Can Shippers and Carriers Benefit from More Robust Transportation Planning Methodologies?

by

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Bachelor of Industrial Engineering
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Abstract

The analysis of transportation contracts using optimization software may yield higher actual freight expenditures due to unplanned events during execution. This thesis explores new methods for developing robust transportation plans leading to lower total cost by developing a transportation plan minimizing unplanned events and quantifying a cost of service for use in existing optimization models.

Robust transportation planning methodology requires the analysis of a variety of transactional related data, the application of analytical tools and performance measurement techniques. This thesis explores analytical techniques utilizing shipment, accept-reject, bid, and planning data. This analysis is then used to augment optimization software capabilities, develop simulation models and provide performance management frameworks by making assessments of shipper-carrier interactions as they occur within the design of an optimized plan.

The results of this thesis include analysis and methods focused on quantification of carrier performance considering various classes of transactional data, bid data, and market data. Methods to determine the amount of additional freight expenditures as a result of the frequency and severity of unplanned freight are provided and supported with simulation output.

Thesis Supervisor: Dr. Christopher G. Caplice
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Professional colleagues: Matt Menner for being a friend and a champion in many ways. Your support is greatly appreciated. Kevin Zweier for teaching me how to run a bid, he is without question the most talented individual I know when it comes to the heavy lifting of making a bid successful. Kevin's people skills and quantitative ability were the secret behind all the sales presentations and hand-waving. I am fortunate to have crossed paths with such talent. Jeff Mitchell for his support and teaching me about the power of blast emails.

Gary Whicker and Woody Richardson for spending time with me and sharing perspectives from the side of the carrier. Trucking is so ubiquitous and so important, yet most do not see it for the valuable role it has in our daily lives. I appreciate your insights and your help.

Dedication

Sufficient words do not exist for the feeling of being part of a family that demands your time for the very essence of their well being.

Likewise, sufficient words do not exist for the feeling that strikes your core when a 5-year old asks, knowing the answer in advance, if you have "the MIT" today as he is planning his adventures and needs a fellow superhero. All in good time, Scotton – you will understand.

My thesis is dedicated to my family, Jen and Scotton, for their love and support.

I adore you both…

Biographical Note

From 1998 to 2004, Matthew Harding has managed and lead optimization-based transportation procurement services on behalf of major shippers including Wal-Mart, Clorox, Hewlett-Packard, and others totaling over \$3B (USD) in annually freight expenditures for U.S. and European transportation operations. For all projects, optimization-based bidding methodologies were used in analyzing bid results with expected value delivered as a result of these efforts estimated in the range of 3-10% of yearly transportation freight expense. Projects focused primarily on truckload/intermodal transportation networks averaging roughly between \$100MM-\$500MM dollars per year. Experience in establishing contracts for other modes include: Ocean, LTL, Air, and European Surface.

During his tenure with transportation software companies, Mr. Harding has also implemented and developed processes supported by transportation execution software focusing on dynamic routing optimization, continuous move analysis, rate variability analysis, backhaul analysis, carrier management analysis, business process analysis and various mode and service level studies.

From 1988-1997 Mr. Harding was employed by Ford/Loral Aerospace and Delta Airlines in the field of flight and weapons system simulation and obtained a Bachelor of Industrial Engineering from Georgia Institute of Technology with Honor.

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1 Introduction

This thesis explores analytical approaches that minimize freight expenditure for shippers by focusing on the uncertainty of the supply of capacity from the domestic truckload motor carrier market. Strategic planning is frequently performed by shippers using optimization software that aligns carrier capacity and rates to a shipper's forecasted freight volume. Shippers have freight to haul, and carriers haul the freight for a fee. The optimization software achieves this alignment by determining the lowest cost solution subject to business constraints provided by both the shipper and carrier. Although the formulations used within the software provide many benefits, there are inherent weaknesses due to the limitations in addressing uncertainty. Formulations of mathematical modeling used in these software tools are designed to only reduce direct costs, an approach limited in addressing the dual objective faced by shippers of also maximizing service. The models are also rigidly designed using fixed parameters including demand values for anticipated freight volume, and fixed supply values for carrier capacity as input data. By design, these tools cannot consider variable supply and demand which can be expected as a result of business cycles, seasonal demand or other random disruptions in the supply chain. Since unplanned events associated with uncertainty are not modeled well in the current software tools, the burden of designing a robust transportation plan currently resides with the qualitative experiences of the transportation managers who establish contracts. This thesis addresses the gap between planned and unplanned events as they apply to the strategic planning process and suggest approaches to mitigate the effects on increased freight expense.

1.1 Motivation – Limitations In Practice

In the early 1990's, the convergence of advanced, low cost computing power, improved optimization techniques, and a rapidly consolidating truckload market spawned a fertile ground for using mathematical methods in establishing transportation contracts. Over the past decade, shippers, carriers and software service providers have developed techniques to establish transportation contracts supported by optimization software and data intensive contracting processes. Shippers with sufficient freight expense to cost justify the use optimization software have adopted these processes as standard practice and will "optimize" their freight contracts roughly every one to two years with a network bid.

Sourcing transportation is a unique process when compared to other corporate sourcing functions. The quantity and characteristics of capacity required at a point in time materialize within a short timeframe prior to consumption. In addition, strategies for sourcing carrier capacity are counter intuitive to cost-focused sourcing strategies because an aggressive position on cost reduction with transportation services will likely lead to poor carrier responsiveness. Transportation providers that promise a lower rate cannot always guarantee capacity at the contracted level, and lower than market rates will always be challenged by more profitable alternatives within a carrier's own network.

This condition is further complicated by the technology employed to optimize transportation contracts because fluctuations in demand are generally ignored when optimization technology is used. To a large extent, more robust planning approaches are limited by the availability of data. However, as transportation management software proliferates, the data necessary to make more informed decisions about carrier capabilities becomes more available to shippers. This is made possible though integrating technologies such as EDI and XML which provides a better view of cost and service trade-offs by supporting quantitative techniques. The goal of this thesis is to determine if the combination of statistical methods and optimization techniques can be established to yield better strategic planning for shippers.

The motivation for this thesis stems from observed limitations of using optimization within the current practices of transportation procurement. Currently, assessing the robustness of a transportation plan is generally an informal process; however, shippers should be thinking ahead to better approaches for aligning their need for capacity with the financial and operational needs of carriers. The obvious goal for the shipper is to reduce transportation costs, but it is limited in its effectiveness when focusing purely on rates provided by carriers in a bid. Saving transportation costs should be in the context of creating a robust transportation plan that effectively aligns providers of transportation services to its consumers, effectively bringing value to both shippers and carriers.

1.2 Literature Review – Transportation Sourcing and Carrier Economics

Given the complexities within the transportation industry, there is a wide body of research focused on the dynamic aspects of networks and the application of mathematical methods to increase profitability for motor carriers. However, research that addresses the specific topic of shipper procurement of carrier services is less plentiful. Ledyard (2000) recounts the first technology based bid and its success at Sears Logistics Services in the early 1990's. Caplice (1996) researches optimization based bidding, shipper/carrier economics, auction design, network design, carrier assignment, and other relevant topics. Song and Regan (2003) cover various economic aspects of combinatorial bids from the perspective of the carrier using simulation techniques. Sheffi (2004) summarizes the application and development of the optimization based bidding tools and techniques over the last decade.

From the carrier perspective, there is extensive research focusing on carrier operations, trucking based asset management and market economics. Powell (2003) explores various optimization models as they apply to operation problems in the context of financial, physical and informational views. Jara-Diaz and Basso (2002) address production and cost functions and their application to various transportation networks as they apply to economies of scope.

Although this thesis does not explicitly address macro-economic trends and their implication on planning, they are a critical component to robust planning. Sources of industry based economic data include the Bureau of Transportation Statistics (BTS 2004) and Standard & Poor's Industry Survey of Commercial Transportation (S&P, 2004). Both indicate tightening capacity in the current (2005) market after a period of consolidation in the North American truckload sector. Research by Lahiri and Yao (2004), Lahiri, Stelker, Yao and Young (2003) have suggested the potential of forecasting macro economic activity with transportation related indices resulting in the recently developed Transportation Services Index. The TSI is now managed by the Bureau of Transportation Statistics and is a key component of economic predictors and is derived by aggregate transportation output across many modes for U.S. domestic freight.

1.3 Methodological Note

Although various sections of this thesis are not reinforced by quantitative analysis and are presented in general terms, the concepts and ideas are the culmination of my experience in managing and performing procurement services. I have interacted with hundreds of shipper and carrier transportation professionals in discussions regarding the planning and execution of transportation. This thesis is the culmination of those observations with the hope of developing approaches that give equal consideration to needs of shippers and carriers a like, ultimately driving additional value in the industry. Any reliance on past experience will be cited as (Harding 2005).

The remainder of this thesis is organized as follows: Chapter 2 provides an introduction to the industry focusing on shippers, carriers and the optimization software that they use to establish contracts. Chapter 3 evaluates shipment data and presents methods to measure carrier performance with a framework to assess robustness of providers. Chapter 4 evaluates the data which captures the acceptance and rejection of freight offers from carriers comparing performance to contracted volume. Chapter 5 explores techniques to integrate the performance measurement with optimization software by adjusting rate and capacity values linking both shipment and acceptance data defined in previous sections. Chapter 6 provides design criteria in developing a simulation model and provides an example of how simulation can be used to assess the robustness of an optimized transportation plan.

2 Industry Overview

The U.S domestic trucking industry is a critical component of the overall economy. The latest numbers from Standard & Poor's Industry Survey for Trucking indicate that for-hire truckload operations accounted for nearly $270B in truckload revenues during 2003 representing roughly 40% of total U.S. commercial freight (S&P 2004). Trucking continues to dominate the U.S. freight transportation mix with current ratios at 64 percent of total value hauled, 58 percent of total tonnage, and 32 percent of total ton-miles for 2002 across all modes including rail, air and ocean (BTS 2004). In addition, transportation labor of for-hire transportation accounted for 4.4 million jobs in 2003, which is roughly 3.5% percent of all domestic employment (BTS 2004).

The trucking industry is also highly correlated to industry trends. In examining the effects of regional and industry level sector shocks on aggregate business cycles, Ghosh and Wolf (1997) quantified differences between various economic shocks to determine the effects at the state and industry level. Their research found that the transportation sector, second only to the retail trade, was highly correlated to both regional and industry level economic shocks. This was perceived to be a result of the high level of dependence for transportation services in other industries. This dependence on transportation can be a key enabler to economic viability or, conversely, a limiting factor since macro level swings in aggregate business cycles require available capacity in the U.S. domestic trucking market. The interconnectedness to all industrial sectors and sensitivity to business cycles make the relationship between shippers and carriers particularly interesting from a contracting perspective.

2.1 Shippers

Shippers purchase transportation services from for-hire truckload carriers under various governance structures including dedicated service, contracted capacity and spot market capacity. A dedicated contract requires the carrier to dedicate a set level of their capacity to a portion of a shipper's network typically focusing on freight that can leverage economies of scope for the carrier. Contracted capacity is generally considered the set of carriers, both primary and backup, who have negotiated rates with a shipper and have agreed to contract terms and rate structures as part of a formal agreement. Spot market capacity is typically channeled to the shipper though brokers and consists of capacity that is needed usually when contract carrier capacity has been exhausted.

Contracts with for-hire carriers typically last one to two years and typically have an addendum of rates and capacity which the carriers agree to as part of their commitment to a given shipper. Lanes in a contract can be defined individually from other lanes as discrete lanes, or combined as "package lanes" or "bundled lanes" meaning that the rates apply only if the shipper commits to all the volume on all lanes in the package. Addendums that define the discrete or bundled lanes are generally referred to the Schedule A and contains all lane awards which are defined as an origin point or region to a destination point or region for a fixed or variable rate such as a flat $500 fee per load or a rate per mile. Service and equipment requirements are also defined such as single or team drivers, and dry, refrigerated equipment making the rates very specific to a particular carrier offering.

Additional costs such as detention fees, stop charges, pallet charges and other costs known as accessorials are also included in the contract. In some cases, these fees are set by the shipper. If the carrier objects to the level or structure of the fees, and the shipper has enough leverage to demand a fixed accessorial fee, the shipper expects the carrier to adjust their line-haul rates to capture the discrepancies in accessorial fees (Harding 2005). This is a common shipper bidding strategy which allows the shipper to compare line-haul rates while maintaining fixed non-line-haul rates. Since the frequency of many accessorials charges are not known in advance, adjusting line-haul rates to reflect anticipated accessorial fees poses a challenge for carriers since converting these expected fees to a single line-haul rate leaves them exposed to lower profits or the possibility of losing the business as a result of uncompetitive pricing.

The process of defining a transportation network typically includes aggregation of historical shipment transactions into lanes with adjustments for projected growth or major supply chain redesign. Changes are inevitable and include adding, moving, adjusting, and deleting freight volume as a result of anticipated activities such as closing of facilities, acquiring new suppliers or mergers with other companies. This information is presented to carriers in the form of a reverse auction where the carriers provide rates and capacity limitations on the business they are interested in winning and the price is driven down in the interest of the buyer.

Once the analysis of the rates and the negotiations are complete, the shipper constructs what is commonly referred to as a "routing guide". The routing guide is used to determine which carrier is assigned a specific load based on the lane and capacity of the carrier during execution. The routing guide takes on many forms in various degrees of sophistication from 3x5 cards, to a central database, to sophisticated software integrated between shipper Enterprise Resource Planning (ERP) systems and carrier ERPs. These systems are known throughout the industry as a Transportation Management System (TMS) and have many capabilities to manage transportation planning and execution. All of the data provided in this study were obtained from TMS technology.

Once contracts are agreed to by both parties and the bid is complete, shippers then transition to the carriers in the newly designed routing guide. This is the period of greatest risk for a shipper. It is common for a shipper to acquire hundreds of thousands of lane bids on thousands of lanes from tens or hundreds of carriers (see Table 2.1). The amount of transition in the network is of great concern to shippers because incumbent and newly introduced carriers are readjusting flows and learning new business requirements which vary at both the origin and destination. If the change is significant, the likelihood of carriers not being able to adjust during the transition is at its highest in the contracting period. Some shippers transition to new contracts during slower periods of their business cycle since the potential for a negative impact to their business is at its lowest.

A common phenomenon that occurs during the transition period, and auctions in general, is the Winner's Curse (Capen, Clapp and Campbell 1971). The Winner's Curse states that the winning bid is a result of imperfect information. Carriers may not fully understand the cost implications of a shipper's business requirements and bid too aggressively. This would result in winning the business based on perceived value and ultimately lead to increased costs for the carrier due to imperfect information. Shippers are well aware of the Winner's Curse and, in some cases, will disregard an extremely low rate from an unfamiliar carrier because of the risk that it will lead to elusive savings. In extreme cases, incumbent carriers may not reduce rates knowing that the high service level requirements of a bidding shipper are not well known to competing non-incumbent carriers. Shippers who use new carriers to leverage rate reductions with incumbent carriers will ensure the Winner's Curse when hidden costs are not well understood by the new carriers. Once the shipper transitions to the new carriers, the unexpected costs challenge the new carrier's commitment. When this occurs, there is a strong likelihood that the shipper will look to acquire the needed capacity in the previous incumbent base. Although these carriers have "lost" the bid, they have a good understanding of the real costs and have demonstrated service capability making them likely candidates for reevaluation. This is termed "Losing the bid, but winning the business" and is an outcome that is highly undesirable from the perspective of the shipper. Unfortunately for shippers in this situation, not all carriers adhere to the rates that were provided in the bid resulting in increase costs.

Once the shipper has made the necessary adjustments during the transition, they are faced with updating their routing guides and evaluating carrier performance for the term of the contract. Shippers vary on the allowable grace period to settle into the new traffic flows from 0 to 6 months and may hold monthly or semi-annual meetings to review performance (Harding 2005). Shippers expect seasonal demand variations and communicate their expectations to the carriers to ensure that the execution of the contracts is performed satisfactorily to corporate objectives which are commonly focused simultaneously on high service and low cost. Interestingly, shippers are not the only entity in this relationship that deal with severe demand fluctuations. Carriers have equally unpredictable demand for their capacity since they are dealing with many shippers in many different industries each with their own seasonal requirements. The hope and expectation for both parties is that the variances in supply and demand will balance out over time and that relationships can be maintained. It is precisely this balance, or lack thereof, that leads to unplanned freight. For the purposes of further discussion, "planned" freight refers to freight that is executed within the definition of the routing guide and typically represents budgeted freight costs. Conversely, "unplanned" freight represents freight that is assigned to non-primary carriers which may be loosely defined in the routing guide using state level rates representing standard pricing, or not defined in the routing guide at all leading to spot market rates.

Once the carriers settle into the business, the management of the carriers and daily execution can occur through the capacity assignments designated in the routing guide; however, the project is termed a success or a failure before the contracting period based on estimated savings. How does this happen? In practice, results are based on estimated future direct costs on forecasted demand using the freight expense captured by lane from the previous period, not the actual freight hauled under contract over the contracting period (Harding 2005). Optimistic savings estimates have significant implications for shippers. Collecting widespread sub-market rates will understate planned (budgeted) costs because carriers will likely default on their commitments due to lack of profits leading to higher priced alternatives for the shipper. Sub-market rates result from bids that focus on collecting the lowest rates and are commonly referred to in the industry as "rate shopping". Rates obtained from rate shopping strategies are commonly termed "paper rates" due to the lack of capacity they provide. Although optimistic savings estimates can lead to overstating expected benefit, bids with reasonable savings estimates are also at risk of overstating expected savings leading to increased freight expenditure. More will be covered on this common miscalculation in section 4.2.

2.2 Carriers

For-hire carriers fall into three basic categories: National, regional and owner operators (OO's). National carriers generally service the entire continental United States, regional carriers focus on specific regions while owner operators are generally individuals or family businesses with 3 or less trucks. Well over 30,000 of the 45,000 estimated trucking companies are estimated to have annual revenues of less than $1MM (S&P 2004). Five of the top carriers have revenues between $1.5 and $3B in an industry that is estimated to be roughly $268B (S&P 2004). Competitive analysis indicates that the industry is highly fragmented with very low barriers to entry. Low costs of operation and low capital costs contribute heavily to this fragmentation. More recent trends include increased consolidation as smaller carriers have exited the business. This brings the estimated total number of domestic truckload motor carriers from 53,000 in 1994 (ATA 1994) to its current level of 45,000 (S&P 2004).

Carriers' generally perceive the competitive bidding process as the least desirable level of interaction with a shipper. Carriers with sufficient analytical and engineering services prefer to offer more custom-tailored solutions and generally stress the position that competitive bidding commoditizes their offerings and limits their total value proposition. Carriers prefer to work with their shipper customers one-on-one without the pressure from their competition. To offset the competition, national carriers have attempted to differentiate their total offering by expanding their logistics services to include supply chain analysis, IT services, multi-modal capabilities and third party logistics services. For shippers with complicated transportation and logistics problems, this differentiation in carrier capabilities can reduce competitive bidding pressure by differentiating their relationship with a shipper beyond the supply of capacity. Although carriers prefer to avoid competitive bidding, it is current standard practice in the industry.

Bidding Strategies

Given the wide range of competencies in the carrier market, bidding strategies vary considerably. Carriers with strong engineering capabilities will generally have a systems view of their network considering the impacts of new business on their existing network using sophisticated tools and techniques. This expertise provides a foundation to be selective when bidding on freight as they look to gain from economies of scope. Conversely, carriers with limited engineering capabilities will be limited to qualitative experiences to determine which freight is beneficial to the organization. Depending upon the competitive forces that carriers face and their ability to design a feasible and competitive response, carriers will range significantly in their approach to a shipper. The following illustrates two generalized approaches that carriers employ when responding to competitive bids.

The most sophisticated approaches supporting bid response strategies utilize detailed execution level data collected from daily operations employing carrier ERP and satellite track and trace systems. This information supports the use of sophisticated tools including forecasting, yield management and activity based costing. Carriers use technology to gain a competitive advantage in the bidding process with the intention to increase profit, increase efficiencies and balance flows in execution. One interesting example of this is the use of activity based costing to capture the expected delay in loading or unloading. Carriers currently employ systems that capture the duration of delays for each load and unload point because delays are a key contributor to lost profits and a major focus for carriers. Excessive delays limit equipment utilization and lead to greater driver turn over, which are translated into increased rates for perpetrating shippers. These data provide a statistical basis for estimating expected inefficiencies and adjusting pricing in response to a bid. If the delays are consistently significant for specific locations within an origin or destination on a lane, rates can be adjusted based on engineered information to cover any negative impact to the carrier's network. Carriers with sophisticated software are also capable of measuring the impact of network effects of new business on profits, and will use this capability to assess a shipper's profit potential given their existing network structure. Economies of scope override economies of scale for carrier networks, and increased freight can lead to lower profits for carriers as a result of imbalances. Balanced flows in the network leads to profitability, not just increases in business. This phenomenon motivates carriers to reduce dwell time and empty miles to increase profits and is the motivation leading to a wealth of operations research based software solutions to manage carrier planning and execution in the market.

The least sophisticated approach is the most difficult challenge for shippers trying to establish new contracts. Carriers, without the capacity or sophistication, will bid aggressively and provide rates and capacity values that far exceed their operational capabilities. Carriers do this with the intention of winning as much business possible. The reasoning behind such a strategy is that the carrier can utilize the transition period to determine which lanes stay in the carrier's network. The lanes that cannot be supported by the carrier are either supported through additional third party relationships (brokers) to cover the excess requirements, or simply dropped from the carrier's network leaving the shipper with no capacity. This approach creates major problems for shippers because carriers who were not awarded this business must be contacted after the bid indicating (informally) that the shipper made a poor choice. The carriers who have lost the business have likely readjusted the capacity to other parts of their network and must consider yet another readjustment to service the lanes with the required capacity. This almost always leads to increased transportation costs and is something that shippers must try to avoid.

Market Forces and Strategy

The competitiveness within the carrier market also has an impact on the way that carriers bid. In periods of tight capacity, demand for carrier services are relatively higher forcing shippers to take new approaches to competitive bidding. Carriers who are part of core carrier programs may be given the first right of refusal prior to a competitive auction. This opportunity allows the carrier to determine where they can best serve a shipper with a focus on service and less significant competitive pressures. Carriers may also decide to extend contracts with shippers beyond the contracting period effectively locking in pricing beyond the agreed contracting period. In periods of over capacity, carriers may face increases in operating ratios that threaten their viability resulting in highly competitive bidding. Carriers have limited leverage when shippers decide to bid during these periods simply because the low demand for freight can result in bids with irrational pricing. This in turn results in a greater number of carriers with financial issues as the consolidation in the market continues.

2.3 Optimization Solutions for Shippers and Carriers

Optimization based bidding technology is widely available to help shippers optimize transportation rates and capacity. This technology enables shippers to address a large number of competing objectives by allocating capacity considering hundreds of thousands of rates, and capacity limitations at various network levels including lane, facility and system-wide. In addition to rates and capacity, these solutions must also consider unique business rules considering factors such as number of providers per geographical region, minimum or maximum revenue targets, and required minimum volume levels. Business rules that control the allocation of capacity are applied at various hierarchical levels in the transportation network. Examples of common business rules that are translated to optimization constraints include: “Limit the number of carriers in the East facility to 15”, “Ensure that Carrier X is award at least 50 loads per week at the West Coast facilities”, etc. The application of business rules for each bid is extensive and can lead to very large mixed-integer programs (MIPs) that include tens to hundreds of scenarios. Each scenario tests various strategies supporting decision making focused on the best allocation of capacity.

Optimization based bids range is size and scope. The following table illustrates project scope and potential opportunity using optimization tools based on bid size as defined by minimum, median, average and maximum statistics for roughly 50 bid events (Caplice & Sheffi 2005):

	Minimum	Median	Average	Maximum
Number of lanes	136	800	1,800	~5,000
Number of annual shipments	~ 6,000	88,000	~200,000	~1,500,000
Annual value of transportation services	$3M	$75M	$175M	$700M
Number of incumbent carriers	5	100	162	700
Number of carriers participating in the auction	15	75	120	470
Number of carriers assigned business from the auction	5	40	64	300
Reduction in the size of the carrier base	17%	48%	52%	88%
Base reduction in transportation costs (without considering service factors)	3%	14%	13%	24%
Final reduction in transportation costs (considering service factors and other business constraints)	0%	6%	6%	17%
Duration of procurement process (months)	<1	3	3	6+

Table 2.1 Size of Transportation Auctions 1997-2001

Formulations to optimize costs are fairly straightforward using operations research techniques. Auction theory refers to this as the Winner's Determination Problem (WDP) and is the basic formulation behind optimization and is defined below by Caplice & Sheffi (2005). Solved as a Mixed-Integer Linear Program (MILP), this formulation minimizes total cost as defined by various types of lane bids that carriers could provide including discrete lane bids and package, or combinatorial, bids which will be discussed in further detail.

