Flexible Planning Method for Manufacturing Resources based on Process-graphs

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Abstract
As the number of product variants keeps increasing while product life cycles shorten, production equipment and product life cycles must be rendered independent of each other to allow for a prolonged utilization of production facilities. Hence, new systems must be planned in a flexible way to consider various products and product changes easily even at short notice during the planning phase and afterwards. In series production, transfer lines respectively rigid connected machines are state of the art. This paper presents an advanced process-graph based approach to the planning of manufacturing resources for the series production. From the process-graphs, the required machining equipment can be derived by building a so-called resource-graph. This method can be adapted for the planning of manufacturing resources. The approach allows for a demand-oriented assessment of current and future needs for equipment to process certain product variants.

Keywords
Planning method, Process-graph, Manufacturing resources

1 INTRODUCTION
The manufacturing industry is worldwide confronted with a rising change of the demands towards their products, e.g. laws and market demands [1]. As product life cycle and product development time shorten and the number of product variants increases [2], a decoupling of the production equipment life cycle and the production phase within the product life cycle is necessary to produce cost-effectively. To enable a decoupling of the production phase of a product and the use phase of the equipment the production equipment must allow for the machining of different products in different product variants during their own use phase. That creates a constant need for modification [3].

To date, manufacturing resources have been planned to fulfill special manufacturing methods, so the functions have been limited to some few methods. If several manufacturing methods are needed to machine a certain part, they have to be realized on different machines. Recent developments aim to implement as many manufacturing methods as possible in one individual machine or to design the machine as reconfigurable as possible, cf.[4] [5]. But until a universal purpose machine that can produce numerous combinations of different parts is going to be developed, a combination of different interacting machines – the manufacturing resource – has to fulfill this task. A manufacturing resource is understood as the combination of different individual machines or manufacturing modules, which can handle a limited number of manufacturing methods only. These modules are combined in a way that they can accomplish complex machining tasks as one functional unit, e.g. a transfer line. Due to their long expected use phase, manufacturing resources have to be designed in a way to satisfy current and future demands towards resources and a free combination of the modules. Here, resources are equal to the needed tools. Several tools, the corresponding drive and the control systems represent a manufacturing module. Thus, individual modules contain different capabilities and interact to execute certain manufacturing tasks. Figure 1 illustrates this relation.

Figure 1 - Setting of a manufacturing resource.

The future demands towards required processes are not known at the time of the manufacturing resource development, which is one of the most important challenges in planning. This paper aims to introduce a new instrument for defining the functional requirements for different specifications of manufacturing resources already at an early stage of planning. A precondition for this is to derive the demands towards the resources for machining recent and potential future products from alternative scenarios. The goal is the planning of a transfer line with the possibility to expand or reduce the functional characteristics in a relatively easy way by adding or removing manufacturing modules.

One of the main tasks during the planning phase is the demand-oriented design in order not to
implement manufacturing skills that will not be used and only increase the procurement costs.

2 GRAPH-BASED PLANNING METHOD

The process-graphs were originally developed for a risk reduced final assembly planning in the automotive industry. They are built successively, starting with a product reference variant and considering miscellaneous configurations by using different variant elements and line types [6][7]. Assembly planning aims to control the assembly of different parts to one product. It defines when the parts will be assembled, by whom and with what equipment. The graph-based assembly planning follows different steps. It starts with the definition of a reference variant which includes most of the characteristics of the product line to be assembled. In the majority of cases this reference variant is the variant with the highest predicted sales figure. In the next step the scenario is supplemented by other important and remarkable product variants. A so-called process-graph is first developed for the reference and then extended successively for all of these variants, based on priority restrictions. These restrictions define the assembly sequence. Processes are the smallest sensible steps the assembly can be divided into. The process-graph illustrates the order and the exact relationship of the different integrated processes. By adding the time for assembly in the individual process, the process-graph can be the basis for cycle time calculation and line balancing. Differences between the variants in assembly technique, assembly time and additional or unnecessary processes concerning the reference variant are considered by so-called variant elements. The processes are connected by these variant elements if required so that all product variants which have to be planned can be clearly represented in one graph. It is possible to filter the graph with regard to certain variants if required. In addition, the possibility to derive a resource-graph with rigid rules is given. This graph shows all the resources which will be needed for the assembly. It is defined that only one resource (R) can be allocated to one process (P), but one resource can handle different processes, see Figure 2. Depending on the type of process connection causing the resources, these can be combined under certain conditions. The result is a minimum of resources for the product assembly. In this context, resource means the equipment which is needed for the assembly.

With some modifications the whole procedure can be adapted for the planning of a manufacturing resource for miscellaneous product variants. The goal is to derive the number and kind of manufacturing modules and the order in which they have to be arranged. The flexibility during the planning phase is based on the possibility to embed any process the manufacturing resource shall fulfil.

3 GRAPH-BASED PLANNING OF MANUFACTURING RESOURCES

Miscellaneous tools exist for the planning and visualisation for products in different development levels and their relations, e.g. the Siemens Tecnomatix products [8] or the different DELMIA Tools for Manufacturing and Production [9]. These software programs manage solutions for PPR (product – process – resource) planning but no solution exists that derives the needed manufacturing resource from the product and process definition.

