MAKE-TO-ORDER TO HYBRID MAKE- TO-ORDER-MAKE-TO-STOCK SUPPLY CHAIN IN STEEL INDUSTRY

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Summary
This thesis analyzed the three levers of information flow, control policies and variability to improve the performance of a supply chain while transitioning from a pure Make-to-order (MTO) supply chain to a hybrid Make-to-order(MTO) – Make-to-stock (MTS) supply chain in a steel industry. We analyzed the sensitivity of performance metrics such as inventory holding costs, lead time and throughput and their response to several exogenous and endogenous factors and suggested the operational changes that can potentially improve the supply chain performance. We also developed a framework that will guide the supply chain practitioners on the steps to be taken while transitioning from one supply chain design to other.

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KEY INSIGHTS

1. Inventory performance for MTS supply chain can be improved by reducing the demand variability. Alternatives such as VMI with key customers in B2B markets can be further explored.
2. Setting up the review period favoring the responsiveness is the crucial tool to improve both inventory and lead time performance when there are no set-up costs.
3. A potential manufacturing metric identified to improve the lead time performance is the utilization. Too high utilization may result in the blocking and starving effect, increasing the waiting time in queue and the lead time.

Introduction

Global supply chains of capital-intensive steel industry have seen a significant increase in competition owing to the surge in demand over the past few decades. Market competition among other factors is strongly driven by customization, delivery speed and price. Successful market segmentation, therefore, requires a firm to be able to provide availability and speed for both standardized and customized products. Standardized product markets often require Make-to-stock supply chain where the demand is fulfilled by maintaining the finish goods inventory. On the other hand, customized product markets are supported by Make-to-order supply chains where the supply chains begin with the customer giving specification of the products and the firm quoting due-dates to fulfil the orders. To be able to serve both these product markets, firms are moving towards a hybrid MTO-MTS supply chain where some items are produced using MTS strategy and others using MTO strategy. But the transition from pure supply chains to a hybrid MTO-MTS supply chain is associated with trade-offs between the performance metrics. Making an item to stock may fulfil the demand instantly, but result in increased inventory in the system. This may further influence the lead time as it tends to increase the congestion effect, thus presenting a trade-off. These challenges must be addressed and the transition has to be associated with operational changes that will improve the performance of both the supply chains. According to Hopp & Spearman (1999), there exist three levers in any firm which are to be effectively managed to improve the performance of a supply chain. Through the lens of systems perspective, we studied the three levers information flow, control policies and variability and generated critical insights to provide a direction to the supply chain practitioners as to '*What operational changes are to be incorporated into an existing supply chain while transitioning from a pure Make-to-order supply chain to a hybrid Make-to-order-Make-to-stock supply chain for an improved* *performance?'* In partnership with a global steel products manufacturer, we developed a framework that can guide the firms to effectively improve the performance of a supply chain while transitioning from one supply chain to other.

Literature Review

The literature in the field of hybrid MTO-MTS supply chain dates back to 1960's when Popp (1965) showed that for a single item production case, the hybrid production strategy is beneficial than the pure strategies. A hybrid production strategy starts with the decision of determining the right production strategy for an item based on characteristics of the system. Olhager (2003) developed a matrix to determine which products should be classified into MTO and MTS based on demand volatility and ratio of production lead time (P) to desired delivery time (D). If P/D ratio is more than 1 such that the production lead time is more than the desired delivery lead time by customer, MTS becomes the favourable strategy. Adopting these strategies to reap desired supply chain performance can be a challenge as these actions may not be aligned with the interests of the supply chain actors i.e., supply chain members are primarily concerned with their individual performance and this focus can lead to suboptimal performance (Kaminsky & Kaya, 2009). However, optimal performance in a supply chain can be achieved by aligning and coordinating each player's objectives with the firm's supply chain objectives. The performance objectives of a hybrid MTO-MTS supply chain involve both inventory and throughput performance for MTS items and lead time performance for MTO items. According to Hopp & Spearman (1999), supply chain performance can be effectively managed by three levers of information flow, inventory control policies which guide the material flow and the buffers for variability in the supply chain. The significance of the information sharing and coordination in a supply chain was studied extensively by several researchers of which Forrester (1958), Lee et al (2000) are noteworthy. Paying attention to this information sharing has a potential to eliminate supply chain inefficiencies like excessive inventory, poor service levels and misguided capacity plans (Cachon & Fisher, 2000). Holweg & Pil (2008) identified five dimensions to assess the information flow in a supply chain. We used these dimensions to compare and contrast the supply chain of the case company which transitioned from pure MTO supply chain to a hybrid MTO-MTS supply chain.

