Analyzing Tradeoffs between Working Capital and Production Capacity for Multi-stage Manufacturing Processes

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Summary: Large pharmaceutical companies struggle to find innovative ways to reduce work-in-process inventory in their production facilities. In our research, we focus on the tradeoff between inventory and production capacity through investing in new facilities and equipment. This tradeoff will depend on the company's objectives and what it is willing to give up in return for reducing inventory. We found that increasing capacity to reduce work-in-process inventory by investing in new facilities is not always the most favorable approach in terms of net present value. However, for flexibility or lead-time improvements, it may make sense to proceed with the investment.

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KEY INSIGHTS

1. As the number of production stages increases, the production capacity and the work-in-process inventory both increase.
2. As the changeover frequency increases, production capacity increases but work-in-process inventory decreases.
3. As the equipment investment or capacity increases, the operational flexibility increases.
4. In our scenario analysis, the production capacity has a much higher impact on NPV than does the working capital
5. An ideal NPV scenario does not always mean an optimal operational strategy.

Introduction

Our thesis examines the tradeoff between net working capital and the capital investment of a major pharmaceutical company. First, we provide an overview of the challenges facing pharmaceutical companies, then break down the different cost elements needed to make specific supply chain investments. Finally, we determine effective supply chain outcomes under different scenarios that consist of multiple stages and different changeover frequencies (the process of preparing a facility for the next stage in a multi-stage manufacturing process). This analysis provides us with tremendous insights into how different parameters can affect the outcomes of the different scenarios and ultimately the key performance indicators (KPI's) that the pharmaceutical company would like to focus on.

The production process for the pharmaceutical product in question is carried out in four stages where raw materials are converted into Active Pharmaceutical Ingredients (API's) sequentially. The output work-in-process inventory of each stage is the input of the next stage and there is considerable

wasted time of about 2 weeks changing over from one stage to the next. We intend to study this production process in a very simplified approach by looking at the production schedule of one anonymized product at first and consequently analyzing how the work-in-process inventory of this product can be reduced while still maintaining an efficient production process. This same analysis is also done for different multi-stage manufacturing processes.

Our sponsor company's objective for this year is to reduce work-in-process inventory, so we have provided different investment scenarios that attempt to reduce this inventory while still maintaining a high return on investment. In an attempt to reduce net working capital, increase free cash flow and generate more profits, our sponsor company has asked us to provide guidelines and procedures to balance working capital and capital investment. Our thesis paper provides a quantitative analysis of specific investment scenarios to be used by key stakeholders at the sponsor company to evaluate options. The quantitative analysis is supplemented with reasoning that helps guide stakeholders to make informed decisions.

Methodology and Approach

We initially looked at two different investments: (1) One large module (2) Two smaller modules. We used financial factors in our supply chain analysis to determine the tradeoff between capital investment and working capital with the primary objective of maximizing the net present value (NPV) for these two different scenarios. We do this by first asking the sponsor company for the cost breakdown of a specific investment, calculating the average inventory according to the company's production schedule, calculating the free cash flows and the NPV of each investment (as displayed in ***Figure 1***), and then ultimately comparing the different scenarios using Key Performance Indicators (KPI's).

We used NPV as a primary metric to identify whether one opportunity was more attractive than the other and then proposed supplementary scenarios to study how alternative situations affect the key performance indicators. The NPV metric, however, was not sufficient on its own to make an investment decision as there were other key considerations that needed to be made such as flexibility and risk.

	Periods			
Incremental Income Statement	**0**	**1**	**...**	**10**
Revenue		£ 88.52		£ 88.52
- COGS	£ -	£ 21.28		£ 21.28
= Gross Income	£ -	£ 67.24		£ 67.24
- Operating Expenses	£ 0.00	£ 1.26		£ 1.26
= (EBITDA)	-£ 0.00	£ 65.98		£ 65.98
- Depreciation & Amortization	£ -	£ 3.25		£ 3.25
= (EBIT)	-£ 0.00	£ 62.73		£ 62.73
- Income Tax	-£ 0.00	£ 12.55		£ 12.55
= (NOPAT)	-£ 0.00	£ 50.19		£ 50.19
Adjustments				
+ Depreciation (not a cash flow)		£ 3.25		£ 3.25
- Net Capital Expenditures	£ 40.00	£ -		£ -
Equipment	*£ 30.00*			
Module	*£ 10.00*			
- Net Working Capital Investment	£ 8.24	£ -		£ -
+ Net Increase in A/R				
+ Net Increase in Inventory	*£ 8.24*	*£ -*		*£ -*
- Net Increase in A/P				
Free Cash Flow	**-£ 48.24**	**£ 53.44**	**...**	**£ 53.44**

Figure 1: FCF and NPV Analysis

Results

In the causal loop diagram in ***Figure 2***, we have listed the key parameters that are affected by our system. The main inputs are SG (number of stages) and CF (changeover frequency). These two inputs ultimately affect the NPV of the investment. For simplicity, we have drawn out the diagram to clarify the relationships and discuss tradeoffs. This relationship is explained via the polarities of the arrows displayed in the diagram.

