The extent of potential long-run demand is estimated for each mode through micro-modeling of the individual shipper's minimization of total logistics costs (the sum of the transportation cost plus all inventory holding costs associated with the shipment) in individual transportation markets, and then the methodology is applied empirically on a macroeconomic basis to estimate the uncapacitated market-wide demand for each mode.

Differences between the model flows based on minimum total logistics costs and historical freight flows can be interpreted as short-run deviations from a long-run optimum. Deviations from model predicted flows could be due to a number of sources, including: model specification or input data error, shipper modal choice decision with information gaps or modal preference, or modal capacity shortfalls. In the long run, short-run anomalies in modal choice will tend to be eliminated if the capacity exists in that mode to accommodate shippers' modal choices. The implication for transportation service providers is that the right capacity type must be created in the long run to support those shippers who will, based on their total logistics cost function, have sufficient potential demand to justify expanded capacity investment.

The following section describes contributing literature, followed by a section describing the modeling assumptions and methodology. The fourth section describes the model's data sources and is followed by results, extensions and conclusions.

LITERATURE REVIEW

Recent research can be divided into the areas of infrastructure capacity planning, shipper modal demand estimation, and shipper logistics optimization.

Freight Transportation Infrastructure Planning

Extensive research on optimal network structure and predictive freight flows has been conducted. Early work by Roberts (1976) and Kresge and Roberts (1971) focused on aggregate freight flows for the purposes of national planning of freight infrastructure. Bronzini and Sherman (1983) build a single-commodity modal route-choice model based on route impedances. Crainic, Florian and Leal (1990) develop a detailed optimization model which describes the optimal freight transportation infrastructure given exogenous modal traffic flows. These studies do not explicitly model the inventory holding costs of specific shippers, origin and destination pairs, and commodity types, nor do they consider the intermodal transportation option.

Recent research on optimal provision of transportation infrastructure has been conducted by authors such as Conrad (2000), Nash (1993) and Winston (1991). Nash (1993) provides a framework for thorough cost benefit analysis of transport infrastructure projects through case study examples of road and rail investment from Great Britain. Winston (1991) focuses on empirical characterizations of efficient roadway investment and issues such as congestion pricing in the U.S. Conrad (2000) presents a comprehensive analysis of transportation infrastructure investment based on detailed microeconomic modeling of transportation as an input to the economy's overall performance. Conrad (2000) tests the model with an econometric model of the German economy. These studies presume a central (government) authority is establishing transportation infrastructure policy for all modes.

Freight Transportation Demand

Kremers, Nijkamp and Rietveld (2002) perform a meta-analysis of 25 different studies of shipper demand for various transportation modes. Although slightly dated, Oum, Waters and Young (1992) provide a more comprehensive survey of more than 60 refereed articles that estimate shipper demand elasticities. In most of these studies, the demand for transportation is typically modeled as a derived demand for an input as a component of total costs facing a firm. The objective of these studies is to statistically characterize the price sensitivities and price-service tradeoffs for shippers making modal choice decisions. Statistical estimation of demand curves is based on the assumption that observed quantities represent the shipper's long-run, unconstrained demand for the various modes. At any point in time, shippers are making short-run modal choice satisfying decisions based on the available capacity in a mode. For capacity planning exercises, this quantity can be misleading as a long-run indicator of modal demand. Additionally, regression estimates of these demands are specific to mode, commodity, origin-destination pair, price for competing mode, equipment type, service level and prevailing economic conditions (such as interest rates and rents). Thus, estimation of such elasticities across a large number of commodities and freight transportation lanes is impractical.

Typically, the modes of transportation have been considered in isolation in these transportation demand-elasticity studies. Notable exceptions are Oum (1979), which looks at the price-service trade-off for a subset of Canadian shippers choosing between truck and rail, and Friedlander and Spady (1980), which performs a similar analysis for U.S. shippers. Neither study explicitly models the inventory holding costs experienced by the shipper due to various shipment attributes, nor the value of understanding shipper behavior for establishing optimal infrastructure investment. Both studies vastly simplify the geographic component of the shipper's decision because of data availability. Oum considers 69 regions and eight commodity groups; Freidlander and Spady considers 96 commodity groups, but only five broad geographical regions. By way of comparison, this study is based on 250 Standard Transportation Commodity Codes (STCC) for over 7,200 origin and destination zip codes in the United States, 75,000 product lanes in total.

Finally, Fernandez, et al. (2003) have proposed a novel mathematical general equilibrium model for the supply and demand of freight infrastructure, but have not applied their work in an empirical setting.

Freight Transportation and Logistics Optimization

Sheffi, et al. (1988) looks at transportation/inventory tradeoffs facing a shipper deciding between truck and rail. Optimal mode choice is defined as the mode which minimizes the total logistics costs (TLC) of the shipper, including transportation fees as well as inventory costs which arise from shipment speed, reliability and equipment capacity (lot size). This method was designed as a decision support tool for shippers making modal choice and a marketing tool for a U.S. railroad to better understand and cater to shipper freight transportation needs. Sheffi focuses on the microeconomic issues and does not utilize the TLC model to examine the market level demand for each mode nor to estimate the requirements for capacity expansion.

