Incorporating Cycle Time Uncertainty to Improve Railcar Fleet Sizing

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Summary: In this research, we address the issue of developing a method for a private fleet manager to determine the appropriate number of railcars in a fleet. We focus on incorporating the variability of railcar cycle time into the fleet-sizing decision. In addition, we recommend a process that enables fleet managers to use distribution fitting and simulation to understand the expected requirements of their fleet capacity. Finally, we suggest an economic approach to making the fleet sizing decision.

KEY INSIGHTS

1. By measuring cycle time variability and using it to drive fleet sizing decisions, managers can identify lanes that are forcing excessive fleet requirements.

2. The use of distribution fitting and Monte Carlo simulation can help a fleet manager gain a more accurate projection of fleet size requirements.

3. By comparing the cost of excess capacity with the cost of under-capacity, a fleet manager can determine how much risk he or she should take in selecting a fleet size.

Introduction

Determining the appropriate fleet size for a shipper that operates a private fleet is a challenging task. In selecting the size of the fleet, fleet managers must balance the high customer service expectations of their channel partners, the variability of product demand and transit operating times, and the desire to achieve high asset utilization performance from the capital invested in their fleet.

In this research, we address the issue of developing a method for a private fleet manager to determine the appropriate number of railcars in a fleet. Specifically, we focus on the incorporating the variability of railcar cycle time (the time it takes a railcar to make a complete trip from origin to destination and back to the origin) into the fleet-sizing decision. In addition, we recommend a process that enables fleet managers to use distribution fitting and simulation to understand the expected requirements of their fleet capacity. Finally, we suggest an economic approach to interpreting the results of the simulation in order to make the fleet sizing decision.

The intent of this research is to improve the process by which managers perform the fleet-sizing analysis and to develop a method that provides greater insight into the effect of cycle time variability on fleet size requirements. By considering the effect of cycle time variability on the requirements of the fleet, managers can ensure that their fleet size selection is in line with the risk tolerance appropriate to balance the needs of customer service with the asset utilization of the fleet.
Research Scope

We worked with a large chemical manufacturer that ships a variety of liquid products in bulk form. The identity of this chemical company has been masked in this report and will be referred to as Kendall Square Chemical Company (KSCC) in the remainder of this document. The primary customers of KSCC are industrial manufacturers who use these products as raw material inputs into their own process. The primary transportation mode used by KSCC is rail. Because of the specialized handling requirements of its products, KSCC, like many companies in the chemical industry, is forced to maintain a private fleet. KSCC’s fleet includes several sub-fleets which are each divided along product families. All cars in the fleet are either owned by KSCC or leased under a long-term agreement (10 to 20 years). We used actual transit time data from KSCC’s fleets in order to conduct the analysis in this research. However, all data and fleet sizes displayed in this document have been masked in order to disguise proprietary data.

Research Approach

In our research, we evaluated three different methods of fleet sizing strategies in order to compare and contrast their benefits. In the first two methods, we performed deterministic analysis using basic descriptive statistics to arrive at a recommended fleet size. In the third method, we used a stochastic model that involves distribution fitting of the underlying cycle time data and a Monte Carlo simulation to develop distributions of required fleet sizes. From this third model, we have also demonstrated the potential value of using an economic model to select an appropriate fleet size by comparing the cost of extra railcar capacity with the cost of insufficient capacity. These methods are described in the following sections.

Method #1: Current Practice – Mean Buffering

The current method employed by KSCC is to determine a fleet size by calculating the mean cycle time for each origin-destination pair within a fleet. Once the mean cycle time is calculated, it is combined with information about the annual demand of the customer and the capacity of a railcar to determine the number of railcars required for servicing this customer. Once the requirements are determined for each pairing, KSCC buffers the total fleet size by increasing these mean requirements by fifteen percent. This buffering is intended to protect against uncertainty and variability in the system.

The most significant limitation of this model is that it does not use the variability of railcar cycle time as input to help determine an appropriate fleet size. By failing to use this property of the cycle-time data, the current model is forced to use a percentage buffer against the mean.

Method #2: Incorporating Transit Time Variability

In this method we introduced the standard deviation of transit time data into the fleet sizing process. This method arrived at a fleet sizing decision by using the mean and standard deviation of transit time data under the assumption that the data can be characterized by a normal distribution. While we will later show that the assumption of a normal distribution is, in some cases, flawed, this method can be used to demonstrate the insight that can be provided by incorporating transit time variability.