For example, as SG increases, the EC (Equipment Capacity) increases which, in turn, requires an increase in capital investment. The higher capital investment ultimately lowers the final NPV metric. In the same manner, as SG increases, the batch size increases which increases the amount of work-in-process inventory produced. In this case, as inventory produced rises, the working capital increases, increasing the required capital investment ultimately driving down the NPV. The same dynamic applies for CF.

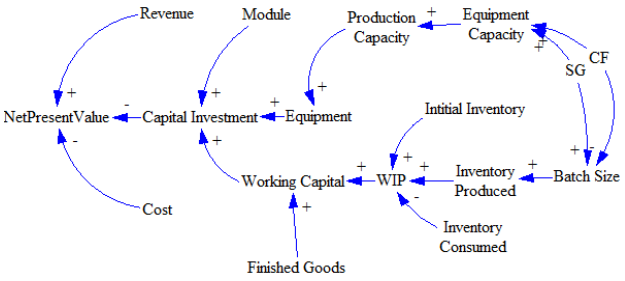

Figure 2: Causal Loop Diagram of Production System

These relationships were used to analyze the tradeoff between working capital and production capacity. In order to materialize these relationships, we created supplementary scenarios, as mentioned earlier, that would mimic real-life situations for the sponsor company.

Figure 3 below shows some example scenarios that we proposed for a 4-Stage production process.

	4 Stages			
	One Module	Two Modules		
	Base Scenario	Base Scenario	Scenario 2	Scenario 3
Changeover Frequency (CF) (times/year)	4	12	8	4
Number of Stages/module	4	2	2	2
Changeover Time (Weeks)	8	24	16	8
Number of batches/module	4	12	8	4
Total Production Time	44	28	36	44
AVG production quantity for each batch	52.0	8.7	13.0	26.0
Production time for each batch (Week/batch)	11.0	2.3	4.5	11.0
Equipment Capacity (Tons/week)	5	4	3	3
Maximum Annual Production Capacity (Tons)	260	208	156	156
Actual Annual Production Volume (Tons/year)	208	104	104	104
Production Utilization Rate (%)	80%	50%	67%	67%
Machine Operating Time Rate (%)	85%	54%	69%	85%
Actual Production Volume (Tons)	52	52	52	52
Maximum Production Quantity (Tons)	55	56	54	66
Allowable Demand Fluctuation %	6%	8%	4%	27%
Inventory Investment (£M)	8.24	3.68	4.32	6.22
Lead Time (weeks)	39	14	20	41
Profitability Index (%)	610.9%	447.8%	571.4%	547.0%
Module Investment (£M)	10	10	10	10
Equipment Investment (£M)	30	48	36	36
Total Capital Investment (£M)	48.24	61.68	50.32	52.22
NPV	294.70	276.18	287.53	285.64

Figure 3: Scenario analysis using key performance indicators

Comparing multiple scenarios shows a trade-off between production capacity and inventory, and that the production capacity has a much higher impact on the NPV than does the inventory. The ideal NPV is achieved when the production capacity reaches its tipping point. The tipping point here is defined as that point where production capacity changes from one integer value to another.

The results of each of the 4-stage and 2-stage investment scenarios depend on the changeover frequency that is selected. Often, the changeover frequency that can reduce the equipment capacity generates a high NPV. For the 4-Stage process example in ***Figure 3*** above, the production process consists of three capital investment elements: equipment investment, module investment and the working capital investment. The module investment remains the same for all of the investment scenarios. Furthermore, the working capital is negatively correlated with changeover frequency and the module investment is positively correlated with CF.

The equipment capacity is a step function as it is calculated with a roundup function and, as such, it is only triggered to increase when the changeover frequency reaches its tipping point: in this scenario, 8 times per year. We consider the changeover frequency of 8 to be the point at which NPV is maximized for this case. The same can be said regarding the 2-stage production process. The ideal NPV can be found when the changeover frequency is 8. However, the inventory here is not the lowest it can be. In the same manner, the lead-time is also not the lowest, which compromises flexibility.

Conclusions

Our research reveals important considerations when making tradeoffs between the production capacity and working capital. These tradeoffs will depend on what the company would like to achieve and if it has the appropriate backing and funding. The research tries to provide different scenarios to mimic real-life situations for companies where the decisions to invest in new facilities become challenging. As our sponsor company noted, it is not sufficient to only focus on NPV when making investment decisions. Additional factors and considerations should guide stakeholders to make decisions. Our research describes key considerations in designing the pharmaceutical supply chain.

Finally, although pharmaceutical companies are reluctant to adjust finished goods safety stock levels, our analysis indicates that those inventory levels can be reduced. Shorter production lead times should enable lower finished goods inventory without jeopardizing the customer service levels that pharmaceutical companies would like to maintain. Future research should consider broadening the scope by including demand variation, multiple SKUs, and/or considering new product introductions.