Intermodal Pricing Model Creates a Network Pricing Perspective at BNSF

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Burlington Northern and Santa Fe Railway (BNSF) is exploring methods of pricing its network of intermodal services effectively. The problem is challenging because cost interactions between the markets arise from equipment imbalances at endpoints in the network. The intermodal pricing model takes a global perspective when establishing market prices to improve network profitability. Accounting for the vagaries of marketplace demand proved to be critical to gaining management's confidence in the plausibility of model results. BNSF has applied the model to many pricing scenarios. In the application I describe, I identified a potential for 3.5 percent improvement in net profitability through a 61 percent reduction in empty repositioning. Since 1998, BNSF has increased loaded miles by five percent and simultaneously reduced repositioning by three percent per year.

Burlington Northern and Santa Fe Railway (BNSF) generates over $9 billion a year in revenues by moving products, such as coal, agricultural products, chemicals, metals, lumber and consumer products, over the second largest rail network (33,500 route miles) in North America. The BNSF network spans most of the western half of the United States, from Chicago, Kansas City, and Dallas to Los Angeles, San Francisco, and Seattle. Its intermodal services, in which a variety of

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products move over a combination of truck, ship, and rail, generated $2.6 billion in revenues in 1999 while moving 3.2 million customer loads. BNSF Intermodal offers services to over 4,100 origin-destination pairs. For each origin-destination pair, BNSF offers as many as four intermodal service levels in as many as eight van and container lengths. All told, BNSF offers over 20,000 intermodal services.

BNSF must regularly reposition its empty equipment to account for traffic-flow imbalances in the network. Although over 96 percent of equipment miles in 1999 were loaded, BNSF generated over 200 million miles of costly empty van and container movement.

BNSF perceived an opportunity to use prices for its services to help reduce its equipment imbalances. However, because of the sheer number of services and prices offered, the uncertainty of future demand conditions, and the complex interrelations of the network, manual approaches were time consuming and ineffective. I got involved to find an automated methodology for exploring this opportunity.

Pricing managers often consider nodal imbalances in an overly simplified manner.

I developed a methodology for establishing profit-maximizing prices for intermodal services that would take into account both the market conditions facing BNSF in the markets for its services, and the equipment-repositioning requirements that resulted from those market flows. By fully incorporating repositioning costs into pricing decisions, I hoped to identify key markets for profitable pricing initiatives, to reduce equipment imbalances, and to improve profitability.

Problem Description

I designate an *equipment class* by equipment type (van or container), length (for example 28, 40, or 52 feet), and owner (BNSF or privately owned). An *intermodal market* (service or product) is an origin-destination pair and a service level (transit time) for an equipment class. I set out to find a set of prices in BNSF intermodal markets that would maximize network profits given the nodal imbalances that result within an equipment class.

The intermodal pricing model (IPM) supports BNSF's quarterly pricing strategy. It addresses the structural and persistent imbalances in the BNSF network over the upcoming quarter.

Pricing managers think primarily of the markets to which their prices directly apply and only secondarily of the resulting equipment imbalances created for locations in the transportation network. BNSF routinely tracks the costs for repositioning and allocates them back to individual markets; however, how it should allocate these costs to individual markets is not clear. Many markets contribute to the equipment flow at a location, but which ones are responsible for the imbalance? Pricing managers tend to focus on the performance of their particular markets as measured by well-recognized metrics (such as volume and gross contribution) and to discount their effect on network-wide equipment imbalances.

