Prod. Eng. Res. Devel.
DOI 10.1007/s11740-017-0740-9

PRODUCTION MANAGEMENT

The Hanoverian Supply Chain Model: modelling the impact of production planning and control on a supply chain's logistic objectives

Matthias Schmidt[1] · Philipp Schäfers[1]

Received: 7 December 2016 / Accepted: 27 April 2017

Abstract Within production planning and control (PPC) complex interdependencies are present. Companies have to deal with fields of tension created by frequently opposing logistic objectives. Conducting an active and expedient positioning within the conflicts between the logistic objectives is of utmost strategic importance. This paper presents an approach for modelling the impact of tasks of production planning and control on a supply chain's logistic objectives. A production planning and control framework is thus established. First of all the PPC tasks are described universally valid. Moreover the framework contains systems of logistic objectives for the core processes of a company's internal supply chain showing the interdependencies and highlighting existing fields of tension. Quantitative logistic models are located within the framework, so that they can be used for calculating values for PPC parameters and moreover for positioning the production within the indicated fields of tension. In addition a case study is introduced to illustrate the use of the approach in industry.

Keywords Modelling · Production planning · Production control · Supply chain · Logistic objectives

1 Introduction

The mission of production planning and control is to plan the production in matters of volumes and dates on a regular basis and to realize the plan despite unavoidable disruptions like the lack of staff or delayed deliveries as economically as possible [1]. In contrast the mission of supply chain management 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 [1].

Mathematically modelling logistic processes makes it possible to generate simplified depictions of real-life situations. The resulting logistic models are characterized by reduced function (due to dispensing with unimportant factors present in the real world) and idealized function (due to simplifying indispensable factors found in the real world) [2]. Logistic models are thus excellent tools for procuring information and supporting decision-making.

There are different types of models including task and process models as well as quantitative descriptive, impact and decision-making models. Task and process models are generally oriented on describing processes and interactions between processes. They deliver references for designing tasks and processes in various areas (e.g. planning and control). The Supply Chain Operations Reference Model (SCOR-Model) is an example here [3]. It is kept consistently structured, branch-neutral, generic and universally valid. Focussing PPC the advanced Aachen PPC Model provides a coherent description of a reference process landscape for production planning and control [4]. Quantitative descriptive, impact and decision-making models are oriented on quantitative interactions of concrete variables (e.g. logistic objectives)—however, in turn, do not take into account the whole of relationships occurring in or between processes. An example of a quantitative impact model is the Logistic Operating Curve Theory. 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 Work-in-Process (WIP),

✉ Philipp Schäfers
schaefers@ifa.uni-hannover.de

[1] Institute of Production Systems and Logistics (IFA), Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

Published online: 13 May 2017

throughput time and utilization [5, 6]. 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. There are numerous, rich in detail, quantitative logistic models. Nevertheless, since the individual models are not linked, holistically analysing and designing planning and control processes remains a challenge.

An established example of an integrative logistic model joining both of these perspectives is the manufacturing control model developed by Lödding [7]. It generally consists of the basic objectives, control variables and actuating variables linked with universally defined manufacturing control tasks. Individual elements of the task and process models (e.g. the order release) are connected with individual objectives examined in the quantitative descriptive, impact and decision-making models (e.g. WIP in the Logistic Operating Curves). However, it has to be pointed out that since the manufacturing control model has a clear focus, the object being considered is restricted. Thus, for example, control tasks are depicted, however, planning tasks are, for the most part, not. Moreover, the core processes of a company's internal supply chain bordering production (e.g. procurement and dispatch) are not addressed.

In order to close this gap, the Hanoverian Supply Chain Model (HaSupMo) was developed at the Institute of Production Systems and Logistics (IFA). It takes into consideration the entire production planning and control and is thus not just limited to production control. This amounts to an extension of Lödding's approach—both vertically, to additional planning and control tasks, as well as horizontally, to additional processes in the company's internal supply chain.

