The Importance of Managing Events in a Build-to-Order Supply Chain: A Case Study at a Manufacturer of Agricultural Machinery

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Abstract This application-oriented research focuses on customer-orientation in the context of build-to-order supply chain management (BOSC) and supply chain event management (SCEM). The last decade was characterized by increasing volatility and complexity in the supply network. As a consequence, companies with traditional supply chain management were confronted with more exogenous and endogenous disturbances. As a result, customer-oriented supply chains show poor performances in regard to the service rate, delivery time, inventory level and capacity utilization. Finally a “Lose-Lose-Situation” occurs, because customers do not get what they want and enterprises lose profit. This paper presents a case study of a manufacturer of agricultural machinery whose production system is following a BOSC strategy. Recently two supply chain disturbances, a strike in the production and a supplier shortage of a just-in-sequence part, significantly affected the service rate. The performance-related effects of these two disturbances are demonstrated in an elaborated system dynamics model, policies for their mitigation (e.g. capacity flexibility) proposed and their effectiveness evaluated.

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Introduction

In the field of supply chain management, firms find their suppliers to be unreliable because the required delivery rates are often missed. In turn, suppliers find the ordering patterns of their customers to be volatile and unpredictable. Generally, it creates a vicious cycle between sales, production and suppliers (Christopher and Holweg 2011; Holweg and Pil 2001). Inside each firm, managers find their forecasts of incoming orders are rarely correct and always changing. On the one hand, the sales forecasts lose all credibility with the production people. On the other hand, the marketing and sales organizations complain that unreliable production makes forecasting and selling difficult. The endogenous instability caused by exogenous events and the structure of a supply chain undermine trust within and between supply chain partners. The conflict creates supply chain instability and is usually aggravated by a lack of transparency. The latter is strongly needed as a prerequisite for a successful, early identification of supply chain events from real-time status data (Heinecke et al. 2011).

As a result the approach of build-to-order (BTO) production has become a popular operations paradigm after the successful implementations at Dell Computers. It refers to a demand-driven production approach, where a product is scheduled and built in response to a confirmed customer order (Holweg and Pil 2001). Hence, firms like the one in the following case study follow the approach of BOSC management to (re)act to the fluctuations in demand and to handle the increasing complexity of the value network (Gunasekaran and Ngai 2005; Gunasekaran 2007). The BOSC model is now being actively pursued in several different industries such as computers, automotive and manufactures of construction and agricultural machinery (Holweg and Pil 2004; Parry and Graves 2004; Salvador et al. 2004). BOSC can be defined as ‘‘the value chain that manufactures quality products or services based on the requirements of an individual customer […] at competitive prices, within a short span of time by leveraging the core competencies of partnering firms or suppliers and information technologies […] to integrate such a value chain” (Gunasekaran and Ngai 2005).

However, supply chains are continuously subjected to disturbances e.g. in demand, production rates and material deliveries. These disturbances or events constantly knock BOSC out of equilibrium. In the literature, different approaches are discussed to define the right product delivery strategy (Christopher and Towill 2001; Olhager 2010). Furthermore, research has strongly focused on the topic of preventive measures to minimize the potential for events. Approaches like supply chain risk management and BOSC that aim at achieving a robust and economical supply chain are state of the art in theory and practice. The case study will show, however, that supply chain events occur nevertheless and knock event-prone BOSC out of their equilibrium. The authors have thus conceived a generic system dynamics model to evaluate the performance-related effect of supply chain events.

According to Huang et al. (2007) events can be classified into three categories: deviations, disruptions and disasters. Deviation events refer to changes in parameters from their expected or mean value. Disruption events are occurrences that are so significant and far reaching that normal operation is disturbed considerably. For example, if product mixes or demand have changed significantly, it will take a span of time for the system to recover from deteriorating performance. During the recovery, performance becomes unpredictable and remedial actions must be taken in order to bring the system back to a more stable state. Disastrous or catastrophic failures lead to a temporary irrecoverable shut-down of a supply chain network (Gaonkar and Viswanadham 2004).