Because of time constraints and computational complexities, pricing managers often consider nodal imbalances in an overly

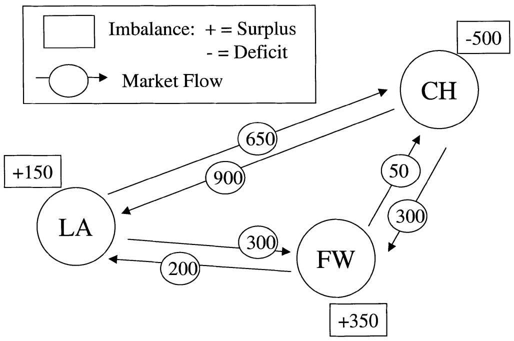

Figure 1: In this sample network, shipments between Los Angeles (LA), Chicago (CH), and Fort Worth (FW) produce equipment imbalances.

simplified manner when making pricing decisions. For example, managers often simplify their task by isolating two markets and locations in the network: the headhaul (high volume) market and the backhaul (low volume) market. They reduce nodal imbalances by either increasing the price (lowering quantity) in the headhaul market or decreasing the price (increasing quantity) in the backhaul market. One of my first tasks was to dispel this headhaul-backhaul mindset. Clearly, nodal imbalances are not perfectly correlated with market headhaul and backhaul differences. To illustrate, let Los Angeles to Fort Worth be the headhaul market and Fort Worth to Los Angeles be the backhaul market. Both Los Angeles and Fort Worth could be net surpluses because of the impact of Chicago-based market flows (Figure 1). Balancing the headhaul and backhaul markets may reduce Fort Worth's surplus but only at the cost of expanding the surplus at Los Angeles. Understanding these relationships is not easy in a more complicated network. The point is that market imbalances do not create the need for repositioning; nodal imbalances do.

Many markets affect the imbalance of a location, and balancing headhaul and backhaul market prices may be ineffective or even counterproductive in addressing nodal imbalances in a profitable manner.

Going beyond looking at the primary market or at headhaul-backhaul pricing to looking at the whole network vastly complicates the problem. The imbalance at each location is a function of all the markets that location serves as an origin or destination, and each market affects the imbalance at two locations. Dissecting the network significantly limits one's ability to improve network profitability, so I developed a methodology to take a whole-network approach to pricing.

Approach

I used a combination of basic microeconomics, Monte Carlo simulation, and simple heuristic hill-climbing techniques to arrive at pricing recommendations [Gorman 2000a]. I will not emphasize the technical elements of the problem here but rather the approach I took to gain end users' understanding and acceptance of the model results.

BNSF formed a group of six specialized pricing managers to establish network-focused pricing recommendations for the rest of the organization to follow when making day-to-day pricing decisions. The group needed a decision-support tool to help it determine quarterly and annual pricing strategies. I had the opportunity to make a large impact on BNSF pricing strategy by supporting this small group.

I realized that it would be difficult to persuade pricing managers to make the leap from their current pricing approach to a more sophisticated method. To gain

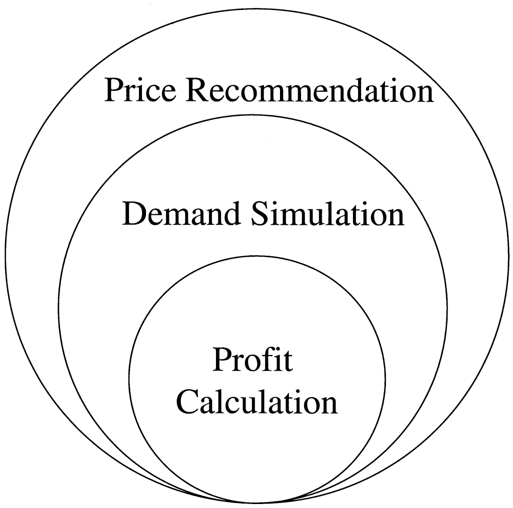

Figure 2: The intermodal pricing model is comprised of three nested modules that can be run independently, giving pricing managers the ability to initially run simple profit calculations and eventually run the more sophisticated price-recommendation module.

their confidence, I allowed for multiple levels of sophistication of usage of the IPM (Figure 2). As pricing managers came to understand the basic components of the model, they could go on to more sophisticated uses of the IPM. I introduced them to the IPM modules—profit calculation, demand simulation, and price recommendation—in stages to create trust in and understanding of the model.

