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Key performance indicators in the production of the future

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Abstract

Industry 4.0 promises numerous potentials in production, ranging from data-driven machine optimization to improving the entire production planning. The lack of transparency about the effects and benefits of Industry 4.0 is one of the key obstacles to its introduction.
Key Performance Indicators (KPIs) are a way to capture changes in production. This paper analyses typical KPIs and represents their mathematical interconnection in a graph representation. In addition, a structuring framework is presented, in which KPIs are linked to Industry 4.0-related changes in production. We conclude how current typical KPIs capture these changes and demonstrate the benefit of additional, IT related KPIs.

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1. Motivation

Industry 4.0 is regarded as the next development step in production and is associated with a lot of potentials. This evolutionary step is largely based on the digitalization of the production. Development scenarios ranging from self-organizing intralogistics to fully connected production are conceivable [1]. To this day, a wide variety of use cases with change possibilities have been identified, described and structured with concrete application examples [2]. The basis for all changes is the increased use of production data.

In this context, numerous potential benefits of the application scenarios and examples are described. Examples for such potentials are a better control of complexity and a shortening of production and development times. Studies imply considerable cost reductions of up to 20% and productivity increases of up to 50% [3].

However, making changes and potentials tangible in detail is very difficult today. In production controlling, there is a multitude of different key figures and key figure systems, also known as Key Performance Indicators (KPIs) [27], [35], [36]. KPIs are numbers which reflect the process in the company in a compact form and, as a management tool, provide the opportunity for rapid analysis [12], [34], [37]. The best-known indicators include, for example, Overall Equipment Effectiveness (OEE), throughput time, scrap rate and space utilization. However, these conventional KPIs do not sufficiently capture changes in production due to digitalization. Current KPI systems, for example, are often only focused on product quality, throughput times or overall effectiveness. On the other hand, data management processes or information on the degree of transparency and digital networking in production cannot be recorded. However, these factors are of great relevance in the context of Industry 4.0. While changes caused by digitalization have thus been described in various analyses to date, the instruments for recording them with the aid of production management indicators have hardly been considered to date.

The aim of this paper is to present a concept for Key Performance Indicators in the production of the future. The

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concept considers existing, current and newly developed Key Performance Indicators. Furthermore, changes are collected and structured within the framework of a digitalized production. It is shown which changes influence which KPIs and to what extent they can already be recorded today. In addition, new KPIs are proposed in order to record changes within the context of digitalization.

The paper is structured as follows. In the following section 2, the problem is analysed. Afterwards existing key figure systems and concepts are presented in section 3. Section 4 describes the concept for structuring changes and KPIs in production. The paper concludes with a summary and outlook in section 5.

2. Analysis of the problem

Challenges in production are continuously increasing. This also includes the challenge of recording changes and making them assessable. In the following section 2.1, the increasing challenges in production will be discussed. Afterwards, section 2.2 describes Industry 4.0 as a vehicle to respond to the increasing challenges within production. Finally, section 2.3 deals with key figures in production.

2.1. Increasing challenges within production

Manufacturing companies are confronted with more complex and individual technical systems and at the same time shorter development and planning cycles, increasing quality demands as well as necessary flexibility for specific customer requirements. In addition, there is a general increase in cost pressure [4], [5]. The increased requirements for the production can be illustrated by the course of product volume and variants depicted in figure 1.

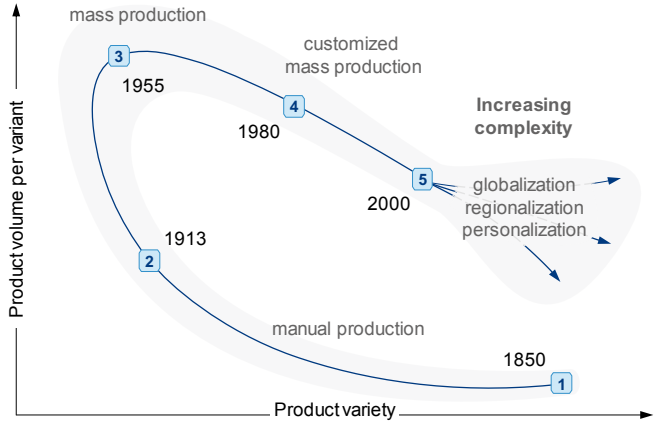

Fig. 1. Development of production volume and variety of variants [6].

In 1850 the variety of products was very high, while the production volume was very low. Products were produced manually. The product volume increased over time and the variety of products fell sharply. In 1955, the term mass production was present. Afterwards, the product variety increased again a lot while the product volume declined significantly lower. The term customer-specific mass production was the result. This development continues until today [6].

