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A Large U.S. Retailer Selects Transportation Carriers under Diesel Price Uncertainty

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A large U.S. retailer which procures transportation services from third-party carriers experienced an unexpected jump in fuel surcharges as the price of diesel skyrocketed in the summer of 2008. As a result, the retailer sought to limit its future exposure to diesel price risk. We collaborated with the retailer to create a Lane Assignment Optimizer (LAO) which incorporates diesel price risk when selecting carriers for its transportation lanes. The LAO tool has significantly improved the retailer's capability to evaluate the tradeoff between the two crucial components of a lane's per-shipment cost: base price and risk-adjusted fuel surcharge. As a result, the retailer can now select cost-effective carriers for its lanes taking into account diesel price risk, negotiate fuel surcharge limits to share diesel price risk with its carriers, and better align the fuel surcharges it pays with the true cost of diesel. We estimate that the more favorable contract terms the retailer negotiated for 2009-2011 translate to nearly \$5 million in potential savings for years with unexpected diesel price hikes like 2008.

Key words: price uncertainty, risk aversion, service contract, transportation

On July 14, 2008, the price of diesel in the United States peaked at \$4.76 per gallon, representing a whopping year-over-year increase of 65% (U.S. Energy Information Administration 2009c). This price shock was experienced by consumers at the pump, and even more so by businesses with

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year-long transportation services contracts. In particular, a large multi-billion dollar U.S. retailer, which procures transportation services from third-party full-truckload carriers, found itself paying substantially more for freight than expected due to fuel surcharges paid to carriers.

The retailer, like others in its industry, pays carriers diesel-price dependent fuel surcharges in addition to per-truckload base prices; thus, as the price of diesel rose, so did transportation costs. Most alarmingly, these surcharges sometimes rose faster than the fuel price itself! The retailer was overshooting its annual transportation budget by millions of dollars, and needed to act fast to curb its expenses. Fortunately, the retailer was able to renegotiate some of its contracts, but this required significant effort.

The high diesel prices did not persist long: by Christmas, diesel was down to \$2.34 per gallon – roughly half what it was five months earlier (U.S. Energy Information Administration 2009c). In conjunction with the renegotiated contracts, the retailer was out of trouble for the time being. However, the retailer learned an important lesson: diesel price risk should be explicitly managed. Up to that point, the retailer was accustomed to evaluating transportation contracts using a rough proxy for expected cost.

The retailer initiated a project with us in the spring of 2009 to improve its processes for 1) selecting transportation carriers, and 2) negotiating better contract terms with them. Together, we developed a linear programming (LP) decision support tool called the Lane Assignment Optimizer (LAO) to help the retailer’s analysts select transportation carriers under diesel price uncertainty. In addition to base prices, LAO uses carriers’ fuel surcharge schedules and analysts’ estimates of future diesel prices to select a carrier for each of the retailer’s transportation lanes. LAO can incorporate different levels of the retailer’s risk aversion, and can also guarantee the proportion of lanes won by any given carrier falls within a retailer-specified range. We implemented LAO in Excel using Microsoft Solver Foundation to allow the retailer’s transportation professionals to easily query LAO while negotiating with carriers.

By using LAO, the retailer was able to identify and evaluate opportunities to adjust the shape of the fuel surcharge curve it faces. When the retailer renewed its contracts in October 2009, it

was able to get all carriers to agree to a common fuel surcharge schedule that has a lower slope (i.e. lower surcharge rate) as well as a cap (a maximum surcharge rate which applies for all diesel prices above a given threshold). As we will see, changing the slope of the fuel surcharge curve benefits the retailer by aligning surcharges with the true cost of diesel, while capping the surcharge curve allows the retailer to share some diesel price risk with its carriers. Such modifications can be crucial for controlling transportation costs in years when the price of diesel rises dramatically. Had the retailer bent and capped its surcharge curves in this manner in October 2007, we estimate it could have saved nearly \$5 million in 2008.

LAO's specific focus on diesel price risk makes it stand out from other implementations of optimization-based transportation procurement. Although LAO's underlying math program is essentially a general carrier assignment model as described by Caplice and Sheffi (2004), specific implementation-based details are what makes LAO useful in practice. In particular, our way of modeling diesel price risk by extrapolating trajectories from a single baseline forecast and then weighting the trajectories according to a risk aversion parameter contributes to practice 1) by being fast to calculate, 2) by avoiding burdensome data requirements like distributions for each period's diesel price or price evolution models, and 3) by being intuitive – our risk aversion parameter is easily tuned because it is not just a nebulous number: its relationship to our model's diesel price trajectories can be seen graphically in LAO's Excel interface.

Our paper also complements existing optimization-based approaches such as those by Powell et al. (1988) and Ergun et al. (2007) which focus on maximizing the profitability of carriers by minimizing the number of empty miles driven between loaded trips. While we do not explicitly consider the optimization problem of pairing lanes with backhauls, we do also care about reducing empty miles, and discuss how shippers can provide incentives for carriers to solve that problem. From our perspective, fewer empty miles means less diesel used, which lowers diesel price risk.

Finally, our paper contributes to the transportation planning literature by discussing the concept of a fuel surcharge cap and by showing how one retailer has successfully implemented fuel surcharge caps to share diesel price risk with its carriers.

Our paper is organized as follows. We begin by describing how the retailer purchases transportation contracts and how fuel surcharges are computed in practice. We then describe the retailer’s negotiation process prior to our collaboration, and describe an improved negotiation process which is aided by LAO. We next describe how LAO computes the risk-adjusted expected cost of each candidate carrier-lane pairing, and how LAO uses these costs along with other constraints to find an optimal carrier-lane assignment. We also describe LAO’s easy-to-use Excel interface, as well as LAO’s principal benefits: 1) LAO provides an intuitive, automated way to compute optimal carrier-lane assignments under diesel price uncertainty; and 2) LAO empowers the retailer to negotiate better contractual terms. We conclude with a description of the benefits observed to date.

Background

Fuel Surcharge Basics

The price of diesel fluctuates over time; in some years – notably 2008 – this fluctuation is quite severe (see Figure 1). As a result, it is common practice for carriers to pass on their diesel price risk by charging a fuel surcharge *on top of* the agreed-upon per-truckload price. That is, the price carriers charge for a full-truckload shipment is:

$$\text{Price per Shipment} = \text{Base Price} + \text{Fuel Surcharge}.$$

The *base price* stays fixed over the duration of the contract, whereas the *fuel surcharge* varies according to the price of diesel at the time of shipment. The function which maps the current diesel price to the fuel surcharge levied is called a *fuel surcharge schedule*.

Fuel surcharges transfer diesel price risk from carriers to shippers (retailers), making it safer for carriers to negotiate long-term high-volume transportation contracts with shippers. If fuel surcharges could be implemented perfectly, the surcharge billed to the shipper would be exactly equal to the carrier’s cost of diesel. However, as we will see, fuel surcharges are only rough approximations of the true cost of diesel, and typically do not account for factors which affect a carrier’s fuel economy on specific routes, such as terrain, traffic patterns, speed driven, class of truck, weight of load, and what proportion of time the carrier’s trucks are empty vs. full. Furthermore, fuel surcharges