Profit Calculation

At the core of the pricing model is a profit calculator. The profit calculator computes networkwide profitability given the current or anticipated prices, the quantities in the various markets, and the resulting equipment-repositioning costs. It obtains market profit (before subtracting repositioning costs) for each market by making a straightforward calculation based on average revenue per unit, average cost per unit, and quantity. It then runs a classic transportation-problem to calculate repositioning costs. Profitability for the network equals the sum of all market profits less the equipment-repositioning costs associated with servicing the markets (Table 1).

The profit calculator allocates the costs of repositioning empties back to the markets that caused them and credits the markets that reduced them. The duals from the transportation problem represent the value of an additional unit of equipment at a particular location (positive in the case of a deficit or negative in the case of a surplus). I defined the bonus or penalty for a market as the difference in the duals of the origin and destination of the market. The difference indicates the change in value incurred as a piece of equipment moves in that market. The calculator adds the bonus or penalty to the market profit to give a network-level estimate of profitability.

I found the bonus-or-penalty mechanism extremely valuable for speeding up the search for optimal prices in productive directions. However, it implies a novel method for allocating repositioning costs, which is an extremely political issue. Because it changed the measures of individual markets' profitability used to calculate network profit, it affected the markets' perceived value. Ultimately, the six pricing managers were not willing to change corporate cost-allocation standards. They thought that it was outside their scope of responsibility, would hinder progress, and could jeopardize the project. While I believed that the cost-allocation method could help the larger organization to understand the effects of repositioning empties on markets' profitability, I did not

Market	Price	Quantity	Cost/Load	Market Profit
CH-LA	$1,200	900	$650	$495,000
LA-CH	$750	650	$650	$65,000
CH-FW	$600	300	$500	$30,000
FW-CH	$350	50	$500	($7,500)
FW-LA	$850	200	$600	$50,000
LA-FW	$700	300	$600	$30,000
Total		2,400		$662,500
Repositioning		Quantity	Cost/Empty	Total Repo Cost
LA-CH		150	$500	$75,000
FW-CH		350	$300	$105,000
Total Repositioning		500		$180,000
Total Network Profit				$482,500

Table 1: For the sample network in Figure 1, the IPM calculates profit based on price and cost per van shipped. The cost of repositioning 500 vans to equilibriate the network is subtracted from the total market profit to determine the network profit.

pursue this subject with the broader organization because I wanted to continue working on the more focused project.

I presented the results from the pricing calculator to the six pricing managers: actual historical volumes, prices, gross profits, and network imbalances. Pricing managers gained confidence in the core of the model because I carefully benchmarked the results against historical performance metrics. While holding everything else constant, managers could evaluate the repositioning plan, market revenues and costs, and network profitability. From this global perspective, they learned to appreciate the impact of repositioning costs on network profitability given exact market quantities and prices.

Demand Simulation

The pricing managers were quick to point out that BNSF faced extremely uncertain future demand. Knowing that they would be reluctant to accept any model results pinned to particular market parameters, I allowed them to randomly vary the input parameters around their estimates to reduce dependence on the estimates. Doing this caused the models to generate more robust results, which increased the managers' confidence in the results. I thus eschewed pinpoint model results that depend on precise estimates of market conditions to achieve less precise recommendations that would apply to a wide variety of market conditions.

I identified two forms of marketplace uncertainty that had to be addressed by the model: the uncertainty of shifts in demand and the uncertainty of price elasticity of demand. To represent these uncertainties, I used Monte Carlo sampling to draw random samples from a distribution of possible demand levels and customer-price elasticities. The Monte Carlo simulation produced results based on a broad range of input parameters so that the managers would not have to specify exact market conditions.

