DOI: 10.2195/lj_NotRev_baumgarten_en_201302_01
URN: urn:nbn:de:0009-14-35797

An Approach for Reducing Dynamics in Production Networks

Reduzierung der Dynamik in Produktionsnetzwerken

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The growing dynamics in the economic environment necessitate new approaches for analyzing and influencing the dynamic behavior of production networks. Analysis of nonlinear dynamics can help to differentiate the causes of the formation of dynamics. One key cause is the production network partners' differing responsiveness, i.e. the logistics capability to react.

[Keywords: Supply chain design, logistics reactivity, peripheral production network, dynamic systems]

Als Reaktion auf die zunehmende Dynamik im wirtschaftlichen Umfeld sind neue Ansätze zur Analyse und Einflussnahme des dynamischen Verhaltens in Produktionsnetzen von Bedeutung. Durch die Analyse der nichtlinearen Dynamik kann eine Differenzierung der Ursachen der Dynamikentstehung erfolgen. Eine sehr bedeutende Ursache ist die unterschiedliche Reaktionsfähigkeit von Netzwerkpartnern.

[Schlüsselwörter: Supply Chain Management, logistische Reaktionsfähigkeit, dezentrale Netzwerke, dynamische Systeme]

1 INTRODUCTION

Since the early 1990s increasing the capability to react to customer demands (responsiveness) has played an important role in the corporate organizations of manufacturing companies. As a result, the organizations have become less complex and more process-oriented [WIE05]. Increased responsiveness is characterized for example by an enterprise's ability to quickly deliver goods if demand is higher than anticipated. If the responsiveness is greater than that of its competitors, an enterprise gains additional sales opportunities. Moreover, if there are disruptions in the production network (e.g. delivery bottlenecks or a loss of capacity) a high capability to react with specified measures is critical in order to adjust and still meet the customers' needs.

Due to the increased division of labor in a production network, the impact of disruptions or changes in customer demand is no longer isolated to individual enterprises, but rather affects the complete supply chains [BEC04, SYD06]. Thus, surviving in this environment requires measures for increasing responsiveness to be set and implemented in a coordinated way across all production network partners involved. Failure in communication and coordination can lead to misinterpreted signals by production network partners. For example, a one-time increase in demand by a purchaser to raise his inventory level can be misunderstood as a greater demand from the end customer. The impact of such misjudgments can build up and amplify over a number of tiers in a production network, thus, leading to the bullwhip effect [FOR62].

The method introduced in this paper for resolving this situation targeting the synchronizing responsiveness both in-house as well as across the production network. The logistics capability to react is determined by the ability of an enterprise to realize logistics measures in response to dynamic changes in the production network such as disruptions and fluctuating demand. Logistics measures include adjusting the capacity and inventory but also the production network design. Synchronization refers to the alignment of these measures both between and within enterprises in a production network, in order to prevent misjudgments and to avoid generating dynamic effects (e.g. the bullwhip effect).

2 MOTIVATION

The production systems of network partners amplify the system dynamics because each production system can react differently to changes (e.g. by altering quantities or delivery times), thus, cause unpredictable behavior. This is also known as intrinsic system dynamics and is not part of classical production planning and control [WOR03].

Dynamics generally arise when a change (cause) triggers a time-dependent process (effect). The types of cause and effect relationships in dynamic systems can differ (see Figure 1). In linear cause and effect relationships, the results are reproducible, i.e. the same initial conditions lead to the same results. This allows long term forecasts of the system behavior, which is not always the case in non-linear interactions. The prediction of values with stochastic interactions using statistical or probabilistic methods is limited. Deterministic systems can vary from stable periodic behavior to instable chaotic behavior. Deterministic chaotic interactions are apparently random and can normally not be distinguished from stochastic interactions. They are not predictable in real-world scenarios because even the smallest change of the initial conditions can grow exponentially over time (e.g. because of self-enhancing characteristics). All changes, no matter how small, must be known in order to make a prediction. Periodic behavior (values repeat after a period of time) and quasi-periodic behavior (periodic, but not with same exact values), in contrast, are predictable.