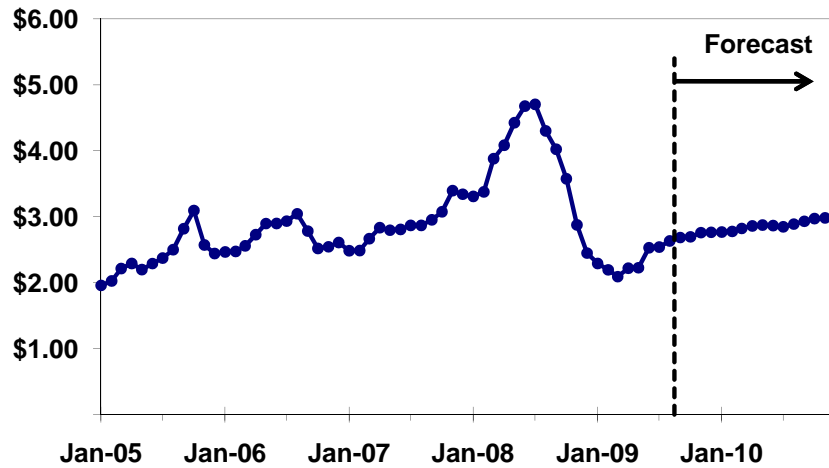


Figure 1 A plot of the U.S. retail diesel price (per gallon) shows the dramatic spike which occurred in the summer of 2008. Although a modest price increase was forecasted throughout 2009-2010, there was of course a chance that prices could jump back up to 2008 levels. Source: U.S. Energy Information Administration (2009a).

typically depend on the price of diesel as published in a national or regional price index, whereas carriers buy diesel at different times and places than specified by the index, and may even buy diesel wholesale instead of paying the on-road retail price. Therefore, there is room for retailers to negotiate more favorable fuel surcharge terms with carriers.

Contract Negotiation

Each year, the retailer's contracted carriers accumulate millions of miles moving tens of thousands of truckloads over the retailer's transportation network. This network is composed of hundreds of *lanes*, where each lane is a one-way link between a pair of cities. Figure 2 illustrates a hypothetical transportation network where each directed arc represents a lane. Every two years, the retailer negotiates new contracts with carriers to provide service on its transportation network. This negotiation process begins with the Request-for-Proposal (RFP), in which the retailer invites 7 to 10 carriers that cover wide geographic areas – such as Schneider National, Werner Enterprises, and J. B. Hunt – to submit bids for each lane they would like to operate. The retailer discloses lane volume forecasts; thus, carriers know approximately how many full truckloads they will be asked to transport should they win the contract for a given lane.

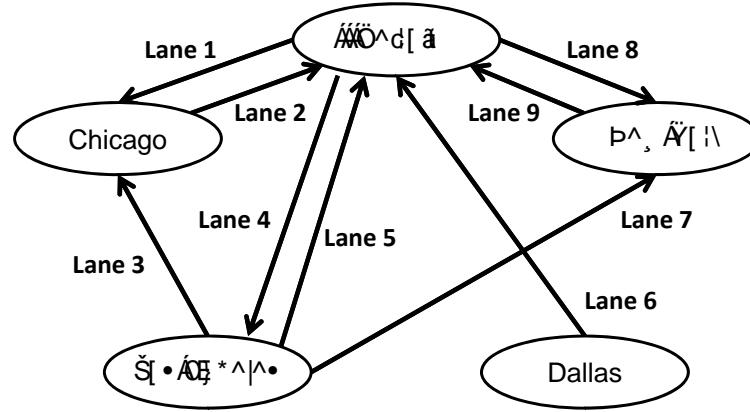


Figure 2 A subset of the retailer's transportation network. Nodes represent cities and directed arcs represent lanes.

With the first round of bids in hand, the retailer would produce a preliminary assignment of carriers to lanes such that each lane was assigned to exactly one carrier – typically the carrier with the lowest expected cost, computed as the sum of the base price bid and the carrier's fuel surcharge evaluated at the average price of diesel from the previous year. Due to secondary objectives and side constraints, however, the retailer sometimes chose a different carrier to operate a lane. In particular, the retailer ensured each carrier was allotted at least a few lanes to keep carriers participating in the RFP year after year. Also, the retailer would limit its dependence on any one carrier by making sure no carrier was assigned too many lanes; doing so moderates supply chain risk and allows the retailer to retain bargaining power for future RFP's. Such market-share constraints are typical in other auctions for similar reasons; for example, they are also used in auctioning school meals in Chile (Epstein et al. 2002).

The retailer would use this preliminary assignment as a starting point for negotiations with carriers. If an incumbent carrier was reliably running a lane, the retailer typically would prefer to renew the incumbent's contract rather than switching carriers. In this case, the retailer might give the incumbent a chance to match the lowest bid. Similarly, the retailer might also ask a carrier which is known to be the most reliable or the best organized with their paperwork to match the lowest bid. Several iterations of this manual process would take place, in which carriers would

provide the retailer with updated bids. Once the retailer reached mutual agreement with its carriers for all of its lanes, the lane assignment would be finalized and become contractually binding.

In the negotiation process we just described, each bid is for a single lane. It is worth mentioning that a more sophisticated process for selecting carriers called a *combinatorial auction* would allow carriers to bid on a *group* of lanes with a single “package” price. Combinatorial auctions can yield more efficient lane assignments by virtue of the fact that they encourage carriers to offer discounts on bundles of routes which might reduce their costs, for example, by forming complete circuits in their own networks. According to Sheffi (2004), many large retailers use third-party market-makers to run combinatorial auctions for them, and as a result have reduced their transportation costs by 3-15%. It is interesting to note, however, that fewer than 10% of the lanes won via combinatorial auctions are bid as a group of lanes (see Sheffi 2004), indicating that combinatorial auctions’ cost savings result from a few substantial modifications to an otherwise lane-independent bidding process. The retailer we collaborated with does not use combinatorial auctions at this time, so we do not discuss this further. Our approach to valuing diesel price risk, however, is also applicable to the combinatorial auction framework.

Fuel Surcharge Details

Each carrier has its preferred way of implementing fuel surcharges; the two most common methods are *percentage of base price* and *surcharge per mile*. Of the seven carriers that participated in the retailer’s October 2007 RFP, three implemented *percentage of base price* while the other four implemented *surcharge per mile*. Carriers which implement *percentage of base price* define fuel surcharges as a $k\%$ factor of the lane’s base price, where the factor k varies with the price of diesel. For example, given a base price of \$1000, according to the fuel surcharge schedule in Figure 3, if diesel is between \$1.55 and \$1.59 per gallon, the fuel surcharge is $5\% \times \$1000 = \50 . On the other hand, carriers which implement *surcharge per mile* define fuel surcharges as being $\$x$ per lane-mile, where x varies with the price of diesel. For example, suppose the surcharge of a carrier is \$0.50 per mile when the price of diesel is \$3.60 per gallon. On a 600-mile lane, this corresponds to a per-shipment fuel surcharge of $\$0.50 \times 600 = \300 .

ITEM 201 FUEL SURCHARGE (FSC)		
<p>Except as otherwise stipulated, all line haul rates provided in Pricing Agreements and Contract Schedules governed by and subject to this publication will be subject to a Fuel Surcharge (FSC) as provided in the table below. The FSC will apply when the U. S. National Average Fuel Index, as reported by the U. S. Department of Energy, exceeds 109.9 cents per gallon. No FSC will apply when the index is below 110 cents per gallon. The surcharge will be shown as a separate entry on the freight bill and will apply as a percentage of net line haul charges. The FSC will not apply on accessorial charges. The index will be updated every Monday. Revisions to the FSC will go into effect on the following Wednesday. The surcharge amount will be based on the following:</p>		
When the index price is at least:	But less than:	Fuel surcharge will be:
110 cents per gallon	115 cents per gallon	.5%
115 cents per gallon	120 cents per gallon	1.0%
120 cents per gallon	125 cents per gallon	1.5%
125 cents per gallon	130 cents per gallon	2.0%
130 cents per gallon	135 cents per gallon	2.5%
135 cents per gallon	140 cents per gallon	3.0%
140 cents per gallon	145 cents per gallon	3.5%
145 cents per gallon	150 cents per gallon	4.0%
150 cents per gallon	155 cents per gallon	4.5%
155 cents per gallon	160 cents per gallon	5.0%
160 cents per gallon	165 cents per gallon	5.5%

For each 5 cent increase in the U.S. National Average Fuel Index beyond 165, the FSC will increase .5%.

