Intermodal Variability and Optimal Mode Selection

By: Tianshu Huang and Bernarda Serrano
Thesis Advisors: Dr. Chris Caplice and Dr. Francisco Jauffred

Topic Areas: Transportation, Mode Choice, Inventory

Summary: This research focused on incorporating the transit time variability into the transportation mode selection process. We identified a probability distribution for the transit time per unit of distance to quantify the impact of transit time uncertainty on inventory cost. Then, we built a model that calculates the total logistics costs and compares the results for two transportation modes: intermodal and truckload. Results show that a particular lane is more likely to be assigned to truckload for high load values and/or high service levels.

Before coming to MIT, Tianshu worked at Weston Foods and Unilever for various roles related to logistics. He holds a Master's in Operations Research and a Bachelor's in Engineering Science, both from the University of Toronto.

Before coming to MIT, Bernarda worked as a Supply Planner for a company in the consumer goods industry. She holds a Bachelor's degree in International Business from Tecnologico de Monterrey.

KEY INSIGHTS

1. Retailers often select the transportation mode based on the carrier's rate and the expected transit time. However, they should also consider the impact of transit time variability on logistics cost.
2. To quantify the impact of transit time variability, a probability distribution can be used. For the dataset used in this analysis, results show that Normal and Lognormal distributions model the transit time in a very similar way.
3. The sensitivity analysis shows that an increase in load value or service level makes truckload more favorable than intermodal.

Introduction

Transportation cost is one of the major drivers of logistics costs in any retailer's supply chain. Since it is dependent on the mode of transportation, optimizing mode selection is imperative to minimize costs. Different transportation modes and different carriers within a mode offer varying rates, lead times and service level.

The traditional approach to the mode selection process is to choose the carrier that offers the lowest rate or the shortest delivery time. However, each mode also has an associated transit variability that impacts the total logistics cost.

Given this uncertainty, retailers need to increase the safety stock in distribution centers to maintain a high service level, resulting in higher inventory holding costs.

Our research sought to incorporate additional variables, such as lead time uncertainty and service level into the mode selection process. We developed a model that calculates the total logistic cost incurred by the company for two transportation options: over the road truckload (TL) and intermodal (IM).

Our sponsor company, ABC Stores, uses a mix of truckload and intermodal to move goods from vendor facilities to distribution and mixing centers. The company assigns most of the shipments to truckload, but they believe that there is a cost savings opportunity by switching some of the lanes from truckload to intermodal. Therefore, ABC Stores was interested in knowing what the tradeoff between costs, lead time, transit variability and service levels is for each mode choice.

Transit Time Distribution

Because this study focuses on quantifying the impact of transit time variability, finding the most appropriate probability distribution to model transit time was critical. We used data of shipments between October 2015 and November 2016 to find the best distribution of Time/Distance (in hours per mile) for each mode.

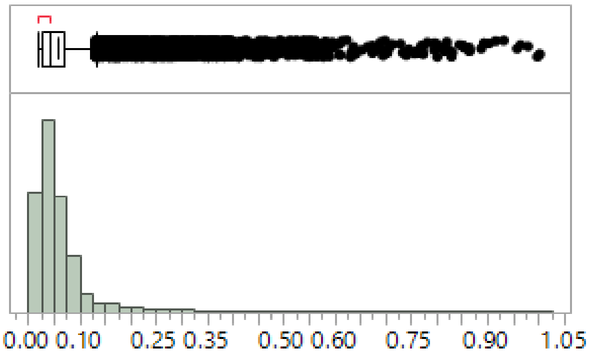

Figure 1: Time/Distance Histogram (h/ mi.) - Truckload

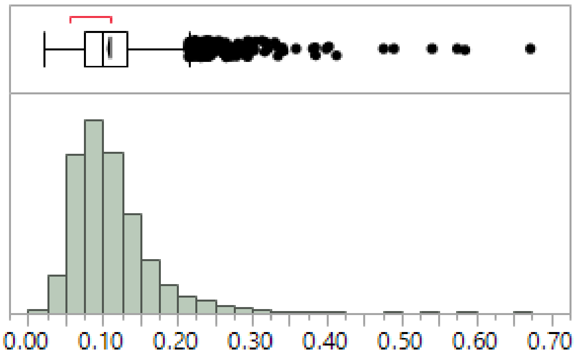

Figure 2: Time/Distance Histogram (h/ mi.) - Intermodal

As shown in Figures 1 and 2, both truckload and intermodal have right-skewed transit time distributions. The goodness-of-fit results show that the Normal and Lognormal distribution fit the data well. The probability that the data do not follow the Normal or Lognormal distributions for Truckload is less than 1%. For Intermodal, the probability that the data do not follow a normal distribution is less than 1%, and the probability it does not follow a lognormal distribution is less than 4%. Neither number is statistically significant. Therefore, both distributions were used for modeling the transit time.

Required Time/Distance

The required Time/Distance is expressed in our model as$t(\mu, \sigma, service\ level)$. It is measured in hours per mile. It represents the transit time over one unit of distance given a certain mean (μ), a standard deviation (σ), and a specific service level. The service level refers to the percentage of time that an order is delivered on time.

For a normal distribution, the $t(\mu, \sigma, service\ level)$ can be found using the standard normal table. For other distributions, it can be found by calculating the area under the distribution curve that covers the required service level. For example, in Figure 3, the transit time does not follow a normal distribution. The required time/distance can be found by finding the point in the x-axis that covers 95% of the total area under the curve.

