Production Planning with Complex Cost Drivers

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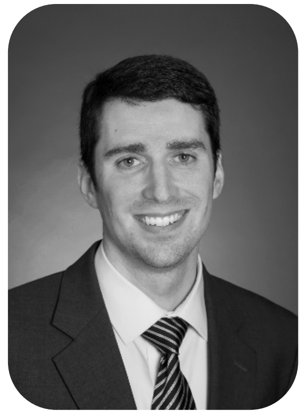
Summary: This thesis provides a new lot sizing model formulation for manufacturing firms that contract third party logistics (3PL) provider's warehouses. The formulation extends existing models to account for the change in inventory holding costs depending on 3PL warehouse utilization. In addition, it provides a novel method for considering multi-tiered setup costs for products that share common setups. The new formulation produces production plans that reduce relevant supply chain costs for firms with these features.

Before coming to MIT, Ian Chua graduated with his Bachelor's degree in Mathematics & Economics from Pomona College. Following that, he has worked around the world in the seafood and sand commodity industries. Upon graduation, Ian will join The Fung Group in their Management Development Program.



Before coming to MIT, Thomas Heyward graduated with his Bachelor's degree in Mechanical Engineering from University of Virginia. Following that, he gained experience managing equipment suppliers as a subsea engineer at Chevron. Upon graduation, Thomas will join Aurora Flight Sciences as a Supply Chain Engineer.

Key Insights

1. Manual planning processes are time consuming and limited in the number of cost drivers that can be focused on.
2. Implementation of lot sizing problems requires the right formulation that fits the business environment.
3. Production lot sizing optimization is not always a trade-off between setups and inventory. In some cases, improvements can be made in both areas simultaneously.

Introduction

Many manufacturers have to strategize around seasonality and capacity constraints when planning production schedules. Companies need to come up with production schedules that consider demand, inventories, production capacities, and when to use 3PL services. Typical production strategies prioritize maximizing line efficiency which favors large lot sizes and few setups. On the other hand, logistics strategies prioritize minimizing inventory costs which favors smaller lot sizes and more setups. Lot sizing problem formulations provide a means for considering both setup and inventory costs to achieve the optimum balance.

Niagara Bottling Co (Niagara) sponsored thesis research with MIT to improve their production planning process. Niagara wanted a method that explicitly considered the cost impact that production lot sizing decisions have on utilization of 3PL warehouse space.

Operational Context

Niagara operates with a complex network of production facilities. Each plant has multiple production lines capable of producing a variety of products. The products produced on a line can have shared attributes of bottle size and package size. Switching between products that do not share these attributes constitute a longer changeover time than switching between products that do.

Niagara demand has seasonality with peak demand exceeding production capacity during certain periods of the year. Niagara prepares for the peak season by building inventory during periods with excess capacity. The inventory needed for peak seasons are stored in 3PL warehouses.

Niagara plants have some limited inventory warehousing capacity. The plant warehousing cost structure is significantly lower than the cost structure for the 3PL warehouse. Additionally, there are transfer costs associated with transporting and handling of inventory entering the 3PL warehouse. Niagara expects that because of this cost structure, transfers to the 3PL warehouse should only occur during periods where inventory is being built for the peak season.

