JOURNAL OF THE TRANSPORTATION RESEARCH FORUM

Volume XXXII Number 1 1991

TRANSPORTATION RESEARCH FORUM

Grain - Railroads.
Railroads - freight cars
Railroads - Freight - Yield manage. model.

Railroad Grain Car Pricing And Supply Models

by Gregory R. Pautsch, Marty J. McVey*, C. Phillip Baumel**

Since the passage of Staggers Rail Act of 1980, railroads have implemented various types of market oriented pricing systems including contracts, guaranteed car supply programs, and the Certificates of Transportation (COTs). These pricing systems were designed to increase railroad revenues from the transport of grains. Railroad companies are beginning to investigate the use of airline yield management concepts to price and manage their car inventories (Davies, 1991). Shippers, however, are complaining about these market oriented pricing systems (Interstate Commerce Commission, 1991) claiming that market pricing reduces shipper profits. Moreover, one study has suggested that railroad grain car shortages will be inevitable during the decade of the 1990s (Norton and Klindworth, 1989). Thus, grain car shortages and grain car pricing are likely to be major issues facing the railroad and agricultural sectors during the next decade.

One reason for persistent car shortages and surpluses is the large fluctuations in the demand for grain cars. The sources of these fluctuations include (1) political events such as grain embargoes and guaranteed export credits, (2) government programs such as the Export Enhancement and domestic acreage reduction program and (3) weather. A typical situation which increases the demand for grain cars is a temporary surge in grain exports. Figure 1, using a 4-week moving average, shows the trend in railroad car loadings for domestic and export destinations during the 1988-1990 period. Grain car loadings for domestic destinations were relatively stable, whereas, three major surges in car loadings for export destinations occurred during the three-year period.

Surges in exports or other demand factors cause shippers to face highly volatile cash grain prices. Grain traders use hedging to replace the risk associated with volatile cash grain prices with the more predictable changes in the futures basis. The basis is defined as the difference between the local cash price and the price of a specific futures contract. As the delivery date for the futures contract nears, the elevator expects the basis to narrow reflecting the decreasing cost of storing the grain to contract expiry. Since most grain merchants hedge their grain purchases and sales, it is the unexpected change in the basis that signals shippers to sell grain and order cars.

The expected per bushel profit to a grain merchant from selling grain to market j and lifting the hedge in the futures market at time t is expressed by equation 1:

$$E\pi_t = (EB^j_t - B_o) - S_t - ETC^j_t \qquad (1)$$

where:

$E\pi_t$ = the expected per bushel profit,
EB^j_t = the expected basis in market j,
B_o = the initial basis,
S_t = the accumulated storage and handling costs,
ETC^j_t = the expected transportation cost to market j,
t = time.

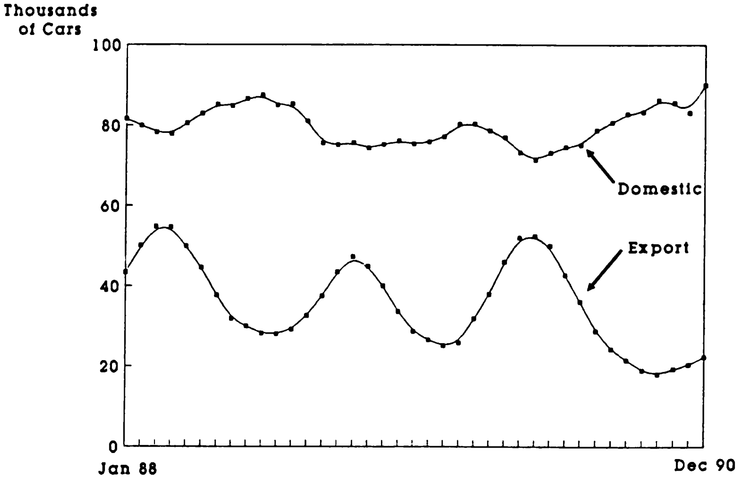
Equation 1 states that the expected per bushel profit is the basis improvement minus storage and expected transportation costs. In Figure 2, the per bushel expected profit to the grain merchant under a fixed tariff transport rate is 10 cents a bushel. The expected profit is zero at time t', increases to 10 cents at time t^*, then decreases to zero at time $\bar{t}$. To maximize profits, the grain merchant will sell the grain to market j and lift the hedge at time t^*. As a result, the merchant will order cars at the beginning of the horizon to be delivered at time t^*. In an extreme case of many identical and risk neutral grain merchants, all car orders would be for delivery at time t^*.

