The Impact of Fuel Price Volatility on Transportation Mode Choice

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ABSTRACT

In recent years, the price of oil has driven large fluctuations in the price of diesel fuel, which is an important cost component in freight logistics. This thesis explores the impact of fuel price volatility on supply chains by examining the sensitivity of decisions under various scenarios. Specifically, we analyze the transportation mode choice decision between truckload and intermodal (truck combined with rail) transportation using a model to calculate the total relevant cost, consisting of transportation cost and inventory holding cost. We use input from the North American operations for a global retail company regarding annual demand, product characteristics, load size, lead time, transportation rates, fuel surcharges, inventory policies and holding cost to perform sensitivity analysis of the mode choice decision to fuel price and the value density of the product. For several origin-destination pairs we identify the diesel price at which intermodal offers lower total cost than truckload as well as the magnitude of savings that can be achieved by switching modes. We then generalize the insights from this case by providing an equation to calculate the fuel price for this mode choice tradeoff.

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1. Introduction

1.1. Motivation

Setting up an efficient supply chain is a complicated and costly task – one that requires the full cooperation from all players involved from the factory all the way through to the retail store. Dynamic market conditions in the global economy only make this goal harder to achieve, especially in environments such as recent times with crude oil and the resulting fuel prices varying with such magnitude that many supply chain organizations had to re-think their transport operations.

This research explores the impact of this volatility, specifically considering the transportation mode choice for a US retailer, analyzing which key factors have the biggest impact on logistics cost decision and the best supply chain process. The selection of transportation mode is more complicated when facing dramatic changes in price of crude oil and diesel fuel. For our research, we will look at the impact of fuel price on total logistics costs in order to provide insights to optimize short-term decision making based on a mathematical model.

The first section gives background of the elements that are relevant to cost functions to build a model used to calculate total logistics costs. We will examine the impact of various factors to explain the tradeoff point between cost savings on different modes of transportation, specifically truckload and intermodal (truck combined with train).

The next section is a case analysis of a global retailer, where we analyzed their current supply chain system in the US. We built a total logistics costs model, which takes into account inventory holding cost and transportation cost considering fuel surcharges for both truckload (TL) and intermodal (IM). We ran several sensitivity analysis based on value density (value-to-weight ratio, i.e. $/lbs), diesel fuel price, and utilization, trying to find the tradeoff point at which it made sense for the company to change modes of transportation for cost optimization, focusing on seven major cities where products are sold and study those lanes..

1.2. Problem Description

Our research focuses on transportation mode choice in logistics managements in order to provide optimized solution to minimize the costs. Hence we explore the factors that affect the mode choice decision and build a model including transportation cost and inventory holding cost. The questions in our research to discuss are as follows.

What are the key factors which affect the mode choice? How much cost savings can be achieved by switching transport mode? What is the tradeoff point of fuel price at which truckload cost (TL) and intermodal cost (IM) have equal cost? What is the tradeoff point of value density of product at which truckload cost (TL) and intermodal cost (IM) have equal cost? How can we induce the effect of fuel price on the total logistics costs?

1.3. Terminology

Modes of Transportation : Supply chains use a combination of the following modes of transportation: Air, Package carriers (such as FedEx, UPS and the U.S Postal Service), Truck, Rail, Water, Pipeline and Intermodal. This thesis focuses on truck and rail, though the insights can be generalized to selection between any modes where one offers lower cost but also longer lead time (and higher inventory cost).

Intermodal freight transport : movement of goods in one and the same loading unit or vehicle by successive mode of transport without handling of goods themselves when changing modes (European Conference of Ministers of transport, 1997). In this thesis, we focus on intermodal transport with truck drayage to rail for long haul.

Value density : Value per demand unit. In this thesis, we use COGS (cost of goods sold) per weight ($/lb).

Phase 1. Comprehensive Exploration

Motivation
Problem definition
Terminology
(Chapter 1)

▼

Literature Review
(Chapter 2)

Current challenges
Framework of mode choice
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Phase 2. Modeling

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-Total logistics cost model
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Base Scenario
Fuel Price
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▼

Conclusion
(Chapter 5)

Table1. Thesis Structure

2. Literature Review

This section provides an overview of the literature related to our research. First, we present current challenges in transportation mode choice of logistics management. Second, we review frameworks and methodologies used in previous publications. Third, based on this review we try to draw attention to the context of our research and position our research in the academic field and explain the contribution of our research.

2.1. Current challenges in transportation mode choice

Transportation mode choice is an important decision to logistics managers. It often involves many attributes and tradeoffs between cost, time, service level, carrier performance, carrier reliability and so on. Furthermore, with many issues such as the global economy, volatility of fuel price, growing concerns for the environmental impact of transportation and many others, this transportation mode choice decision becomes more complicated.

Meixell and Norbis (2008) identify five logistics challenges that influence transportation mode choice by reviewing a selection of 48 papers for last 20 year span that consider capacity shortages, international growth, economies of scale, security concerns and environmental and energy use concerns.

Byrne (2004) discusses the impact of fuel price on the rate of motor carriers while considering service, tighter hours-of-service regulations, driver shortages, and higher tolls. Meixell and Norbis (2008) discuss that international growth is an important challenge because global transportation from factories to markets yields higher cost and longer transit times. In many cases, these challenges are alleviated by the participation of third-party logistics services and partnership arrangements (Wisner, 2005; Ireton, 2007). They also address examples such as providing adequate transportation and storage, getting items through customs, delivering to foreign locations in a timely fashion at an acceptable cost. Caplice and Sheffi (2003), Esper and Williams(2003) and Moore et al (1991) discuss economies of scope referring to empty backhauls and present shipment size is a relative topic. Voss et al. (2006) address that security is a new criteriafor carrier selection. Bennett and Chin (2008) performed quantitative analysis of security container scanning and showed that cost and delay implications may be less severe than industry anticipated.

A growing concern over the environment and energy use are addressed in the papers to reduce carbon footprints and excess packaging (Harvery, 2007; Neff, 2007), air pollution, acid rain and noise (Coyle et al, 2006; Srivastava, 2007). Andrieu and Weiss (2008) examine the tradeoffs between carbon footprint, cost, time and risk with case studies to provide an optimized solution of mode choice and network architecture.

Our research focus on the impact of fuel price on mode transportation mode choice and considers shipment size impact on the total logistics costs (through economies of scale). In addition, we suggest the value-to-weight ratio (value density) of a product and fuel price as a criteria of mode choice decision.

Challenges	Approaches
Transportation capacity shortage	Attribute identification
International growth	Decision process
Economies of scale and scope	Supply chain integration
Security concerns	
Environmental and energy use	

Table 2. Current challenges in transportation mode choice (Source : Meixell and Norbis, 2008)

2.2. A framework for the mode choice

In mode choice research, survey methodology, mathematical modeling (Meixell and Norbis, 2008) and scenario analysis have been widely used (Andrieu and Weiss, 2008).

First, the survey methodology usually is used to examine attributes of transportation mode to make a good decision. Bagchi et al. (1987) found four attributes for mode choice by questionnaire: rate, customer service, claims handling/follow-up and equipment availability/service flexibility. McGinnis (1990) reviewed the carrier attribute literature before and after deregulation of the transportation industries in the 1980s and found six factors to mode choice: freight rates, reliability, transit time, loss/damage/claims, processing/tracing, shipper market considerations and carrier considerations. Gibson et al. (1993) found that shippers and carriers choose to form a long-term alliance instead of the traditional transaction-based relationship and they focus on partnership. In this relationship, shippers ranked cost, effectiveness and trust as most important; and carriers ranked trust, effectiveness and flexibility as the top attributes. Evers et al. (1996) focus on how perceptions of a mode in general influence for a logistics manager on mode choice decision without an economic analysis. They found that timeliness and availability are top attributes, suggesting that carriers can reduce misconceptions by focusing on these two factors.

Second, mathematical models to calculate the total logistics costs are used to find an optimized of mode choice decision. Sheffi et al. (1988), Mehta (2006) and Chopra (2007) developed a mathematical model to calculate the total logistics costs as the sum of transportation, safety stock, and in-transit inventory costs. Mehta (2006) illustrated that while diesel price, equipment maintenance, inventory holding costs and lead time affect mode choice decisions to varying degrees, truck driver wages are most likely to have a strong impact on total logistics costs. He addressed the shortage of qualified truck drivers that is anticipated over the next ten years will likely strain supply chains.

Third, scenario analysis is used to determine transportation mode (Khoo et al, 2002) and optimal network design. The authors compare optimized base model with various what if scenarios and analyzed them.

For our research, we develop a quantitative model to be able to predict the sensitivity of transportation mode choice to the changes in various factors, such as the fuel cost, lead time, value density and shipment size. We also analyze what if scenarios with various changes to provide insights in decision making of mode choice.

Research Framework
Survey methodology
Mathematical model
Scenarios analysis

Table 3. Framework method summary

2. 3. Context and contribution of our research

Our research draws from recent fuel cost volatility, caused by the sharp increase in the crude oil in 2005 and 2006 and the subsequent decline. We consider its impact on the transportation mode choice, a key decision for logistics managers. Global supply chain and international trade makes transportation more complicated and important because transportation is a significant component of the costs incurred in total logistics. Since fuel cost contributes to truck and rail rates by 12% and 16% respectively (Mehta, 2006) and we should keep an eye on the volatility of fuel cost and tactically review mode decisions to minimize the total logistics costs.

We focus on the short-term decision of mode choice to obtain economical logistics cost and develop the mathematical model. We determine the total logistics costs as a sum of transportation costs and inventory holding costs based on previous research. Among various factors, we put importance on value density and fuel cost which impacts on inventory holding costs and transportation costs respectively. Value density means value-to-weight ratio and COGS (cost of goods sold) per weight. Transportation decision should consider of trade off between time and cost characteristics, and value density is important because it affects the inventory holding cost differential resulting from different lead times for various modes. For higher value density products, longer lead times more dramatically increase the inventory holding costs than for lower value density products. It is the same logic behind the justification to use expensive air freight and frequent shipments for high value density products in order to reduce inventory cost. For high value density products, the longer lead time for less expensive modes means more inventory holding costs that can outweigh the cost saving from transportation. Therefore to examine tradeoff between transportation costs and inventory costs, we look at fuel cost as a component of transportation costs and value density as a component of inventory holding costs.

