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Data based analysis of order processing strategies to support the positioning between conflicting economic and logistic objectives

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Abstract

The order processing strategy directly influences the economic and logistic objectives of manufacturing companies. In industrial practice, the order processing strategy is usually chosen based on a few primarily qualitative decision criteria or employees' experience. The increasingly volatile markets require a differentiated decision of the order processing strategy for each product and a continuous review of the decisions made. The high number of factors influencing the decision of order processing strategy and a wide range of products offered by manufacturing companies make it impossible to manually make a fast and at the same time holistic decision. The digitalization and the increasing availability of data and its quality provide the basis for developing a decision support system.

This paper presents an approach for a data based analysis of order processing strategies. As logistic models reflect the interdependencies of conflicting economic and logistic objectives, they are applied to derive the costs of the strategies based on desired adherence to the delivery time and the desired service level of the finished goods store. In addition to the description of the procedure for comparing different order processing strategies, the transfer of the theoretical model into a software demonstrator is outlined. A case study is presented to show the practicality of the proposed approach.

Keywords: Data analysis; Order processing strategies; Interdependencies; Decision-making; Software demonstrator

1. Introduction

Order processing strategies are a frequently discussed topic in the literature. This include the selection of an order processing strategy [1] as well as the optimization of a system with a fixed order processing strategy [2]. Unless the product is developed specifically for a customer, manufacturing can choose between a Make-to-Order (MTO), an Assemble-to-Order (ATO) and a Make-to-Stock (MTS) production [3]. Numerous variations of these three strategies exist in industrial practice, complicating the determination of the most suitable order processing strategy [4] [5]. In addition, the choice of order processing strategy is influenced by numerous factors [6], e.g. the durability of a product.

The order processing strategy is interrelated with upstream decisions, such as the location of the production site [7] or the product design [8] as well as downstream decisions, like the sequencing rule [9] or the order release process [10]. In the literature, numerous assumptions are made and the decision criteria are strongly restricted to simplify the decision of the most appropriate order processing strategy [11]. Nevertheless, there are no rules for the determination of these criteria and their characteristics. Therefore, the results differ strongly and represent only recommendations commonly based on one or a few objectives. Simulation-based models consider a large number of criteria. However, besides a massive amount of data, this requires a high computational and modeling effort. Consequently, the results cannot be transferred to other companies easily.

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As a result of the lack of practice-oriented approaches and required know-how, the systematic selection of the order processing strategy presents a major challenge for manufacturing companies. In industrial practice, time pressure is high and the majority of companies has no planning department dedicated to the elaboration of such a decision. Thus, the selection typically is not made for each product individually and relies primarily on qualitative criteria or the experience of employees [12]. Even if the production processes of the products are very similar, the order quantities, order times, and delivery times requested by customers vary. Consequently, the required logistic performance can differ. As logistic performance is crucial in the competitive environment of manufacturing companies [13], such a practice can negatively affect the company's success. Increasingly volatile markets leave companies facing major uncertainties. The Covid-19 pandemic highlighted the importance of high logistical performance and the need for a continuous review of previously made decisions and fast adaptability to changing circumstances [14]. A detailed and systematic analysis based on quantitative data is required to effectively determine the order processing strategy for each product and thus achieve high logistic performance [15].

This paper presents a decision support model to determine the most appropriate order processing strategy from an economic and logistical point of view. The subsequent section addresses the interdependencies regarding order processing strategies and outlines the general idea of incorporating logistic models in the decision process. The procedure for comparing different order processing strategies is explained in section three. This provides the framework for the transfer into a software demonstrator. Section four provides details on the software demonstrator and shows the results of its exemplary use in a company. In section five, a summary is given and future research possibilities are outlined.

2. Conflicting economic and logistic objectives

The decision between MTO, ATO and MTS is directly related to the desired values of the economic and logistic objectives of the respective company. A MTS production enables very short delivery times and a MTO production offers the advantage of a customized product while keeping the storage costs at a low level [16]. In case the primary purchasing criteria of the customers is the delivery time, a MTS production is the obvious choice. Assuming that the requirements of the customers highly differ, companies most likely will choose a MTO production. In reality, it is not that simple. Globalization and the rise of huge online platforms selling a wide range of products have intensified the competition [17]. Today's customers expect individual products at low prices in combination with short and reliable delivery times [18]. To compete successfully achieving a balance between the partly conflicting economic and logistic objectives is mandatory. To combine the strengths of a MTO and a MTS production, hybrid order processing strategies such as an ATO production are frequently recommended in the literature [19].