The expected profit from the basis creates the temporary surges in car orders and loadings. Therefore, the demand for railcars is derived from the demand for grain and the value of transportation to the shipper depends upon demand conditions. If the export demand for grain is high and the basis narrows, the value of transportation will be

Journal of the Transportation Research Forum
Volume XXXII, Number 1, 1991

FIGURE 1

Grain Car Loadings, Class I Railroad, By Four Week Periods*



* Moving Average

Source: U.S. Department of Agriculture, 'Grain Transportation Situation'

greater for a shipper than if the demand for grain is low and the basis is wide.

The basic purpose of this paper is to present models of railroad grain car pricing and covered hopper car supplies which incorporate varying demand conditions in market oriented pricing systems. First, we explore the relevance of the common carrier obligation to market oriented pricing models. Next, we compare the consequences of a regulated tariff system to market oriented systems. Then we use airline yield management techniques to allocate grain cars over corridors and priority classes. Finally, we present a railcar pricing model that incorporates fluctuating railcar demand.

COMMON CARRIER OBLIGATION

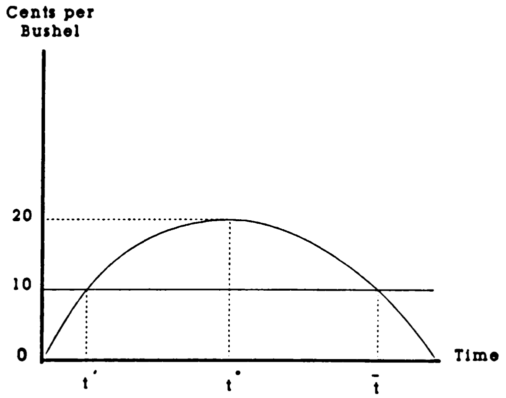
Perhaps no transportation concept is taken more for granted, as an evident legal standard, then common carriage. Its origins appear to be in the English common law in an effort to control the conduct and service of public hackney coaches. References to common carriage may be found in many sections of the Act to Regulate Commerce (U.S. Congress, 1887). Nowhere, however, is it defined in that Act. Further references may be found in many cases of the Interstate Commerce Commission (ICC), usually in the context of "common carrier obligations" or "duties".

Despite assumptions regarding those "obligations" or "duties," its use in case law provides no definition. There seems to be no statutory or regulatory authority for its meaning, although it may be deduced from historical precedents. A common carrier seems to be one that offers its transport service, either for the movement of commodities or passengers, to all who would demand such service on terms and conditions that are generally applicable to all. But nowhere are the terms and conditions defined.

To the extent that the common carrier obligation has been applied to the distribution of rail grain cars, that obligation began to erode in the 1960s with the introduction of the dedicated rent-a-train and unit-grain-trains with consecutive trip requirements. The last times the ICC applied the common carrier concept to the allocation of covered hopper rail cars were in car service orders 1223 (Oswald, 1975) and 1304 (Homme, 1975). Both car service orders required railroads to reduce the number of their jumbo covered

FIGURE 2

Expected Hedging Profit



hopper cars in unit-grain-train service to 20 percent of their owned fleet. However, car service order 1304 ended up with 13 exceptions (Burns, 1978) which substantially diluted the impact of the original order.

Since 1980, several railroads have developed covered hopper car allocation procedures that differ substantially from the common carriage procedures that existed for about 100 years. These new car allocation procedures were developed to:

a. eliminate over-ordering of cars during peak demand periods,

b. allocate cars to shippers who had historically shipped large quantities of grain by rail or had recently made large investments in facilities to ship grain by rail,

c. allocate cars to services that were priced at non-tariff levels,

d. allocate cars to the most efficient moves during peak demand.