Figure 3 An example fuel surcharge schedule shows how the fuel surcharge, computed as a percentage of the base price, changes with the price of diesel.

The distinction between *percentage of base price* and *surcharge per mile* can be important, as we will show later. But for now, it is important to note that regardless of how a fuel surcharge is implemented, it can be expressed in absolute dollar terms; i.e. the per-shipment fuel surcharge (in dollars) can be expressed as a function of the current diesel price. As depicted in Figure 4, fuel surcharge schedules are often piecewise-linear: no surcharges are levied when the price of diesel is below a threshold called the *peg*, in this case \$1.10 per gallon, and the per-shipment surcharge increases linearly as the price of diesel rises above the *peg*.

In general, however, fuel surcharge schedules do not need to be piecewise-linear with two segments. Prompted by the run-up in diesel prices in 2008, shippers began experimenting with different fuel surcharge functions, and as described by Bonney (2011), some switched to so-called “zero-peg” fuel surcharge schedules that are purely linear and start accruing surcharges on the first cent of diesel paid. As Chris Caplice, executive director of the Center for Transportation and Logistics at

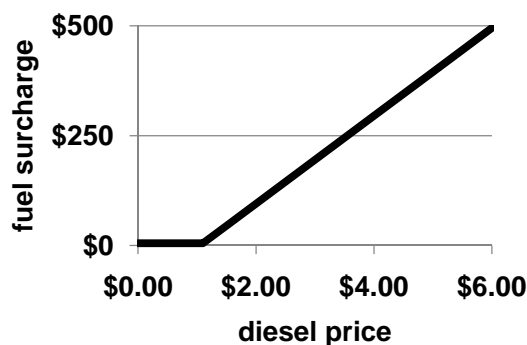


Figure 4 The fuel surcharge schedule from Figure 3 expressed in absolute dollar terms for a lane with base price \$1000. The per-truckload fuel surcharge (in dollars) is plotted as a function of diesel price.

the Massachusetts Institute of Technology points out in the article, zero-peg surcharge schedules make fuel surcharges more transparent, so they can be more easily measured and managed. In general, a fuel surcharge schedule with a $\$k$ peg will begin accruing surcharges when the price of diesel exceeds $\$k$. Thus, the higher the peg, the lower are total fuel surcharges. On the other hand, the first $\$k$ of every dollar the carrier spends on diesel is “hidden” in the base price, and so we can expect higher base prices when higher pegs are used, as shown in Figure 5.

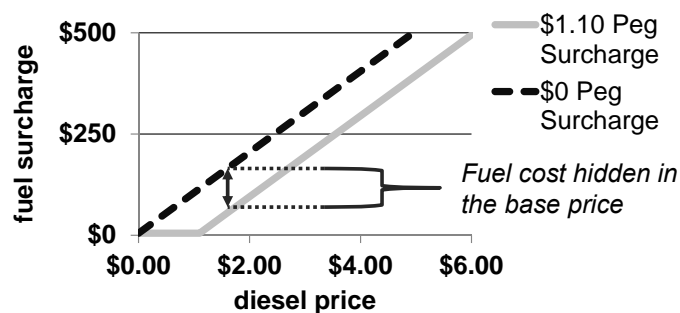


Figure 5 Using the \$1.10-peg fuel surcharge schedule from Figure 3 leads to some fuel costs being hidden in the base price, as indicated.

The retailer we worked with has surcharges with pegs in the \$1.10-\$1.30 range. While this means some fuel costs are hidden in the base price, this is not a problem for quantifying diesel price risk since the likelihood that the price of diesel drops below the peg is negligible; i.e. this hidden charge remains constant in all future scenarios.

The Importance of Explicitly Managing Diesel Price Risk

We define diesel price risk as an *unexpected* price increase above the level forecast. This is consistent with our claim that fuel surcharges are important to managing diesel price risk, since if all price increases could be accurately predicted by carriers then the corresponding costs could be built into base prices without a need for fuel surcharges. Along this line of reasoning, we argue that *basis risk* – the risk that carriers face because fuel surcharges are computed using a published price index which may differ from the actual price paid at the pump – is something that carriers can effectively manage by including a risk premium in their base prices. This is because basis risk depends on the *volatility* of the spread (index price minus on-road price) rather than a drastic upward shift in the price of diesel; thus, basis risk can be viewed as a normal cost of doing business which is not the case for diesel price risk.

It is important for retailers to take diesel price risk into account when choosing which carriers' bids to accept, because the carrier that is cheapest depends on the current diesel price, and thus may change as price does. Figure 6 illustrates this point by plotting the cost per shipment (base price plus fuel surcharge) for a single lane as offered by three carriers in the retailer's October 2007 RFP. Notice that carrier 5 is the lowest cost carrier when diesel is below \$3.30 per gallon, yet above \$3.30 per gallon carrier 6 is the cheapest. As we will see, the "best" carrier for a given lane depends on the retailer's diesel price forecast, the uncertainty of this forecast, and the retailer's tolerance for diesel price risk. Often, a risk averse retailer may be willing to accept a transportation contract with a higher base price if the fuel surcharge schedule has a shallower slope.

The New Contract Negotiation Process

To incorporate fuel surcharges into the retailer's RFP, we initially proposed that each bid for a lane should include not only a base price but also a lane-specific fuel surcharge schedule. This would entice carriers to modify their fuel surcharge schedules on a lane-by-lane basis to express local comparative advantages in fuel economy driven by, for example, the terrain of the route or the number of empty miles required to pick up a subsequent load. Although the retailer agreed

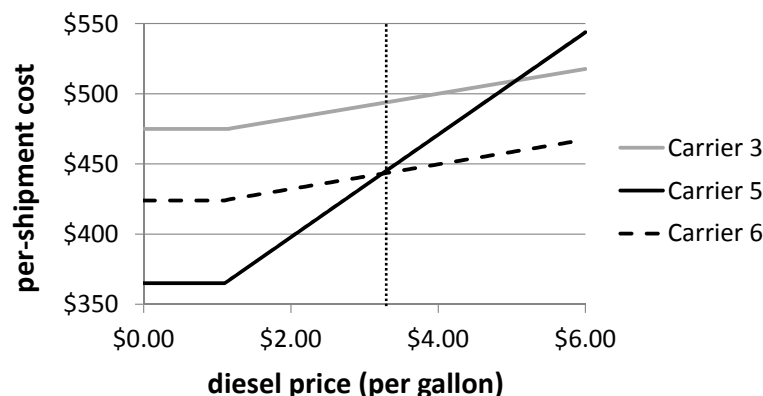


Figure 6 For three different carriers offering to operate lane 121, we plot the cost per shipment (base price plus fuel surcharge) as a function of diesel price. Whether carrier 5 or carrier 6 is cheapest depends on whether diesel is above or below \$3.30 per gallon.

that lane-specific fuel surcharge schedules would be beneficial, the retailer decided, at least for the time being, to limit the number of variables that it negotiates with carriers by instead having each carrier bid a single fuel surcharge schedule to be *shared* across all of that carrier's lanes.

Given this bidding structure, we developed a decision support tool called the Lane Assignment Optimizer (LAO) to compute the cost of each candidate carrier-lane pairing and subsequently solve for an optimal assignment of carriers to lanes using Excel and Microsoft Solver Foundation. The retailer's transportation professionals can use LAO to compute optimal lane assignments as they iterate through the contract negotiation process, as illustrated in Figure 7. A crucial component of LAO is how potential diesel price paths and thus diesel price risk is incorporated into the objective function in a computationally cheap, intuitive way. We describe the details of LAO next.