2.2. Industry 4.0 as a vehicle to respond to the increasing challenges within production

In order to meet increasing challenges within production, Industry 4.0 or rather digitalization is considered a solution and at the same time the next development step in manufacturing [5], [7]. The focus is on connecting all systems and technologies involved in the value creating process and use the captured data to increase productivity [7], [8].

As a structuring framework, changes in production can be divided into different stages of development through digitalization. [9]. The development stages are shown in figure 2.

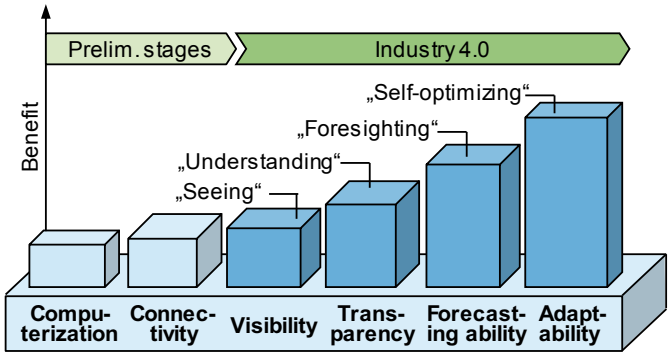

Fig. 2. Development stages of Industry 4.0 [9].

Computerization and connectivity are regarded as the preliminary stages or the foundations of Industry 4.0. The development stages of Industry 4.0 are divided into the phases visibility, transparency, forecasting ability and adaptability. A foresight and self-optimization is thus based on an understanding of the processes and an analysis of these. Key Performance Indicators are of central importance and an important controlling instrument [10].

2.3. Recording of operating conditions and changes in production

The status and performance of production are recorded and processed in the form of Key Performance Indicators (KPIs). Key Performance Indicators are thus a means of ensuring that information is prepared correctly, up-to-date, as comprehensively as possible, but in a way that is easy to understand. The danger of information loss, misinterpretations or even the low significance of individual KPIs can be countered by combining related key figures to form a key figure system [11]. Production controlling plays a central role in production planning and control. The task of controlling is the comparison and interpretation of the determined data.

The goals in production are decisive for production planning and control. Goals are particularly important for management and are an important factor in the selection of KPIs. Through their evaluation, coordination and control functions, they can be used as a management tool [11]. Maximizing profitability is the overarching goal of a production system. In addition, the target system of production is completed by a minimization of lead time, schedule deviation and inventory as well as a

maximization of capacity utilization [4]. It can be stated that such a target system cannot be consistent [11], [5]. By the use of different KPIs the achievement of different goals can be seized and evaluated.

A concept for Key Performance Indicators in the production of the future must take into account changes in the production environment and thus in particular the digitalization of processes.

3. Current methods and approaches

Numerous KPI systems and structuring frameworks for KPIs in production can be found in literature. A distinction can be made between general systems and specific KPI systems for production [5]. Due to the function of KPIs as an instrument for management, general KPI systems usually have a financial or strategic focus. Among the best-known financial KPI systems are the DuPont System of Financial Control and the ZVEI KPI system or the Profitability-Liquidity KPI system [12]. The Balanced Scorecard provides a framework for structuring key figures with regard to a company's vision and strategy.

The ISO standard 22400, on the other hand, provides an explicit framework for structuring KPIs only for production. The aim of the standard is to provide an overview of relevant KPIs and their classification in the plant management level of the automation pyramid [13], [14]. In both parts of the standard published so far, the basic principles of KPIs are first explained, different KPIs are precisely defined and possible forms of structuring (e.g. top-down) are also explained. The relationships and dependencies are to be explained in more detail in a further part of the standard planned but not yet published [13]. Thus, the standard does not yet provide a complete system of key figures. However, there is a large number of other, less common KPI systems or collections of KPIs for production. These can be adapted to individual company requirements.

The focus of previous approaches has thus been on classic production structures. Due to their different orientations, these structures are able to grasp different interrelationships. However, the existing key figure systems and structuring frameworks do not take into account changes in production in the context of digitalization. There are also no suitable KPIs for recording these changes. The changes include the processing and use of production data and information as well as increasing flexibility and individualization, increased networking and transparency or even novel assistance systems. These changes are the focus of Industry 4.0 and are intended to increase the competitiveness of companies [15]. Only the final results that are supposed to arise from digitalization can be recorded. These include increases in efficiency and performance, shortened development and production times, new revenues and falling costs [16]. The connection to the causes, e.g. increased transparency, cannot be established.

The existing key figure systems thus cannot comprehensively record changes in production. This shows the need for research in the area of key figures in the production of the future.