The contribution of our research is to investigate the component of total logistics costs and each component's effect on the total logistics costs in order to be sensitive in changes of various factors in transportation mode choice. By quantitative modeling and analyzing the what-if scenarios, we can provide the insights in selecting modes in the current environment of fuel cost volatility.

3. Methodology

To analyze the mode choice decision in our thesis, we built an excel model taking into account all relevant factors such as fuel costs, transportation rates and inventory holding costs of in-transit stock and safety stock – resulting in total annual logistics costs. With this model we made some general assumptions (see Table 1 lists), as well as integrated real information from a retail company along with current fuel prices.

We ran an array of analysis primarily focusing on the key factors of the mode choice decision:

- Value density
- Fuel price
- Load size

We ran two different cases: without safety stock and with safety stock. First we looked at base scenario of current supply chain to compare the total costs of truckload (TL) and intermodal (IM) and looked at cost savings by mode shift. Second, we calculated the fuel price incorporating fuel surcharge, at which total relevant cost of truckload and intermodal are equal - this is the tradeoff point where the optimal mode switches. Third, we also determined a similar tradeoff point for product value density, given various fuel prices ranging from \$2/gal to \$5/gal. In our last scenario, we looked at load size and determined its impact on the tradeoff point of fuel price.

Case Study

M&E[1] corp. is a global retailer with two primary product lines, which we classify as high value and low value products with respect to product weight. For this analysis, we focus on M&E's North American distribution to stores. M&E currently runs a highly centralized distribution system with the Midwest US as its point of origin for distribution to stores. All inbound goods are shipped to the central warehouse via air, water and land transportation. From there, the finished goods are transported by ground (truckload or intermodal) in consolidated cargo loads that mix product categories. To focus the study, we looked at seven key destination cities for goods shipped from the central warehouse, as listed in Table 4 below. These cities were selected in cooperation with the company because they are the most viable lands for intermodal transport at this time.

Jacksonville, Florida	JAX
Orlando, Florida	ORL
Miami, Florida	MIA
San Antonio, Texas	SAT
Denver, Colorado	DEN
Los Angeles, California	LAX
Seattle, Washington	SEA

Table 4. Seven cities

[1] This case was prepared by Michael Nsiah and Eun Hie Kim (M&E) with the cooperation of a global retail company. Data in the case retain key relationships that represent operations at the time this thesis was written, but the company name and proprietary information have been disguised.

3.1. Objective Functions

The objective function of our research is to examine total relevant costs (TRC) in the different possible scenarios. TRC is comprised of two influential factors, transportation costs (T) and inventory holding costs (I). We present these equations in the more general form of a Fast mode (F) and Slow mode (S), which in our case study represent truckload and intermodal but could extend to other mode choice decisions such as air vs. ocean.

$$\mathbf{TRC = T + I}$$

- **Transportation costs (T)**

  $= \text{cost per mile} * \text{miles from DC i to destination j} * \frac{\text{Annual Demand}}{\text{Load size}}$

  i) Fast mode : $T_F = c_{ij,F} * d_{ij} * \frac{D}{Q} = (b_{ij,F} + (\frac{f_C - f_B}{0.06}) * 0.01) * d_{ij} * \frac{D}{Q}$

  ii) Slow mode: $T_S = c_{ij,S} * d_{ij} * \frac{D}{Q} = (b_{ij,S} + (\frac{f_C - f_B}{0.06}) * 0.0075) *$

  $d_{ij} * \frac{D}{Q}$

- **Inventory holding cost (I)**

  = (in-transit stock + safety stock) * inventory holding cost % * value density

  i) Fast mode: $I_F = (\frac{D}{365} * t_{ij,F} + \frac{D}{365} * t_{ij,F} * \frac{1}{2}) * r * v$

  ii) Slow mode: $I_S = (\frac{D}{365} * t_{ij,S} + \frac{D}{365} * t_{ij,S} * \frac{1}{2}) * r * v$

Abbreviations	Meaning
$c_{ij,F}$	Cost per mile from DC i to destination j for Fast mode(F)
$c_{ij,S}$	Cost per mile from DC i to destination j for Slow mode(S)
d_{ij}	Distance from DC i to destination j
D	Annual Demand
Q	Load size
$b_{ij,F}$	Base cost per mile of Fast mode(F) at diesel price of f_B
$b_{ij,s}$	Base cost per mile of Slow mode(S) at diesel price of f_B
f_C	Current Diesel price
f_B	Base Diesel price for cost per mile rates
$t_{ij,F}$	Lead time from DC i to destination j for Fast mode(F)
$t_{ij,S}$	Lead time from DC i to destination j for Slow mode (S)
r	Inventory holding cost percentage
v	Value density, value per demand unit

Table 5. Notation for TRC Calculation

3.2. Assumptions and Parameters

This model is based on several assumptions that are summarized in Table 6. Further discussion of each assumption follows in the sections below.

1. **Deterministic demand-** For the purpose of the mode choice decision we assume demand to be given.
2. **Load size-** We vary the parameter for the typical size of a transportation load.
3. **Inventory holding cost-** Based on discussion with the company we use 17% of the value of the product as the cost of carrying inventory.
4. **Lead time-** We assume intermodal lead time is one day longer than the lead time for truckload, which varies according to destination.
5. **Safety Stock-** To simply the model, we assume safety stock is half of demand over the lead time of transport to final destinations. We also run scenarios where safety stock is not included.
6. **Value Densities-** This is the cost of the goods sold per unit of weight. We use the following values: High Value = $35/lb., Low Value = $3.50/lb.; Typical Load = $24.11/lb. given the observed load mix of High Value (65%) and Low Value (35%) products.
7. **Transportation Cost-** Truckload rate varies by destination; and Intermodal rate is 80% of truck rate.
8. **Fuel surcharge-** For every 6¢ increase (decrease) in the base diesel fuel price ($/gal):

   -Truckload rate is increased (decreased) 1¢ for fuel surcharge

   -Intermodal rate is increased (decreased) 0.75¢ for fuel surcharge

Table 6. Assumptions for Mode Choice Analysis

Transportation mode choice

We consider two transportation modes, truckload (TL) and intermodal (IM), since all products in our case are transported by land. Truckload means that all goods are primarily transported in one move by truck; whereas intermodal means the use of two or more modes of transportation (in our case, truck and train). Truckload is usually faster but more expensive means of getting goods into customers hands, as they have a higher rates (on per mile basis) than intermodal. Economically, intermodal is more favorable as total cost is usually lower than truckload (drayage[2] included) but has the disadvantage of taking longer due to additional handling and routing. Therefore, deciding which mode is best for business involves many factors, keeping in mind one principle rule in retail that "it is much cheaper in retaining a customer then going out hunting new one". So the extra day of lead time from intermodal comes into question, in this situation the store operator has to keep more stock in-house to prevent falling short of demand and in return results in higher annual inventory costs. For truckload, goods can be received more directly and the store operator can keep less in stock hence lowering inventory costs but with higher transportation costs.

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[2] Drayage service is usually provided by a national trucking/shipping company or an International shipment brokerage firm in addition to the transportation of the freight to and from the exhibit site. Drayage service provides for:

1. Completing inbound carrier's receiving documents.
2. Unloading and delivery of the goods to your booth/stand space from the receiving dock
3. Storing of empty cartons/crates and extra products at a on/near-site warehouse
4. Pickup of the goods from your booth/stand space to the receiving dock and loading back into the carrier
5. Completing outbound carrier's shipping documents.

Load size

Ideally trucks are either cubed out (ft^3) or weighed out (lbs) with produced goods ready for transport. The choice of measurement usually relies on the product being moved, for example, products that are heavy weigh out on a truck and light products cube out the space. Given input from the company, their loads typically weigh out; and thus in our thesis all measures of demand are in pounds (lbs).

However, companies often do not fully utilize the capacity of the truck or container due to customer service objectives that require a shipment to be moved before a full load of demand is required. Since we will be analyzing 7 different city lanes that M&E products are transported on, we used historical data to measure the typical load size that is shipped to these destinations (see Table 7)

	Actual loadsize	Utilization
JAX	24,918	62%
ORL	31,807	80%
MIA	28,338	71%
SAT	27,659	69%
DEN	21,824	55%
LAX	28,537	71%
SEA	25,098	63%

Table 7. Actual load size and utilization (%)

Lead times

The U.S. Department of Transportation (DOT), which regulates the trucking industry, in the Federal Motor Carrier Safety Regulations Section 395.3 sets Maximum Driving Time to 10 hours per driver. This limits the distance a driver can cover within a business day, leaving organizations with the decisions to either send out drivers in teams or absorb an extra day of lead time. We assume that a driver can cover 500 miles within 10 hours We only considered cities 800 miles and above, since this would have an impact on TRC (Total relevant costs) between TL (Truckload) and IM (Intermodal) due to the extra day long lead time IM has over TL and the associated inventory holding cost with this lead time.

Safety Stock

Also known as buffer stock, Safety Stock is what stores keep in-house in case of unexpected increases in future demand, factoring in the amount of time it takes new orders to come in. With longer the lead time in getting goods to stores, the retail owner may want to keep more stock on hand to cover the time between when orders are made and received. In our model we set safety stock at half of each cities demand over the transportation lead time. However, the company felt that stores may already have enough safety stock to cover one extra day of lead time. So we will also see how taken out Safety Stock changes the dynamics of the mode choice decision.

Value Density

This is value to weight ratio ($/lbs) of the cost of the goods sold (COGS). It is measured in many different ways, primarily depending on how an organization wishes to define its products. You can calculate value density by looking at the cost of weighing out a truck ($/lbs) or for the amount of space used by cubing out ($/ft$^{3)}$ capacity. M&E typically weighs out shipments headed outbound. Table 8 below is an example of how we calculated the value density for M&E's High value product line, considering the various costs and weights for each carton of goods and computing a weighted average based on the overall sales for each category of High value product.

Category	$ COGS/carton	lbs/Carton	$COGS/lbs	Sales by category	
A	$ 1,102.46	17.14	$64.32	38%	$24.44
B	$684.82	17.14	$39.95	16%	$6.39
C	$333.58	17.14	$19.46	11%	$2.14
D	$257.47	17.14	$15.02	2%	$0.30
E	$83.52	17.14	$4.87	31%	$1.51
F	$93.38	17.14	$5.45	1%	$0.22
Overall Weighted Average					**$35**

Table 8. M&E product line

The two product lines with value densities of $35 and $3.50 make up M&E's high value and low value lines respectively. This is important in determining which modes of transport is best suited for products being transferred, as M&E sends out mixed cargo's consisting 65% high value products and 35% low value. Keeping this in mind, then we can figure out the value density per truckload of the goods being transported (figure $ below) which for M&E is $24.11/lbs.