These developments suggest that the common carrier obligation had a declining impact on covered hopper car allocations as long as two decades prior to the passage of the Staggers Rail Act and has had little or no impact on car allocation for a full decade following passage of the Staggers Act. The lack of a precise definition and the declining relevance of the common carrier obligation in actual covered hopper car distribution procedures suggest that the common carrier obligation should have little impact on the development of railroad grain car pricing and allocation models.

REGULATED TARIFF PRICING SYSTEM

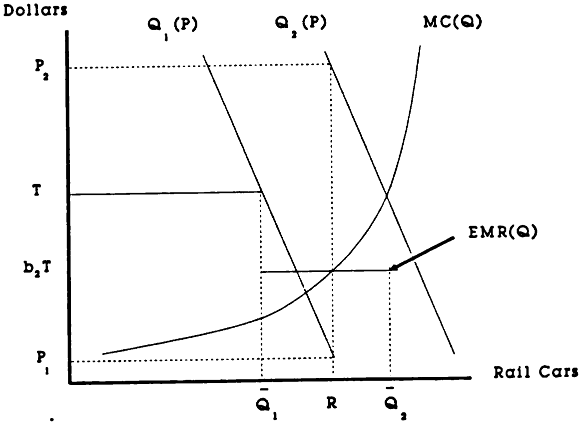
Prior to the Staggers Rail Act, most railroad rates were posted tariffs that were essentially "take it or leave it" rates. Tariff rates were relatively rigid because of a 30-day minimum notice for rate changes and up to 10 months if an investigation was initiated. Since Staggers, tariff rates have been less sticky but remain relatively rigid compared to truck and barge grain rates. In this section, we examine the consequences of inflexible tariff rail rates when the demand for grain cars fluctuates.

For the purpose of the analysis in this paper, we assume the railroad can estimate the demand for rail cars at any time t. For simplicity, assume the railroad expects to be in one of two demand states. The demand curve $Q_1(P)$ is grain car demand under normal conditions, while $Q_2(P)$ is grain car demand if there is a sudden surge in grain exports. The railroad expects to face a normal demand with probability b_1 or an increased demand from a surge in exports with probability b_2 ($b_1 + b_2 = 1$). The cost of acquiring and operating a fleet of Q cars, C(Q), is assumed to be independent of the demand state s. Assume the fixed tariff rate is \$T.

In Figure 3, the demand for grain cars at the tariff rate is $\bar{Q}_1$ under normal demand conditions and $\bar{Q}_2$ under a surge in exports. The railroad will acquire cars until the expected marginal revenue of a car, EMR(Q), is equal to the expected marginal cost of operating and purchasing a car, MC(Q).

FIGURE 3

The Optimal Size Fleet Under Tariff Rates



Assume that the marginal cost is upward sloping and that the tariff is at a level such that the marginal cost of $\bar{Q}_2$ exceeds its expected marginal revenue, b_2T. Further, assume that the expected marginal revenue of $\bar{Q}_1$ exceeds the marginal cost of the car. The expected marginal revenue of the first $\bar{Q}_1$ cars is equal to $\$T$, since the railroad expects to use these cars under either demand state. However, the expected marginal revenue of the next $\bar{Q}_2 - Q_1$ cars is $\$b_2T$, because the railroad expects to use these cars only if a surge in exports occur.

In Figure 3, the optimal fleet of cars for railroad is R. If a sudden surge in exports occurs, there will be a shortage of $\bar{Q}_2$-R cars. But under normal demand conditions, there will a surplus of R-$\bar{Q}_1$ cars. If all shippers face a constant tariff price, no grain shipper can be certain of receiving cars for loading during periods of car shortages. One method of eliminating the persistent shortages and surpluses of cars is to allow prices to clear the market. Allowing railroad rates to vary in Figure 3, the railroad with a fleet of R cars will receive P_2 during surge periods and P_1 during normal periods.