4. KPIs in the production of the future

The concept for KPIs in the production of the future combines existing, current and newly developed KPIs with changes in a digitalized production. It shows how changes can be recorded with the help of existing and new KPIs. In section 4.1, the relationships between the existing common indicators are first analyzed. Then, Section 4.2 shows a systematization of changes in digitalized production. Section 4.3 then describes the development of new KPIs, while section 4.4 brings the results together in the overall concept. Finally, section 4.5 shows the application of the concept.

4.1. Relationships between existing, common KPIs

Through the analysis of 18 different collections of KPIs from a variety of literature sources*, the 38 most frequent production KPIs could be determined, for instance the performance level, the throughput time or the degree of automation. In order to structure them, they were divided into five different subject groups (logistics, degree of utilization, production process, quality and order processing). In this way, a key figure system of the existing KPIs is created. The OEE serves as the system's top KPI [5], [38].

In addition to the systematization of the production KPIs in the functional groups, an objective view of the relationship between the KPIs can be established on the basis of the input variables of the key figures. For this purpose, the calculation formulas and all input values are examined. Thus, two KPIs have a connection if at least one identical input variable exists. With this evaluation, clusters of KPIs can be identified. These include order-related, employee-related, quality-related and machine-related key figure groups. Some of these clusters are very similar to the functional groups of the created key figure system. The relationships between the key figures are shown in figure 3 (see following page).

4.2. Systematisation of changes in digitalised production

The basis for the concept for KPIs in the production of the future is a collection of changes in different areas of production. The focus of the collection of changes is on the use of information and data, the flexibilization of the production system and the individualization of products and services as well as new assistance systems. As explained above, these changes have already been described and various scenarios have been created. However, this paper also presents a proposal for systematizing changes in production.

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* Literature sources: ISO/FDIS [14], BRUNDAGE ET AL. [19], BAUER ET AL. [20], BESTMANN [21], AICHELE [22], ARBEITSGEMEINSCHAFTEN FÜR VITALE UNTERNEHMENSENTWICKLUNGEN [23], DOMBROWSKI ET AL. [24], GÖTZE ET AL. [25], INTRIERI [26], KRAUSE ET AL. [27], MEYER [28], PREIßLER [29], POSLUSCHNY [30], SERVICENOW [31], VOLLMUTH, ZWETTLER [32], WACHENDORF PROZESSTECHNIK GMBH [33]

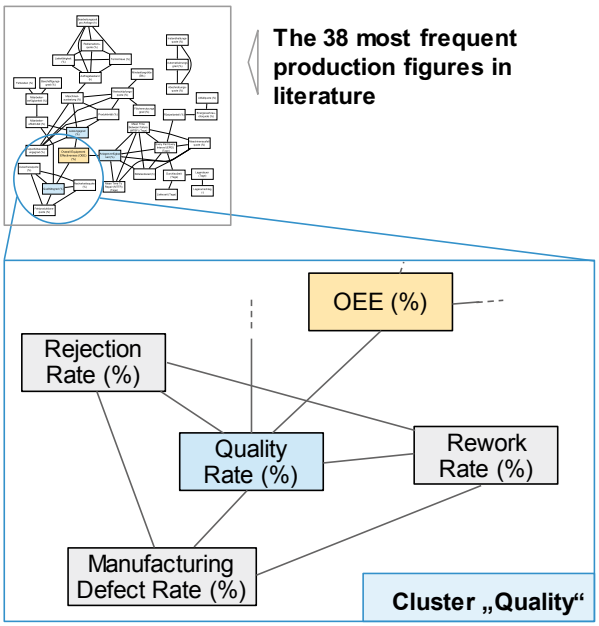

Fig. 3. Graph representation of common KPIs.

A widely recognized model, which represents the activities and processes of a company, is the value chain according to Porter [17]. The model considers individual activities of a company on an abstract level. A distinction is made between primary and supporting activities. The former provide a direct value-adding contribution. The supporting activities, on the other hand, provide the necessary prerequisites, such as personnel planning, and thus support only indirectly. The slightly adapted value chain according to Porter is shown in figure 4.

