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# Approach for the Evaluation of Production Structures

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**Abstract.** Turbulent environment evoking intrinsic complexity of production systems dares in particular series production. As a result, sophisticated structures for production are inevitable to manage these challenges. Due to path dependency, stepwise optimization of production processes leads to pseudo-optimums. During factory operation, minor changes of the production program may result gradually in a suboptimal configuration of the production system. Production systems are forced to cope with these changes by adjusting their temporal and / or spatial structure. For the purpose of an adequate adaption, all options for adjustment should be considered. The evaluation of proper adaption requires suitable figures that assess the appropriateness of the production structure regarding the pending tasks and demands. This paper introduces an approach that enables a deduction of adequate measures. It aims at matching the temporal and spatial structure with the production program by revealing operational and strategic gaps.

**Keywords:** Production structure, suitability of system's configuration, structural adaption, evaluation procedure

## 1 Introduction

Only a few analytical approaches exist evaluating the appropriateness of the production structure regarding pending customer demands [1]. Most planning approaches try to pre-determine a flexible system structure [2]. For this reason, we introduced the Structural Quality (SQ) that enables the assessment of the spatial and temporal structure [3]. In this paper, we illustrate an SQ-based approach and its application potential.

The arrangement of the elements of a production system (spatial reference) and the planned configuration of the relations a product undergoes to its production (time reference) is called structure [1]. As an essential (planning or design) activity for the configuration of production systems, structuring determines the implementation costs of the production processes. Based on the specific type and number of workstations (system's composition) and the relationship between them, a production structure defines the basic structure of a production system (system's setup) as well as its function (system's behavior) [4].

Spatial system configuration, reflected as the economic arrangement of workstations, is done by optimizing the layout on the basis of relevant design criteria, such as transport performance and the communication index. Thus, it is aimed at minimizing

expenses when “using” the relations during operation [3, 5]. The system’s behavior – processes and their interactions as temporal structure – is based on the system’s pre-defined setup, and is influenced by the basic principle of the order processing’s flow and sequence. Thus, it is aimed at maximizing the performance of resource elements [6].

The vector SQ as key figure enables verifying the suitability of the installed system structure and a specific production program in terms of a proper function of the production system. According to Chandler's insights into the interrelations between structure and strategy, the production task (expressed by the production program) is one of the main inputs to structural design within the framework of production structure planning [7, 8]. Theoretically, any change in the production program per se leads to a changed structure in terms of a modified spatial-temporal organization of the production system. On the contrary, industrial production processes require a long-term stable cost function. Therefore, long-term valid structures for production systems are typically sought in production management [9]. In practice, any established production structure is a transition between the function-oriented and the object-oriented type of structure [10]. Consequently, the definition of a structure is commonly a long-term decision of the general principle of structuring.

However, the underlying assumptions of such a defined structure are counteracted by the increasing individualization of customer requirements. Due to significant shifts in production program, there is increasing pressure to change an installed production structure. Beyond the limits of the equipment's flexibility [9], adaptations to the inherent system-related properties are necessary, i.e. a re-configuration of the system's composition, setup, and behavior. Companies do not use every change in the production program as an opportunity to adopt the installed production structure. Typically, more often rationalization measures are introduced, such as process-specific modification or integration of production steps. Finally, there are adapted structures in the form of case-specific operation solutions. This results in huge amount of different transitional structures.

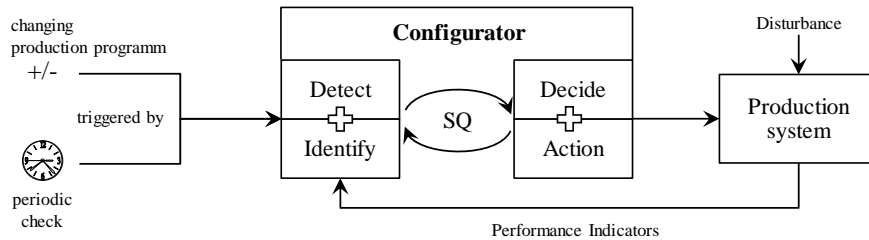
SQ reveals the potential of an adaptation of the production structure. At this point, SQ facilitates an assessment of changing the spatial and temporal structure. Both in the planning phase as well as in the operation and optimization phase, suitability of production structures for the present production task can be evaluated. If the existing production structure is a planning construct, an anticipatory structure evaluation takes place, whereas structure is actively monitored during operation.