Computing Carrier-Lane Costs

LAO computes the cost of each candidate carrier-lane pairing using formulas which synthesize information from a *monthly forecast of diesel prices*, a *volatility parameter*, and a *risk aversion parameter*, as well as the base prices and fuel surcharges from the carriers' bids. This section elaborates on these parameters and how they affect cost. To be consistent with the retailer's current practice – i.e. their forecasts for diesel prices and lane volumes only being available for one year ahead – we evaluate LAO over a one-year horizon, despite the contracts' durations being two years.

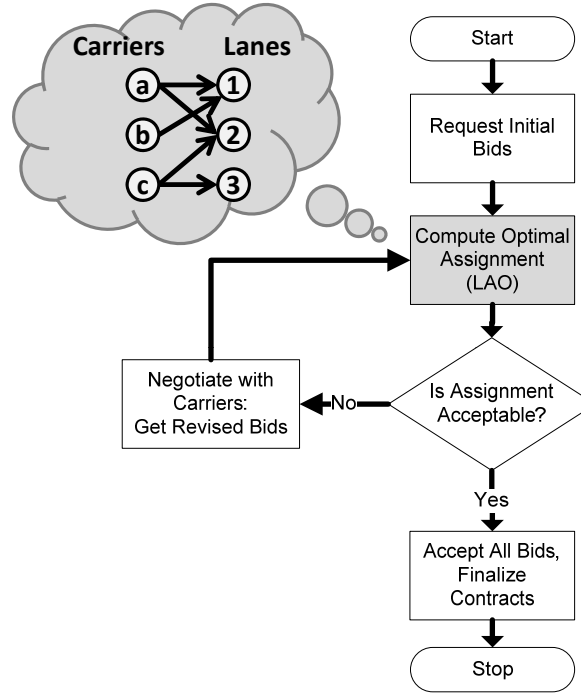


Figure 7 The retailer’s transportation professionals can use the Lane Assignment Optimizer (LAO) to compute optimal lane assignments at each iteration of the contract negotiation process.

The standard approach to modeling a risk averse decision-maker (e.g., Kreps 1988 and references therein) involves modeling the decision-maker’s utility function as concave increasing and computing his expected utility over uncertain prices. For example, for expected mean-variance utility, a risk-averse retailer’s expected utility for a candidate-lane pairing would be expected annual cost minus some multiple of the variance of annual cost. This approach, however, is cumbersome: to compute the variance of annual cost, the retailer would need to estimate the covariance matrix for monthly diesel price – a task it preferred to avoid. Furthermore, the retailer felt that picking a multiplier for scaling the variance in the expected utility calculation was nonintuitive. Thus, in consultation with the retailer, we devised a more intuitive and simpler way of computing risk-adjusted expected costs.

LAO computes the risk-adjusted expected cost of each candidate carrier-lane pairing from a sum of monthly costs. Each monthly cost is the product of an estimated shipping volume times a per-shipment cost. The per-shipment cost is equal to a base price plus a *risk-adjusted expected fuel*

surcharge which varies by month. Finally, each risk-adjusted expected fuel surcharge is computed by appropriately weighting and summing together the lane’s fuel surcharge evaluated along several possible diesel price trajectories. In order to describe how a risk-adjusted expected fuel surcharge is computed, we first need to describe how we generate diesel price trajectories.

Generating Diesel Price Trajectories

The U.S. Energy Information Administration publishes a freely-downloadable report called the Short Term Energy Outlook (see U.S. Energy Information Administration 2009a). Included in this report is a *monthly forecast of diesel prices* – a monthly diesel price time series which extends one year into the future. We take this forecast as our baseline, which we call the “median trajectory” or the “50th percentile trajectory.” We assume there is an equal chance that the future price of diesel will be above or below this baseline.

To construct additional trajectories, we model the uncertainty of the diesel price at the end of the 12-month horizon. Following the common assumption from the finance literature (cf. Dixit et al. 1994) that price changes are lognormally distributed, we assume the price of diesel at the end of the horizon is lognormally distributed with median equal to the baseline forecast. The scale parameter of this lognormal random variable (called the *volatility parameter*) is provided as input to LAO by the retailer; the retailer uses a combination of historical data, market conditions, and its own beliefs about future price uncertainty to estimate the volatility parameter. Different percentiles of this lognormally distributed random variable give different possible end-of-horizon diesel prices. For details, please refer to the Appendix.

In addition to the median (50th percentile) trajectory, LAO uses six trajectories which correspond to price paths that begin at today’s price and terminate at the horizon at the 10th, 30th, 70th, 85th, 95th, and 99th percentiles of the lognormally distributed end-of-horizon price. The number of paths and their percentiles were selected in consultation with the retailer; more or different levels could easily be accommodated. The price points along each trajectory are interpolated such that no deviation from the baseline occurs today, a 50% deviation from the baseline occurs halfway to

the horizon, and a 100% deviation from the baseline occurs at the horizon (for details, please see the Appendix). Figure 8 illustrates the seven price trajectories which LAO generates.

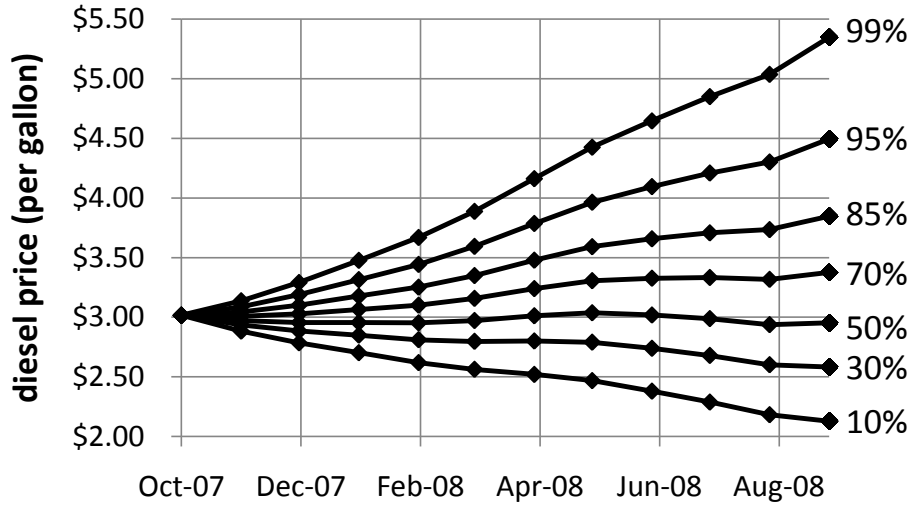


Figure 8 An example of the seven price trajectories. Notice that the seasonality exhibited in the baseline forecast is mimicked by all trajectories. These trajectories were generated using a baseline forecast from October 2007, which we used to evaluate LAO over the 2008 run-up in diesel prices.

Weighting Diesel Price Trajectories

LAO weights and sums the fuel surcharges evaluated along the seven price trajectories to compute a risk-adjusted expected fuel surcharge in each month, for each candidate carrier-lane pairing. If the retailer is risk-neutral, LAO selects weights so that the risk-adjusted expected fuel surcharges are simply expected fuel surcharges. However, because the retailer tends to be averse to diesel price risk, risk-adjusted expected fuel surcharges are typically higher than expected fuel surcharges.

Exactly how much higher is determined by the retailer's *risk aversion parameter*, which LAO uses to skew the weights away from the risk-neutral case. As the risk aversion parameter is increased, more weight is given to the higher-percentile trajectories, thereby shifting the emphasis of the retailer's plan from using expected diesel prices to using higher-than expected prices. Therefore, risk aversion is not aversion to price increases from the current price level, but rather aversion to price increases above the projected future price level, as modeled by the forecast (50th percentile

trajectory). Figure 9 illustrates how the weights for each trajectory behave as the retailer's risk aversion level is increased. For specifics on how the weights are computed, please see the Appendix.