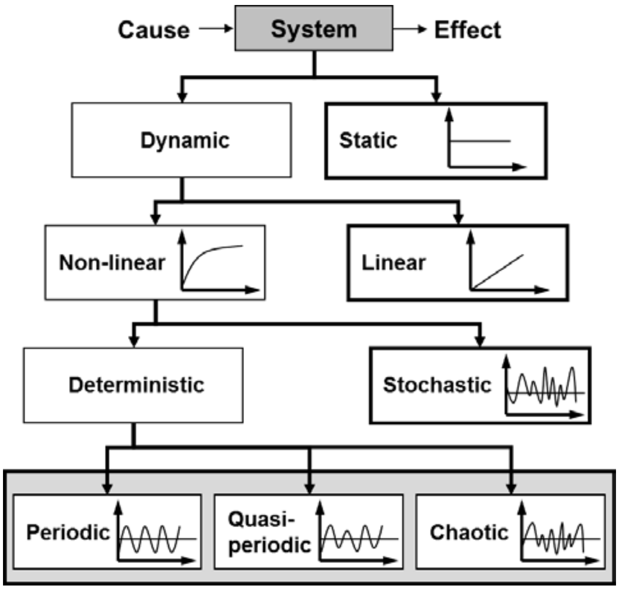

Figure 1. Cause and effect relationships of systems and their predictability [WOR03]

A variety of cause and effect relationships can arise in production networks. The ability to differentiate between stochastic and deterministic factors can contribute to identify the causes of growing dynamics. For example, if the reactions of the production network partners are not aligned, the deterministic dynamics within the production network will increase. These deterministic causes can be reduced by changing the parameters (e.g. redefining the flexibility of capacity or redefining the inventory). Several scientific works [e.g. DIA00, PET03, WOR03] have proven that the behavior of production systems can vary from periodic to chaotic when parameters are changed. Using a simulation study of an assembly process with changing assembly buffers, WORBS shows how altering the buffer sizes influences the dynamic behavior. Nonetheless, explicit analyses of deterministic dynamics in production networks are still not used today.

3 EXISTING APPROACHES TO REDUCE DYNAMICS AND THE IMPORTANCE OF SYNCHRONIZATION

One of the most important measures against dynamics in production networks and one of the elementary principles of production network management is the intensive cooperation between production network partners. One of the well-known measures in this context is Collaborative Planning Forecasting Replenishment (CPFR). The integrated management of material flows across all tiers of the production network and the consolidation of inventory data of CPFR make the provision of goods and inventory management more efficient. Actions recommended within the frame of CPFR include developing information management systems across the production network, using standard interfaces (e.g. electronic data interchange interfaces between manufacturers and suppliers) and developing a common joint sales plan [DUD04]. Despite existing concepts and recommended actions, there is a general lack of willingness to cooperate in supply networks [BEC04, SCH06]; information is not forwarded with the necessary extent and the synchronization of measures is disrupted. The process and possible compensations (e.g. additional inventory), therefore, have to be contractually regulated.

In order to synchronize responsiveness, the logistics objectives of the production network partners have to be aligned while taking into account their interdependencies. Accordingly, the goals of the production network as a whole are more important than the individual goals of the production network partners. Quantitative information concerning the interactions within the production network is a prerequisite for this. Key figures, which are defined and allocated to processes within, e.g., reference process models (such as the SCOR Model [SCC06] or VDI Guideline 4400 [VDI00]) can be drawn on here.

Typically, logistics targets are set only for an enterprise or even a department within a company. There is a lack of methods for measuring the attainment of targets based on processes across a number of tiers in a production network. A method such as this requires the objectives to be coupled to the interfaces (e.g. at inventory and supply points). Figure 2 depicts possible 'coupling-parameters' for the receiving points, which enable a synchronization of reactions across departments or network partners. For example, the replacement time is primarily derived from the order lead time of the supplier and as such, is dependent on the type of procurement. If supplies are sourced from stock, the replacement time is dependent only on the supplier's lead time. If supplies are manufactured in a make-to-order production the replacement time depends on the supplier's lead time and (part of) the manufacturing time [FAS97].