Among the key works in the inventory control policies literature, Silver, et al., (1998) articulated different inventory policies by considering various constraints in the supply chain. Of these, a time based periodic review policy (R, S) for infinite planning horizon and random variable demand is more practical in a production setting with set-up times and changeover times. Kaminsky & Kaya (2009) noted a holistic approach of MTO-MTS hybrid system and developed effective heuristics for the make-to-order/make-to-stock decision and to find the appropriate inventory levels for make-to-stock items. They considered the trade-off between the lead time performance of MTO items and inventory performance of MTS items as suggested by Rajagopalan (2002).

Buffers for variability can be well managed by reducing the variability in the supply chain. Variability can be classified into three types namely, demand variability, process variability and supply variability. In the first part of this research work, we studied the information flow, proposed the inventory control policies and measured the magnitude of variability associated with the supply chain of case study company and then we studied the impact of these levers on the performance metrics to recommend the relevant operational changes.

Methodology

We adopted a case study approach as it allows the investigator to examine the contemporary phenomenon and triangulate with the help of interviews, direct observation, artefacts and archival data to answer the research question. The case study company GSS (firm's real name has been disguised), is a steel manufacturer headquartered in Australia. GSS caters to the construction industry using MTO supply chain strategy. With the increasing growth potential in the retail segment, GSS is moving towards a hybrid MTO-MTS supply chain to cater both the standardized retail market and customized construction market. We considered the downstream customers, midstream manufacturing and upstream suppliers of the sponsor company and analyzed the three levers as mentioned above.

Information Flow

The information flow of GSS hybrid MTO-MTS supply chain is studied using the five dimensions of 1) Permanence of flow 2) Horizon of the flow 3) Frequency of flow 4) Accuracy of flow and 5) Directionality of flow. The information flow data is collected and the value stream and information flow are mapped using the interviews with the sponsor company as shown in Figure 1 and the relevant 5-dimensional analysis is tabulated in table 1. As GSS moved from MTO to hybrid MTO-MTS, new information flows i.e., the SKU level forecast and additional buffers are introduced into the system to support MTS items. Despite the introduction of new flows, it is identified that the actual midstream planning and production scheduling remained unchanged. The perceived information accuracy of these new flows varies from 36% to 100% and the supply chain actors find it challenging to adhere to these flows. Literature supports that the accuracy of the information flow has a negative impact on the inventory levels which is assessed in the next section.

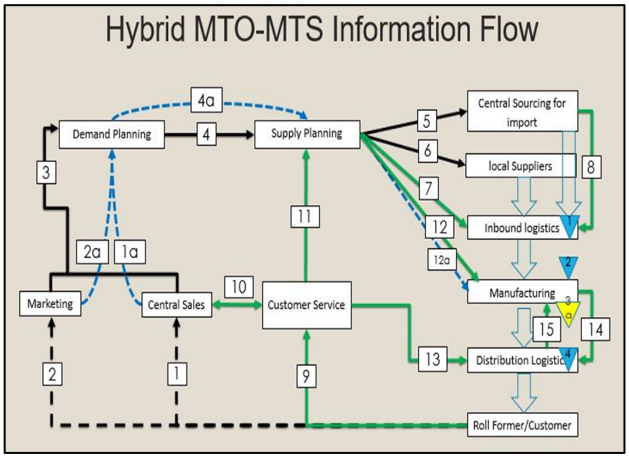

Figure 1: Hybrid MTO-MTS Information flow

	FLOW	Actual (a) Forecast (F/C)	Horizon (day)	Frequency (day)	Accuracy (%)	Directionality
GSS	1	F/C	120	30	-	1
	1a	F/C	120	30	-	1
	2	F/C	120	30	-	1
	2a	F/C	120	30	-	1
	3	F/C	120	30	-	1
	4	F/C	120	30	65%	2
	4a	F/C	120	30	36%	2
	5	F/C	30	30	80%	2
	6	F/C	30	30	100%	2
	7	a	7	2	98%	1
	8	a	90	15	95%	1
	9	a	NA	-	80%	2
	10	a	1	1	100%	2
	11	a	1	0.5	100%	2
	12	a	7	0.5	98%	2
	12a	F/C	15	0.5	70%	2
	13	a	7	1	98%	1
	14	a	1	0.5	100%	2
	15	a	2	0.5	100%	2

Table1: 5-Dimensional analysis of Hybrid MTO-MTS information flow of GSS

Control Policies

Control policies refer to the inventory policies that determine the material flow. GSS offers 2987 SKUs to its customers out of which 27 are identified as MTS SKUs for retail market. Focusing on the Malaysian business of GSS, we collected the historical demand data of these 27 MTS SKUs and devised a periodic review inventory control policy for all the SKUs based on their demand distribution.
Periodic Review policy: Order up to S units every R time periods.

$$S = \mu_{(R+L)} + k * \sigma_{(R+L)}$$

Where $\mu_{(R+L)}$ is the mean demand over R+L; $\sigma_{(R+L)}$ is the standard deviation of demand over R+L and K is the safety factor which depends on the cycle service level requirements. This policy was subjected to the sensitivity analysis to understand the response of the inventory to varied endogenous and exogenous factors.

