Improving order fulfilment of intermediate core products

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Public summary

Context

In this research we studied the assortment planning problem at an industrial organisation. The organisation considered faces problems in order fulfilment of intermediate core products at the beginning of its supply chain. This is caused by the production planning and production of this product, contributing to a low delivery performance perceived by its customers at the end of supply chain. The research therefore investigated how the production planning can be improved in terms of effectiveness, while taking into account the efficiency, by using so called "support products". The research answered the following research question:

To what extent can the use of support products improve the production planning at the industrial organisation in terms of effectiveness (precision and reliability), while taking into account the efficiency (costs)?

Support products are specific products which can be used to cover different customer orders, based on various technical possibilities. In relation to the research question, the industrial organisation already chose to change their order fulfilment strategy. In this research we investigated how to implement this strategy for the intermediate core products and described the actions to do so. It is important to note that this means we did not aim to find optimal inventory levels for customer ordered products, which is also part of the strategy chosen. We investigated the use of and inventory levels for support products for the intermediate core products. In the text following we refer to these tactical decisions as the development and implementation of an *alternative order fulfilment strategy*. By improving the effectiveness of the production planning we intended to contribute to improving the delivery performance overall.

We limited the scope of our research to a specific selection of intermediate core products. We explain why we chose to do so by describing the problems in the production planning which arise due to differences in production frequencies. This can be explained by making three groups of the intermediate core products at the industrial organisation. The characteristics of these groups in their demand and supply, is graphically shown in Figure 1.

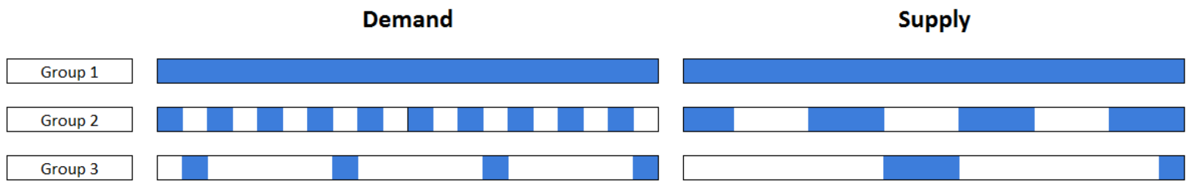

Figure 1: A graphical representation of the distinction between intermediate core products in three groups, based on their differences in demand and supply intervals

The products in group 1 have a more or less constant demand, resulting in a more or less constant supply. In this group advances and arrears do not really appear and if so, these are solved by the system itself due to the high frequency of both demand and supply. Group 1 represents the products which are produced every week or every 2 weeks. Next, the products in group 2 have a demand pattern which shows more peaks than the demand for products in group 1. Due to the less frequent demand, orders are collected in order to produce them in batches, which is shown by the supply pattern of group 2. This pattern in supply results in advances and arrears. The products which are produced every 3, 4, 5, 6, or 7 weeks belong to group 2. Finally, the products in group 3 have a demand pattern which is most irregular. Therefore, the intervals between supply of these products is the biggest of the three groups. Advances and arrears occur even more compared to group 2. All products which are produced every 8 weeks and less belong to group 3. The differences between these three groups, based on their demand and supply pattern show the problem in order fulfilment, which is investigated in this research.

In this research we focus on the products in group 2, to narrow down our scope. We choose to focus on these products, since the most potential to improve delivery performance with support products exists for the products in this group. Products in group 1 are produced so frequently, that it is not worth to keep stock of these products, since they will always be produced soon. Products in group 3 are ordered at such a low frequency, that it is also not worth to keep stock of these products: these orders can wait. Nevertheless, for the products in group 2, it could for example occur that a batch is produced this week and that an order for a product of that batch comes in next week. When this product is produced once every seven weeks, in such a case the order has to wait for six weeks to be produced again. If stock of support products for this product would exist, the time to fulfil the order could be greatly reduced. Therefore, it is worth to keep stock of support products that cover demand of products in group 2.

Approach

The approach of this research was as follows. First, the research described the business rules for the production planning and production of the intermediate core products itself. We did so by conducting interviews and analysing internal documents. Important aspects of the intermediate core products were distinguished, such as standard specifications. Also costs related to ordering products, the material of the products, handling, holding inventory and not fulfilling orders on time were identified.