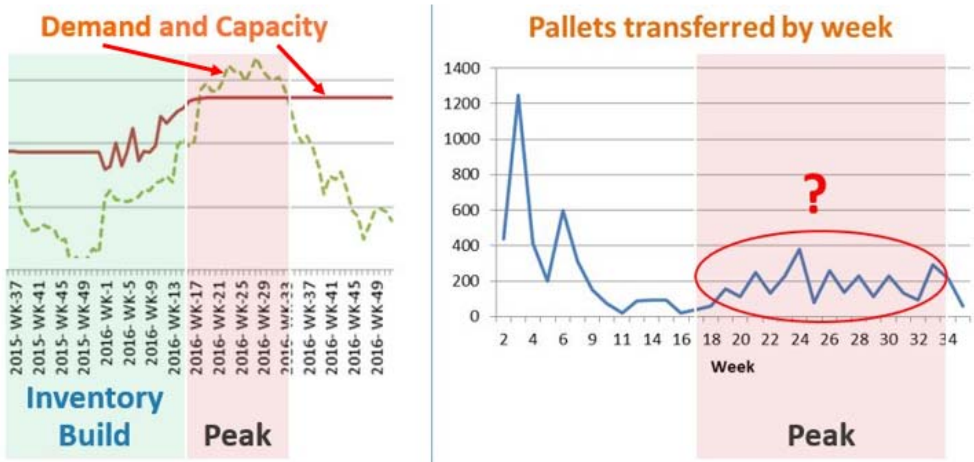


Figure 1: Transfer events during peak demand

Instead, Niagara has observed that even during peak periods, inventory is being transferred to the 3PL warehouse as shown in the Figure 1. This behavior is attributed to large lot sizes that maintain high utilization of the machines, but are incurring increased inventory holding costs. Hence this thesis focuses on explicitly incorporating 3PL holding costs into Niagara's production planning process.

Capacitated Lot Sizing Problems

Given the specific features of Niagara's business, we developed a formulation based on the Capacitated Lot Sizing Problem (CLSP). The basic CLSP formulation accounts for the capacity limitations and seasonal demand changes faced by Niagara. The different production features of each line are incorporated using an existing extension in the literature for multiple machines.

However, certain aspects of Niagara's business could not be modeled using the existing formulations. A new extension for the formulation was devised to address these features. Additional variables were introduced to track the amount of inventory in 3PL warehouses and when an inbound shipment occurred. Other variables were added to track the changeover of major setups for bottle sizes or packaging separate from minor setups for labels.

Adding these features to the model provided the necessary integrated framework for assessing tradeoffs between production and logistics cost considerations.

Implementation

The model formulation was implemented using Gurobi optimization and Python software. These tools allowed the model to find a solution when considering the myriad products and machines in Niagara's network. The model has the flexibility to span the planning process from strategic to operational. For the purposes of this thesis, we focused on tactical planning using a weekly time period and aggregated product demand at a bottle-package level. This presented the greatest opportunity for Niagara since tactical planning is relatively less developed.

Setup costs were derived as the opportunity cost of not producing bottles while the machine is down during the changeover. Holding costs were calculated using annual warehouse costs including labor, insurance, rent, and tax. The annual costs were converted into a weekly cost per footprint of storage.

A representative subset of Niagara's national network of plants and 3PL warehouses was used to validate the functionality of the model. This representative region included twelve production lines across three plants capable of producing 90% of Niagara's products. The region also includes a central 3PL warehouse for extra inventory storage.

Some comparison with actual production data was made, however, its utility as a benchmark is limited. Production data reflects daily plans on an SKU level whereas planning results are aggregated. In addition, the model used the actual demand data for the entire time horizon, which was not available at the time production decisions were made. Therefore, an additional benchmark was performed comparing the model results to a manual plan developed using current practices at Niagara.

Sensitivity analysis was performed to assess the robustness of the model to changes in the relative holding and setup costs. The holding and setup costs were increased by a factor of two and four independently. The resulting number of setups and amount of inventory held were compared to assess the impact these changes had on the plan.

Results

The representative region benchmark demonstrated the full functionality of the model. The results showed a 33% reduction in setup and inventory costs compared to the actual production data. Although the cost comparison is suspect for the reasons already stated, the model results do reveal a possible way to reduce inventory costs. The actual inventory data showed that the plant warehouse