Winner's Determination Problem with Discrete and Package Bids (Caplice & Sheffi 2005):

Minimize: $\sum_c \sum_k \left[\left(\sum_{\forall i,j \in k} {}_c c^k_{i,j}\, {}_c\delta^k_{i,j} \right) {}_c y^k + \sum_{i,j} \left({}_c c^k_{i,j}\, {}_c x^k_{i,j} \right) \right]$

Subject to:

$$\sum_c \sum_k \left({}_c x^k_{i,j} + {}_c\delta^k_{i,j}\, {}_c y^k \right) = x_{i,j} \quad \forall i,j$$

$${}_c x^k_{i,j} \geq 0 \quad \forall i,j,c,s,k$$

$${}_c y^k = [0,1] \quad \forall c,k$$

Indices

i in Shipping Origin
j in Shipping Destination
c in Carrier Identification
k in Bid Package Identification

Decision Variables

${}_c x^k_{i,j}$ in number of loads per time unit (week, month) on lane i to j, with assigned carrier c, under package bid k

${}_c y^k$ 1 if carrier c is assigned to package bid k, 0 otherwise

Parameters

$x_{i,j}$ Volume of loads on lane i to j that are being bid out

${}_c c^k_{i,j}$ Bid price per load on lane i to j, for carrier c as part of package k

${}_c\delta^k_{i,j}$ Volume of loads on lane i to j that carrier c is bidding on in package k

The WDP has 4 main benefits which are summarized below:

1. It allows the combination of simple discrete bids to be considered with packaged bids which is difficult, if not impossible, to consider manually with a large set of discrete and package bids as a result of interdependencies of capacity.
2. It allows the application of a wide range of constraints that represent business requirements. Shippers must quantify their business objects effectively in terms of modeling constraints to constrain the model to more operationally feasible solutions.
3. It allows non-financial trade-offs to be represented as rate adjustments using a Multi-Attribute Rating System (MARS) (McNamara, Nagle & Smith 1996). This is a key capability in addressing robustness in transportation planning. More will be discussed in Chapter 5 with examples.
4. It can be easily extended to other business constraints originating from both the shipper and the carrier. For example, carrier capacity is provided by the carriers at many levels and applied to the WDP in the form of capacity constraints. Carriers can bid on every lane, but limit their total capacity to a feasible level allowing the optimization model to determine where feasible capacity is most advantageous to the shipper without overburdening the carrier with too much volume.

Package bids have practical applications for carriers. WDP allows carriers the ability to express the combination of rates and capacity as separate bidding items known in auction theory as combinatorial bids. Song and Regan (2003) state that combinatorial auctions can be applied to any asset allocation process when complementarities and substitution effects exist and where bidders prefer bundled items over single items. With combinatorial bids, carriers can combine lane level bids into a bundle to capture economies of scope particularly where profitable operations are more likely. The shipper then awards all or none of the business ensuring that the discounted rates apply to the bundled package. Extensive work in combinatorial bids with applications in transportation has been performed by Caplice (1996), Song and Regan (2003), Sheffi and Caplice (2003), Caplice and Sheffi (2005), Plummer (2003), and Hohner et al (2003).

In addition to modeling business constraints, some of the more advanced formulations allow the application of penalty or bonus functions to reflect adjustments in the carrier's rate. The ability to consider adjustments to a carrier's rate for the purposes of quantifying additional factors is a system called "Multi-Attribute Rating System" (MARS) (McNamara, Nagle & Smith, 1996). This approach provides the ability to engineer differences in rates for qualitative and quantitative factors. For example, if a carrier has a 99% on-time performance rate, this may equate to a -5% bonus adjustment to a rate since on-time performance is highly valued. Conversely, carriers with a 75% on-time performance may be penalized with a 25% reduction to their rate. The optimization would consider the adjusted rate in the objective function for modeling purposes.

An extension to the WDP formulation presented above is the application of hierarchical capacity constraints. Carriers need the flexibility to bid on many lanes but limit their bid capacity to higher aggregate levels. This allows the carriers to bid aggressively for more lanes than they can feasibly support, but constraining them at higher levels in the network. This effectively allows the carrier to win where their rates are competitive, but not win more volume than they can ultimately handle. As an example, a carrier can have only 5 units of capacity and bid on every lane which could exceed 2,000 units of capacity. As long as the carrier adds a system constraint of five units, that carrier will only win the five units where the capacity is most cost effective and part of the optimal solution.

The WDP has been widely adopted to solve procurement problems in transportation, but there are inherent weaknesses in the WDP since rates and capacity are only two basic components in making a procurement decision. Equally important is the carrier service capability. The shipper's perception of service extends beyond simply arriving at the pickup location and final destination on time with a complete, undamaged load. It is also defined by the carrier's ability to fluctuate with demand and provide backup capacity in times of increased demand as the contracting cycle unfolds. Shippers also consider other service capabilities including on-time pickup and delivery, trailer pool management and accurate freight payment all of which can be addressed through optimization solutions, or in most cases qualitatively from experience. The framework for a quantitative approach to the service problem is lacking in current literature and has been a difficult area for shippers to address using WDP based tools to solve their procurement problems.

The term "optimization" is widely used to describe the application of operations research to a complicated problem either minimizing or maximizing decision variables subject to various constraints. However, the implication that actual transportation freight expenditure is optimized using an "optimization" software solution is a significant misrepresentation because it generates a solution independent of unplanned events.

Planned and unplanned freight are considered very differently in optimization software solutions. A significant characteristic of "optimized" output is that it represents what will occur as planned transportation freight expense. Unplanned freight is basically not considered. Thus, the inputs to optimization algorithms do not consider the cost of unplanned freight that is not only dependent on the level of cost reduction driven by the model, but also potentially increased as the optimization reduces total cost well below market rates. Unrestricted application of the WDP provides increased risk of unplanned freight volume leading to the potential of higher actual freight expenditures under the following conditions:

1) Accepting significantly lower than market rates will lead to less capacity resulting in increased freight expenditure when replacement capacity is needed.
2) Acquiring new rates after a bid will result in decreased leverage since negotiations are complete. This is because of the competitive pressure that results from greater volume awards is less prevalent.
3) Relationships with carrier organizations at the execution level can be a source of strategic value. Moving to a new carrier may introduce a net loss of responsiveness and result in less committed capacity at a given rate.
4) Service failures have a significant cost in terms of higher freight expense including service penalties from customers, lost production or higher supply chain costs as a result of transportation related inefficiencies.

Organizational strategy also influences the applicability of "optimization" as it applies to a shipper's network. A cost-focused shipper where transportation is a significant component of the costs of goods sold will have a more aggressive position on freight expense than an organization that is focused more on service. The risks and requirements, for example, to haul low value items such as paper towels are much different than high value products such as laptops or health care products.

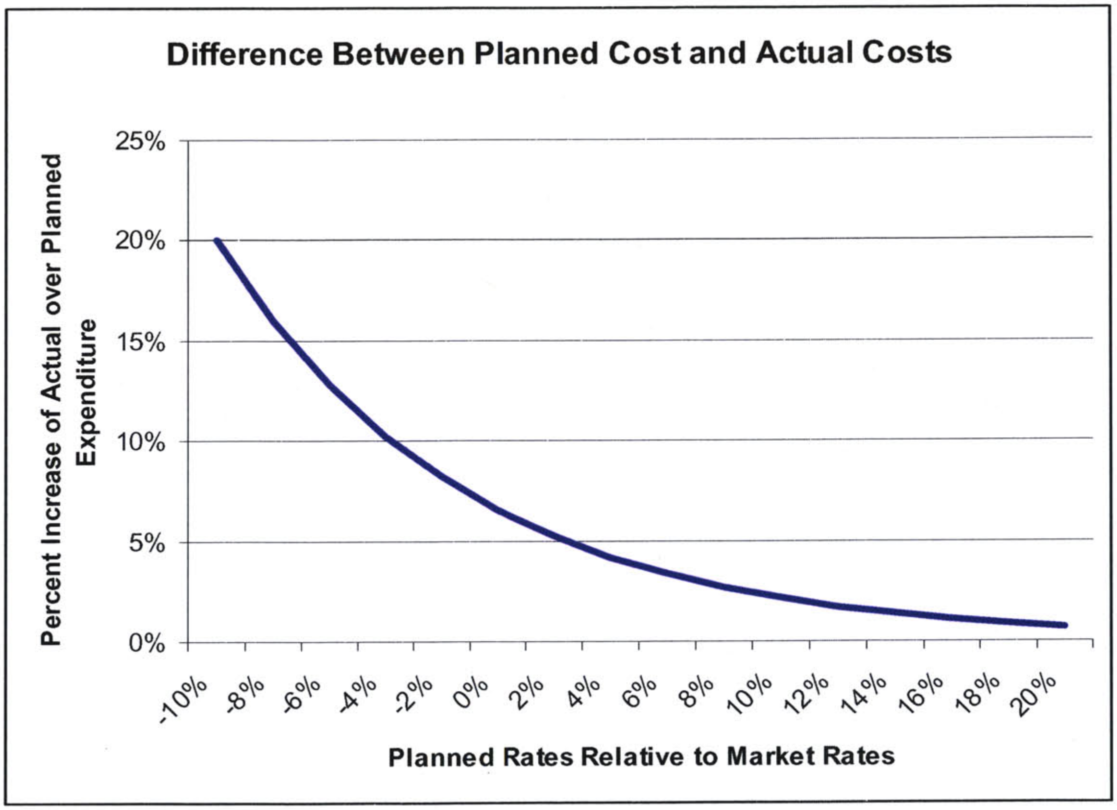

Figure 2.1. Conceptual Difference Between Planned and Actual Costs

Figure 2.1 illustrates the concept of actual freight expense relative to planned freight expense in relation to market pricing. The concept is straightforward: the greater the negative difference between routing guide rates and market pricing, the greater the actual freight expenditure will be relative to the planned freight expenditure. For rates that are much below market, the capacity will be less available leading to higher costs for alternatives and a greater percentage of freight that is unplanned. For rates that are much higher than market, the capacity will be a source of profit for many carriers and the costs will likely attract capacity from many carriers.

Is the optimal solution always to minimize planned cost? Arguably, shippers with high value goods that have significant profit margin are not concerned at all about differences between bid rates, particularly if service failures result in losses that far exceed the cost of a load, or the transportation is a miniscule fraction of the cost of goods. The effectiveness of the WDP for a service based solution is limited by the ability to restrain the algorithm by considering service-based criteria. This requires translating service into cost related benefits that the WDP can "optimize" by adjusting bids and capacity. In practice, measuring service is not trivial due to the subjective quality of service and the lack of data to support a quantitative approach. Conversely, shippers focused on cost reduction could conceivably increase actual freight costs without the proper restraints on the WDP if a large percentage of their freight is contracted well below market with carriers that do not share the notion of a strategic relationship, commit capacity to the rate, or experience economies of scope.

The service component is needed to truly optimize freight expense in all cases where the WDP provides analytical value for shippers. Whether shippers are focused on cost or service, they cannot accept the lowest cost solution across the entire network. Therefore, the focus on service always exists but varies only in scope and scale based on the needs of the shipper.

The remainder of this thesis addresses robust transportation planning techniques using the accumulation of transactions that occur between shippers and carriers. Tools and techniques to integrate performance into the WDP will be presented with a simulation that tests the robustness of an optimization. The purpose of this work is ultimately to improve shipper and carrier relationships by providing shippers a framework to not only assess carrier performance, but also to have at their disposal a foundation to build more strategic and mutually beneficial relationships with their carriers. More important, using optimization software without properly considering service can be disruptive and lead to higher total direct freight expense. Although the techniques may appear to increase costs in the optimization, the objective of this work is to achieve the lowest total *actual* cost which is not the same as lowest expected costs based on a forecasted plan that assume 100% compliance.

3 Shipment Data and Robustness

When a shipper has obtained bid data from carriers and is considering future contracts there are five classes of information that can be used for the analysis of robustness:

1) Transactional data from the previous contracting period.
2) Routing guide data from the previous contracting period representing what was planned.
3) Qualitative experiences of the shipper.
4) Bid data itself collected from the carriers including rates and capacity.
5) Business information obtained from the carrier, or other sources, detailing carrier finance, operations, security, insurance, IT capabilities and business strategy.

Each class of data is a form of input to the procurement decision making process and is, in essence, the raw data necessary for analysis. The synthesis of this information results in a strategic plan.

Transactional Shipment Data

Shipment data are widely available for shippers but seldom used to the fullest extent in procurement projects even though most TMS applications and freight payment systems provide detailed shipment information (Harding 2005). Although shipment transactions are the basis for defining the transportation network, shipment data can be further extended into detailed transportation metrics for specific carriers including volume flexibility or surge capability, adherence to planned costs, relative costs between same service and capacity of primary and backup carriers. For any detailed procurement process, shipment detail is mandatory for a quality network design since accurate representation of the shipper's network is a key component in enabling carriers to provide the most competitive pricing. Ambiguity of service requirements and fluctuations in demand typically lead to the Winner's Curse or hedging of the rates due to the uncertainty, both which are undesirable from the shipper's perspective. Historical shipment data typically includes origin, destination, shipment date, assigned carrier and line-haul cost. Although there are many benefits to using this information, there are also inherent limitations by focusing only on what was shipped and not the decisions that lead to the carrier assignment (see Figure 3.1).

Shipment data can also be used to measure the effectiveness of past procurement processes. Carriers that overbid are generally replaced during transitions to the new contracts. The success of the transition phase is easily captured by comparing shipment data to the initial version of the routing guide but is seldom performed in practice (Harding 2005).

Measuring the success of a transition by capturing where failures occurred and understanding the reasons is very useful at two levels: First, it helps shippers to adopt practices which prevent similar outcomes by measuring a carrier's bidding strategy. Secondly, this measurement captures the shipper's ability to make sound choices prior to transitioning. Measuring the effectiveness of past procurement projects in this manner provides a foundation for adopting and internalizing best practices for use in future procurement activities. The following representation of the transportation execution process illustrates what is captured by transactional shipment information in comparison to standard load planning processes:

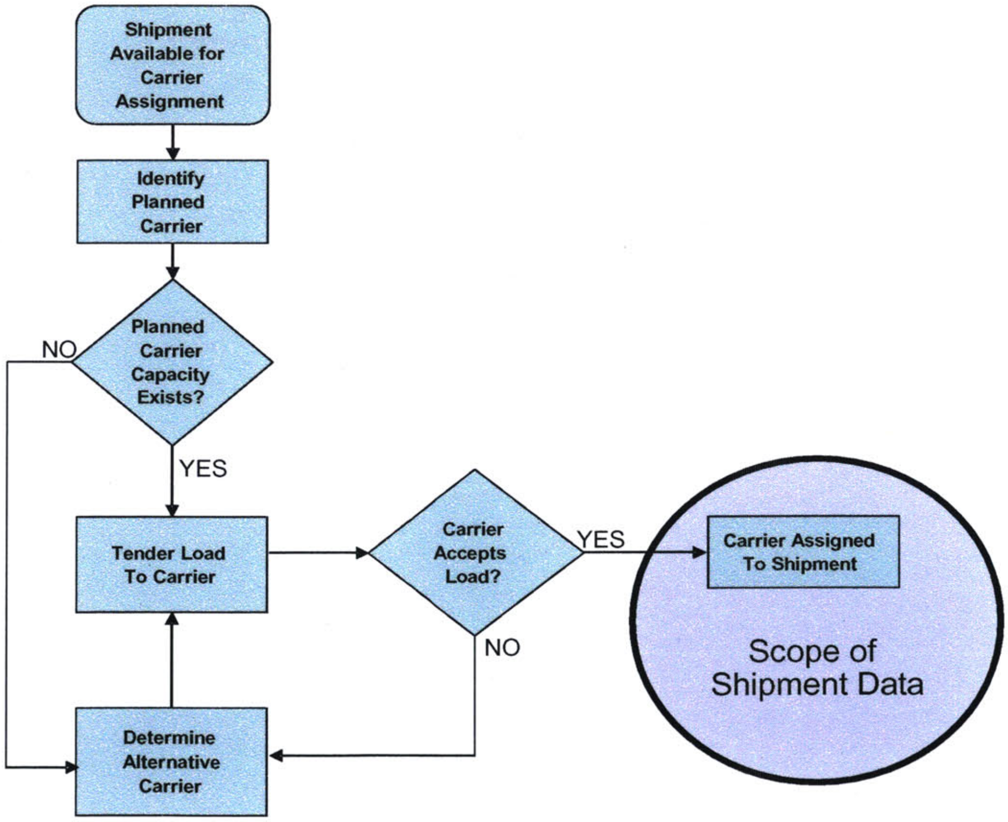

Figure 3.1 Scope of Shipment Data in Execution

3.1 Carrier Performance Measurement

Carriers that perform well during periods of seasonal slowdowns may not perform as well during peak demand and vice-versa. Shipment data can identify carriers that provide higher levels of capacity on lanes than what was originally contracted as planned freight and the relative price difference for that additional capacity if rates are not the same throughout the year. Deviations from the planned freight costs may be the result of inaccurate freight forecasts, unexpected lanes or primary carrier failure.

Carriers are not always formally defined in the routing guide as a primary or secondary carrier on a specific lane yet appear in the shipment data. Carriers are often assigned to shipments which are designated to other carriers in the routing guide. This outcome is sometimes the result of acquiring capacity on a very short notice. As a result, understanding the relative cost impact of a carrier that is consistently "saving the day" is also important since some carriers may take opportunities to charge significant premiums when capacity is tight, and others may charge closer to market rates. Other reasons for the use of carriers that are not in the routing guide include the shift of giving freight to carriers on lanes in which they have growing capacity as existing primary carriers lose the ability to service the lane.

Shipment data can also be used to assess carrier flexibility. Contracts generally include some level of volume expectation as part of the pricing (e.g. 5 loads per week at $1.23/mile). These levels are only targets and by no means fixed quantities since the variability in demand makes it impossible for all carriers to adhere to specific levels. A carrier's ability to fluctuate from period to period in maintaining capacity is a key component in developing a robust transportation plan and can be easily captured with transactional shipment data. Carriers that can fluctuate and maintain volume commitments should be recognized for this capability. More on this topic will be presented regarding specific calculations under 3.2 Shipment Based Performance Metrics.

Changes Impacting Measurement

The most significant limitation in assessing carrier performance over a 1-2 year contracting period is driven by the fact that freight flows change over time. Any comparisons to a specific plan must occur with the understanding of how and why the plan changed over time. However, this can be difficult in practice to maintain when analyzing shipment transactions. Capturing changes is a requirement to better utilize the information and losing that visibility would challenge more robust techniques for assessing carrier performance.

Each node in the network including suppliers, manufacturers, distribution centers, and customers is subject to change. Large suppliers may be added or deleted from networks requiring significantly different inbound flows. Inventories may be repositioned between distribution centers impacting transportation flows. Forecasted freight volumes may be held confidential if they are associated with strategic initiatives. Network changes effectively redirect flows impacting previously planned freight and create changes that require rebalancing capacity flowing differently than what was established in prior contracting. Analyzing shipment data over periods when large-scale operational changes occur can give the appearance that carriers have not performed well if not properly captured. Conversely, carriers that are flexible enough to manage large scale changes in flows should recognized this service capability.

3.2 Shipment Based Performance Metrics

How are carriers measured? More important, how can carriers be measured where the analysis is integrated with optimization techniques or performance measurement that aids the development of a robust transportation plan? The following metrics were generated via standard spreadsheet and desktop database tools. This analysis can be used when making trade-offs between carriers where incumbent data exists. There are four levels of shipment aggregation that will be used throughout this thesis to represent the hierarchical levels found within transportation networks. Each of these levels provides a different view of carrier or network operations and all levels are important for assessing robustness.

The lowest level of shipment aggregation is the "lane" level which can be loosely defined as the geographic representation of origins, destinations and service and equipment requirements necessary for a contracting commitment. It is important to note that in some cases service, equipment and contract types are defined as part of a lane prior to bidding; in other cases, they are options that are considered when rates are provided by the carriers. This needs to be evaluated on a case by case basis when using any of the techniques in this section since lane definition is not always fixed and rates apply to different service levels or equipment options.

Lanes are defined from the facility level to the state or region level. There is a general relationship between the specificity of a lane and its volume that shippers use when collecting lane bids from carriers. In cases where volume is less predictable, lane origins (or destinations) are expanded in size to capture a level of volume needed to leverage better pricing from carriers. Where volumes are heavy, both the origin and destination are specific to postal code or facility to allow the carrier a more accurate view of the volume requirements with the expectation of better pricing since there is little or no ambiguity in terms of operational or volume requirements for the carrier. A lane is defined as a discrete item for which a carrier bid can be received and it can be defined at any level from facility to state or custom region independently for both the origin and destination.

The next intermediate level of shipment aggregation is at the "facility" level considering inbound and outbound direction separately. This separation is important when requirements are markedly different. In cases where manufacturing or distribution processes are tightly coupled to transportation, carrier performance on the inbound side to a facility could be much more critical than on the outbound. Late arrivals for an inbound shipment that shuts down a production line have much greater ramifications than an outbound shipment to a customer that has flexible arrival times. For these reasons, facility aggregations are presented at the inbound and outbound levels.

The highest level of shipment aggregation is at the "system" level. Performance metrics calculated at this level reflect a carrier's overall performance with the shipper organization. The pooling of performance metrics to the system level can be effective in filtering out sporadic cases of poor performance, or elevating visibility of system-wide performance for comparative analysis across competing providers.

3.3 Shipment-Based Performance Metrics and Multi-Level Aggregation

The ability to weigh metrics at various levels in a network is important because the same shipment metrics can be used at various levels of aggregation to focus on a variety of carrier relationships ranging from the strategic relationship with the shipper to an operational relationship on a specific lane. This approach allows the decision maker to weight the trade-offs with performance that may not be the same at different levels. Poor performance on a lane, does not always translate into poor performance at a facility or system level. Using the aggregated metrics also provides the opportunity to take advantage of optimization capabilities since the same hierarchies are typically found in the formulations of the winner's determination model used to optimized transportation contracts. The following includes a discussion about the calculation, application and inherent limitations of metrics captured from shipment data.

3.3.1 Relative Cost Index

The Relative Cost Index (RCI) measures the relationship between the percent of lane costs and the percent of freight hauled. Comparing rates for the same business allows shippers to define the market response to their freight. If a carrier hauls 55% of the volume on a lane and contributes to 52% of the total lane cost, the RCI = 0.52/0.55 = 0.95. Carriers with values that are less than 1 correspond to rates that are less than the other carriers serving that lane. Aggregating this information for each carrier to higher levels beyond a lane indicates the relative difference to their competitors pricing if they have hauled loads on the same lanes. An effective approach is to capture the effects at various levels indicating the broader carrier-shipper relationship. Metrics can be weighted by volume and summed for values at the facility and system levels to gauge a carrier's relative pricing across all other carriers used. This metric is good when more than one carrier is used on individual lanes.

The Relative Cost Index is defined as follows:

$$\text{Relative Cost Index} = \frac{\left(\dfrac{\sum_{s} C_{c.l}}{\sum_{s} C_{l}}\right)}{\left(\dfrac{\sum_{s} V_{c.l}}{\sum_{s} V_{l}}\right)} \quad \forall c,l$$

Where

l in Lane
c in Carrier
s in Shipments
C in Shipment Cost
V in Volume

Limitations

RCI does not capture the relative cost to the general transportation market since the only comparison used is the rates obtained by the shipper. In addition, carriers that haul 100% of the lane volume will always have an RCI of 1 (100% of cost divided 100% of volume). So it is possible for a carrier with higher than market rates to show a neutral RCI rating.

3.3.2 Price-based Coefficient of Variation

The Price-based Coefficient of Variation (PCV) indicates the level of cost variability for a carrier on a given lane. This metric is defined as the standard deviation of all costs for a carrier-lane divided by the average cost of that carrier-lane and typically uses only the line-haul portion of the costs. A carrier-lane is the subset of capacity which can be all or a fraction of lane volume depending upon how much freight a carrier has hauled on a lane. The Price-based Coefficient of Variation is defined as:

$$\frac{\sigma_{c,l}}{\mu_{c,l}} \quad \forall c,l$$

Where
c in Carrier
l in Lane
$\sigma_{c,l}$ = Standard Deviation of Carrier c on Lane l
$\mu_{c,l}$ = Average Cost for Carrier c on Lane l

Limitations

PCV is based only on standard deviation and does not capture asymmetric variability. Therefore, it makes no distinction for rates that are significantly less than the average cost on a lane and only measures the variation between shipments with different rates. If a carrier suddenly drops rates because of a surplus of capacity within a subsection of the network, then the PCV could be higher than other carriers. The main focus of this metric is to bring to the surface carriers that charge more when the constrained capacity favors opportunistic pricing.