## **2 Holistic Evaluation Approach**

### **2.1 Basic Process Model**

Derived from control theory, we illustrate our re-configuration model as a block diagram of a closed-loop control system (Fig. 1). The object of observation is a production system with a planned or already installed production structure as described above. Typically, key performance indicators are recorded during system operation. Such performance indicators along with sufficient input variables are necessary for an overall

re-configuration or adjustment of production structures. Starting point for such a re-configuration is a relevant change to the production program. Such changes affect variations in the type and quantity of the products to be manufactured in relation to the original design specifications of the production system.



**Fig. 1.** Configuration Procedure as closed-loop system.

In a multi-stage procedure, the SQ-based structure evaluation is performed in the configurator. Thus, necessary adaptation measures can be derived. Nevertheless, unlike the actual "control theory", such measures refer to the change of the control system, i.e. the present structure of the production system. Thus, the following integrated configuration procedure is based on human decisions. However, proper indicators and detailed analysis of the Structural Quality of the production system support the detection of changes and the adopting of appropriate measures.

## 2.2 Integrated Configuration Procedure

The configurator carries out a two-step evaluation and decision-making process. At first, changes of the production program are detected by a preliminary evaluation. Moreover, the amount of value alternation facilitates decisions about further steps. After this rough assessment, a detailed analysis is based on Structural Quality [3]. The more in-depth evaluation procedure enables an identification of significant shifts within the production program. Thereby planning and design activities are taken into account simultaneously. As a result, proper measurements in terms of structural adaptations are revealed. This allows the planner both, to evaluate the suitability of the current production structure and to identify adequate structural solutions in case the present production system is not sufficient regarding the pending tasks anymore. Thus, the integrated configuration procedure is an iterative evaluation and decision-making process.

During preliminary assessment, the planner gets first impressions about the effect of the changed production program on the already installed production structure. Thus, the planner can detect if there are certain alterations within the production program. If the limits defined by the planner in advance are adhered to, then no action is necessary. If the indicator values go beyond defined thresholds, then a detailed structure evaluation is carried out using SQ-determination. Based on this SQ-determination, the planner finally decides which specific changes have to be worked out. This refers to both, temporal and spatial aspects of the production structure.

The determination of the Structural Quality within the integrated configuration procedure is an event-driven process, triggered by a changing production program. In this case, the vector SQ serves as an important criterion for allowing the planner to weigh the need for changes in the production structure (cf. Fig. 1). Structural decisions are consequently long-term decisions regarding the general principle. For this reason, a periodic check of the functional structure also is recommended. Then, the configurator runs as a time-discrete application.

### **3 Key figures for Evaluation of Production Structures**

#### **3.1 Spatial Structure**

In order to evaluate the spatial structural component, an assessment of the relevant spatial layout is required. Basically, we focus on the complexity of material flow. Minimal “complexity of the material flow” is found within the purest form of a production line. Precisely one upstream and one downstream workstation without return flow characterize such a production line. However, maximum “complexity of the material flow” is found in a fully meshed job-shop structure. In order to assess the “complexity of the material flow”, we use two indicators: The degree of linearity and the standardized degree of cooperation.

The latter determines the number of material flow relations existing between the workstations [11]. For the standardized degree of cooperation, the value 1 is defined as a threshold value: In the range  $0 \leq \kappa \leq 1$ , the working stations are directly connected to one another in a sequence. Thus, structure of such arrangements tends to be a linear. If more than one workstation is connected to more than two other workstations, the values’ range is  $\kappa > 1$ . Such arrangement tends to be a job-shop structure. The degree of linearity takes into account the number of return flows in contrast to the prevalent sequence of operations.

A change in intensity and basic orientation of the relations imply the trend of a potential structural change. Minimum “complexity of the material flow” exists when the degree of linearity assumes the value of 1 and the standardized degree of cooperation has a value of 0.

#### **3.2 Temporal Structure**

The temporal structure considers the workflow, i.e. the logical and temporal linking of the partial tasks of production [11]. The sequence of relations between the system elements (workstations) expresses the temporal component of the processes running in the production system. Based on the intensities of the relations as dynamic variables, different temporal courses can be characterized.

Parameters of the system-related temporal structure are mean value and variance of material flow’s intensity. These figures refer specifically to the (variable or constant) amplitude of the system load. The regularity of the intensity is determined by the load-oriented coefficient of variation. It provides reliable information on the variability of the load resulting from a changed product and / or quantity mix.