2 Setting up a new framework for PPC and SCM

The Hanoverian Supply Chain Model is a framework for PPC and SCM. It consists of two parts (see Fig. 1). The first part of the model (PPC part) brings the main production planning and control tasks along with their sub-tasks into an approximate chronological and logical sequence. The terms and the sequence used result from a literature review (a. o. [4, 8, 9]). In addition to the main and subtasks, the incoming or resulting information is indicated for each task. Furthermore, iteration loops are depicted (e.g. in case a feasibility check turns out to be negative). The second part of the model (supply chain part) depicts a company's internal supply chain. The structuring of the supply chain part is based on the structuring of the SCOR-Model [3]. From the perspective of PPC, it is important to distinguish whether production deals with primary or secondary requirements. Based on this consideration the structuring of the SCOR-Model was refined. Now five core processes represent a company's internal supply chain: procurement, preliminary production stage, interim storage, end production stage and dispatch. The focus in this part of the model is on the relation between the target, planned and actual variables in the material flow and their impact on the logistic objectives in the five core processes mentioned. The type of modelling is oriented on Lödding's approach [7]. Thus a system of logistic objectives, control variables and

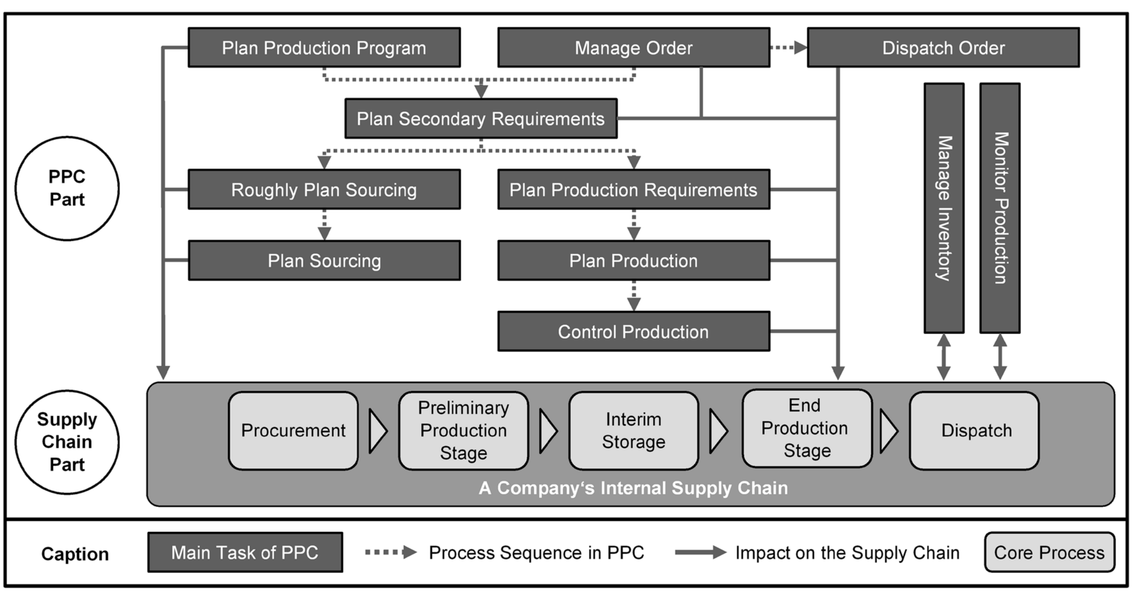

Fig. 1 Structure of the Hanoverian Supply Chain Model

actuating variables is established for each core process (see Sect. 3).

3 Defining systems of logistic objectives for the core processes

In order to identify the relevant logistic objectives for each of the five defined core processes in a company's internal supply chain, a literature review was conducted (a. o. [10]). The identified objectives were recorded in profiles and compiled in a database. Criteria for the selection of logistic objectives for the five core processes were collected. The most important selection criteria were that the logistic objectives represent the logistic performance of the supply chain and are directly influenced by fulfilling the PPC tasks. In the end mainly the classical logistic objectives from the Hanoverian approach to model supply chains based on the funnel model were chosen [11, 12].

