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MODELLING CIRCULAR MATERIAL FLOW AND THE CONSEQUENCES FOR SCM AND PPC

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ABSTRACT

This paper discusses the consequences of product return and circular material flow on a supply chain as well as on production planning and control. Furthermore, this paper presents an approach to incorporate the ideas of product return and circular material flow into the Hanoverian Supply Chain Model. To reach this goal a reverse supply chain is added to the existing framework. First of all, the flows of material in the reverse supply chain are defined in an abstract way. Secondly, the reverse supply chain is divided into core processes. The connections between these core processes of the forward and the reverse supply chain are depicted. Subsequently, systems of KPIs are set up for the core processes of the reverse supply chain. In a last step, the consequences of the integration of a reverse supply chain on planning, controlling and monitoring production are discussed.

JEL: L2, L6

KEYWORDS: Logistics, Modelling, Circular Material Flow, Product Return

INTRODUCTION

Energy and material efficiency become more and more important for producing companies. On the one hand, companies use these leverages to reduce costs in order to stay competitive or to reach a competitive advantage. On the other hand, the environmental awareness of people is changing. A rising number of customers claim "green" products and a "green" production of these products as buying criteria. To some extent purchase decisions are based on these criteria. Governments and public authorities respond to the change of mind in society and, moreover, to scientific proven developments like global warming and decreasing natural resources with new laws and standards. As an example the "Directive on Waste Electrical and Electronic Equipment - WEEE" passed by the European Union can be stated. The developments described, especially new laws and standards, do have a strong impact on the supply chains and on production processes of industrial companies. Existing logistics and supply chain models do not cover all aspects of these developments. The Hanoverian Supply Chain Model is an integrative logistics model and a framework for production planning and control (PPC) as well as supply chain management (SCM). It links the tasks of PPC with logistic actuating variables, control variables and objectives alongside a company's internal supply chain. The model depicts cause-effect-relationships. It supports companies to design processes and to position within fields of tensions created by opposing logistical objectives. This paper presents an approach to incorporate the ideas of product return and circular material flow into the Hanoverian Supply Chain Model. By that, the existing body of literature is extended. The consequences of product return and circular material flow on a supply chain and on PPC are shown.

After this introduction the current state of literature regarding logistic models and reverse supply chain management is presented. Then the methodology of research is introduced. Afterwards the results are presented. The investigation shows that product return and circular material flow do have a strong impact on the setting of a company's internal supply chain and on PPC. The paper will close with a conclusion.

LITERATURE REVIEW

Supply Chain Management (SCM) and Production Planning and Control (PPC)

The goal of supply chain management (SCM) is to plan and control the flow of material and information in supply chains or production networks with the aim to satisfy the customer and to minimize costs (Wiendahl, 2014). In contrast the goal of production planning and control (PPC) is to plan the production concerning volumes and dates on a regular basis and to realize the plan despite unavoidable disruptions like delayed deliveries or the lack of staff as economically as possible (Wiendahl, 2014).

Logistic Models

Mathematical models are simplified depictions of real-life situations. They possess a reducing function (due to dispensing with unimportant factors present in the real world) and an idealizing function (due to simplifying indispensable factors found in the real world) (Stachowiak, 1973). Quantitative logistic models result from mathematically modelling logistic processes. They are excellent tools for procuring information and support decision-making (Nyhuis and Wiendahl, 2009). Digitalization and the concept of Industry 4.0 lead to more and better production feedback data. This development intensifies the need for easy but meaningful tools like quantitative logistic models (Nyhuis et al., 2014).

One can distinguish different categories of logistic models. The first category comprises task and process models. They describe processes and interactions between processes. This is why they can be used as a reference for designing tasks and processes in various areas. The Supply Chain Operations Reference Model (SCOR Model) works as an example (Supply Chain Council, 2010). Focusing PPC the Material Requirements Planning (MRP) concept (Orlicky, 1975), the MRP II concept (Wight, 1984) and the advanced Aachen PPC model (Schuh, 2006) can be named. The second category of logistic models covers quantitative descriptive, impact and decision-making models. These models are oriented towards quantitative interactions of concrete variables (e. g. logistic objectives). An example of a quantitative descriptive model is the throughput diagram (Heinemeyer, 1974). It is a visualization of the input, the output, the Work-In-Process (WIP), the range and other values of a workstation or a production area. An example of a quantitative impact model is the Logistic Operating Curve Theory (Nyhuis, 2006) (Nyhuis, 2007). Using approximation equations, the Logistic Operating Curves make it possible to position a production within the field of tension created by the opposing logistic objectives WIP, throughput time and utilization. A positioning is necessary because a minimization of WIP, a minimization of throughput time and a maximization of utilization cannot be reached at the same time. An example of a quantitative decision-making model is the lot size calculation model presented in (Münzberg, 2013) and (Schmidt et al., 2015). There are numerous, rich in detail, quantitative logistic models. They are applied in science and industry successfully. Nevertheless, since the individual models are not linked, holistically analysing and designing planning and control processes remains a challenge.

