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Support of engineering changes in manufacturing systems by production planning and control methods

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Abstract

Due to changing customer demand and development of new technologies, manufacturing companies have to implement engineering changes in manufacturing systems. Planning and control of these engineering changes is a key task for the company because of the involved costs and time exposure. To improve the organization of several engineering changes in manufacturing systems, methods of production planning and control are evaluated which can support the planning and control of engineering changes.
The purpose of the paper is to introduce existing methods for production planning and control in the planning and control of engineering changes in manufacturing systems. In the first step, the tasks of production planning and control and tasks for the implementation of engineering changes are listed. The handling of several parallel engineering changes is of particular importance. The tasks required for pre-selection, detailed planning and control of engineering changes are analyzed. In the second step, these tasks are compared with tasks from the production planning and control on similarities. Furthermore, methods to support these tasks will be considered. In the third step, methods are exemplarily investigated to requirements and usability for the implementation of engineering changes.
With the Support of engineering changes in manufacturing systems by production planning and control method, proven existing methods can enhance the engineering changes. Knowledge about relationships in manufacturing systems can be transferred from production planning and control and optimize the implementation of engineering changes.

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Keywords: Planning; Control; Manufacturing; Methodology; Productivity

1. Introduction

Manufacturing companies have to develop their products continuously and adapt their production program and quantity due to changing customer demand and development of new technologies. A number of engineering changes need to be performed to adapt existing plants to these developments [1]. Engineering changes in production are defined by Rößing [2] as the reconfiguration of resources, the addition, replacement or removal of equipment or changes in the interaction of resources. The coordination of several engineering changes in manufacturing is an important factor for the efficient planning and implementation due to the involved costs and the high time effort [3 - 5]. The time that is available to implement a single change decreases due to the increasing number of engineering changes. This results in a loss of time for analyzing and planning and reduces the quality of the planning. This in turn leads to deviations in engineering changes and causes high costs, because planning processes have to be repeated or appointments need to be moved [6,7]. An essential part of the involved costs and time consists of unwanted and unplanned shutdowns of production caused by deviations of engineering changes [8, 9]. This leads to worse productivity and increases the need of engineering changes (Fig.1.). Therefore, engineering changes should be implemented as soon as possible and with minimal financial resources [10].

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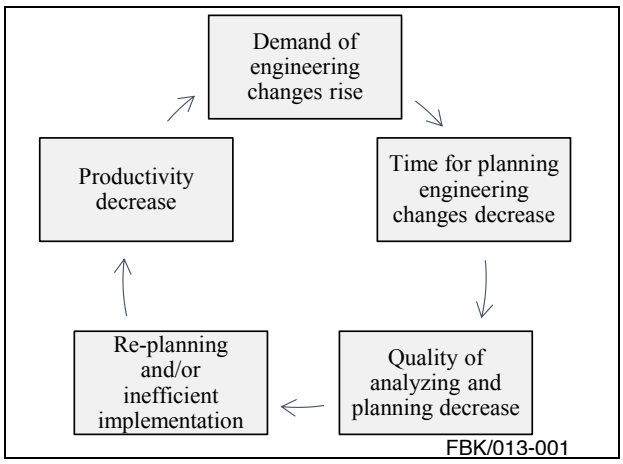

Fig. 1. Demand of engineering changes

Production planning and control (PPC) methods can be used to support engineering changes in manufacturing systems in order to improve the planning and implementation of engineering changes. Numerous methods are available in the PPC that have already been validated and tested in practice. These existing and proven methods can also be used for the implementation of engineering changes and improve their planning. There are many similar tasks like the optimization for machine capacity. For example, PPC methods can be used to avoid unnecessary production downtime, which can be caused by insufficient capacity resource planning. This planning must also be considered during the implementation of engineering changes. The organization of several engineering changes in manufacturing could be improved by PPC methods.

If PPC methods are used for the implementation on the other hand, the integration of the engineering changes to the PPC is much easier. Work steps of the engineering changes can directly transferred into the production plan of the PPC, if there is an integration of the changes in the PPC.