If the production system is fundamentally capable of dealing with the upcoming production program, order-induced average system load as estimated value of processing times characterizes the dynamics of load situation. It combines the mix of the production task and the intervals of the specific customer demands. If both aspects are differentiated, the workload for each order and the average time span between the respective customer orders result. However, the effect on the production system is only apparent when considered aggregated.

### **3.3 Functional Structure**

The functional production structure is based on different product characteristics (demand profiles) and thus leads to a segmentation of the production in bestseller (quantity focus) and exotics (diversity focus) [11]. The distinction with regard to a product specification requires a certain diversity of the product range with divergent continuity and contrasting order volumes, i.e. the primary structuring takes place according to the type of production demand. Both the assessment of quantities as well as product changes are thus of central importance for evaluating the suitability of an existing or planned production structure.

The quantity index indicates the average number of products for each order. The average order volume combined with the corresponding coefficient of variation expresses the quantity mix of a production program. In contrast, the variance index represents the number of product variants of an organizational unit (product mix). In this case, nominally different types of orders can be combined into identical product families due to their process-related system load.

An increasing quantity index and a decreasing variation index indicate a concentration of the production program on a decreasing number of rather homogeneous products. Similarity is expressed particularly by a reduction of the coefficient of variation. On the contrary, the organizational unit tends to a broader and more heterogeneous product spectrum if the trends are reverse. By using these indicators, a decisive characterization of the production program is carried out which takes account of both the quantity and the product mix. Thus, a decision regarding the basis segmentation of the production system into organizational units is enabled.

## **4 Case Study**

### **4.1 Indicator-based Check of Production Structures**

In the following, we will present an overview of the practical use of SQ by means of case study data, whereby the “Basic Process Model” forms the framework. In addition to the integrated SQ-assessment for the evaluation of the spatial and temporal aspects of production structures (event-driven process), the periodic check of the functional structure of a production system (time-discrete process) is also shown using the “Integrated Configuration Procedure”. According to the presented approach, the mode of operation of the configurator is described; both for the evaluation of the spatial and

temporal structure components (event-driven mode) as well as the assessment of the functional structure of the given system (time-discrete mode).

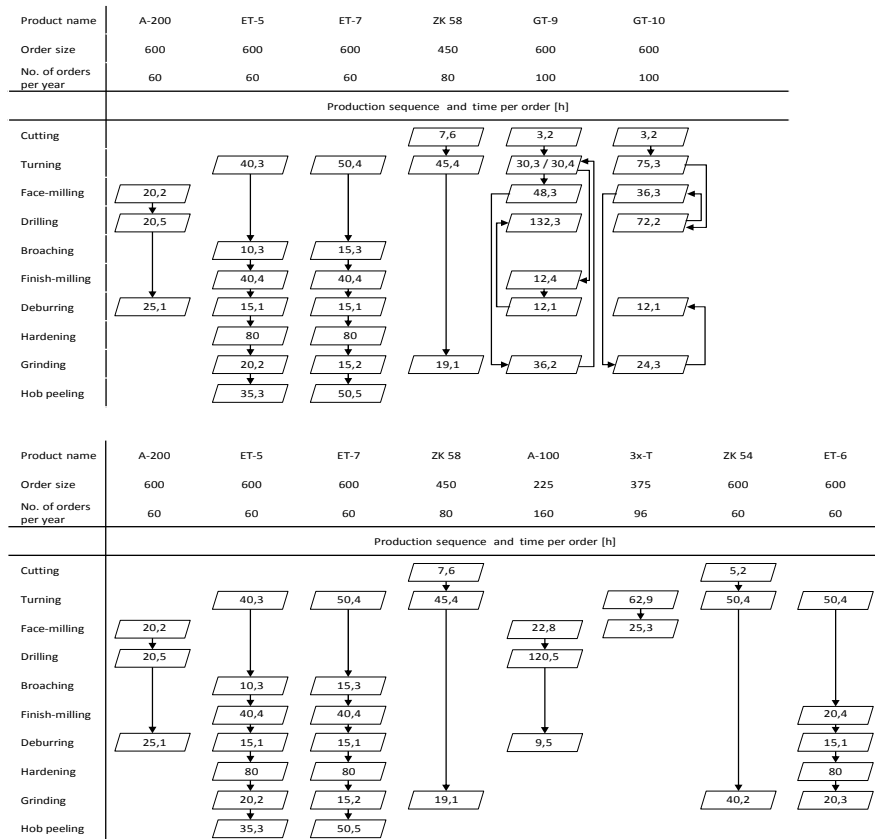


Fig. 2. Former production program (top) and actual production program (bottom).

