Manufacturing strategy decision in a complex aerospace supply chain

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Abstract

It has long been considered a strategic decision of when to assign inventory to a particular customer. This decision was crucial for the complex Aerospace Co. supply chain. Aerospace Co can be considered complex as they serve many different customer segments and have an extensive range of products that often require customisation. This paper proposes a combination of mathematical calculations and human judgement for deciding on manufacturing strategy. The formulas combine forecast accuracy, volume variability, relative volume and supply chain depth. The calculations assisted the process, but human judgement was necessary to finally determine the most appropriate manufacturing strategies.

Keywords: order penetration point, aerospace, manufacturing strategies.

Introduction
Making the decision of when to assign inventory to a specific customer has long been considered a strategic issue (Sharman, 1984, Hoekstra and Romme, 1992, Olhager, 2003, Olhager, 2013). Hence, the concept of the order penetration point (OPP) or the customer order decoupling point (CODP) can be defined as "the point in the manufacturing value chain for a product where the product is linked to a specific customer" (Olhager, 2003). There has been some research conducted to explore the factors that influence order penetration point from a strategic standpoint. Notably, the seminal work of Olhager (2003) identified the 1) market-related, 2) product-related and 3) production-related factors that impact lead times and thus the order penetration point decision.

There has been work conducted that explores the strategic link between the CODP and lean and agile strategies (Mason-Jones et al. 2000) and value chain management (Olhager, 2013). Considerable work has been completed to explore the factors influencing order penetration point and the different manufacturing strategies known as make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and engineer-to-order (ETO). However, this work has tended to be more heavily focused on exploring MTS and MTO (for example: Shao and Dong, 2012 and Teimoury and Fathi, 2013). There is far less empirical work conducted that proposes and tests a method for calculating order penetration point for the full breadth of manufacturing strategies and based on the full breadth of factors identified by Olhager (2003).

This paper focuses on addressing that gap, it tests a two-stage process of determining the OPP using data from large aerospace manufacturer (Aerospace Co.) which has many interactions with internal and external customers. This empirical setting is a perfect test bed for this as it is faced with complexity across Olhager's (2003) factors, Aerospace Co. can be characterized by:

- **Market-related factors:** Aerospace Co. faces product demand volatility which Olhager (2003) explained effects the extent to which it is possible to make to order or to stock.
- **Product-related factors:** Aerospace Co. has an extensive range of over 20,000 SKUs, hence, range complexity exists (Christopher, 2011). Furthermore, customisation requirements/opportunities exist (Olhager, 2003, Christopher, 2011). The product range tends to grow as a specific requirement is manufactured for a specific aircraft.
- **Production-related factors:** Aerospace Co. is a vertically integrated organisation with many resources and plants across Europe, USA and China, hence, according to Olhager (2003) they have a large number of planning points. This means there are also many internal customer interactions as well as external ones.

Aerospace Co.is undertaking a supply chain strategy project to standardise processes across their plants. Thus this paper will use the empirical data to explore the possibility of determining manufacturing strategy in this complex scenario. This paper has three main objectives:

1. Identify the quantitative factors that determine ideal manufacturing strategy in a complex aerospace supply chain.
2. Develop a means for calculating the optimal manufacturing strategy for a complex aerospace supply chain.
3. Test the effectiveness of the method for calculating optimal manufacturing strategy through expert opinion.

Design/methodology/approach

A two-phase methodology was used in the research, the first phase focused on identifying variables to calculate the key characteristics, setting up the parameters and performing the calculations. The second phase involved using expert opinion to validate and extend the results.

Phase 1: Calculating OPP

The first phase determined the factors that could be mathematically determined, based on Olhager's (2003) model and the empirical data. Hence, the following variables were used: supply chain depth, forecast accuracy, volume variability, relative volume, as articulated onto Olhager's (2003) model, shown in Figure 1.