2. Objectives

The main objective of this paper is to introduce existing PPC methods to the planning and control of engineering changes in manufacturing. The introduced approach is divided in three steps (Fig. 2.). In the first step, the tasks of PPC as well as the tasks for the implementation of engineering changes will be listed. Here, handling of several parallel engineering changes is of particular importance. Tasks which are required for pre-selection, detailed planning and control of engineering changes are in focus. In PPC, tasks for production program planning, production resource planning and production control are considered. In the second step, the tasks for the implementation of engineering changes in manufacturing are analyzed and compared with tasks of the PPC. Similarities of both tasks will be examined. Methods from PPC can be transferred to engineering changes to improve their tasks or integrate the task of engineering changes in the methods of PPC. For the third step, an example for a precedence diagram of two engineering changes is shown to get knowledge about the requirements of implementing engineering changes. This precedence diagram can be created with help of time scheduling in PPC.

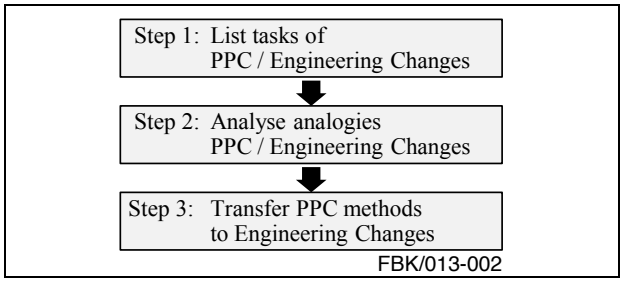

Fig. 2. Approach

The planning of engineering changes can be harmonized by using PPC methods. Better cooperation between the two planning areas can be created by using the same methods, as the planning of engineering changes in manufacturing depends on the production program and this in turn is part of the PPC. For example, the production downtime during engineering changes can be improved by using PPC. Manufacturing steps of the machines which are affected by engineering changes can be migrated to other machines with free capacity with help of the PPC methods. So, production downtime can be avoided through integration of methods between PPC and the engineering changes. The rearrangement of the manufacturing steps is part of PPC, but caused through engineering changes.

3. State of the art

In the following, relevant tasks of PPC are summarized for the comparison. The summary will highlight all necessary tasks for production program planning, production resource planning and production control, which are important for engineering changes. Then, tasks for the implementation of engineering changes are listed. Tasks are examined that are required for pre-selection, planning and controlling of engineering changes.

3.1. Tasks of PPC

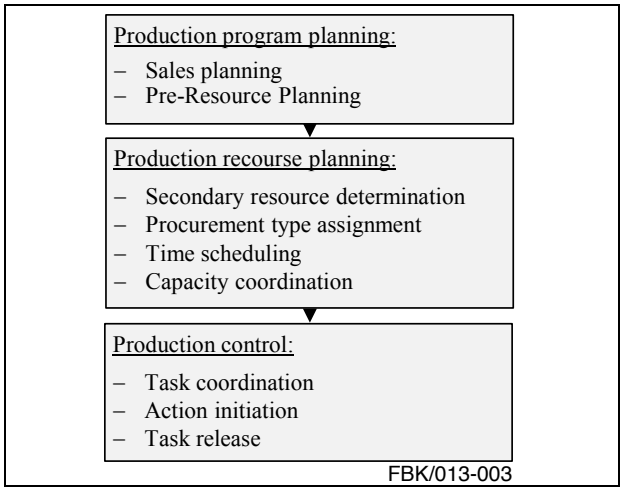

Fig. 3. Relevant tasks of PPC

PPC supports the production management during the design of the production program and production processing. The objective of PPC is operational, temporal and quantitative planning, management and control of all operations that are required for the production [11, 12]. The PPC is divided into the production program planning, production resource planning and production control (Fig. 3.).

3.1.1. Production program planning

The objective of the production program planning is the ensuring of the requirements of the market and customers while taking into account an economic production operation. The planning process tries to find the balance between optimizing the utilization of capacities and ensuring high flexibility at low cost with respect to the distribution [14]. A combination of the corporate functions of sales, production planning and production is a key prerequisite to ensure the right amount of production output for an advantageous manufacturing system. The production program planning is used to determining the type and amount of different products at the various plan periods. It is distinguished between the strategic, the tactical and operative production planning [15]. As part of the strategic production program planning the product fields are selected, in which the company wants to be active in the future. The objective of the tactical production program planning is to determine the tactical production program on the basis of identified or expected customer orders or in the production of the anonymous market based on sales forecasts. In the context of operative production planning it is determined which quantities of products and components are manufactured in the next plan period. This is based on a fixed stock of production equipment and personnel.