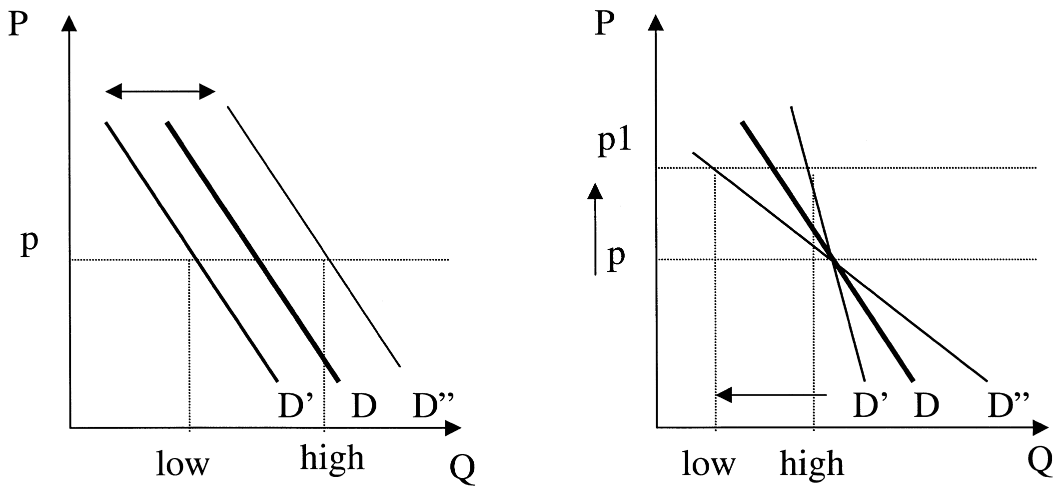

Figure 3: The IPM allows for both demand shift and demand elasticity uncertainty to increase market managers' acceptance of model results. Figure 3 left exhibits a range of quantity given a price due to nonprice fluctuations; Figure 3 right shows the range of customer quantity responses to a price increase.

Demand uncertainty can be represented by a shifting demand curve (Figure 3 left). Given a fixed price, what quantity will result? Exogenous factors, such as future macroeconomic fluctuations, trucker strikes, and fluctuations in interest rates and exchange rates directly affect the quantities sold. Repeated sampling of demand shifts addresses these market uncertainties. I run the profit calculator for each sampling of demand. After incorporating all these samples, the calculator produces a profit-distribution curve and expected profit level.

The price elasticity of customers is also notoriously difficult to predict. I use Monte Carlo sampling here as well to capture this uncertainty. For every price change the pricing manager investigates, the model evaluates a range of possible customer quantity responses and reports an expected profit level (Figure 3, right).

Pricing managers can experiment with different pricing scenarios with the demand and elasticity sampling to get a robust projection of the effects of their proposed price changes. By simulating demand, managers add stochastic elements to the price calculator while still retaining control of the price changes. From the variation of the demand parameters in the model, the pricing managers come to appreciate that the IPM is not heavily dependent on particular market parameters.

The demand-simulation module is strictly a descriptive tool that does not identify which are the best markets for pricing initiatives; pricing managers must search for desirable pricing strategies manually. However, as with the profit calculator, I found it invaluable to allow pricing managers the opportunity to see the workings of the core modules before attempting automated methods for recommending prices.

Price Recommendation

Once they became comfortable with the first two modules, the pricing managers understood that the price-recommendation module essentially performs repeated what-if games in an automated fashion, thereby freeing them from manually searching for desirable prices.

The linear program for repositioning empty equipment that is embedded in the demand calculator creates nondifferentiability and discontinuity in the network-wide profit function. The Monte Carlo sampling in the demand-simulation module further complicates the optimization problem. Because of these complexities, I used simple heuristics to find improvements in the complicated network-profit function (Appendix).

The heuristic is based on a steepest-ascent method, basing the search direction on a computational gradient. It takes full advantage of the known attributes of the markets, such as estimated elasticity and the bonus and penalty associated with repositioning requirements, to reduce the computational requirements of the search [Gorman 2000a].

I explored other, more-exhaustive and complete search methods, but because the solution space was large and complex and the model's input parameters were uncertain, I thought that more sophisticated methodologies were unwarranted. In any case, the pricing managers didn't expect or believe in a single, optimal solution. They primarily wanted to be confident that their pricing recommendations were directionally correct before taking them to senior management; a heuristic suited their needs.

