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Logistic Changeability - Application of a Methodological Framework for Designing Logistic Changeability

Sebastian Bertsch

Abstract**—**In the past decades, the environment of production companies showed a permanent increase in dynamic and volatility in the form of demand fluctuations, new technologies or global crises. As a reaction to these new requirements, changeability of production systems came into attention. A changeable production system can adapt to these changes quickly and with little effort. Even though demand for changeable production exists for some time, the practical application is still insufficient.

To overcome this deficit, a three year research project at the Department of Production Systems and Logistics at the Leibniz University of Hanover/ Germany was initiated. As a result of this project, different concepts have been developed to design production changeable. An excerpt of the results will be presented in this paper. An eight step procedure will be presented to design the changeability of production logistics. This procedure has been applied at a German manufacturer of high demanding weighing machines. The developed procedure, their application in industry, as well as the major results of the application will be presented.

Keywords**—**Changeability, Change Drivers, Production Logistics.

I. Introduction: Changeability as an Answer to New Requirements

NOWADAYS, production companies are exposed to changes in their environment more than ever [1], [2]. The globalization and saturation of numerous markets has led not only to an increase in demand fluctuation but also to a surge in the number of variants [3], [4]. Fig. 1 illustrates the increasing dynamic based on the example of the German automobile industry. During the last 20 years, the demand could fluctuate by 25% within a brief time span and the product lifecycle was almost halved.

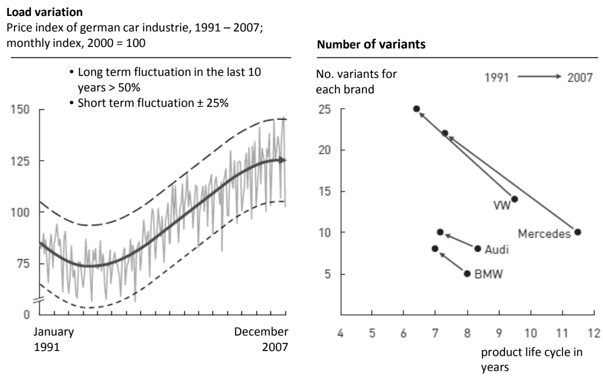

Fig. 1 Volume Fluctuations and Number of Variants Based on the Example of the German Automobile Industry

Due to the ongoing changing requirements, the ability to adapt to changes quickly and effectively has become to an essential ability for companies [5]-[7]. As a reaction to this new requirement, different design concepts for production systems that facilitate a quick adaption got published [8]. Especially the concepts of flexibility [9] and changeability are discussed and analyzed by many authors [10]-[13]. Even though these concepts are widely known in the respective field of research, their application in practice is still at the beginning [14]. One of the reasons for the moderate progress of these concepts is that research only presents little assistance in how to implement these concepts in the everyday work of a production company.

To support the implementation of changeable production systems, the German Federal Ministry of Education and Research (BMBF) initiated the framework concept “Research for Tomorrow’s Production“. In this framework concept the research project “Change-Beneficial Process Architectures” (WaProTek) was sponsored for three years. A group of twenty researchers of universities and different companies investigated and applied technical, organizational, human, and logistical solutions for a changeable production system. As a part of this research project, a methodological framework for designing the changeability of production logistics was developed. This framework was applied by a German manufacturer of weighing machines. The different steps of this framework, as well as the practical application will be presented in this article.

Dipl.-Wirtsch.-Ing. Sebastian Bertsch is with the Institut für Fabrikanlagen und Logistik (IFA), An der Universität 2, 30823 Garbsen, Germany (Tel. +49 (0)511 762-19881, Fax +49 (0)511 762-3814; e-mail: bertsch@ifa.uni-hannover.de or Internet: www.ifa.uni-hannover.de).

II. Fundamentals of Changeability

This chapter covers the basics of logistics and changeability as a design concept. At first, the definition of changeability in contrast to flexibility will be explained. Afterwards, the different elements of production logistics will be explained, that can be designed more or less changeable.