3.1.2. Production resource planning

The objective of the production resource planning is to determine the amounts of primary and secondary resources that are required in a planning period. In this framework, the period and sequence for the corresponding sales volume are defined, the primary and intermediates products are determined and production volumes are divided in production batches [13]. The primary resources are the final products. The secondary resources are the amount of the minor parts required to manufacture the primary resources. In this subsection, the disposition of the primary and secondary resources as well as the time scheduling of production and purchase orders takes place [12]. For these tasks, the PPC provides different methods to support. Demand forecasts for production resources are predicted due to the historically observed requirements using simple prediction methods supported by the expected demand quantities. In production resource planning it is differentiated between deterministic, stochastic and heuristic methods [16]. With the help of customer order management, known or expected customer orders can be managed and recorded. The needed secondary resources have to be procured. The type of the procurement is assigned in the procurement type assignment. After the production resources are specified, working steps are arranged and the time scheduling will be performed. This includes the timing of production. The time scheduling can be executed backwards and forwards. In forward time scheduling, the earliest end date is calculated from a fixed start date. Backward scheduling is based on a fixed end date and calculates the latest possible start date. After time scheduling, the capacity of the manufacturing equipment is assigned.

3.1.3. Production control

The central task of production control is the execution of the production process planning. The coordination task is a central point of the control. For the execution of production processes, incoming order coordination and order monitoring are relevant. The availability of the necessary equipment and materials needs to be checked continuously. In the order coordination, all job-related tasks are summarized in the process monitoring. These relate to the various sub-tasks of the PPC [17]. Another objective of the order coordination is to provide the latest information about the order processing status to internal or external requests. This task is often summarized under the terms “order tracking”, “monitoring” or “tracking and tracing” [12]. If there are capacity bottlenecks or derivations to the planning, counter actions have to be initiated and performed. Furthermore, the production task release is within the scope of production control to direct the capacity utilization. If all pervious tasks are performed, the following tasks can be released.

3.2. Tasks of engineering changes in manufacturing systems

The implementation of engineering changes in manufacturing proceeds in three phases. First, a pre-selection and grouping of the engineering changes is proceeded. This is followed by the planning of the engineering changes. The last step is to control the engineering changes in the execution of the operations. [18]

3.2.1. Pre-selection

In the first phase of the pre-selection, engineering changes are filtered and grouped. A prioritization is performed regarding the relevance of engineering changes and their urgency [4]. First, a selection decides which projects should be implemented. The individual projects are evaluated in order to make a selection of the projects to be implemented.

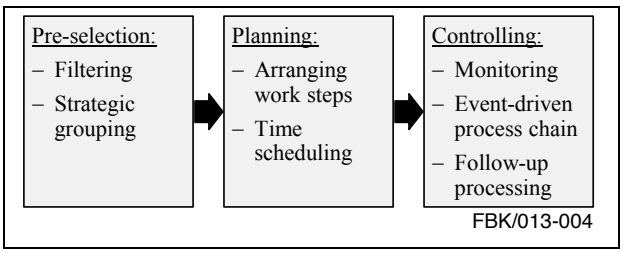

Fig. 4. Tasks of engineering changes in manufacturing

Then they are analyzed and evaluated on their substantive strategic dependencies. Engineering changes are divided optimally, in order to avoid duplication and to achieve economies of scope in several parallel projects. The dependencies can be evaluated and visualized qualitatively or quantitatively using matrices, charts or modified utility analyzes [19, 20]. The resource constraints of engineering changes are considered in the last step of resource interdependence analysis. In the resource interdependence analysis, possible processing sequences are taken into account and, if necessary, excluded due to insufficient resources [4].

3.2.2. Planning

The objective of the planning of engineering changes is to create a plan for the implementation of the selected changes in the available time. For the planning of engineering changes, it has to be investigated which conditions are required to implement engineering changes parallel or in sequence. The necessary work steps are listed for the creation of the implementation plan on base of the information of production and the data of the engineering changes [21]. Subsequently, the work steps are arranged according to availability and demand of the necessary resources and divided temporally. Furthermore, milestones are defined which divide the schedule into so-called execution sections. The milestones are used for the following checking in the controlling.

3.2.3. Controlling

In the controlling of engineering changes, the execution of the work steps is monitored and intervened by controlling events if there are deviations from the planning. Three types of deviations are possible. First, the criteria for the prioritization can change and thus affect the pre-selection. Second, the properties of engineering changes such as required time, employed components or storage position may vary. As third type of change, unplanned changes in capacity are taken into account. The changes can be counteracted using event-driven process chain (EPC). Rules are defined which lead to appropriate actions, if they occur [22]. After the completion of the engineering change succeeds a follow up processing, in which possible improvements in the implementation of engineering changes are discussed and saved.