The authors present a case study of a supply chain whose operations are affected by unpredictable events. When these occur, firms must take immediate actions to assess potential impacts and, if necessary, activate contingency plans for mitigation of their worst effects. The case study is based on the supply chain of a manufacturer of agricultural machinery who follows the BTO principle to achieve high performance in an increasingly complex environment. Simultaneously unpredictable events, however, erode the stability of the production program and endanger overall performance. Thus, as this paper's case study will illustrate, BTO production systems do not guarantee high performance when they lack flexibility. In a nutshell, the paper focuses specifically on the following key points:

1. Building a generic system dynamics model based on the manufacturing supply chain of the case study.
2. Reconstructing the two supply chain events (strike and delivery failure of a supplier) in the model that led to a lower service rate. Verification of the assumption that variations or disturbances knock BOSC out of equilibrium.
3. Identification and evaluation of possible policies (e.g. capacity flexibility) that can be applied to ensure high performance of a BOSC with respect to market and operational targets.

Case Study

Manufacturing Supply Chain

The present case study is based on data from the supply chain of a medium-sized manufacturer of agricultural machinery that produces combine harvesters, forage harvesters, balers, forage harvesting machinery and tractors. These markets are characterized by low volumes, seasonal demand, series production, increasing product variety and globalization of operations. The production system is following a BTO principle where every production job is triggered by a customer order. Hence, disturbances and volatile demand have both a significant impact on the behaviour of the production system. Due to the competitive landscape, the agricultural machinery market has high requirements on quality, service, price, delivery reliability and short delivery times to generate customer satisfaction.

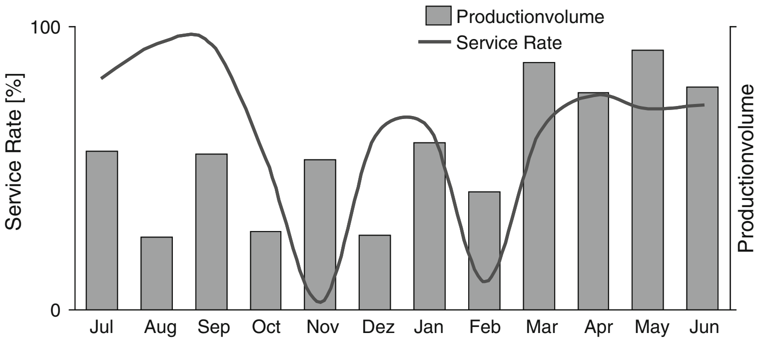

Fig. 1 Service rate and production volume at the manufacturer of the case study

Furthermore, the BOSC is strongly influence by unplanned endogenous and exogenous factors like supplier issues, sales campaigns, strikes and demand and price changes.

Figure 1 shows the service rate (line) and production volume (bars) over a period of 12 months. In general, the production volume in August and December is lower than the other months because of the summer and winter break. The other two significant falls in production volume in November and February, however, are due to two major disruptions. Both had a delayed effect on the service rate, which is defined as the percentage of punctually fulfilled orders compared to the total amount of orders during a certain time span.

In October a strike affected a plant of the manufacturer for over one week. As a result of this event, most of the scheduled machines were only produced weeks later. Now, if an event leads to a delay in production then all following, sequenced orders are not punctual regarding to their confirmed delivery date. Thus, many of the confirmed delivery dates were missed and the service rate declined significantly in November. As a main result, the monthly service rate fell dramatically. A second supply chain event happened in late January and early February. A specific module that is sourced just-in-sequence from a certain supplier could not be delivered in the required quantity for weeks. Hence, the OEM was unable to manufacture certain product variants and the service rate significantly declined again in February.