A. Definition of Changeability

According to Nyhuis 2010, the changeability of a production system is defined as "the potential to be able to carry out technical, organizational, human, and logistical changes outside the maintained flexibility corridors of a production system in a short time, with low investments and considering the interaction of the system elements in case of need. A changeable production system can be adapted in the various dimensions of change, such as quantity, quality, time, product, and cost structure." [15] Changeability therefore describes the ability of a production system do adapt quickly to fast changing conditions as well as external and internal change drivers.

Therefore, changeability can be distinguished from flexibility, which describes the ability of a production system to perform changes within a constant and predetermined corridor. Following this definition, changeability can be called the flexibility of the flexibility, since it primarily addresses the ability of a production system to change the existing flexibility corridors.

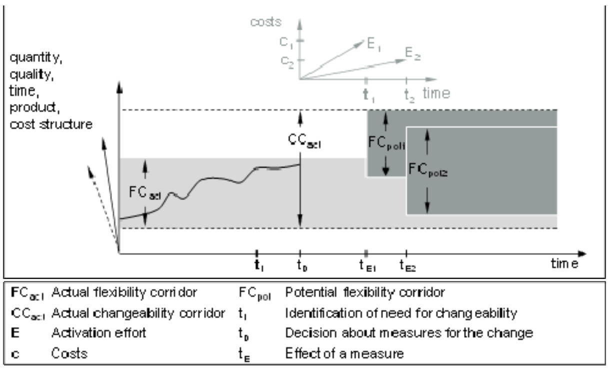

Fig. 2 Definition of Changeability [15]

Flexibility and changeability are both visualized in Fig. 2. Flexibility and changeability can occur within the five dimensions of change: quantity, quality, time, products and cost structures. Each of these dimensions has a current active flexibility corridor that defines the potential to change the dimension quickly. If it is identified at time point (t_I) that the existing flexibility does not suffice for the required change, a decision can be made to introduce a change measure (t_D). In doing so, the potential flexibility corridor can be activated. The sum of the flexibility corridors that can potentially be attained by reconfiguring the production system determines the change corridor. The greater the change corridor and the quicker and more easily the potential flexibility corridors can be attained, the greater the changeability of the production system [15].

B. Design Elements of Logistics

The logistics of a production system can be mentally divided into individual objects, so called 'design elements' (DE). A design element describes a part of logistics which can be differently planned or configured and which, due to its nature, influences the logistics' performance [16]. Examples for design elements are methods for planning and adjusting capacities, the procurement model or the methods for releasing orders in the production process. A more complete enumeration and explanation of the different design elements of logistics can be found in [17]–[19].

The logistic DEs describe parts that can be designed differently in every enterprise. Accordingly, for each of the DE concrete methods or characteristics can be identified which, due to their properties, are suitable for different conditions and differently influence the logistic objectives. Such a characteristic of a DE will be referred to, in the following, as a specific configuration of a DE. One configuration of the DE "order release" can for example be ConWIP or Workload Control. One configuration for the DE “Procurement Model” is consignment, contract stock or just-in-time procurement. Equal configurations can be distinguished for all of the DEs in the field of logistics [20].

C. Configuration Relevant Criteria

We introduced the DEs which production logistics are comprised of and explained that these DE can be differently configured based on the actual application case. Which of these configurations is practical in a concrete application depends on diverse factors and conditions of the production. In the following, these will be referred to as configuration relevant criteria. The configuration relevant criteria can be sub-divided into the groups: logistic objectives, production properties and market influences.

The logistic objectives encompass the importance of low logistic costs as well as the significance of a strong logistic performance. The production properties are comprised of internal production properties or abilities such as the percentage of the operation time that setup times represent. Market influences incorporate design restrictions or requirements that originate externally and impact the enterprise, e.g. seasonal demand fluctuations [21].

The configuration relevant criteria are suitable for evaluating the applicability of an element configuration. If, for example, we consider the DE ‘order release’, a common configuration in the industry is kanban. With kanban, manufacturing orders are generated and released as soon as a downstream area withdraws material from a kanban stock. Whether or not this configuration can be practically applied depends on the criteria introduced above. For example, to apply kanban reasonable, it is necessary that load fluctuations are minimal and that the replicating area has highly flexible capacities. Setup times have to be short so that the manufacturing can be conducted in small lots. In addition, highly complex material flows and strongly varying work contents impede the applicability of kanban. Moreover, there should be a minimal number of variants, since the resulting kanban store grows proportional to the number of variants. Each configuration of the logistic DE is suitable for a different expression of the configuration relevant criteria mentioned above.