Integrative Logistic Models join both of the perspectives mentioned before. An established example is the manufacturing control model presented in (Lödding, 2013). Universally defined manufacturing control tasks are linked with logistic objectives via actuating and control variables. Like that, single elements of the task and process models are connected with single objectives from the quantitative descriptive, impact and decision-making models. But, it has to be emphasized that since the manufacturing control model has a clear focus, the object being considered is limited. The tasks of production control are depicted, however, the tasks of production planning are, mostly, not. Furthermore, the core processes of a company's internal supply chain aside from production are not addressed. Examples for other core processes are procurement and dispatch.

Another integrative logistic model is the Hanoverian Supply Chain Model developed at the Institute of Production Systems and Logistics (IFA) at Leibniz Universität Hannover in Germany (Schäfers and Schmidt, 2016) (Schmidt and Schäfers, 2017). It is not limited to production control and covers PPC completely. The approach of Lödding was extended in two ways: On the one hand vertically to additional PPC tasks and on the other hand horizontally to additional processes in a company's internal supply chain. The Hanoverian Supply Chain Model will be introduced in detail in the next section.

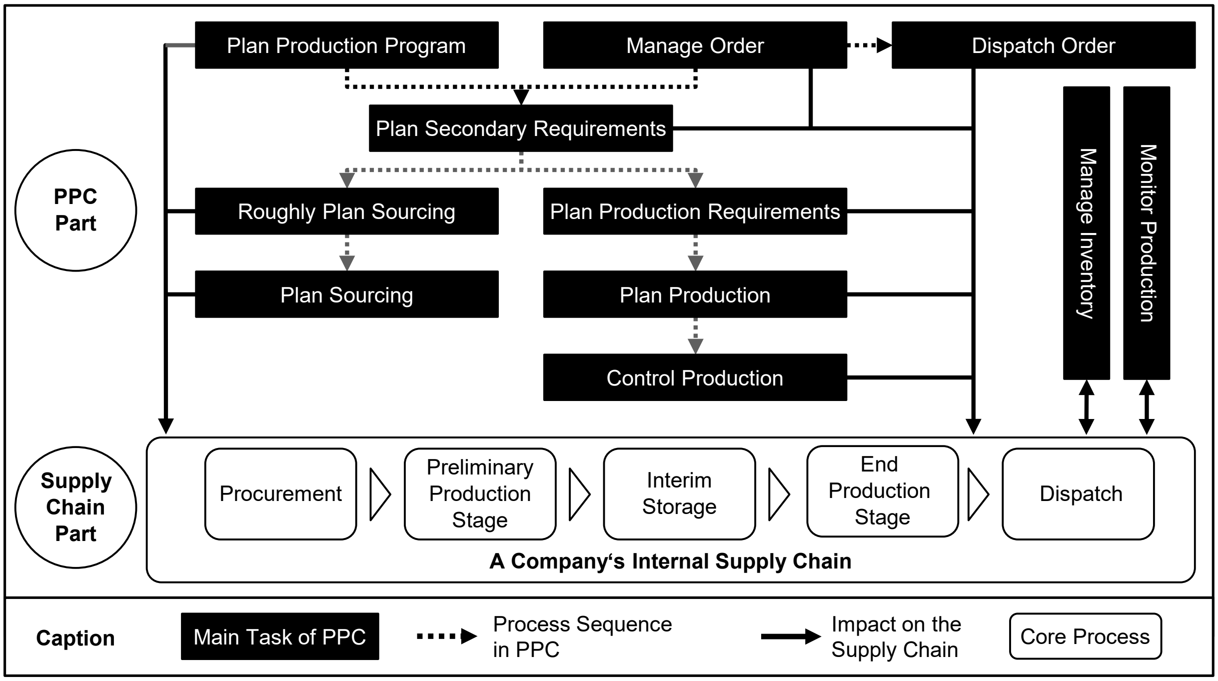
The Hanoverian Supply Chain Model

The Hanoverian Supply Chain Model is a framework for PPC and SCM (Schmidt and Schäfers, 2017). As you can see in figure 1, the framework consists of two parts: The PPC part (top) and the supply chain part (bottom). There are several connections between both parts. The PPC part (top) brings the tasks of production planning and control into an approximate chronological and logical sequence. For each main task there is an individual representation with further details. These representations contain the sub-tasks allocated to the main tasks, incoming information, resulting information and iteration loops. These process descriptions can be used by companies to design or improve processes. The supply chain part (bottom) depicts a company's internal supply chain and features the most important logistic objectives. The structuring of the supply chain part is based on the structuring of the SCOR model (Supply Chain Council, 2010) - but it was refined. Now five core processes represent a company's internal supply chain: procurement, preliminary production stage, interim storage, end production stage and dispatch. In the supply chain part the focus is on the relation between the target, planned and actual variables in the material flow within a supply chain and consequently the impact on the core process specific logistic objectives. Hence, for each core process a system of logistic objectives, control variables and actuating variables was arranged following the approach of (Lödding, 2013). The influence of the PPC tasks on the systems is illustrated. The resulting systems show the relevant relations at a glance. Summing up, the Hanoverian Supply Chain Model pictures the impact of PPC on a supply chain's logistic objectives.