Key Performance Indicators

Key performance indicators (KPIs) of a production system according to Wiendahl are (1) delivery time, (2) service rate, (3) capacity utilization and (4) inventory level (Wiendahl 2010). From the market perspective a very short delivery time and adherence to delivery dates, which lead to a high service rate, are crucial. From the perspective of the operational level, the goals is to have a high and stable

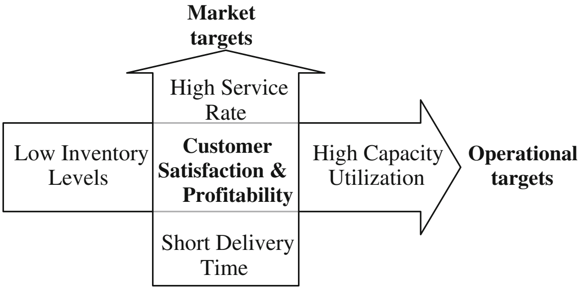

Fig. 2 Key performance indicators and the polyemma of production controlling

utilization of capacity and low inventory levels of raw material, work in process and final stock. The four performance measures are shown in Fig. 2. The four targets have a huge influence on customer satisfaction and on enterprise profitability. On the one hand they create an internal conflict between having high service rates and short delivery times. On the other hand to have low inventory levels and high capacity utilization. In the literature this contrary target set is called the polylemma of production controlling (Wiendahl 2010), which means it has at least more than two conflicting objectives (options) compared to a dilemma situation. Regarding to the presented case study, where the manufacturer operates in a saturated buyer market, the operational targets are arguably less important than the market targets. The latter ensure lasting customer loyalty for services and future product versions even in the face of severe competitive pressure. Nevertheless, since operational targets affect enterprise profitability, all four KPIs will be embedded in the simulation model. This approach enables a comprehensive evaluation of the manufacturing supply chain performance.

Description of the System Dynamics Model

The described system of the manufacturing supply chain is transformed into a continuous simulation model to evaluate the cause-effect structure and the impact of supply chain events on the KPIs. Furthermore, different supply chain reactions are simulated and evaluated in order to determine appropriate policy decisions that can mitigate the effects of these events.

System dynamics is a specific approach of system theory and is adequate to analyse complex system behaviour. The benefits of system dynamics are a unified notation of continuous flow modelling and a graphical interface. The user-friendliness, aggregation of system parameters and understanding of the system behaviour are considered as another important advantage. In addition to the possibilities of continuous flow modelling based on differential equations, it also offers the possibility of implementing discrete elements like random and trigger functions, which facilitate an intuitive modelling (Scholz-Reiter et al. 2008; Morecroft 2007). In short, “system dynamics is well suited for supply chain modelling and policy design. It is a method to enhance learning in complex systems and […] to help us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies" (Stearman 2000). Potentially, other simulation tools (e.g. Plant Simulation, OTD-NET Simulator) may be also adequate to demonstrate this purpose. However, system dynamics fits perfectly to build a generic model, which illustrates the system behaviour of a supply chain on an abstracted level. This generic model makes it possible to verify and evaluate the performance-related effects of supply chain events (variations and disturbances) in manufacturing supply chains.

The generic model in Fig. 3 is based on the manufacturing model in (Stearman 2000). Additionally to the basic manufacturing supply chain model, the KPIs and supply chain events are added. The simulation was created with the software Vensim® PLE. Figure 3 illustrates the model with its three main areas: The supply chain structure (a), a basic market structure (b) and key performance indicators (c). The supply chain structure in block a consists of the order, material and production flow from the supplier, via the manufacturer, to the customer. These supply flows are limited by the maximum available capacity (e.g. in production or material supply). Delays and adjustment times (e.g. material delivery time and production time) are embedded in the simulation model. The material and production rates are determined with a time delay. The market structure (block b) contains a customer order rate per time unit, backlog of orders, order fulfilment rate, target of delivery delay and desired shipment rate. The backlog shows the total amount of orders per time unit. The desired shipment rate defines by the quotient between the backlog and target delivery delay. The order fulfilment rate is determined by the shipment rate. The delivery delay is equal to the backlog divided by the order fulfilment rate. If the final stock is greater than or equal to the desired shipment rate, the service will be 100 %. Hence, the service rate measures the number of punctually fulfilled