A modified form of Sheffi's TLC model is developed and tested empirically against thousands of actual historical U.S. freight flows. To the extent shippers optimize mode choice, the TLC model should predict U.S. freight flows of truck and rail accurately. However, the extent to which the TLC model and actual flows differ represents long-term modal shift potential.

MODELING METHODOLOGY

This paper models the shipper's modal choice decision as in Sheffi's (1988) total logistics cost (TLC) model which models the trade-offs between transportation mode decisions and inventory holding costs.

The inventory required to support a shipping decision is a function of lot size, shipment speed, and shipment time variability. The lot size of the shipment affects average inventory at both origin and destination. Shipment speed affects the pipeline inventory – the amount of inventory in transit. Shipment time variability affects the required safety stock - inventory at destination to protect against stockouts due to transportation time and demand variability.

Key attributes of the shipment include:

- Transportation cost – the door-to-door fee paid to the transportation service provider(s) for moving product from origin to destination. As in Sheffi (1988), and given the assumption of full truckload shipments this cost is accurately defined as dollars per shipment,
- Shipment size –the capacity of the transportation vehicle which limits the total shipment size (expressed in tons). Depending on the commodity being shipped, the vehicle may "weigh out" due to legal restrictions on truck size, or "cube out" as the trailer space is filled.
- Transit time – total expected elapsed time from origin to destination. The shipper must carry the inventory cost for this "pipeline" inventory in transit.
- Transit time variability – variance around the expected elapsed time of delivery. The shipper must carry "safety stock" inventory to protect against the uncertain timing of shipment arrival.
- Inventory carrying costs – the total cost of owning the shipped items while in transit and at destination before sale. Inventory holding costs are a function of the value of the commodity being shipped, and the inventory carrying charge (typically expressed in a percent of the total value of the commodity per year).

Shippers minimize the total logistics cost of a shipment by minimizing the transportation cost of shipment plus the inventory cost associated with the mode of choice.

Lot Size

As is well known from the economic order quantity (EOQ) literature, a major determinant of shipment (lot) size is the rate of consumption of the product at destination. Given the aggregation of shippers by geographic region, it is impossible to discern the rate of demand between any single shipper and receiver. Thus, it is not possible to establish optimal lot size based on that demand rate. For the purposes of this model, lot size specification is not necessary for the following reasons. First, only freight traffic which is currently moving in full truckload lot sizes is considered in this analysis, either in over-the-road truck, or in rail intermodal, and therefore whose EOQ is approximately one truckload. Because of the 10-fold cost premium and one-third of a full truck lot size which is typical in less-than-truckload service, it is unlikely that a large portion of traffic under consideration is errantly moving in full-truck service when it should be moving in smaller lot sizes.

For larger-than-full-truckload lot sizes, a typical rail car is two to four times larger than the full truck-lot size. Although full railcars move at a significant discount relative to truck, approximately 20% of all shippers have rail-direct service, so the probability of a rail-served origin and a rail-served destination is less than one in 20 for any typical flow. It is assumed that the minority of shippers that have both rail-served origin and destination are well versed in rail economics and are utilizing a railcar shipment lot size when possible. Following this logic, the focus of this study is on historical full-truckload-shipment lot sizes and the truck-versus-intermodal decision, excluding other lot sizes from the analysis.

A more subtle EOQ issue arises when considering various truck sizes. There are two predominant equipment capacities: 48-foot and 53-foot trailers and containers. When evaluating the economics of shipment, the differences in rates for transportation for each of these equipment sizes is included. However, in practice, these options do not appreciably affect the EOQ decision. A full truck can be defined as one that has reached the maximum legal weight allowed ("weighed out") or that has used all the space in the trailer ("cubed out"). Each commodity type has a different density; more dense product weighs out before it cubes out and moves in 48-foot equipment and less dense product cubes out before it weighs out and moves in 53-foot equipment. Because density of a commodity is fixed, each commodity is projected to always move in the same equipment size and thus a "full truck" is always the same lot size regardless of the multiple options in equipment size. Thus, by limiting the analysis to full truckload quantities, the transportation buying decision is simplified to one based strictly on the transportation cost/service continuum.

Inventory and Transportation

Queuing of inventory at origin and destination of shipment is the same regardless of mode because lot size is fixed in this study. Accordingly, the model can focus strictly on pipeline inventories in transit driven by transit time, and safety stock of inventories because of variability of transit time.

To explicitly measure the cost of service variability, the model measures the cost of holding safety stock inventory at a destination to protect against stockouts. As in Sheffi (1988), the requirement of the shipper is specified in terms of a required "fill rate" which is the percentage of the time that demand is met from in-stock inventory. The required fill rate is assumed to be 98%, meaning that shippers plan on the 98th percentile arrival time to meet their customers' orders.[1] The 98th percentile measure of transportation arrival time then includes all inventory required to be held to account for both longer average duration as well as any arrival time variability in the transportation mode. Thus, the model captures both pipeline and safety stock. As modified from Sheffi (1988), the total logistics cost (TLC) per unit is:

$$\text{TLC} = \text{TC} + V * i * t \qquad (1)$$

where TC is the transportation cost per ton, V is the value of the product per truckload (value per ton times tons per shipment), i is the inventory holding costs (measured as a percentage), and t is the expected 98th percentile transit time of the shipment.