An interactive web page has been developed for presenting the Hanoverian Supply Chain Model. It can be reached at www.hasupmo.education (English) or www.halimo.education (German). The web page is freely accessible on the internet. Scientists, students and companies can use the web page as a reference work for production planning and control.

Product Return and Reverse Supply Chain Management

The term of return is connected with activities that include a material flow from the customer to the supplier (Supply Chain Council, 2010) (Werner, 2013) (Pittman and Atwater, 2016). A reverse supply chain (RSC) deals with all activities that are linked to the product return and value addition or material recovery (Prahinski and Kocabasoglu, 2006). A reverse supply chain requires the part of reverse logistics and the part of product recovery management. The terms reverse logistics and reverse supply chain are used as synonyms, sometimes (Agrawal et al., 2015) (Pittman and Atwater, 2016). Reverse logistics includes all activities of collecting and transporting a product from a customer back to the producing company. It also includes the planning, execution and controlling of the flow (Fleischmann et al., 1997) (Rogers and Tibben-Lembke, 1999). Product recovery management stands for these process flows, which occur during value addition or material recovery. These activities lead to a long-term maintenance of value or an addition of value as well as a multiple usage of natural resources (Thierry et al., 1995) (Fleischmann et al., 1997) (Novoszel, 2012). In addition to the terms defined so far, reverse supply chain management deals with designing the flows of material and information with the aim to use the resources and information as efficiently as possible (Novoszel, 2012). There are several other terms and concepts like closed-loop supply chain, rebound logistics, and recycling economy that all deal with the connection of forward and reverse supply chains (Novoszel, 2012)

Figure 1: Structure of the Hanoverian Supply Chain Model (Schmidt and Schäfers, 2017)



This figure shows the structure of the Hanoverian Supply Chain Model. It is divided into two parts: the PPC part (top) and the supply chain part (bottom). Both parts are connected. The fulfilment of the PPC tasks impacts the supply chain's logistic objectives.

The integrative reverse supply chain reference model extents the existing approach of the SCOR model and its forward supply chain (FSC) (Novoszel, 2012). It defines five core processes of a reverse supply chain: plan, collecting, selecting, reprocessing and reintegration. In the core process plan the reverse supply chain actions are defined and the execution is prepared. The starting point of the reverse supply chain is the customer with its end-of-life-product, which is transferred to the producing company. Afterwards the product will be inspected and classified according to its condition. The product can be classified for the reprocessing and direct reuse, for the reprocessing and value adding recovery or for the reprocessing and material recovery. It is always possible to dispose a product based on its condition. Subject to the reprocessing capabilities within a company, the product can also be returned to the supplier. The last core process describes the multiple ways of reintegration.