Second, the research described useful concepts and methods from literature. In order to find relevant literature, Scopus, Google Scholar and the University of Twente Library catalogue were used. Keywords used to distinguish applicable articles and books were for example: *production planning*, *order fulfilment*, *inventory control*, *optimisation model, simulation*, *safety stock, forecast*, and *intermittent demand*. Furthermore both forward and backward search were used as well.

Third we developed a tool in Excel to identify all technical possibilities of support products for each customer order. Following, we used Linear Programming to distinguish different scenarios of support products to keep in inventory. We used these scenarios as the input of our simulation model to determine control rules for and the effect of using support products.

Literature

Since the development and implementation of an alternative order fulfilment strategy for intermediate core products at the industrial organisation, is the ultimate goal of this research, we explained what order fulfilment strategies are. Furthermore, we presented the method of Linear Programming (LP). Although this research dealt with a dynamic problem (which support products to have available, against which costs and how to use them), LP was applicable as a first demarcation in our optimisation. Since part of the development of an alternative order fulfilment strategy was found in the stock levels at which selected support products should be kept, we described the concept of safety stock. The method of simulation was explained, since we used this method to optimise the dynamic and stochastic problem of this research. As input for the simulation study, we needed to distinguish the right method to forecast demand patterns. In the case of the intermediate core products we studied, this meant we had to forecast intermittent demand. That is why we explained the forecasting of demand patterns of intermittent demand.

Order fulfilment strategies

First, we explained what order fulfilment strategies actually are. We did so, since the ultimate goal of this research is to develop and implement an alternative order fulfilment strategy. The process of order fulfilment starts at the moment orders are received from the customers and ends whenever the finished goods are actually delivered. Since an order fulfilment process is normally composed of multiple activities, which are executed by different parts of a company and which are interdependent among tasks, resources and agents involved in the process, the order fulfilment process is often complex (Lin and Shaw, 1998). Three main activities can be distinguished in an order fulfilment process: order management, manufacturing (including production scheduling, material planning, capacity planning and shop floor control), and distribution. Main objectives are (Lin and Shaw, 1998): “(1) delivering qualified products to fulfil customer orders at the right time and right place, and (2) achieving agility to handle uncertainties from internal or external environments”. The agility in the latter objective can be measured in dimensions as efficiency (reduction of the time between order receipt and product delivery), flexibility (minimising costs due to changes in the process), robustness (maintaining good performance under uncertain situations) and adaptability (the ability to incrementally improve the process).

Within order fulfilment strategies, the customer order decoupling point (CODP) is an important factor for determining the type of strategy used. The CODP separates the supply chain into two pieces: the part existing to directly satisfy customer order and the part of the supply chain which is based on planning (Hoekstra and Romme, 1992). As a rule, the CODP usually corresponds to the most important stock point in a supply chain (Olhager, 2010). The position of such a decoupling point is influenced by the market, product properties and process factors (Olhager, 2003). Factors include demand volume and volatility, and the relationship between delivery times and production lead times (Mather, 1988). Some authors distinguish five different configurations of the customer order decoupling point (Hoekstra and Romme, 1992): Engineer-To-Order, Make-To-Order (MTO), Assemble-To-Order, Make-To-Stock (MTS) and deliver from (local) stock. Other authors (Verdouw et al., 2008) describe the five configurations mentioned to exist at an aggregate level, while in practice companies have multiple CODPs, for example per individual product or product-market combination and per level of customer commitment.

Linear Programming

Second, we described the concept of Linear Programming. In order to achieve the goal of this research, developing and implementing an alternative order fulfilment strategy for intermediate core products using support products, Linear Programming (LP) is a method which helped us to demarcate our dynamic optimisation problem. We aimed to find those product specifications that can cover the largest amount of volume as support product. This optimisation problem is similar to the bin packing problem, which also uses LP to solve the problem (Fernandez de la Vega and Lueker, 1981). Although LP is a static tool for optimisation, it allows us to bound the number of product specifications with the potential to serve as support products, before using these specifications to optimise the problem more dynamically.

LP is “a tool for solving optimization problems”, which follows the following steps (Winston, 2003):

1. We attempt to maximize or minimize a linear function of decision variables. The function that is to be maximized or minimized is called the objective function.
2. The values of the decision variables must satisfy a set of constraints. Each constraint must be a linear equation or linear inequality.
3. A sign restriction is associated with each variable. For any variable, the sign restriction specifies that that variable must be either nonnegative or unrestricted in sign.