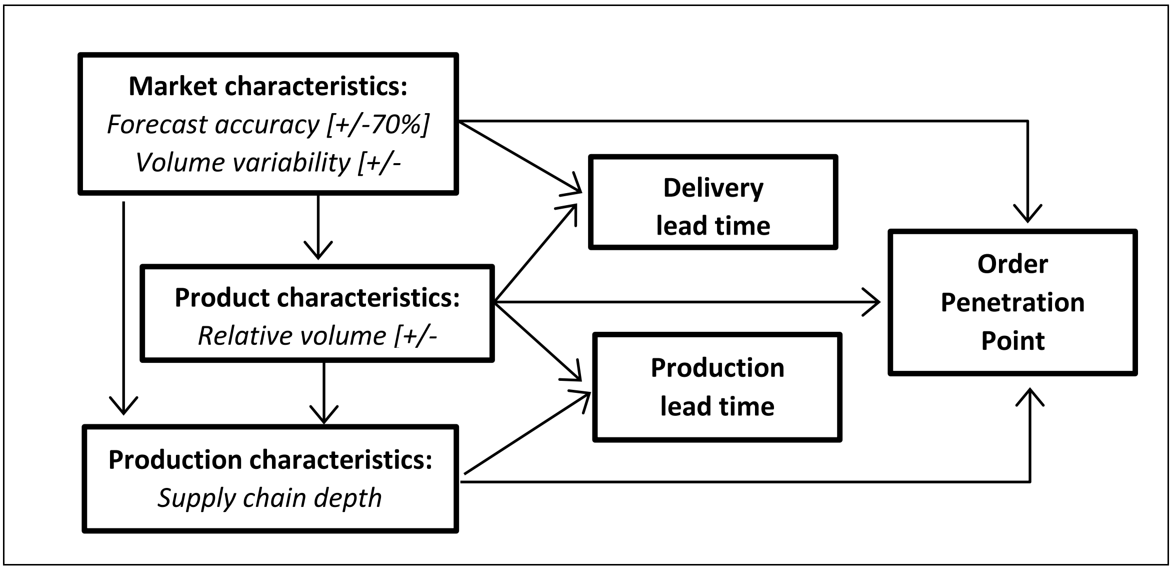

Figure 1 – Quantitative variables in Italics used in determining manufacturing strategy (articulated onto Olhager's (2003) model)

The data was then collected and the manufacturing strategy calculated for a sample of SKUs from the European supply chain.

Phase 2: Validating the manufacturing strategy decisions using expert opinion

The material managers at each of the plants were then asked to review the results of the mathematical model based on their opinion.

Findings

It was evident that Aerospace Co was operating in a complex supply chain, which meant that determining the most appropriate manufacturing strategy was not a simple process. Considering Christopher's (2011) definition of complexity Aerospace Co showed many different types of complexity, as explained below:

1. Network: The internal supply chain has 18 different nodes within it, the different plants were internal customers and suppliers hence, there are cross flows. These movements and co-ordination across this network indicate complexity.
2. Process: Christopher (2011) explains this as haphazard development with handovers, this is not really the case at Aerospace co. However, across Aerospace Co there are many same or similar processes existing. These processes are organised differently across these plants.
3. Range: Aerospace Co has an extensive range of over 20,000 SKUs to deliver to their internal and external customers. Furthermore, there are frequent customisation requirements from customers. These customisations continue to increase.
4. Product: Aerospace Co does not experience this as acutely, as there are the common products of fiber, core and matrix used.
5. Customer: Aerospace Co serves many segments: aerospace, wind turbine and other industrial customers. The types of customers have different needs.
6. Supplier: Aerospace are largely vertically integrated.
7. Organisational: There are many functions and processes in different locations in different time zones and cultures across Europe, USA and China.
8. Information: There is a vast amount of data in separate systems across Aerospace Co.

The particularities of the supply chain meant that two variants of make-to-stock were used to distinguish between aggregate stock of generic products that will be consumed (repeaters) and customer forecasted stock for a specific customer (customer-focused). The repeaters were classified as Make to Forecast (MTF). The calculations revealed that across the eight plants the full range of manufacturing strategies were required in order to serve the customers effectively. Assemble-to-order and make-to-stock (customer-focused) were the dominant strategies, hence, plants need relatively high flexibility to be able to switch between the strategies. One plant was faced with all manufacturing strategies, hence, the complexity of that plant is significant.