Variability

The ability to capture and manage variability has a potential to be an important performance driver for any firm. In an attempt to measure this variability, we extracted the downstream customer demand data, midstream manufacturing data and the upstream supply data of raw materials of GSS. The objective of using this data was to study the impact of this variability on the inventory, lead time and the throughput performance. For this purpose, we measured the variability associated with the customer demand, manufacturing process and the supplier delivery.

The customer demand variability was calculated using the coefficient of variation of demand volume and order placing frequency of the 137 customers of GSS. Process variability comprising of the arrival variability and the flow variability was calculated using the manufacturing data of GSS. The coefficient of variation (CV) of arrival rate into the line and CV of process time were extracted from the data to measure the output manufacturing cycle time variability. Coefficient of variation is given by $CV = \frac{\sigma}{\mu}$ where σ is the standard deviation of relevant data and μ is the mean pertaining to that data. The resulting cycle time variability has a direct impact on the lead time performance. Supply Variability was calculated using the supplier delivery and reliability data. The coefficient of variation of delivery lead times from the supplier was extracted based on the historic data. This variability was expected to negatively impact the raw material inventory costs. We then studied the sensitivity of the performance metrics with respect to key parameters to confirm the robustness of our findings

Results

Inventory Performance

The inventory performance was assessed using the periodic review inventory model. The expected on-hand inventory cost was subjected to the sensitivity analysis to parameters lead time, review period, demand variability and lead time variability (process variability) which shows that the inventory cost is more sensitive to the combined effect of demand and process variability. As both the variabilities are reduced by 10% the inventory cost lowered by 15%. When only the demand variability, forecast error or only the process variability is reduced by 10% an 8% reduction in the inventory cost is observed. Similarly, reducing the review period and lead time by 10% are identified to have a positive impact on the inventory cost savings as shown in Figure 2

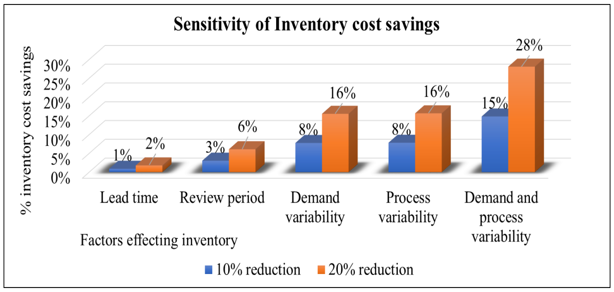

Figure 2: Sensitivity analysis of inventory cost savings

Lead time Performance

In assessing the lead time performance and its sensitivity to different factors, we employed the lead time equation $l = CT + k * \sigma_{CT}$

where CT is the total cycle time for manufacturing, k is the safety time factor and is used to quote a lead time to the customer. It also depends on the cycle service level and σ_{CT} is the standard deviation of the cycle time which is measured by the process variability. To better understand which factors, influence the lead time performance, a sensitivity analysis was conducted and the results obtained are summarized in figure 3.

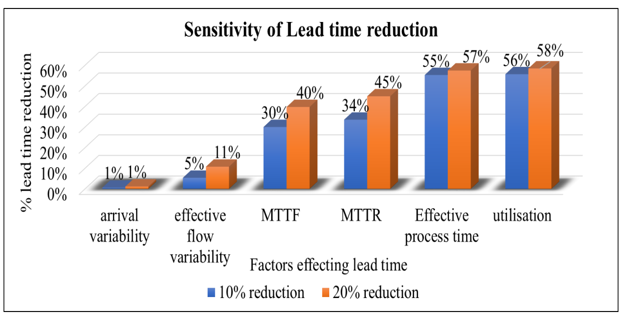

Figure 3: Sensitivity of lead time performance

The sensitivity analysis shows that the decreasing utilization by 10% can have maximum impact on the lead time improvement of 56%. This is due to the disappearance of blocking and starving conditions in the manufacturing line and resulting reduction in the waiting time in a queue and thereby the lead time. This reduction in the utilization is capped at 20% as further reduction is observed to reduce the output rate of the line with no improvement in the lead time. When the effective process time is reduced by 10%, the lead time is identified to decrease by 55%. Our analysis on MTTR (Mean time to repair) and MTTF (Mean time to failure) showed that a 10% reduction in MTTR and a 10% improvement in MTTF can result in 34% and 30% reduction in the lead time respectively.