METHODOLOGY

The goal of the research presented in this paper is to picture the concept of circular material flow, for example triggered by product return, and to show the consequences for SCM and PPC. To reach this goal, the Hanoverian Supply Chain Model was used as a basis and the idea of circular material flow was integrated into this framework.

The concept of the Hanoverian Supply Chain Model was introduced in the section before. More information about the development of the model and the methodology used during the development can be found in (Schmidt and Schäfers, 2017).

The start of the research presented in this paper was a collection of terms used in the context of recycling and product return. These terms were defined and distinguished from each other to reach a clear and consistent understanding of the terms. After that, an extensive literature review was performed. Existing work was gathered and assigned to the terms defined before. This summary of the state of the art was used for the conceptual work.

Following the definition of terms and the literature review the conceptual work started. As outlined above the Hanoverian Supply Chain Model and the summary of the state of the art were used as a basis. In the first step the supply chain part of the Hanoverian Supply Chain Model was focused. The possible flows of material of a reverse supply chain were defined in an abstract way. Based on this consideration the reverse supply chain was specified by defining core processes. Then the connections between the reverse supply chain and the forward supply chain were discussed. Finally relevant key figures were identified respectively defined for the new core processes of the reverse supply chain. In the second step, the PPC part of the Hanoverian Supply Chain Model was examined. The consequences for the PPC tasks resulting from circular material flow were depicted. Moreover, new tasks required for realizing a reverse supply chain were outlined.

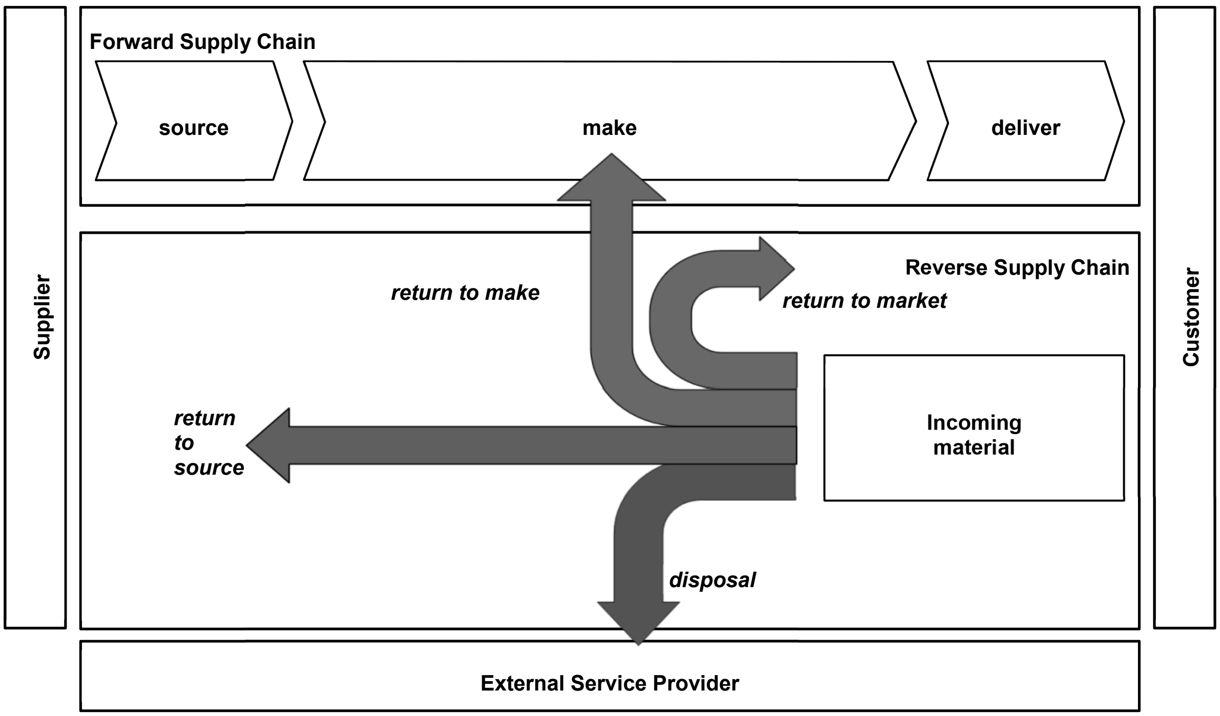
RESULTS

Figure 2 depicts the possible material flows in the reverse supply chain in an abstract way. The incoming material stream can have four different directions in the outcome. In the first direction the incoming goods are cleaned or updated or recovered, so that a reuse is possible ("return to market"). Another flow direction is to the company's make process ("return to make"). That means that complete products or subassemblies or raw materials are used in the forward supply chain. Another possibility is the reuse at the supplier ("return to source"). If it is not possible to use the old products or subassemblies or materials, they are disposed ("disposal"). A disposal of the whole products or only parts of the product can be triggered at different stages in the process – e. g. straight after the inspection or if recovery failed. After clarifying the possible flows of material in the reverse supply chain, a partition of the reverse supply chain into core processes can take place.