	% of product on cargo	*Value Density ($/lbs)*	
High Value	*65*	*35.00*	*$22.75*
Low value	*35*	*3.50*	*$1.25*
Value of Mixed Cargo	*100*		*$24.11*

Table 9. Value of Cargo outbound

Fuel Surcharge and Relation to Fuel Price

With the price of oil reaching record highs, much attention has been paid to the price of diesel fuel and the adjusting of fuel surcharges. Diesel fuel, like heating oil and jet fuel are known as distillates which are produced from crude oil. Demand is what drives decisions on what to allocate crude oil towards; for example if there is a winter storm, demand for heating oil rises and refineries shift production from diesel fuel to meet excess demand. The demand for crude oil has grown sharply in past couple years with the Organization of Petroleum Exporting Countries (OPEC) which produces 40% of worlds oil supply, see production reach maximum capacity.

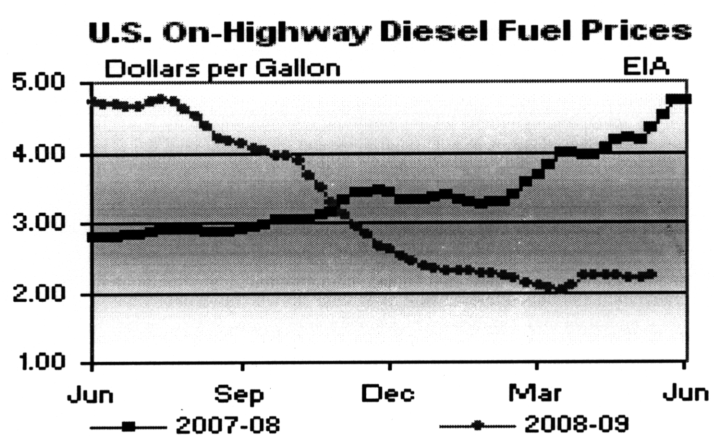

Figure 1. U.S. on-Highway diesel fuel prices(http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp)

A direct result has been the sharp increase in fuel prices followed by a sharp decline. Therefore in responding to demand for a closer correlation to the actual increases and decreases of diesel fuel pricing, many transport companies have implemented a methodology that associates rising diesel fuel prices with increases in the rate, called a fuel surcharge. We use a common approach that for every 6¢ increase in the base price of diesel ($/gal), truckload surcharge increase by 1¢ and intermodal by 0.75¢.

The formula is:

$$\text{Fuel Surcharge} = (b_{ij,F} + (\frac{f_c - f_B}{0.06}) * 0.01)$$

To illustrate how surcharge cost is added to the base rate charged per lane, let us look at an example. For the example we set the diesel price at $2.09/gal. The base rate of diesel for the fuel surcharge on M&E's rates is set at $1.21/gal.

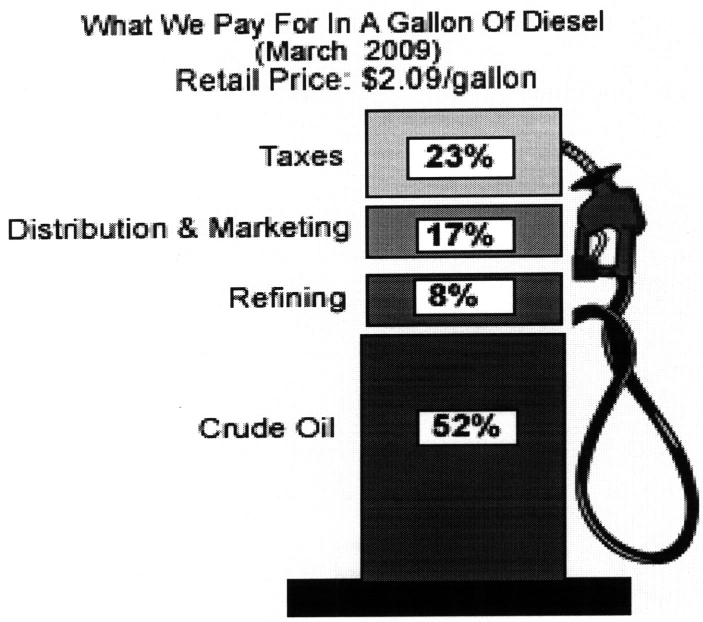

Figure 2 Component of diesel (http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp)

And we consider the transportation lane for Jacksonville (JAX), Florida, which has a base rate charge of $1.94/mile. The calculation follows:

$$(b_{ij,F} + (\frac{f_c - f_B}{0.06}) * 0.01) \quad \rightarrow \quad [\$1.94+(2.09-1.21)/0.06*0.01] = \$2.08$$

So an additional 14¢ of fuel surcharge was added to the base rate of $1.94.Note that while the actual implementation follows a step function, as you see in Figure 4, our formula represents a linear approximation to ease algebraic calculation. However, the spreadsheet used to conduct the sensitivity analysis formally incorporates the step function.

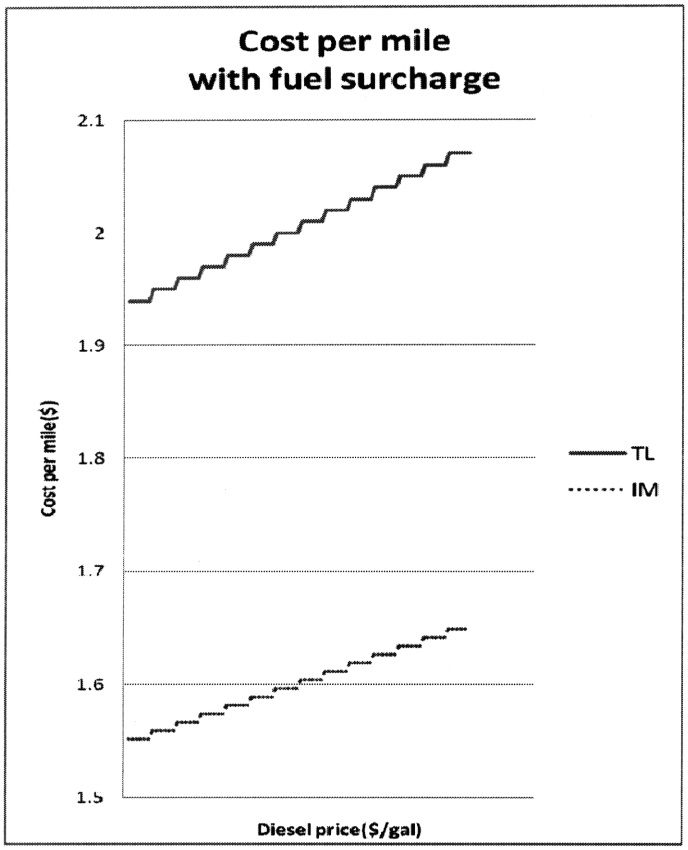

Figure 3. Cost per mile with Fuel surcharge

4. Analysis

4.1. Total Relevant Costs of Base scenario (Truckload vs. Intermodal)

In this section, we looked at TRC (Total Relevant Costs) for all seven cities using both Truckload(TL) and Intermodal (IM). TRC is composed of Transportation costs and Inventory holding costs. As stated earlier, we built a model using Microsoft excel factoring all costs to run our sensitivity analysis comparing TRC's (see a snapshot of excel model in the Appendix).

Looking at the TL and IM lane for JAX in table 11, for instance:

	TL	IM
Miles	805	805
Actual load size(lbs)	24,918	24,918
Transportation cost($)	$ 350,972	$ 280,778
Lead time	1	2
Safety stock(lbs)	15,342	23,014
In-transit stock(lbs)	30,685	46,027
Inventory cost($)	$ 188,668	$ 283,002
Total Cost($)	$ 539,640	$ 563,780

Table 10. JAX Lane, example of total cost calculation

Using the actual load size (from data) and fuel price of $1.21 (no surcharge) we calculated transportation cost (T) and inventory holding cost (I) as shown below:

Transportation costs (T) = cost per mile * miles from DC i to destination j * $\frac{\text{Annual Demand}}{\text{Load size}}$

$$T_{JAX,\,TL} = c_{ij,TL} * d_{ij} * \frac{D}{Q}$$ = $1.94 /mile * 805 miles * 5.6MM/24,918lbs= $350,972

Inventory holding cost (I) =(in-transit+ safety stock) * inventory holding% *value density

$$I_{JAX,\,TL} = \left(\frac{D}{365} * t_{ij,TL} + \frac{D}{365} * t_{ij,TL} * \frac{1}{2}\right) * r * v = (30{,}685+15{,}342) * 0.17 * 24.11 =$$

$188,668

TRC = Transportation cost + Inventory holding cost = $350,972 + $188,668= $539,640

From table 11 above, we see transportation costs are lower for IM considering a cost per mile that is 80% of TL's rate charge. Also factoring in the extra day of lead time for IM, we see a greater amount of safety stock required as well a higher in-transit stock as they are being charged for an extra day. With a high value density ($24.11/lbs) of goods being transported we see inventory costs are $94,300 more a year for IM than using TL, Table 12 below shows us the difference in costs between choosing both mode choices (TL – IM) for all 7 cities. In this analysis we assumed both mode choices have the same requirement of safety stock and diesel price (set at $1.21/gal), but have a one day differential in lead time. We find TL is attractive at diesel price $2.09/gal for JAX, ORL, MIA and SAT, while IM is more economical for DEN, LAX and SEA.

	Total Costs ($) (value density: $24.11 / lbs)		
	Actual loadsize		
	Truck Load	Intermodal	Difference(TL-IM)
JAX	$ 539,640	$ 563,780	-24,140
ORL	$ 1,454,220	$ 1,521,846	-67,625
MIA	$ 2,189,189	$ 2,199,438	-10,249
SAT	$ 1,094,499	$ 1,118,510	-24,010
DEN	$ 1,037,195	$ 1,031,901	5,295
LAX	$ 2,945,137	$ 2,895,162	49,976
SEA	$ 1,265,161	$ 1,201,605	63,555

Table 11. Total Relevant costs of base scenario(with safety stock, Diesel price=$ 2.09/gal

Safety Stock Effect

One of the big assumptions made in all our scenarios thus far, is that we have safety stock (SS) which we set to be equal to half of demand lead time. This is a simplistic approximation; and in fact, the retail company said that they may not adjust SS based on mode change since store stock levels are already buffered significantly. So we decided to also conduct our analysis without any safety stock and see how this changes our tradeoff points between IM and TL.