By running the price-recommendation module with repeated sampling for model-parameter uncertainty, the pricing managers gained high confidence in the recommended prices. Statistically, I define high confidence as having a 95 percent statistical likelihood of improving network profitability over the existing prices in a wide range of demand conditions.

Illustrative Results

I applied the pricing model to the sample network in Figure 1. The model recommends new prices that significantly affect market quantities, total network repositioning, and profitability (Table 2). The model shows potential to increase profits in the sample network by $110,777 or 23 percent (Table 3).

I used the output of the model on the sample network to illustrate to pricing managers some of the devilish complexities of effective pricing decisions (Table 2 and 3). The IPM makes pricing recommendations that reduce market-level profits for individual markets. However, these changes have a positive impact on network profitability because they drastically reduce repositioning. For example, the IPM recommends closing the seemingly profitable Chicago-Fort Worth market and makes no change to the unprofitable Fort Worth-Chicago market. The IPM recognizes that the shortage of equipment in Chicago in this fictitious example is costly, but demand conditions in the Fort Worth-Chicago market make inducing more flow in that direction financially undesirable, so the model reduces flow in the Chicago-Fort Worth market. Even for this fairly trivial case with perfect certainty of model parameters, pricing managers were impressed by the surprising results.

When running the price-recommendation module, the pricing managers no longer

Market	Demand Elasticity	Price	Quantity	Cost/Load	Market Profit
CH-LA	7.5	$1,211	866	$650	$485,826
LA-CH	4.0	$738	723	$650	$63,624
CH-FW	2.3	$700	0	$500	$0
FW-CH	6.0	$350	50	$500	($7,500)
FW-LA	3.4	$861	190	$600	$49,590
LA-FW	7.0	$689	333	$600	$29,637
Total			2,162		$621,177

Repositioning	Quantity	Cost/Empty	Total Repo Cost
LA-CH	0	$500	$0
FW-CH	93	$300	$27,900
Total Repositioning	93		$27,900
Total Network Profit			$593,277

Table 2: The price recommendations from the IPM significantly affect the market quantities, repositioning, and network profits for the sample network in Figure 1.

create pricing recommendations but rather apply their expert opinions to evaluate the input parameters for their intuitive appeal and the model's pricing recommendations for their likelihood of success. Because of their experience with the more rudimentary profit-calculation and demand-simulation modules, they are comfortable with the model's pricing recommendations.

Market	Price	Quantity	Market Profit
CH-LA	$11	(34)	($9,174)
LA-CH	($12)	73	($1,376)
CH-FW	$100	(300)	($30,000)
FW-CH	$0	0	$0
FW-LA	$11	(10)	($410)
LA-FW	($11)	33	($363)
Total		(238)	($41,323)

Repositioning	Quantity	Total Repo Cost
LA-CH	(150)	($75,000)
FW-CH	(257)	($77,100)
Total Repositioning	(407)	($152,100)
Total Network Profit		$110,777

Table 3: The difference of Tables 1 and 2 reveals that the IPM pricing recommendations result in a net loss of quantity and market profits but a net increase in network profits because of drastically reduced equipment repositioning.

An Example Application

BNSF has applied the IPM to support six quarterly and annual pricing initiatives and occasional ad hoc studies across numerous equipment types. To illustrate its effectiveness, I highlight a particular application of the model to rail-controlled 48-foot containers. The BNSF network has 47 locations that handle this type of equipment, with a total of 394 products (origin-destination markets).

As a starting point for the search, I use the current quarter's market price, quantity, average cost per load, and average cost per empty container for each origin-destination pair. Using the current market price as the starting point allows pricing managers to view all pricing recommendations in terms of deviation from current prices, which is intuitive for them.

I had difficulty finding a good source for price-elasticity estimates, which proved to be an early stumbling block in the application. Statistical methods at best produce notoriously questionable and often contradictory results [Tellis 1988], which provide little utility in decision making. To overcome the shortcomings of statistical methods, I based my estimate of market elasticity on the assumption that market managers use all information available to them to maximize profits. Under that assumption, I derived an implied elasticity of demand that proved to be a good starting point for elasticity sampling. For this estimate I needed only three pieces of information to estimate the implied price elasticity of demand: current price, current quantity, and average cost in each market [Gorman 2000b].