3.3.3 Correlation to Total Volume

Correlation to Total Volume (CTV) is calculated by measuring the correlation of a carrier's volume per period on a lane to the total volume that was available on the lane. This metric is unit-less and the example below illustrates how a carrier that fluctuates significantly and is much more flexible will have a higher correlation to total volume. CTV is simply the correlation coefficient (r) comparing the correlation of carrier-lane volume (y) to total lane volume (x) for every lane as defined below:

$$r_{x,y} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - \left(\sum x_i\right)^2}\sqrt{n\sum y_i^2 - \left(\sum y_i\right)^2}}$$

This metric also measures a carrier's responsiveness to "surge" and is a characterization of the type of capacity being purchased by the shipper. CTV values closer to one indicate strong indication to surge, values between -1 and 0.5 indicate less flexibility in fluctuating to demand. Surge requirements can be defined as variability of demand. When carriers are highly flexible during peak periods, they are effectively matching their supply of capacity to demand requirements that are difficult to predict. This metric is useful in bringing surge capabilities to the surface, and is a strong indicator of carrier flexibility at the facility and system level. Examples in Figures 3.2 and 3.3 illustrate the differences in CTV between carriers on the same lane.

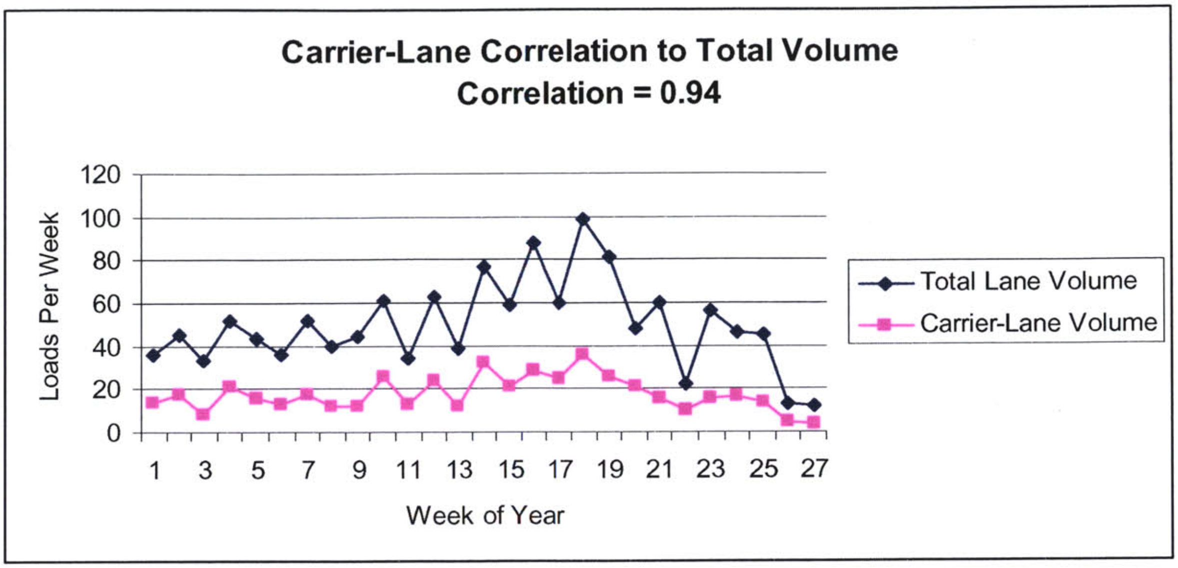

Figure 3.2 Example of Carrier-Lane Correlation to Total Volume – CTV=0.94

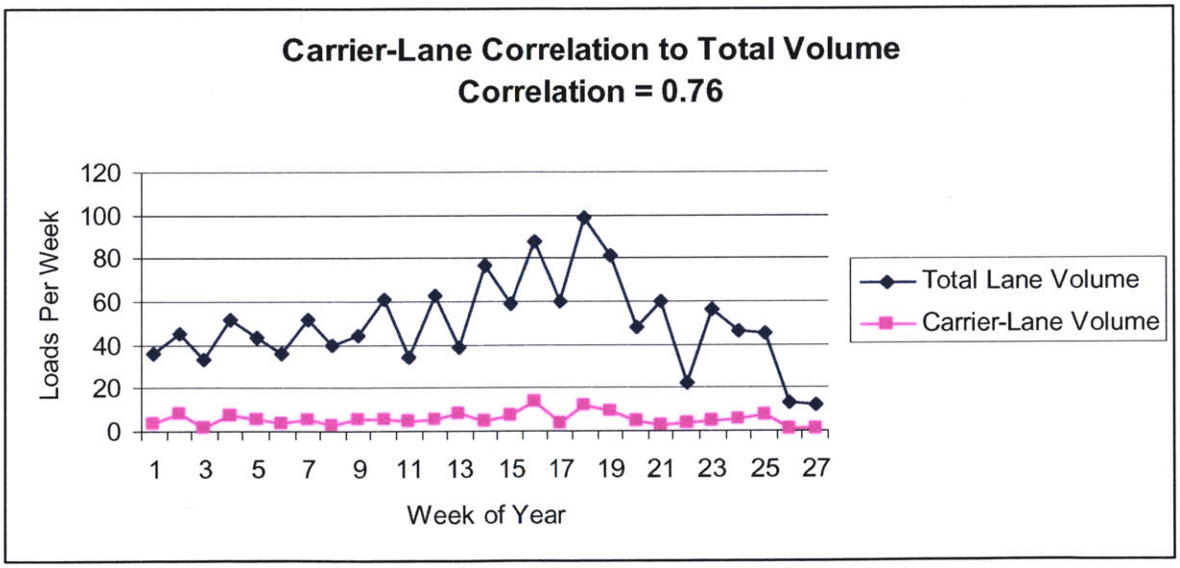

Figure 3.3 Example of Carrier-Lane Correlation to Total Volume – CTV=0.76

Limitations of CTV

CTV does not capture the decisions made between the shipper and carrier that are typically determined by accept-reject information since it only uses shipment data. Carriers that show lower CTV values may be doing precisely what is expected based on the routing guide or may be providing back-up capacity for primary carriers who are turning down freight due to a lack of capacity, or more profitable options.

3.4 Designing a Framework Using Shipment-based Metrics

The metrics presented here are useful in evaluating carriers based on only shipment data where relative price, surge and consistent pricing are important factors in the assessment future contracting options with the current incumbent base of carriers. The applications for benefit are more varied from simple reporting to integrating the results into the optimization software. The following details the creation of a sample framework. Applications to optimization will be discussed further in Chapter 5.

One approach in marrying the performance metrics to bid information is to create categories as a framework and presented as carrier performance reports. Table 3.1 illustrates how metric values can be categorized to assess carrier performance:

Applying Categories	Low	High
Relative Cost Index	<=1	>1
Price-based Coefficient of Variation	<0.1	>=0.1
Correlation to Total Volume	<0.8	>=0.8

Table 3.1 Applying Categories for a General Framework

Arguably, this approach has some inherent weakness since the creation of categories will transform quantitative data into a qualitative assessment of carrier performance. The breakpoints are a significant component and should be chosen carefully to better reflect the decision maker's assessment of performance for the purpose of choosing robust alternatives in a bid. Reviewing specific cases with transportation personnel responsible for bid outcomes can lead to realistic breakpoints. With the wide range of transportation requirements and carrier capabilities in the market it is extremely difficult to give benchmarks that are valid for every shipper. In addition, the application of categories should stratify the metrics in a manner that is easily recognizable by the decision makers. The binary "high" and "low" relationship presented here could be relaxed with the inclusion of more ranges such as "neutral".

Combining this data with unit-based shipment metrics such as loads per year, or total cost per year with external market-based information can provide a more complete picture of carrier performance. Table 3.2 illustrates one example of a system level report. Facility level reporting is also an important part of identifying regional differences among providers. The application of ranges for "Total Costs" and "Percent to Market" were added. "Total Costs" are the total paid to the carrier over the previous period and the "Percent to Market" is the relative position the rate has with respect to market estimates. Market data would be provided by an external provider that offers this service.

NETWORK SCOPE			METRICS					EVALUATION
Carrier	Facility ID	Lane ID	Relative Cost Index (RCI)	Price-based Coefficient of Variation (PCV)	Correlation to Total Volume (CTV)	Percent to Market	Total Costs	Carrier Assessment
SCAC1	**All**	**All**	H	H	H	**<95%** **95-100%** 100-105% **>105%**	**Tier 5: <$100,000/year** **Tier 4: $100K-$500K/year** Tier 3: $500K-$1MM/year **Tier 2: $1MM-$5MM/year** **Tier 1: >$5MM/year**	**Higher Relative Costs** **Unstable Pricing** **Flexible Capacity** **100-105% to Market** **Tier 3 Provider**
SCAC2	**All**	**All**	H	H	L	**<95%** **95-100%** **100-105%** >105%	Tier 5: <$100,000/year **Tier 4: $100K-$500K/year** **Tier 3: $500K-$1MM/year** **Tier 2: $1MM-$5MM/year** **Tier 1: >$5MM/year**	**Higher Relative Costs** **Unstable Pricing** **Less Flexible Capacity** **>105% to Market** **Tier 5 Provider**
SCAC3	**All**	**All**	H	L	H	**<95%** **95-100%** 100-105% **>105%**	**Tier 5: <$100,000/year** **Tier 4: $100K-$500K/year** **Tier 3: $500K-$1MM/year** **Tier 2: $1MM-$5MM/year** Tier 1: >$5MM/year	**Higher Relative Costs** **Stable Pricing** **Flexible Capacity** **100-105% to Market** **Tier 1 Provider**
SCAC4	**All**	**All**	H	L	L	**<95%** 95-100% **100-105%** **>105%**	Tier 5: <$100,000/year **Tier 4: $100K-$500K/year** **Tier 3: $500K-$1MM/year** **Tier 2: $1MM-$5MM/year** **Tier 1: >$5MM/year**	**Higher Relative Costs** **Stable Pricing** **Less Flexible Capacity** **95-100% to Market** **Tier 5 Provider**
SCAC5	**All**	**All**	L	H	H	<95% **95-100%** **100-105%** **>105%**	**Tier 5: <$100,000/year** **Tier 4: $100K-$500K/year** **Tier 3: $500K-$1MM/year** Tier 2: $1MM-$5MM/year **Tier 1: >$5MM/year**	**Lower Relative Costs** **Unstable Pricing** **Flexible Capacity** **<95% to Market** **Tier 2 Provider**
SCAC6	**All**	**All**	L	H	L	**<95%** **95-100%** 100-105% **>105%**	**Tier 5: <$100,000/year** **Tier 4: $100K-$500K/year** **Tier 3: $500K-$1MM/year** **Tier 2: $1MM-$5MM/year** Tier 1: >$5MM/year	**Lower Relative Costs** **Unstable Pricing** **Less Flexible Capacity** **100-105% of Market** **Tier 1 Provider**
SCAC7	**All**	**All**	L	L	H	**<95%** 95-100% **100-105%** **>105%**	**Tier 5: <$100,000/year** **Tier 4: $100K-$500K/year** Tier 3: $500K-$1MM/year **Tier 2: $1MM-$5MM/year** **Tier 1: >$5MM/year**	**Lower Relative Costs** **Stable Pricing** **Flexible Capacity** **95-100% of Market** **Tier 3 Provider**
SCAC8	**All**	**All**	L	L	L	**<95%** 95-100% **100-105%** **>105%**	**Tier 5: <$100,000/year** Tier 4: $100K-$500K/year **Tier 3: $500K-$1MM/year** **Tier 2: $1MM-$5MM/year** **Tier 1: >$5MM/year**	**Lower Relative Costs** **Stable Pricing** **Less Flexible Capacity** **95-100% of Market** **Tier 4 Provider**

Table 3.2 Example of System Level Framework

Using more tiers than necessary may yield far too many categories. A simple system will have greater aggregation of metrics and hence clearer lines between categories of performance. The total number of categories in this example would be 2 x 2 x 2 x 4 x 5 = 160 different combinations. It is unlikely that all combinations will be found within a shipper's network. For example, the possibility of a carrier with high volumes, low percent to market rates, and a high relative cost index is not likely. However, too many categories would not provide enough delineation to be interpreted by decision makers.

The final step is to align the shipper's strategy to the carrier assessment by allocating price adjustments for those qualities that promote the various strategies. By allocating a percentage or fixed cost differential carriers that have demonstrated better alignment can be recognized in the optimization software using MARS. Determining which components of the assessment are critical and allocating a percentage adjustment to the rate to be considered in the optimization has proven to be the best approach in practice and yield the best results. For example, it is very common for shippers to request an optimization scenario that forces in the incumbent base of carriers to minimize the risk of transition by adjusting the incumbent rates far below their actual values. This approach simply suggests that shipment data can provide a more focused method to achieve this goal by identifying those qualities which are important to the shipper and rewarding those carriers which are strategically aligned versus any and all carriers that were used in the past. There are literally dozens of strategies shippers may have ranging from consolidating to a national core carrier mix to deconsolidating to more regional carriers because of superior surge performance, or using more brokers or intermodal carriers in greater numbers. Because of the wide variety of applications there are no concrete rules for any shipper regarding the best strategy. What is presented here is a flexible framework to be used by any shipper for any strategy with the assumption that strategic alignment can be captured to some degree by shipment data and utilized in widely available optimization solutions. The following chapter takes this approach to the next level by looking at the interaction of shippers beyond what can be captured by shipment data, and provides additional methods of strategic alignment.

4 Accept Data and Robustness

4.1 Accept-Reject Processes

Shipment data captures which carrier accepted a load on a given day, for a specific price. Tendering data provides a deeper level of understanding because it captures who was first notified by the shipper, and how many times subsequent carriers were notified prior to a carrier accepting a tender, hence the commitment to haul a shipment. To fully understand the importance of shipper-carrier interaction, a review of the standard terminology associated with these activities needs to be established.

Shippers employ load planners, either directly or via third party logistics providers, who communicate on a daily basis with carriers that haul their truckload freight. The planners are responsible for ensuring that unassigned loads are presented to the carriers designated in the routing guide. Carriers are expected to coordinate the pickup and delivery of a load on a specific date to meet the delivery requirements of all shipments that fall under their routing assignments. Depending upon the technology used by the shipper, this process can be performed manually by phone, fax, email; or automated by integrated technology using integrated technology consisting of either EDI or emerging XML. Common EDI transaction sets for truckload carriers include 204, 990 and 214 which represent "Motor Carrier Load Tender", "Response to a Load Tender" and "Transportation Carrier Shipment Status Message" respectively. Regardless of the technology used, the carriers respond to a request for their services with an agreement to haul a specific load on a scheduled pick up and delivery time.

There is standard nomenclature that is used in the industry regarding interaction between planners and carriers. Communicating the requirements of a load with a request for services is commonly referred to as a "tendering" a load. Tendering a load is only a request for services and not a commitment from the carrier. If the carrier accepts the tendered load this is referred to as an "accept" by the carrier. Once the carrier accepts a load, the carrier is the obligated to arrive on time for the pickup and deliver on time as defined by the information contained in the original load tender. Conversely, carriers do not always accept every tendered load leading to a "rejected" load. Shippers measure a carriers responsiveness with a metric called the "accept ratio" defined by the total loads accepted over all loads offered. The accept ratio captures the carrier's responsiveness to tendered freight.

The ability for a carrier to accept and reject freight throughout the year poses some interesting problems for shippers. Carriers that frequently reject cannot be considered reliable resources and can lead to cost increases when similarly priced alternative carriers are not readily available. Load planners facing lead time pressures, seasonal variations in demand and cost reduction goals are challenged to cover freight with assigned carriers when faced with rejections. For shippers where the transportation service is tightly coupled to other processes, this can lead to line stoppages, significant queuing or congesting at distribution centers and warehouses leading to late deliveries. In some cases, shippers may use trailers to store goods when storage capacity within plants or warehouses is exceeded.

4.2 Accept-Reject and Opportunity

When a shipper tenders a load to a planned carrier in the routing guide, the acceptance of that load is seldom guaranteed with absolute certainty. Shippers expect that a percentage of their freight will not be accepted by a carrier in the routing guide. If the load is rejected, there is a strong likelihood that a replacement carrier will take the load at a different rate. Because of this uncertainty, every lane in the network consists of planned volume that is accounted for by the routing guide, and unplanned volume which is open to market pricing or less competitive rates commonly known as backup rates. Shippers lose control of freight expense when carriers reject freight. The degree to which rejected volume affects budgeted transportation expense depends on two factors: the frequency of unplanned freight and the severity of cost overruns for unplanned freight. If, for example, a primary carrier rejects freight 50% of the time they are tendered a load, but the market offers the same or better price on a spot basis, there is no financial impact. The combination of lower accept-ratios and higher cost alternatives contribute to freight budget variances. The following calculations illustrate the percent increase in freight expense based on both the accept ratio and the severity of the cost increase.

The expected Percent Over Planned Freight Expenditure (X) can is defined as:

$$X = \left(\frac{U}{P} - 1\right)(1\text{-}A)$$

Where

X : Percent Over Planned Freight Expenditure

A : Planned Accept Ratio (0-100%)

U : Unplanned Cost

P : Planned Cost

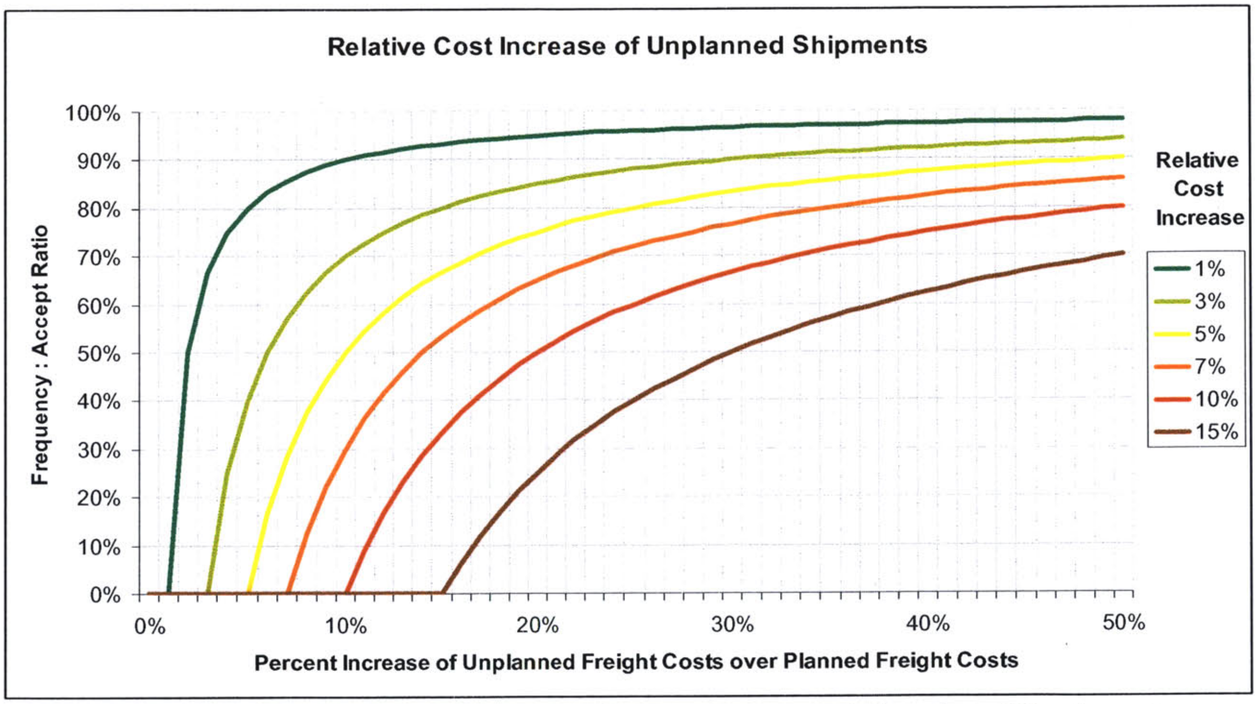

Figure 4.1 Efficient Frontier of Transportation: Frequency and Severity of Unplanned Freight

This chart represents the maximum theoretical opportunity available from eliminating unplanned freight as a benchmark to determine the relevance or applicability of robust strategic planning to a shipper network. By determining the accept ratio and the cost for unplanned freight the percent opportunity can be determined at any level of the network. For example, if a facility has an accept ratio of 70% and the cost of unplanned freight is 23% over planned freight expense, then the total impact of unplanned freight expense is 7%. A logical result of this analysis is to question the source of cost increases from unplanned freight: Are unplanned shipments occurring on specific lanes that are driving additional costs? Can these additional costs be mitigated in the planning cycle? Will future procurement decisions reduce or eliminate future cost increases with marginal increases in negotiated rate agreements?

Aside from determining where to focus in the network for benefit, considering unplanned freight in the calculating savings in a bid is at risk of over stating savings. A common approach to calculate savings is to compare a new rate to the average cost of a lane from all shipments from the previous year in review. If the historical level of unplanned shipments is significant either in volume or cost, then the average cost of a lane will be overstated since the planned carrier rates are combined with unplanned rates for rate benchmarking analysis. If a shipper touts 7% cost reductions year after year, they need to ensure they are comparing planned *actual* rates to planned *forecasted* rates and not overstated historical rates. For example, if a lane has 20% of the historical shipments indicating an average of a 35% cost increase due to unplanned freight this will lead to a 7% increase built in to the actual average freight expenditure. Savings will be stated at 7% as a result of the optimized output, but in effect will be much closer to 0% if unplanned shipments are used on lanes as a benchmark to measure cost savings as a result of an "improved" plan.

4.3 Evaluating Accept & Reject Data

Two anonymous shippers have provided 2004 accept-reject transaction data for this thesis. Data were captured using EDI and web based technologies which are replacing traditional phone and fax operations. "CPG-Co" is a consumer packaged goods manufacturer and "IND-Co" is an industrial products manufacturer. As evident by the destination locations displayed in Figures 4.3 and 4.5, the U.S. domestic coverage is significant with over 2,000 locations captured in the data and shipments nearing 170K and 110K per year respectively. The total number of carriers captured in the transactional data provided was 91, and 261 respectively for CPG-Co and IND-Co respectively.

Interestingly, both shippers have large swings in volume with an apparent correlation to the accept ratio. A common perception in industry is that the greater the increase in weekly volume the greater the amount of rejects that will occur. Each system level data set of volume and accept ratio was tested for correlation. CPG-Co and IND-Co were measured at 0.17 and -0.28 respectively. Figure 4.4 and 4.6 illustrate the observations of weekly volume and accept ratio at the system level.

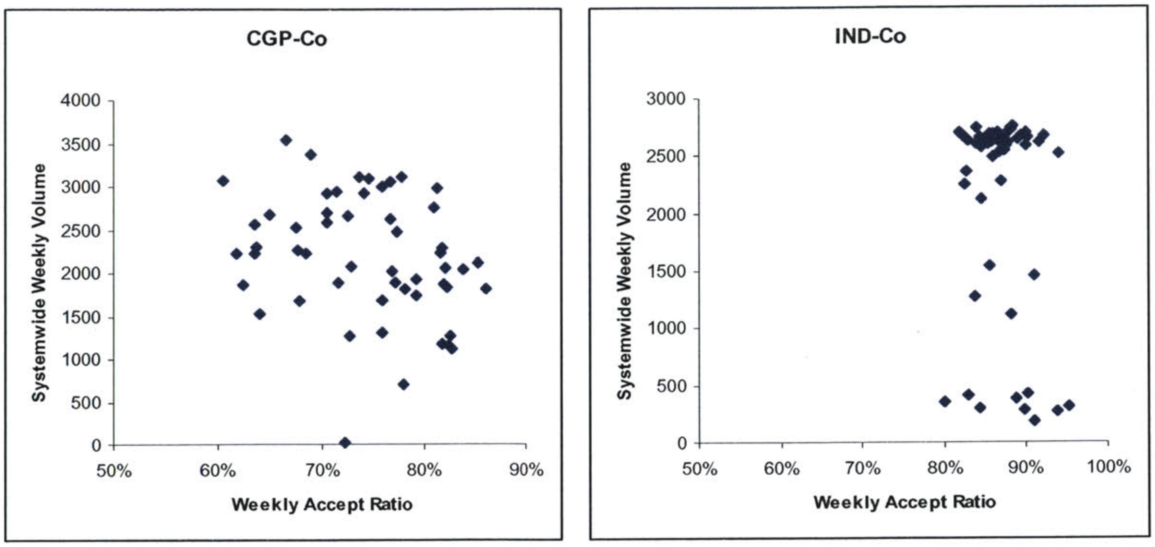

Figure 4.2 System Level Accept Ratio versus Volume Scatter Plots.