	Total Costs ($) (value density: $24 / lbs)		
	Actual loadsize		
City	Truck Load	Intermodal	Difference(?=TL-IM)
JAX	$ 476,751	$ 469,446	$ 7,305
ORL	$ 1,283,520	$ 1,265,796	$ 17,724
MIA	$ 1,975,815	$ 1,879,376	$ 96,438
SAT	$ 978,828	$ 945,002	$ 33,825
DEN	$ 910,855	$ 863,447	$ 47,408
LAX	$ 2,608,230	$ 2,015,429	$ 162,278
SEA	$ 1,146,738	$ 1,043,708	$ 103,030

Table 12. Total Relevant costs of base scenario (without Safety Stock, Diesel price=$ 2.09/gal)

Table 12 shows the results with no safety stock included. We see IM is more economical for every city, whereas in our previous analysis (Table 12) we saw TL more economical for JAX, ORL, MIA and SAT. Safety Stock is a big cost factor in choosing IM due to the extra day of charge on lead time for Safety Stock and in-transit stock (not changed).

Studying lane LAX to further demonstrate our research we see that IM has a TRC difference of $449,210 (=$2,464,639-$2,015,429) which is primarily from the difference in inventory holding cost as demonstrated in Table 13:

	IM with Safety stock	IM without Safety stock
Transportation Costs	$1,547,532	$1,547,532
Safety Stock	109,589	0
In-transit Stock	114,148	114,148
Inventory Costs	$917,107	$467,897

Table 13. IM lanes with/without safety stock

So without the use of Safety Stock, we see inventory holding costs go down dramatically (IM's greatest source of costs), making IM more cost efficient, which has a lower transportation cost than TL due to lower CPM rates (80% of TL's CPM).

4.2. Tradeoff point of Fuel Price

We look at Total Relevant Costs (TRC) with fuel surcharge. Fuel surcharges are very important because of the significant difference between the surcharges in truckload (TL) vs. Intermodal (IM) transportation (for every 6 cents increase in diesel there is a 1 cent per mile surcharge for TL and 0.75 cent for IM). In addition, the higher base rates and surcharge of TL effects transportation costs; with longer distances TL's costs are much higher than IM.

In this calculation, we use base diesel price of $1.21/Gal and value density of $24.11/lbs of mixed items. We obtain tradeoff point of diesel price up to which truckload is more economical than intermodal transportation by sensitivity analysis using from $1 to$10 price range. Results are as follows.

City	up to fuel price TL < IM
JAX	$ 4.45
ORL	$ 4.57
MIA	$ 1.57
SAT	$ 2.41
DEN	$ ≤ 1
LAX	$ ≤ 1
SEA	$ ≤ 1

Table 14. Tradeoff point of diesel price(up to which TL<IM, with safety stock)

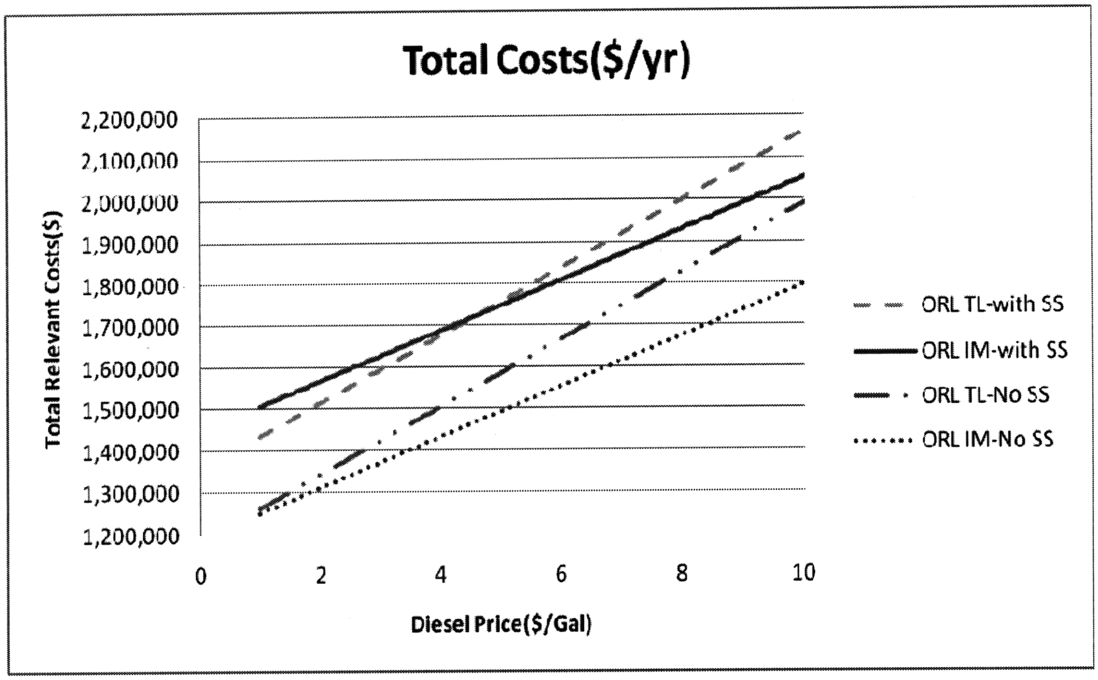

Figure 4. Total Relevant Costs of TL vs. IM for ORL with/without Safety Stock

TL is more economical up to diesel price of $4. 57/Gal for ORL with Safety Stock

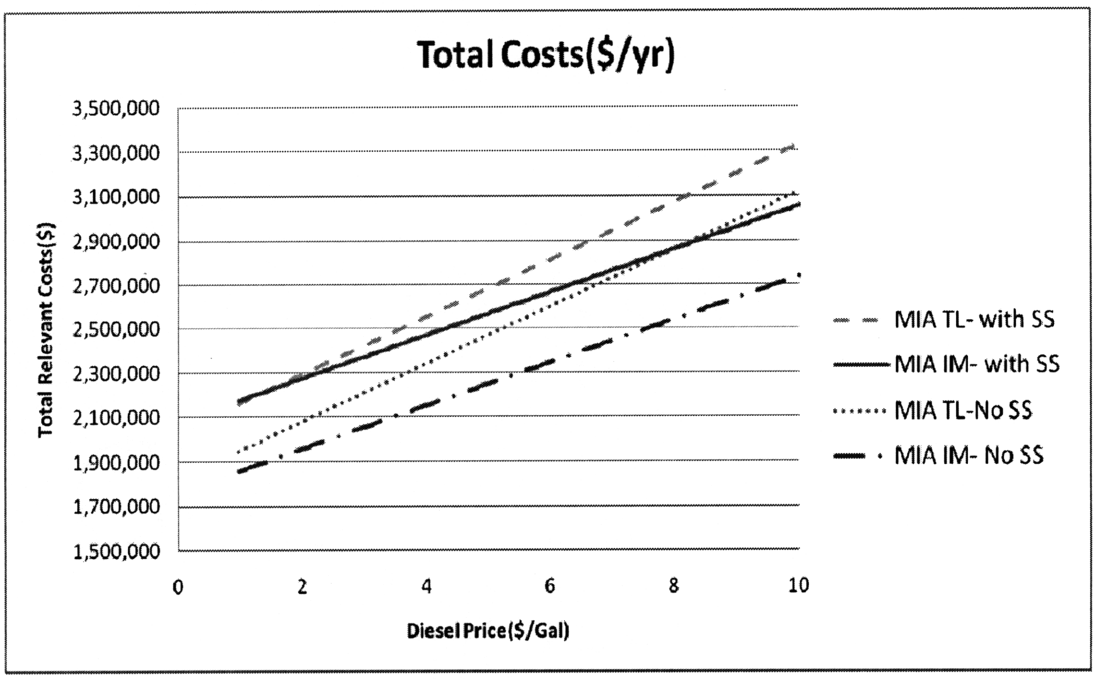

Figure 5. Total Relevant Costs of TL vs. IM for MIA with/without Safety Stock

TL is more economical up to diesel price of $1. 57/Gal for MIA with Safety Stock

4.3. Utilization and Tradeoff point of Fuel Price

We know the maximum utilization truckload is 40,000 lbs, but as mentioned earlier, most trucks are not shipped out at full capacity. Out of the 7 cities being analyzed, ORL carries the biggest load size utilizing 80% of the 40,000lbs max (32,000 lbs) every time en route to make delivery and smallest load going to DEN utilizing 55% (22,000lbs). In this section, we see how the scenario changes when M&E is able to utilize more of the capacity available for delivery; at 4 different stages utilizing 70% (28,000 lbs), 80% (32,000 lbs), 90% (36,000 lbs) and 100% (40,000 lbs) of truckload capacity. Currently only three cities (ORL, MIA, LAX) out of the seven cities under observation utilize more than 70% of truckload size.

In this scenario we looked at fuel prices ranging from $ 1 up to $10 per gallon. Trying to capture real case scenario's similar to previous experiences, where companies absorbed large amounts of unexpected transport expenses due to unpredictability of crude oil being so volatile. We assessed in regards to different load sizes at what fuel prices where TL more economical than IM. our results are as follows.

	Up to fuel cost TL< IM	JAX	ORL	MIA	SAT	DEN	LAX	SEA
Actual loadsiz	No Safety stock	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1
	With Safety stock	$ 4.45	$ 4.57	$ 1.57	$ 2.41	≤ 0.97	≤ 1	≤ 1
28,000lbs	No SS	$ 1.33	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1
	With SS	$ 6.01	$ 3.07	$ 1.45	$ 2.53	$ 2.95	≤ 1	≤ 1
32,000lbs	No SS	$ 2.65	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1
	With SS	$ 7.99	$ 4.69	$ 2.83	$ 3.79	$ 4.21	$ 1.09	≤ 1
36,000 lbs	No SS	$ 3.97	$ 1.45	$ 0.97	$ 1.27	$ 1.63	≤ 1	≤ 1
	With SS	$ 10.03	$ 6.25	$ 4.21	$ 5.05	$ 5.47	$ 1.81	≤ 1
40,000 lbs	No SS	$ 5.29	$ 2.53	$ 1.39	$ 2.11	$ 2.47	≤ 1	≤ 1
	With SS	≥ 10	$ 7.87	$ 5.59	$ 6.31	$ 6.79	$ 2.53	$ 1.51

Table 15. Fuel price sensitivity analysis (with various load size)

The first row gives us the tradeoff points up to which TL is more appealing in terms of costs and efficiency. With current fuel price at $2.09/gal, IM is attractive for all cities with and without safety stock. Factors attributing to this is the fact that only 63% (25,000 lbs) is utilized per truck, so with a higher CPM rate then IM times the long distance, we have a higher transportation cost. Also less in-transit stock brings down the inventory holding cost (which is the exponential factor due to lead time in expenses for IM), at least until they increase the amount of load size utilized up by 27%; where TL only becomes attractive when you utilize 90-100% truckload. Looking at each lane, as you increase the load size being delivered, we find a higher break point till which TL is attractive primarily due to the value and cost of inventory being transported.