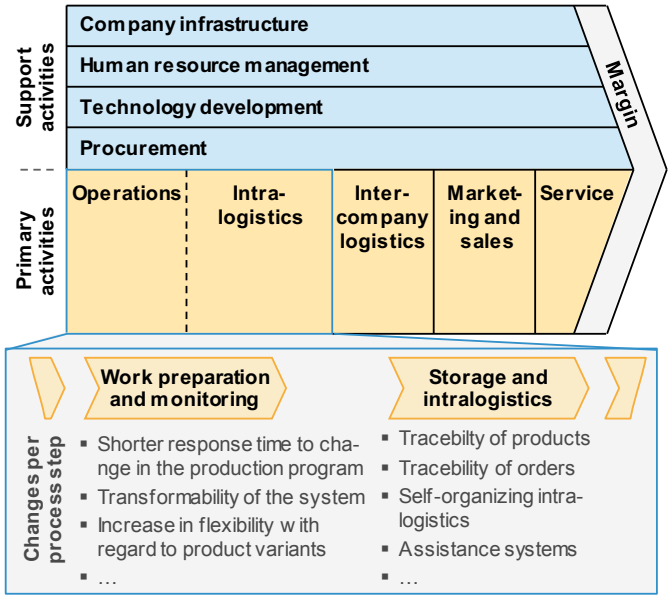

Fig. 4. Porters value chain with generic process steps in the area of operations and intralogistics and classified changes [17].

In order to describe and categorize changes and potentials due to digitalization, the activities within Porter value chain have to be concretized. This can be done on an abstract level independent of the company. The activities of operations and intralogistics are merged since they are highly interconnected. A typical process chain was created. This process chain starts by work preparation and monitoring and continues with storage and intralogistics, followed by material planning and so forth. In this way, changes and potentials due to the concrete digitalization processes can be structured. For the process step work preparation and monitoring changes shorter response time to changes in the production system and an increased flexibility with regard to product variants were identified for example.

All in all, it is recognized that the limits of the production system are dissolving and are merging with parts of the company. A clear delimitation of the production system is difficult and also not target-oriented. The principle of integration along the value chain within the framework of Industry 4.0 describes, among other things, the dissolution of divisional boundaries [8].

4.3. Development of new KPIs

New KPIs can be developed on the basis of the existing, common production key figures and the changes considered in a digitalized production. This is aimed at recording every change and every potential in the best possible way. In addition, it is attempted that the new KPIs are derived as far as possible from existing KPIs in the literature. Numerous KPIs also exist in the areas of IT and data management as well as in product management and product development [18].

For example, a large part of the literature on the new KPI concepts is taken from and transferred to the production area. In addition, new KPIs are proposed, such as the degree of self-organization and self-optimization, digital coverage or virtual controllable resources. These KPIs are characterized by the recording of novel changes in digitalized production.

In addition to the existing categories of KPIs, three new subject groups are proposed. These include data management, transparency and networking as well as product management. They serve to structure new KPI concepts. The data management indicators refer to changes in the infrastructure or to the use of data. KPIs such as data quality or IT availability belong to this category.

The subject group of transparency and networking requires functioning data management and contains key figures that can record data-based changes. These include, for example, the degree of visualization and the proportion of virtually controllable resources. The KPIs thus refer in particular to the machines and systems in production. Finally, the key figures for the company's products and services are grouped under the Product Management group. These include the key figures number of products or new product rate. The subject groups of the KPIs are shown in figure 5.

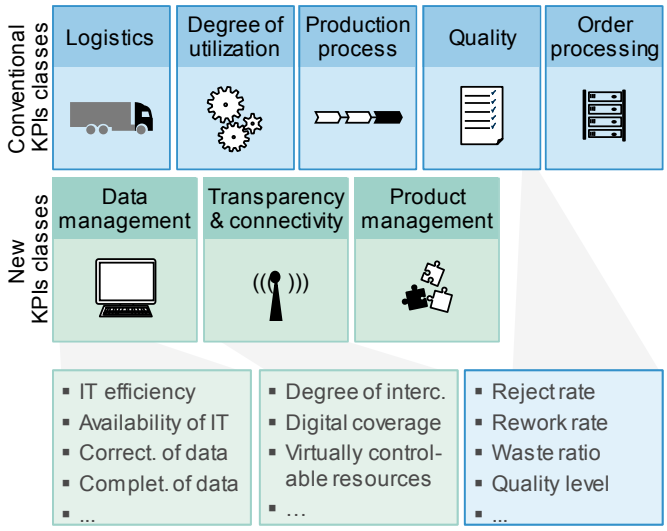

Fig. 5. Subject groups of the Key Performance Indicator system for the production of the future with examples.

All existing and new subject groups thus contain relevant KPIs in the production of the future. It is therefore possible to create a key figure system on the basis of these groups.

4.4. Concept for structuring changes and key figures based on the processes in Porter's value chain

The overall concept is developed on the basis of the existing, current and newly developed key production figures and the systematization of changes and potentials using Porter's value chain. The first step is to check which key figure can record which changes. At the same time, at least one key figure ensures that every change under consideration can be recorded. For the developed concept, 48 different KPIs are required for 30 changes.