Construction of Shortest Paths

For each shipment analyzed, the road distance and expected travel time is used for calculating the total logistics cost of a truckload move. For the rail network move, minimum total logistics cost of a move can be found using Dijkstra's algorithm (Dijkstra, 1959) employing a method similar to that used by Barnhart and Ratliff (1993). Because of the large number of shipments and paths to consider and the size of the network, this method proved to be computationally burdensome.

A greedy heuristic method performed admirably because of the special structure of the problem. For the trucking option, the problem is trivial. A single arc from origin to destination includes the truck rate plus the total inventory holding costs for the transportation time. For the rail network, each path from origin to destination consists of three legs: an origin dray and destination dray connected by rail long haul. Because the cost for dray is typically four times the cost per mile of the rail component of the move, it is usually true that the shortest-cost path through the rail network is via the origin ramp and destination ramp closest to shipper origin and destination. However, because of differentials in rail rates and service that are origin-destination specific, occasionally a longer dray is warranted. Thus, the nearest five origin and destination ramps are considered as candidates for routing, and the lowest cost path based on that subset of the paths is chosen for comparison to the cost of a truckload move.

For capacity planning purposes, a conservative approach is taken for estimating potential rail demand. First, intermodal options are limited by considering only rail ramps within 500 miles (one day's trucking distance) of origin and destination. Typically, a one-day dray is the maximum that is economically advisable. Second, any intermodal option that has a 98th percentile transit time that is in excess of two days longer than the trucking option in that lane is excluded. Although longer transit times can be accommodated by additional inventories, this constraint is imposed to recognize an upper bound on a shipper's willingness to accept longer shipment times, regardless if such time and increased inventory is justified economically by lower transportation costs. In both cases, the rail options are limited and costs of rail are overstated, thereby reducing the estimated total opportunity for shippers to convert to intermodal.

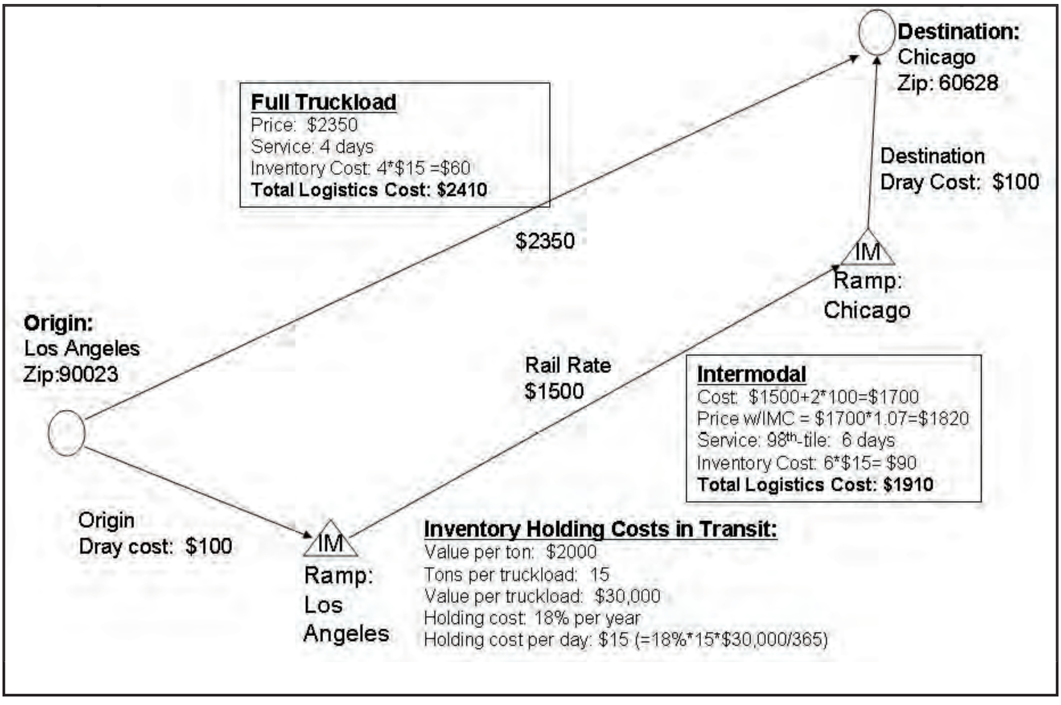
Figure 1 illustrates the calculus for a shipment choice from Los Angeles to Chicago for a fictitious shipper. The illustrative commodity, general mixed freight, has an average value per ton of $2,000 according to estimates from the Bureau of Transportation Statistics, *Commodity Flow Survey*. Using an inventory holding cost of 18% per annum and 15 tons per truckload, the cost per day of a truckload of inventory in transit is $15 per day per truck ($2,000 per ton * 18% per year * 15 tons per truck/365 days per year). The truck transportation price is the door-to-door truckload rate ($2,350); the rail price is the sum of origin and destination dray, rail line haul, and Intermodal Marketing Company (IMC) fees ($1,820).