However, the majority of authors focus on identifying the optimal point for changing the production process from forecast-driven to customer order-driven [20], the so-called customer order decoupling point (CODP) [21]. As the CODP is moved along a company's internal supply chain, various scenarios are generated. This requires numerous assumptions to be made, thus such approaches are not generally valid.

A holistic model is required to determine the most suitable order processing strategy analytically. Considering the cause-effect relationships of the decision on the order processing strategy decision and the objectives, it is crucial to select the most suitable strategy from an economic and logistical point of view. [15]

3. Decision support model

3.1. Selection of the order processing strategy

To select the most suitable order processing strategy for each product from an economic and logistic point of view the costs of all possible order processing strategies need to be compared. Whether an order processing strategy is applicable for the respective product is directly related to achieving the desired values of the economic and logistic objectives. As logistic models reflect the interdependencies of the partly conflicting economic and logistic objectives [22], they can be used to check the applicabilitiy and derive the strategies' costs [15]. The feasibility of this general idea was shown by a case study at manufacturer for construction industry components [23]. To a certain extant the same logistic models can be applied for different order processing strategies. Nevertheless, the order processing strategy affects the shape of operating curves as well as the position of operating points in the models. To select suitable models and identify possible needs for adaptations the impact of the order processing strategies MTS and MTO on the operating curves of logistic models were studied using a data set from industry [24]. As a result the following models were combined to generate an overall decision support model:

- Multicriterial lot sizing model [25]
- Schedule deviation histograms
- Schedule compliance operating curve [26]
- Storage operating curves [27]

The respective input and output variables were systematized and the dependencies between the models were analyzed. Based on this and under consideration of various influencing variables the individual models were mathematically connected. In the case of a wide range of products, the modeling and computational effort can be reduced by predefining or excluding an order processing strategy. This can be done based on specific product requirements, e.g. the need for a certificate may make a MTS production impossible, for each product individually or by using classifications for entire product groups. Classification methods, such as an ABC- or a XYZ-analysis [28], can be used to limit the scope of the analysis and can function as reference points while defining the required values of the economic and logistic objectives.

Fast-moving customer products, such as sweets or flour, are typically classified as CX products and therefore produced MTS [29]. For other products, e.g. products classified as CY, the choice of order processing strategy is not so obvious. The procedure presented can be used for a detailed analysis. Based on the desired values of the logistic objectives schedule compliance and service level the order processing strategies MTO, ATO and MTS are evaluated. If a strategy is not considered feasible, it is excluded from the procedure. For a MTO and an ATO production the delivery time required by the customer is used as elimination criterion and for a MTS production it is the product durability. In case multiple order processing strategies are meeting the desired values of the logistic objetives, the costs of these strategies are derived. The costs are compared and the strategy with the lowest costs is selected.

In the following, the application of the selected individual models and their function in the context of the overall model is outlined. The schedule compliance operating curve is used to evaluate the desired adherence to the delivery time. Combined with the information derived from input and output deviation histograms, the safety time required to meet the desired schedule compliance is calculated. Given that the majority of manufacturing companies uses standard delivery times, for each product one delivery time instead of a distribution of delivery times is applied. This product specific delivery time is compared with the sum of the time required for order management, the customer order-specific throughput time and the time required in the dispatch area. By multiplying the production lot size with the processing time for a product, adding the duration of the elements of the inter-operation time and including the information about the schedule deviations the customer order-specific throughput time is determined. In MTO and ATO production, the production lot size equals the quantity of a customer order. If the requested delivery time is achievable at the desired schedule compliance, the costs for the set-up processes, the storage of completed orders and delays in delivery are calculated using the following equations:

$$C_{MTO,su} = S \cdot \frac{Q_{OUT,rp}}{Q_{OUT,m}} \tag{1}$$

$$C_{MTO,s} = h \cdot m \cdot \frac{Q_{OUT,rp}}{rp} \cdot \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot \int_{-\infty}^{ST} \int_{-\infty}^{ST} e^{\frac{-(L_{out}-\mu)^2}{2 \cdot \sigma^2}} dL_{out} \cdot dL_{out} \tag{2}$$