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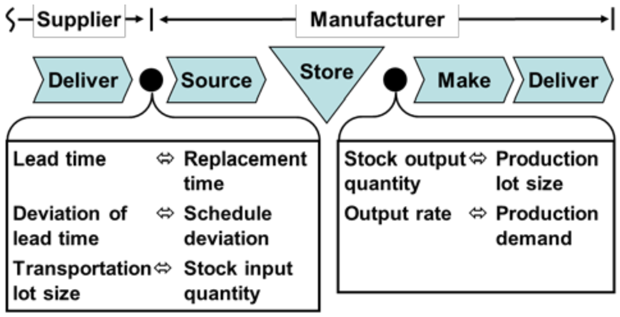

Figure 2. Possible coupling parameters for a receiving goods store (input and output) [FAS97]

The measuring and coupling points along the process chain as well as the key figures (coupling parameters) have to be defined so that the interactions between the capacity, inventory and lead times are recorded. Production logistic measures (e.g. making capacity more flexible) have to be evaluated with regard to their effect on the dynamics within production networks. Until now there has been a lack of methodical support for synchronizing the responsiveness of all production network processes while taking into account their interdependencies. This can contribute to reducing dynamic effects while increasing the logistics performance with low inventories in the production network.

The economic crisis in 2009 and the subsequent recovery in 2010 highlighted the problems that can arise from asynchronous responsiveness within production networks. For example, the semiconductor industry did not ramp up its production quickly enough to keep up with the growing demand from the automotive, electronics and other industries. This led to severe bottlenecks and disrupted production. As a result, 56 % of the 800 German companies surveyed for the Handelsblatt Business Monitor in 2010 plan to improve coordination and cooperation within their production networks [SEM10, BUC10].

This article presents the results of a simulation study that shows how unsynchronized responsiveness can intensify network dynamics and how this can affect the logistics performance of the production network. Afterwards, a mathematical approach to synchronize responsiveness is explained.

4 Simulation Study

A simulation study was conducted to determine how different logistics capabilities to react within a production network, influence the resulting dynamics and the logistics performance. Therefore a simulation model with two converging processes was designed (see Figure 3). Between the two production processes and assembly, inventory is held. The processes A and B converge before assembly. Assembly can start only when components from both production processes are available. Dynamics occur as the assembly demand fluctuates periodically between 50 and 70 items per day, i.e. when the capacity of production needs to be adjusted. The responsiveness of the production processes to assembly demand is determined by their respective capacity's flexibility and by their respective stock level. The responsiveness of process A and B differ, in process A, the flexibility of capacity is lower, but the stock level is higher compared to process B.

Two structures were compared in the simulation model. In the first structure, the converging processes are coupled, i.e. the stock level in one process influences the other parallel process. The coupling of parallel production processes before an assembly process requires that two prior conditions are met. First, production must be controlled by the stock level, e.g. through a Kanban system; second, material must not be reserved or booked for assembly before all the materials needed are available. As a result, the actual assembly demand is not communicated to the production processes because the assembly rate is limited by the lowest production rate. In the second structure, the processes are decoupled, and the stock level of one process does not affect parallel processes. Only the scheduled demand of assembly has an impact on the production processes. Components are reserved or taken out of stock for assembly according to the schedule, regardless of whether all required components are available yet. That way the production processes know the actual demand of assembly. The simulation study was done with Plant Simulation, a discrete event simulation software. During the first set of simulation tests, stochastic processes were not included in the model, ensuring that dynamic behavior was related to deterministic effects.