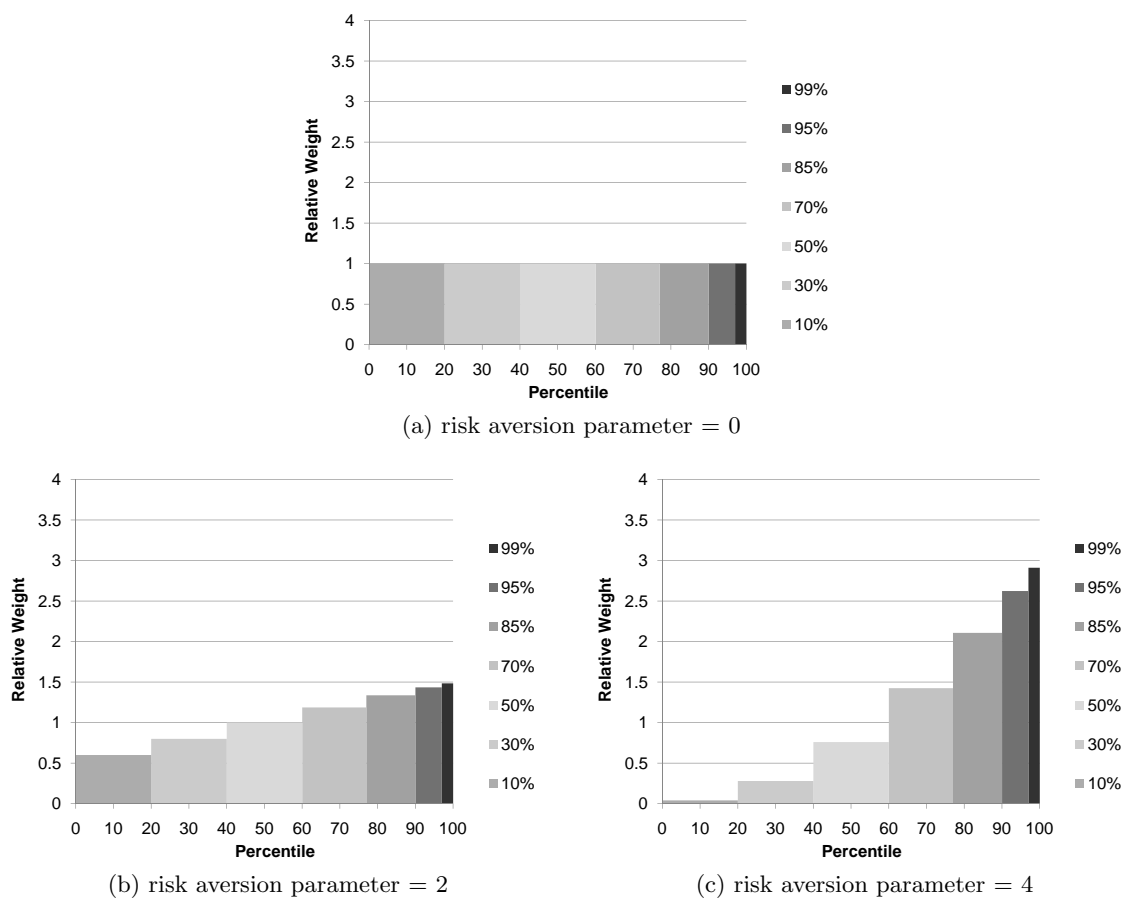


Figure 9 More weight is given to higher-percentile trajectories as the risk aversion parameter is increased.

Using LAO to Compute Optimal Lane Assignments

We implemented LAO in Microsoft Excel to allow the retailer's transportation professionals to easily interact with LAO as they negotiate contracts with carriers. LAO contains five main spreadsheets: **Settings**, **Model**, **SolverFoundationResults**, **Solution**, and **Lane View**.

The main inputs – a monthly forecast of diesel prices, a volatility parameter, and a risk aversion parameter – are entered on the **Settings** sheet, which includes the charts shown in Figures 8 and 9 to guide the user in providing these parameters. In conjunction with lane volumes and the carriers' bids for each lane (input on the **Model** sheet), Excel formulas use these parameters to calculate

the total annual risk-adjusted expected cost for each carrier-lane combination. The computed costs are stored in matrix form on the **Model** sheet for easy reference.

LAO solves for the optimal carrier-lane assignment using Microsoft Solver Foundation for Excel, which pulls data from the relevant spreadsheets and outputs the complete solution to the **Solver-FoundationResults** sheet. Since LAO is meant to be used interactively throughout the negotiation process it must be fast – and it is, taking less than a second to find the optimal carrier-lane assignment which minimizes risk-adjusted expected costs subject to lower and upper bounds on the number of lanes each carrier can win. The formal representation of the linear program is provided in the Appendix.

There are two spreadsheets which summarize the solution: the **Solution** sheet slices the total annual cost by lane and then by carrier. As well, it reports the total annual cost of the optimal allocation evaluated along each of the seven diesel price trajectories, thereby providing *sensitivity analysis*. Base prices and fuel surcharges are separated out for all of the above.

Finally, the **Lane View** sheet graphically displays, for a single lane, the cost of accepting each carrier’s bid as a function of the diesel price, as in Figure 6. This interface is particularly useful, since the retailer’s transportation professionals can use it to understand how awarding a lane to a carrier other than the one selected by LAO would impact the annual cost of running that lane at various diesel prices.

Implementation

In October 2009, the retailer used LAO when negotiating its new contracts. The retailer’s transportation professionals appreciated LAO’s user-friendly interface, which helped the retailer decide how to (a) *bend the cost curve* to more closely align surcharge rates with the true cost of diesel, and (b) *cap the cost curve* to share diesel price risk with its carriers. We next discuss these two important cost curve improvements, and estimate their cost savings.

Bending the Cost Curve

Carriers use fuel surcharges to transfer the amount they pay for diesel to their customers (i.e. retailers). In practice, this transfer is seldom perfect, leading carriers to either overcharge or undercharge

for diesel on a lane-by-lane basis. Graphically, overcharging occurs when the upward-sloping part of the fuel surcharge schedule is too steep. Thus, the retailer would like to identify when a carrier is likely to be overcharging, so it can negotiate to flatten the slope and “bend the cost curve” (see Figure 10).

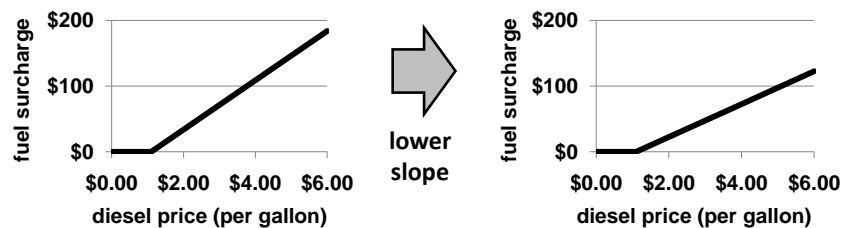


Figure 10 By bending the cost curve, the slope of a fuel surcharge schedule is more closely aligned with the true cost of diesel.

It is difficult for the retailer to know exactly how fuel efficient its carriers are. As mentioned previously, fuel efficiency depends on many factors, including class and age of truck, driving speed, traffic patterns, flatness of terrain, and load weight. As a starting point, however, the retailer may choose a benchmark fuel economy to compare carriers. For our benchmark, we will use the published national average fuel economy of 6.0 miles per gallon (mpg) for freight trucks, as measured by the U.S. Energy Information Administration (2009b).