The companies represented in 4.2 have very different volume patterns and there are significant differences with respect to the weekly fluctuation of accept ratios. IND-Co which has a more consistent volume level through out the year has a much tighter range of overall accept ratio at a much higher level than CPG-Co. Both have average volume levels at roughly 2000-2500 loads per week. Another interesting observation is that IND-Co uses 261 carriers versus CPG-Co with 91 represented in the data. The common assumption that a smaller set of providers give better service due to increased leverage is somewhat challenged with this observation.

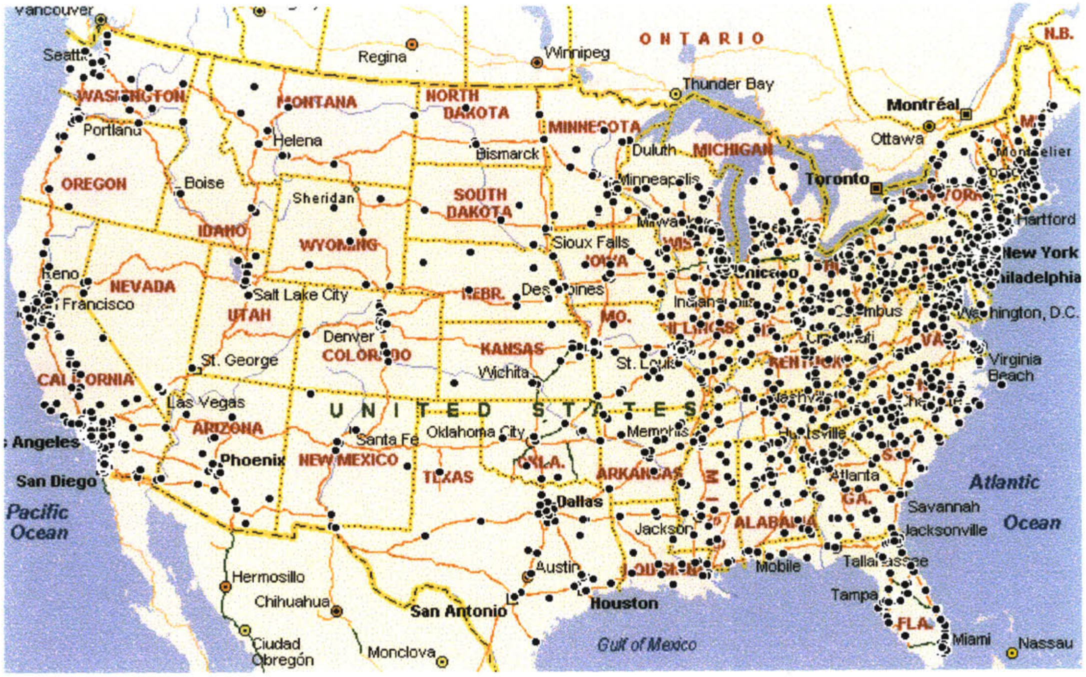

Figure 4.3 CPG-Co - US Domestic Network: 170K Shipments per Year, 2,338 Destinations

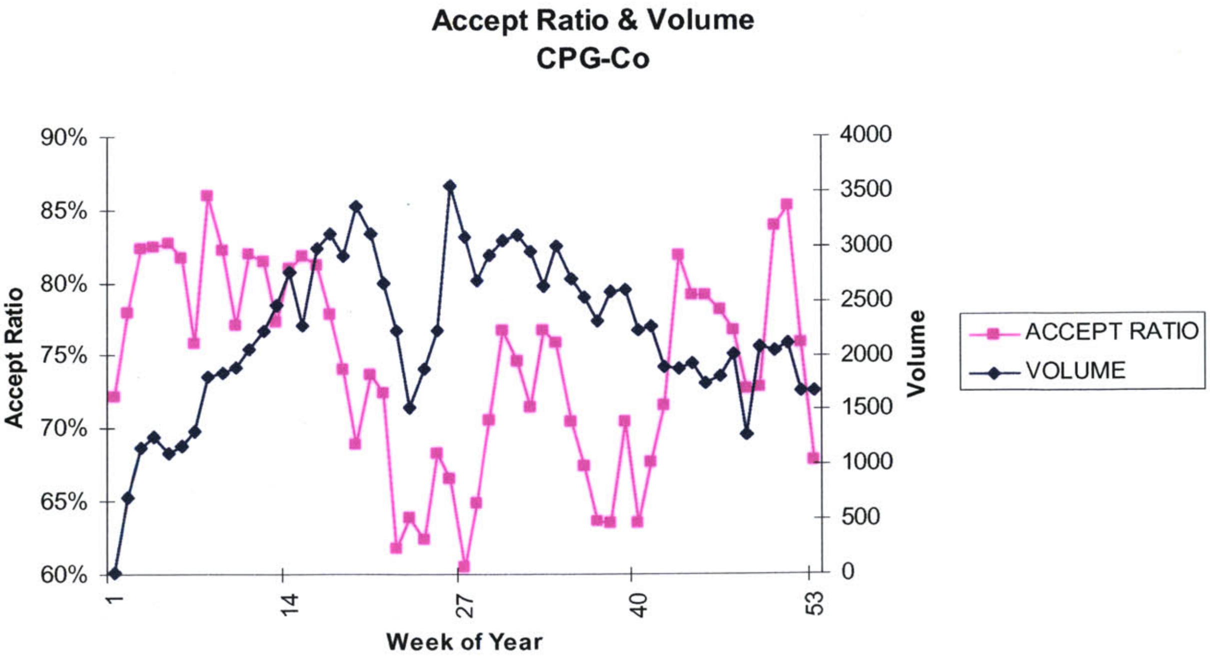

Figure 4.4 Accept Ratio & Volume – CPG-Co

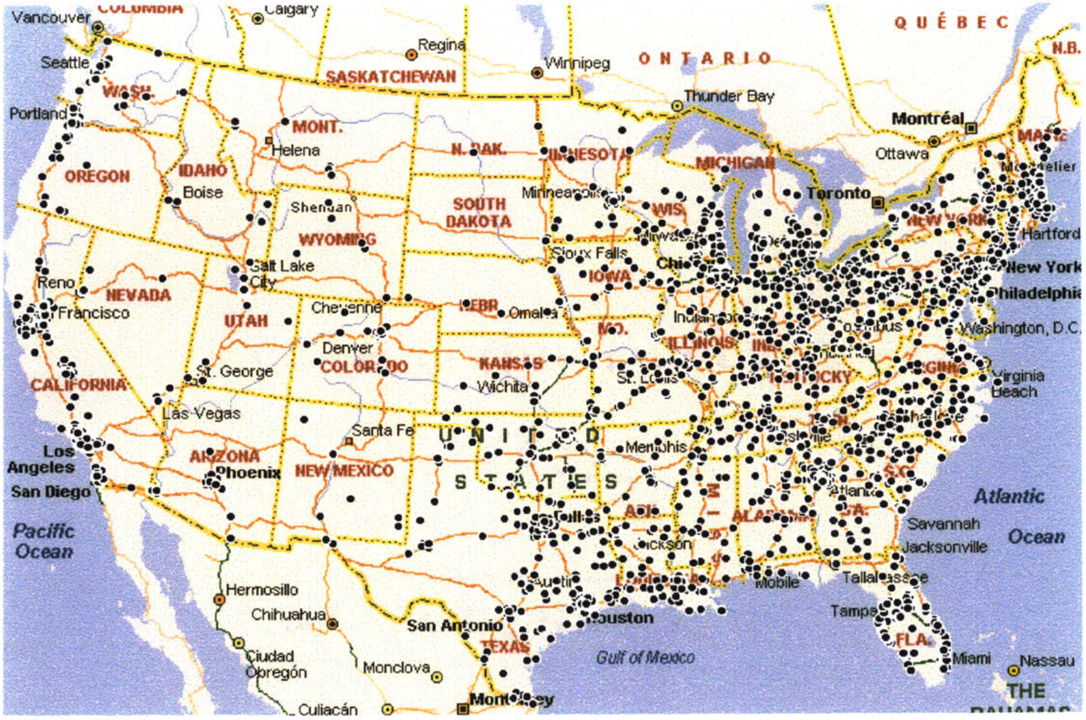

Figure 4.5 IND-Co – US Domestic Network: 110K Shipments per Year, 2,474 Destinations

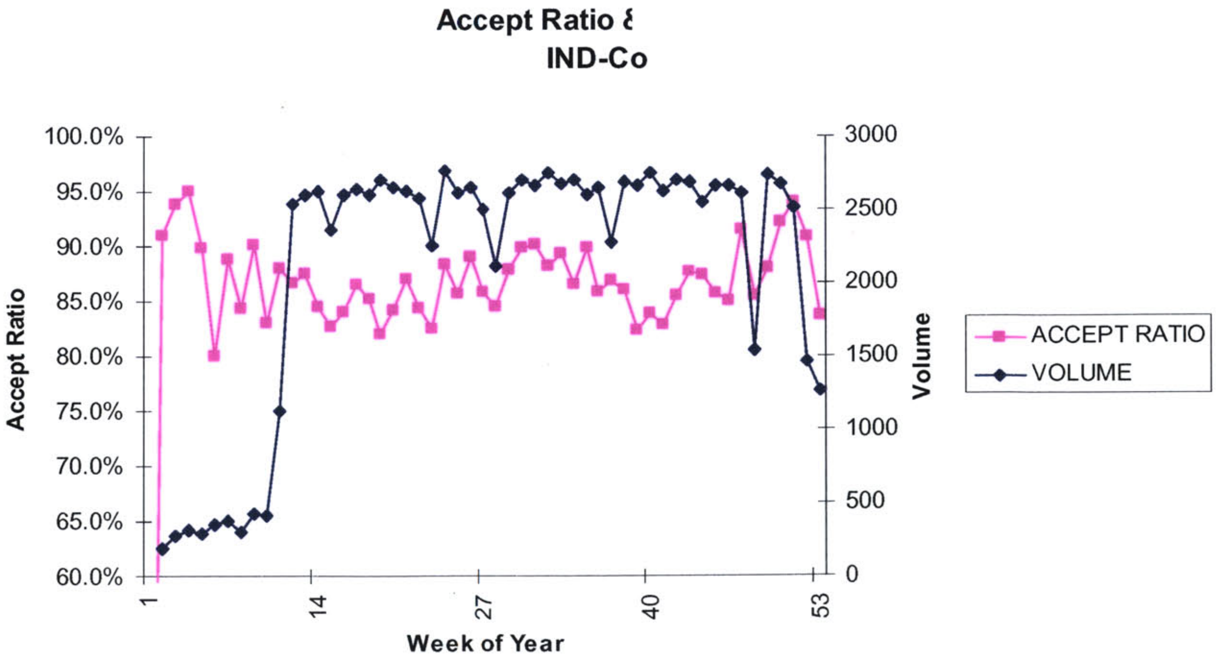

Figure 4.6 Accept Ratio & Volume – IND-Co

Reject Summary Statistics

Capturing transaction data between load planners and carriers would require a significant amount of manual effort in the absence of an automated system. Reject data were captured in 2004 in transportation management systems for both shippers. Rejected shipments were evaluated to determine how often the reject lead to additional rejects. The cases where only a single reject message was received for a shipment are represented in row 1. Interestingly, the number of rejected shipments does not equate to the number of rejected messages received. Rejects occur many times on the same shipment (Table 4.1). Figure 4.7 provides a graphical representation of the percent of rejected shipments by reject count.

	CPG-Co				**IND-Co**			
		Reject Responses				**Reject Responses**		
Rejects Per Shipment	**Shipments**	**Total**	**Percent**	**Cumulative**	**Shipments**	**Total**	**Percent**	**Cumulative**
0	147051				99450			
1	11566	11566	27.0%	27%	5604	5604	32.9%	33%
2	5228	10456	24.4%	51%	1800	3600	21.1%	54%
3	2758	8274	19.3%	71%	865	2595	15.2%	69%
4	1359	5436	12.7%	83%	432	1728	10.1%	79%
5	636	3180	7.4%	91%	250	1250	7.3%	87%
6	313	1878	4.4%	95%	114	684	4.0%	91%
7	130	910	2.1%	97%	86	602	3.5%	94%
8	75	600	1.4%	99%	55	440	2.6%	97%
9	37	333	0.8%	99%	28	252	1.5%	98%
10	10	100	0.2%	100%	13	130	0.8%	99%
11	9	99	0.2%	100%	3	33	0.2%	99%
12	5	60	0.1%	100%	3	36	0.2%	100%
13	0	0	0.0%	100%	3	39	0.2%	100%
14	0	0	0.0%	100%	2	28	0.2%	100%
15	0	0	0.0%	100%	1	15	0.1%	100%
TOTALS (1-15)	**22126**	**42892**	**100.0%**		**9259**	**17036**	**100.0%**	

Table 4.1 Reject Summary Statistics for CPG-Co and IND-Co for Shipments with >= 1 Reject Message

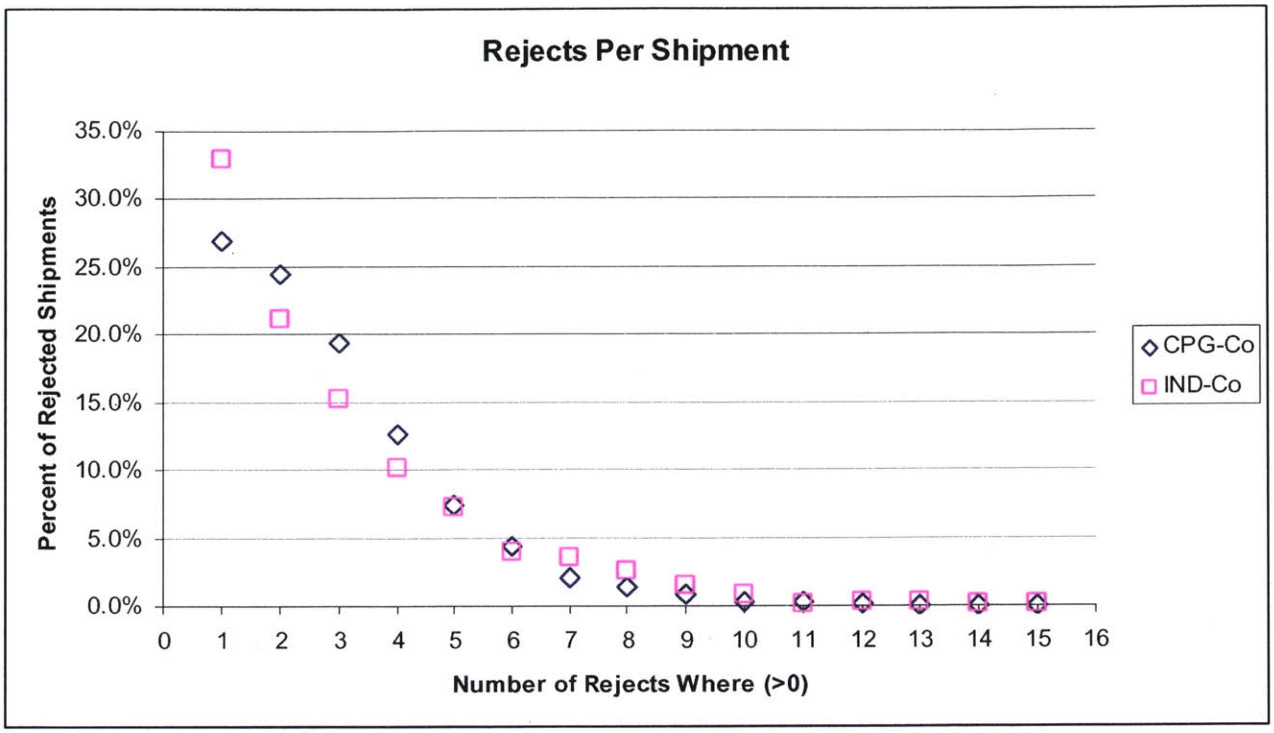

Figure 4.7 Rejects per Rejected Shipment – CPG-Co and IND-Co

The data indicate that five or less rejects are received for 91% and 87% of shipments for CPG-Co and IND-Co and roughly ten percent of all carrier rejects occur on shipments that have been rejected at least 5 times. Each reject requires an additional load tender and a subsequent delay from the carrier to determine if driver and equipment are available on that date before they formally accept or reject the load. Notifying carriers that a load is available and waiting for a response can lead to delays or significant amounts of rework adding cost and inefficiency to the process of acquiring transportation services. In 2004, 13% and 20% of all transactions captured from carriers to CPG-Co and IND-Co were notification that a load could not be accepted.

4.4 Accept-Reject Based Performance Metrics

Accept-reject based performance metrics capture significantly more information regarding the interaction with a shipper and its carriers. Figure 4.8 illustrates the processes that are captured with accept-reject levels of detail. The data provided in the study fall within this general framework of shipper-carrier interaction.

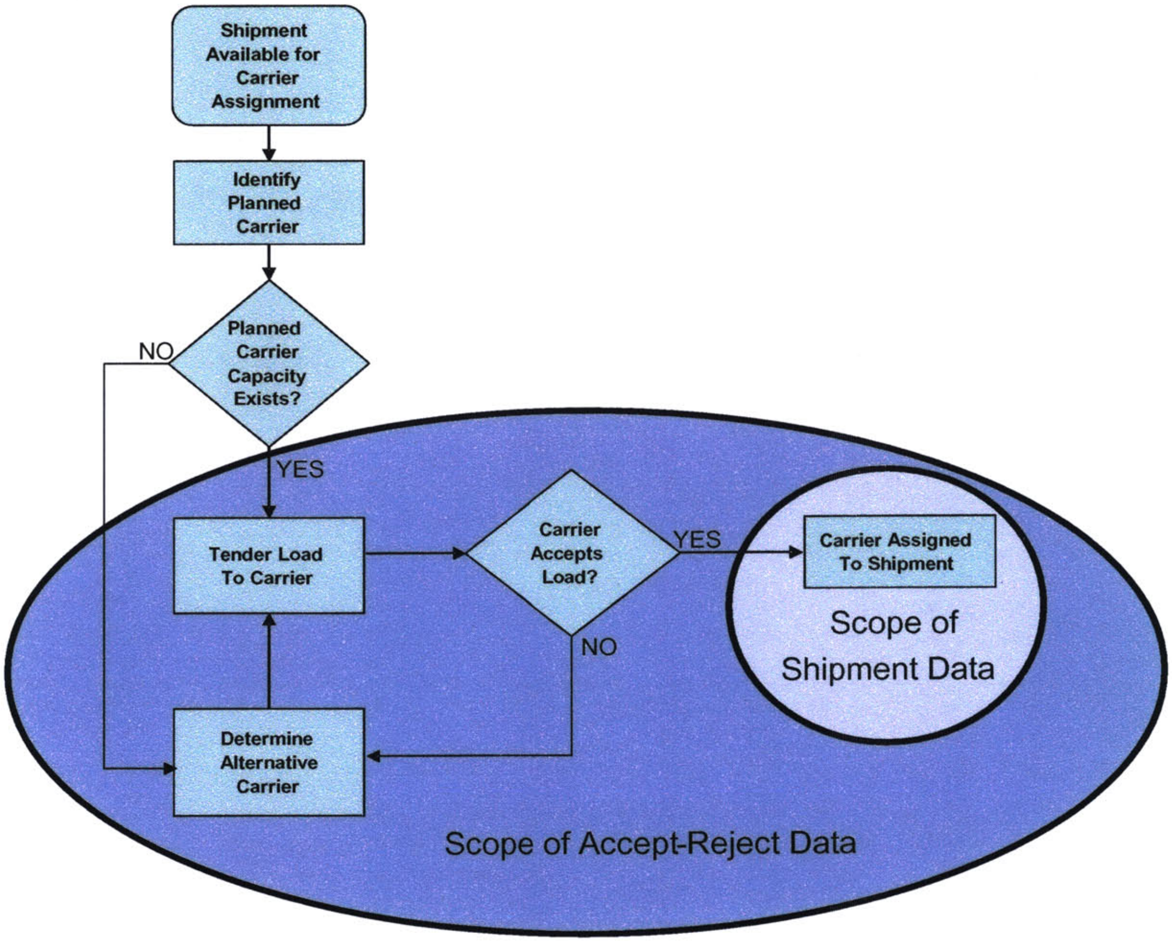

Figure 4.8 Shipper-Carrier Interaction and Scope of Accept-Reject Data

Determining whether or not planned capacity exists prior to tendering to a carrier is a task that load planners perform manually outside of TMS systems. It is not uncommon for a carrier in the routing guide to reject freight and indicate via telephone that no capacity exists for a short timeframe. When this happens, load planners will alter the assignment of a planned carrier and select an alternative carrier prior to the first tender of a shipment. As a result, a subset of the tendering data will indicate the first tender to an unplanned carrier and, as a result, is not captured by accept-reject data (Harding 2005).

This section illustrates the calculations of accept-reject data performance metrics their limitations and characterize how they can be used to support simulation and optimization techniques.

Carrier-Lane Level to System Level Accept-Reject Metrics

Carrier-lane to system level metrics cover the spectrum for which accept-reject metrics can be calculated and provide separate focus to different issues. The calculation is the total number of shipments accepted divided by the total number of shipments tendered at any aggregation level or time period and can be calculated by carrier or by all volume for a given aggregation:

$$\text{Accept Ratio} = \frac{\sum_i A_i}{\sum_i T_i}$$

A : Number of Accept Messages at a Network Level of Aggregation-Time Perdiod i
T : Number of Total Messages at a Network Level of Aggregation-Time Perdiod i
i : Network Level of Aggregation-Time Period (Lane, Facility In, Facility Out, System)

	Scope	Focus of Accept-Ratio
Carrier-Network Level	**Carrier-Lane**	Indicates the level of carrier specific performance on a lane
	Carrier-Facility	Indicates the level of carrier specific performance on all lanes entering or leaving a facility
	Carrier-Network	Indicates the level of carrier specific performance to the sum of a shipper's requirements
Network Level	**Lane**	Indicates the level of responsiveness to a shipper's carrier-base has on a specific lane
	Facility	Indicates the level of responsiveness to a shipper's carrier-base has at a specific facility
	Network	Indicates the level of responsiveness the entire shipper's carrier-base has on a shipper's freight

Table 4.2 Scope of Network and Carrier Level Accept Ratios

Since the number of accept messages will never exceed the number of total shipments, this value is represented by a percentage and ranges from 0-100%. Table 4.2 compares the focus of the carrier-network and network level accept ratio metrics. The level of correlation is important where carriers have a significant percentage of lane volume since the lines between network effects and carrier effects become less clear. Aggregations reduce this effect since there are typically dozens if not hundreds of carriers as the level of aggregation increases.

4.5 Planned versus Unplanned Accept-Rejects

The accept-ratios alone are not sufficient to measure carrier behavior because carriers are often requested to service unplanned freight which was rejected by the primary carrier. As defined, shippers commonly use backups, or secondary carriers to haul unplanned freight. Once accept-reject transactions are flagged as a result of their association with a planned or unplanned carrier, the sum and percentage of tracking messages can be combined from carrier-lane to system level aggregation in the following form:

	Planned Freight	Unplanned Freight
Accept Messages	Planned Accepts	Unplanned Accepts
Reject Messages	Planned Rejects	Unplanned Rejects

Table 4.3 Planned/Unplanned Accept-Reject Matrix

The following data represent an example of a carrier-system perspective of unplanned and planned freight volumes using data obtained in the study. Each graph represents total messages (planned and unplanned) that were sent to a carrier at the system level. The top graph indicates the week-of-year counts, and the bottom graph shows the cumulative values as the year unfolds. Accept and reject messages are separated by planned and unplanned values.