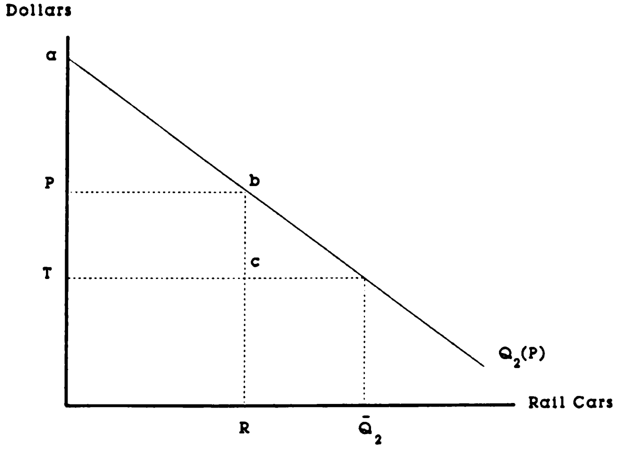
PRIORITY PRICING

Many mechanisms exist in the rail industry to allocate cars during equipment shortages. One mechanism is to maintain fixed rates during peak demand periods and implement a program to allocate cars. Under the fixed tariff system, cars have been historically allocated using a first come, first serve basis and more recently by a historical use basis. A shortage or surplus of cars will persist under either program since rates are fixed. Also, cars are not likely to be allocated to their highest valued use. Assuming tariff rates and a fleet of R cars, figure 4 shows the benefit to shippers during peak demand is the area under the demand curve abcT and the shortage of cars is $\bar{Q}_2$-R. Since there is a shortage of cars, shippers have no guarantee of receiving cars to load. The additional costs imposed on shippers from unreliable car supplies are increased interest and inventory costs, late delivery penalties or foregone sales. Hence, the net benefit to shippers is the area abcT minus the costs from unreliable car supplies.

Wilson (1989) introduced the concept of priority pricing to allocate cars among shippers, eliminate car shortages and surpluses and to reduce grain merchandising costs. The purpose of priority pricing is to allocate cars to shippers with the highest value for transportation and to provide a method of ensuring car supply for a future date. One method of implementing a priority pricing system is to use an auction to allocate the scarce cars. Shippers compete with each other for the given fleet of cars by offering bids. The maximum amount a shipper will bid is the value the shipper places on transportation and is reflected by the height of the demand curve. If all shippers bid their maximum value, the area of benefit to shippers under the demand curve in Figure 4 is zero. This area of benefit has been transferred completely to the railroad, but bidding shippers will gain from the decreased costs from a guaranteed car supply.

FIGURE 4

Shipper Surplus During Peak Demand Under Various Pricing Schemes For a Given Fleet Size



AIRLINE SEAT INVENTORY AND RAILCAR INVENTORY MODELS

A rail car inventory control model is presented using airline yield management techniques. The analysis assumes the railroad offers a menu of services consisting of two priority classes called guaranteed and nonguaranteed car supply. The model finds the optimal allocation of cars across priority classes and corridors which maximizes expected railroad revenue for a given fleet size.

The airline seat inventory control problem and the railroad car inventory control problem have similar characteristics. An airline is uncertain about the number of orders it will receive from the fare classes for the seats on a flight. Likewise, the railroad is uncertain about the number of car orders it will receive from shippers in different priority classes. Assume the full fare class for a railroad are the shippers willing to pay a premium for guaranteed car supply, while the discount fare class includes the shippers willing to take the risk of nonguaranteed car supply. The airline decides the optimal number of seats on a flight to be allocated to each of the two fare classes, while the railroad decides the optimal number of cars to be allocated to each priority class on a corridor. A difference between the airline and railroad inventory control problems is that the number of seats on a flight is fixed, while the number of railcars on a corridor can vary.