![Figure 1: Comparison of Methods 1 & 2](image)

For this method, we set the fleet requirement for an origin-destination to cover the total cycle time of the 65th percentile value on the cumulative distribution function, in order to offer an alternative to the current method of buffering the mean by 15%. The resulting values for each O-D pairing are then summed to find a total recommended fleet size. As can be seen in Figure 1, the aggregate total fleet size recommendations of Method #1 and Method #2 are similar at 136.2 and 134.6 respectively. However, by looking at the requirements for individual O-D pairings, significant differences between the two models can be seen.
To demonstrate this difference, consider the cases of City B and City F. In city B, the coefficient of variation of transit times is high, and as a result of this high degree of variability, Method #2 recommends 3.6 railcars more than Method #1. In City F, which has a coefficient of variation of only 0.11, Method #2 recommends 2.5 fewer cars than Method #1 because of the low variability of the destination. This highlights an important advantage of a method that incorporates transit time variability. Incorporating variability enables fleet managers to set high buffers for highly variable destinations, while maintaining smaller buffers for less variable destinations. In addition, Method #2 would help a fleet manager to easily identify the components of cycle time for destinations that account for the most variability. He or she can then focus on managing the variability in these components in an effort to reduce overall fleet size requirements.

While Method #2 allows for the recognition of transit time variability in the fleet sizing process, it is flawed in its assumption that all transit time distributions follow a normal distribution. This flaw is explained in more detail in the following section during the discussion of Method #3.

**Method 3: Distribution Fitting and Monte Carlo Simulation**

In Method #3, we used a Monte Carlo technique to simulate railcar cycle times in order to create a distribution of required fleet sizes. The first step in this approach was to use historical cycle time data to fit probabilistic distributions for each leg of the railcar cycle for each origin-destination pairing. In the Monte Carlo simulation, railcar cycle times were replicated using a random number generator and the probabilistic distributions of cycle times. These simulated cycle times were then converted to railcar requirements to form a histogram of required fleet sizes. This histogram maps the range of possible outcomes for fleet sizes based on the distributions of the transit data used in the simulation process.

This method has several important implications for fleet managers. One such implication is the importance of distribution fitting to characterize the skewness of the underlying cycle time data. By not assuming a single distribution type to characterize transit data, this method enables the fleet size requirements to accurately reflect the nature of the underlying data. To illustrate this we offer the following two examples.

Figure 2 shows an example of a destination in which the distributions for each of the three phases of the cycle time have a small amount of skewness. As such, the resulting distribution of fleet size requirements is symmetric around the mean.

![Figure 2: Fleet Size from Symmetric Distributions](image)

However, our research demonstrated the distributions of cycle time data for KSCC are frequently not symmetric. As a result, the fleet size requirements in these cases will also be skewed, as you can see in Figure 3. If these distributions were assumed to be Normal, as in the case of Method #2, the result would be an over-estimation of fleet size requirements.

![Figure 3: Fleet Size from Skewed Distributions](image)

An additional benefit of Method #3 is that by creating a distribution of fleet size requirements rather than a deterministic value, it enables a fleet manager to employ a variety of risk management techniques to arrive at an appropriate fleet size. We describe one such technique in the following section.
An Economic Model: The COST PERCENTILE Method

In order to determine the point on the distribution of possible fleet sizes that best balances all of the competing goals in fleet management, we recommend that an economic model be used which balances the cost of having excess capacity of railcars with the cost not having enough to meet demand. In order to develop this idea, we adopted a concept from inventory management known as the Newsvendor Model.

In an inventory context, the Newsvendor analysis is applied when a set of conditions are met that require someone to purchase material before true demand is known. In this context, there is a cost penalty associated with not satisfying demand as well as a cost associated with ending the selling period with excess inventory. In order to find an order quantity that balances the risks of these two costs, the Newsvendor model uses a calculation known as the critical ratio. We have adopted for use in railcar fleet sizing and refer to it as the COST PERCENTILE. After discussions with a KSCC stakeholder regarding the cost impact of various mitigation strategies for a railcar shortage, we calculated the COST PERCENTILE to be 0.70.

After determining the COST PERCENTILE value, we select the point on the cumulative distribution of fleet sizes that corresponds to the COST PERCENTILE value (in this instance, 0.70). This point is at the intersection of the two arrows in Figure 4, and occurs at a value of 125 railcars.

Therefore, the recommendation for this fleet using the COST PERCENTILE method with the stated overage and underage assumptions is to select a fleet size of 125 railcars. It must be noted that although there are similarities between Newsvendor analysis and railcar fleet sizing decisions, further research should be conducted before directly applying this economic model.

Conclusion

The implications of our research for a fleet manager are as follows:

1. Incorporating cycle time variability into a fleet sizing model is necessary in order to gain an accurate understanding of the underlying sources of volatility in the fleet. By measuring variability and using it to drive fleet sizing decisions, managers can begin to identify lanes that are forcing excessive fleet requirements and focus efforts to reduce variability.

2. In the case of Kendall Square Chemical Company, assuming that the distributions of transit times are normally distributed leads to an over-estimation of fleet sizes. This over-estimation of railcar requirements can be prevented by recognizing the distributions of cycle time data. In many cases, transit and customer holding time data exhibit positive skewing. This skewing results in the mean providing an inaccurate depiction of the central tendency of the data. The use of distribution fitting and Monte Carlo simulation can help a fleet manager gain a more accurate understanding of fleet size requirements.

3. There is potential to factor in economic considerations when selecting a fleet size from a distribution of size requirements. By comparing the cost of excess capacity against the cost of under-capacity, a fleet manager can determine how much risk he or she should take in selecting a fleet size.