4.4. Tradeoff point of Value Density

We then decide to re-run our value density analysis with and without any Safety stock and compare our results from our previous tradeoff points.

up to value density	Value density($/lbs)	
IM < TL	No SS	with SS
JAX	$ 27.0	$ 18.0
ORL	$ 27.0	$ 18.0
MIA	$ 35.5	$ 23.5
SAT	$ 31.5	$ 21.0
DEN	$ 38.0	$ 25.5
LAX	$ 42.0	$ 28.0
SEA	$ 56.0	$ 37.5

Table 16. Value density analysis (with / without Safety stock)

As can be seen in table 17, our results with safety stock shows that IM is economical than TL up to a lower value density, than value density without stock. Which means considering safety stock IM is less attractive because IM has longer lead time than TL hence requiring more safety stock, which increases inventory holding costs as demonstrated in the graphs below.

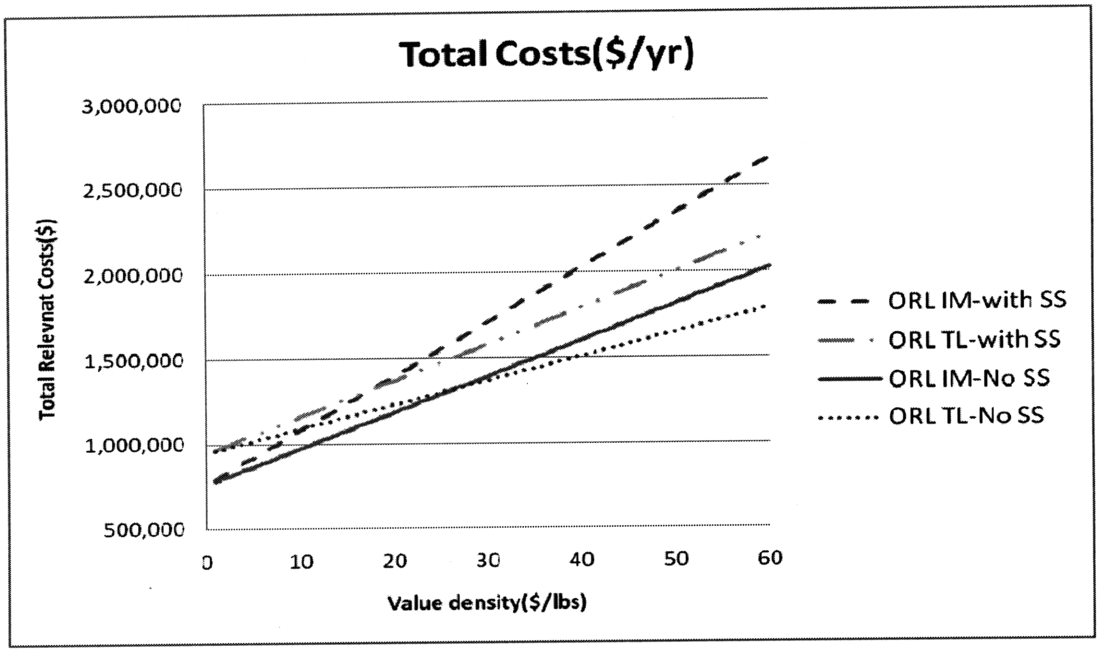

Figure 6. Total Relevant Costs of TL vs. IM for ORL with/without Safety Stock

IM is more economical up to $27/lbs of value density than TL without Safety stock and $18/lbs of value density than TL with Safety stock for ORL.

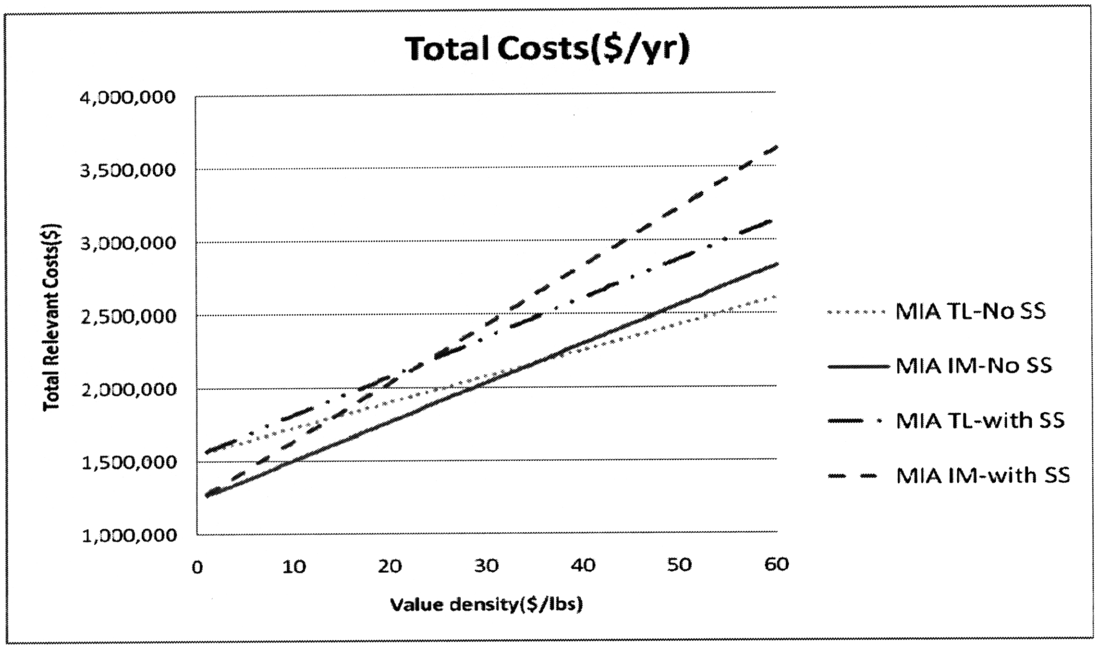

Figure 7. Total Relevant Costs of TL vs. IM for ORL with/without Safety Stock

IM is more economical up to $35.5/lbs of value density than TL without Safety stock and $23.5/lbs of value density than TL with Safety stock for MIA.

These graphical examples show us, the differences between having Safety Stock and without Safety stock for seven cities. We can see that the IM lines are steeper than the TL lines at any given distance; because IM has a longer transportation lead time than TL hence requiring larger Safety Stock, hence increasing the capital cost of holding inventory. Also looking at figure of MIA, SAT which have longer distances than JAX, ORL have steeper TL lines because the transportation cost per mile decreases over the longer distance.

Tradeoff Value Density under various fuel price scenarios

We calculated TRC of 4 scenarios with different diesel prices ($2, $3, $4 and $5) to see what impact surcharge has on the values of good being transported. In comparing TL vs. IM, we found the tradeoff value densities for all 7 cities (Table 17); up to these values IM is more economical than TL.

	up to value density($/lbs), IM < TL						
Fuel Price ($/Gal)	JAX	ORL	MIA	SAT	DEN	LAX	SEA
2	$ 27.5	$ 27.0	$ 35.5	$ 32.0	$ 38.5	$ 42.5	$ 56.5
2.5	$ 29.0	$ 28.5	$ 37.5	$ 34.0	$ 41.0	$ 46.0	$ 61.0
3	$ 30.5	$ 30.0	$ 39.5	$ 36.0	$ 43.5	$ 49.5	$ >= 65.0
4	$ 33.0	$ 33.0	$ 43.0	$ 40.0	$ 48.5	$ 56.5	$ >= 65.0
5	$ 36.0	$ 35.5	$ 46.5	$ 44.5	$ >= 65.0	$ 63.5	$ >= 65.0

Table 17. Total Relevant Costs-Value density analysis (in 5 scenarios of diesel price, without Safety stock)

Assuming diesel is $2/Gal, TL is only attractive with value densities higher than $27.5 so we will assume value density at $28. At these rates we have a surcharge (calculated in figure $) of $1.93 TL and $1.53 IM (TL is 40¢ more per mile), with everything else constant (Miles * #of deliveries =180,913) we see a higher transportation cost of TL at $70,903 (348,560-277,657) more per year over IM. But due to the high value density that we have set (at $28) we see IM absorbing higher inventory costs at $73,030 (219,090-146,060) more than TL. The difference between higher transport cost of TL and inventory cost of IM being $2,127 (73,030-70,903), we see IM taking up more expenses making TL more cost efficient.

TL	IM
$(b_{ij,TL} + (\frac{f_C - f_B}{0.06}) * 0.01)$	$(b_{ij,IM} + (\frac{f_C - f_B}{0.06}) * 0.0075)$
$(1.80 + (\frac{2 - 1.21}{0.06}) * 0.01)$	$(1.55 + (\frac{2 - 1.21}{0.06}) * 0.0075)$
= $1.93/mile	= $1.53/mile

Table 18. Surcharge rates

Now considering the same scenario, only changing diesel prices to $3/gal; we see an increase of 3¢ more per mile on surcharge (43-40) than our previous scenario. This is because our new surcharges at $3/gal is $2.09 TL and $1.66 IM leaving us with a higher difference in transport cost of $78,441 (378,712-300,271) which is greater than our higher inventory cost in IM (as we keep value density at $28) leaving us with a difference of $5,411 (78,441-73,030) making IM more attractive. Explaining why we see in Table 18, that as diesel prices increase, the break point to which IM is more economical also increases. Because as gas prices go up, transport costs for TL increases therefore we need a higher V which increases the inventory costs of IM to make TL look attractive.