What is significant about the examples in Figures 4.9 and 4.10 is the dynamic relationship from week to week of all variables measured. Total messages (loads offered) range from about 10 to 140 loads per week with accepts for planned freight ranging from 0-60 loads per week and unplanned accepts ranging from 0-20. There are many unanswered questions which need to be addressed; however, they cannot be determined by data alone which should be addressed: Why was this carrier offered so much freight? Did the carrier perform satisfactorily? Was this a result of another carrier's failure? Did the shipper meet the commitment? Did the carrier meet the commitment? Were expectations properly communicated in the planning phase? The answers to these questions are important when better strategic relationships with suppliers of capacity.

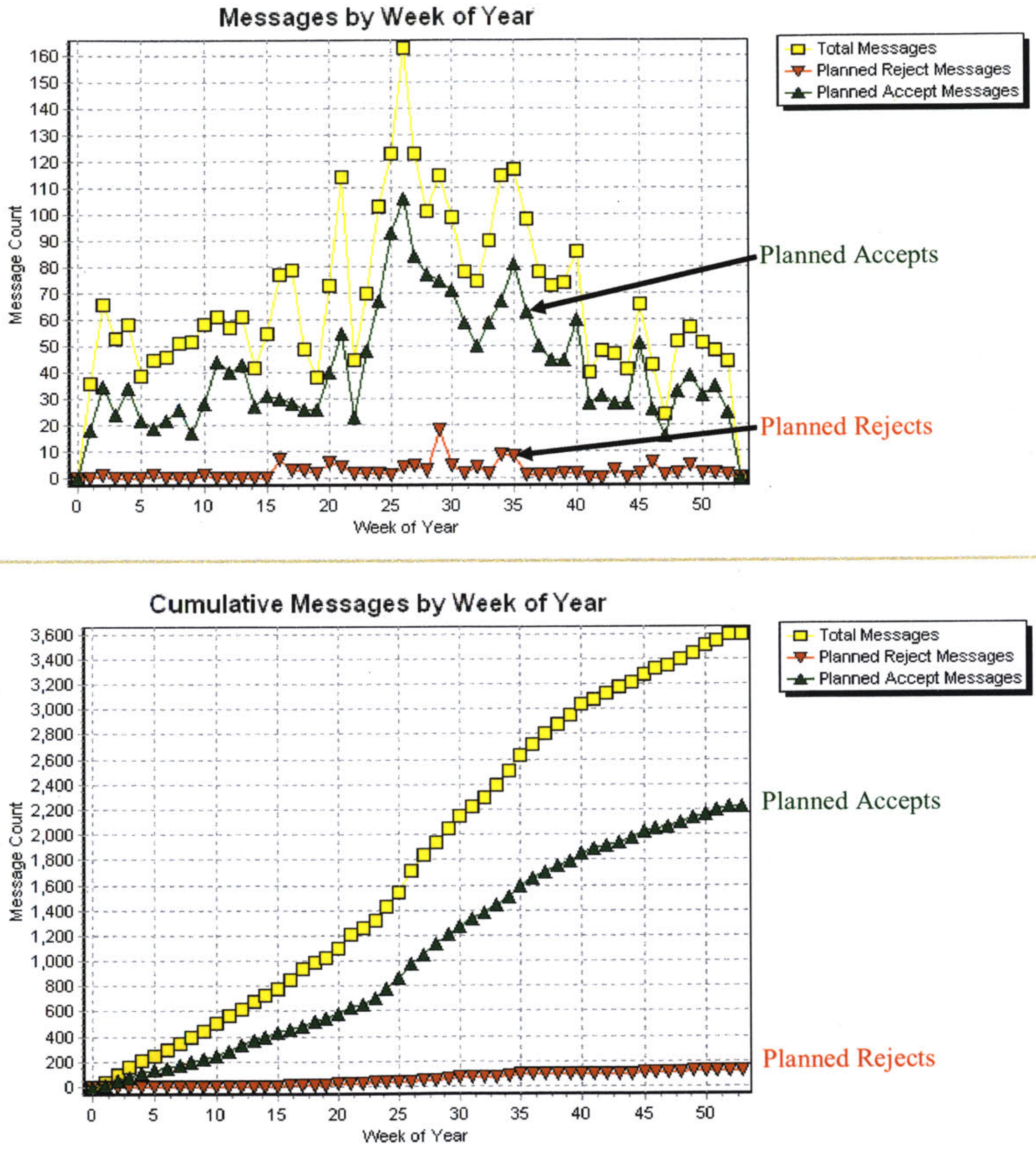

Figure 4.9 Planned Accept and Reject Messages for Carrier at System Level

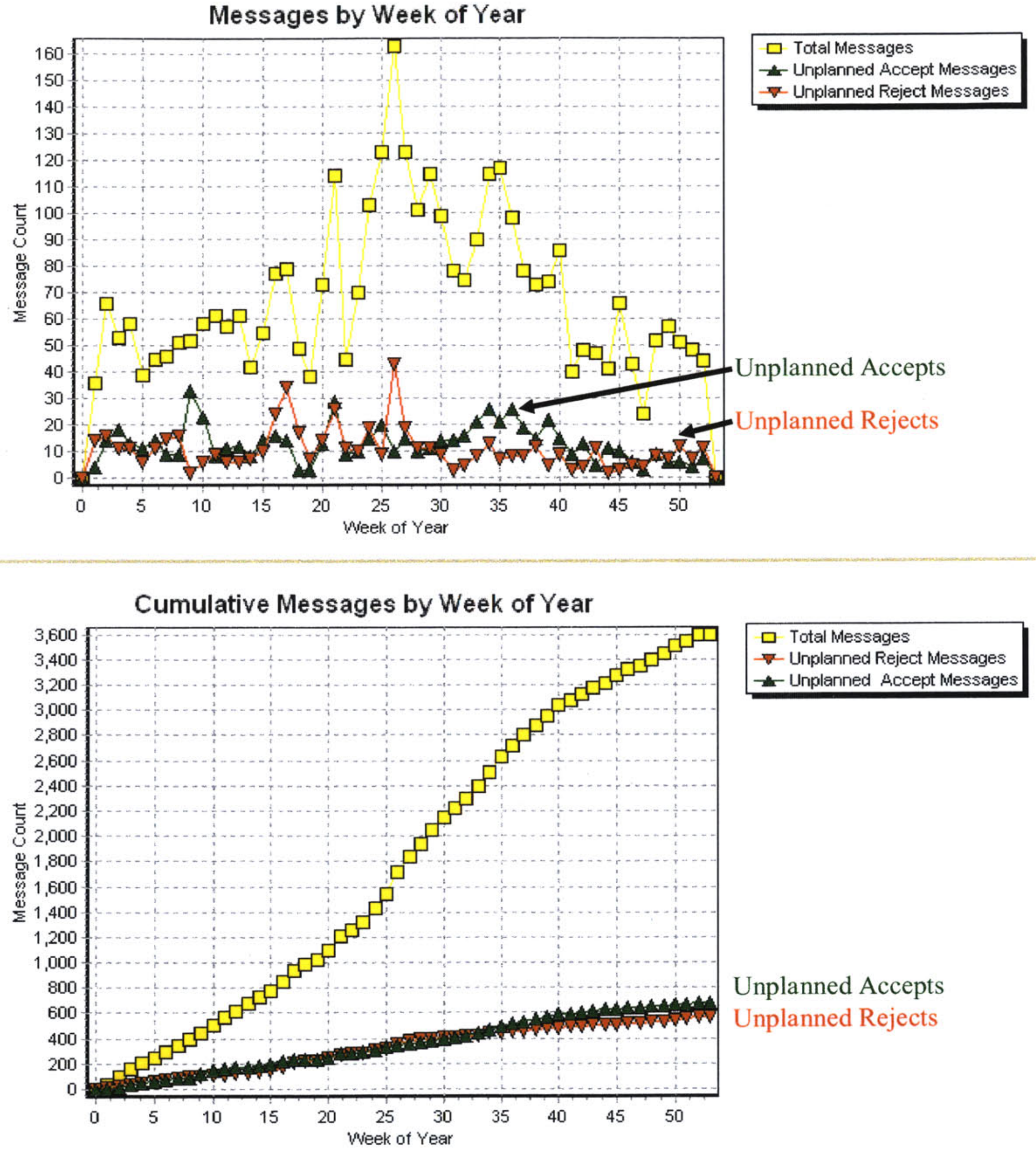

Figure 4.10 Unplanned Accept and Reject Messages for Carrier at System Level

The information found in Figures 4.9 and 4.10 can be summarized for the total year in review in Table 4.4:

Total Message Count (3597)	Planned Freight	Unplanned Freight	**Total**
Accept Messages	2229	677	**2906**
Reject Messages	126	565	**691**
Total	**2355**	**1242**	**3597**

Percent	Planned Freight	Unplanned Freight
Accept Messages	62.0%	18.8%
Reject Messages	3.5%	15.7%
Accept Ratio by Category	95%	55%
Total Accept Ratio	81%	

Table 4.4 Planned-Unplanned Accept Ratio Statistics for a Carrier

Many shippers may consider an 81% reject ratio as unacceptable, however, in this case, the accept ratio relative to freight that was originally contracted in the routing guide is much higher at 95%. This carrier was offered 1242 loads of unplanned freight as a backup carrier in addition to the 2355 loads that represented committed freight.

This data can be used at various levels to measure carrier commitment. The following matrix characterizes the commitment of carriers relative to the level of accept ratios for each category of freight:

		Unplanned Accept Ratio	
		Low	High
Planned Accept Ratio	Low	Unresponsive	Random Response
	High	Focused Response	Broad Response

Table 4.5 Carrier Response Matrix

High and low values are set relative to qualitative thresholds for each case. Each quadrant represents a class of carrier responsiveness. Carriers with low unplanned and planned accept ratios are likely challenged by their internal costs of the business or simply cannot provide the trucks. In any case, there is little or no response. Carriers with high planned accept ratios and low unplanned accept ratios are maintaining the commitment in the strategic plan but for unknown reasons to not respond well to unplanned freight tenders. Carriers that have high accept ratios for both planned and unplanned freight show a level of responsiveness to the shipper for all types of tenders.

Carriers might have low accept ratios for planned freight but high accept ratios for unplanned freight for many reasons. A carrier could be taking unplanned freight when it is profitable, or when it serves a particular backhaul opportunity within the network. Also, a carrier could be vying for long term contracts and handling business that may lead to greater volumes in future bids by proving their ability as a newly introduced carrier. Shippers should understand the reasons for various degrees of performance as a basis for future contract awards and as a basis for understanding the sources of robustness in a transportation network.

4.6 Combining Accept-Reject Metrics with Contracted Volume

Building on the previous framework the following table combines the previous data with the volumes designated in the routing guide which were established at the start of the contracting period. This information summarizes what was offered to the carrier, what was accepted by the carrier, and how close the original contracted values were to the actual activity. Contracted volume represents the sum of all shipments contracted in the prior year using average weekly volumes from the bid.

Total Message Count (3597)	Planned Freight	Unplanned Freight	Total
Accept Messages	2229	677	**2906**
Reject Messages	126	565	**691**
Total	**2355**	**1242**	**3597**

Contracted Volume (Shipments)	**8480**
Planned - Percent to Contract (Planned Accepts/Contracted Volume)	**26%**
Unplanned+Planned - Percent to Contract (All Accepts/Contracted Volume)	**34%**
Total Messages - Percent to Contract (All Accepts/Contracted Volume)	**42%**

Table 4.6 Combining Accept-Reject with Contracted Volume

In this example, the carrier had 2,355 opportunities to haul planned freight rejecting 126 of them. The carrier's 95% accept ratio of planned freight brings the percent to contract to 26% (2,229/8,480) for planned freight only. If the unplanned freight is included, the carrier actually hauled 34% of their committed volume due to accepting unplanned freight. Interestingly, this carrier did not meet the commitment of freight hauled because only 42% was offered and 26% was not primary freight. If the shipper were measuring accept ratios and measuring commitment on all freight without distinguishing between planned and unplanned freight, this carrier's performance would be sorely misrepresented.

This example illustrates the level of detail obtained by looking at a single carrier at the system level for a shipper. More important is the complexity of all of these relationships when making decisions about rates and capacity provided by all carriers. Techniques similar to those presented in Table 3.2 for building a framework of qualitative factors can provide a clearer picture of both sides of the shipper-carrier commitment equation, and the resulting differences in total cost or increased tendering.

The differences between CPG-Co and IND-Co lead to bigger questions for all shippers and carriers. Why does IND-Co have much higher accept ratios? Why are IND-Co carriers more responsive? If companies have different management structures, does centralized load planning versus decentralized load planning offer better performance? Which company is paying relatively more for their freight? Does volatility in demand lead to higher transportation costs and lower accept ratios? The answers to these questions will lead to a better understanding of carrier-shipper execution and should be pursued in further research. What is clear for the purposes of this thesis is that accept-reject data can provide a benchmark for evaluating shipper and carrier interaction and, in these examples, varies by company making any simplistic rule-of-thumb ineffective. Further discussion will illustrate how shipment and accept-reject metrics can be used to enhance the effectiveness of optimization and build a foundation for simulation techniques.

5 Optimization Techniques for Robustness

Once carriers are effectively separated by classes using shipment or accept-reject data, these classes can then be used within the optimization model for more robust results. There are two basic approaches in configuring the optimization model: rate adjustments and/or capacity adjustments.

5.1 Rate Adjustments

Rate adjustments using MARS are used in the WDP when factors that affect the rate need to be considered. The factors can be qualitative or quantitative. Examples of quantitative factors include cases where carriers can guarantee equipment types with greater cubic space. If a carrier can commit 53' trailers over 48' trailers and the shipments are generally constrained by cubic space, then an 11% reduction to the rates submitted in the bid is needed to make the rates equal to other carriers who cannot make this commitment. Greater loading capacity in this case means that the rates provided need to be engineered relative to the quantitative differences that exist. In this case, it is defined by the extra loading capacity of the trailer.

More elusive are qualitative factors. If metrics are not easily compared to a cost, then the adjustments can be used by the optimization to force carriers on to lanes since the objective function is to minimize cost. These reductions allow the optimization to minimize total cost based on altered rates but still obey capacity limitations and other constraints without creating infeasibilities in the modeling. Once allocations are made in the optimization, the costs are reported using the "real" rates and a comparison can be made to previous software optimization scenarios to assess the cost implications.

Calculating expected cost per load (E) which includes the carrier bid rate (R) and an adjustment (1-A)(U-R) considering system level carrier performance in (A) is given as follows: $E = R + (1 - A)(U - R) \forall l, c$

Where:

l : in lanes

c : in carriers

R : Carrier rate for lane l

U : Cost of unplanned shipments for lane l

A : System-level accept ratio for carrier c

Cost Per Point Reject (P) = $(U - R)/100$

Reject Cost (J) = (1-A)P

Table 5.1 provides a simple example:

Bid Data					Historical Data		Unplanned Impact		Costs used for Optimization	
		Lane Volume	Rate	Capacity	Per Load Cost of Unplanned Freight	System Level Accept Ratio	Cost Per Point Reject	Reject Cost Per Load	Estimated Cost Per Load	Estimated Cost Per Year
		L	***R***	***C***	***U***	***A***	***P***	***J***	***E***	
Carrier X	Lane 1	15	$ 450.00	15	$ 550.00	95%	$ 1.00	$ 5.00	$ 455.00	$ 354,900
Carrier Y	Lane 1	15	$ 475.00	15	$ 550.00	90%	$ 0.75	$ 7.50	$ 482.50	$ 376,350
Carrier Z	Lane 1	15	$ 435.00	15	$ 550.00	75%	$ 1.15	$ 28.75	$ 463.75	$ 361,725

Table 5.1 Calculating Expected Cost Using Service Criteria

Carrier Z bid $435 per load with a 75% accept ratio. Assuming the cost of unplanned freight is $550 per load, an adjustment of $28.75 per load is applied offsetting the expected additional unplanned freight expenditure caused by this performance. The carrier's bid will then be optimized at this adjusted rate making the $450 rate from Carrier X more attractive. Determining the level of bonus or penalty can be scaled to better reflect specific cases for each carrier-lane since the cost of unplanned freight may vary throughout the network. Furthermore, this approach should only be applied where unplanned freight expense is greater than the contracted rates.

Each rate provided is only as effective as the carrier's expected accept ratio, and each carrier rate has a cost for a reject that is dependent upon the bid rate. If a rate is lower than the cost for unplanned freight, actual freight expenditures will be higher than planned in the case of poor performance. This example focuses on performance criteria at the system level; however, the framework is flexible for more detailed levels of aggregation such as carrier-facility or carrier-lane. In practice, rate adjustments are an effective approach to convert performance into a carrier's rate; in this case the adjusted costs are estimated but based both on measured performance, and measured costs.

Handling non-incumbent carriers poses some challenges and there are no hard and fast rules for dealing with uncertainty as a result of using a new provider. One approach is to create a default value that is neutral for all non-incumbent carriers and represents the expectation of future performance. The value could be set either at the system level measurement for all incumbent carriers or some universal value that is set as a standard which can be incorporated as a performance target for assessment during the future contract period.

5.2 Capacity Adjustments

While rate adjustments allow the optimization algorithms to consider different costs, they do not constrain the optimization model. Capacity constraints must be used to constrain the allocation of capacity. Capacity constraints limit the amount of volume awarded to a carrier and can be applied at any level: lane, facility, system, custom region, etc. Carrier-facility capacity constraint ($C_{c,f}$) considering historical volume levels and performance at the facility level are calculated as follows:

$$C_{c,f} = \min\left[B_{c,f}, A_{c,f} \sum_{l} O^{l}_{c,f}, G_{c,f}(P_{c,f} + U_{c,f}) \right] \quad \forall c, f$$

Where

c in carrier

f in facility

l in lane

$B_{c,f}$: Carrier provided facility level capacity constraint (given in bid)

$\sum_{l} O^{l}_{c,f}$: Sum of outbound carrier c lane volume on lane bids for a facility f for lane l

$A_{c,f}$: Planned Accept Ratio for carrier c at facility f

$P_{c,f}$: Planned Volume for carrier c at facility f

$U_{c,f}$: Unplanned Volume for carrier c at facility f

$G_{c,f}$: Allowed growth from previous year (given)

Bid Data			Historical Data								
Carrier	Facility	Total Outbound Volume Bid (Loads/Week)	Planned Accept Ratio	Planned Volume (Loads/ Week)	Unplanned Volume (Loads/Week)	Estimated Planned Volume	Difference of Bid to Historical	Allowed Growth	Planned + Unplanned at Growth	Bid Less Growth	Facility 234 Carrier Capacity Constraint
		O	***A***	***P***	***U***	***E***	***D***	***G***	***T***	***L***	
Carrier X	234	34	90%	40	5	30.6	-9.4	10%	49.5	-15.5	None
Carrier Y	234	65	87%	23	0.5	56.55	33.55	10%	25.85	39.15	39.15
Carrier Z	234	23	70%	45	1	16.1	-28.9	10%	50.6	-27.6	None

Table 5.2 Limiting Capacity at the Facility Level Based on Service Parameters

Additional Columns for Table 5.2 are defined as follows:

E : Estimated Planned Volume = AO for carrier *c* at facility *f*

D : Difference of Bid to Historical Volume = P-E for carrier *c* at facility *f*

T : Planned + Unplanned at Growth = G(P+U) for carrier *c* at facility *f*

L : Bid Less Growth = O-T for carrier *c* at facility *f*

Table 5.2 illustrates how performance can be used to limit capacity by comparing the volumes of unplanned and planned freight for a carrier-facility to the carrier bid volume. In this case, three carriers bid at different aggregated volume levels for facility 234. Carrier Y has bid on more volume than what was performed at this facility for both planned and unplanned freight volumes and was constrained to 25.85 loads per week. The overriding message is that facility capacity can be limited to previous performance levels with some of control based on past performance preventing over allocation of capacity to highly aggressive or poorly performing carriers.

The three terms in the calculation define different views of capacity and will vary in their applicability depending upon the strategy of the shipper:

1. The term ($B_{c,f}$) represents the capacity constraint that the carrier provides in the bid. If the carrier has a history of providing more capacity, the optimization should always consider this as a deliberate attempt to reduce business. Allocating more than this will create greater risks without further negotiations with the carrier.

2. The term ($A_{c,f}\sum_{l} O^{l}_{c,f}$) represents the application of the planned accept ratio from the previous period applied to the lane bids provided by the carrier. Since the carrier is constrained by the facility constraint ($B_{c,f}$), this term limits the carriers lane bids to the accept ratio from historical performance for contracted freight if the facility constraint is not sufficient to control the lane bids. Sometimes facility capacity is submitted at the sum of the lane bids, providing no constraint for the WDP.

3. The term ($G_{c,f}(P_{c,f}+U_{c,f})$) represents the planned and unplanned volume that the carrier has performed historically with some level of allowed growth. This calculation will award to levels performed in the past regardless of the type of freight. Assuming better shipper discipline, planned freight could be better directed, or the commitment could be increased with the expectation that continued usage for unplanned needs will arise and should be considered in the WDP.

The purpose of this approach is to prevent carriers from aggressive bidding tactics if past performance has indicated capacity capabilities that are significantly different from the bid. This approach allows carriers to shift volumes from the current obligations, but prevents severe increases by comparing what they bid ($B_{c,f}$) to either the planned accept ratio ($A_{c,f}\sum_{l} O^{l}_{c,f}$) or the total amount of planned and unplanned volume historically performed ($G_{c,f}(P_{c,f}+U_{c,f})$). Based on the types of carriers (aggressive versus conservative) or the size of carrier (national versus regional), this approach could be applied to a specific set of carriers to focus on minimizing the risk associated with allocating too much capacity to a misaligned carrier.

6 Simulating Planned and Unplanned Events

Building more complex optimization models by adjusting rates and capacity constraints is one approach to prevent optimization software from making suboptimal recommendations. This chapter extends into the application of the optimization results in a simulation model that considers uncertainty of supply or planned carrier capacity and demand represented by fluctuating freight volumes.

Demand of freight volumes is highly variable. Figure 6.1 and 6.2 illustrate the variability of weekly lane volume using the coefficient of variation divided by the mean for the average weekly volume for both CPG-Co and IND-Co. The results confirm that lane volumes fluctuate significantly throughout the year. Based on pervious observations CPG-Co has a significantly greater amount of variation in demand which could correspond to the lower accept ratios but remains to be proven.