To test these estimates, I developed a survey that asked market managers to estimate the impact of price increases and decreases in various markets. I found that my quantitative method was within the range of the survey responses of market price sensitivity. The survey had the important benefit of building pricing managers' confidence in the elasticity parameters.

To ensure that the results were robust and not dependent on particular market conditions, I allowed for a wide range of values for demand shift and price elasticity of demand uncertainties. For the demand-shift sampling, I used double the range of market quantities experienced in for the past four quarters. For the elasticity sampling, I used from one-half to two times the point estimate, which in most cases was well outside the range of survey responses received. Because of the wide range of demand shifts and elasticities employed, the pricing managers realized the model results are not highly sensitive to the method used to generate the model's input parameters.

To maintain accurate nodal imbalances and repositioning requirements, I included the movement quantities for all markets of 48-foot rail-controlled containers in the analysis. However, I exogenized markets that contain extremely low volumes from price changes. In this way, I focused attention on the roughly 10 percent of the markets that produce almost 90 percent of the volume for this equipment type. Price changes in small markets have little impact on network imbalances because of their low volumes, so their inclusion in the pricing decision would create little effect. Further, the lower the volumes in the market, the more misstated the linearization of the stair-step demand becomes. As a practical note, market managers liked the ability to control which markets to consider for pricing initiatives.

> From this global perspective, they learned to appreciate the impact of repositioning costs.

The model produces no single price strategy due to the sampling of market parameters. The model results indicate directional price changes with some confidence level that they will produce increases in profits. For example, for most markets examined, the model was consistent 100 percent of the time in its pricing recommendations. In other words, regardless of the market conditions sampled, the direction of pricing recommendations was the same.

This consistency gave pricing managers confidence in the directional correctness of model recommendations.

To measure the potential improvement in profitability for BNSF, I plugged the average recommended price changes into the profit calculator. As the average of the optimal prices, the changes represent a middle-ground recommendation for price change; they are by no means the most aggressive price changes.

Even with conservative pricing recommendations, the potential gains from the network-based pricing approach are sizable. I found that BNSF could achieve a 3.5 percent increase in networkwide profits through a 61 percent reduction in empty-equipment-repositioning costs. However, these gains could only be realized by accepting a 1.4 percent reduction in revenue and a 4.1 percent reduction in direct market profits.

> Without a strong promotion of the benefits, model use can stall.

It is difficult to obtain these benefits in practice. To increase networkwide profits in this case, pricing managers must accept a reduction in both total revenues and direct market profits, which are more than recovered from the reduced repositioning costs. Historically, managers have resisted such decisions because they perceive repositioning costs as outside of their area of responsibility and authority, they can't solve the pricing problem because of its complexity, and they would have to coordinate multiple managers' pricing strategies to successfully implement the plan.

The creation of the network-pricing group is an important first organizational step towards taking a network view of pricing, coordinating pricing strategies, and reducing the cost of the externality. The IPM supports the group in making sound pricing recommendations.

Use of the IPM in Practice

In practice, pricing managers do not make wholesale changes based solely on the IPM recommendations but work iteratively with the model to come to their pricing recommendations. First, they use the price calculator on the input data to check the inputs for soundness. They then run the price-recommendation module on target markets, which are based on size, executive recommendation, or intuitive understanding of potential gain from pricing changes. After running the price-recommendation module and interpreting the output, they run the what-if tool to fold in their own ideas with model recommendations. Finally, they take the proposed price changes and test them through the profit calculator to estimate the expected outcome. They propose recommendations to senior managers for approval, who approve a subset of the price changes. For these reasons, the actual experienced results pale in comparison to the potential benefits identified.