$$C_{MTO,d} = \begin{cases} 0, L_{out} \leq 0 \\ \sum_{1}^{Q_{OUT,rp}} L_{out} \cdot dp \cdot p, L_{out} > 0 \end{cases} \tag{3}$$

where
$C_{MTO,d}$ costs for delays in delivery [€]
$C_{MTO,s}$ storage costs [€]
$C_{MTO,su}$ set-up costs [€]
dp delivery penalty [€/(day·unit)]
DT delivey time [days]
h holding rate [%]
L_{out} output lateness [days]
m manufacturing costs [€/unit]
p frequency [%]
$Q_{OUT,m}$ mean output quantity [units]
$Q_{OUT,rp}$ output during reference period [units]
rp reference period [days]
S costs for a set-up process [€]
ST safety time [days]
μ mean output lateness [days]
σ standard deviation of output lateness [days]

As the schedule compliance is used as a starting point instead of being the result of the evalutation of historical data, the output during the reference period is equals the planned demand for reference period. In case a MTO production is not possible, the same check is carried out for ATO production due to its shorter customer order-specific throughput time.

Storage operating curves are used to determine whether the product shelf life is exceeded. This check only applies to a MTS production. Unless the production process prescribes the production lot size, it is calculated using the multicriterial lot sizing model while considering possible existing lower bounds and rounding values, e.g., due to load carriers.

$$x = \begin{cases} x_{min} + rv, x_{opt,log} \leq x_{min} \\ x_{opt,log} + rv, x_{opt,log} > c \end{cases} \tag{4}$$

$$x_{opt,log} = \sqrt{\frac{2 \cdot S \cdot a_{rp}}{LF \cdot h \cdot m}} \tag{5}$$

where
a_{rp} planned demand for reference period [units]
LF logistics cost factor [-]
x lot size [units]
x_{min} lower bound of lot size [units]
$x_{opt,log}$ economic-optimal lot size according to logistics oriented model [units]

Based on the desired service level of the finished goods store, the average storage time of a product is determined and compared to the shelf life. If this time is not exceeded, the costs for the set-up processes, delays in delivery, capital tied-up, unsalable products, and operating the finished goods store are determined by:

$$C_{MTS,su} = S \cdot \frac{Q_{OUT,rp}}{x} \tag{6}$$

$$C_{MTS,s} = \left(SL_0 \cdot \left(1 - \sqrt[c]{1 - t^2}\right)^2 + (SL_1 - SL_0) \cdot t\right) \cdot (h + r) \cdot m \tag{7}$$

$$C_{MTS,d} = \left(DD_1 \cdot \sqrt[c]{1 - t^C}\right) \cdot dp \cdot Q_{OUT,rp} \cdot (1 - S_w(t)) \tag{8}$$

where
C parameter for the C_{norm} function
$C_{MTS,d}$ costs for delays in delivery [€]
$C_{MTS,s}$ storage costs [€]
$C_{MTS,su}$ set-up costs [€]
DD_1 practical minimum delivery delay limit [days]
r risk rate regarding unsaleable products [%]
SL_0 lot stock level [units]
SL_1 practical minimal stock level [units]

$S_w(t)$ weigthed service level [-]
t running variable ($0 \leq t \leq 1$)

The lot stock level is equal to half of mean store input quantity. In the finished goods store and the semi-finished goods store, the mean store input quantity equals the production lot size. Whereas, in the produced goods store, it corresponds the procurement lot size. The practical minimal stock level is determined by taking into account the safety stocks necessary to counteract disturbances. The practical minimum delivery delay limit can be calculated in a similar way. The running variable can be derived from the desired service level. The parameter C of the C_{norm} function describes how closely the operating curve is positioned to the coordinate system. In practice 0.35 is a commonly used value, although in the literature values betwee 0.25 and 0.4 are considered appropriate [30]. If the safety stock is calculated dynamically based on the current demand pattern, a lower value such as 0.31 is recommended [31].