The overall concept can be visualized on the basis of the relationships and the systematization of changes and potentials using Porter's value chain. The basis for this is the systematization of changes. For the considered activities of the value chain a matrix of correlations between the key figures and changes is set up. In this way, it can be visualized which key figure records which change.

Based on the pure determination of correlations, the degree of recording is also evaluated. For this a four-stage scale is developed, which reaches from barely captured with several auxiliary key figures up to completely captured with only one key figure. This is visualized by a circle representation known as Harvey Balls. The degree to which it can be recorded provides information about the relevance of individual key figures for changes.

A target development is also determined for each individual key figure. This describes an increase or decrease in the size of the key figure value due to one or more changes in production. The target development results from the statement and calculation formula of the key figure itself. Nevertheless, the target development in combination with the connection to a change makes it clear whether this leads to a measurable influence. This can be used to check the success and profitability of a change over time. Basis for the evaluation of this is thus the goal development of the characteristic numbers and the degree of the capture of a change by a characteristic number.

Figure 6 shows a section of the visualization of the concept. The overall visualization follows the same principle as this representation and can therefore be anticipated on the basis of the extract. In the figure, only a part of changes and potentials caused by the digitalization of production are shown. Likewise only some of the existing and newly developed KPIs are listed.

The presented concept represents the pure denomination of the key figures and changes. Each key figure and change due to the digitalization are further described in fact sheets.

An extension of the concept is planned for the other areas of the value chain according to Porter. KPIs and changes can be added or removed. The presented concept already contains some key figures, which only record a single change. Other key figures, on the other hand, have connections to several changes. Nevertheless, all changes considered are recorded by the KPIs and made measurable.

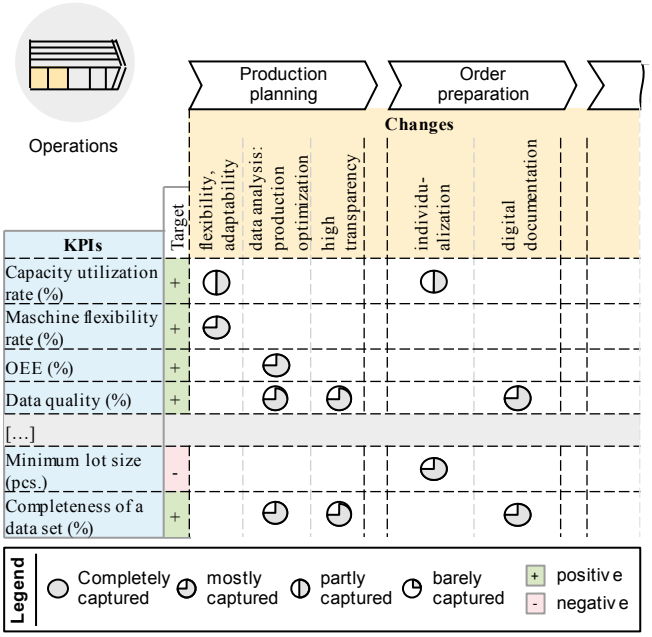

Fig. 6. Concept for structuring changes and key figures based on the processes in Porter's value chain.

4.5. Application of the concept

The developed theoretical concept can be applied to different applications. The first step is to record the respective production process of a company. Based on this process, optimization potentials can then be identified. By comparing changes and potentials of the presented concept, suitable KPIs can be assigned to the identified potentials. This is based on the relationships between the key figures and changes and potentials presented in this paper. The visualization of the concept using Porter's value chain provides the necessary information. A subsequent evaluation can take place if the selected KPIs have been implemented in the controlling instruments. The success of using the optimization potentials can be evaluated by monitoring the KPIs.

5. Conclusion and Outlook

Industry 4.0 promises numerous potentials in production. These potentials mainly originate from using data. Capturing these potentials is a main challenge today. Key Performance Indicators are one way to do so.

In this paper we presented a concept of Key Performance Indicators in the production of the future. Based on literature research and project work we analysed typical KPIs and represented their mathematical interconnection in a graph representation. In addition, a structuring framework is presented, in which KPIs are linked to Industry 4.0-related changes in production. We concluded how current typical KPIs capture these changes and demonstrate the benefit of additional, IT related KPIs.

Future research concerns the extension of the generic process steps within the value chain of Porter like it is presented for operations and intralogistics. Moreover, an empirical evaluation on the interaction between key figures can be done with the help of the graph representation of the key figures. This refers also to an extended validation, since the presented work is based on literature review and a retrospective evaluation of projects.

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