Based on the selected logistic objectives, actuating and control variables were derived for each of the core processes, in order to design a system following the schema developed by Lödding [7]. By definition an actuating variable is directly influenced respectively adjusted by PPC respectively by fulfilling the PPC tasks. An example for an actuating variable is the planned output of the core process dispatch. On the other hand control variables result from the deviation of two actuating variables and directly impact the logistic objectives. An example for a control variable is the lateness distribution in the core process dispatch.

The supply chain's core processes are connected. Looking at a company's internal supply chain the inputs and outputs of materials or orders of the core processes are important values. These inputs and outputs exist as planned and actual variables and occasionally also as target variables. The inputs and outputs are directly planned and controlled by the tasks PPC is responsible for. The actual inputs and outputs of the core processes result from the de facto measured inputs and outputs. Thus the inputs and outputs are the actuating variables for all core processes. The actuating variables immediately impact the control variables, which is the stores respectively WIP for all core processes. For some core processes, the due date behaviour on the output side of the core processes is another control variable. The stores in the system can be calculated looking at the inputs and at the outputs. The quantitative backlog and the lateness of the orders can be determined comparing the actual values with the planned values. The control variables then directly impact the logistic objectives, which are specific to every core process. The values of the respective logistic objectives are consequently determined by the fulfilment of the PPC tasks via the actuating and control variables.

Following, the system developed for the core process dispatch, will be introduced as an example (see Fig. 2). The dispatch's logistic objectives include delivery capability (from the customers' perspective) and finished goods stores (stock and buffered orders). In a make-to-stock production, the service level is also an objective. Looking at a make-to-order production, the delivery time and the due date compliance are objectives. The differences between the target and planned outputs directly describe the logistic objective delivery capability. The target output directly reflects the customers' preferences in relation to their orders, whereas the planned output corresponds to the date and quantity the company promises to customers. Once resources are planned and scheduling is completed, the planned dispatch output frequently no longer agrees with the customers' preferences. Logistic objectives are influenced by actuating variables (inputs and outputs) and control variables. The first control variable in the core process dispatch is the

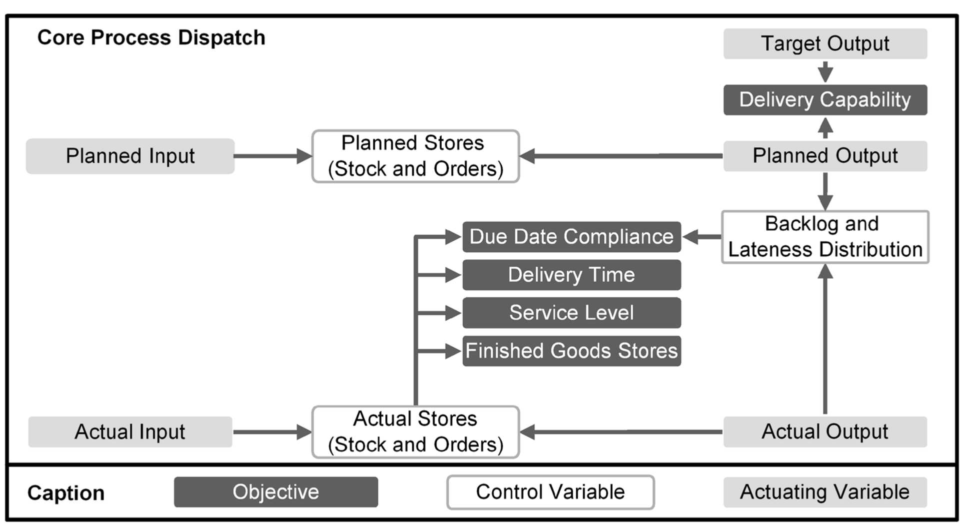

Fig. 2 System of logistic objectives for the core process dispatch

finished goods stores (stock plus buffered orders). The finished goods stores results from the actual inputs and actual outputs. The second control variable is the backlog and the distribution of lateness of the output in the dispatch process, which results from the difference between the planned and actual output.

Some of the logistic objectives within one core process or across core processes are opposing. Fields of tension are created. Companies are confronted with those conflicts of objectives while fulfilling the tasks of PPC. The arising fields of tension are illustrated and discussed in the Hanoverian Supply Chain Model. Following, two such conflicts are described as examples. For consistency sake, again the dispatch process is considered.