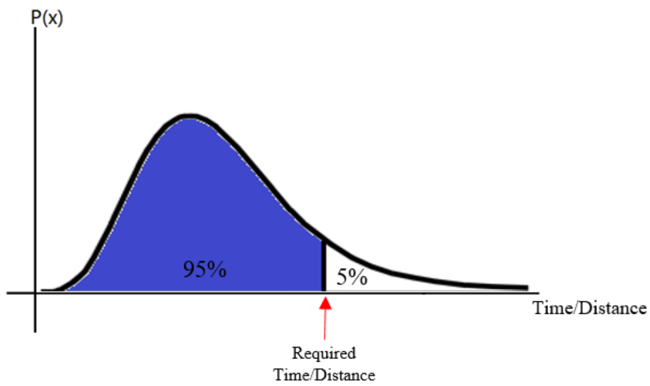

Figure 3: Finding Required Time/Distribution for Non-normal distributions

Total Cost Equation

The total cost includes two components: transportation cost and inventory cost.

$$\underbrace{Total\ Cost: [CPL \times D]}_{\text{Transportation Cost}} + \underbrace{\left[\frac{h}{8760} \times C \times D \times d \times t(\mu, \sigma, service\ level)\right]}_{\text{Inventory Cost}}$$

Where:

CPL= Carrier cost per load ($/l).

D= Annual demand of the lane in number of loads (l).

h/8760 = Inventory holding rate ($/$/h).

C= Value of the load ($/l).

d= Distance (mi.).

t(μ, σ, service level)= Time/Distance for a given service level (h/mi.).

1) The transportation cost is a function of the carrier's cost and the volume of the lane. This rate is provided by carriers and varies between lanes. It considers not only the distance between the origin and destination points but also geographic factors that could impact the transportation mode performance. The rate is also dependent on the volume of demand.

2) The inventory cost is determined by the level of safety stock (SS) that the company should maintain in order to protect against transit time uncertainty. The safety stock is a function of the demand during the transit time plus a buffer to cover for the transit variability. The transit time and its variability are given by the distance and the parameters we set for the Time/Distance probability distribution. To calculate the cost of the safety stock we included the monetary value of a load and the inventory

holding rate defined by the company.

Discussion

ABC Stores' dataset contains 1662 different transportation lanes. Of these 1662 lanes, ABC Stores uses truckload more frequently for 64% of the lanes, intermodal more frequently for 35%, and uses both modes with the same frequency for less than 1% of lanes (13 lanes). This last set of lanes was excluded from the analysis.

Having constructed the total cost equation, we applied the model to ABC Stores' dataset to generate transportation mode recommendation for 1649 lanes. For this initial comparison, we used the actual demand of each lane provided in the dataset. For the load value, we assumed an average of $25,000.

Our model's recommendation coincides with ABC Stores' mode choice on about 74% of the lanes. For 4% of the lanes, our model recommends intermodal while the company uses truckload. Twenty-one percent of lanes were assigned to truckload by our model while ABC Stores uses intermodal. These results show that the total cost equation recommends truckload more often than what ABC Stores selects.

Sensitivity Analysis

To investigate the impact of different load values on mode selection, a wide range of load values, from $1,000 to $120,000 were used to compute the total cost using the total cost equation. Values ranging from 1 to 100 were used to evaluate how changes in the volume affect the percentage of lanes assigned to each transportation mode. We also measured the dynamics of mode selection changes with respect to service levels from 0 to 100%.

These sensitivity analyses show that:

- The variation in the model's recommendation when using parameters of the Normal vs. Lognormal distribution is insignificant, as can be seen in Figure 4. The horizontal axis represents the load value measured in dollars per load and the vertical axis represents the percentage of lanes assigned to a specific mode. The blue (TL(ND)) and grey (TL(LnD)) lines represent the percentage of lanes assigned to truckload using normal and lognormal distribution, respectively. The orange (IM(ND)) and yellow (IM(LnD)) lines represent the percentage of lanes assigned to intermodal using normal and lognormal distribution, respectively.

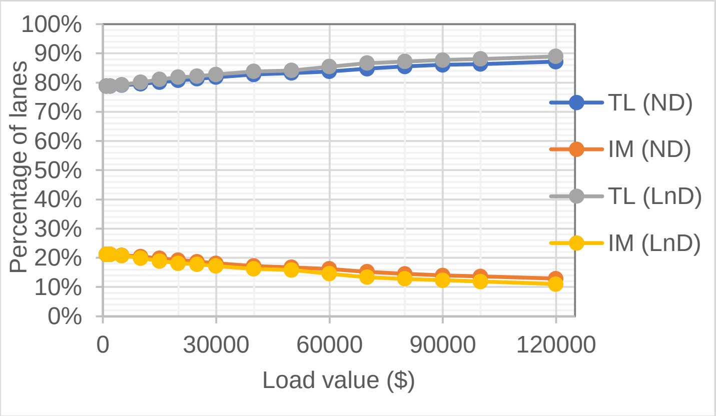

Figure 44: Sensitivity Analysis based on Load Value

- An increase in the load value would enlarge the difference in inventory cost, increasing truckload's cost advantage.
- As the volume increases between 0 and 20 loads per year, the percentage of lanes assigned to Intermodal increases.
- The percentage of lanes assigned to truckload increases as the service level increases.

Conclusion

We investigated how to optimize the transportation mode selection process for ABC Stores. We developed a total cost equation that integrates transportation costs and transit time variability in terms of inventory costs. The main findings of this study show that:

- The average and standard deviation of transit time are impacted by distance. The relationship between average transit time and distance is non-linear as there are many other factors such as driving hour limitation, pick up delay, etc. that are also relevant to transit time.
- The expected transit time of truckload is shorter than the expected transit time of intermodal (lower mean).
- For this particular dataset, the model generally favors Truckload over intermodal because the lower average and standard deviation result in lower inventory costs. Therefore, most of the lanes are assigned to truckload.