Analyzing Carton Efficiency

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Supply chain professionals are often faced with the difficult packaging tradeoff between streamlining with a few carefully selected carton sizes or cutting down on void space at the expense of throughput with a larger selection of carton sizes. The cost benefit analysis quickly becomes quite complicated when there is due consideration for material suppliers' volume discounts, freight charges, damage claims, order history, and more. In a recent trip to a client's distribution center, we learned that they made the decision to streamline and ship several thousand random piece orders per day with only a handful of different carton sizes. Making the decision to cut down to only a few carton sizes has brought benefits. After feeling the pressure from increasing order demands, cutting down on the number of sizes brought a welcomed boost to operator performance. Excess material costs from operator error also decreased, because the farther apart cartons are in size the less likely an operator will overshoot and use the next larger size. They have negotiated competitive volume discounts from their consumable supplier because they are ordering large volumes of only several carton sizes to meet their order demand. This example builds a case for the advantages of cutting down on the number of different cartons sizes a distribution center uses, but raises questions: What number of different carton sizes is most efficient? When does the cost of adding another carton size exceed the benefit of reduced void space? What are the best carton sizes to use?

For the distribution center in this example four sizes appear to be working well enough, but this begs the question: How did they choose those carton sizes?—and how would their material, labor, and freight costs change by shifting the sizes around, adding another size, or cutting out a superfluous size? With the advantages brought by reducing carton sizes comes the risk of elevated costs associated with using inefficient carton sizes. Since many warehouses are storing dimensional and weight data for each item, it possible to perform large scale quantitative analysis on a distribution center's order history. With an item file and some orders for a given span of time it is possible to repeatedly model "what-if scenarios" and provide insight into what costs could have been, given changes to the number and size of cartons used. Such careful analysis is critical to encapsulate the advantages from cutting down on carton sizes while maintaining efficient carton utilization. The frequency distributions in the figures 1 and 2 show the smallest possible cartons a population of orders could fit. The blue shaded regions show the subset populations that fit inside of a particular carton size. The arrows point to the largest area of the order population within each carton size. The arrow location is an indication of the carton's efficiency. Orders close to the right side of a carton's range take up the most space in the carton and are hence an efficient fit. Choosing carton sizes that cover a range where large areas of the population reside on the right side of the carton's distribution means more orders are going into a well suited carton. By

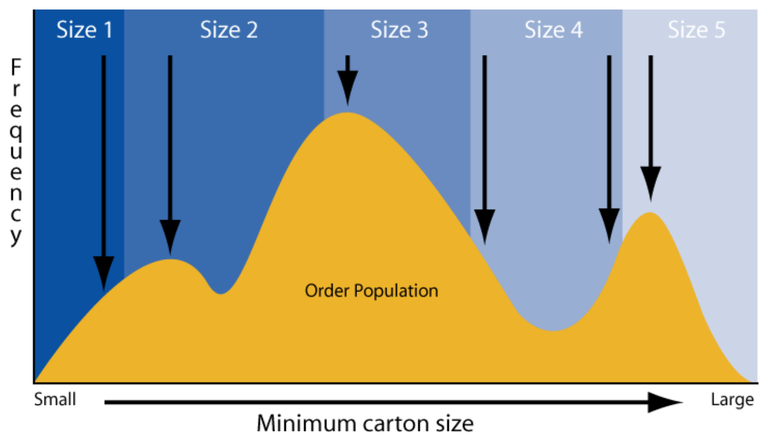

Fig. 1— Poorly suited carton sizes

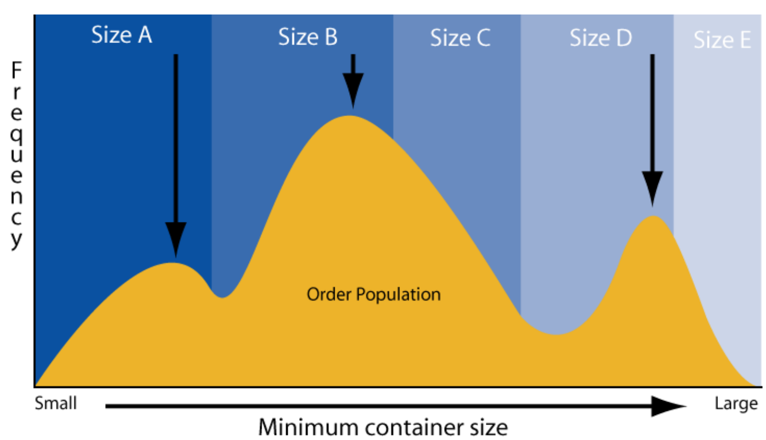

Fig. 2— Improved carton sizes

adjusting the carton sizes thus changing their subset populations, it is possible to produce the more desirable scenario shown in figure 2. Analyzing an order population's packaging needs is essential to make informed decisions about carton sizes.

Taking dimensions for individual items in an order and determining the best possible carton is an extension of the well known "knapsack problem" that has occupied the minds of mathematicians and professionals in almost every industry. For every order there is a theoretical perfect carton size that leaves the smallest amount of void space. Visually, this is packing the items together as tightly as possible and then drawing a cuboid around the ensuing combination. Assuming an infinite number of carton sizes, with the proper software algorithm it is possible to take an order population and generate a frequency distribution of these perfect carton sizes. Previous methods to answer these questions have been attempted using liquid volumes (the product of the dimensions), but these methods fail to provide a high enough level of precision. A liquid volume discards information about the shape of each item that is necessary to choose a specific carton size. Liquid volume estimates provide insight into neighborhoods of carton sizes by volume, and with summary data about the dimensions of items, reasonable guesses can be made about what size cartons to use. However, an infinite number of cartons can have identical volumes. Choosing the ratio of the carton's dimensions is an integral part of choosing optimum carton sizes for which liquid volumes provide no insight.