Throughput Performance

The throughput performance is evaluated using the equation

$$Throughput = Bottleneck\ rate * Bottleneck\ utilisation$$

Throughput performance is sensitive to both the bottleneck rate and bottleneck utilization. As increasing utilization was observed to have a negative impact on the lead time performance, we chose to explore the throughput using bottleneck rate. The effective bottleneck rate can be improved by reducing the cycle time at bottleneck. All the factors in Figure 3 are expected to improve the cycle time at bottleneck and thereby the throughput.

Framework

Based on the literature review and the analysis performed, we developed a framework that will assist the supply chain practitioners to improve the supply chain performance while transitioning from one supply chain to the other as shown in Figure 4.

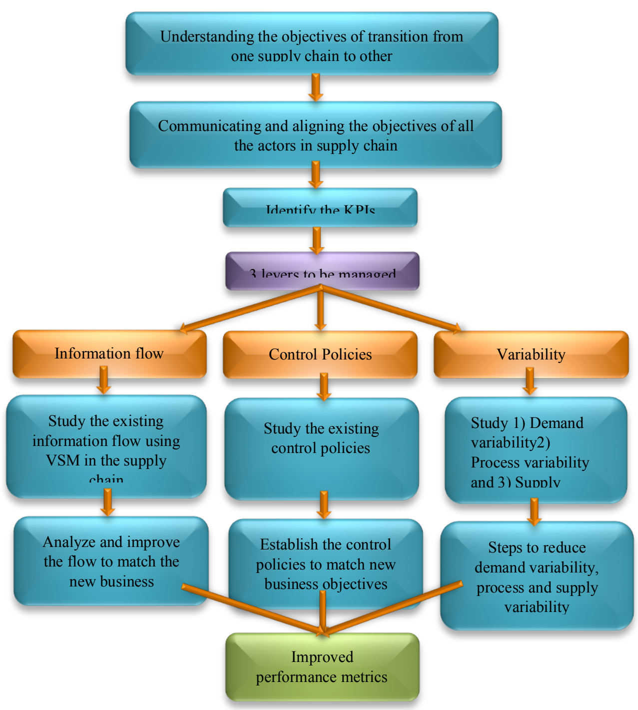

Figure 4: Framework to improve performance of a supply chain

Conclusions

Firms will benefit from the systems view of the supply chain rather than looking at piecemeal improvements. When firms shift from one supply chain to other, the organizational goals and the perspectives and objectives of all the supply chain actors have to be aligned to shift the focus towards new collective purpose, even before considering the operational changes. Any misalignment results in the suboptimal performance of the supply chain. Our research shows the following key findings:

Information flow

Poor information flow accuracy has a negative impact on the perspectives of the supply chain actors as well as inventory performance. Improving the accuracy using suitable forecasting techniques in case of MTS items will reduce the inventory costs and can drive the savings ranging from 8 to 10% for every 10% improvement in the forecast accuracy.

Control Policies

A periodic review inventory policy was devised to support the material flow of GSS. A sensitivity analysis was carried out which suggested that the process variability, demand variability and review period are the important drivers of inventory costs and the lead time. Shifting towards more responsive review period can improve both inventory as well as accelerate the lead time performance. Significant savings of 30% in the inventory costs are observed as one shift from a review period of once in a month to twice in a month.

Variability

Any kind of variability in the system degrades the performance of the system. Demand variability negatively impacts the inventory performance of MTS items. Manufacturing process variability negatively impacts the lead time performance for MTO items as well as inventory and throughput performance for MTS items. Supply variability impacts the raw material inventory. To mitigate the demand variability, prioritizing those customers using segmentation and variability contribution and introducing Vendor Managed Inventory (VMI) policy with those customers will improve the inventory performance of MTS items. MTTF and MTTR are identified as the two key factors that contribute to process variability and increase the effective process time. Improving these parameters by training the operators and increasing the frequency of preventive maintenance can improve the lead time and throughput performance significantly. Measuring and reducing the supply variability by negotiating suitable terms with the suppliers will reduce the need for excess raw material buffers.

We believe that the above suggested operational changes can improve the supply chain performance of a firm while transitioning from one supply chain to other. However, the magnitude of the performance improvement observed in the sensitivity analysis may vary from firm to firm.

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