In a make-to-stock production, an important objective is to provide a high service level for the customers. To attain this, correspondingly high stock levels must be maintained in the finished goods store, so that customer's needs can always be met. This in turn results in high inventory costs. It is obvious, that there is a conflict between the logistic objectives stock level and service level as well as the delivery capability of a make-to-stock production.

So that a make-to-order production can ensure strong due date compliance, safety times are frequently scheduled in for production orders allocated to customers. Planned delivery dates can thus be met despite disruptions in the production processes that result in dispersed throughput times and output lateness (planned output versus actual output). On the one hand, with a given output date deviation, the due date compliance increases alongside the safety time. On the other hand, as the safety time increases, so does the delivery time from the customers' perspective and the buffer of finished orders.

We can thus see how there are different conflicts between the logistic objectives in the core process dispatch. Companies then have to position themselves within the field of tension created by these. This means that they have to prioritize logistic objectives above others respectively find a balance. Furthermore, companies have to orient the PPC processes and parameters on the defined objectives. Knowledge about the interactions between the PPC tasks and the logistic objectives is therefore urgently required for conducting an active and expedient positioning.

4 The influence of PPC on the systems of logistic objectives

A fundamental comprehension is necessary on how production planning and control affects actuating variables and consequently the logistic objectives. For these purpose the Hanoverian Supply Chain Model features further levels of details. As an example Fig. 3 shows the developed system for the PPC main task "manage order" from the upper part of the model (PPC part). As well for all other main tasks of PPC (see Fig. 1) there is an equivalent system.

By fulfilling the PPC main task "manage order" customer orders are implemented into PPC. They complement the production program. The procedure is launched by a concrete customer request. The incoming customer order directly affects the actuating variable target output of the core process dispatch for a make-to-order process. After clarifying the order with the customer the production orders are roughly scheduled and the safety time is planned to compensate potential disruptions in the production process leading to a difference between the actual and the planned throughput time of production orders. The planned start and end dates of the customer specific production orders result. On this basis the resources are planned roughly and order specific. When all data is available, there is a check, if the production orders are feasible. In case of a negative result the orders have to be planned and scheduled again. In case of a positive result the customer order can be accepted. By accepting the customer order and communicating the delivery date to the customer the actuating variable planned output of the core process dispatch is defined. The production orders for the accepted customer order are finally created. Rescheduling of orders in consultation with the customer can be executed later on if there is information resulting from another PPC main task about delay or overload of capacities so that a order cannot be realized as declared. Production orders resulting from the PPC main task "manage order" are being integrated into the production program and thus affecting the actuating variables planned input and planned output of both production stages.

It becomes apparent, that the sub-tasks differ distinctly in their scope and their result. While some tasks (e.g. "clarify order") represent rather a required process step and generate respectively consolidate information, the fulfilment of other tasks (e.g. "plan safety time") leads to reaching important decisions and determining parameters of production planning and control. The decisions affect actuating variables (e.g. the safety time influences the actuating variable planned output of the core process dispatch) and consequently as well the logistic objectives (e.g. looking at the core process dispatch the logistic objective delivery capability results from the balance between the actuating variables target output and planned output).