Empirical Results

In practice, it is impossible to isolate the impact of the IPM from that of other factors that affect business levels from quarter to quarter. For this reason, no formal estimation of exact benefit created solely by the IPM can be conducted. However, since 1998, the trend of BNSF's equipment imbalances has shown improvement (Fig-

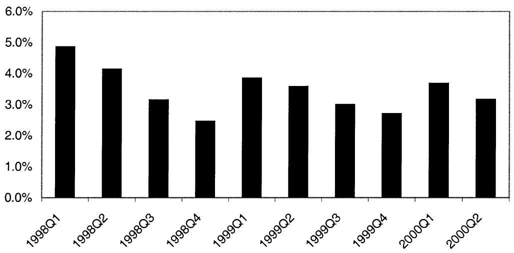

Figure 4: BNSF's quarterly ratio of van and container empty-to-loaded miles has trended downward over the last three years. In all quarters but one, this ratio has fallen year over year in like quarter comparisons.

ure 4). Such improvements allow BNSF to generate greater revenues through better utilization of vans and containers. BNSF has increased loaded miles by five percent on average and simultaneously reduced empty miles by an average of three percent (Table 4).

Lessons Learned

Despite early success in generating user acceptance of the IPM, I have learned valuable lessons from its implementation about the need for close integration with business processes and the need for senior management support even for a stand-alone tool developed for a small group. The small size of the group enabled quicker adoption of the pricing model, but because organizational awareness of the tool is not widespread, it is a challenge to champion the continued use of the model through organizational changes. Using the IPM to generate high-quality pricing recommendations generally requires more effort in data collection and results analysis than traditional, less-quantitative methods. Without upper managers' insistence, time-constrained pricing managers fall back on quick-and-dirty methods. Despite the demonstrated benefits of networked-based pricing, managers need to be continually coached on the benefits of using the IPM. Without a strong promotion of the benefits of the approach, model use can stall.

Extensions

I can extend the pricing model in a number of directions. First, based on the survey of our market managers, they perceive the demand curve facing them to be kinked; that is, they pessimistically see customers reacting greatly to price increases by reducing volumes but not responding as greatly to price decreases. The net effect of this intuition is that prices are sticky, or managers have a disincentive to change prices. To emulate managers' intuition for price sensitivity, I allowed for this pessimistic view by implementing kinked demand curves. I continued to find high probability for significant (though reduced) opportunities for price changes.

Up to this point, I assumed that customers do not substitute one product for another because of price changes. For small,

	1998–1999				1999–2000		
	Q1	Q2	Q3	Q4	Q1	Q2	Average Change
Loaded Miles Percent Change	7%	2%	3%	4%	7%	9%	5%
Empty Miles Percent Change	−15%	−12%	−2%	15%	2%	−4%	−3%

Table 4: Since 1998, BNSF average quarterly loaded miles have increased by an average of five percent a year, while empty miles have fallen an average of three percent a year. BNSF is better able to serve its customers and generate additional revenues because of the resulting improved equipment utilization.

short-lived price changes, this is likely to be the case. In the long run, shippers will substitute between service levels, equipment types, and even origins and destinations if given enough economic incentive. The IPM can account for this product substitution, but it is difficult to estimate the degree to which customers will substitute. I have added this cross-price substitution functionality to the model, but because it is heavily parameter-driven, it is rarely used.

Perhaps the greatest opportunity and need for extension of the model lies in the tactical pricing arena. Given the market pressures brought to bear by the use of the Internet, market managers will be forced to make daily or weekly pricing decisions in the spot market. The need to make well-informed, network-based pricing decisions quickly based on current network conditions will drive the development of model-based solutions. I am currently exploring modification of the model for application in more tactical settings. I am focusing on integrating the model with data from production systems, creating new business processes for creating tactical or spot pricing, and tuning solution techniques to find faster solutions to more limited problems.

Conclusion

BNSF developed the intermodal pricing model (IPM) to identify improvements in market pricing, to reduce equipment repositioning, and to improve networkwide profitability. Pricing managers use the tool periodically to determine pricing strategies, to calculate network profits, to do what-if analyses, and to seek optimum prices. It accounts for the uncertainties surrounding market conditions and makes pricing recommendations with high probabilities of improving network profits.