The model compares the total logistics cost in this lane and chooses the option with the lowest total logistics costs. In this illustration, the lower transportation cost of intermodal justifies holding additional inventories and the intermodal option is superior in terms of total logistics costs. Although in this illustration truckload is two days faster than intermodal and therefore requires 33% less inventory ($90 for rail, $60 for truck), the transportation cost premium does not justify the reduced inventory requirements. By modeling this decision thousands of times across multiple geographic regions, commodities and shipper proximity to rail ramps, the model can help identify the traffic flow patterns that seem to diverge from TLC model recomendations.

DATA SOURCES AND EMPIRICAL METHODOLOGY

Year 2000 U.S. freight traffic flows were analyzed to evaluate the potential demand for each mode evaluating each shipper's actual modal choice decision against the total logistics cost (TLC) model results. If the TLC model

Figure 1: Logistics Optimization Example: Los Angeles to Chicago Full Truckload Shipment of Mixed Freight



indicates an alternative mode mix than was recorded in the traffic flow database, then it is interpreted as an indicator of feasible modal shift and the basis for considering incremental rail capacity.

Traffic Flow Data

Transearch® Freight Market Data from Reebie and Associates is used to characterize current traffic flows in the United States. The flow file indicates total tons by commodity class shipped between basic economic areas (BEA) in the United States. Only the shipments that moved by full truckload, private truckload, and intermodal (truck and rail combined) are considered in this analysis, eliminating all air, water, less-than-truckload and full railcar movements. The U.S. Department of Transportation Bureau of Transportation Statistics *Commodity Flow Survey* indicates that these modes account for 70% of all the tons moved in the United States each year. The analysis is limited to shipments that travel between BEA's in the contiguous 48 states, which accounts for more than 90% of the intercity truckload traffic overall (based on summary analysis of Reebie *Transearch* data).

This data represent more than 932,000 commodity-origin-destination combinations over which freight has flowed historically. As a matter of practicality, only the origin-destination pairs that average more than two trucks per week in 2000 are included in the analysis. This limitation reduces the number of freight flow combinations to just over 75,000 (8% of the total commodity origin-destination pairs in *Transearch*), but excludes only 14% of the tons in the base data file. As such, the most important flows in the United States are included while vastly reducing the number of records to process.

Shipper Sampling

Basic economic areas can encompass wide geographic regions and as such are inadequate for determining total logistics costs for intermodal movements. Proximity to the rail ramp is a critical determinant of the economic feasibility of the rail option. A second data source was required to give a more precise understanding of origin and destination of shipments. Reebie and Associates' *Freight Locator*® data identifies a sample of specific producers' total output by commodity and specific location at the street address level of detail.

However, this source does not indicate the destination of shipments. Thus, the two data sources were combined: total traffic flows from *Transearch* and precise origin and destination of shipments from *Freight Locator*. It doesn't matter which shippers would utilize each mode; only the geographic areas within BEAs that generated and received freight are important for planning. A cumulative probability density function (CDF) is thus created for each BEA that expressed the probability of shipment from each ZIP code in the BEA as a function of the total outbound shipments of the ZIP code based on *Freight Locator* estimates. The same CDF is used at the destination of each shipment, based on the assumption that the ZIP codes that produce the economic activity receive freight in the same relative quantities.

ZIP codes within the origin and destination BEA's are randomly sampled for each commodity that flows between two BEA's based on the commodity's volume-weighted CDF, using the centroid of the ZIP code as the location of the shipper and receiver. In effect, high-volume origin-destination pairs are more frequently sampled because the more flows between two BEAs, the more shipper locations within the BEA's were sampled. This volume-weighted random sampling more narrowly defines likely shipper locations and more exactly specifies shipment and total logistics costs. Because of the large number of origin-destination-commodity combinations, extensive sampling is conducted. Resampling does not appreciably change the results.

Truck and Rail Data Requirements

To maintain comparability to trucking, a door-to-door intermodal rail cost is calculated based on four factors: rail rate, dray (origin and destination truck transportation), equipment costs, and management fees.

Rail data from the Burlington Northern Santa Fe Railway (BNSF) was collected on the location of more than 40 rail ramps in major metropolitan areas in the western United States for calculating dray distances from customers to rail ramps. The cost of dray per mile by location and equipment type is derived from BNSF experience. A minimum dray cost is specified for drays of short distance, and a maximum dray distance is constrained based on the customer's service expectation (500 miles, or one-day's dray, maximum).

BNSF provided 2001 intermodal rail rates and historical 98th percentile service levels (hours in rail transit) for all rail ramp pairs for which it provides service. In the cases when the rail rate does not include equipment in the rate, the total is calculated based on the transportation-only rate plus an imputed lease rate per day of trailer or container equipment.

Finally, a 7% management fee is assessed for the management of each intermodal shipment. Because intermodal is inherently more complicated a product to buy and execute than trucking, intermodal marketing companies, or IMC's, have emerged. Similar to freight forwarders and truck brokers, the IMC's handle the intricacies of an intermodal shipment for the shippers to mirror the transactional simplicity of purchasing truck. Thus, from a shipper perspective, a third party manages the hand-offs between the modes, making the product truck-like in all ways but service speed and variability.

Full truckload costs are based on the North American Truckload Rate Index, a comprehensive source of truck rates, and financial statements of major trucking companies.