4. Analogies of engineering changes and PPC tasks

In the following conceptual part, the tasks for the implementation of engineering changes will be analyzed in detail and assigned to the tasks of the PPC, which have analogies. It is considered, whether PPC methods can support the engineering changes or whether the implementation of engineering changes can be improved by integration in the PPC.

4.1. Pre-selection

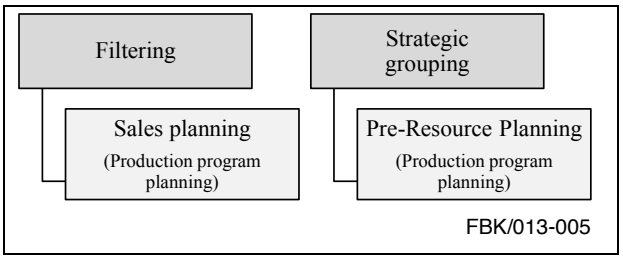

Fig. 5. Pre-selection of engineering changes

In the pre-selection, engineering changes are first filtered and then grouped strategically. For the filtering, the engineering changes are prioritized and evaluated individually. On the basis of future scenarios, the benefits of the engineering changes are evaluated by strategic, tactical and operative aspects. This task has a strong analogy to the sales planning of PPC. The production program is adapted due to the projected sales figures. This has a direct impact on the resources needed in production. Which in turn plays a large role in the prioritization and evaluation of engineering changes. It has to be investigated whether existing methods can be transferred from the sales planning or implementation can be optimized by the integration of engineering changes in order to improve the pre-selection of engineering changes.

Pre-resources planning can be used to support the strategic grouping of engineering changes. Here it is checked if the sales plans and production programs can be realized with the existing resources. With the material-availability-calculation for example, the needs of material is calculated with material profiles [23]. This method can also be used with the dependency and resource analysis for the strategic grouping of engineering changes. Required steps can be evaluated according to their resource requirements and possibly merged to achieve economies of scope and avoid duplication of effort.

4.2. Planning

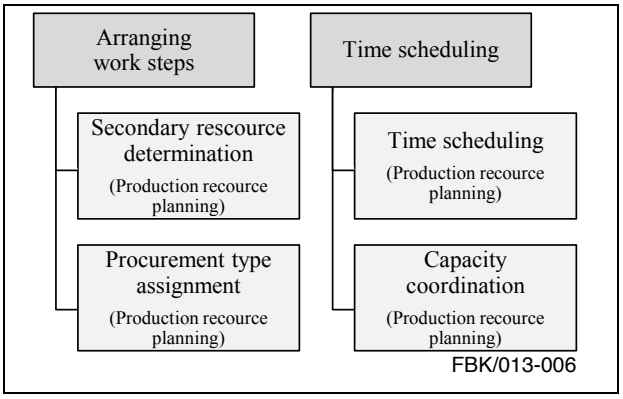

Fig. 6. Planning engineering changes

In the planning of engineering changes, the work steps are arranged and scheduled in the execution plan.

First, the operations of the engineering changes need to be determined and assigned. This can be resorted to methods of secondary resource determination and procurement type assignment. From the secondary resource determination the deterministic methods are considered in particular (Chapter 3). Analog to the deterministic bill of materials explosion, the needed working steps are determined on the basis of preliminary work, which can be stored in a database and the resources are calculated. Based on that the processing sequence can be created. The processing sequence can be represented in a precedence diagram. Similarly to the procurement type assignment, it is determined whether a work step is carried out internally or contracted to an external firm. This can either be generally stored in the database as in the procurement type assignment or can be decided case by case. The assignment will be based on competencies and capacities within the company. In case by case decision, the required skills are available within the company but can also be carried out by external companies.

After the work steps are set up, the time scheduling of these steps is next. In this case, a forward or backward scheduling is executed analogous to time scheduling of PPC. In the time scheduling, first unlimited or free capacity is assumed, this means the load capacity is not considered. The capacity coordination shall be performed afterwards. Thereby, at the engineering changes and at the PPC, capacity requirements and the available capacity are compared. In contrast to the time scheduling the actual capacity utilization is taken into account. On the one hand, methods of capacity coordination can support the time scheduling of engineering changes. On the other hand, the capacity coordination between both can be improved by integrating the engineering changes in PPC. For example, if a machine is replaced in the manufacturing system due to an engineering change, the capacity of this machine is discounted for a certain period of time. This extraordinary loss has to be included in the PPC.