D. Change Drivers and Their Influence on Logistics

Change drivers are internal or external events that influence the targets or the environment of the production system and in consequence require a reaction in order to maintain the current performance [8], [22]. Examples for change drivers are the bankruptcy of a supplier or the market entrance of a new competitor. The bankruptcy may influence the availability of material and hence the production environment in case no other supplier can the acquired in time. The new competitor might influence the importance of a high logistic performance as a competitive edge and therefore influence the targets for logistics. Therefore, both events require a reaction to maintain the current situation. In the developed methodological framework, the influence of change drivers is described by changes in the configuration relevant criteria. Since these criteria describe every aspect relevant for the configuration of logistics, every change driver relevant for logistics in some way has to change the value of one or more criteria.

III. A Methodological Framework for Designing Logistic Changeability

The concepts described in chapter II are combined in a framework for designing the logistic changeability. Before the different steps of the framework will be explained in detail, the general approach of the framework will be summarized briefly.

As describes above, the production logistic is comprised of different components, so called design elements, like the procurement model, the capacity control or the order scheduling. For each of these components, different configurations can be separated. If a configuration of one element is suitable for a company depends on the value of a series of criteria, so called configuration relevant criteria. Knowing the values of the configuration relevant criteria, it is possible to derive a suitable logistic configuration.

The influence of change drivers leads to a change in the value of the configuration relevant criteria. As described above, the change driver “bankruptcy of supplier” might change the configuration relevant criteria “availability of material”. Given the change in the “availability of material” the current configuration of logistics might not fit any longer. A demand for change in the production system is the result. Consider, for example, the design element “procurement model”. Assume the current configuration of this element is a just-in-time procurement (JIT). Due to the reduced availability of material, JIT procurement might not be possible any longer. An alternative can be a standard inventory sourcing. A change in the configuration of the affected design element is therefore a reaction to an identified change driver and can hence be called a change measure.

These relationships can be facilitated to design the changeability of logistics. For each change driver, the influence on the configuration relevant criteria and the resulting changes in the configuration of the logistic design elements can be derived. A quick change between the different identified configurations ensures an optimal performance of logistics, despite of the influence of the change driver. If the change between the identified configurations is prepared before the change driver hits the company, the changeability of the production system is selectively increased. As described in the definition of changeability in Fig. 2, by preparing the change between different configurations, the time and effort to activate a new flexibility corridor is being reduced. This results in a higher changeability of the production system. The flexibility corridors in this situation represent the changes possible within a fix configuration.

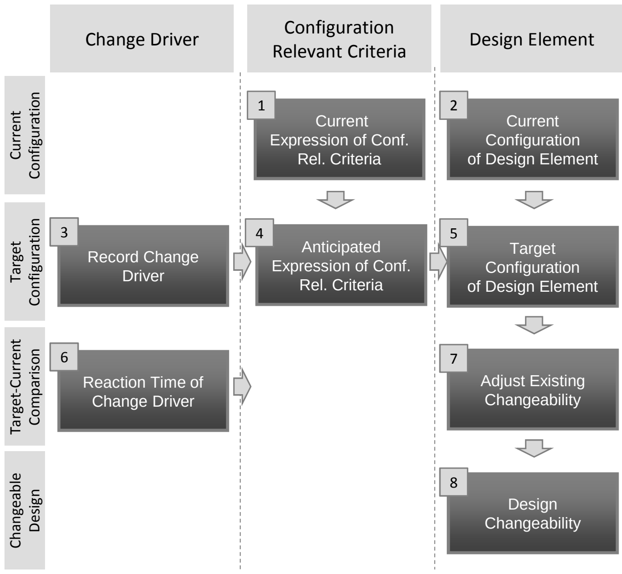

Fig. 3 Steps for designing logistic changeability

Fig. 3 summarizes the above described approach for designing logistic changeability in eight different steps.

In steps one and two the current expression is documented for both the configuration relevant criteria and the logistic DE (specific configuration). In the third step the change drivers for the logistics have to be documented and prioritized with regards to their relevance for the enterprise. Following that, in step four the results from steps one and three are combined. The influence of each of the identified change drivers on the configuration relevant criteria is investigated in order to determine which of the criteria are changed by them and how each of those impacted are expressed after the driver's influence.

