Modeling the Tradeoff between Inventory and Capacity to Optimize Return on Assets

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Summary: In the agrochemical industry, balancing supply with extremely seasonal demand has been a struggle for most companies due to their capacity constraints. Stocking enough inventory ahead of the peak seasons and increasing the production capacity are two ways of resolving the issue. Our research examines an approach to achieve the optimal mix of production capacity and inventory for a company to meet customers’ demand at the highest net present value (NPV) of operating assets value add (OAVA). We use a multi-period, multi-stage, multi-product mixed integer linear optimization model to determine the best combination of resources.

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KEY INSIGHTS

1. When several products compete for the same production resources, priority should be given to the one with the highest ratio of value to processing time.
2. Having enough capacity to meet demand at all times could be financially counterproductive.
3. A capacity increase in a bottleneck resource across the production process might switch the bottleneck status to another resource. Management must keep an ongoing effort to continuously find out constraints of their production process.

The Problem

When faced with an extreme seasonality in demand driven by the crops’ growing cycles, companies in the agrochemical industry might accommodate such fluctuating demand by stocking inventory or increasing capacity. But either alternative comes at a cost. This research seeks to find out the optimal mix of production capacity and inventory for the company to meet customers’ demand at the highest net present value (NPV) of operating assets value add (OAVA) over the planning horizon. We aim to improve companies’ financial performance by both fulfilling demands in peak seasons and achieving the highest level of return on operating assets in the form of OAVA.

Methodology

We analyzed the sponsoring company’s production process to understand the current configuration. Figure 1 shows the conceptual model of the production process.

Figure 1: Conceptual Model of the Production Process
The production facility receives raw materials from different vendors, which are initially processed at the pre-mixing and formulation tanks. Afterwards, the chemicals move into a storage tanks before they can be packed in either bottles or drums. Each one of the stages briefly described has a different processing time and capacities. In order to evaluate the best possible configuration of the process, we first defined a metric of success that we could aim to optimize. Such metric is the OAVA. The logic behind selecting the NPV of the OAVA as the ultimate metric of success is to model the return on operating assets in a linear way, while still capturing the combined financial effects of revenues, costs, operating assets and cost of capital. The outputs of the model are the detailed master production schedule as well as a suggested capacity management.

**Defining the Model**

The mathematical logic underneath the optimization model is expressed as follows:

1. **Objective Function:**

Maximize the NPV of OAVA over the 10-year planning horizon. The OAVA is the revenues minus cost, or gross profit, minus the cost of capital times the average asset value. The components are broken down in the following way:

- Revenue is obtained as a markup of the production cost times the demand.
- Cost includes holding, manufacturing, outsourcing, overtime, and depreciation costs.
- Asset value includes capacity and inventory values. These refer to the average value of the equipment and the inventory during the planning horizon.

2. **Constraints:**

The model is subject to the following set of constraints:

- The solution must meet demand for each period combining resources in the most efficient way.
- Any stage in the production process can only produce as much as is available from the previous stage.
- Each production stage has a specific capacity that cannot extend at regular cost.
- We cannot dispose of capacity once we chose to increase it at any point in time.
- Third party manufacturers have a minimum and maximum quantity they are willing to outsource.
- Production and inventory can never be negative.
- Optionally, we can force all variables to be integers.

**Capacity Management Suggested by the Model**

As applicable to our sponsor company’s operations, there are three options to increase capacity: acquiring new assets, outsourcing and overtime (OT).

1. **Acquiring New Assets**

Pre-Mix & Formulation (PM&F), Storage, and Packaging (PCK) are the three stations that can acquire assets and upgrade capacity limits.

Since the investment in acquiring new assets increases the value of operating assets significantly, and the straight-line depreciation as an operational cost recurring from the first period of the asset acquisition further burdens the operating assets value add (OAVA), our model suggests to acquire new assets for all three expandable stations only after exhausting other capacity increase options such as outsourcing and overtime resources.

For example, before the 1st capacity upgrade for PM&F in the 5th year, there were at least 5 consecutive periods each year where utilization rate reaches 100% from Year 1 to Year 5. Similarly, in each year prior to the 2nd capacity upgrade in the 8th year, utilization rate for the peak season reaches 100% and lasts for 5 consecutive periods as well. The yellow shaded areas in Figure 2 illustrate the capacity upgrade timings in Year 8 for PM&F and PCK respectively.

The reasons for such postponed asset acquisition might be two-folds. Firstly, the cost calculations from either outsourcing or overtime might be more preferable than the double impact on OAVA from acquisition in both the asset value increase and the asset depreciation as an operational expense. Secondly, the demand can be fulfilled by outsourcing or overtime, making asset acquisition not necessary.
2. Outsourcing

With a 40% markup to the production cost, our model shows that outsourcing should be enabled only after applicable overtime capacity, which is entitled a 25% markup, is pursued. This idea is demonstrated in the upper chart of Figure 2, where the light green columns, representing outsourced volume, only appear after the pink columns, representing OT volume, are present.

However, the lower chart of Figure 2 doesn’t show the prioritization for OT. This is because outsourcing takes over the end-to-end production process through PM&F and PCK in series. That is, once outsourcing is pursued, the same amount of products will be outsourced for both stages. Therefore, overtime cannot replace either outsourcing production stage and is not an applicable alternative even though its cost is lower.

3. Overtime (OT)

Since 25% markup makes OT a preferable alternative to other capacity increase options, the model suggests pursuing OT during the peak season (Aug to Dec) throughout the 10-year horizon of our research scope.

Remarks on Asset Utilization

The optimal solution did not employ more than 80% utilization for any stage of the production process. We developed a second scenario in which the objective function aimed to maximize asset utilization, and constrained the model not to produce beyond the level of demand. Figure 3 below summarizes the contrasts between these two approaches.

In the max utilization scenario, the utilization rate is well above the optimal solution and the total production cost (manufacturing, outsourcing and overtime costs) is lower than in the optimal solution. However, OAVA drops significantly when compared to the optimal solution, thus confirming that utilization alone cannot judge the system’s performance as a whole.

Conclusions and Future Research

There are a variety of resource configurations that can help drive the corporate objective based on different demand patterns. Therefore, a strategized combination of these resources is critical in accomplishing the optimal net present value of OAVA. The master production schedule, the resulting inventory levels, and the recommended timings for external resources and asset acquisition serve to communicate with stakeholders across different functional teams with potentially conflicting interests.

Our optimization model handles a simplified version of reality. Managers should not assume that the outcome of this simulation is a perfect predictor of the future and should further tweak the model to better assess the reality of their environment.

The problem addressed in this research is not restricted to the agrochemical industry. Rather, the insights can be applied across virtually every industry that deals with a similar problem.