Inventory Carrying Cost Data

Estimates of inventory carrying costs are required for comparing transportation modes with different service speeds and reliability. The cost of holding inventories includes interest; insurance; warehousing; shrinkage and damage; and management, handling, and administrative costs. Although exact inventory carrying costs vary by product and company, these costs are typically estimated in the 20-30% of commodity value per year range in Delaney (2000). This means that for every $1 in inventory, a cost of 20-30 cents is assessed per year for holding this inventory. A 17% per annum carrying costs for products in transit is used in this study, because equipment costs are included in the transportation rate and no warehouse is being used while product is in transit. Data provided in the U.S. Department of Transportation, Bureau of Transportation Statistics *Commodity Flow Survey* was used for the value of major commodity groups per ton.

EMPIRICAL RESULTS

The TLC model was run on the *Transearch* database of 75,047 potential shipment lanes over which 825 million tons of freight flow. Because of shipper or receiver distance from an intermodal ramp with BNSF service, 16,226 of these lanes had feasible rail service defined. The maximum dray distance constraint of 500 miles and the western U.S. geographic limitations of BNSF railway eliminated many origins and destinations from rail consideration. Further, rail origin-destination pairs are limited because less than 30% of all intermodal ramp pairs in this study have defined service. For example, although BNSF has an intermodal rail ramp in both Phoenix and Seattle, no intermodal service is defined for that origin-destination pair. Only 146 million tons have feasible access to intermodal ramps, thus 82% of all potential freight traffic is excluded from rail consideration because no rail service exists.

For markets served by BNSF, the model indicates opportunities for modal shift in both directions. Table 1 shows aggregate results in mode shift opportunity.

Summary results from Table 1 indicate that 50 million tons could be shifted from truckload to intermodal, representing a reduction of 44% of existing truck freight shipments (or equivalently, a 145% increase in intermodal) in lanes where viable intermodal service exists. It should be noted that despite the large modal shift potential in the high-volume, western U.S. lanes under consideration, this conversion represents only 5% of the total U.S. truck and rail freight market.

Figure 2 shows the modal shift potential for the markets addressed, expressed as a percentage of the total existing flows: 62% of the flows stay in existing modes, but 38% should shift modes, 36% of which is shifting from truck to rail. Caution should be taken in interpreting

Table 1: Summary of Total Logistics Cost Model Results for Origin-Destinations with Rail Options

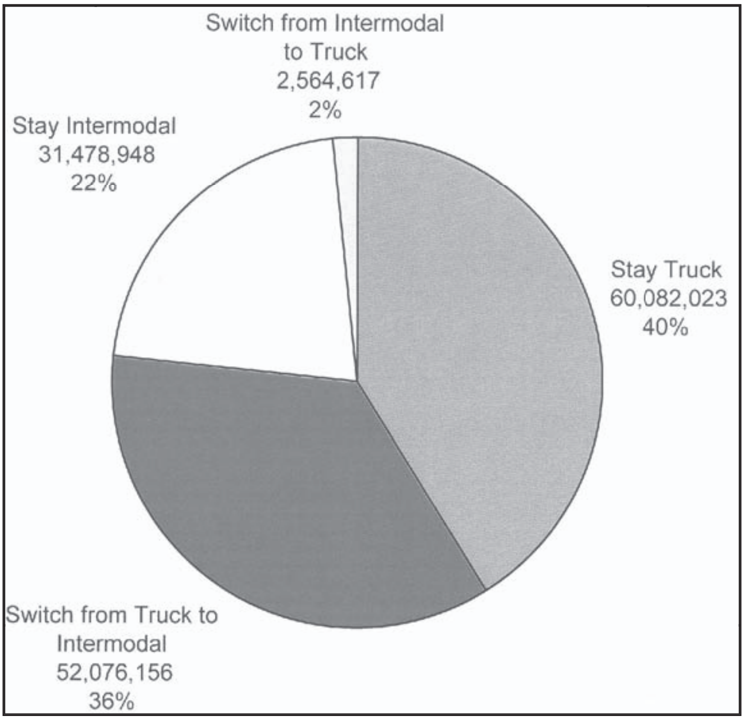
	Truckload Tons	IntermodalTons	Existing Total Tons
Total Existing Tonnage Flows	112,158,179	34,043,565	146,201,744
Model Recommended Tons	62,646,640	83,555,104	146,201,744
Percent. Change	44%	145%	

these results. By the nature of the modeling used, each market and commodity is either better off using truck or rail. In practice, because of a number of factors such as capacity availability, varying commodity values, shipper-negotiated rates, distances from rail ramps, and shipper preferences, a mix of modes is the norm. Only the *potential* for modal shift is demonstrated, actual shift will vary depending on modal capacities, pricing, and the level of marketing effort employed.

The average savings in total logistics costs from shifting modes, including inventory carrying costs, is 21%. The total potential savings for shippers from modal shift is $1.5 billion. As a point of comparison for the order of magnitude of this savings, the BNSF railway as a whole has revenues of approximately $10 billion, with only $2.5 billion of that coming from its intermodal product.