$$SL_0 = \frac{Q_{IN,m}}{2} \tag{9}$$

$$SL_1 = SL_0 + \sqrt{(L_{max}^{+} \cdot RD_m)^2 + (Q_{max}^{-})^2 + ((RD_{max} - RD_m) \cdot TRP)^2} \tag{10}$$

$$DD_1 = \frac{Q_{IN,m}}{2 \cdot RD_m} + \sqrt{(L_{max}^{-})^2 + \left(\frac{Q_{max}^{+}}{RD_m}\right)^2 + \left(\frac{(RD_m - RD_{min}) \cdot TRP}{RD_m}\right)^2} \tag{11}$$

$$t = \sqrt[c]{1 - (1 - S_w(t))^c} \tag{12}$$

where
L_{max}^{+} maximum positive lateness [days]
L_{max}^{-} maximum negative lateness [days]
QIN_m mean store input quantity [units]
Q_{max}^{+} maximum positive quantity deviation [units]
Q_{max}^{-} maximum negative quantity deviation [units]
RD_m mean demand rate [units/day]
RD_{min} minimal demand arte [units/day]
RD_{max} maximal demand arte [units/day]
TRP replenishment time [days]

The dimensioning of the stock of raw material, and the stock of semi-finished product in the case of an ATO production, and the derivation of the associated costs are also based on storage operating curves. In addition to the costs of the individual strategies, changing the order processing strategy may result in company-specific costs, e.g. an additional effort for control tasks, as the CODP is moved upstream in the company's internal supply chain.

As the calculations are mainly based on either historical data or predictions, variations in demand need to be considered. A sensitivity analysis is conducted to estimate the effects of demand variations and, at the same time, encourage a foresighted instead of a rushed change of the order processing strategy. The order quantity and the total amount of orders are varied and the order processing strategies are re-evaluated for these values.

For the validation of the individual models and the overall model, a simulation model was created. The simulation software Plant Simulation, which is widely used in academia for the modeling of logistic processes [32], was used for this purpose. The results of the simulation studies were discussed with experts from the industry to ensure practical relevance.

3.2. Additional analyses

Optimizing each product individually without considering possible interactions between different products may negatively affect the entire production system. As a way of counteracting this, additional analyses can follow the determination of the order processing strategy. In the present model, an analysis of the potential for workload balancing as well as other aspects, such as the calculation of the necessary storage space in the case of a MTS production and the ratio of the inter-operation time to the throughput time in the case of a MTO production, have been integrated. As an example, the procedure for analyzing the potential of workload balancing is outlined in the following. A critical work system is selected and the decoupling examined. In case MTS and ATO are possible for the decoupling, the costs are calculated and the strategy with the lower costs is selected.

Simulation studies have investigated that a certain proportion of products should be produced on stock to decouple a critical work system such as a bottleneck and thus enable a better balancing of the workload. To this end, the share of the workload related to products with a CODP downstream of the critical work system should be increased. For this purpose, the additional costs of decoupling due to the conversion of a product are compared with the share of the burden on the work system due to the product under consideration as the degree of decoupling. [33] With an increased share of MTS products the logistic performance can be improved. In addition, the selected values of the economic and logistic objectives should be examined in detail. In case of an insufficient achievement of these values, an investigation of the underlying reasons is required. Examining the company's internal supply chain step-by-step helps to decide if the low values result from the processes of the company itself or the order processing strategy. Consequently, either the strategy is ruled out or measures to improve the values of the objectives are initiated.

4. Software demonstrator

To encourage a broad use the model was transferred into a software demonstrator. For the validation of the demonstrator, simulation studies using the previously developed simulation model and tests with real company data were conducted. The foundation for the software demonstrator was built by designing a data linkage. This included the declaration of the input and output parameters of the overall model and the parameters to be exchanged among the previously selected individual models. A plausibility check of the overall model and the parameters was realized through interviews with companies from a wide range of industries. Companies can use freely available software not requiring programming skills such as KNIME [34] to adjust their data to the required form.

A high quality and integrity of the input data are essential for the software demonstrator to function effectively. Data has a high integrity if it is complete, free of contradictions and errors [35]. As initial step in the software demonstrator, the user has to configure the system to match the general conditions to the respective company. Among other things, this includes the specification of the number of production stages, the positioning of the semi-finished goods store, and the available capacity of different company divisions. Data that are separately requested for each product can be imported from the company's Enterprise Resource Planning (ERP) system. This is followed by an automatic check and cleansing of the data. The software demonstrator along with exemplary datasets and a handbook can be downloaded free of charge through the homepages of the research institutes involved in the project.