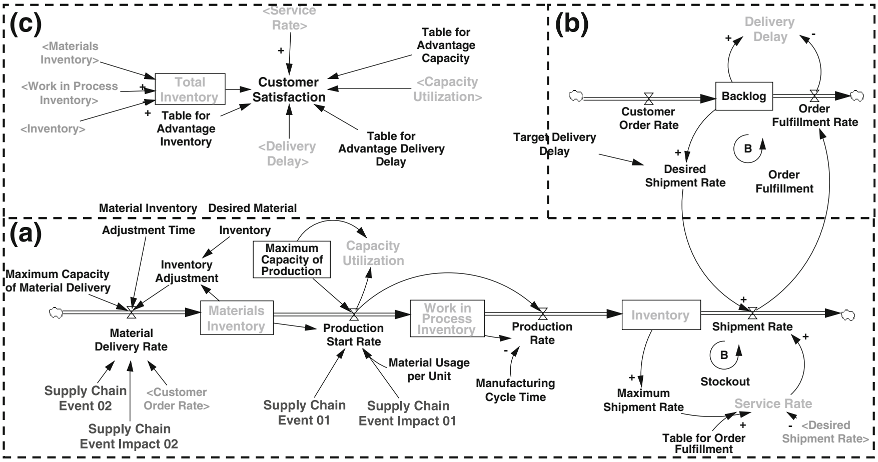

Fig. 3 System dynamics model of a manufacturing supply chain with the KPIs

orders. Besides the service rate, the three other KPIs (block c) of production control are embedded. Those indicators have a direct and important link to the customer satisfaction and ultimately also to enterprise profitability.

Analysis of the Base Case Scenario

This subsection compares performance of the model (1) when operations are stable and (2) when they are disrupted by two events to verify the performance-related effects of supply chain events on BOSC. Table 1 shows the employed parameters of the base case scenario.

The dashed line in Fig. 4 shows that a stable supply chain leads to the levelling of the market targets, service rate as well as the delivery delay. In this base scenario the manufacturing supply chain achieves a high service rate of about 90 % and a delivery delay of about nine weeks. The effect of the first weeks is neglected because the simulation needs several weeks to calibrate the behaviour of the system.

The first supply chain event (e.g. strike at the OEM) occurs from week 15 to 17. The service rate falls sharply from 90 to 48 % and needs more than 10 weeks to recover to 65 %, where it levels off. The delivery delay is directly linked to this performance. Its value increases from 9 to 17 weeks and, after several weeks, balances itself at 12 weeks. This effect happens because the production constantly operates at its maximum capacity limit of 600 units. Customer orders still arrive at the same rate, however, and therefore the production is continually booked with old orders and the new arrivals have to wait longer than they usually would. Furthermore, the unfulfilled orders increase the order backlog and desired

Table 1 Base case parameter for the manufacturing supply chain model

Parameter	Base case value
Simulation time	52 weeks
Customer order rate	600 units/week
Target delivery delay	8 weeks
Manufacturing cycle time	4 weeks
Maximum capacity	600 units
Desired material inventory	600 units
Material inventory adjustment time	4 weeks
Maximum capacity of material delivery	600 units
Material usage per unit	1
Supply chain event time 1 (strike at OEM)	week 15
Supply chain event impact 1	−600 units
Supply chain event time 2 (supplier delivery issue)	week 32
Supply chain event impact 2	−600 units