The car inventory problem can be viewed as a two step approach. First, the railroad determines the optimal number of cars to be allocated to each priority class on each corridor given the fleet of cars on that corridor. Next, the railroad determines the optimal allocation of cars over its corridors given its fleet size. On each corridor, the railroad is assumed to be able to calculate the probability of a car order occurring and the average price paid from each priority class. Denote q_{ij} as the number of cars requested from priority class i over corridor j and $\alpha_{ij}(q_{ij})$ to be the probability density function for the total number of cars requested from priority class i over corridor j. The probability of having at least Q_{ij} cars requested from priority class i over corridor j is $A_{ij}(Q_{ij}) = \alpha_{ij}(q_{ij} \geq Q_{ij})$. The railroad decides the optimal number of cars to allocate to each priority class in order to maximize the expected revenue on the j^{th} corridor given the size of the fleet on the corridor as expressed in equation 2:

$$\text{Max } \bar{Y}_j = f_{1j}\bar{B}_{1j}(C_{1j}) + f_{2j}\bar{B}_{2j}(R_j - C_{1j}), \quad (2)$$

where:

$\bar{Y}_j$ = expected revenue,

f_{ij} = the average price from priority class i,

$B_{ij}(C_{ij})$ = the expected demand from priority class i, given a car allocation of C_{ij},

C_{ij} = the number of cars allocated to priority class i,

R_j = $\sum_{i=1}^{2} C_{1j}$ = the fleet of cars on corridor j,

j = corridor.

Differentiating equation 2 with respect to C_{1j} yields the revenue maximizing first order conditions shown in equation 3:

$$f_{1j}A_{1j}(C^*_{1j}) = f_{2j}A_{2j}(C^*_{2j}) \quad \text{for all j.} \quad (3)$$

Equation 3 states that to maximize expected profits on each corridor, the railroad equates the expected marginal revenue of a car across priority classes. In other words, the total expected revenue from a given fleet size on corridor j cannot be increased by reallocating a car between guaranteed and nonguaranteed car classes. The optimal allocation of cars to each priority class on corridor j will depend on the probability density function of expected demand, the average price paid by each priority class and the fleet of cars on corridor j.

To find the optimal revenue across corridors, the optimal priority class allocations of $C^*_{1j}(R_j)$ and $C^*_{2j}(R_j)$ are inserted into equation 2. The maximum expected revenue of the railroad is the sum of the maximum expected revenue generated by a fleet of R_j cars over each corridor and is shown in equation 4:

$$\bar{Y}(R) = \bar{Y}_1(R_1) + \bar{Y}_2(R-R_1), \quad (4)$$

where:

$\bar{Y}(R)$ = the maximum expected revenue given a fleet size R,

$\bar{Y}_j(R_j)$ = the maximum expected revenue over corridor j from a fleet of R_j cars,

Differentiating equation 4 with respect to R_1, yields the revenue maximizing first order conditions shown in equation 5:

$$MR_1(R^*_1) = MR_2(R^*_2). \quad (5)$$

where:

$MR_j(R^*_j)$ = expected marginal revenue over corridor j.

Equation 5 states that to maximize profits, the railroad equates expected marginal revenue from a car across corridors, and the total expected revenue for the railroad from a given fleet size R cannot be increased by reallocating a car across corridors.

The railroad car inventory model, based on the airline seat inventory model is presented in a static framework and assumes independent demands between priority classes and corridors. It is a short-run model since fleet size is assumed constant. A more complicated and realistic model would allow the demand for cars between priority classes and over corridors be interdependent (Brumelle, et al., 1990). It would simultaneously determine fleet size as well as prices and allocations across users and corridors. The following railcar pricing model is designed to achieve this simultaneous determination of optimal fleet size and allocation.

RAIL CAR PRICING MODEL

The railcar pricing model allocates cars to shippers with the highest value for transportation and allows prices paid by the priority classes to fluctuate with demand. Moreover, shippers receiving the same type of car supply service would pay the same price.