4.5. Utilization and Tradeoff point of Value Density

We then decided to see how utilization played on value density's affect on transport mode decision. Table 20 below shows our results.

up to value density IM < TL	Actual load size	70% (28,000 lbs)	80% (32,000 lbs)	90% (36,000 lbs)	100% (40,000 lbs)
JAX	$ 27.0	$ 24.0	$ 21.0	$ 19.0	$ 17.0
ORL	$ 27.0	$ 30.5	$ 26.5	$ 24.0	$ 21.5
MIA	$ 35.5	$ 35.5	$ 31.5	$ 28.0	$ 25.0
SAT	$ 31.5	$ 31.0	$ 27.0	$ 24.0	$ 22.0
DEN	$ 38.0	$ 29.5	$ 26.0	$ 23.0	$ 21.0
LAX	$ 42.0	$ 42.5	$ 37.5	$ 33.0	$ 30.0
SEA	$ 56.0	$ 50.0	$ 44.0	$ 39.0	$ 35.0

Table 19. Value density analysis with various utilization(%) (without Safety Stock)

From the first column (representative of actual goods transported) we can infer that IM is more economical for each city as all tradeoff points are higher than our actual value density of $24. But as the load size increase per city, value density break points decreases simultaneously. For example, looking at lane JAX we see at 70% IM is attractive up till $24 (current value density) but if you increased utilization by 10%, the break point dropped $3 ($24-$21). This happens because with all things the same, inventory cost is a percentage of your value density, so with a higher value density we see inventory costs go up higher for IM (due to extra day lead time) than for TL. Increasing load size will decrease the number of deliveries per year to each city.

TL	IM
SS*r*v	SS*r*v
83,288*.17*20	124,932*.17*20
=$297,388	=$424,769

4.6. Equation to calculate the fuel price for mode choice tradeoff

In this section, we induced the equation of tradeoff fuel price at which total relevant costs of truckload and intermodal is equal based on algebraic manipulation of our cost function. Up to this tradeoff point of fuel price, Truckload is attractive and more economical than Intermodal. This equation is helpful for the logistics manager to decide the optimized mode choice easily without calculating the total relevant costs of both transportation modes at various price levels. First, we looked at tradeoffs between Truckload and Intermodal, that means to decide between transportation costs and inventory holding costs. As we mentioned earlier, Truckload has more transportation costs and has more impact of diesel price, but less inventory holding costs than Intermodal due to shorter lead time, having less in-transit stock and requiring less safety stock. From our model, we induce following equation of tradeoff point of fuel price.

Truckload Total Relevant Costs = Intermodal Total Relevant Costs

$$T_T + I_T = T_I + I_I$$

i) With Safety stock

$$(b_{ij,F} + (\frac{f_C - f_B}{0.06}) *0.01)*d_{ij} * \frac{D}{Q} +(\frac{D}{365} * t_{ij,T} * \frac{3}{2})*r*v = (b_{ij,S} + (\frac{f_C - f_B}{0.06}) *0.0075)* d_{ij}* \frac{D}{Q} + (\frac{D}{365} *(t_{ij,F} +1) * \frac{3}{2})*r*v$$

Hence, $f_C = f_B + \frac{36}{365} * \frac{r\,v\,Q}{dij} - 4.8\, b_{ij,F}$

Without safety stock

$$(b_{ij,F} + (\frac{f_C - f_B}{0.06}) *0.01)*d_{ij} * \frac{D}{Q} + \frac{D}{365} * t_{ij,T} *r*v = (b_{ij,S} + (\frac{f_C - f_B}{0.06}) *0.0075)* d_{ij}* \frac{D}{Q} + \frac{D}{365} *(t_{ij,F} +1) *r*v$$

Hense, $f_C = f_B + \frac{24}{365} * \frac{r\,v\,Q}{dij} - 4.8\, b_{ij,T}$

5. Conclusion

Our analysis shows that the relevant logistics costs in making mode choice decisions are in the tradeoffs between transportation costs versus inventory holding cost plus lead times associated to target cities. While studying M&E's seven lanes we observed that transportation cost increases as the distance from its central distribution increases; as does the inventory holding cost, but varies depending on the value density being transported. Since M&E sends out a mixed cargo (65% HV+35%LV) with value density of $24/lbs we find that transportation costs (CPM*M) take a greater percentage of TRC (T+I) than inventory holding cost (at least till we reached value densities ≥$29 from our sensitivity analysis). This leads us to conclude that IM is the economical mode of choice over longer distances than TL due to a higher CPM (as we assumed IM's CPM to be 80% of TL's).

Additionally we see that value density has a big impact on mode choice preferred, and is an informative factor for supply chain managers to consider when making decisions. For high value density products TL is the mode of choice preferred, as it is the fastest and most efficient form of transport; however it is the most expensive out of the ground transportation modes discussed. This in theory makes sense due to the cost of products being transferred, as M&E will want to mitigate the risks of goods being damaged, lost in transit, stolen etc. while being delivered to retail stores throughout its North American operations. Also, IM is the mode of choice preferred for low value density products due to its lower cost.

In conclusion, after exploring the impact of fuel price volatility on mode choices; we discovered that for high fuel prices, IM is the mode choice preferred. This is because of a higher increase in transportation cost than inventory holding cost which is the major cost component for IM due to its extra day lead times. Likewise, for low fuel prices, TL is more economical up to tradeoff points. In our research we provide an equation to calculate the fuel price for mode choice trade-off at which intermodal offers economical cost than truckload. This equation can be generalized in all the mode choice cases with modifying assumptions about lead time, fuel surcharge, and safety stock. Therefore with recent oscillation in fuel prices, supply chain managers of M&E need to consider mode choice setup between TL and IM in order to minimize the overall costs of operations and can use this equation to obtain trade-off fuel price with convenience.

This research provides generalized insights to mode choice, which is an important factor for logistics managers, and identifies the trade-off fuel price at which intermodal offers lower total cost than truckload. This is helpful to make decisions in switching modes, and contribute to save magnitude of cost.

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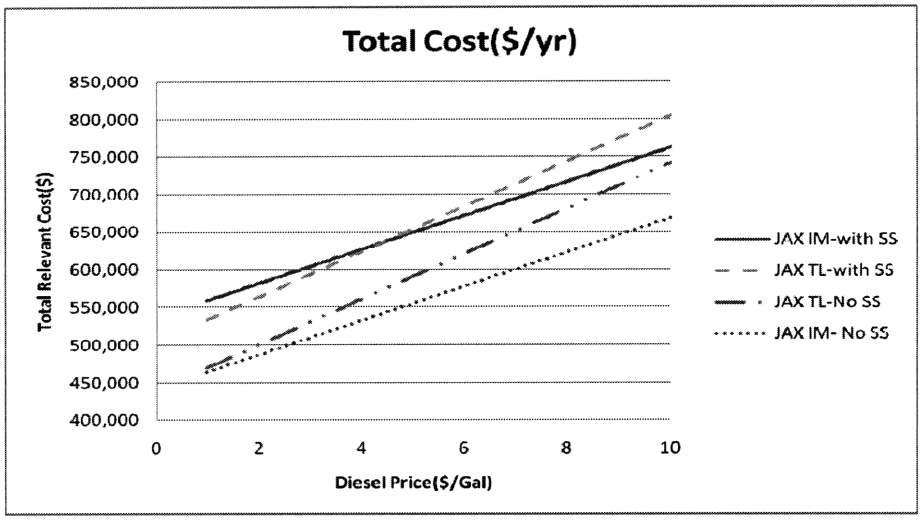
The US Energy Information Administration(EIA)

< http://www.eia.doe.gov/oiaf/kyoto/economic.htm >

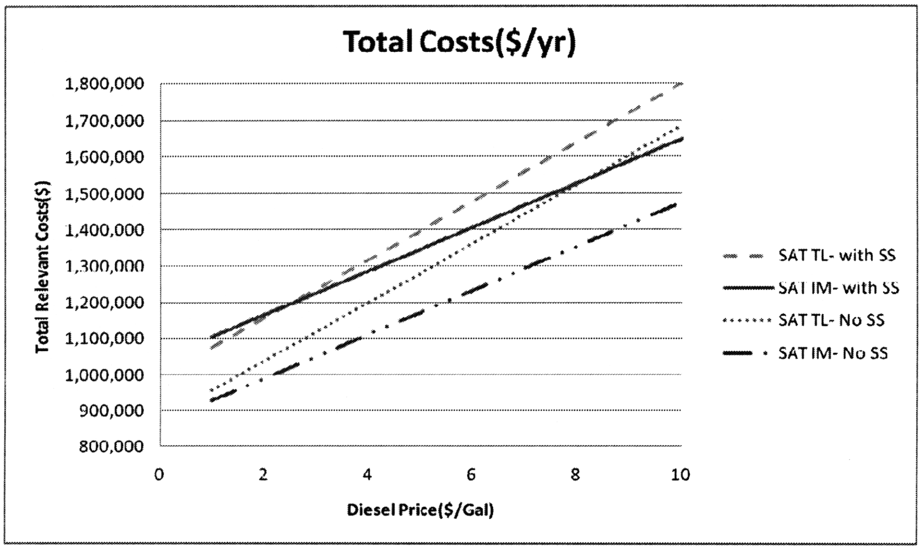
Appendices

Appendix 1 – Total Relevant Costs Sensitivity Analysis (Tradeoff point of Fuel price)