As shown in figure 3, five core processes have been defined for the reverse supply chain based on the work of (Novoszel, 2012). The first core process is the *collection*. A company can collect old products in two ways. On the one hand, a customer can bring his used products to a particular place (e.g. point of sale). On the other hand, the company can pick up used products at the customer in a defined time-slot. The second core process is the *selection*. There is an incoming inspection, cleaning and disassembling to a certain degree of breakdown. This core process is very important, because - based on their condition - the products are classified for further proceeding. Further proceeding can be divided into *direct reuse*, *value adding recovery* or *material recovery*. Products with only little marks of usage could be sorted for *direct reuse*. The products with greater damage could be sorted for *material recovery* or *disposal*. All other products could be sorted for *value adding recovery*. Before the further treatment is performed, an *interim storage* can be placed in the reverse supply chain. This can be reasonable depending on the organization of the following steps in the reverse supply chain, for example, if the capacities for product recovery are limited or if product recovery is only performed on demand. Subsequently, the *product recovery* is placed in the reverse supply chain. The last core process *return* deals with the reintegration of the earned results of the reprocessing.

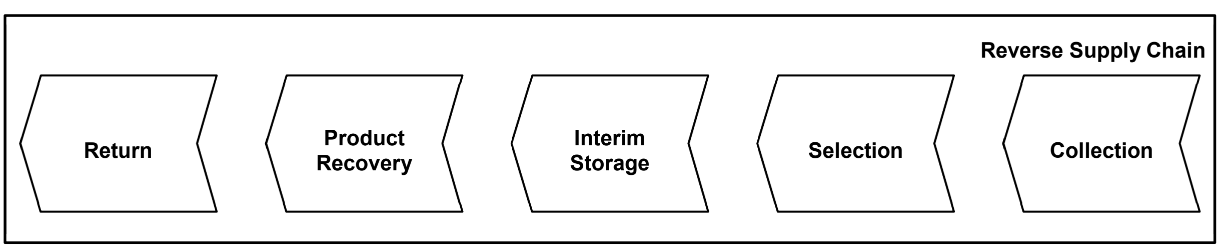
It is important to emphasize that these core processes stand for functions of the reverse supply chain, but can be physical identical with elements of the forward supply chain. For example, the product recovery can be performed using workstations of the production stages of the forward supply chain. Or the interim storage of the reverse supply chain can be identical with storages of the forward supply chain. Or the tasks of the return process are executed physically in the same area like the dispatch process of the forward supply chain. The more the forward and the reverse supply chain use the same facilities, the more the complexity of planning and control rises, which will be discussed at the end of this paper. In the next step, the links between the functions of the forward and the reverse supply chain are discussed and the abstract flows of material in the reverse supply chain introduced before are detailed (see figure 4). All products coming in go through the processes of *collection* and *selection*. After this – based on the result of the selection process – not all parts pass the processes of *interim storage* and *product recovery*. This concerns, for example, products being returned to the supplier for a further usage or treatment or – in case the damage of the products is too high – being disposed directly after *selection*. After *product recovery* there are different possibilities. Of course, products or parts can be disposed as well.

Figure 2: Abstract Material Flows in the Reverse Supply Chain (on the basis of Novoszel, 2012)



This figure shows the four possible material flows in a reverse supply chain in an abstract way: Return to market, return to make, return to source and disposal.