In order to model an appropriate representation of a real-life situation, the decision variables of an LP model must satisfy the Proportionality Assumption, the Additivity Assumption, the Divisibility Assumption and the Certainty Assumption. This means that each decision variable contributes to the objective function proportional to the value of the decision variable and contributes to the objective function independent of the values of other decision variables. Furthermore, each variable contributes to the left-hand-side of each constraint proportional to the value of the variable, while a variable contributes to the left-hand side of each constraint independent of the values of the variable. Next, it is assumed that each decision variable allows fractional values, whereas in the case of linear programming problems where some of the variables must be nonnegative integers, an integer programming problem (ILP) is made. ILPs are often solved using the technique of branch-and-bound: methods using this technique find the optimal solution to an ILP by efficiently enumerating the points in a sub problem's feasible region. Finally, in an LP model each parameter (being the objective function coefficients, right-hand side and technological coefficients) is known with certainty.

A major operational issue in many industries is related to assortment planning (Goyal et al., 2016). Also in this research an assortment planning problem was applicable. In general, for assortment planning problems, given a set of products that are differentiated by attributes such as the quality and price, it has to be decided which product assortment to hold and in which quantities (stock levels). Such decisions are even more important when products are substitutable and customers also show substitution behaviour. Substitutability like this requires joint multi-product assortment and inventory decisions, which normally involve complex optimisation models (Goyal et al., 2016). The existence of substitution is also relevant for the problem we aim to optimise: which products should be kept as support products (which can be used for multiple ordered products and are therefore substitutable) at which stock levels. Goyal et al. describe that literature has extensively studied static substitution models, while customers normally exhibit dynamic substitution behaviour instead of static substitution behaviour. Demand for products are not only affected by the assortment offered, but also by the inventory levels which change over time. Therefore, assortment and inventory decisions must be made simultaneously. As such, we used LP as a first step in our optimisation to demarcate the input of our dynamic simulation model, being the second step in our optimisation.

Safety stock

Third, part of the development of an alternative order fulfilment strategy in this research, was the determination of stock levels for support products. For each of the potential support products, determined using LP, we needed to determine different possibilities of stock levels: these stock levels were used as input to solve our optimisation problem which support products to keep at what level of stock. In order to determine different possibilities of stock levels for the potential support products, we used the concept of safety stock. We used safety stock, since we aimed to keep the stock levels of support products as low as possible, thus reducing the costs. Safety stock is the average level of inventory just before a replenishment order arrives: in other words, the minimal inventory level.

In supply chain management an important question is how to coordinate activities and inventories over a large number of stages and locations, while providing a high level of service to end-item customers (Graves and Schoenmeyr, 2016). If service guarantees are used with base-stock policies at individual stages in a serial-system supply chain, then concentrating inventory at a few key locations is found to be the optimal safety-stock strategy: decoupling the supply chain into independent segments (Simpson, 1958). When being one unit short, it is normally difficult to determine the accurate costs. Therefore it is often decided to control shortages by meeting a specified service level. Two measures of service level are (Winston, 2003):

- *Service level Measure 1 (SLM1)*: the expected fraction (usually expressed as a percentage) of all demand that is met on time.

- *Service level Measure 2 (SLM2)*: the expected number of cycles per year during which a shortage occurs.

In this research we used a service level approach to determine the safety stock level, more specifically we use SLM1 to do so. We assumed a continuous review (r, q) policy and assumed all shortages to be backlogged.

Simulation

Fourth, we used the method of simulation, as was already mentioned. This method allowed us to optimise a dynamic and stochastic problem: determining which product specifications to hold as support products at which levels of stock. We demarcated the number of potential support products we consider dynamically using LP and determined safety stock levels for these product specifications using different service level measures. Using simulation we made a trade-off between the availability of products and costs: which support products should be kept at which stock levels?

According to Law (2015) simulation is "one of the most widely used operations-research and management-science techniques". The technique is used to imitate operations of real-world facilities or processes, for which normally assumptions have to be made. As such a model is developed which helps to understand how a system behaves. Such a *system* is a collection of entities which work together to achieve some sort of objective. A system always has a certain *state*, which defines the collection of variables necessary to describe the system at a particular moment in time. A state is chosen in such a way that it allows to achieve the goals of a study. A distinction is made between two types of systems: discrete and continuous. In a continuous system, variables change continuously in time, for example in case of a railway train moving from A to B, where its position continuously changes. In a discrete system, variables changes at separate points in time, for example in case of a queuing line of customers, where variables only change when a customer arrives or a customer leaves after being helped. Discrete-event simulation concerns the modelling of a discrete system, where the points in time were variables change are the ones where an event occurs. Such an *event* is defined as "an instantaneous occurrence that may change the state of a system" (Law, 2015). In our research we used discrete-event simulation.