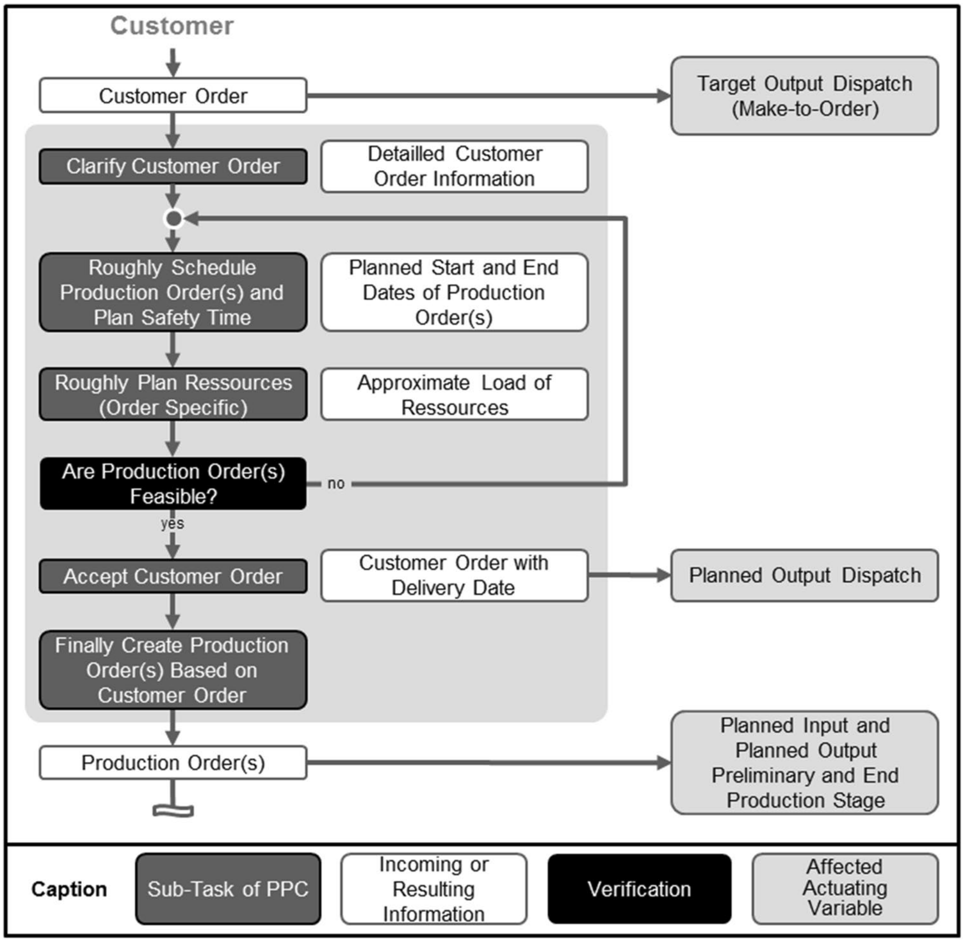

Fig. 3 PPC main task manage order

5 Using quantitative logistic models for determining PPC parameters and positioning within conflicts between logistic objectives

As mentioned before, the Hanoverian Supply Chain Model is destined to be a framework. It represents a link between the various tasks conducted within PPC, the actuating variables, the control variables and the logistic objectives in a company's internal supply chain. The impact of the decisions made within the PPC tasks on the supply chain's logistic objectives is foregrounded. The focus is thus a representation of the interactions, which allows the relationships to be understood and highlights existing conflicts between logistic objectives. Furthermore, existing quantitative logistic models are located within the framework. In this way they are combined into a unified context. The quantitative logistic models can be implemented for calculating values for PPC parameters and moreover for positioning the company's internal supply chain processes within the indicated fields of tension created by logistic objectives.

In Sect. 4 the different scope, result and importance of the PPC tasks was stated. Especially the fulfilment of the important tasks and the target-oriented parametrization of the procedures used there should be supported using quantitative logistic models. There are decision-making, impact and descriptive models. An example for the use of a decision-making model is the multi-criteria approach for determining lot sizes [13] for PPC task "calculate lot size" in PPC main task "plan production". An example for the use of an impact model is the use of the Schedule Compliance Operating Curves [14] for PPC task "plan safety time" in PPC main task "manage order". If research is not advanced further, also descriptive models are relevant. Examples are the use of the Throughput Diagram [11] or Capacity Envelope Curves [15] for PPC task "align capacities" at PPC main task "plan production requirements".

To illustrate the approach to use quantitative logistic models a case study from industry will be introduced subsequently. We will look at an equipment manufacturer with an annual turnover of about 300 million €. By using the impact model Schedule Compliance Operating Curves the PPC parameter safety time should be adjusted. Thus a positioning within the prior to this in Sect. 3 presented field of tension created by the logistic objectives due date compliance, delivery time and finished goods stores has to be conducted.