We call a fuel surcharge schedule *perfectly aligned* if the rate at which fuel surcharges are billed to the retailer is equal to the rate at which the carrier spends money on diesel to serve the contracted lane. Thus, a fuel surcharge schedule is perfectly aligned when its slope (as represented in gallons/mile) is equal to the carrier’s actual fuel consumption in gallons/mile. A zero-peg perfectly-aligned fuel surcharge schedule will make sure that the total fuel surcharges billed in dollars over the life of the transportation contract are equal to the carrier’s actual diesel expenditures. Moreover, a $\$x$ -peg perfectly-aligned fuel surcharge schedule will, if $\$x$ is small enough for the price of diesel to exceed $\$x$ for the entire life of the transportation contract, yield a total surcharge in dollars equal to the carrier’s actual diesel expenditures, minus the first $\$x$ dollars of each gallon of diesel which is assumed to be included in the lane’s base price.

The benchmark 6 mpg fuel economy implies a fuel consumption rate of $1/6$ gallons/mile, which we can quickly compare with the slopes of the fuel surcharge schedules from the retailer's October 2007 RFP. Doing this, we notice that *all* carriers which implemented per-mile surcharges charged exactly 20 cents per mile for every dollar a gallon of diesel was priced above the peg (the peg itself was carrier-specific and in the range \$1.10-\$1.30). This gives each of these carriers an implied fuel consumption rate (fuel surcharge slope) of $\$0.20/\text{mile} \div \$1/\text{gallon} = 1/5$ gallons/mile, which is 20% higher than the $1/6$ gallons/mile benchmark. Therefore, from this rough analysis, we can conclude these carriers are overcharging for fuel by about 20%; i.e. the retailer has some negotiating room to bend the cost curve.

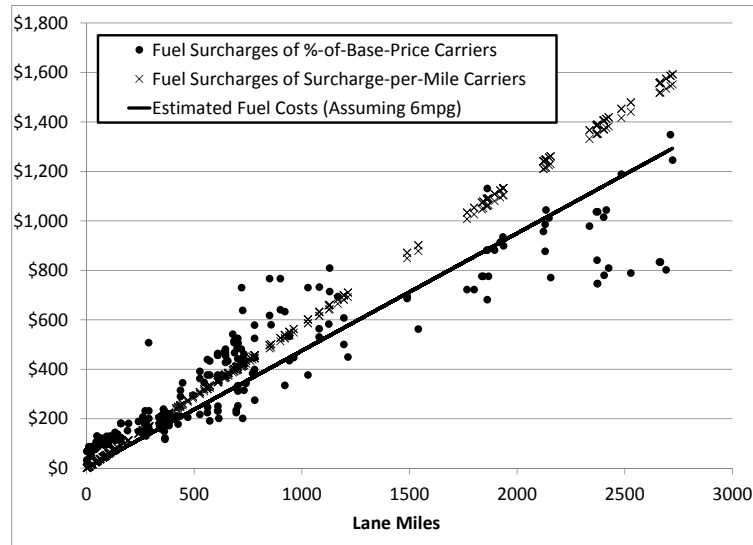
Of course, this simple analysis does not take into account the effect of empty (deadhead) miles driven by a carrier to pick up the next load after the retailer's shipment is made. Since rising diesel prices also increase the carrier's costs of running empty miles and thus decrease the profitability of a given lane, one can argue that a properly aligned fuel surcharge schedule should also transfer the cost of diesel from deadhead miles to the retailer. In this case, a better benchmark for fuel consumption is 0.2033 gallons/mile, which we compute by inflating the old $1/6$ gallons/mile benchmark by 22% to account for the fact that, in 2008, truckload carriers reported they were driving empty 22% of the time (see ATA 2008). This benchmark is likely a tad high, since we have not accounted for the fact that empty trucks weigh less and therefore should have an average fuel economy higher than 6 mpg. Nonetheless, it is interesting to note that when the cost of diesel for running empty miles is included, carriers no longer appear to be overcharging. Thus, a normative question presents itself: *Should retailers encourage carriers to use the fuel surcharge or the base price to transfer the cost of diesel used for empty miles back to them?*

Lazarus (2010) advises carriers to inflate fuel surcharges to transfer diesel costs for empty miles back to shippers (retailers). While this approach is prudent for carriers, it may undermine supply chain efficiency. Indeed, if a carrier is bound by a surcharge schedule with a shallower slope than its diesel consumption rate, the carrier will have a strong incentive to lower its fuel consumption to curb its exposure to escalating diesel prices; i.e. carriers will spend more effort finding backhauls

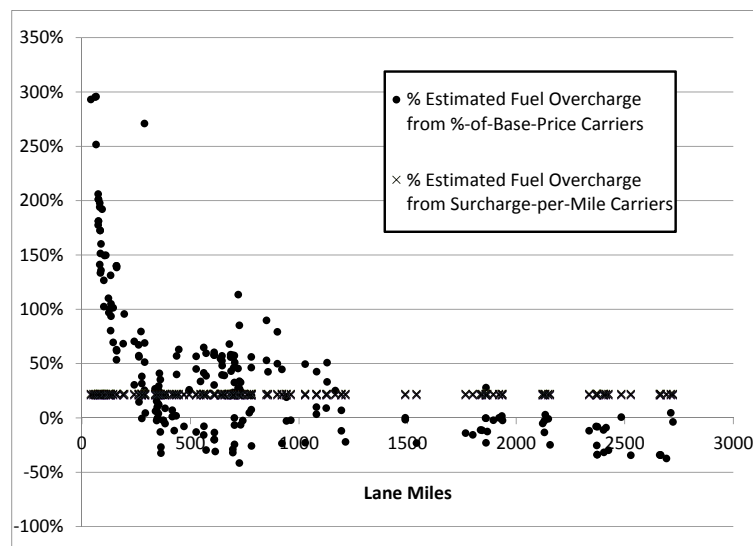
to lower the number of empty miles driven, and spend more upgrading their fleet to boost fuel economy. Therefore, a retailer that is averse to diesel price risk, or perhaps one with sustainability initiatives that encourage fuel efficiency, may want to accept a higher base price in return for a fuel surcharge schedule with a shallower slope. For this reason, we believe it is appropriate to use 1/6 gallons/mile as a broad fuel consumption target – a fuel consumption rate that will be roughly aligned with the true cost of diesel on lanes where the carrier is efficiently chosen.

Figure 11 compares our rough 1/6 gallon/mile fuel consumption benchmark with the implied fuel consumption rates offered in the retailer’s 2007 RFP. Each point represents the fuel surcharge for a single candidate carrier-lane pair assuming diesel is \$4/gallon. The upward-sloping solid line in Figure 11a is our benchmark, and represents a carrier with a fuel surcharge schedule with a slope of 1/6 gallons/mile and a peg of \$1.15 (appropriate, since carriers had pegs in the \$1.10-\$1.30 range). Points below the line are “good” while points above are “bad”; i.e. carrier-lane pairs below (resp. above) the line have shallow (resp. steep) fuel surcharge schedules that pay for fuel at a rate lower (resp. higher) than 1/6 gallons per mile. As mentioned previously, all carriers with surcharge-per-mile-based schedules (indicated by x-marks) have schedules with a 1/5 gallon/mile slope, and are thus above our benchmark.

An interesting pattern surfaces when we look at the carrier-lane pairs from carriers that have percentage-of-base price surcharges (cf. the solid circles in Figure 11). From Figure 11a, we see that the majority of short-haul carrier-lane pairs are above the line and are therefore overcharging for fuel relative to our benchmark, while the majority of long-haul carrier-lane pairs are below the line and are undercharging. Moreover, Figure 11b shows that the carrier-lane pairs with the lowest lane-miles tend to overcharge the most in percentage terms (computed by taking the gap between fuel surcharge and benchmark from Figure 11a, and dividing by the benchmark). To some extent, this pattern is expected because long hauls have a lower fuel consumption rate than short hauls which spend a larger proportion of time in stop-and-go traffic. But to a larger extent, this pattern manifests for a different reason.