The detailed nature of this modeling effort allows BNSF to observe in which geographic regions to plan its expansion and base its marketing effort. Tables 2 and 3 show the largest truck-to-rail shift opportunities by origin and destination state; Tables 4 and 5 do the same by city. Recall that only BNSF rates were used in this analysis, thus, the majority of opportunities are in western states. To explain opportunities identified to or from eastern states, BNSF has

Figure 2: Mode Shift Analysis Based on Total Logistics Cost Tons and Percent of Total



some limited "through rates" with eastern carriers for which BNSF can sell intermodal product that extends beyond its rail network. Additionally, dray can be conducted from BNSF's eastern most points (e.g. Chicago, Kansas City, and Memphis) to reach some eastern locations.

Although California emerges as both a top origin and destination for rail opportunity, it is important to note that top rail traffic opportunities are not within California, but to and from California. Table 6 shows top origin-destination state pairs.

Table 7 shows the top modal conversion by commodity type. Note that fresh vegetables are the top conversion commodity, and that these products tend to have a short shelf life (translated as a high inventory holding cost in this model). Two additional days transit could significantly reduce their salability. Other high-conversion commodities tend to be products of higher value. Model sensitivity to increased inventory holding costs is measured below.

Figures 3 and 4 show the the distribution of preferred mode by transit distance. In general,

Table 2: Top Modal Conversion Opportunities by State of Origin

State	Converted Tons
California	22,867,415
Washington	3,991,827
Texas	3,915,085
Illinois	1,853,715
Michigan	1,713,794
Indiana	1,661,034
Oregon	1,634,973
Ohio	1,617,768
Arizona	998,069
Louisiana	914,435
Wisconsin	794,529
Pennsylvania	731,283
Florida	650,013
Minnesota	634,370

Table 3: Top Modal Conversion Opportunities by State of Destination

State	Converted Tons
California	11,215,371
Texas	5,588,605
Illinois	5,340,805
Indiana	2,761,091
New Jersey	2,473,288
Michigan	2,158,736
Ohio	2,047,299
Pennsylvania	2,001,354
Wisconsin	1,606,492
Washington	1,414,275
Minnesota	1,340,635
Georgia	1,202,120
New York	1,107,194
Connecticut	998,047

Table 4: Top Modal Conversion Opportunities by City and State of Origin

City	State	Tons
San Francisco	California	1,901,360
Indio	California	1,359,850
Los Angeles	California	1,272,409
El Segundo	California	1,087,434
Wilmington	California	642,305
Santa Fe Spring	California	539,854
Fresno	California	524,755
Martinez	California	511,852
Dallas	Texas	435,945
Blaine	Washington	433,848
Long Beach	California	399,302
Orange	California	382,036
Torrance	California	372,640
Fort Worth	Texas	363,879

Table 5: Top Modal Conversion Opportunities by City and State of Destination

City	State	Tons
Indio	California	913,538
Chicago	Illinois	842,497
Houston	Texas	832,248
Los Angeles	California	779,677
North Chicago	Illinois	724,207
San Antonio	Texas	689,811
Wilmington	California	624,407
Dallas	Texas	529,611
San Francisco	California	427,921
Riverside	California	412,459
East Chicago	Illinois	410,348
Saint Louis	Missouri	394,615
Torrance	California	391,711
Indianapolis	Indiana	368,334

as would be expected, rail is superior over long distances. The handoffs between dray and rail give rail short hauls a higher cost structure and lower service levels. The average distance for which rail was the desirable option was 2,070 miles; the distribution of these distances is shown in Figure 3.

On the other hand, truck-preferred shipments averaged 1,122 miles with the distribution depicted in Figure 4. It is worthy of note, however, that considerable overlap exists between truck and rail in the 750-2,000 mile range. These shipment distance distributions correspond well with the data reported by the U.S. Department of Transportation *Commodity Flow Survey*, confirming the model's predictive capability.

Implications for Railroad Executives and Public Policy

Overall, the model results indicate that a substantial amount of current long haul truck freight could be moved with lower total logistics costs by intermodal rail, while relatively little freight currently using intermodal

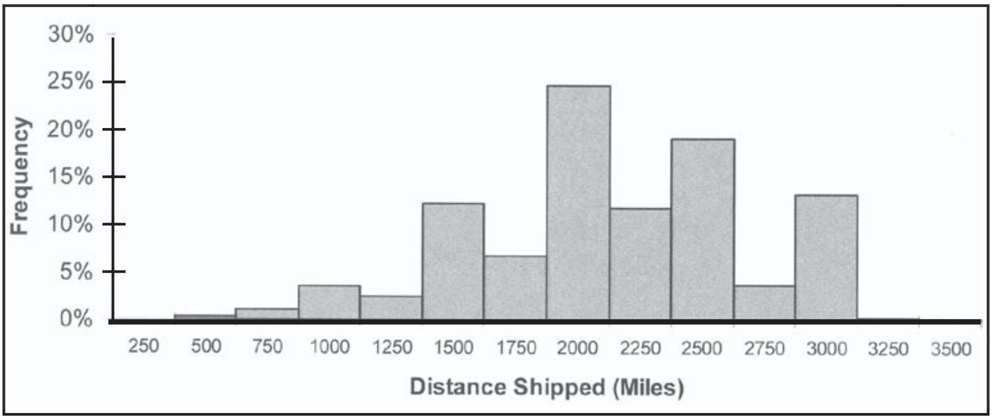
Table 6: Top Modal Conversion Origin-Destination Pairs by State