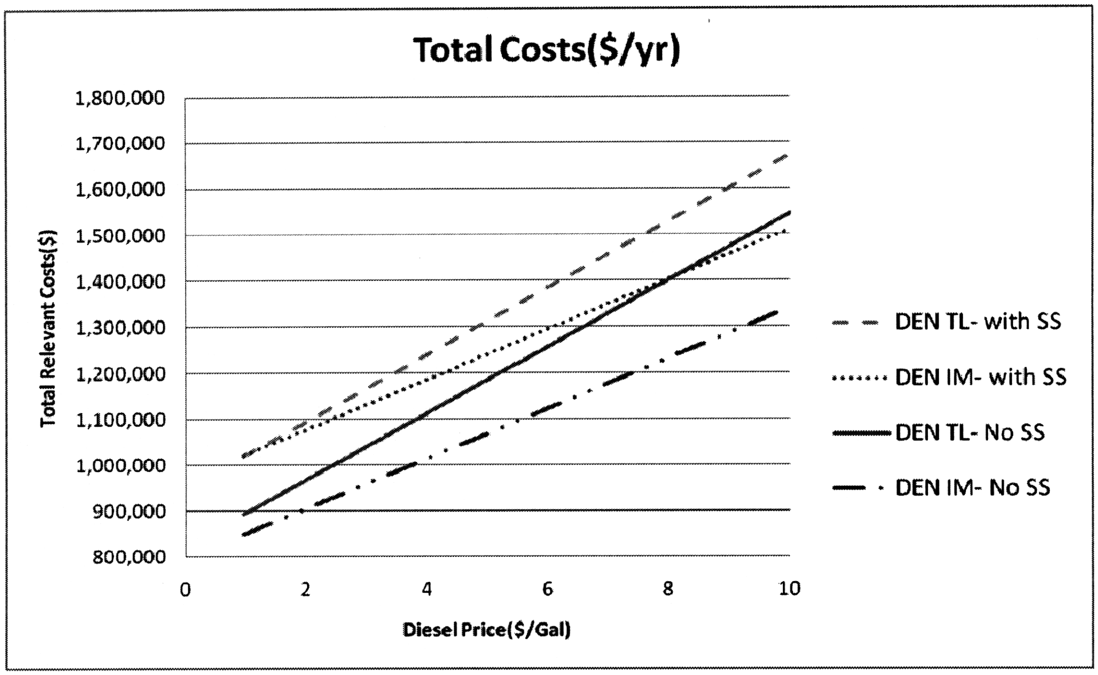
(Actual loadsize) Up to fuel cost TL< IM	JAX	ORL	MIA	SAT	DEN	LAX	SEA
No Safety stock	≤0.97	≤0.97	≤0.97	≤0.97	≤0.97	≤0.97	≤0.97
With Safety stock	$ 4.45	$ 4.57	$ 1.57	$ 2.41	≤0.97	≤0.97	≤0.97



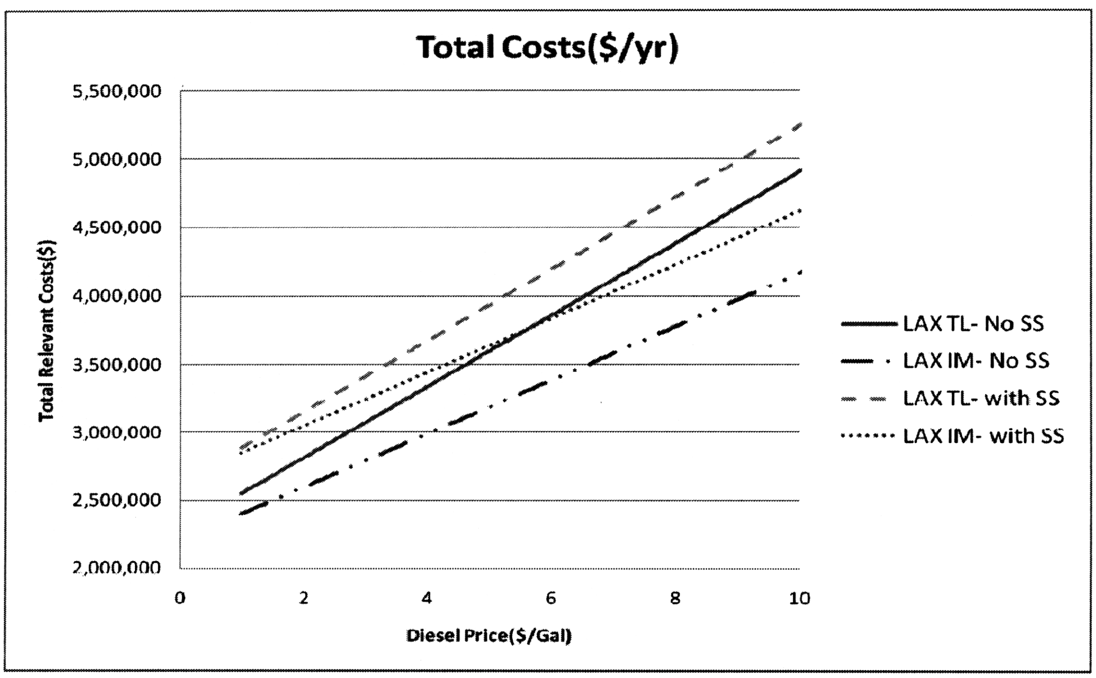
TL is more economical up to $ 4. 45/gal of diesel price than IM with Safety stock for JAX



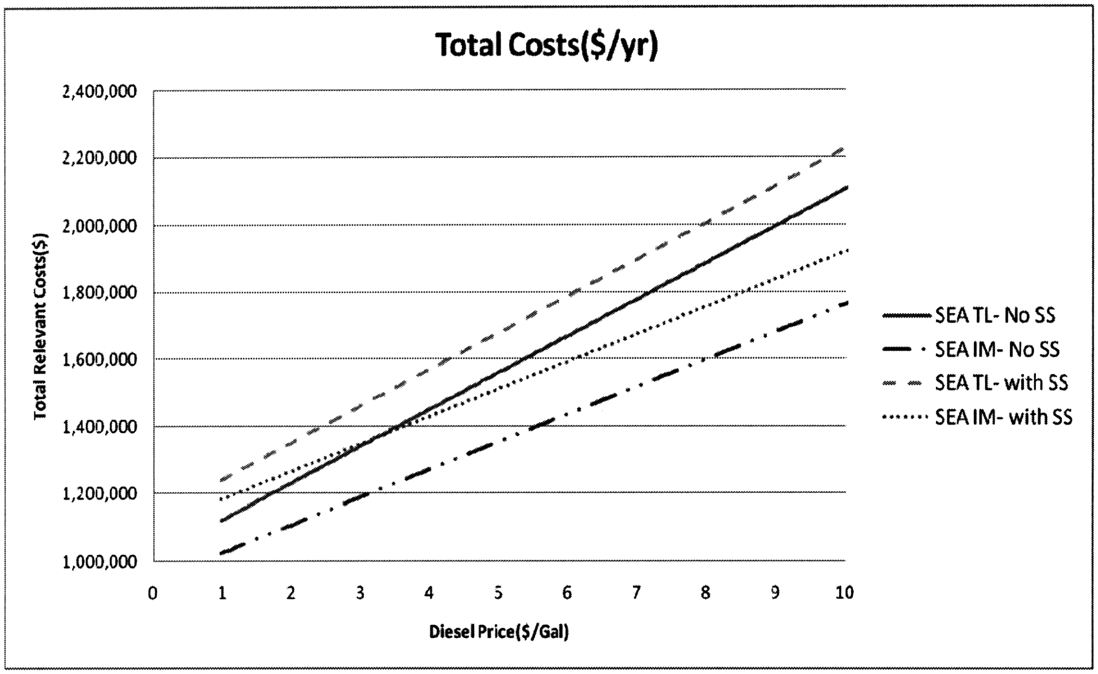
TL is more economical up to $ 2.41/gal of diesel price than IM with Safety stock for SAT.



TL is more economical up to $ 1/gal of diesel price than IM with Safety stock for DEN.



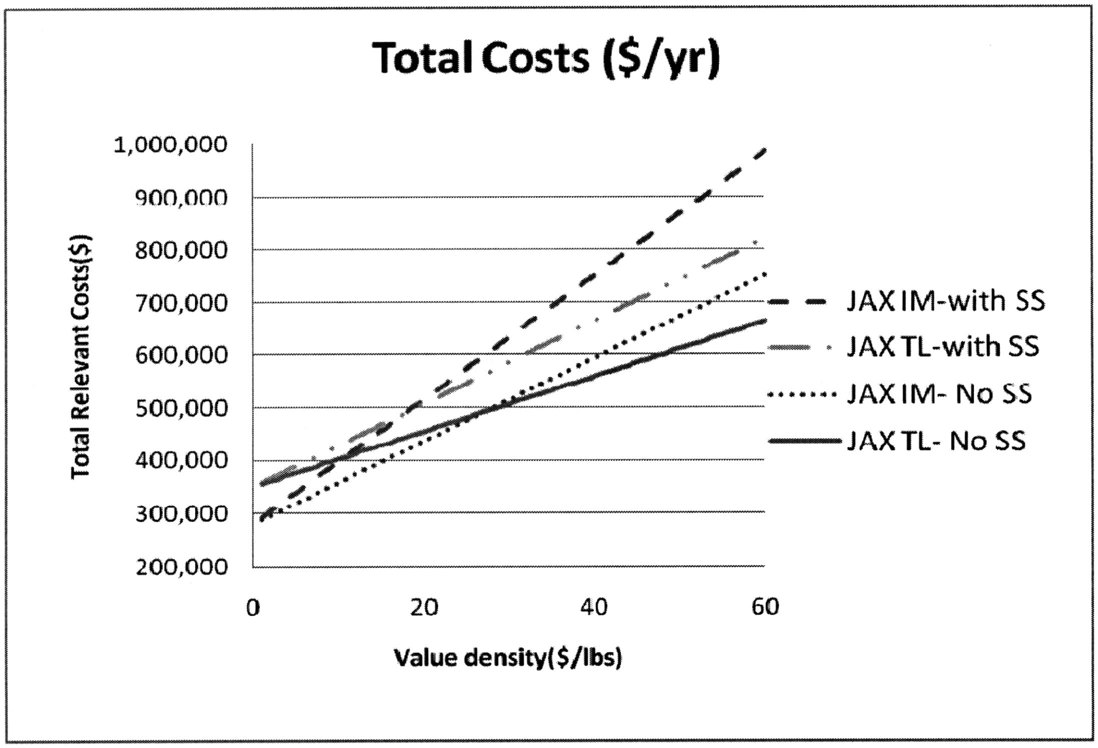
TL is more economical up to $ 1/gal of diesel price than IM with Safety stock for LAX.