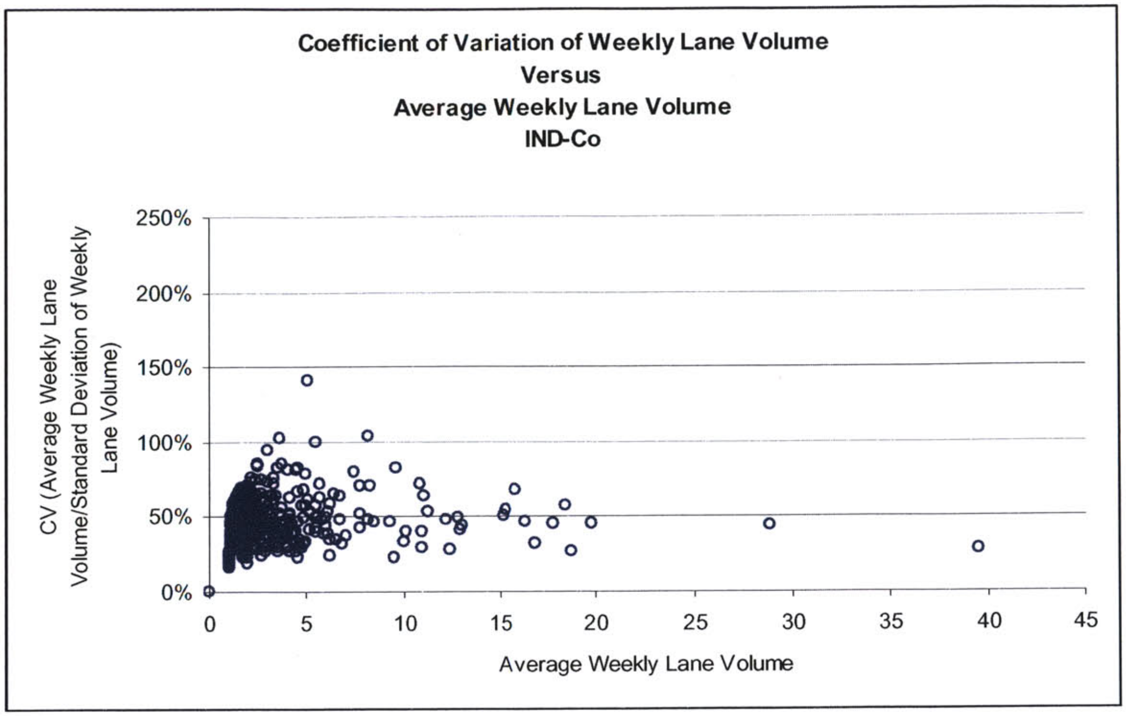

Figure 6.1 IND-Co Variability of Lane Demand

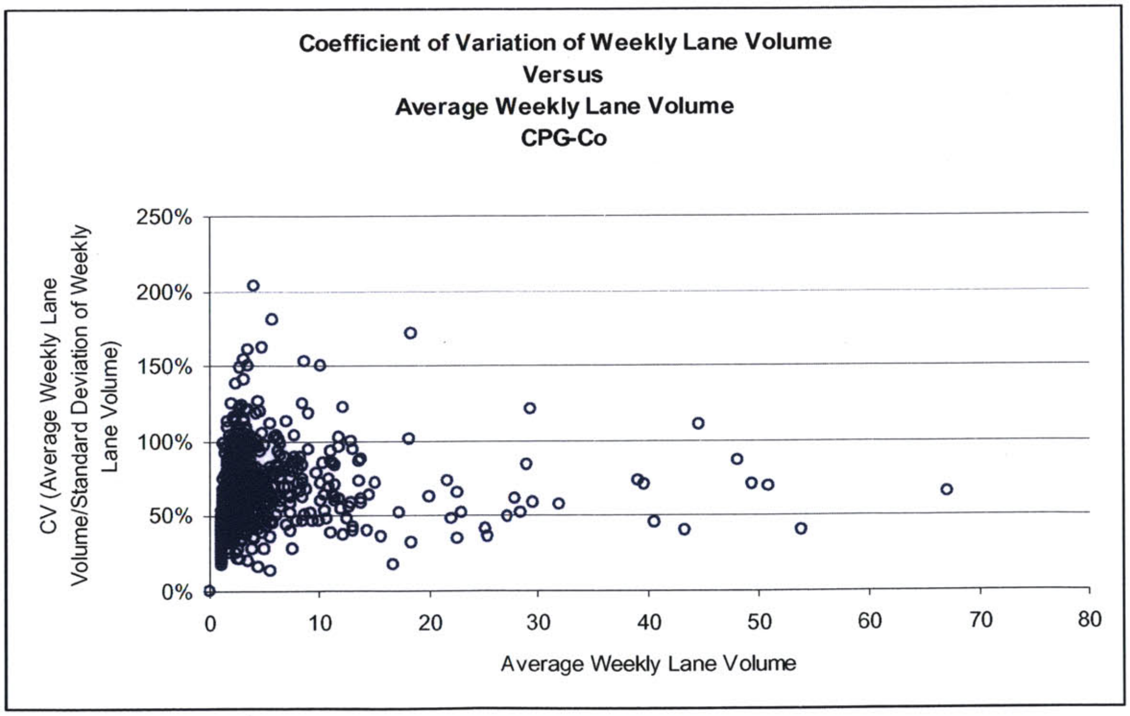

Figure 6.2 CPG-Co Variability of Lane Demand

In addition to volume swings which represent the variability in demand, the accept ratios, representing the variability of supply within the carrier base also vary. Figure 6.3 shows the system level accept ratios for 96 truckload carriers in CPG-Co over 2004:

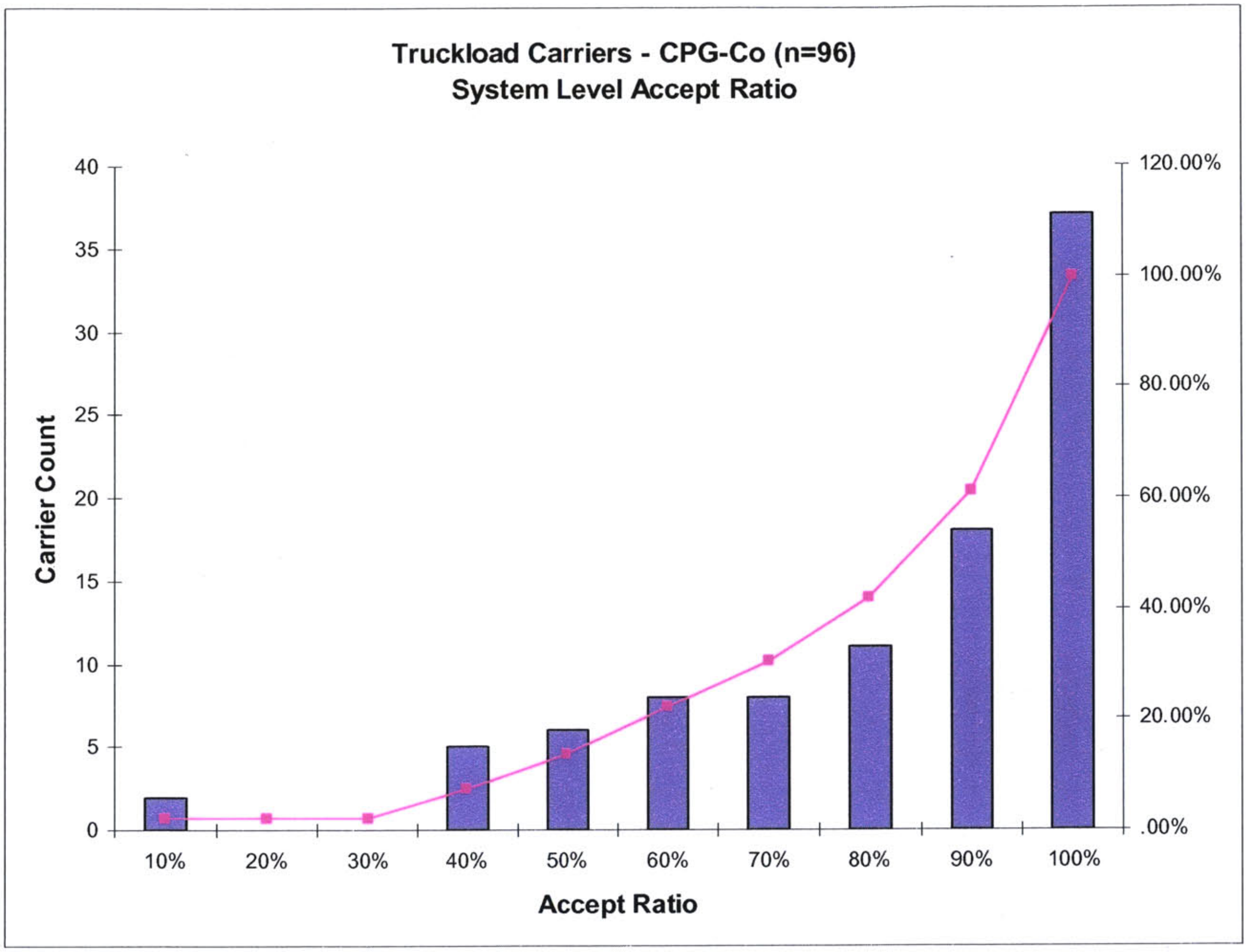

Figure 6.3 CPG-Co - System Level Accept-Ratio for Planned and Unplanned Freight by Carrier

Although some carriers haul a significantly lower percentage of freight volumes and may be used as backups, the variation of accept ratios is significant across the carriers. In this case 40% of the carriers have less than 90% accept ratios for all freight.

Optimization does not consider fluctuations in freight volume demand or planned or unplanned capacity and requires static inputs to minimize planned freight expense.

Carriers provide static capacity typically in loads per week, which are in turn used to allocate lane volume which is also stated in loads per week. In practice, changing something as simple as lane volume on an optimization model can lead to a great deal of unintended consequences. Minor changes to the network can lead to a proliferation of infeasibilities in the model or the invalidation of carrier capacity constraints at aggregated levels. In addition, managing a single static network is a labor intensive process consisting of submitting, collecting, validating and preparing data which is significant for both the shipper and carrier. Given the increased labor to manage these types of changes and computational factors associated with maintaining the optimization model, attempting to use optimization software to assess probabilistic scenarios would not be feasible as a result of the static requirements of the formulation. The following section details various simulation models that integrate accept-reject behavior and variable demand with optimization results from a WDP.

6.1 Simulation Design

Simulation models are used to measure the behavior of complex systems with many applications in supply chain. Using simulation to measure planned and unplanned costs in a transportation network is trivial compared to more complex models that are found in manufacturing or distribution. The process being modeled in this thesis is presented below:

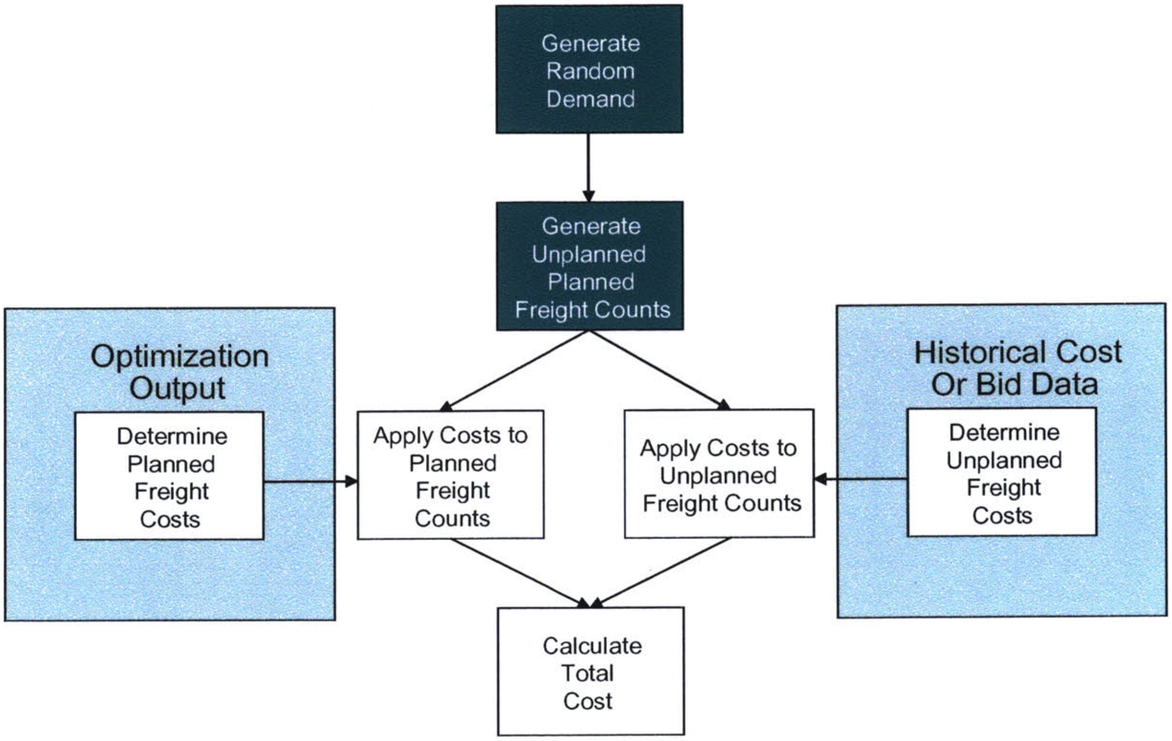

Figure 6.4 Robust Transportation Simulation Processes

The process is presented separately from the underlying design since there are many approaches using theoretical or empirical distributions to model each sub process. The following defines each component of the simulation process presented in Figure 6.4.

Generate Random Demand - Replicates the variability associated with demand since many lanes vary significantly from week to week in terms of required capacity.

Generate Planned & Unplanned Freight Counts – This is the process that defines which type of carrier, planned or unplanned, accepts freight and to what volume level based on demand. Once the ratio of planned and unplanned rate is determined, the volume levels for both planned and unplanned freight counts within “Apply Costs to Planned Freight Counts” and “Apply Costs to Unplanned Freight Counts”.

Determine Planned Freight Costs - Creates expected planned costs using the output of the optimization software.

Determine Unplanned Freight Costs – Values can be determined by historical transaction data or bid data as defined by expected backup rates when planned carriers reject.

Calculate Total Cost Estimate - This is the combination of planned and unplanned costs as determined by the model. Each simulation run will perform these processes over many iterations capturing statistics to determine the variability associated with model input configuration and its impact on total costs and hence its robustness.

6.2 Replicating Planned and Unplanned Freight Flows

The previous sub-processes define the framework of the simulation. The next level of design is precisely how randomness occurs, answering how it is measured and how it should be applied in a model. At the lowest level of detail, randomness occurs with each interaction with a carrier and for large networks there are hundreds of thousands, and in some cases, millions of interactions in a year. Simulating at this level may be too complex or too time consuming to both design and produce results. Conversely, simulating at a system level for an entire year would be too much aggregation and omit the differences between regional costs and performance at various times of the year. Since simulation tools require accurate representation of randomness to better reflect the range of possible outcomes, the choices made in model design have a direct impact on the results. The design will then define how input probability distributions are constructed based on available sources of data.

Input probability distributions which drive the behaviors of each sub-process in the model can be designed using bid data, transactional data and historical shipment data as follows:

1) Generate Random Demand (Transactional Data)
2) Generate Planned/Unplanned Freight Counts (Transactional Data)
3) Determine Planned Freight Costs (Bid Data)
4) Determine Unplanned Freight Costs (Bid or Historical Data)

Furthermore, there exist three approaches in which the input data can be used for simulation modeling which is summarized below (Law & Kelton 1991):

1. **The data values themselves are used in the simulation.**
    a. Benefits
        i. Good data to validate empirical and theoretical distributions within simulation model.
    b. Limitations
        i. Does not provide continuous function.
        ii. Constrained by data, cannot go beyond data values.

2. **The data values define an empirical distribution.**
    a. Benefits
        i. Can determine any value between the minimum to the maximum through extrapolation.
    b. Limitations
        i. Does not capture the underlying distribution.
        ii. Limited to range of collected values, cannot model extreme values.
        iii. May have "irregularities" as a result of limited data samples.

3. **Techniques of statistical inference are used to "fit" the values to a theoretical distribution.**
    a. Benefits
        i. Compact representation.
        ii. Computationally more efficient than large empirical distributions.
        iii. Can be used to validate underlying behaviors.
        iv. Generally preferred over (1) and (2).
    b. Limitations

i. Situations exist that cannot be "fit" to a theoretical distribution and empirical (2) distribution must be used.

6.3 Designing Empirical and Theoretical Distributions

The two methods which will be discussed for creating input probability distributions are empirical and theoretical. Each of these methods has specific design considerations for use in applications of robust transportation planning. These design considerations should be well understood prior to creating a model because the choice will impact the level of validity in using a model which is constrained by the design effort required and ultimately the cycle-time for results.

One design consideration is the time period. Before distribution fitting can occur with samples of data, creating theoretical input probability distributions requires aggregating transactional data for a specific period. For example, freight demand can be generated in a simulation in loads per week for an entire year, or by day for an entire year, or by month. Each period will be better represented by discrete or continuous distributions depending on the number of periods and the aggregation caused within the periods. The period used will also have further consequences on the design, validation and maintenance of a model.

In addition to the aggregating at the level of time period, aggregating at the network level has similar consequences. Lane metrics can be spotty in cases where lanes may have less than, for example, ten shipments per year. Calculating metrics at higher levels in the network can lead to clearer representations of the observed behavior at the expense of losing specific regional effects associated at the lane.

Figure 6.5 illustrates the range of design possibilities for input probability distributions for transportation planning applications. The more specific the period and network level used in the model design, the greater the required number of empirical or theoretical representations necessary to capture specific behaviors for those levels.

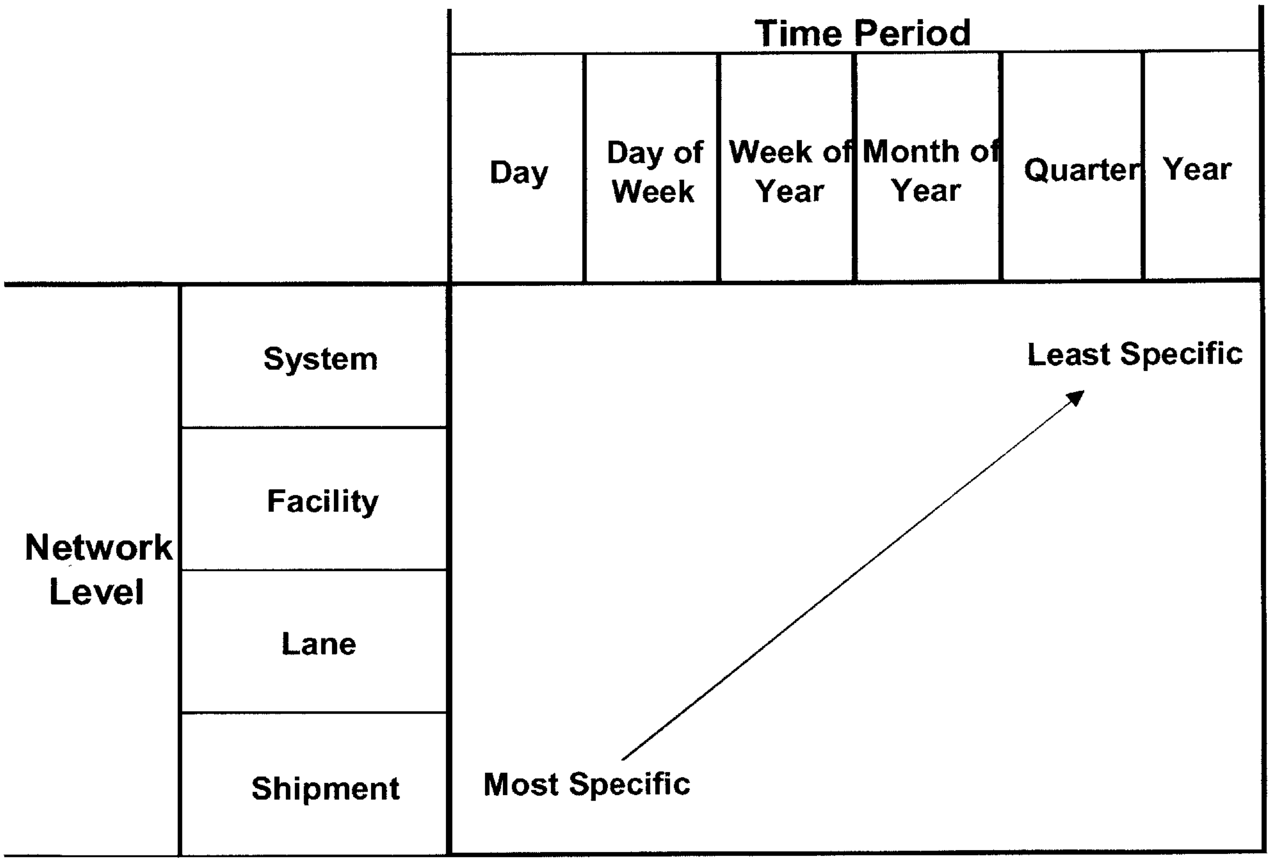

Figure 6.5 Aggregating by Level and Time Period

6.4 Application of Input Probability Distributions to Model Design

Selecting the type of input probability distributions is a key aspect of model design. The model used in this study was defined at the lane network level with a hybrid of periods. Each process will be further defined with observations and limitations as a result of the design criteria. The following matrix describes each process and the design of input probability distribution as defined later in this chapter:

Processes	**Input Probability Design Criteria**			
	Recommended Data Type	**Period**	**Network Level**	**Distribution Type**
Generate Random Demand	Transactional (Shipment)	Week of Year	Lane	Discrete or Continuous
Generate Planned/Unplanned Freight Counts	Transactional (Accept/Reject Data)	Year	Lane	Binomial
Determine Planned Freight Costs	Bid (Assigned Carrier Rates)	Contracted	Lane	Fixed from bid
Determine Unplanned Freight Costs	Historical (Unplanned Shipment Costs)	All Shipment	Lane	Empirical

Table 6.6 Example of mapping input probability distributions to simulation processes.

The processes found in Table 6.6 are defined below with an overview of observations and potential limitations in practice:

Generate Random Demand

Defined as:

$$D_l = \gamma L(P_l) \forall l$$

Where

l : in Lanes

D_l : Random lane volume for lane l in loads per week for one week

L : Continuous or Discrete Distribution with parameters P_l

γ : Growth Factor for Forecasted Planning Period

Observations:

1) Modeling week-of-year volumes at the lane level captures regional effects of seasonality throughout the year.
2) The demand is modeled in the same units as the units presented to carriers in a truckload bid both for available load volumes and capacity.
3) The total number of theoretical distributions required to generate demand are the same as the lane count used in the analysis.
4) Both continuous and discrete distributions are recommended as best-fit solutions depending on the weekly volume of the lane and the characteristics of the volume when theoretical distributions are fitted to empirical data using best-fit software packages.

5) Using empirical distributions limit the model to what has happened.

Limitations:

1) The identification of a range of distributions options will be limited by the amount of automation of goodness-of-fit testing. Prioritization of the best distribution identified for each lane through automation will require additional statistical software to identify the best theoretical input probability distribution. This approach would generate all the necessary parameters and measure goodness-of-fit over potentially thousands of lanes. Empirical distributions can be used to overcome this limitation but are limited to a range within the min and max of observed data.
2) Each run would capture average weekly volume for the year and make calculations at that level versus simulating actual shipments.

Generate Planned/Unplanned Freight Counts

Defined as:

$$VP_l = \max\left[\min\left[N(\mu_l + \alpha, \beta\sigma_l), 1\right], 0\right] \cdot D_l \ \forall l$$
$$VU_l = D_l - VP_l \ \forall l$$

Where
l: In Lanes
VP_l: Planned Freight Counts in Loads Per Week per Lane
VU_l: Unplanned Freight Counts in Loads Per Week per Lane
D_l: Weekly Demand (Generated in Previous Process)
μ_l: Percent of Planned Lane Volume (0..1) for each lane l
σ_l: Standard Deviation of Planned Lane Volume by Week for each lane l
α: Adjustment for Percent of Planned Lane Volume μ (0..1)
β: Variability Factor for Planned Lane Volume (>0)

Observations:

1) Adjustments to the average and variability yields sensitivity to planned and unplanned freight costs calculated in test models.
2) The adjustment factors included in the relationship defined a normal distribution $N(\mu + \alpha, \beta\sigma)$ with mean ($\mu_l + \alpha$) and standard deviation ($\beta\sigma$) and provide a mechanism to alter historical planned accepts at various levels from measuring changes in system-wide carrier market, versus specific cases where a carrier bid can guarantee performance hence improving the ratio of planned or unplanned freight.
3) α and β can be determined by incumbent performance or used to determine the sensitivity of unplanned freight by adding incremental

improvements answering whether or not a 5% increase in accept ratio yields significant savings or does a reduction in variability lead to greater savings.

Limitations:

1) Specific carrier performance can influence historical planned accept information. Calculated an average by year for a lane using historical data may be inapplicable to new non-incumbent carrier bids. Validation and review of individual carrier influences would mitigate cases where poor carrier performance overrides network effects of accept-reject behavior.
2) "Bounded" Normal Approximation likely not best statistical fit for all cases. Further analysis should identify the benefits, or lack thereof, of better approximations.
3) Interactions between planned freight and demand could be further explored with respect to covariance from week to week. This model assumes independent and identical random distributions for all weekly volumes.

Determine Planned Freight Costs

Defined as:

$$CP_l = VP_l \cdot W_{BID} \forall l$$

Where

CP_l: Planned cost per week

VP_l: Planned Freight Counts (Generated in Previous Processes)

W_{BID}: Planned Capacity Weighted Average Cost per Lane by Load from Bids

Observations:

1) Calculates weekly cost for each simulation run based on estimated volume.
2) Bid data would correspond to a particular set of output, there may be many over the course of each bid.
3) Alternatives to a weighted average could be the maximum planned rate where multiple carriers have won a lane (conservative) or the minimum planned rate (aggressive).

Limitations:

1) Weighted average cost assumes that planned freight will follow the capacity provided by the winning carriers.