Based on the new predicted expressions of the configuration relevant criteria, it can now be determined in the fifth step if and how the individual logistic design element's configuration have to be changed. In doing so a new target configuration of the logistics is derived that can then be used to react to the change driver's influence. If, in comparison to the actual configuration identified in step two, the configuration of a DE has to be changed, then the required steps for the change have to be documented, including the estimated time. In step six, the reaction time is determining for each change measure. The reaction time is the time between a driver being clearly identified and when it actually comes into play [23]. In step seven, this reaction time is compared to the time required for reconfiguring the design element. If the design element cannot be reconfigured in the reaction time, the available changeability is not sufficient [24]. If the reconfiguration is not possible within this time frame, the reconfiguration steps that have to be prepared even before the driver has been clearly identified can be determined. By planning these reconfiguration steps ahead of time, the changeability of the logistics is selectively increased so that the logistics can react to the relevant change drivers.

IV. Practical Application: Designing the Logistic Changeability of a Weighing Machine Manufacturer

The theoretical framework for designing logistic changeability has been applied at a German manufacturer of weighing machines. In the following, the primary results of the analysis will be described. After a brief introduction of the company, the configuration of the logistic design elements, as well as the configuration relevant criteria will be explained. Afterwards, two different change drivers will be discussed.

The company under investigation is building premium weighing machines and measurement devices for demanding laboratory applications. The weighing machine under investigation is being built in several hundredths of variants with a quantity of approximately 10.000 pieces a year.

Fig. 4 Weighing machine under investigation

Fig. 5 provides a schematic description of the work flow to produce the weighing machine. The work flow can be separated in a make-to-stock and a make-to-order part. The make-to-stock work flow is characterized by few different variants (22 different platforms), time consuming process steps and a high degree of automation. The process steps contain of the manual physical structure of the weighing machine and different calibration and adjustment steps. In the make-to-order work flow, the weighing machine is completed and finally tested. The focus of the further investigation is on the make-to-order process chain.

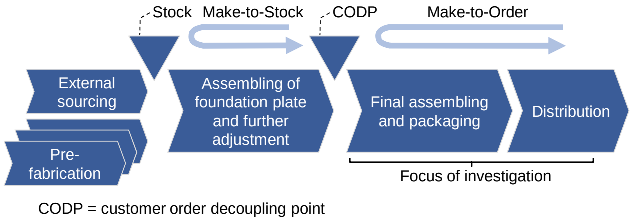

Fig. 5 Schematic description of the work flow

Current Expression of Configuration Relevant Criteria

The logistic objective in the analyzed make-to-stock work flow is to achieve high schedule reliability and short throughput times. This can be achieved at the expense of work in process and capacity utilization. In contrast to the make-to-stock work flow, several of hundredths of different variants are being built in the make-to-order work flow. Despite of the high number of variants, the resulting material flow is linear. All variants pass the same work stations. Since manual assembling is the major process step, high capacity flexibility can be achieved with working time accounts, Saturday work, reserve pool employees, additional shifts or doubling of work stations. In addition, the manual assembling is characterized by low setup times. The variation of the workload of different manufacturing orders is low, while the availability of material for this workflow is high. The demand of weighing machines requested by customer has a short and midterm medium fluctuation as well as medium seasonal fluctuation. The predictability of the short term demand fluctuation is low, since no frame contracts or long term delivery commitments with customers exist.

Current Configuration of Logistic Design Elements

The following part will explain an excerpt of the current configuration of the logistic design elements.

Due to the linear material flow, the assembling is organized according to the principle of continuous flow, despite of the high number of variants. Due to capacity reasons, the assembling is divided into three different assembling lines, one for each product family of the weighing machines. The scheduling of order is conducted under consideration of the available capacity. Capacity accounts with the maximum production capacity exist for each of the product families. The quantity of the incoming customer order is compared to the available capacity in the respective account, in order to derive a feasible delivery date.

The lot size is directly derived from quantity of the customer orders. An additional aggregation of customer orders to a manufacturing order is not required, since the low setup times allow equally low lot sizes. The average lot sizes accounts to 3-4 weighing machines.