The installed production structure is based on the former production program shown in Fig. 2 (top). Currently, a change in the production program is apparent, as shown in Fig. 2 (bottom). If this change is significant, the need for structural adaptation is analyzed in the following sections.

Consequently, at first the preliminary assessment of relevant indicators is executed. The standardized degree of cooperation amounts 0.92 (previous: 1.29). The degree of linearity amounts 1 (previous: 0.85). Thus, after the change of the production program, a consistently forward-directed sequence of operations is present. With regard to the standardized degree of cooperation, a production line appears to be suitable. Thus, the complexity of material flow decreases. According to the change of the indicator values, the production structure gradually migrates from a job shop production towards a production line.

Indicators for the temporal aspect of the production structure show an ambiguous development. The mean workload remains approximately constant. Accordingly, the capacity of the production system and thus the system composition is still sufficient. In contrast, the coefficient of variation alters from 98% to 132%. Diversity of process times increases, which is indicative for a shift towards a job shop production. This contradicts the development of the other indicators.

With regard to the functional structure, quantity index increases and variation index decreases. In contrast to the coefficient of variation, the variation index compares the similarity of production processes and their workload for every workstation. Whereas the number of products grows, their homogeneity also enlarges. There are different groups of products with nearly the same production sequence (e.g. group 1: ET-5, ET-6, and ET-7; group 2: A-100 and A-200 etc.). This underpins in particular the change of the spatial indicators. However, a further in-depth analysis seems to be necessary.

## **4.2 Detailed Analysis of Production Structures**

Finally, detailed structure evaluation determines spatial, temporal, and functional SQ. For a detailed SQ-assessment regarding material flow, we refer back to known (ideal-typical) arrangement algorithms for minimizing transport effort. For the purpose of a comparison of future and actual structure types, a visualization in form of scaled block-layouts is helpful. Transport effort decreases from 59,023 to 51,809 transport units per year. Subsequently, the ideal spatial arrangement was used as normalization value of 100% transport effort. Based on the previous production program that indicates a job shop production, spatial component of Structural Quality improves from 1.90 to 1.67. Additionally, a simulated shift from a job-shop structure to a production line reveals a potential improvement of about 13.9%.

Derived from three logistic performance indicators: throughput time, output rate and work in progress (WIP), the quality of Temporal Structure refers to the operation point of the production systems. To sum up, all figures decrease when retaining the current control strategy: CONWIP (Constant Work-in-Progress). Output rate declines from 338.3 h per SCD to 313.2 h per SCD, WIP decreases from an average workload of 5718.8 h to 3437.5 h, and mean throughput time lowers from 17.28 days to 11.27 days. The decrease of the output rate reveals a less effective system behavior, whereas the reduction of WIP and lead-time represents an improvement. However, the simulation-based assessment of operating points shows that the existing system composition is still capable to fulfill respective production tasks. Thus, the Temporal Quality improves from 2.71 to 1.43.

The evaluation of the functional structure emphasizes that a splitting of the existing organizational unit according to product families revealed seems to be promising. However, further segmentation of the organizational unit may require other structural solutions respectively. In this case, the integrated configuration procedure and in particular the SQ-determining is conducted iteratively until an adequate segmentation including suitable production structures is found.



## 5 Conclusion and outlook

The integrated configuration procedure facilitates an easy detection of structural changes by indicators. These indicators reveal the amount and direction of change. If defined thresholds are exceeded, an in-depth analysis is conducted. This detailed analysis comprises an assessment of the suitability of current production structure by determining the Structural Quality vectors. During this procedure, planning and design alternatives are considered systematically. Thus, an iterative improvement of suitability is enabled. The evaluation of different structural variants is supported by simulation studies because only in this way dynamic behavior and performance of the altered production system become obvious.

The case study highlights the application of the multi-stage approach. If thresholds of indicators are exceeded or indicator's development shows an ambiguous trend, a detailed analysis of Structural Quality is inevitable. Assessment of functional structure indicates a different segmentation of the considered organizational unit. With regard to proper product families in terms of homogeneous processes and workload, at least three new organizational units are reasonable. Each of these units need an appropriate production structure. In this regard, further research is necessary to extent the iterative procedure.

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