(a) The fuel surcharge levied in dollars per truckload for each (carrier, lane) bid, compared to our benchmark. The price of diesel is assumed to be \$4/gallon.



(b) The relative amount each (carrier, lane) bid is overcharging for diesel, as compared to our benchmark. Ten outliers are not shown (the highest is a 12,943% estimated overcharge on a 1.1-mile lane).

Figure 11 Fuel surcharges for each carrier-lane pair in the retailer's 2007 RFP, ordered by lane-miles and compared to the 1/6 gallons/mile fuel consumption benchmark.

The overcharging / undercharging pattern of Figure 11b is predominantly a side-effect of the retailer's choice to have each percentage-of-base price carrier adopt a single surcharge schedule

for all of its lanes. To see why, note that a carrier incurs both fixed costs and variable costs for transporting a truckload on a lane. The variable costs, which include diesel, increase with the number of lane-miles, but the fixed costs do not. As a result, short hauls have a higher *proportion* of fixed costs than long hauls, and extremely short hauls (~ 1 mile) have almost no variable costs (or diesel costs!) at all. When fuel surcharges are levied directly on lane-miles, short hauls are appropriately surcharged very little. However, when fuel surcharges are levied on base prices, short hauls overcharge because the base price, which includes fixed costs, does not approach zero as lane mileage approaches zero. This effect is strongest for the shortest lanes, as can be seen in Figure 11b, where the estimated percentage overcharge blows up to infinity as lane-miles approach zero.

When one surcharge schedule is shared across all of a carrier's lanes, the base price is the only lever the carrier has to express how efficient they would be operating a lane, and because base price includes fixed costs and other non-fuel variable costs, it is difficult for a carrier to use base price alone to show a retailer that a specific lane has a low fuel consumption rate – an important metric for retailers explicitly managing their diesel price risk. Moreover, because base price is not directly proportional to lane mileage, there is no way to use a single percentage-of-base price schedule to perfectly align fuel surcharges to all of a carrier's lanes. The best we can hope for is that the same carrier wins a good share of both short and long hauls, so overcharges are roughly balanced by undercharges. In general, this outcome is hard to guarantee without imposing constraints on the distribution of lane lengths assigned to each carrier, and constraining LAO's assignment problem in this manner would increase the cost of the optimal carrier-lane assignment.

Even in the case where fuel surcharges are levied per mile, we may benefit from lane-specific surcharges. This is because the specific economics of each lane (which depend on the number of empty miles driven to collect the next load) could motivate the use of different fuel surcharge slopes for similar-length lanes that have different backhaul opportunities.

For these reasons, we recommend lane-specific fuel surcharge schedules be used whenever possible. However, we recognize that a balance must be struck between more degrees of freedom to optimize with and fewer degrees of freedom to speed up the RFP's negotiation process. Thus, while

the retailer agrees that lane-specific fuel surcharge schedules would be beneficial, and continues to enhance LAO and its negotiation process, the retailer decided to stick with carrier-specific fuel surcharge schedules in its recent October 2009 RFP.

Capping the Cost Curve

Typical fuel surcharge schedules like the one depicted in Figure 4 have unbounded surcharges; that is, if the price of diesel continues to climb, the fuel surcharge assessed to the retailer also continues to increase. As a result, unlimited diesel price risk is exclusively borne by the retailer. An upper bound to the fuel surcharge schedule, called a *surcharge cap*, causes diesel price risk to be *shared* between the retailer and the carrier. With a cap, the most extreme price increases are borne by the carrier while moderate price increases are borne by the retailer. Using LAO, the retailer can negotiate to “cap the cost curve” by establishing a maximum fuel surcharge (see Figure 12).



Figure 12 A fuel surcharge cap limits the retailer’s exposure to diesel price risk by sharing some risk with its carriers. Shown: Carrier 2 on lane 138.

Certainly, the retailer prefers to lower its exposure to diesel price risk, but instituting a surcharge cap may be costly because carriers could increase their base prices to compensate for the burden of having a cap. Therefore, the retailer must balance its desire to mitigate diesel price risk with its objective of minimizing the expected cost of transportation; the point where this balance is struck depends on the retailer’s risk aversion level.

Ultimately, if either party – retailer or carrier – is assigned a higher level of diesel price risk than they are comfortable with, they could engage in *hedging* by purchasing call options in the diesel futures market. Then should the price of diesel rise, higher fuel costs would be (partially) offset

by revenue generated from exercising the call option. Since diesel is more integral to the carriers' business than to the retailer's, the retailer has argued that carriers can leverage their knowledge of diesel prices to potentially hedge diesel price risk at a lower cost than the retailer, motivating the retailer's use of surcharge caps to transfer some diesel price risk onto carriers.

Estimated Cost Savings

In its October 2009 RFP, the retailer began to actively manage diesel price risk by negotiating with its carriers to bend and cap their surcharge schedules. The end result of this negotiation was a common fuel surcharge schedule adopted by all carriers that significantly reduced the retailer's exposure to diesel price risk. This common surcharge schedule computes surcharges via the percentage-of-base price method, and when compared with the surcharge schedules from 2007 has a shallower slope and includes a surcharge cap (a completely new feature). In response to the lower negotiated fuel surcharges, carriers raised their base prices by 7.26% over 2007 levels. But, savings from lower fuel surcharges exceed costs from higher base prices under nearly all diesel price trajectories, and are most significant for the highest trajectories (i.e. cases with the largest unexpected increase in diesel price).

Table 1 describes the before and after picture using two cases: "without LAO" and "with LAO." The "without LAO" case runs the October 2007 RFP (the last RFP for which we have complete data) according to the retailer's previous evaluation criterion (the cost of a carrier-lane combination is its base price plus the fuel surcharge evaluated at the prior year's average diesel price; i.e. the retailer is risk neutral and expected fuel cost is based on historical data). In comparison, the "with LAO" case runs the October 2007 RFP using LAO to optimally select carrier-lane assignments that minimize base price plus risk-adjusted expected cost (using risk aversion level 4). The "with LAO" case additionally uses the common fuel surcharge schedule introduced in October 2009 and raises the base prices of all bids by 7.26%. Fuel surcharges were computed from actual 2008 prices (labeled "Actual"), as well as from forecasted price trajectories (labeled Trajectories 10%, ..., 99%). Expected costs (labeled "Expected") were computed by appropriately weighting and summing the possible price trajectories.

Trajectory	Without LAO			With LAO		
	Base Charges	Fuel Surcharges	Total Cost	Base Charges	Fuel Surcharges	Total Cost
10%	\$71.9	\$13.3	\$85.2	\$76.9	\$8.6	\$85.5
30%	\$71.9	\$15.6	\$87.5	\$76.9	\$10.0	\$86.9
50%	\$71.9	\$17.5	\$89.4	\$76.9	\$11.2	\$88.1
70%	\$71.9	\$19.5	\$91.4	\$76.9	\$12.6	\$89.4
85%	\$71.9	\$21.6	\$93.5	\$76.9	\$13.8	\$90.7
95%	\$71.9	\$24.3	\$96.3	\$76.9	\$15.7	\$92.6
99%	\$71.9	\$27.8	\$99.8	\$76.9	\$17.1	\$94.0
Expected	\$71.9	\$17.9	\$89.8	\$76.9	\$11.5	\$88.4
Actual	\$71.9	\$26.3	\$98.2	\$76.9	\$16.8	\$93.6

Table 1 We estimate \$4.6 million dollars could have been saved in 2008 (compare \$93.6 million with \$98.2 million). All figures are in millions of dollars.