At a manufacturer of pharmaceutical equipment, the software demonstrator was uses to support the decision of the order processing strategy (Fig. 1). The company's internal supply chain was composed of the procurement, two production stages, an interim storage, and the dispatch. The production process required a lot size of 1 and the maximum allowed shelf life was 1 year for all products.

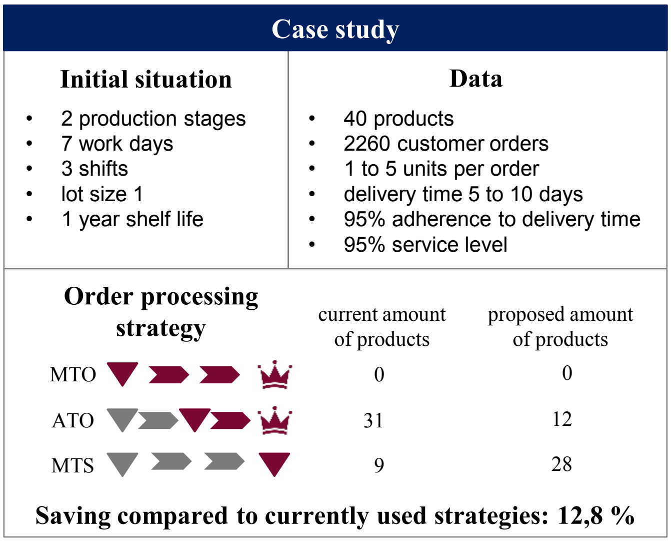

Fig. 1. Overview of a case study at a manufacturer of pharmaceutical equipment

The order processing strategies of 40 products (31 ATO and 9 MTS) were examined using 7 months of operating data as well as historical data on the customer demand. This included 2260 customer orders with a quantity between 1 and 5 product units per order. The delivery times requested by customers varied between 5 and 10 days. The throughput time of all products exceeded the required delivery times and thus made a MTO production impossible. In case of an ATO production the desired adherence to the delivery time of 95% was achievable for all products. The desired service level of the finished goods store of 95% resulted in the violation of the shelf life constraint for 1 product. Thus, this product was directly assigned to be an ATO product. For the remaining products the costs of a MTS production and an ATO production were compared. Changing 19 products from an ATO production to an MTS production revealed overall a saving potential of 12.8% of the costs directly related to order processing strategy. For the indivdual products the reduction varied between 19.3% and 28.2% due to the different order frequency and quantity. Changing data in the ERP system is not part of the software demonstrator. The responsibility remains with the people in charge of controlling the operations in a company as they most likely have additional information, e.g., planned releases of new products or variants. Regarding the case study, such additional information led the company to change the strategy from ATO to MTS for only 2 of the selected 19 products.

5. Conclusions and Outlook

Numerous interdependencies have to be taken into account when choosing an order processing strategy. The approaches existing in the literature either heavily restrict the decision criteria or are not generally valid. Given the dynamic environment of industrial practice, the selection of the order processing strategy should be low effort, fast, continuously reviewed and at the same time product-specific. The decision between a MTO, an ATO and a MTS production is directly related to achieving the desired values of the economic and logistic objectives of a company. Therefore, the approach presented uses logistic models to check the feasibility of these strategies and to derive the costs resulting from the desired values of the objectives. Transferring the theoretical model into a software demonstrator provides the opportunity to achieve a transparent, scientifically grounded decision without requiring a high modeling effort. Moreover, the demonstrator highlights potentials and thus its use might initiate additional analyses or measures to improve individual values. Providing information, such as the ratio of the inter-operation time to the throughput time, can lead to the evaluation of measures to reduce the inter-operation time and thus might move the CODP towards a MTO production. Besides the already implemented analyses, such as examining the potential of workload balancing, optimizations regarding the storage space or similar aspects are beneficial for companies. In a distribution of desired delivery times for a product, a very low delivery time to be achieved is usually selected from the distribution to serve most customer orders. Compared to the assumption of a fixed delivery time, heterogeneous desired delivery times per product could still be considered. In connection with the use of fast-track orders, a more extensive solution space could be achieved in the examination with which order processing strategies the desired delivery times can be fulfilled and thus a logistics cost could be reduced. The developed model was intended for production lines. Investigating different organization strategies in the context of order processing strategies could provide additional interesting insides.

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