The hypothesis for this study was that the dynamics will be amplified in the first structure with coupled processes because of the parallel processes' different logistic capabilities to react. Consequently, the dynamics were expected to be lower with the decoupled processes. The dynamics can be assessed by the variance of inventory trends. In the simulation tests, the assembly demand increases and decreases periodically 30 times at intervals of eight shop calendar weeks. Figure 3 shows a section of the inventory trends at the various stockholding points. Although the assembly demand is periodic, no periodicity can be recognized in the inventory trends in the first structure. Instead, the inventory trends seem chaotic. The simulation test of the second structure results in periodic and quasi-periodic inventory trends. As a conclusion it can be stated that the parallel processes' different logistics capabilities to react of the do not affect each other. The stronger dynamics also have an impact on the logistics performance, which is measured by the mean inventory (I_m) and the customer-oriented service level (SL_C), i.e. the availability of stock at both stockholding points before the assembly process. The mean inventory of all stockholding points is higher with coupled processes than with decoupled processes. The customer-oriented service level is higher with decoupled processes.

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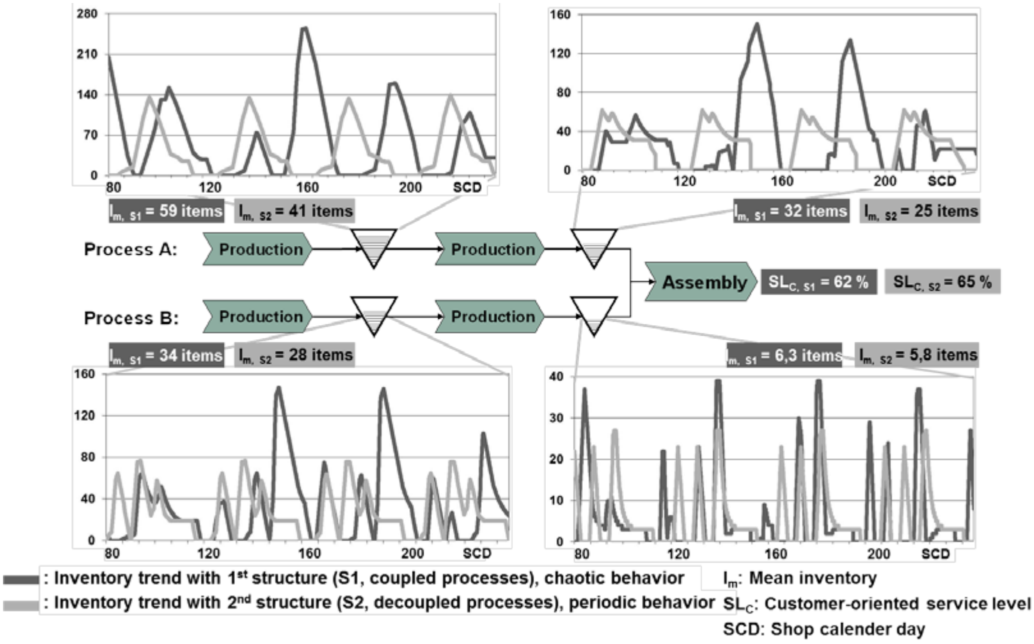

Figure 3. Inventory trends of stockholding points and logistics performance indicators for coupled (S1) and decoupled (S2) processes

In the second set of simulation tests, stochastic distributions for lead times and demand were created in the discrete simulation model. The standard deviation was 20 %. In this model the mean demand fluctuated between 30 and 40 items. In addition to the differentiation of coupled and decoupled processes, the effect of synchronizing the processes' logistics capability to react was examined (measures for synchronizing responsiveness are described in Section 5). The hypothesis for this study was that the dynamics in the first structure with coupled processes will be reduced if the logistic capability to react of the coupled processes is synchronized. For a better overview, the inventory trends of only one stockholding point (the one of process A before the assembly) are shown in Figure 4. The logistics performance indicators are again the average stock and the customer-oriented service level.