The impact model Schedule Compliance Operating Curves [14] describes the correlations between the logistic objectives due date compliance, delivery time and finished goods stores in a production area or company. The PPC parameter for influencing these objectives in a make-to-order production is the safety time. Figure 4 shows, that the schedule compliance operating curves present the due date compliance, the safety time and the buffered finished orders as a function of the selected safety time in a diagram.

The schedule compliance operating curves can be directly generated from the operation feedback data of a production area. The impact of a change in the safety time on the logistic objectives (due date compliance, delivery time and buffered finished orders as part of the finished goods stores) can thus be calculated. Moreover, by assuming a distribution of the output lateness, the impact of measures for improving the due date situation in the considered production area, can be evaluated. In practice this is realized by transferring data from the manufacturing execution system (e.g. SAP) into a spreadsheet document (e.g. Microsoft Excel) where the formulas for calculation [14] are implemented. The results are visualized in diagrams.

The initial situation at the previously introduced equipment manufacturing company is marked in Fig. 4. A safety time of 27 days was provided (x axis). The delivery capability was 90%. In average the stock of finished goods caused by production orders finished too early was 20 million €. The planned delivery time was 90 days.

To realize a higher due date compliance towards the customer, a major safety time has to be provided. As Fig. 4 shows the delivery time rises linear with the safety time. The rise of due date compliance weakens with increasing safety time. The rise of finished goods stores firstly increases and converges to a boundary value afterwards. After having reached this boundary value the finished goods stores proceed proportional to the safety time.

Reaching a shorter delivery time towards the customer can be supported by shortening the safety time. Looking at the case discussed here the company has to accept a reduced due date compliance in favour. On the other side the finished goods stores could be lowered.

Implementing a safety time is a measure to deal with an unsatisfying logistic performance of production areas within the core processes preliminary production stage or end production stage. The ultimate cause of the unsatisfying logistic performance is not addressed. If the company implements measure to improve the logistic behaviour a production area for example by installing due date oriented sequencing rules, the lateness of the production area will be reduced. Consequently, the stress field between the logistic objectives of the core process dispatch (due date compliance, delivery time and buffered finished orders) is weakened. Since the schedule compliance operating curves are generated from the operating feedback data of a production area the form of the curve changes directly with new data. The altered stress field can be considered for calculating a new safety time which is to be implemented in the PPC system.

As the example of the equipment manufacturer illustrates the safety time is a parameter of PPC a company can use for positioning in the stress field of opposing logistic objectives. It confirms the capability of the expedient application of quantitative logistic models in industry.

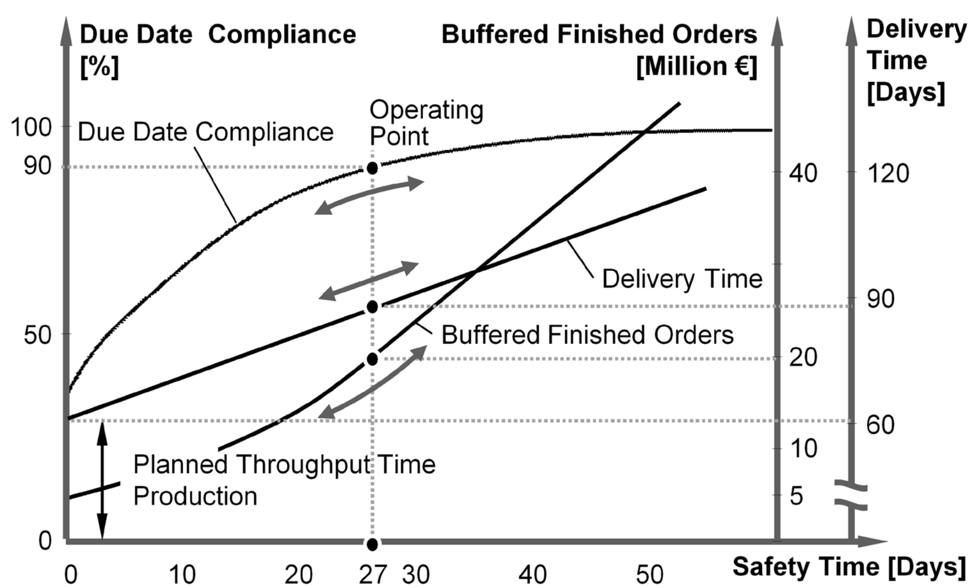

Fig. 4 Schedule Compliance Operating Curves

The framework Hanoverian Supply Chain Model discloses which models should be used in a certain case. Due to the positioning within the framework individual quantitative logistic models are combined into a unified context.