Determine Unplanned Freight Costs

Defined as:

$$CU_l = \left(f_l\left[U(0,1)\right]\right) \cdot VU_l$$

Where

CU_l = Unplanned Freight Expense by Lane l

$U(0,1)$ = Uniform Random Number

$f\left[U(0,1)\right]$ = Empirical Unplanned Freight Expense Function by Lane l

VU_l = Unplanned Freight Counts per Week by Lane l

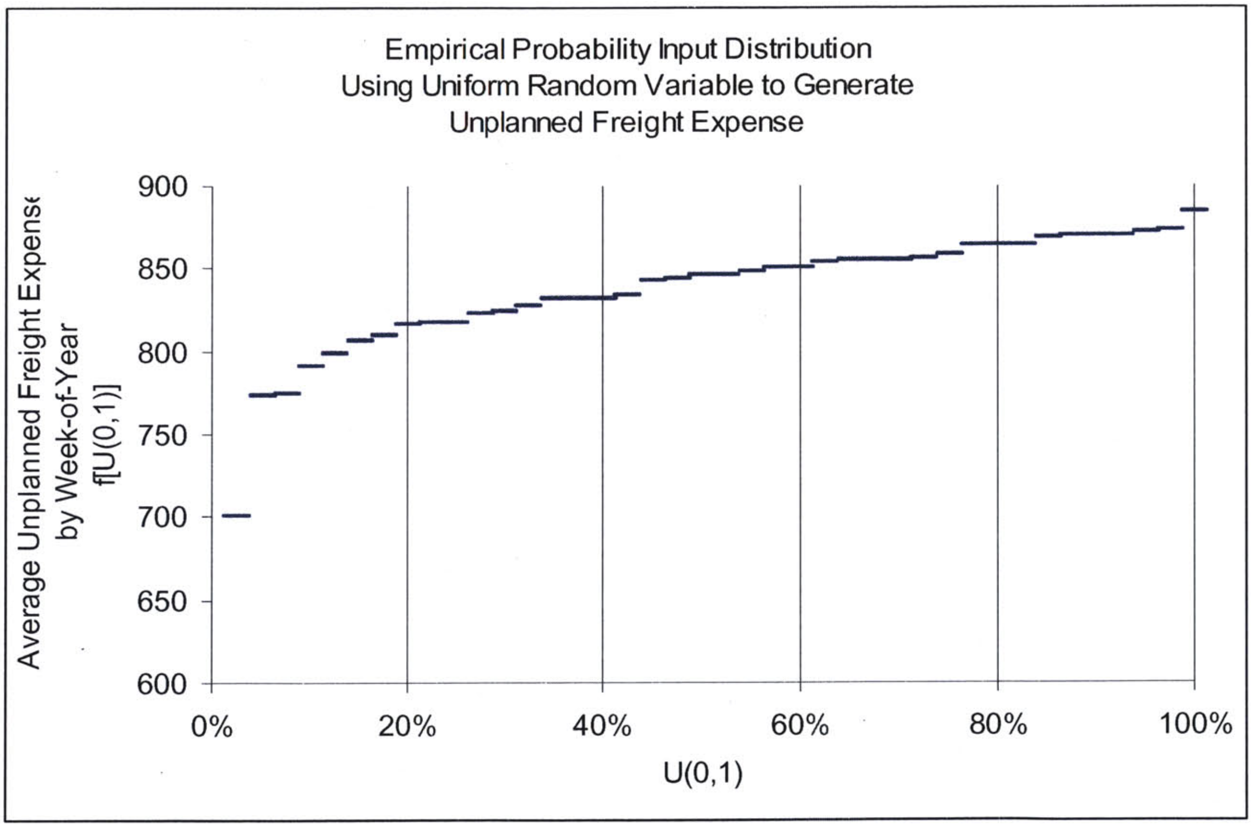

Figure 6.6 Application of Empirical Distributions to Unplanned Cost for a Specific Lane Using Monte-Carlo Techniques

Generating uniform random variables U(0..1) as an index to determine the estimated unplanned costs will yield values that range from \$700-\$875 in the example above. Using this approach for each lane that is simulated will yield values that were obtained in the backup market from the previous period in the percentages that a shipper would expect. The empirical distribution presented in 6.5 indicates that unplanned costs on this lane are less than $825 for 40% of the weeks of the year, less than $850 for 80% of the weeks etc. This is a powerful technique to determine the overall total cost impact when combining the performance of carriers on lanes with fluctuating backup costs.

Observations:

1) Using the average unplanned freight expense per week-of-year limits the range of empirical intervals to a maximum of 52 per n lanes modeled.
2) Using historical data to capture unplanned costs combines the costs associated with the market versus the planned costs in the bid.
3) Opportunities for the addition of non-freight related costs to capture accessorials or charges resulting from non-freight cost related variables.
4) Using backup rates from the bid may provide additional data that could be used in combination with empirical data.

Limitations

1) Averaging unplanned lane costs by week-of-year limit the range of extreme values that shipment data would provide. However, empirical lookups by shipment would yield more computational overhead.
2) Unplanned costs are limited by what occurred historically.
3) This method yields far less empirical calculations for lanes with low volumes since many lanes do not ship every week.

Calculate Total Costs

Defined as:

$$TC_l = CP_l + CU_l \quad \forall l$$

$$\sum_l TC_l = \text{Total Network Expenditure per Week}$$

Observations:

1) Total Cost is calculated for each week
2) Simulation runs should occur many times to determine yearly costs.

   Calculating total cost for a 10 year period of yearly costs would require

   52 x 10 = 520 runs.

The following section will present this design using lane data from CGP-Co.

6.5 Simulation Results

Following the previously defined simulation model from section 6.4, Table 6.2 and 6.3 illustrate the application within a spreadsheet. Demand data was used from actual lanes, unplanned data was estimated for the purposes of illustration but follows observations in practice. Starting from the left, lane demand parameters P_l in estimate normally generated random demand (D_l). In this example Growth (γ) is set to 5% with the Planned Accept Adjustment Factor (α) indicating a 10% improvement. Variability Factor (β) is set to 1 with no effect on the standard Deviation of Planned Accepts (σ). Examining the Historical Percent of Planned Lane Volume (μ) versus the Simulated Planned Lane Volume shows intuitively the random 10% increase. The final two columns indicate average weekly Planned and Unplanned Freight Volumes.

Generate Random Demand				Generate Planned and Unplanned Freight Counts						
Demand Parameters		Growth	Generate Random Demand	Planned Accept Adjustment Factor	Variability Factor (1=Parity)	Standard Deviation of Planned Accept Ratio	Historical Percent of Planned Lane Volume	Simulated Planned Lane Volume Percentage	Planned Freight Volume	Unplanned Freight Volume
P_l		γ	D_l	α	β	σ	μ	$\max[\min[N(\mu_l+\alpha,\beta\sigma_l),1],0]$	VP_l	VU_l
μ_D	σ_D									
1.13	0.34	5%	0.80	0.10	1.00	0.07	0.78	0.90	0.72	0.08
1.60	0.75	5%	1.38	0.10	1.00	0.02	0.38	0.48	0.66	0.72
44.71	49.31	5%	135.70	0.10	1.00	0.00	0.73	0.82	111.52	24.18
49.46	35.07	5%	36.00	0.10	1.00	0.07	0.74	0.85	30.73	5.27
1.78	0.85	5%	1.61	0.10	1.00	0.05	0.80	0.86	1.38	0.23
1.43	0.51	5%	1.20	0.10	1.00	0.02	0.59	0.72	0.86	0.34
1.00	0.01	5%	1.07	0.10	1.00	0.01	0.80	0.90	0.96	0.11
1.08	0.29	5%	1.35	0.10	1.00	0.06	0.35	0.39	0.53	0.82
1.66	0.86	5%	1.50	0.10	1.00	0.01	0.73	0.82	1.23	0.28
1.00	0.01	5%	1.04	0.10	1.00	0.05	0.83	0.95	0.99	0.05
1.15	0.38	5%	0.71	0.10	1.00	0.00	0.87	0.97	0.68	0.02
1.28	0.67	5%	0.84	0.10	1.00	0.00	0.91	1.00	0.84	0.00
2.20	1.18	5%	4.10	0.10	1.00	0.03	0.54	0.66	2.70	1.40
1.00	0.01	5%	1.06	0.10	1.00	0.04	0.89	1.00	1.06	0.00
1.51	0.64	5%	1.72	0.10	1.00	0.02	0.82	0.91	1.56	0.15
2.24	1.77	5%	1.19	0.10	1.00	0.01	0.40	0.49	0.59	0.60
1.00	0.01	5%	1.05	0.10	1.00	0.04	0.17	0.28	0.30	0.76
29.46	35.67	5%	51.08	0.10	1.00	0.07	0.78	0.80	40.81	10.27
1.48	0.51	5%	2.14	0.10	1.00	0.00	0.94	1.00	2.14	0.00
1.42	0.58	5%	1.46	0.10	1.00	0.02	0.97	1.00	1.46	0.00

Table 6.2 Creating Simulated Demand and Estimating Planned Volume Percentages

Once freight volumes are generated, the costs are estimated using data from the optimization output (W_{BID}) and the empirical distributions defined by $f[U(0,1)]$. The column labeled Blended Unplanned + Planned Rate per Load illustrates the impact the ratio of planned to unplanned freight has on the cost of the loads. The final total costs are calculated both with the Total Expected Planned Costs ($D_l W_{BID}$) representing the rates obtained from the optimization software multiplied times total demand representing the "perfect world" scenario of all planned volume at the bid rate along the Total Expected Planned and Unplanned Costs (TC_l). The final column (Expected Increase of Total Cost Over Planned Cost) compares the "perfect world" solution to the simulated costs indicating the percent increase or decrease for the lane..

	Determine Planned/Unplanned Freight Cost						Calculate Total Costs		
Lane ID	Planned Freight Cost at Volume	Unplanned Freight Costs at Volume	Weighted Average Costs from BID [Planned Cost per Load]	Blended Unplanned + Planned Rate per Load based on Planned Ratio	Empirical Unplanned Cost Function [Unplanned Cost per Load]	Uniform Random Number for Empirical Distributions	Total Expected Planned + Unplanned Costs	Total Expected Planned Cost	Expected Increase of Total Cost over Planned Cost
	CP_l	CU_l	W_{BID}		f[U(0,1)]	U(0,1)	TC_l	$D_l W_{BID}$	$TC_l / D_l W_{BID}$
1	$72	$10	$ 100	$ 102	$ 119	0.52	$ 82	$ 80	2%
2	$132	$140	$ 200	$ 197	$ 194	0.50	$ 272	$ 276	-2%
3	$6,440	$1,328	$ 58	$ 57	$ 55	0.29	$ 7,768	$ 7,837	-1%
4	$1,815	$472	$ 59	$ 64	$ 90	0.90	$ 2,288	$ 2,127	8%
5	$356	$57	$ 257	$ 256	$ 250	0.06	$ 413	$ 414	0%
6	$719	$411	$ 832	$ 938	$ 1,205	0.81	$ 1,130	$ 1,003	13%
7	$718	$105	$ 745	$ 767	$ 963	0.93	$ 823	$ 799	3%
8	$173	$358	$ 327	$ 394	$ 437	0.58	$ 531	$ 441	20%
9	$245	$57	$ 200	$ 201	$ 206	0.09	$ 302	$ 300	1%
10	$253	$19	$ 255	$ 260	$ 355	0.69	$ 271	$ 266	2%
11	$85	$5	$ 126	$ 128	$ 192	0.84	$ 90	$ 89	2%
12	$105	$0	$ 126	$ 126	$ 131	0.65	$ 105	$ 105	0%
13	$270	$131	$ 100	$ 98	$ 93	0.08	$ 401	$ 410	-2%
14	$631	$0	$ 595	$ 595	$ 795	0.67	$ 631	$ 631	0%
15	$469	$52	$ 300	$ 304	$ 343	0.35	$ 522	$ 515	1%
16	$59	$74	$ 100	$ 111	$ 123	0.65	$ 133	$ 119	11%
17	$116	$434	$ 390	$ 522	$ 574	0.64	$ 550	$ 411	34%
18	$5,101	$1,387	$ 125	$ 127	$ 135	0.23	$ 6,488	$ 6,385	2%
19	$595	$0	$ 278	$ 278	$ 325	0.38	$ 595	$ 595	0%
20	$406	$0	$ 278	$ 278	$ 293	0.19	$ 406	$ 406	0%

Table 6.3 Determining Expected Increase Over Total Expected Planned Cost

Model Input

Five scenarios were evaluated to determine the impact of unplanned cost by adjusting the amount of planned freight in the network. All lanes were reduced or increased by a fixed amount using the adjustment factor (α) in the relationship defined by $N(\mu_l + \alpha, \beta\sigma_l)$. The net effect of this adjustment on all lanes across the sample network is represented by Average Weighted Planned Accept Ratio. Each scenario was run 520 times using 32 randomly selected lanes with the additional model parameters:

Scenarios	Average Weighted Planned Accept Ratio (32 Lanes)	Growth	Planned Accept Adjustment Factor	Variability Factor (1=Parity)	Standard Deviation of Planned Accept Ratio
		γ	α	β	σ
-20% Lower AR	54%	0%	-10%	1	0
-10% Lower AR	64%	0%	-20%	1	0
Baseline	74%	0%	0%	1	0
+10% Better AR	84%	0%	10%	1	0
+20% Better AR	94%	0%	20%	1	0

Table 6.4 Simulation Scenarios with Adjusted Accept Ratios

Scenarios 1-5 refer to the weighted average of the accept ratios across all lanes starting from worst case to best case: 54%, 64%, 75%, 84% and 94%. 74% represents the baseline accept ratio for the sample.

Figure 6.7 provides more detail on the specific lanes and the adjustments made to the planned accept ratios for each of the scenarios. As indicated, roughly 14 lanes were adjusted to perfect performance and many of the poorer performers were increased significantly.

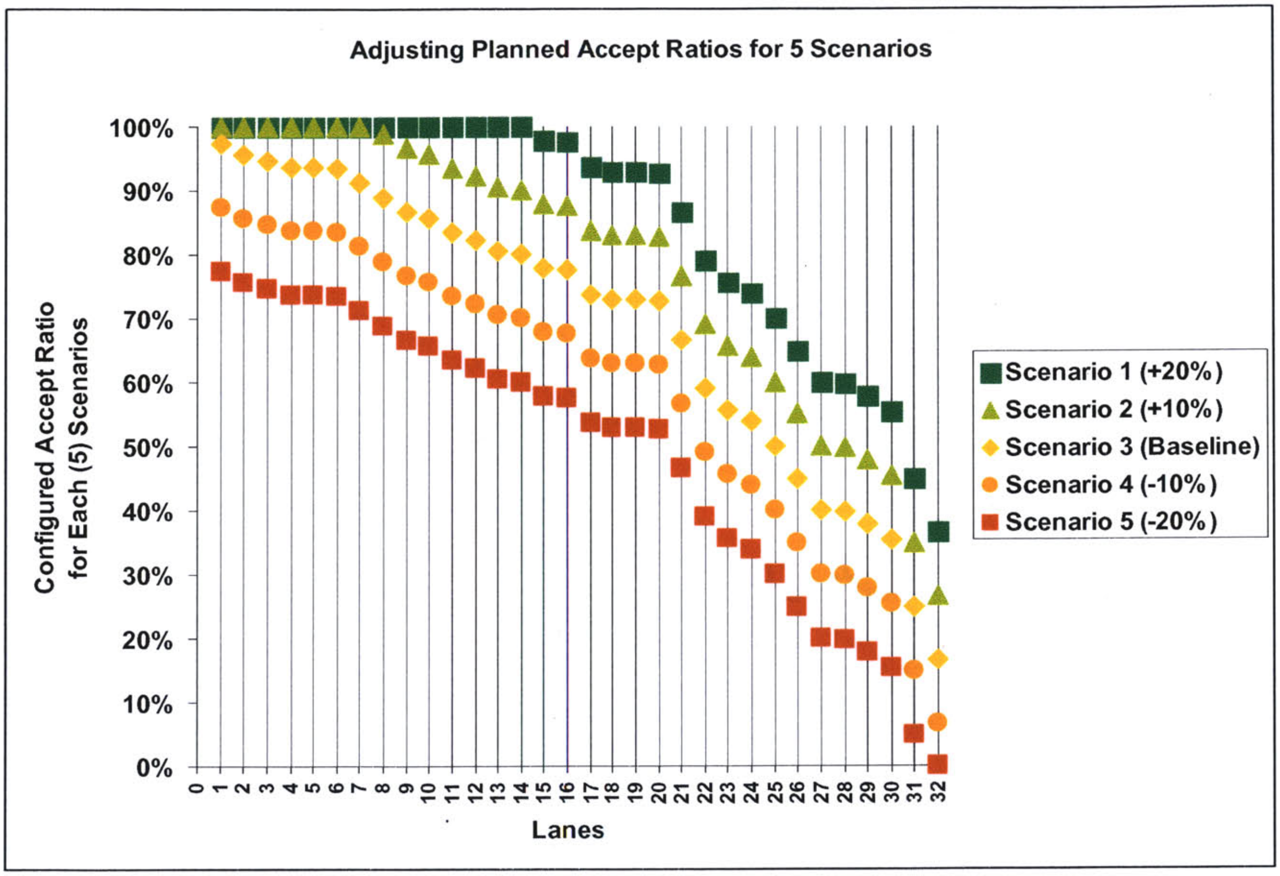

Figure 6.7 Lane Adjusted Accept Ratios for Planned Freight

The empirical unplanned costs were estimated in this study. The values have a significant effect on the output since any volume that is not planned will be subject to the cost profile represented for each lane. Each value in the empirical distribution represents the average weekly cost of unplanned freight for a lane and the values are sorted from lowest to highest for 52 weeks. Table 6.5 indicates how those values compare to the lane bid rate. In many cases, the unplanned rates are less than the planned. Lane 1 indicates that 13% (7/52) of values produced from this function will yield a lower rate than W_{BID}.

Obtaining a lower rate from an unplanned carrier is not uncommon in practice. The values extending from 11-52 were omitted from view. Using a uniform random number to determine which week is used as a reference creates an estimated unplanned cost for each cycle of the simulation run specific to each lane.

	1	2	3	4	5	6	7	8	9	10
Lane 1	94%	94%	99%	99%	99%	99%	99%	104%	104%	104%
Lane 2	94%	99%	99%	103%	109%	109%	109%	109%	109%	114%
Lane 3	98%	98%	98%	98%	103%	103%	103%	109%	109%	109%
Lane 4	93%	93%	93%	93%	93%	98%	98%	103%	108%	108%
Lane 5	99%	99%	99%	104%	104%	104%	104%	104%	104%	104%
Lane 6	96%	96%	96%	101%	106%	106%	111%	111%	111%	111%
Lane 7	95%	95%	95%	100%	100%	100%	100%	100%	100%	100%
Lane 8	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%
Lane 9	86%	86%	86%	86%	86%	86%	86%	86%	86%	86%
Lane 10	87%	91%	91%	91%	91%	91%	91%	96%	100%	105%
Lane 11	96%	96%	101%	101%	106%	111%	111%	111%	111%	111%
Lane 12	90%	90%	94%	94%	94%	99%	99%	104%	104%	104%
Lane 13	94%	98%	98%	98%	98%	98%	98%	98%	98%	98%
Lane 14	97%	97%	97%	97%	102%	102%	102%	102%	102%	102%
Lane 15	97%	97%	102%	107%	107%	107%	107%	107%	107%	107%
Lane 16	87%	87%	87%	87%	87%	87%	87%	91%	91%	96%
Lane 17	85%	85%	90%	90%	90%	94%	94%	99%	99%	104%
Lane 18	99%	99%	99%	99%	99%	99%	99%	104%	104%	104%
Lane 19	88%	92%	92%	92%	92%	92%	92%	97%	97%	97%
Lane 20	91%	95%	95%	100%	105%	110%	110%	116%	116%	116%
Lane 21	92%	96%	96%	96%	96%	96%	96%	96%	96%	96%
Lane 22	86%	86%	86%	91%	91%	91%	95%	95%	95%	95%
Lane 23	94%	94%	94%	94%	94%	94%	94%	94%	94%	94%
Lane 24	89%	93%	93%	93%	93%	93%	93%	93%	98%	98%
Lane 25	91%	91%	91%	96%	101%	101%	101%	101%	101%	101%
Lane 26	88%	88%	88%	88%	92%	92%	97%	102%	107%	107%
Lane 27	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Lane 28	91%	91%	91%	91%	91%	91%	91%	91%	91%	91%
Lane 29	99%	104%	104%	104%	104%	104%	104%	104%	104%	104%
Lane 30	87%	87%	87%	87%	87%	91%	91%	91%	91%	96%
Lane 31	99%	99%	99%	104%	109%	109%	109%	109%	109%	109%
Lane 32	95%	100%	100%	100%	100%	100%	100%	100%	100%	105%
MIN	**85%**	**85%**	**86%**	**86%**	**86%**	**86%**	**86%**	**86%**	**86%**	**86%**
AVG	**93%**	**94%**	**95%**	**96%**	**97%**	**98%**	**99%**	**100%**	**101%**	**102%**
MAX	**100%**	**104%**	**104%**	**107%**	**109%**	**111%**	**111%**	**116%**	**116%**	**116%**

Table 6.5 Ratio of Unplanned to Planned Model Input: Calculating f(U[0..1])/W_{BID} for all Empirical Values.

A summarized view of the range of values across all lanes provides a network-wide perspective of the range of unplanned rates used in the simulation. Later in the chapter this view will also be helpful in determining the efficient frontier. Figure 6.8 presents calculations for the minimum, average and maximum values of the lowest unplanned freight ratio which is represented at the bottom of column 1 in Table 6.5 as 85%, 93% and 100% respectively across the 32 lanes presented. Figure 6.8 illustrates this relationship across the lowest amount for unplanned freight (Column 1) and the highest (Column 52) for all lanes.

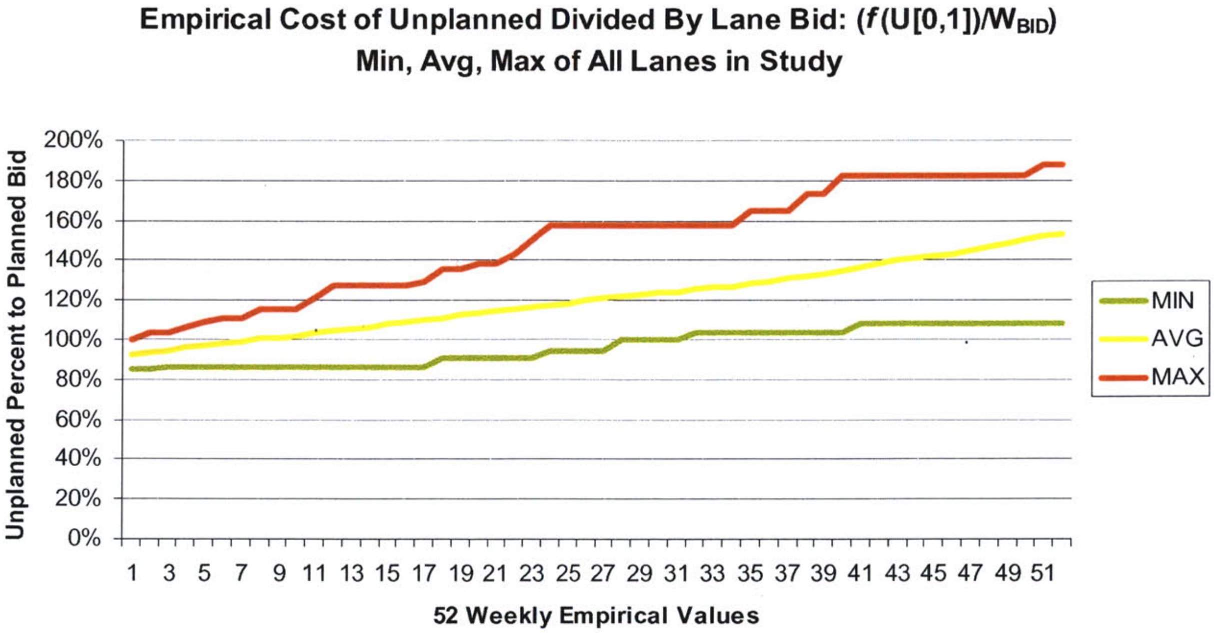

Figure 6.8 Ratio of Empirical Estimates to Weighted Bid Rates

Revisiting the Efficient Frontier

Estimating reasonable output values of the simulation can be made using the methods presented in section 4.2. Recall that the "Percent Over Planned Freight Expenditure" (*X*) is given as:

$$X = \left(\frac{U}{P} - 1\right)(1\text{-}A)$$

Where

X : Percent Over Planned Freight Expenditure

A : Planned Accept Ratio (0-100%)

U : Unplanned Cost

P : Planned Cost

The ratio of the cost of unplanned freight $\left(\frac{U}{P} - 1\right)$ is calculated based on the empirical values (see Figure 6.9) used for the sample network. A 20% increase over planned freight expense was calculated by taking the average ratio of all unplanned freight to the respective planned freight for each lane. The arrows represent the average of all lanes (not weighted by volume).