Concerning the output analysis of simulations, two types of simulation can be distinguished: terminating and nonterminating. A simulation is of one of either types based on the way of determining the run length (Law, 2015). For a *terminating simulation* a natural event exists that specifies the length of each run (replication). Such an event is specified before any runs are made, for example when a store closes at 8 pm or the production of a number of fixed orders is completed. In these cases the initial conditions of the simulation usually have a great effect on the measures of performance. For a *nonterminating simulation* an event which determines the length of a run, does not exist. In these simulations one is generally interested in the behaviour of a system in the long run. Therefore steady state performance measures or performance measures based upon steady state cycles are considered in such simulations. A steady state parameter is the characteristic of the steady state distribution of an output stochastic process. In most simulations steady state distributions are used since it is assumed that characteristics of the model do not change over time, opposed to the real-life situation.

Since the simulation study in this research was used to determine the configuration of an alternative order fulfilment strategy and its effect on the behaviour of the system in the long run, we used a nonterminating simulation. That is why we had to deal with the problem of the initial transient or the start-up problem (Law, 2015): observations from the beginning of the simulation depend on the initial conditions, among other an empty system. In order to do so we "warmed up the model", which means we deleted some observations from the beginning of a run and used the remaining observations (in the steady state) for performance measurements (Law, 2015). To enable this, we used the replication/deletion approach: we made n independent runs and ignored observations from the warm up period. We used multiple independent runs, since randomly selected numbers were used in every run which resulted in a certain stochastic behaviour of the model. This behaviour therefore changed per run, so that multiple runs were necessary in every experiment to end up with reliable performance measurements. In order to use the same random numbers in different experiments, we used so called *seed values*, which determined the starting value of a sequence (or *stream*) of random numbers. Furthermore, for each experiment, we deleted the transient state data to have a good representation of reality in the data remaining.

Forecasting demand patterns of intermittent demand

Fifth, our choice to focus on the intermediate core products in group 2 (Figure 1) had an effect on forecasting the demand pattern of these products. The products in this group often do not have a smooth demand pattern. Instead demand patterns of products in group 2 are often somewhat intermittent. In order to use the right demand pattern as input in our simulation model it was relevant to investigate how forecasting of intermittent demand can be done. Syntetos et al. (2005), Willemain et al. (2004) and Teunter and Sani (2009) describe various methods to forecast intermittent demand. Teunter and Sani also make the link between forecasts and inventory control, a link we also aimed to make between the forecasts of demand and stock levels for support products.

Results

By combining the production process, its business rules and different production methodologies, we determined which specific products can be used to cover different customer orders. We identified these specific products using the already mentioned tool in Excel. Next we developed an LP model for this specific research to determine which of these products had the most potential to serve as so called support products.

Using the methods distinguished in literature related to safety stock, forecasting intermittent demand patterns and simulation, together with the potential support products identified, we developed a simulation model. With this model we developed a strategy which described which products should be used as support products. We determined the safety stock levels at which these support products should be kept, and in which situations and for which orders these support products should be used to fulfil to customer orders. Aspects we considered in the simulation model are the precision at the factory where the intermediate core products are used and costs for deploying support products to various customer orders using specific production methodologies.

Our research showed that at equal total costs per intermediate core product ordered, using support products increases the percentage of orders fulfilled and decreases the lead time. Furthermore, we found that taking into account the costs for not fulfilling orders is important and results in different choices compared to not taking these costs into account. We recommended how to deal with the sensitivity of the parameter settings when using support products and presented a roadmap to guide the changes related to using support products.

We recommend future research to focus on a step by step process to adjust and monitor the identification and use of support products. We also recommend to use our identification tool in Excel and simulation model. Furthermore, we recommend to investigate guiding customers to desired products and study the impact on decision making related to support products by considering the complete production process instead of only a part of it. Finally, we recommend to continue studying holding inventory of customer ordered intermediate core products in addition to holding inventory of the identified support products.