The IPM increases managers' ability to quantify pricing strategy impacts on equipment imbalances. Perhaps more important, the tool has generated a philosophical change towards pricing strategies that reduce networkwide equipment-repositioning costs. Because of constantly changing business conditions, it is impossible to precisely quantify the benefits the IPM has brought to BNSF. However, BNSF's empty-to-load ratio, which has steadily improved over the last two years, is evidence of the IPM's effectiveness.

As the Internet moves BNSF towards more active short-term pricing, the IPM will allow it to develop more profitable network-based pricing with less manual effort.

APPENDIX

Intermodal Pricing Model (IPM) Problem Formulation

The firm's objective is to maximize network profit (Π^n) across all markets (M_{ijk}):

$$\prod^n = \sum_i \sum_j \sum_k (\mathrm{TR}_{ijk} - \mathrm{TC}_{ijk}) - \sum_k (\mathrm{TRC}_k).$$

Where the direct market profits for equipment k, from node i to node j, are given by

$\Pi^d_{ijk} = \mathrm{TR}_{ijk} - \mathrm{TC}_{ijk}$—direct market profit function,

$\mathrm{TR}_{ijk} = P_{ijk} * Q_{ijk}$—total revenue function,

$\mathrm{TC}_{ijk} = \mathrm{AVC}_{ijk} * Q_{ijk}$—total cost function, and

$P_{ijk} = a_{ijk} - b_{ijk} * Q_{ijk}$—demand curve.

Network market profits must include total repositioning cost (TRC):

$$\begin{aligned} TRC &= \sum_k \text{Min } TRC_k \\ &= \sum_k \sum_i \sum_j RC_{ijk} R_{ijk} \\ &\quad \text{subject to } \sum_i R_{jik} \\ &\quad - \sum_i R_{ijk} = I_{ik} \quad \text{for all } j. \end{aligned}$$

i = node origin index.
j = node destination index.
k = equipment type index.
M_{ijk} = arc in network; market from origin node i to destination node j for equipment k.
N_{ik} = node in network; origin or destination of markets of equipment k.
Π^d_{ijk} = direct profit associated with market M_{ijk}.
Π^n_{ijk} = network profit associated with market M_{ijk}, including repositioning-cost impact.
Π^n = total network profit equals the sum of $\Pi^n{}_{ijk}$.
Q_{ijk} = total quantity shipped in M_{ijk}.
P_{ijk} = price charged in M_{ijk}.
AVC_{ijk} = average variable cost per unit of providing service in M_{ijk}.
TR_{ijk} = total revenue generated in M_{ijk}.
TC_{ijk} = total direct costs of service in M_{ijk}.
a_{ijk} = price axis intercept of demand curve in market M_{ijk}.
b_{ijk} = slope of demand curve in market M_{ijk}.
E^d_{ijk} = price elasticity of demand for M_{ijk}.
TRC_k = total network repositioning cost for all equipment k.
I_{ik} = imbalance at node i for equipment type k.
R_{ijk} = quantity of equipment repositioning from node i to node j for equipment type k.
RC_{ijk} = cost repositioning one unit of equipment type k from node i to node j.

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R. Mark Schmidt, AVP Strategic Studies, The Burlington Northern and Santa Fe Railway Company, P.O. Box 961065, Fort Worth, Texas 76161-0065, writes: "Michael Gorman has developed the Intermodal Pricing Model (IPM) model to assist BNSF in establishing pricing strategies that will reduce repositioning and increase profitability.

"The model has been productively employed in a number of studies:

—*Market rationalization*. We found that some markets were unprofitable, given the cost implications of network wide repositioning.

—*Ramp Imbalance Study*. We examined markets affecting chronically surplus or deficit locations on the network (e.g. Denver, Chicago) for best pricing initiatives.

—*Network-wide Price Planning*. We have used the model as an input to strategic pricing initiatives to achieve more fine-tuned pricing ability.

"Perhaps the greatest usefulness of the IPM will be in the ability to fulfill the tactical pricing requirements brought to the forefront by the Internet."