The release of orders in the assembling occurs three day prior to the planned delivery date. After the orders are released, the sequencing in the assembling as well is based on the calculated due dates. Unpredictable disruptions in the manufacturing process can be compensated by short term capacity flexibility.

The procurement of material occurs according to the inventory sourcing concept (reorder point principle), because the purchased amount is not sufficient to apply a more advanced procurement concept.

Change Driver: Introduction of Low Quantity Niche Products

Subsequently, the influence of two different change drivers will be analyzed:

The first analyzed change driver is an introduction of niche products to supply markets with special requirements for weighing machines. These nice products have a low demand per year but tolerate a comparatively long delivery time. In different workshops with experts from the company, the influence of this change driver on the logistic configuration was discussed.

As a result of the workshop, the production structure requires no change to cope with the additional variants. Only the provision of material to the assembling stations has to be changed. Due to the low production quantity, the material for the new niche weighing machines has to be provided separate for each manufacturing order, which is different to the current material provision. The order specific material provision in consequence requires a new order specific picking process in the warehouse and an order specific material procurement process, which is not required in the current batch production process.

According to the industry partner, the reaction time before identifying the demand for niche products is at least six month, because the construction of the machine requires this forerun. A discussion of the implementation time of the change measures revealed, that all required changes of the production system can be completed within the time span of six month. Hence, no change measures have to be prepared prior to the occurrence of the change measure. The current changeability is sufficient to cope with the change driver of new niche products.

Change Driver: Express Delivery

The second change driver is a spontaneous customer demand for express deliveries for single variants. The purpose of the express delivery is, to create a new and unique selling pitch to support sales and distribution department.

As a result of the workshop, a change of the order processing showed the most potential to further reduce to delivery time. Variants picked for express deliveries will be produced in a finished goods store independent of existing customer orders. A further reduction of the delivery time compared to the current situation is hence possible, because the throughput time in the current make-to-order value chain is no longer part of the delivery time.

Changing the production structure in consequence requires an adoption of the planning and control. The previously applied method for scheduling customer orders becomes needless when orders are supplied from stock. Manufacturing orders now get generated by a reorder point method and no longer by incoming customer orders. This in turn requires an adaptation of the lot sizes. A lot-for-lot method (manufacturing order equals customer order) is no longer necessary and methods for calculating economic lot sizes can be applied.

Subsequently, the required time and effort for implementing the change measure has been discussed. Changing the order processing to make-to-stock requires the construction of a finished goods store including storage techniques and storage software as well as the complete storage organization. The estimated time to install the store adds up to six month. In case the installation is prepared by predefining the storage organization and preselecting the storage techniques, the installation time can be reduced to three month.

Changing the order processing also requires a new order release (reorder point method). Typically, this can be achieved by changing the material master file. The estimated time for accomplishing the change measures was six month. A preparation reduces the time to three month.

As a last step, the employees have to be trained working in the new processes. Development and execution of the training approximately requires two month.

The estimated reaction time before identifying the change driver is three month, since the sales department requires a certain forerun for promotion. A preparation of the training is not necessary, since the design and execution can be initiated after the occurrence of the change driver. Both, the construction of the finished goods stock and the adjustment of the material master files require a preparation to be completed in time. Without preparation the current changeability is not sufficient to react to the identified change driver of express deliveries.

V. Summary and Conclusion

This paper introduced a holistic framework to design the changeability of production logistic. The influence of change drivers on logistic design elements has been systematically investigated. For each design element necessary reconfigurations have been derived to react to the identified change drivers. A comparison of the time to reconfigure the design elements with the reaction time of the change driver specified if the reconfiguration has to be prepared before the existence of the change driver can be stated with certain.

The design framework has been applied at a German manufacturer of weighing machines. The influence of two different change drivers on the logistic processes has been investigated in detail. The application of the framework enabled a systematic identification of missing changeability and showed the necessary measure to improve it.

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Sebastian Bertsch is research associate at the Institute of Production Systems and Logistics, Leibniz University of Hanover. After studying Industrial Engineering at the University of Hanover, Polytechnic University of Pomona/Los Angelos and the Polytechnic University of Milan he joined the Institute of Production Systems and Logistics in 2010.