While the necessary computational power previously required costly mainframe computers, modern consumer computers are now powerful enough to apply algorithms that examine items in an order as their respective shapes and keep track of the ideal cartons (the cuboid drawn around each combination) for every possible arrangement of the items. Having all of the possible arrangements, not just the arrangement with lowest total volume, is important. For every ratio chosen to be examined, there will possibly be a different ideal carton resulting from a different arrangement of the items inside, because the ratio of the arrangement dimensions likely does not exactly match the ratio of the carton used. Generating frequency distributions of ideal carton sizes for an order population has the caveat that a fixed ratio of the carton's dimensions must be chosen. While this necessitates analyzing multiple frequency distributions, a systematic approach to this analysis can readily determine the ideal combination of cartons.

This method is essentially a "ground up" approach to determine optimal carton sizes for a given order population. With the frequency distributions, one can take a particular carton size and view the subset of the population that will fit inside of it. This generates a good estimate of how many orders would go into this carton on the average if it was used in the distribution center, but more importantly it also shows the carton's relative efficiency for void fill. For each carton and order, there is a total liquid volume of the items in the order and a total liquid volume of the carton. The difference is the amount of void space remaining. For a population compatible with a given carton there is a distribution of orders by volume that shows the quantity of orders that are going to leave the most and the least void space. The best possible scenario is for an upward sloping distribution with a peak at the end, which would mean most orders going into this carton leave little void space. In such a case, the efficiency of the carton is high, average cost per order is at an optimal level. Looking at these distributions can guide the selection of carton sizes. For instance, a parabolic distribution strongly suggests splitting the population between two carton sizes. A downward sloping distribution indicates relatively low efficiency and a high cost per carton, suggesting a different carton size should be chosen.

For each frequency distribution, the goal is to isolate large populations (peaks) and choose a carton size that accommodates them. When going on to analyze further distributions with other carton dimension ratios, the efficient population of orders meant to go into a chosen carton size should be removed and the remaining population examined. This method of looking for peaks in distributions, assigning an ideal carton size, removing them from the population, and then reexamining the remaining population can be repeated until all of the orders are taken out. This method requires a structured approach to examine many different combinations of carton sizes using many different carton dimension ratios, but through multiple analyses clearly optimal solutions emerge. Thus, the order population frequency distribution in figures 1 and 2 is just one of many for a given fixed ratio. Several apparent peaks suggest optimum carton sizes, while the sizes that are not ideal may be better suited to fit in carton with a different ratio of dimensions.

A method of analyzing multiple ratios is to start with a cube shaped ratio (1:1:1) and work outward. This ratio has the largest volume per square inch of cardboard making cube shaped cartons the best value. Isolating populations and examining remaining orders by looking at distributions for carton dimension ratios that become more and more elongated rectangles (increasing the cost per cubic inch of the carton) is reasonable heuristic, but it is also appropriate to examine other possible combinations. What eases the complexity of this process is that two different sets of cartons can be objectively compared and one appear decidedly better. The final result of this analysis is a set of carton sizes that have been rigorously shown to have produced outstanding results if previously used in the distribution center.

Going forward, getting the best results from these optimized sizes requires regular reevaluation of ongoing sets of orders to monitor the order population for changes. When distributions for the current sizes in use appear to fall out of optimized calibration, adjustments can start to be made to prevent waste from non-optimized carton sizes. Regularly reevaluating order distributions introduces a dynamic element to packaging that most operations lack. This level of responsiveness can significantly increase efficiency when applied at time intervals ranging from quarterly to every couple years. Alternately, when it is known that the order population is going to change (from the addition of a new category of items or beginning to distribute to a new audience of customers for example) applying this kind of analysis can prevent a costly trial and error period when determining the best carton sizes.

An additional application of this is to examine order populations in a seasonal fashion to look for differences in the peak season and off season. Analysis can determine an optimized set of peak season carton sizes and a set of off season carton sizes. This can prove to be very efficient compared to merely adding extra sizes for peak seasons. Using a large numbers of cartons may appear to save on void fill, but can incur other costs that erode savings. Operators have an easier time quickly selecting the right carton when a handful of cartons sufficiently spaced apart in size are used. Increasing the number of cartons requires more time to select the proper size, can slow down operators if they choose a carton that is too small and must start over, or can end up not being beneficial at all if the operator overshoots and does not use the best carton, erroneously opting for the next size up. The last scenario increases in likelihood as the number of available carton sizes increases.

For any distribution center, looking at the frequency distributions for the current carton sizes in use can be very telling. Before reevaluating the number of cartons and their sizes, examining current cartons provides a starting point that can used be preview the significance of potential cost savings from optimization. The goal of robust order analysis to recommend carefully selected carton sizes that would have produced outstanding results if used during the given order history. Ongoing dynamic analysis can show when these sizes are becoming outdated and guide further adjustments. For high volume warehouses, careful shifts in carton sizes can significantly improve material, labor, and freight costs and command reexamination by any supply chain professional looking to cut costs.