Solving for each scenario yields:

$$X_{54\%} = (0.2)(1\text{-}0.54)\text{=}9.2\%$$
$$X_{64\%} = (0.2)(1\text{-}0.64)\text{=}7.2\%$$
$$X_{74\%} = (0.2)(1\text{-}0.74)\text{=}5.2\%,$$
$$X_{84\%} = (0.2)(1\text{-}0.84)\text{=}3.2\%$$
$$X_{94\%} = (0.2)(1\text{-}0.94)\text{=}1.2\%$$

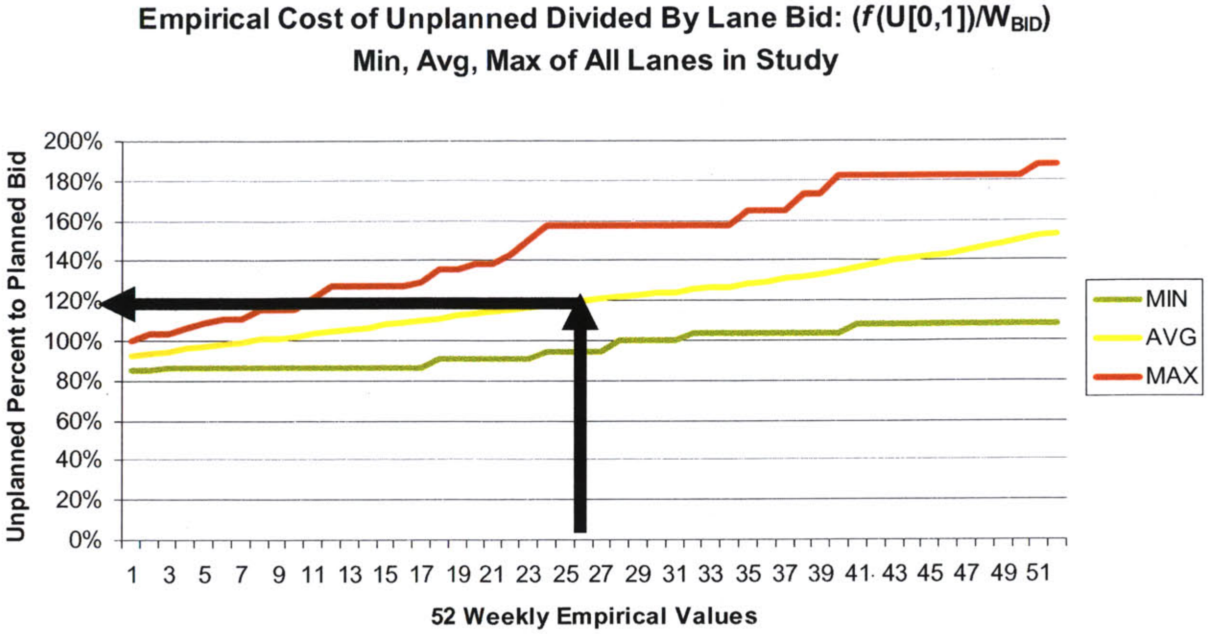

Figure 6. .9 Calculating Average Unplanned to Planned Cost Ratio

Generating Results

Each scenario was run 520 times estimating 10 years of weekly activity. The results are presented in Figure 6.10 as the "Percent Over Planned Freight Expenditure".

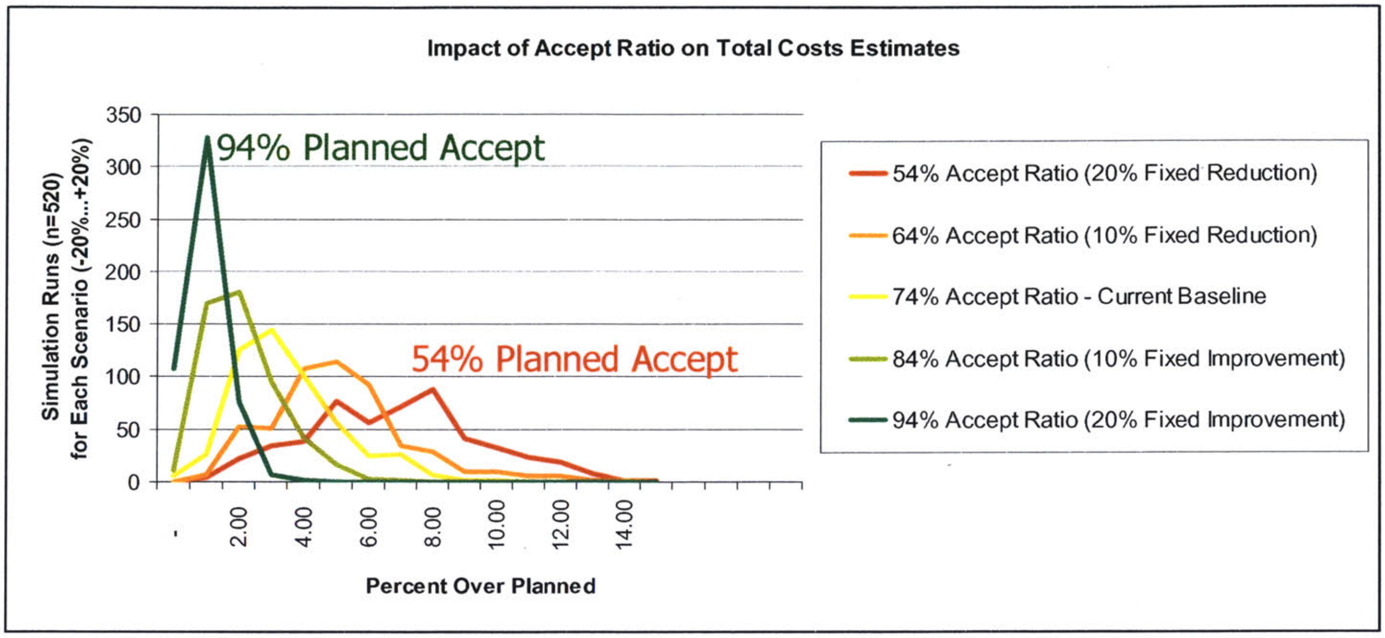

Figure 6.10 Simulation Results for Various Planned Accept Ratios

Figure 6.10 illustrates the impact on total cost as a function of accept ratio for planned freight. As the planned accept ratio increases, the variability and additional costs both decrease. The results indicate that the unplanned rate structure has a significant impact on the variability of total costs. The greater the amount of freight that is determined by the unplanned rate structures, the broader range of possible outcomes even though the average is roughly 7%.

The unplanned rate structure used in the model was the same for every run and the results suggest that lower accept ratios for planned freight have not only a significant impact on freight expense but also on the variability of the results. Figure 6.11 shows the same information presented in terms of the variability of the output represented in (+/-) 1,2,3 standard deviations from the average. Not only are shippers at risk of paying more when accept ratios are low, but the range of possible outcomes is much wider as a result of the amount of unplanned freight that occurs over the planning period, hence more risk to overages.

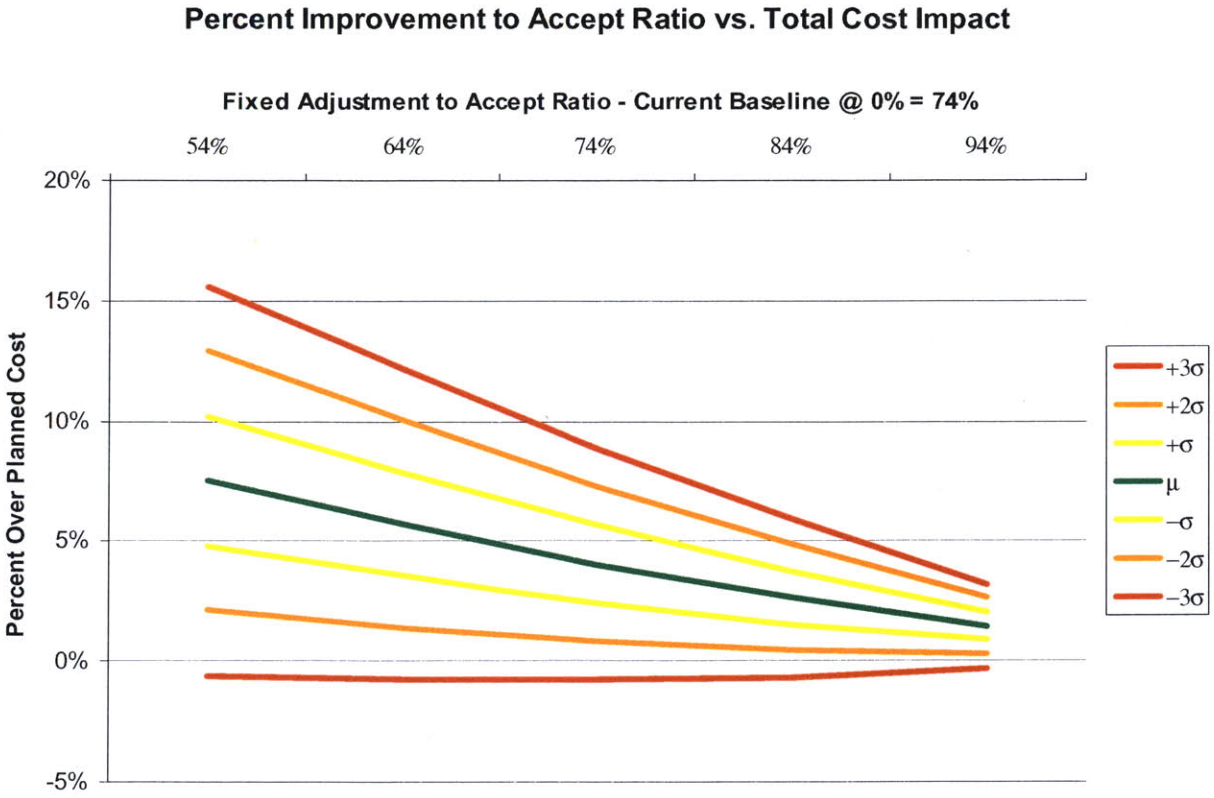

Figure 6.11 Accept Ratio and Variability of Results

Undocumented scenarios were generated adding variability in accept ratios with no significant changes in the results indicating that the variability in accept ratio is much weaker in terms of impact on total costs and that unplanned freight expense and the severity in which it occurs is the overriding factor in driving additional freight expense.

Results and the Efficient Frontier – Litmus Test for Opportunities

Figure 6.12 and Table 6.6 below compare the theoretical values of "Percent Over Planned Freight Expenditure" to the corresponding values from the simulation. The simulated relationship of accept ratios and unplanned freight supports the notion that the combination will impact freight expenditure.

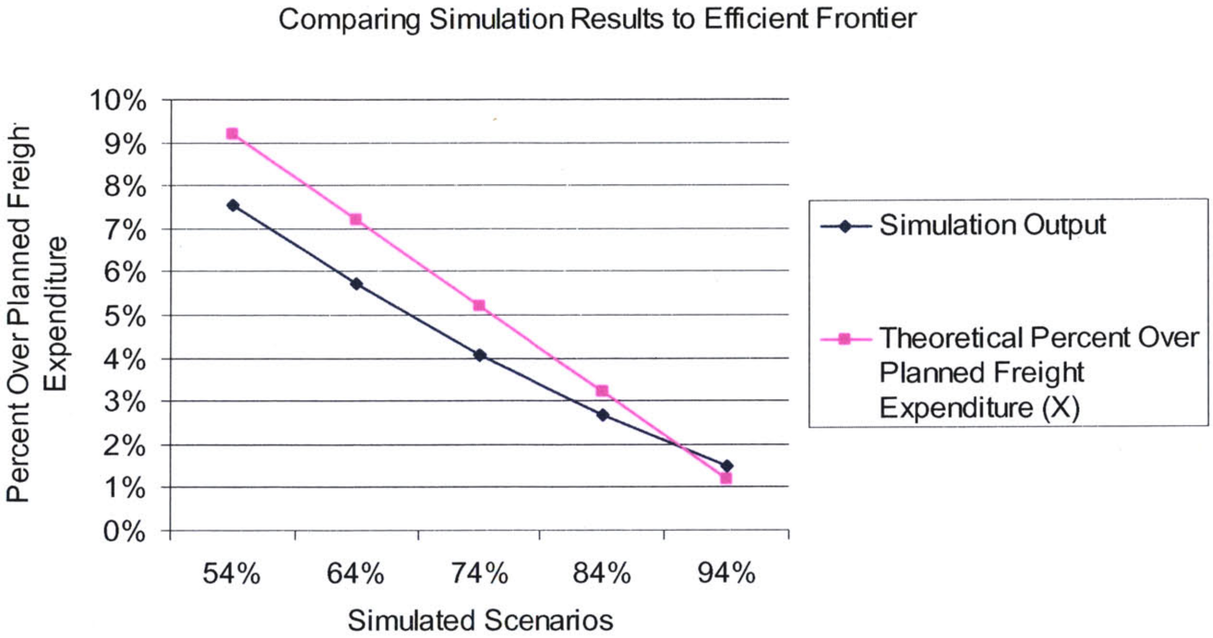

Figure 6.12 Percent Over Planned Freight Expenditure: Comparing Theoretical and Simulated

Planned Accept	Simulation Output	Theoretical Percent Over Planned Freight Expenditure (X)
54%	7.5%	9.2%
64%	5.7%	7.2%
74%	4.1%	5.2%
84%	2.7%	3.2%
94%	1.5%	1.2%

Table 6.6 Percent Over Planned Freight Expenditure Raw Data

What can be inferred from the simulation output that is useful to the decision maker? Understanding the relative cost impact of a single point increase in accept ratio is important when making trade-offs between carriers and rates when measured performance exists. Simple regression analysis on the simulation results evaluating the "Percent Over Planned Freight Expenditure" (POPFE) as a function of Planned Accept Ratio yields the following relationship based on the simulation output:

$$X' = 0.155 - 0.151A'$$

Where

X' : Simulated Percent Over Planned Freight Expenditure

A' : Simulated Planned Accept Ratio

Extending this to a benefit per point accept ratio can be extended by taking the slope (15.1%) and diving by 100 yielding an estimated 0.15% reduction for every percent improvement in planned accept ratio. Extending this to the total freight expense at \$1.87MM yields \$2,829 per percentage point improvement on the planned accept ratio. Not much for a small sample of lanes, but most network wide bids are in the range of \$100-500MM/year. Extending this formula to a much larger amount such as system-wide value in the range of \$200MM per annual freight expense yields roughly \$300K total cost reduction for every percentage point improvement of planned accept ratio. A ten-point improvement would be equal to \$3MM in cost savings based on the assumptions presented in the study. If, for example, the additional rate increase necessary to achieve this level of performance is \$1.5MM in price premiums to the carrier base, the shipper pays more up front but keeps 50% of the benefit assuming sufficient controls in execution to monitor performance. Simulation analysis in this context provides decision makers the focus necessary to control freight expense and make decisions that are counter-intuitive and reduce total cost.

The usefulness in the simulation can also extend beyond "back of the envelope" calculations by providing results that can be integrated back into the optimization. The following section proposes ideas on integrating the results into developing more robust transportation plans.

6.6 Linking Simulation to Optimization

The following expands on the process of developing a simulation model to include updates back to the optimization model:

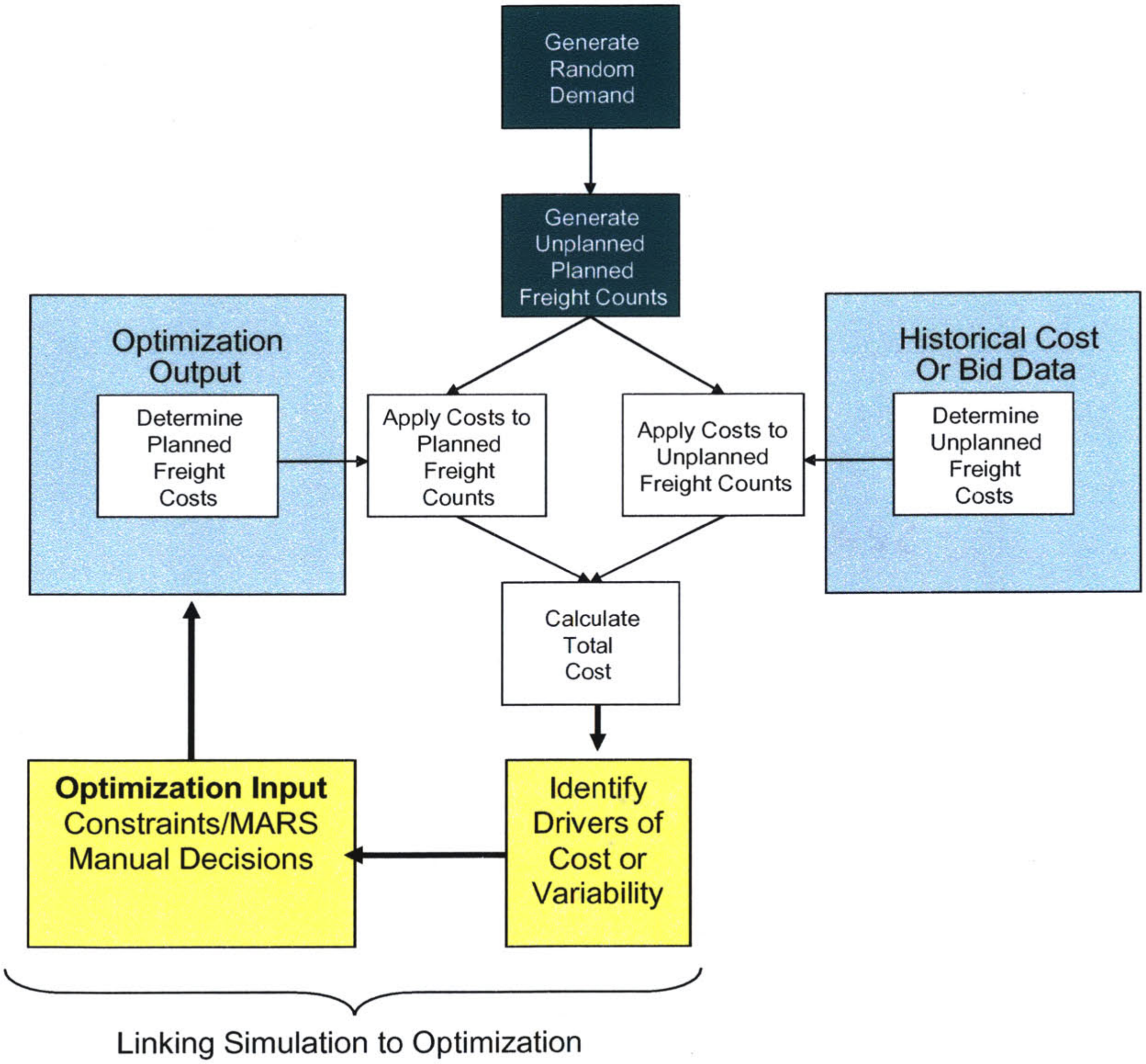

Figure 6.13 Simulation Interface with Optimization

Applying simulation output to the inputs of the optimization software can be performed in one of three ways:

1) Manually: Total cost impact could be used to evaluate the trade-offs of higher cost better performing carriers manually eliminating rates from consideration in the model. This is consistent with the existing processes that shippers employ in determining which rates are worthy of being considered for additional optimization scenarios. It is a part of the initial screening that is performed prior to more detailed evaluation of the bids.
2) Automated: Side constraints or MARS could be used to reformulate the optimization model where variability drives excess costs. Similar to the techniques proposed in Chapter 5, these data would support the application of focused capacity constraints or rate adjustment to narrow in on key providers. Simulation results supporting this approach this range from lanes that have a high CV of total estimated costs to lanes with poor responsiveness from carriers. These adjustments could be focused on 10-20% of the network were volume impacts large values in total cost CV or where better responsiveness would reduce total cost.
3) None: The simulation assesses the impact of unplanned costs based on the optimization validating more or less robust designs. Comparing results and being able to communicate that the projected freight budget will be within a range of values versus a point value is more in line with what actually occurs and could be used to make better supply chain decision with these ranges in mind. Also, using

this as a management tool also trains staff to think of variability as a source of vulnerability (or opportunity) as it applies to cost overruns.

Further research and applications in practice will yield the best approach.

7 Conclusion

Can shippers and carriers benefit from more robust planning methodologies? Based on the framework defined in this thesis, it appears so. Shipment data is helpful in stratifying carriers with various metrics, accept-reject data can quantify responsiveness for planned and unplanned volume and tools such as optimization can be more focused in the applications of MARS and capacity constraints. In addition, simulation can be applied to a the problem to test the robustness of optimization output and shippers can estimate the potential benefit using simple techniques to determine if the further effort is worth the effort.

The irrefutable proof that benefit can be obtained will lie with the future applications that shippers eventually develop and apply. Technology is seldom an independent solution. This thesis lays the groundwork for future research by focusing on areas that have been a source of difficulty for shippers when making trade-offs between carriers during procurement events (Harding 2005).

The benefits from robust planning methodologies are not complete without a brief mention of its relationship to execution. Frequent execution-level performance measurement is a key aspect in maintaining controlled costs. If a justifiable premium should be paid to a carrier who has better performance, then that premium sould be contractually obligated. Performance systems which monitor the planned and unplanned freight costs as a result of carrier responsiveness, is the means to manage their commitment. Performance reviews with carriers would determine the continuance of premium pricing based on the status of unplanned costs. Without this approach, where to apply premiums, and the level of premium is unknown.

A soft benefit which has great importance is the understanding that non-transportation professionals will obtain as a result of this analysis. It is not uncommon for other areas of an organization to view transportation expense as a commodity, or something that can be purchase using buying strategies fit for other areas of the organization such as MRO inventory or direct materials. Understanding the trade-offs between low rates, poor performance and the impact on total costs is not an idea that is widespread for non-transportation professionals (in the opinion of the author). This type of analysis provides rigorous methods at an engineering level to justify not choosing the lowest rate, but also enable a strategic level of inter-company relationships between shipper and carrier with the promise of tangible rewards. Communicating this effectively within the organization will deepen the understating of the challenges with transportation, but also bring to light the sources of variances that can leave financial departments wondering, “what is happening with the freight budget?” throughout the year,

Within the academic community, analysis techniques including Value at Risk (VaR), Real-Options, Monte Carlo Simulation and Portfolio Management, considered predominately as financial tools, are now working their way into the practice of supply chain management and other non-financial projects. The methodology presented in this thesis is an early step toward using new techniques with the goal of addressing risk as it applies to robust transportation planning; and it should be considered a development in response to business environments that are rich with data, but less so with usable information.

Future Research

This work is by no means complete. Further research should focus on the application of the tools and techniques presented in this thesis to assist decision makers with the arduous task of establishing new contracts. The timing of this work and the data intensive requirements to develop an initial definition of a framework did not permit application in a real world setting. The following are areas that would have been pursued if more time were allotted:

1) Minimum data requirements to develop robust plans. The data requirements to apply this approach are significant, and the level of interaction with a shipper required to clean data and coordinate efforts with optimization software processing requires additional time and cost. Do aggregation levels and time periods yield better designs? Do these designs create computationally large problems that take too long for results?
2) Validation of assumptions in designing a robust plan. This work should be tested and validated in a real world setting.
3) Incorporation of other costs associated with unplanned shipments. Line-haul costs are much easier to quantify, but true supply chain costs associated with high impact, low probability events would yield interesting results with respect to events such as terrorist attacks, port congestion or extreme weather.

4) Carrier view of load acceptance. Understanding the elements of the carrier's decisions to accept loads could be better understood. Is it driven by profitable rates alone? Do strategic relationships play a role in driving responsiveness at lower than market prices? Or, does demand variability create the majority of the issues for carriers? In any case, there are barriers to carrier responsiveness that need to be well understood if methodologies are to be effective.

5) Carrier view of capacity levels. Do carriers want more or less consistent demand patterns and can the robustness be linked to the shipper's ability to provide a more exacting demand pattern to the carrier?

6) Shipper service standards. What are the benchmarks for planned accept-ratios? Do they vary by industry, or carrier-base. What are the drivers?

There is no question that technology is changing the way companies do business. However, the ability to capture detailed information of complex interactions does not change internal practices alone. New methodologies take time to develop and it is clear that as more technology is employed, new uses of the information gathered within enterprise systems will drive innovative applications.

Building on the power of optimization software, execution systems will be the sources of information that synthesize data into more robust decision support. However, more important than new quantitative methods are its uses in developing strategic partnerships. Moving shippers beyond the memory of the last late delivery and extending their carrier management functions into developing more productive relationships is the ultimate goal.

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