We assume the railroad is able to segment shippers by their willingness to pay for guaranteed car supply service and is able to estimate the demand for railcars for each priority class under normal and high grain demand. We denote $P_{is}(Q_{is})$ to be the inverse demand of priority class i in state s as a function of Q_{is}, the quantity of railcars demanded by priority class i in state s. State s refers to the level of demand faced by the railroad, either normal grain demand (s=1) or a surge in grain demand (s=2). The total number of railcars, Q_s, demanded in state s is the sum of the number of railcars demanded by each priority class in state s. The railroad expects normal demand conditions to occur with probability b_1 and a surge in export demand to occur with probability b_2. The cost function of the railroad is divided into two components: (1) the cost of operating Q_s cars given a fleet of R cars in state s, $C_s = C(Q_s, R)$, and (2) the purchase cost of acquiring a fleet of R cars, K(R). Finally, the number of railcars operated by a railroad in state s must be less than or equal to the total fleet of the railroad.

The railcar pricing model assumes the railroad acquires and allocates a fleet of cars among car supply priority classes before demand is known. Prices are determined from the interaction of demand and car allocations. The revenue to the railroad in state s from allocating Q_{is} cars to priority class i is the price received for the cars times the number of cars. Total revenue in state s is the sum of the revenue generated by each priority class. Total cost to a railroad is the cost of operating Q_s cars given a fleet of R cars plus the purchase cost of the fleet. The Lagrangian to maximize the profit in state s of allocating a fleet of cars among priority classes is expressed in equation 6:

$$L_s = \sum_{i=1}^{2} [P_{is} (Q_{is}) Q_{is}] - C (Q_s,R) - K (R) + \lambda_s [R-Q_s] \qquad (6)$$

where:

$$Q_s = \sum_{i=1}^{2} Q_{is} .$$

For each state, differentiating equation 6 with respect to Q_{is} yields the first order condition expressed in equation 7:

$$P_{is}(Q_{is}) + Q_{is} \left[\frac{\partial P_{is}(Q_{is})}{\partial Q_{is}}\right] - \frac{\partial C(Q_s,R)}{\partial Q_s} - \lambda_s = 0 \quad i=1,2 \qquad (7)$$

Equation 7 states that to maximize profits, the railroad must equate the marginal revenue of a car across priority classes, which means that total profit cannot be increased by reallocating a car across priority classes. The marginal revenue of a car may exceed its marginal operating cost if the fleet size constraint is binding. Otherwise, the marginal revenue of a car equals the marginal cost of operating a car.

The magnitude of Q_s shows how the fleet of R cars is used. If Q_s is less than R, some cars will be idle in state s. Otherwise, the fleet will be fully utilized. Solving the first order conditions yields optimal values $Q^*_{is} = Q^*_{is}(R)$ (i=1,2) as a function of the fleet size. Placing these optimal values into equation 6 for each state will give the maximum profit in state s. Next, the railroad determines the fleet size, R^*, which maximizes its expected profits. The expected profits from a fleet of R cars is a weighted average of the expected profit from the fleet in each demand state, where the weights are the probability of the state s occurring. The Lagrangian for determining the optimal fleet size is shown in equation 8:

$$L = \sum_{s=1}^{2} b_s \pi_s(R) \qquad (8)$$

where:

b_s = the probability of state s occurring,

$\pi_s(R)$ = the maximum profit from a fleet of R cars in state s,

$$= \sum_{i=1}^{2} [P_{is}(Q^*_{is}(R))Q^*_{is}(R) - C[Q^*_s(R),R] - K(r)].$$

Differentiating equation 8 with respect to fleet size yields the first order condition which state that the railroad will acquire cars such that the expected change in revenue from an additional car in the fleet will equal the expected change in total costs from an additional car in the fleet. Once the railroad determines the optimal fleet size, the railroad can determine the optimal number of cars to allocate to each priority class.

The above model is an alternative to the COT program and guaranteed car supply contracts in implementing a priority pricing system. The railcar pricing model sets the premium of guaranteed service to be the difference between the prices charged to the two priority classes. The premium paid for guaranteed service may be different depending on the demand state.

The railcar pricing model would have all shippers pay the same price for the same level of car supply guarantee. The amount paid by shippers in the same car supply priority class in each priority class is determined by supply and demand. Assuming a fleet of R cars, figure 4 shows shippers paying a price P and the benefit to shippers under the demand curve is the area abP. The shipper benefits transferred to the railroad is the area PbcT. In this case, the shipper benefits under the demand curve are divided between shippers and the railroad. As in the auction case, shippers' costs decrease due to guaranteed car supply and cars are allocated to shippers with the highest value for transportation.