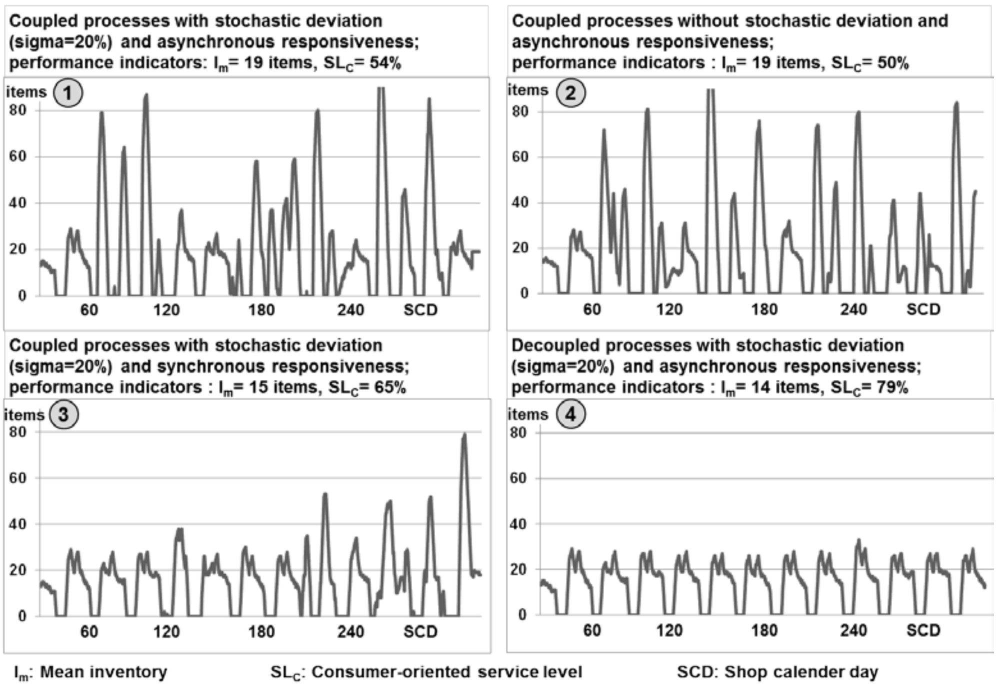

Figure 4. Inventory trends of the stockholding point of process A before assembly, comparing coupled and decoupled stochastic processes

The inventory trends show that in this case, dynamic behavior is more determined by deterministic effects than by stochastic effects. The logistics performance is even lower without stochastic effects (compare inventory trends 1 and 2). With regard to the hypothesis, the simulation showed that the synchronization of logistics responsiveness of the coupled processes has a positive effect (see inventory trend 3). Due to the synchronization, the mean inventory was reduced from 19 to 15 items and the customer-oriented service level was improved from 54 % to 65 % (compare inventory trends 1 and 3). For comparison, the simulation model was also running with decoupled processes with asynchronous responsiveness (see inventory trend 4). This showed decoupling the parallel processes results in even better logistics performance with a mean inventory of 14 items and a customer-oriented service level of 79 %.

The simulation study has shown that the dynamics in the production network can be reduced and logistics performance can be improved significantly through the measures of decoupling the processes and synchronizing the logistic responsiveness. In the next section it will be explained how a production system can react to dynamics (e.g. an increase in demand) and how parallel processes can synchronize their responsiveness to reduce the dynamics.

5 Lowering Dynamics by Synchronizing the Logistic Capability to React

The simulation study showed that an unsynchronized responsiveness leads to greater dynamics within the supply chain and greater dynamics worsen logistics performance. The logistic responsiveness depends on the specific situation of a production system and changes over time. If the utilization of a company's production system is very high, for example, then the capability to react will be low or it might take a long time to activate new resources. The key figure Capable-to-promise indicates the actual quantity a company is able to deliver, including products in stock and the capacity of the production [TEM06]. Additionally, future capacities which can be used for producing the product need to be considered. Capacity can be limited by manpower or by production facilities [NYH08].

As an example, Figure 5 shows the cumulative quantities of the supplier's capacity (S) and the customer's demand (D). As the customer's demand rises, the inventory is used up and eventually a shortage occurs. The supplier has several options to increase the capacity to: first, keep up with the rising demand, and second, to build up the inventory to the target level again (I_T). This backlog results from the inertia, the time during which capacity lags behind demand. The options for increasing supply shown in Figure 5 are related only to manpower, i.e. capacity can be increased within a certain point within the limits set by the production facilities.