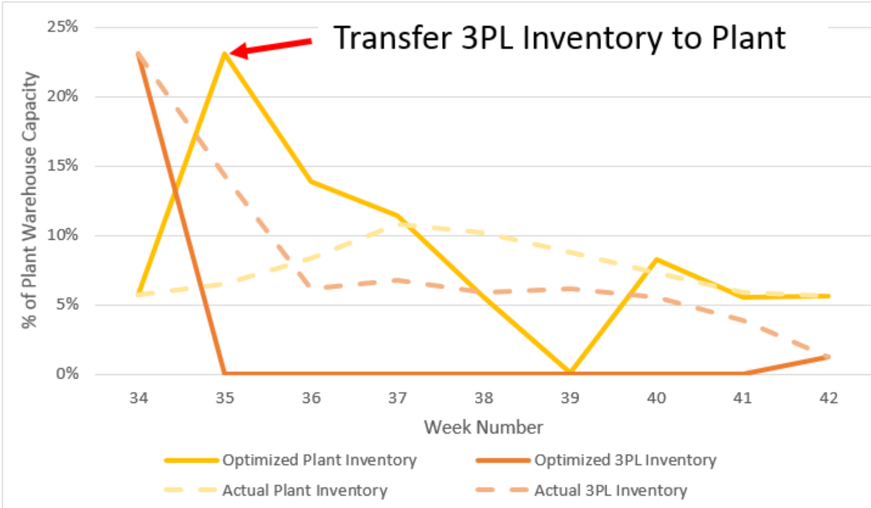


Figure 2: Transfer inventory from plant to 3PL to lower costs

was underutilized while there was still significant inventory in the 3PL warehouse. The model moved this inventory into the plant to reduce holding costs as shown in Figure 2. Although there are some costs not considered by the model in executing this strategy, it represents cost savings worth further exploration by the company.

The benchmark against the existing planning process is more informative on cost comparison. The model formulation showed a 22% reduction in setups, a 9% reduction in inventory, and a 74% reduction in transfer events. The findings are remarkable in that both setups and inventory were reduced. The model reduces setups by increasing inventory of slow moving products. This increase in inventory is offset by reduced lot sizes for the fast moving products. This shows the cumulative demand for fast and slow movers and the cumulative production for the manual plan and the model. It's clear that the manual plan cumulative production for fast movers exceeds demand, which increases inventory. Whereas the model is able to build less than cumulative demand by drawing down existing inventory.

The reduction in transfer events is significant. This is likely a function of the limits of a manual planning process. Visualizing the trade-off between setups and inventory is straightforward. However, understanding which items are best to hold at the 3PL warehouse to reduce costs is more complex and time consuming.

The sensitivity analysis showed a +/-6% change in setups for a corresponding 300% increase in setup cost or holding cost. The inventory increase under these conditions was 174%, but only increased the average plant warehouse utilization from 3.4% to 9.4%. These results indicate that the model is relatively robust to inaccuracies in input costs.

Conclusions:

The implementation of a lot sizing model allows more complex cost considerations to be accounted for in the planning process. This improves cost performance while also reducing the effort required for planning. Capturing cost savings by business process improvements like this are compelling. A company can reduce their costs with little investment because the improvement comes from better utilization of their existing assets.

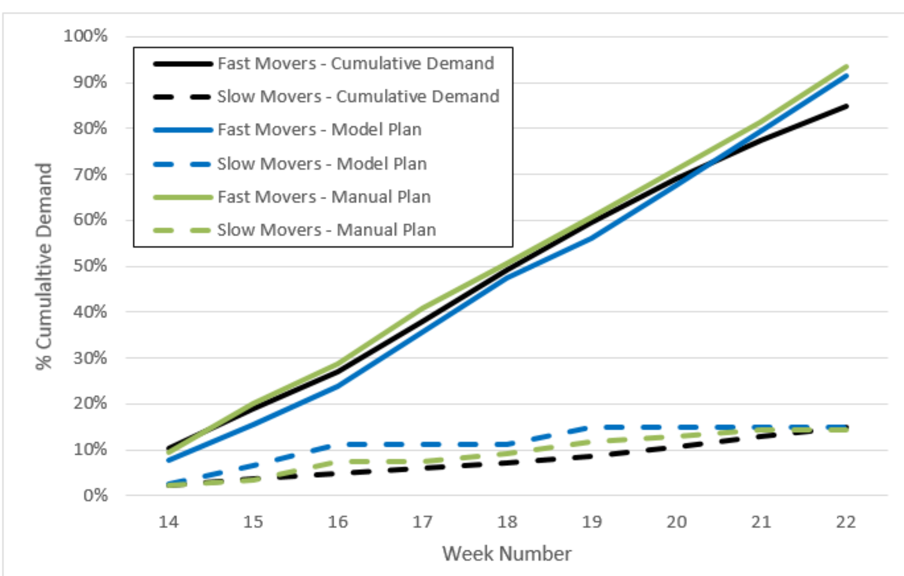


Figure 3: Cumulative Production relative to Demand