When approaching the application of Olhager's model for determining manufacturing strategy (2003) across the Aerospace Co. supply chain, certain aspects of uncertainty proved difficult to quantify. Due to this complexity human judgement within the process was essential to deliver meaningful results as explained below. Although human interaction is important in this process, the use of computers is also valuable to enable objective viewing of decision criteria. Seifert and Hadida (2013) show how best results for prediction are achieved though the combination of both humans and computers. With this mixed approach, both quantitative and qualitative factors can be considered.

Phase 1 Calculation of the Qualitative Factors

The initial categorisation of SKUs was calculated through computer formula. The factors considered at this stage were:

1. Forecast Accuracy
2. Volume Variability
3. Relative Volume
4. Supply Chain Depth

The measure used for ***forecast accuracy*** was the standard Mean Absolute Percentage Error (MAPE) approach. Thus, a comparison was made between the forecast and actual figures. Although MAPE has been criticised in use for low forecasts, it was effective in this case.

Equation (1): MAPE

$$MAPE = \frac{|F - A|}{A}$$

The ***volume variability*** was modelled as the coefficient of variation, using standard formula.

Equation (2): Coefficient of Variation

$$C_v = \frac{\sigma}{\mu}$$

For ***relative volume*** measures, the standard Pareto analysis was calculated. The Pareto analysis exposed the upper 80% of total demand for a given plant. Each item belonging to the upper 80% was flagged.

Finally, ***supply chain depth*** was more difficult to calculate, hence, it was more of a pseudo quantifiable parameter. The expertise of the supply chain managers was utilised to classify each plant with upper and lower equation limit along the MTO to MTS spectrum. The upper limit was closest to MTS and lower closer to MTO.

The overall equation prioritised first the relative volume aspect. If the item was in the top 80% of volume for the plant, it automatically became qualified for the upper strategies. Next the volume variability aspect was examined. If this factor was less than 0.25, the item was considered to have predictable demand and therefore qualified for the upper limit strategy. If the volume variability was greater than 0.25 then demand was considered less predictable and the second highest strategy was selected. If the item was not in the top 80% of volume for the plant, then forecast accuracy was the defining factor on whether the lowest strategy was selected or the second lowest. Through this algorithm, every item for each plant in the Aerospace Co. supply chain was categorised.

Phase 2 Expert Opinion – human judgement
Following this initial computer driven phase, the Materials and Product Managers were asked to give their classification. The human component to this analysis looked at additional supply chain complexities. They were specifically asked to consider other variables: production throughput time, shelf life, change over time and waste, quality performance, line capacity and materials. These variables have particular significance in the Aerospace Co. supply chain. Quality procedures can effect throughput time and handling of materials. For example, material for certain applications requires additional proof of quality, which requires tracking and certification of fibre batches through the supply chain. This means that a MTF or even ATO strategy becomes unsustainable, particularly if demand volumes are small.

The results did vary between plants in relation to the accuracy of the computer models. Analysing the results for Plant 1, the computer agreed with human analysis 66.7% of the time, and the overall distribution of strategies for plant 1 can be seen in Figure 2.