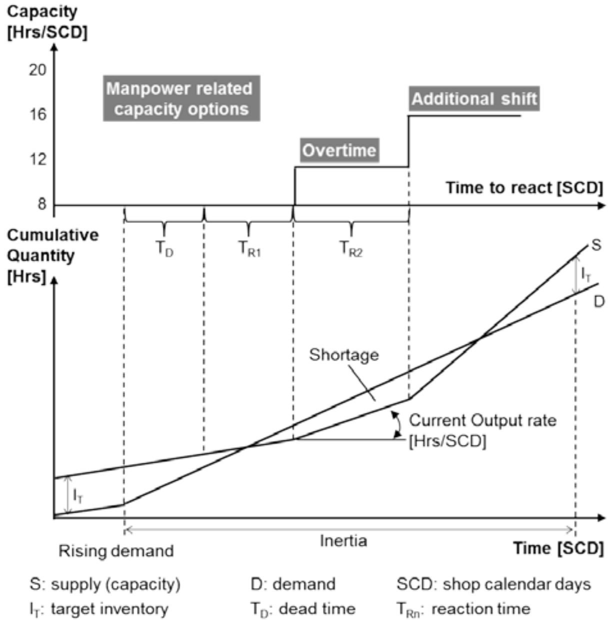

Figure 5. Inertia and shortage of two capacity options

As the supplier implements the various options to increase the capacity, it is important for him to know when the backlog will be cleared. In the simulation, two additional capacity options were sufficient to adjust the supply rate to the increased demand, as can be seen in Figure 6. The demand increases only once, from D_1 to D_2 compared to the supply rate which is increased twice, from S_1 to S_2 to S_3. Given that the supply rate of S_2 is still below D_2 it takes the second raise to S_3 to exceed the demand D_2 and enables the reduction of the backlog. The time from the demand increase until action is taken, is called dead time (T_D). For example, information may be transmitted in this time but nothing is done yet to adjust the capacity. More time passes before capacity options are implemented (reaction time, T_{Rn}) and make an impact on the output.

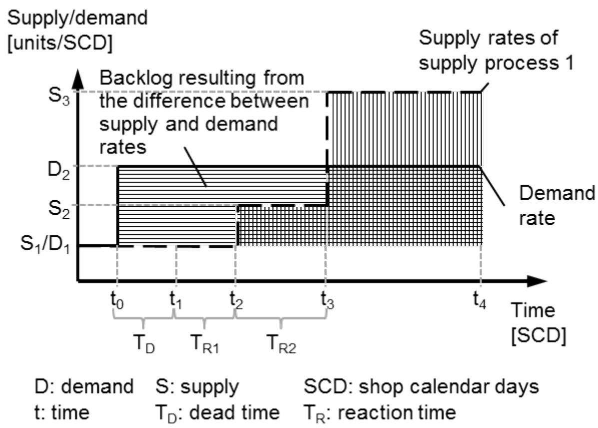

Figure 6. Backlog resulting from the difference between the supply and demand rates

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In general, the backlog can be calculated with the following formula:

$$S_{n-1} < D_2 < S_n \Rightarrow$$
$$B = (D_2 - S_1)(T_D + T_{R1}) + (D_2 - S_2)T_{R2} + \ldots +$$
$$(D_2 - S_{n-1})T_{Rn-1}$$

Where S_n: supply rate (capacity); D_2: new demand; B: backlog; T_D: dead time; T_{Rn}: reaction time

Equation 1. Calculating the backlog

Since part of the backlog can be absorbed by the inventory available (I_T) the actual shortage is calculated by:

$$Sh = B - I_T$$

Where Sh: shortage; B: backlog; I_T: target inventory

Equation 2. Calculating the shortage

Action can be taken by the customer when he knows about the Capability-to-Promise of each supplier. The simulation showed how sharing information and synchronization can improve logistics performance. For example, if for an assembly process the inputs from two supply processes A and B are required (see Figure 7), the supply processes' capacities are adjusted not only in reaction to customer orders but also to one another. That means, if the capacity of supply process A is increased, the capacity of supply process B is increased accordingly, because the customer would not be able to use process A's input without the input from process B. Thus, parallel (i.e. not competing) suppliers in a production network can influence each other's capacities allocated to a specific customer.