The rail car pricing model can be extended in several ways. For example, the railroad can be viewed as a supplier of haul line service and a supplier of cars. The cost of the railroad can be separated into the cost of providing line haul service and the cost of providing cars. The railroad determines prices for its line haul service and car allocation over priority classes. The model can also be extended across corridors and types of grains. The railroad finds the optimal prices and allocation of cars across grains, priority classes and corridors. Shippers requesting guaranteed service on a particular corridor will pay the same premium.

CONCLUSIONS AND IMPLICATIONS

Several conclusions have come from the above analysis:

1. Demand for rail grain cars varies significantly with the demand for grain exports.
2. The common carrier obligation should play little or no role in future rail car pricing and allocation models.
3. Tariff rail rates, which tend to be sticky, result in recurring shortages and surpluses of rail grain cars. Market based rates will eliminate rail car shortages by increasing or decreasing price until demand equals supply.
4. The railcar pricing model is a priority pricing system which accounts for fluctuating railcar demand. The model determines the optimal grain car fleet size and allocations among priority car service classes. The model differs from an auction since it has all shippers pay the same price for the same type of car supply guarantee. However, an auction is a mechanism to discover demand for guaranteed car supply, while the railcar pricing model assumes demand can be estimated.
5. The area of benefit to shippers under the demand curve and the costs associated with unreliable car supply is greatest under a fixed tariff system. Priority pricing reduces the benefit under the demand curve to shippers, but shippers also enjoy decreased costs from a guaranteed car supply. Bidding for guaranteed car supply results in higher railroad profits and lower shipper welfare than if shippers pay the same price for the same type of service.
6. Given the Staggers Rail Act of 1980 and the forecasts and expectations of a declining number of covered hopper railcars, it is important that transportation researchers and practitioners devote more effort to developing models to improve our understanding of the efficiency and welfare implications of the growing number of railroad pricing and car allocation programs.

REFERENCES

Belobaba, Peter P., "Airline Yield Management: An Overview of Seat Inventory Control," *Transportation Science* 21, 2 (1987): 63-73.

Brumelle, S. L. et al., "Allocation of Airline Seats Between Stochastically Dependent Demands," *Transportation Science* 24, 3 (1990): 183-192.

Burns, Joel E., Distribution of Covered Hopper Cars. Exceptions 1-12 to Corrected Service Order No. 1304. Interstate Commerce Commission, Washington, D.C., 1978.

Davies, John, "BN May Follow Airline Strategy to Book Railcars," *The Journal of Commerce and Commercial* February 28, 1991: 1A.

Homme, H. G., Distribution of Covered Hopper Cars. Corrected Service Order No. 1304, Interstate Commerce Commission, Title 49, Chapter X, Subchapter A, Washington, D.C., February 24, 1978.

Interstate Commerce Commission, Docket Number 40169, National Grain and Feed Association vs Burlington Northern Railroad Company et al., Washington, D.C., 1991.

Norton, Jerry D. and Keith A. Klindworth, "Railcars for Grain, Need and Availability," U.S. Department of Agriculture, Office of Transportation, Washington, D.C., July, 1989.

Oswald, Robert L., Distribution of Covered Hopper Cars. Service Order No. 1223, Interstate Commerce Commission, Title 49, Chapter X, Subchapter A, Washington, D.C., October 30, 1975.

U.S. Congress, *Act to Regulate Commerce*. S. 379, Washington, D.C., February 1887.

U.S. Congress, *Staggers Rail Act of 1980*. S. 1946, Washington, D.C., October 1980.

U.S. Department of Agriculture, "Grain Transportation Situation," Office of Transportation, Washington, D.C., various issues.

Wilson, William W., "Posted Prices and Auctions in Rail Grain Transportation." Paper presented at the Transportation Research Forum, Williamsburg, VA, October 11, 1989.

ENDNOTE

* Iowa State University