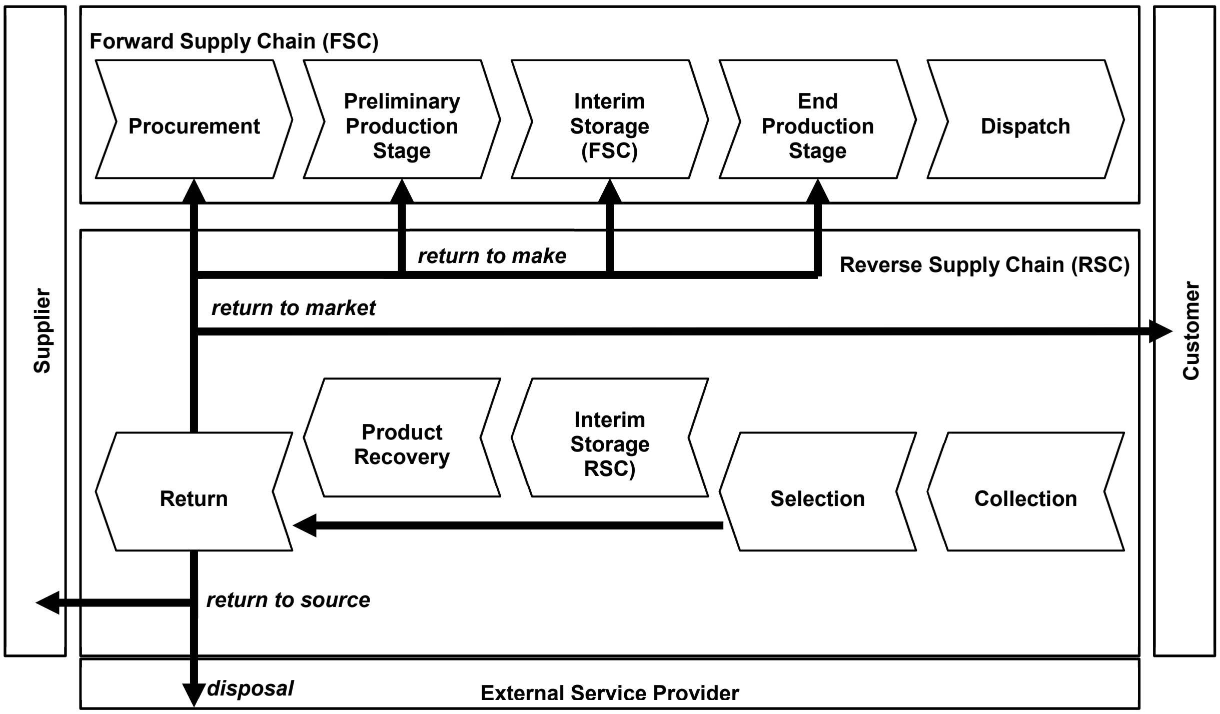
Figure 3: Core Processes of a Reverse Supply Chain (on the Basis of Novoszel, 2012)



This figure shows the five core processes of a reverse supply chain: collection, selection, interim storage, product recovery and return.

If *product recovery* was successful, products can be returned to market. The last option is that parts of the products flow into the make process of the forward supply chain. They can flow into the procurement storage or the interim storage (FSC) depending on whether they are used in the *preliminary* or the *end production stage*. Or they do flow into the *preliminary* or the *end production stage* directly, if such a system is implemented. Beside the flows described so far, it is also possible that material is flowing from the forward to the reverse supply chain. It could be an option that defective parts from preliminary or end production stage flow to the collection process to be reconditioned in the reverse supply chain. It is also possible that materials needed in the reverse supply chain for reconditioning products are provided by the source process of the forward supply chain.

Figure 4: Material Flows Between the Reverse and the Forward Supply Chain



This figure shows the flows of material between the reverse and the forward supply chain. The abstract flows shown in figure 2 are specified. Depending on the condition of the incoming products and, hence, on the result of the selection process the products take different ways.