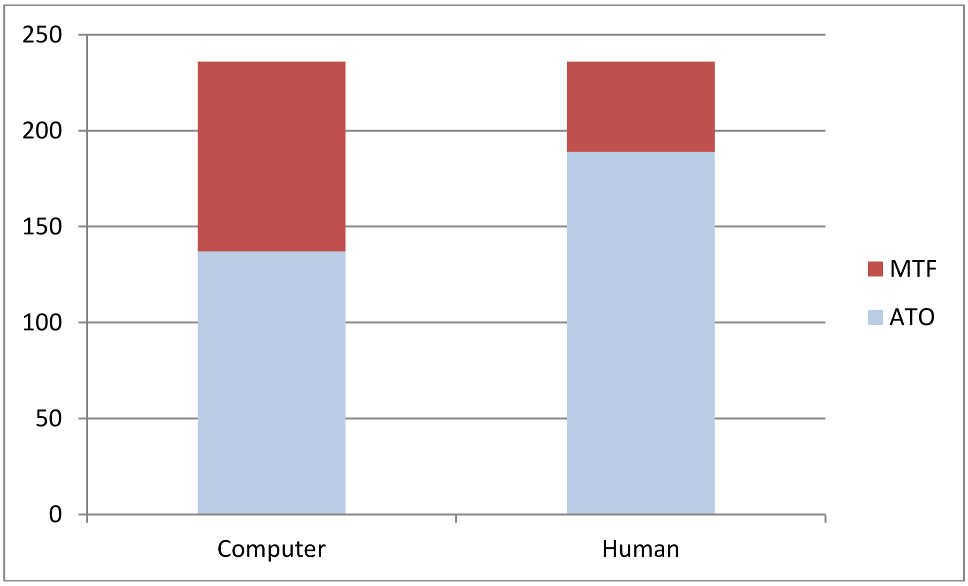

Figure 2 – Plant 1 classification of SKUs, the majority being Assemble to Order, with the expert opinion repositioning many from Make-to-Forecast to Assemble to Order

Analysing the results from plant 2, the algorithm was 58.4% accurate as seen in figure 3.

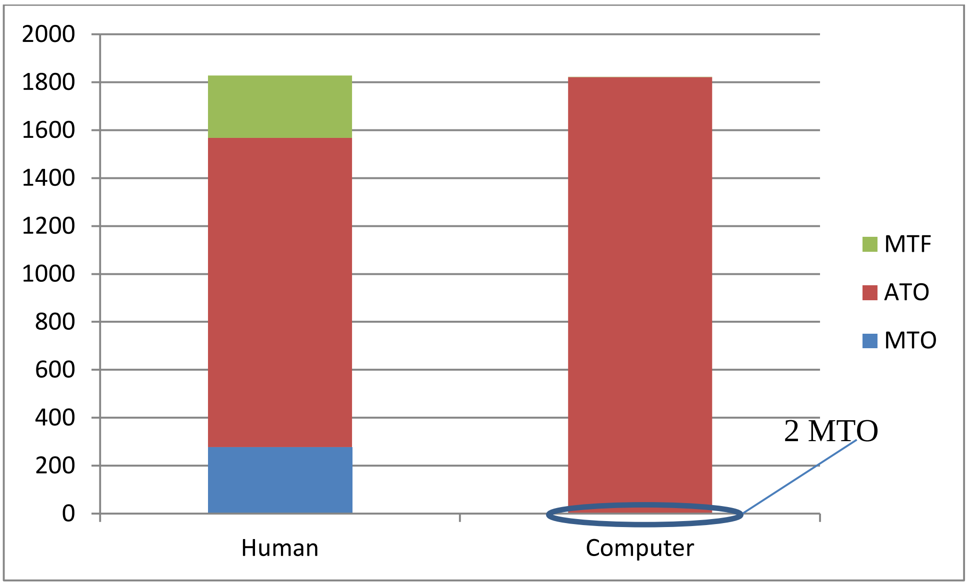

Figure 3 - Plant 2 classification of SKUs, the majority being Assemble to Order, with the expert opinion repositioning many from Make-to-Forecast to Assemble to Order

Having completed this analysis, it is apparent that a purely calculated approach cannot give a fully accurate picture of item classification; however, it can be used as a platform for further analysis through subject matter experts.

Conclusion

This research extends the previous work conducted by Olhager (2003, 2010) which identified the factors that impact OPP (Olhager, 2003) and the significance of the customer (Olhager, 2010). This work is complimentary to the existing consideration of MTS versus MTO (Shao and Dong, 2012 and Teimoury and Fathi, 2013). However, the specific contribution of this work is that it considers a complex supply chain as classified by Christopher (2011) and also includes significant factors identified by Olhager (2003). The paper proves the usefulness of calculating OPP, but the importance of including also qualitative factors and expert opinion in the process of deciding on optimal manufacturing strategies. The application of the model and variable calculation approach is likely to be applicable in other manufacturing settings.

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