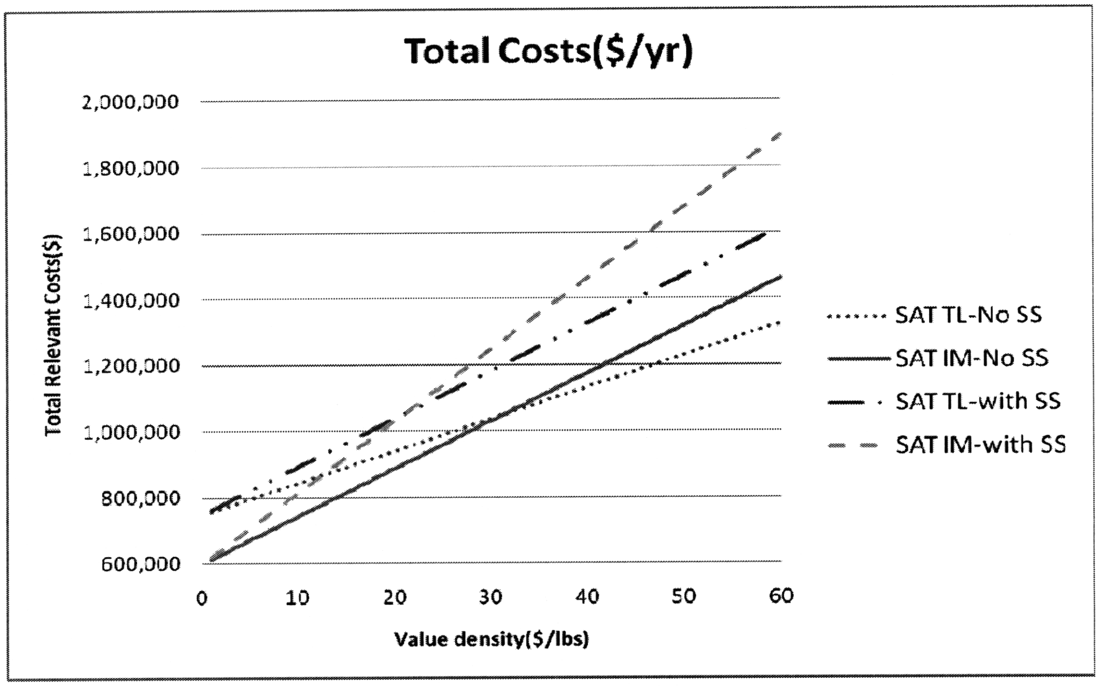
TL is more economical up to $ 1/gal of diesel price than IM with Safety stock for SEA.

Appendix 2 – Total Relevant Costs Sensitivity Analysis (Tradeoff point of Value Density)

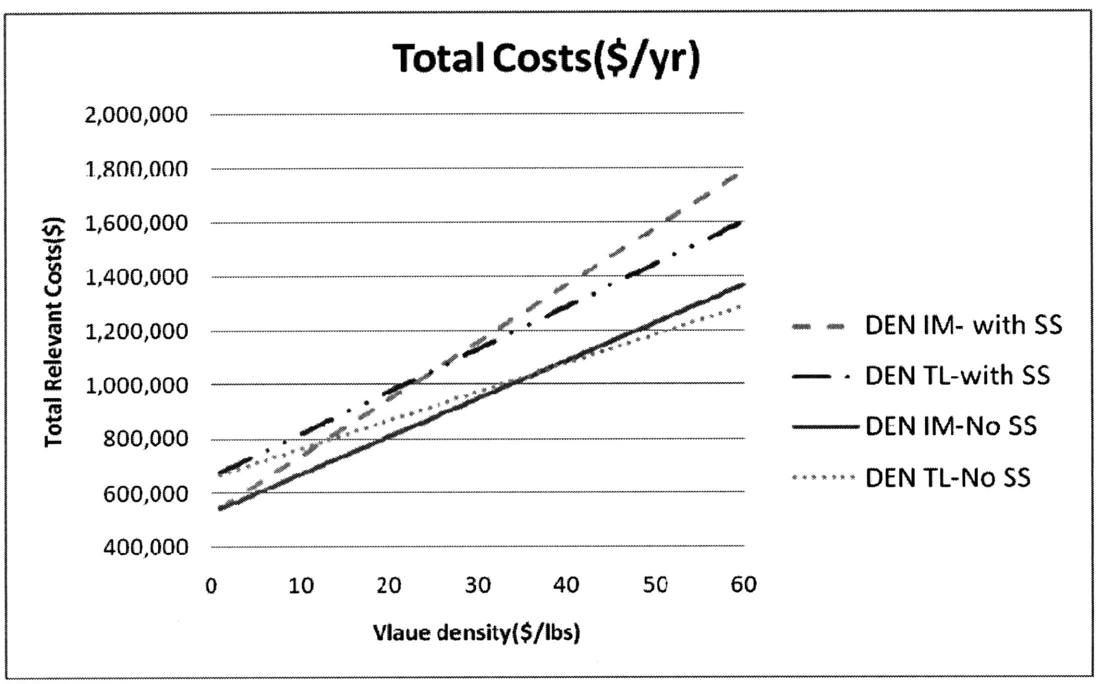
up to value density	Value density($/lbs)			
IM < TL		No SS		with SS
JAX	$	27.0	$	18.0
ORL	$	27.0	$	18.0
MIA	$	35.5	$	23.5
SAT	$	31.5	$	21.0
DEN	$	38.0	$	25.5
LAX	$	42.0	$	28.0
SEA	$	56.0	$	37.5



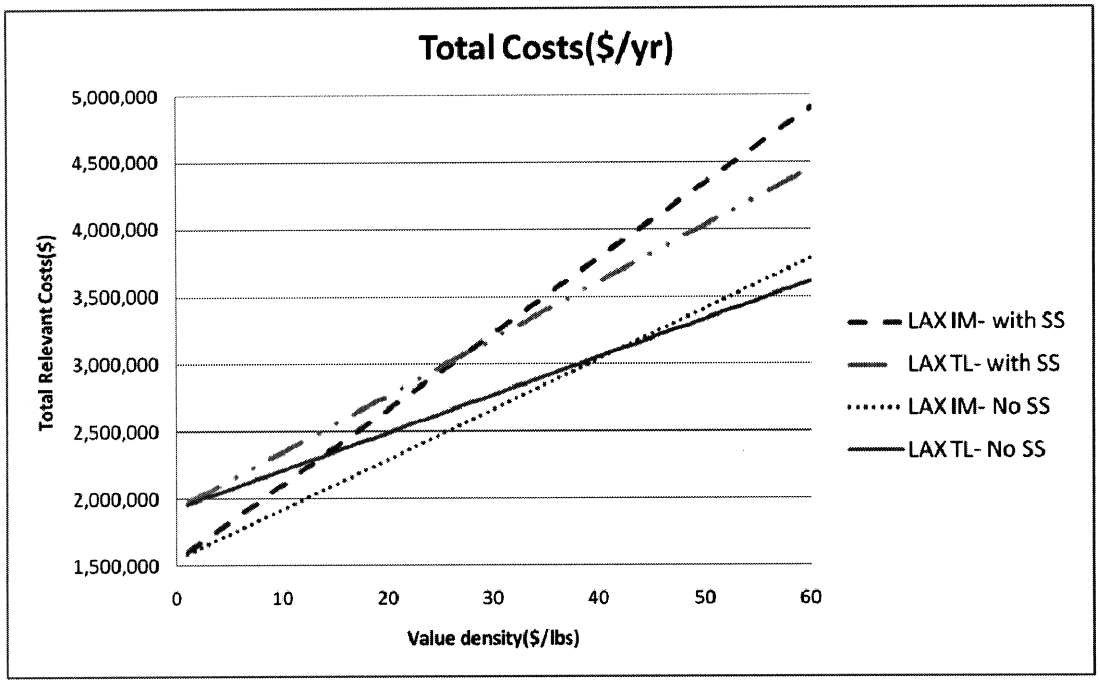
IM is more economical up to $27/lbs of value density than TL without Safety stock and $18/lbs of value density than TLwith Safety stock for JAX



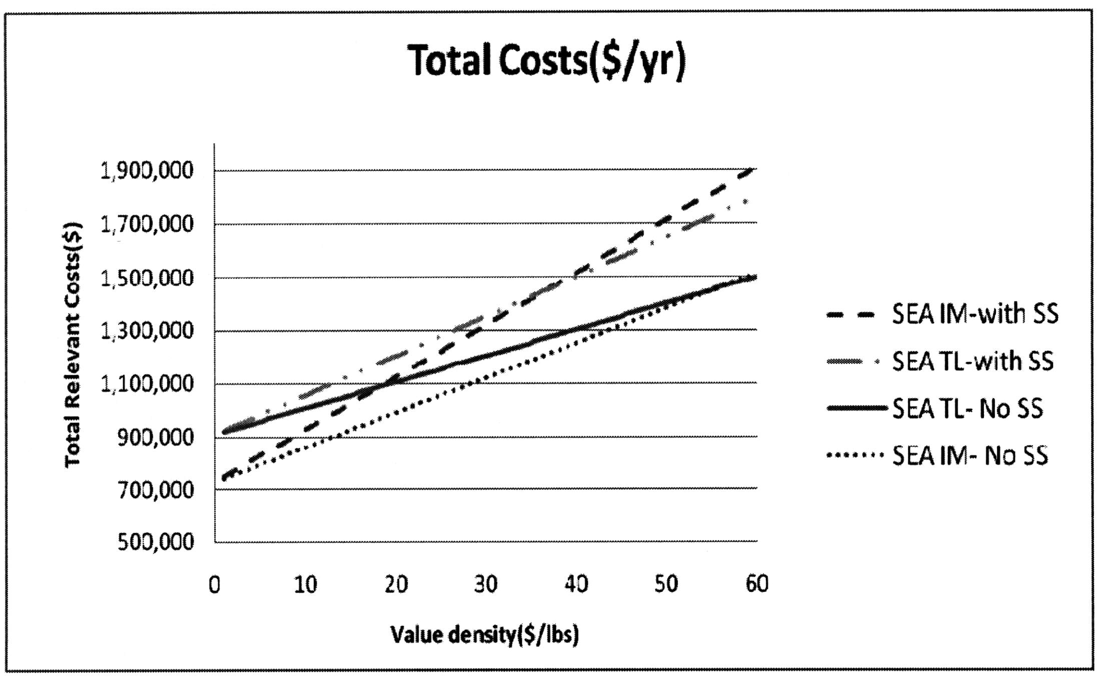
IM is more economical up to $31.5/lbs of value density than TL without Safety stock and $21/lbs of value density than TL with Safety stock for SAT.



IM is more economical up to $38/lbs of value density than TL without Safety stock and $25.5/lbs of value density than TL with Safety stock for DEN.



IM is more economical up to $ 42/lbs of value density than TL without Safety stock and $28/lbs of value density than TL with Safety stock for LAX.



IM is more economical up to $ 56/lbs of value density than TL without Safety stock and $ 37.5/lbs of value density than TL with Safety stock for SEA.