Origin State	Destination Sate	Converted Tons
California	Texas	2,407,404
California	Illinois	2,333,605
California	New Jersey	1,996,383
Texas	California	1,741,892
California	Indiana	1,530,645
California	Pennsylvania	1,450,877
California	Georgia	1,171,449
California	Ohio	1,149,738
Michigan	Texas	1,012,223
California	Michigan	996,266
California	Connecticut	871,054
California	New York	864,338
Texas	Illinois	826,492
Illinois	California	771,843
California	Massachusetts	758,645
Ohio	California	753,897

Table 7: Rail Modal Conversion by Commodity Type

Commodity	Converted Tons
Leafy Fresh Vegetables	3,777,189
Miscellaneous Plastic Products	3,665,949
Motor Vehicle Parts or Accessories	3,094,547
Deciduous Fruits	1,916,708
Plywood or Veneer	1,663,418
Paper	1,081,133
Fiber, Paper or Pulp board	1,011,801

Figure 3: Distribution of Shipment Distance for Intermodal Rail Preferred



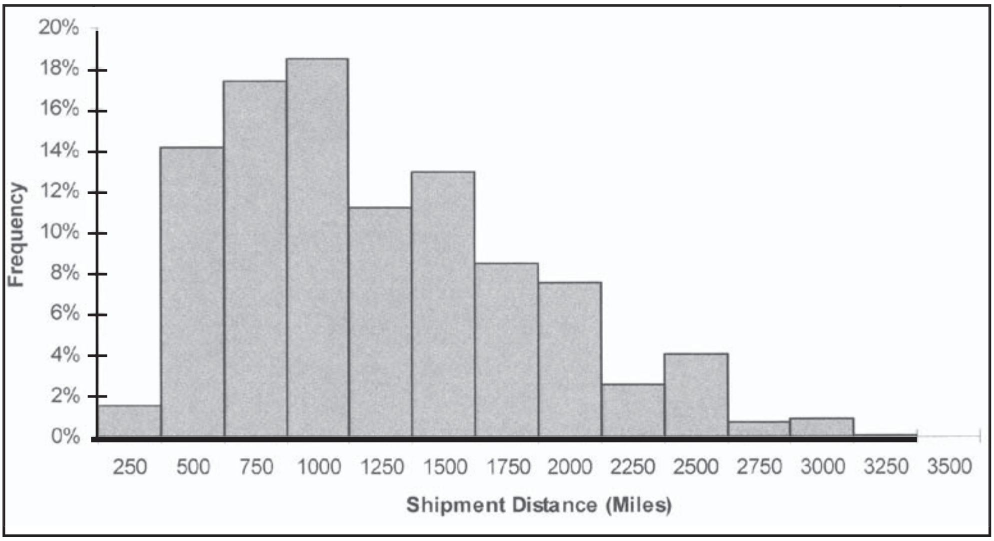
would be moved more cost effectively by truck. For railroad executives who face tight capacity constraints and challenges justifying infrastructure investment to their shareholders, these results suggest that there is potential for intermodal price increases which may help to justify more investment in expanded rail capacity to accommodate these shippers.

For public policy makers, extensive investment in highway capacity based on historical truckload shipments and growth rates may result in a misallocation of funds. Much truck freight could be moved via intermodal with lower total logistics costs for shippers and lower societal costs (e.g. congestion and pollution) if the rail capacity existed. Well-placed public investment in the freight rail infrastructure would help supply the rail capacity for the freight that could move via rail, and may be justified through the savings in reduced highway investment to support that freight movement.

Sensitivity Analysis

The predictive model was evaluated for sensitivity to key assumptions and model parameters. The primary interest is in understanding the likelihood of the predicted modal shift from truck to rail. First, the inventory carrying cost estimate was doubled from 17% to 34% to evaluate the impact on modal shift from truck to rail. (Transit time and inventory holding costs enter into the

Figure 4: Distriution of Shipment Distance for Truck Preferred



total logistics cost function in the same fashion; similar results apply to increasing the rail transit time.) From doubling the inventory carrying costs, 427,000 gross tons that had shifted from truck to intermodal were better off staying truck (approximately 1% of the predicted shifted freight). As would be expected, conversion reversal to truck occurred in the higher valued commodities. The robustness of the finding with respect to this parameter is somewhat expected because the transit time difference between truck and rail averaged 1.3 days in the routes where intermodal was preferred and was at most two days more than truck. (Recall, any rail service that took more than two days longer than truck service was excluded from modal conversion.) Accordingly, the transportation cost constituted the majority of the total logistics costs (roughly 80%), and therefore had a larger impact on modal choice than inventory costs.

The model was further tested for sensitivities to the estimated transportation price to allow for shipper-specific volume discounts for full truckload or under-estimate of IMC brokerage fees or dray costs. To account for these potential errors, any modal shift that was based on a total logistics cost savings of less than 20% from full truckload costs was subtracted from the conversion potential. (For example, a shipper may not be inclined to change modes for less than a 20% savings in total logistics costs, thus smaller savings amounts may not produce modal conversion.) A total of 16 million of the predicted 50 million tons (just under one-third) of freight do not shift from full truckload to intermodal in this scenario. Thus, the transportation cost estimate is a more important determinant of model results than inventory holding costs. Still, the general findings hold for the majority of the freight that is predicted to shift modes even with higher transportation costs.