6 Presentation of the Hanoverian Supply Chain Model

An interactive web page has been developed for presenting the Hanoverian Supply Chain Model and can be reached at http://www.hasupmo.education (English) or http://www.halimo.education (German). The web page is freely accessible on the internet. On the web page the user is able to navigate through the Hanoverian Supply Chain Model freely. Like that the user is able to focus on the sections of the model relevant for him or her. A profile with a definition and further information can be found for each PPC task and each logistic objective. The several connections between the PPC part and the supply chain part of the Hanoverian Supply Chain Model are implemented. In this way the user can retrace easily, how the decisions made during carrying out the PPC tasks influence the systems of logistic objectives.

7 Conclusion

The Hanoverian Supply Chain Model is a new framework for production planning and control and supply chain management. On the one hand the tasks of PPC are described universally valid. For this reason the process description of the model can be used to design or improve processes. On the other hand systems of logistic objectives are defined for five core processes representing a company's internal supply chain. The connection between the PPC tasks and the systems is shown using a systematic approach. Existing fields of tension are discussed. Quantitative logistic models are located within the framework, so that they can be used for calculating values for PPC parameters and moreover for positioning the production within the indicated fields of tension. Summing up the Hanoverian Supply Chain Model clarifies the interactions in PPC and supports companies to position within fields of tension created by logistic objectives.

Acknowledgements This paper presents results of the project "Integrative Logistics Model for Linking Planning and Control Tasks with Logistical Target and Control Variables of the Company's Internal Supply Chain" (SCHM-2624/4-1), funded by the German Research Foundation (DFG) and currently being conducted at the Institute of Production Systems and Logistics.

References

1. Wiendahl H-P (2014) Betriebsorganisation für Ingenieure, 8th edn. Hanser, München
2. Stachowiak H (1973) Allgemeine Modelltheorie. Springer, Vienna
3. Supply Chain Council (2010) Supply Chain Operations Reference Model. Rev. 10.0. Supply Chain Council Inc., Cypress
4. Schuh G (2006) Produktionsplanung und -steuerung - Grundlagen, Gestaltung und Konzepte, 3rd edn. Springer, Heidelberg
5. Nyhuis P (2006) Logistic production operating curves - basic model of the theory of logistic operating curves. CIRP Ann Manuf Technol 55(1):441–444
6. Nyhuis P (2007) Practical applications of logistic operating curves. CIRP Ann Manuf Technol 56(1):483–486
7. Lödding H (2013) Handbook of manufacturing control - fundamentals, description, configuration. Springer, Heidelberg
8. Orlicky J (1975) Material requirements planning - the new way of life in production and inventory management. McGraw-Hill, New York
9. Wight O (1984) Manufacturing resource planning - MRP II - unlocking America's productivity potential, Rev edn. Wight, Essex Junction
10. Hon KKB (2005) Performance and evaluation of manufacturing systems. CIRP Ann Manuf Technol 54(2):675–690
11. Wiendahl H-P (1997) Fertigungsregelung. Logistische Beherrschung von Fertigungsabläufen auf Basis des Trichtermodells. Hanser, München
12. Lutz S (2002) Kennliniengestütztes Lagermanagement. Dissertation, Universität Hannover
13. Schmidt M, Münzberg B, Nyhuis P (2015) Determining lot sizes in production areas - exact calculations versus research based estimation. Proc CIRP 28:143–148
14. Schmidt M, Bertsch S, Nyhuis P (2014) Schedule compliance operating curves and their application in designing the supply chain of a metal producer. Prod Plan Control Manag Oper 25(2):123–133
15. Breithaupt J-W (2000) Rückstandsorientierte Produktionsregelung von Fertigungsbereichen - Grundlagen und Anwendungen. Dissertation, Universität Hannover