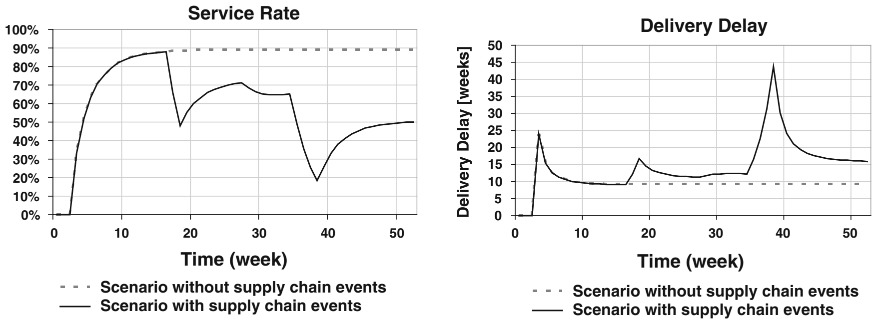

Fig. 4 Service rate and delivery delay in the base case scenario

shipment rate. Hence, if an event like a production strike happens, the delivery delay increases permanently as lost production capacity cannot be made up. The second event, e.g. a shortage of 600 units of a just-in-sequence module, happens from week 35 to 39. The effect is similar to the first event of a production disturbance. Again, the service rate falls sharply - this time from 65 % to under 20 % - and the delivery delay increases from 12 to over 40 weeks, later balancing itself at 16 weeks. It can be concluded that a disturbance of the supply chain temporarily destabilizes the system and leads to generally lower performance levels for the considered KPIs.

Analysis of the Scenario with Capacity Flexibility

A lot of different approaches of counter-measures exist to avoid performance degradation. However, an often discussed solution to avoid performance degradation is to increase flexibility in capacity (Salvador et al. 2007; Howard 2002; Fredriksson and Gadde 2005; Ahlert et al. 2009) to absorb deviations. With the developed model is it possible to show the effectiveness of an increase in flexibility regarding to production capacity and material supply rate.

In the simulation model with production flexibility the maximum production rate, maximum capacity of material delivery and desired material inventory are increased from 600 to 700 units and then in another simulation from 600 to 800 units. Figure 5 illustrates the effects of an increased capacity to 700 units on the KPIs. The average service rate is 15 % higher in the scenario with capacity flexibility. Furthermore, the capacity flexibility also has a positive effect on the delivery delay. The average delivery time is reduced from 14 to 11 weeks. On the other side, the operational targets are worse than before. An increase of the maximum capacity leads to unused resources and consequently the average capacity utilization falls by 6 %. The inventory level shows no noteworthy effects. In essence, the capacity flexibility is only required in case of disturbances in the supply chain. If supply chain events happen, capacity flexibility has a positive effect on the two market targets, service rate and delivery delay. This overall positive effect is illustrates in the customer satisfaction and profitability diagram (bottom left diagram in Fig. 5).

In another simulation the maximum capacity is increased to 800 units. This setup leads to a very high performance regarding the market targets but to a much lower level for the operational ones. Hence, customer satisfaction and profitability achieve an overall lower level because of an over-sized production capacity. The simulations show that flexibility is costly. The operational costs are important factors that need to be considered. Idle capacity and/or high inventory levels do not