EXTENSIONS

The analysis could be expanded in both geographical extensiveness and intensiveness. The results here are based solely on the western United States and existing intermodal service. Because of the more compact geographic distribution of major population centers in the eastern United States, the expected results may be markedly different in new geographies and markets. Due to the generally shorter lengths of haul in the East, the potential truck to rail conversion would be much smaller. Another evaluation of network expansion that could be evaluated is to increase the density of intermodal ramps and connectivity between those ramps to evaluate the modal shift in markets where no intermodal service currently exists.

This methodology could be extended to evaluate different lot sizes and service levels. Although the focus here is on full truckload lot sizes only, this model has been applied to broader ranges of rail freight transportation services such as rail boxcar, which has three times the capacity of truck. By including inventory queuing costs at origins, the shippers' propensity to shift to larger lot sizes can be evaluated. More information would be required of specific shippers' shipment activity in each lane to evaluate shipment aggregation potential, and is thus impossible in this macro setting.

Finally, this modeling and data analysis approach may be applied to other areas of study, such as an optimization-based estimate for shipper price and service responsiveness.

CONCLUSIONS

Optimization-based methods are used to forecast potential modal conversion in specific geographies. By modeling the shipping decisions at a microeconomic level and applying them to a large-scale shipping database, the potential demand for intermodal rail service can be estimated. Deviations from model predictions may have many causes, such as model error, bounded information, rail capacity, previous shipper satisficing, previous experience and preferences, union contract issues, or a host of others. Model results are tested for sensitivity to input data errors and find the model predictions to be robust. The resulting modal conversion marketing opportunities that are based on this methodology are identified and implications discussed.

Endnotes

1. A 95th percentile assumption would advantage rail; a 99th percentile would advantage truck. The 98th percentile assumption is a middle ground and consistent with Sheffi (1988).

References

Barnhart, C. and H. Ratliff. “Modeling Intermodal Routing.” *Journal of Business Logistics* 14(1), (1993): 205-223.

Bronzini, M. and D. Sherman. “The Rail Carrier Route Choice Model.” *Transportation Research* 17(A), (1983): 463-469.

Conrad, K. “Competition in Transport Models and the Provision of Infrastructure Services.” *Journal of Transport Economics and Policy* 34 (3), (2000): 333-358.

Crainic, T., M. Florian, and J. Leal. “A Model for the Strategic Planning of National Freight Transportation by Rail.” *Transportation Science* 24(1), (1990): 1-24.

Delaney, R. “11th Annual State of Logistics Report.” Cass/ProLogis, 2000.

Dijkstra, E. “A Note on Two Problems in Connection with Graphs.” *Numeriche Mathematics*, (1959): 269-271.

Fernandez, L., J. Enrique, and A. Soto. “A Multi-modal Supply-Demand Equilibrium Model for Predicting Intercity Freight Flows.” *Transportation Research (B)* 37(7), (2003): 615-640.

Freidlander, A. and R. Spady. “A Derived Demand Function for Freight Transportation.” *Review of Economics and Statistics* (1980): 432-441.

Kremers, H., P. Nijkamp, and P. Rietveld. “A Meta-Analysis of Price Elasticities of Transport Demand in a General Equilibrium Framework.” *Economic Modeling*, 19, (2002): 463-485.

Kresge, D. and P. Roberts. “System Analysis and Simulation Models.” J. Meyer ed. *Techniques of Transport Planning*. Brookings Institute Washington, D.C. (1971).

Nash, C. “Cost-Benefit Analysis of Transport Projects.” A. Williams and E. Gardina, eds. *Efficiency in the Public Sector: The Theory and Practice of Cost-Benefit Analysis*. Edward Elgar, Aldershot, (1993): 83-105.

Class 8 Solutions, Inc., *North American Truckload Rate Index*, Woodbury, MN.

Oum, T. “A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada.” *Bell Journal of Economics* 10(2), (1979): 463-482.

Oum, T., W. Waters, and C. Yu. “A Survey of Productivity and Efficiency Measurement in Rail Transport.” *Journal of Transport Economics and Policy* 33(1), (1999): 9-42.

Oum, T., W. Waters, and J. Yong. "Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates: An Interpretative Survey." *Journal of Transport Economics and Policy* 26, (1992): 139-154.

Reebie and Associates, *Transearch*® and *Freight Locator*® database, www.reebie.com, Stamford, Connecticut (2000).

Roberts, P. "Factors Influencing the Demand for Goods Movement." Paper presented at the *Annual Meeting of the Transportation Research Board*, Washington, D.C., 1976.

Sheffi, Y., E. Babak, and H. Koutsopoulos. "Transportation Mode Choice Based on Total Logistics Cost." *Journal of Business Logistics* 9(2), (1988): 137-154.

U.S. Department of Transporation, Bureau of Transportation Statistics, *Commodity Flow Survey*, www.bts.gov/programs/commodity_flow_survey/, 1997.

Winston, C. "Efficient Transportation Infrastructure Policy." *Journal of Economic Perspectives* 5(1), (1991): 113-127.

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