The aim is to synchronize the parallel processes' shortage (Sh) in the case of a demand increase. That way a component from one supply process will only be missing when the other supply process cannot deliver its component either. This results in the best possible logistic performance (low mean inventory level, high customer-oriented service level). In order to synchronize the parallel processes' responsiveness in the short term, inventory levels of the process with the lower responsiveness have to be increased. A larger buffer stock gives the process more time to increase its capacity (T_{Rn}) before stock runs out. In the long term, the parallel processes' responsiveness can be synchronized through adapting the capacities' flexibility (T_{Rn}) and/or reducing time needed for transmitting information (dead time, T_D).

A decision-making model using the formulae above helps to synchronize the parallel processes' responsiveness. As a first step, the shortage of the parallel supply processes in the case of typical demand increase is calculated. These quantitative values facilitate the identification of the process with lower responsiveness. Next, options are identified to increase the responsiveness of that process. These can be both short and long-term measures as mentioned above. Since each option impacts on at least one of the variables in the formulae, target inventory (I_T), supply rates (S_n) and dead time (T_D), the shortage resulting from the implementation of each option has to be calculated individually. By comparing those new shortage values with the shortage of the process with higher responsiveness, those options can be identified that will synchronize the two processes' responsiveness.

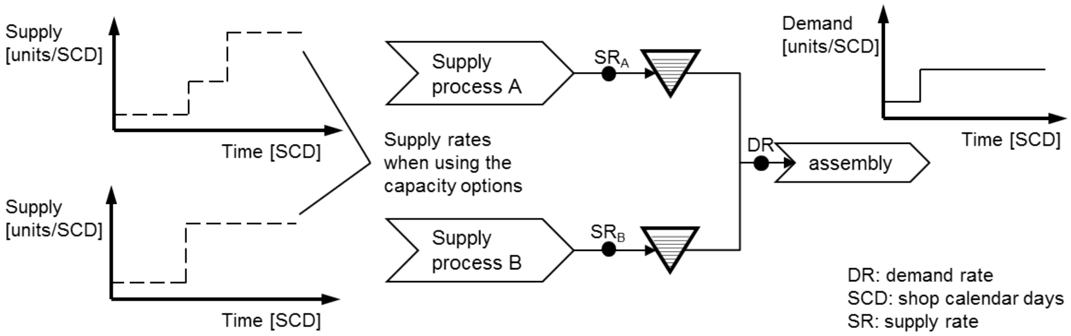

Figure 7. Converging supply processes for assembly

6 CONCLUSION

Due to the ever growing dynamics of markets, enterprises have to possess a high degree of responsiveness, i.e. the logistic capability to react to changes in the customer demand or disruptions in the production network and still ensure their competitiveness. If the reactions of the production network partners are not synchronized, however, it can increase the dynamics within the production network and lead to worse logistic performance. The simulation study showed that structural-related interaction in the production network has a strong impact on dynamic behavior. Likewise, the arising dynamic behavior has an impact on logistics performance. Without stochastic deviations, a stochastic-like, chaotic-deterministic inventory trend could be recognized. Furthermore, the study also established that synchronizing responsiveness within a production network can lower dynamic effects and enhance logistics objectives.

Logistics measures – as a reaction to dynamically induced factors – therefore, need to be coordinated. In order to align the measures in the production network, the interdependencies of the logistic objectives within the production network for all of the processes (source, make and deliver) have to be taken into consideration. The decision making model presented in this paper uses quantitative values to assess different processes' responsiveness and the potential impact of various measures that might be implemented to improve the responsiveness. This provides the basis for selecting the most suitable option(s) to synchronize the processes' responsiveness.

The authors would like to thank the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for their financial support of this research project (Reference Number: NY 4/24-1).

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DOI: 10.2195/lj_NotRev_baumgarten_en_201302_01
URN: urn:nbn:de:0009-14-35797

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