4.3. Controlling

For controlling of engineering changes, there is a monitoring of the work steps, controlling events in case of deviations to the planning and the follow-up processing of the engineering changes.

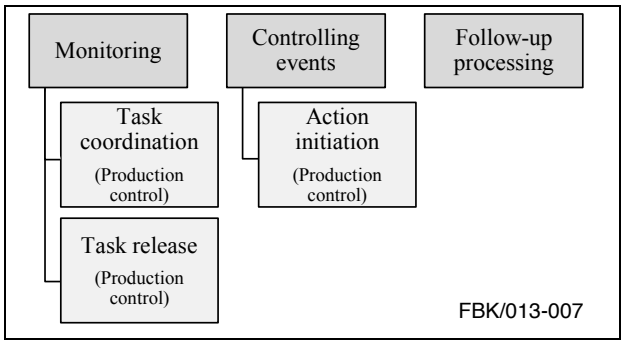

Fig. 7. Controlling engineering changes

To monitor the engineering changes an actual-target comparison is performed. Analog for task coordination of the production control, all processes are summarized to get the latest information about the processing status. Appropriate computer systems for PPC can possibly also be used for monitoring engineering changes. Furthermore, methods for task release in PPC can be used in the implementation of engineering changes. Therefore determined release rules are applied. When a task is performed, it is checked if all prior and prerequisite steps for the next task are have been finished. If all aspects are finished, the next tasks are initiated and the necessary resources for subsequent tasks are released.

If there is a deviation from the target state in monitoring, controlling events need to be made. This can be supported by the action initiation of the PPC. Known relationships are stored in a database and determined response actions are defined. These actions can be possibly automated for deviations or executed as suggestions.

There is no direct reference to the PPC for the follow-up of engineering changes. Up to date, there are no association with PPC methods.

5. Application Example

In the following, a brief example of the support of PPC methods for engineering changes is shown. The processing sequence can be represented using the precedence diagram (Fig. 8.). All necessary steps are shown in a rectangle. Operations that can be performed together, are summarized in these rectangles. The processing sequence and dependencies are represented by using arrows as described in the precedence-diagram-technique. Some steps require that certain previous steps have been completed. These are divided into so-called execution sections (ES) and divided by milestones (MS). In an execution section, all steps are listed which must be finished on reaching the milestone and before starting the next execution section.

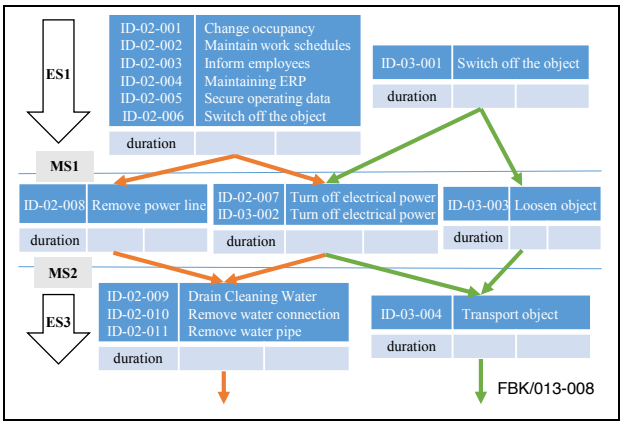

Fig. 8. Precedence diagram

6. Conclusion

With the introduction of methods from PPC, the implementation of engineering changes in manufacturing can be improved with proven methods. There is already knowledge about correlations in production, which are available in the PPC. This knowledge can be used for the implementation of engineering changes and improve these. This paper provides an overview of the analogies between the individual tasks of engineering changes and the PPC. Firstly, the respective methods can be used in the implementation of engineering changes. Secondly, the implementation of engineering changes can be improved by integrating PPC in the process of the management of engineering changes. The industry benefits of this integration due to a better coordination between the production plan and the implementation of the engineering changes. The work steps of the engineering changes can directly be scheduled in the PPC and the production plan can be adapted to these work steps.

7. Outlook

This paper provides an overview of the analogies of engineering changes in manufacturing and PPC. In further work, the individual tasks have to be analyzed in more detail. It is necessary to examine the details of the tasks for engineering changes and PPC to develop a holistic concept for the support of engineering changes in manufacturing by PPC methods. It is necessary to determine whether the respective PPC methods can be transferred unchanged to engineering changes, whether they need to be adjusted or whether a transfer is not useful.

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