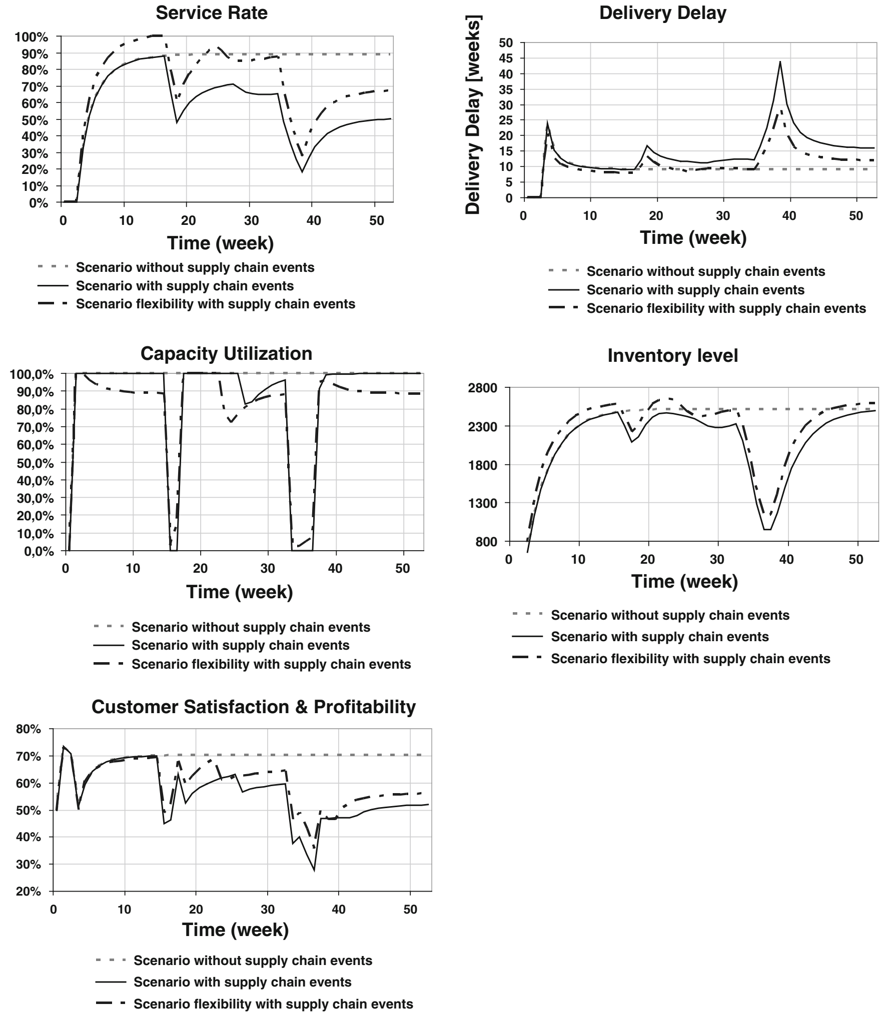

Fig. 5 Performance indicators of market and operational targets

add value to the product itself but still have a direct influence on product prices as these costs have to be carried by the customers.

In summary, the simulation model illustrates the influences of supply chain events and enables their evaluation. Beyond that, different policies can be validated and verified to realize an effective BOSC, which considers the influences of supply chain events. This study showed that increased capacity flexibility helps to stabilize BOSC when disturbances influence manufacturing supply chain performance. Furthermore, the cost of flexibility has to be compared with the loss of operational performance.

Conclusion and Outlook

Although BTO has done much regarding the reduction of costs and, hence, increase customer satisfaction and profitability of the OEM and, it is questionable whether the increased vulnerability of production systems and performance do not necessitate another paradigm shift. It is important to have a holistic view on the supply chain behaviour and the balance of operational and market targets. The developed system dynamics model is a suitable tool to understand the behaviour of a manufacturing supply chain and to simulate different supply chain setups and mechanism of counter-measures to absorb the vulnerability through supply chain events. The results of this contribution can help to design and optimize a BOSC and to achieve a "Win - Win-Situation" between customers and enterprises in future. This paradigm shift can be envisioned as a hybrid production system that utilizes build-to-stock and build-to-order principles combined with an optimized degree of mix and volume flexibility in the supply chain, and consequently harness their respective advantages. A comparison with similar industrial cases will be relevant to validate the methodology, generic system dynamic model and the presented results. Additionally, fundamental research has to focus on the fields of vulnerability of BOSC and the intelligent mitigation of effects of supply chain events through SCEM systems. In further research the elaborated simulation model will be extended to evaluate the cost-benefit rate of a production system that considers also the influence of supply chain events. Furthermore, focusing on the organizational and strategic factors that drive supply chain management decisions with respect to the implementation of a BTO strategy represents a relevant future direction for research.

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