From this comparison, we can see that the “with LAO” case has markedly lower costs for high-percentile trajectories, leading to substantial savings in years like 2008 in which diesel prices increase dramatically. Specifically, evaluating the cost along the “actual” price trajectory observed in 2008, LAO estimates the retailer could have saved \$4.6 ($= 98.2 - 93.6$) million had the retailer used the new fuel schedule with surcharge cap in its 2007 RFP. This analysis serves to illustrate the power that a good decision support tool has in helping negotiate more favorable contract terms.

Conclusions

The LAO tool has improved the retailer’s capability to evaluate the tradeoff between base price and risk-adjusted fuel surcharge, allowing the retailer to cap and bend its cost curves, and select carriers based on lowest risk-adjusted annual cost. The LAO tool has incorporated diesel price risk into the retailer’s carrier selection process, leading to transportation contracts which are robust in the face of uncertain diesel prices.

It is interesting to note that the retailer decided to convince its carriers to use a common percentage-of-base price fuel surcharge schedule for all lanes in its October 2009 RFP. In this special case, the common fuel surcharge can be factored out of the objective, leaving LAO to minimize the sum of the base prices from selected carrier-lane pairs. As a result, the optimal carrier-lane allocation under the given common fuel surcharge schedule is independent of diesel price – a strong condition that implies that regardless of how the price of diesel evolves, the retailer will not have an incentive to switch carriers on any of its lanes. The retailer, however, pays a price

for insisting on this level of homogeneity. As shown in Figure 11, it is impossible to align the slope of this common surcharge schedule with all carrier-lane pairs, thus short-hauls will overcharge. Moreover, by insisting all carriers adopt the same fuel surcharge schedule, the retailer learns less about individual carriers' fuel consumption rates, making it harder for the retailer to know what slope and cap to suggest for its common fuel surcharge schedule.

Allowing carriers to competitively bid fuel surcharge schedules on a lane-by-lane basis is the ideal case, since carriers with the best fuel economies would be more apt to win lanes. However, a balance must be struck between having more degrees of freedom to optimize with and fewer degrees of freedom to speed up the RFP's negotiation process. Fortunately, LAO's ability to manage the complexity of lane-specific fuel surcharge schedules will allow the retailer to strategically introduce heterogeneity into its fuel surcharge schedules to capture additional savings in years to come.

Appendix

This section provides supplementary material for four sections of the paper: *Generating Diesel Price Trajectories*, *Weighting Diesel Price Trajectories*, *Computing Carrier-Lane Costs*, and *Using LAO to Compute Optimal Lane Assignments*.

Generating Diesel Price Trajectories

Let H be the lognormally-distributed end-of-horizon diesel price. Specifically, $H \sim \text{Log-N}(\mu, \sigma^2)$ where e^μ is the diesel price specified by the baseline forecast at the end of the horizon and σ is the scale parameter (*volatility parameter*) specified by the retailer. Denoting h_α as the α^{th} -percentile of H and $\Phi(\cdot)$ as the cumulative distribution function of the standard normal distribution, we have $h_\alpha = e^{\mu + \sigma\Phi^{-1}(\alpha)} = (e^\mu)(e^{\sigma\Phi^{-1}(\alpha)})$. Thus, we can think of the end-of-horizon price h_α at a given percentile α as the baseline price e^μ multiplied by a distortion factor $e^{\sigma\Phi^{-1}(\alpha)}$. To generate the rest of the price points along a trajectory, we progressively attenuate this distortion for price points closer to today. Thus, for a price point on the α^{th} -percentile trajectory at month m of 12, the appropriate distortion factor is $d_{m,\alpha} = e^{(m/12)\sigma\Phi^{-1}(\alpha)}$. Finally, the diesel price in month m along the α^{th} -percentile trajectory is $p_{m,\alpha} = p_{m,50} \times d_{m,\alpha}$, where $p_{m,50}$ is the value of the baseline forecast (median trajectory) at month m .

Weighting Diesel Price Trajectories

Let β be the retailer's *risk aversion parameter* which ranges from 0 (risk-neutral) to 5 (very risk-averse). We treat each trajectory α as a sample path which occurs with probability w_α . This section describes how the retailer's *risk aversion parameter* β determines the "weights" w_α .

Although we have discretized our sample space to just seven trajectories, we can envision a continuous space of trajectories from the 0th-percentile to the 100th-percentile. We assume the α^{th} -percentile trajectory is *representative* of the continuous-space trajectories from some "lower bound"-percentile (lb) to some "upper bound"-percentile (ub), as indicated in Table 2.

α	lb	ub
10	0%	20%
30	20%	40%
50	40%	60%
70	60%	77.5%
85	77.5%	90%
95	90%	97%
99	97%	100%

Table 2 Each trajectory α is representative of continuous-space trajectories from the "lower bound"-percentile (lb) to the "upper bound"-percentile (ub).

When $\beta = 0$ (risk-neutral case), we define the weights as $w_\alpha = ub - lb$. But as β increases, progressively more weight is given to higher-percentile trajectories. The proprietary weighting formulas used for $\beta \geq 1$ were chosen by the retailer to be graphically intuitive. Qualitatively, as β increases, progressively more weight is given to higher-percentile trajectories. Note that the *relative weights* shown in Figure 9 have been normalized by dividing by the risk-neutral weights $ub - lb$.

Computing Carrier-Lane Costs

Using the notation of Table 3, the risk-adjusted expected fuel surcharge for carrier i on lane j in month m is $r_{ijm} = \sum_\alpha w_\alpha s_{ij}(p_{m,\alpha})$, the price per shipment in month m for carrier i on lane j is $b_{ij} + r_{ijm}$, and the annual risk-adjusted cost of lane j under carrier i is $c_{ij} = \sum_m v_{jm}(b_{ij} + r_{ijm})$.

Using LAO to Compute Optimal Lane Assignments

The linear program solved by LAO is displayed in Figure 13. This linear program minimizes the risk-adjusted expected cost of an assignment, subject to the constraints that each lane is assigned

Indices i = a carrier j = a lane m = a month $\in \{1..12\}$ α = a trajectory $\in \{10, 30, 50, 70, 85, 95, 99\}$ **Decision Variables** x_{ij} = 1 if carrier i is assigned to lane j , 0 otherwise**Parameters** $\underline{a}_i, \bar{a}_i$ = min/max # of lanes to assign to carrier i b_{ij} = base price bid by carrier i for lane j c_{ij} = annual risk-adjusted expected cost for lane j if carrier i is chosen to operate the lane $p_{m,\alpha}$ = diesel price in month m on trajectory α r_{ijm} = risk-adjusted fuel surcharge for carrier i , lane j , month m $s_{ij}(\cdot)$ = fuel surcharge function bid by carrier i for lane j v_{jm} = volume of lane j in month m (# runs) w_α = weight of trajectory α **Table 3** **Notation**

to exactly one carrier and that carrier i is assigned at least \underline{a}_i but no more than \bar{a}_i lanes. It is well-known that solutions to this LP are always integer.

$$\begin{aligned}
 \min \quad & \sum_{i,j} c_{ij} x_{ij} \\
 \text{s.t.} \quad & \sum_i x_{ij} = 1 \quad \forall j \\
 & \underline{a}_i \leq \sum_j x_{ij} \leq \bar{a}_i \quad \forall i \\
 & 0 \leq x_{ij} \leq 1 \quad \forall i, j
 \end{aligned}$$

Figure 13 **The linear program used by LAO.****References**

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Statement from Senior Manager for the Retailer

We confirm that the LAO tool has been useful in helping us to develop our new sourcing strategy. As noted in our agreements with the university and project participants, we regret that we cannot allow this article to identify us or include our name.