As mentioned in the literature review, the Hanoverian Supply Chain Model contains a system of logistic actuating variables, control variables and objectives for all core processes of a company's forward supply chain (Schmidt and Schäfers, 2017). To complete the picture, in the following section important objectives of the core processes of the reverse supply chain will be presented. Table 1 shows the objectives of the forward supply chain and the objectives of the reverse supply chain. From the logistic point of view, the same objectives are relevant for similar core processes in the forward and the reverse supply chain. But there are new objectives concerning the material flow in and out of the reverse supply chain. In the core process *collection* there are two new objectives. The *collection capability* depicts the ability to gather products from the customer at the point of time the customer wishes. The definition is based on the definition of the objective *delivery capability* of the core process dispatch in the forward supply chain. This objective underlines that in contrast to the forward supply chain, the starting point of the reverse supply chain is the customer and not a supplier. The second new objective is the *backflow rate*. This figure reflects the proportion of sold products, which come back from the customer to the producing company. In the core process *selection* there is only one new objective. The *selection distribution* shows the share of each reprocessing procedure chosen for the incoming material. The core process *interim storage* does not have a new objective. In contrast, there are two new objectives in the core process *product recovery*. The *added value* indicates the deepness of product recovery compared to the value creation in the forward supply chain. The *new part rate* shows how many parts cannot be provided by the internal recovery processes. In the core process *return* there is one new objective. The *return distribution* reveals the shares of the destinations of material flow out of the reverse supply chain (return to market, return to make, return to source, disposal).

Table 1: (Logistic) Objectives of the Forward and The Reverse Supply Chain

	Forward Supply Chain >>>>>				
Core Process	Procurement	Preliminary Production Stage	Interim Storage (FSC)	End Production Stage	Dispatch
Logistic Objectives	- Due Date Compliance - Service Level - Stores	- Schedule Reliablity - Throughput Time - Utilization - Work-In-Process	- Due Date Compliance - Service Level - Stores	- Schedule Reliablity - Throughput Time - Utilization - Work-In-Process	- Delivery Capability - Due Date Compliance - Delivery Time - Service Level - Stores
				<<<<<	**Reverse Supply Chain**
Core Process	Return	Product Recovery	Interim Storage (RSC)	Selection	Collection
New Objectives focussing material flow in RSC	- Return distribution	- Added value - New part rate	-	- Selection distribution	- Collection capability - Backflow rate
Logistic Objectives	- Delivery Capability - Due Date Compliance - Delivery Time - Service Level - Stores	- Schedule Reliablity - Throughput Time - Utilization - Work-In-Process	- Due Date Compliance - Service Level - Stores	- Schedule Reliablity - Throughput Time - Utilization - Work-In-Process	- Due Date Compliance - Service Level - Stores

This table shows the (logistic) objectives of the forward and the reverse supply chain. A KPI quantifying the different possible flows of material in the reverse supply chain seems to be very important. It was named return distribution.

Setting up a reverse supply chain does also generate consequences for planning, controlling and monitoring the activities in production and the whole supply chain. Nearly all tasks of PPC are affected, because it is necessary to plan, to control and to monitor both supply chains. On the one hand, the production of products and on the other hand, the reprocessing of used products need to be considered simultaneously. It is necessary to harmonize both activities. As stated before, the more the forward and the reverse supply chain use the same facilities, the more the complexity rises. More processes and more parts in a different status have to be operated. To sum up, in most cases more effort will be necessary to fulfill the PPC activities when there is an additional reverse supply chain. On the contrary, the use of the same facilities can be of great potential. Companies can use the workload resulting from the reverse supply chain to fully load their capacities. If the boundary conditions allow, the workload from the reverse supply chain could be released into production very flexible to balance fluctuations. Another big advantage is that producing companies gain more independency from suppliers, because they return products and materials for production. The roles of supplier, producing company and customer do change because of the circular material flow.

CONCLUDING COMMENTS

This paper presents research to portray the concept of circular material flow caused by product return and to show the consequences for SCM and PPC. To reach this goal, a reverse supply chain was added to the Hanoverian Supply Chain Model. First of all, the flows of material in the reverse supply chain were defined abstractly: return to market, return to make, return to source and disposal. Secondly, the reverse supply chain was divided into five core processes: collection, selection, interim storage, product recovery and return. The connections between the core processes of the forward and the reverse supply chain were shown. Subsequently, systems of KPIs were defined for the core processes of the reverse supply chain. A KPI quantifying the different possible flows of material in the reverse supply chain seems to be very important. In the last step, the consequences of the integration of a reverse supply chain on planning, controlling and monitoring production was discussed. Potentials were identified, but realizing these potentials is connected to an increase in complexity. There are some limitations of the research presented in this paper and resulting from these, some ideas for further research. First of all, there could be a more profound description of the new process steps. More process levels could be added. Additionally, the developed concept has got a universal character. The model could be specified for certain use cases (e. g. different industries). In addition the presented research ended with a theoretical concept. This concept should be applied and thus validated in industry. The operating experience should be used to further improve and detail the concept.

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