3.1 Construction of the process-graph

In the demand-oriented planning of manufacturing resources the process-graph is not used to visualize the steps to assemble different parts to a product but to show the individual steps to machine a part. Demand-oriented means that the manufacturing resource is designed for the current and a possible future demand of manufacturing methods, in which the future demands can be chosen freely during planning.

The first planning step is the selection of the favoured part portfolio enlarged by prospective future variants. In the next step a reference variant is chosen which is representative of the products to be machined. For this main variant the priority restrictions - the definition of the order the geometric characteristics will be machined in - are defined and the process-graph is constructed. This order represents logical sequences, e.g. a hole must exist before tapping. Hence, that shows the rough sequence; the exact planning of the individual machining steps follows. Geometric characteristics are attributes of the product which represent a sensible unit for processes, e.g. the mentioned hole with the thread. A process is defined as a single manufacturing step, i.e. one operation during the generation of a geometric characteristic. In most cases it will be necessary to perform more than one process for a complete generation of a geometric characteristic. When successively extending the graph like the assembly process-graph described in [6], the differences towards the further variants are considered with the relevant variant elements, see line 1-4 of Table 1. The variant elements enclose the affected processes in each case. Following these steps a process-graph is built which includes the entire spectrum of processes for all considered variants.

The connections between the processes underlie special restrictions which are indicated by different

![Figure 2 - Process - Resource allocation.](image-url)
colours. Table 2 explains the different cases and colours. The priority restrictions define the sequence of the geometric characteristic generation and must not be changed. In this case the connection type is type 1. In contrast, within the generation of the geometric characteristics it may be possible to change the order of the processes, visualized by connection type 2 or 3. With this convention certain degrees of freedom exist during line balancing.

In order to allow for the deriving of the resource-graph the processes are linked with important data like corresponding resources and machining parameters. The knowledge about the total machining time for every individual process is important for the machining time assessment of the whole product variant. With the machining hour costs the part manufacturing costs can be estimated afterwards.

### 3.2 Construction of the resource-graph

As every process is connected with its related resource, a simple replacing of the processes by the resources leads to the resource-graph. Due to the line-types of the processes causing the resources, some resources can be eliminated and the final resource-graph arises. The resources do not underlie connection restrictions, so there is no differentiation by line colours. The variant elements for Addition and Subtraction are taken over into the resource-graph. The differentiation in Time and Technique is replaced by a grey resource variance symbol, due to the fact that only the resource type differs but no further information is needed, see line 5 of Table 1. By using the resource-graph it is possible to calculate the preliminary number and the kind of resources for the entire products. The next two steps can be performed simultaneously. On the one hand the minimal number of resources for every geometric characteristic can be identified from the graph – the result is a list with the required resources for every geometric characteristic. On the other hand the resources can be divided into classes. These classes contain resources with similar motion sequence and similar manufacturing techniques. For example, the classical manufacturing techniques drilling and milling should be combined. Grinding with rotational tools can also be added to this class. In this case, turning has an exceptional position and serves as initial process because it provides the wrought material which is going to be machined by the manufacturing resource to be planned here. These resource classes again can be combined as sensible units to manufacturing modules. Thereby, it can also occur that one module is represented by one resource class only.

By now it is known which modules are needed to machine the individual geometric characteristic and vice versa which characteristic is machined by which manufacturing module. In the next step the modules are arranged referring to the sequence of the geometric characteristics. It can occur that a certain module is placed several times in series. Multiple modules which succeed another immediately can be replaced by a single one. Finally, a concluding matching is performed. If the sequence of the modules fits the sequence of the geometric characteristics the manufacturing resource can be built up in this way. The modules are only equipped with the needed resources for the characteristics they machine. If the sequences do not fit, the process and resource combination for certain modules has to be restated or the definition of the priority restrictions towards the geometric characteristic machining order must be changed. During the line balancing it can also be necessary to double certain modules, but this depends on the individual case and is not going to be considered here.

The modules can be exchanged if required, and in this way the manufacturing resource can be adapted to new or changed product variants. Figure 3 summarizes the procedure of planning a demand-oriented manufacturing resource. Final results of the planning are the concrete kind and number of the resources as well as the number and order of the manufacturing modules. The possibility of a recursion is given to include new variants in hindsight, also allowing the identification of the positions for a potential reconfiguration due to a production change.

<table>
<thead>
<tr>
<th>Variant elements</th>
<th>Description</th>
<th>Visual display</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Processes differ in machining time but not in machining method</td>
<td></td>
</tr>
<tr>
<td>Technique</td>
<td>Processes differ in machining method</td>
<td></td>
</tr>
<tr>
<td>Addition</td>
<td>Supplementary process that is not needed for the reference variant</td>
<td></td>
</tr>
<tr>
<td>Subtraction</td>
<td>Process needed for the reference variant but not for the other variants</td>
<td></td>
</tr>
<tr>
<td>Resource-Variance</td>
<td>Resources differ for different variants</td>
<td></td>
</tr>
</tbody>
</table>

*Table 1 - Variant elements (analogous to [6]).*
4 CONCEPT APPLICATION

4.1 Construction of the process-graph

As a fictitious example a hose coupler has to be manufactured in two concrete variants: once with a male thread (V1) and once with a female thread (V2). In addition, an angled variant (V3) with male thread (V1) and once with a female thread has to be considered which shall be manufactured in the future, see Figure 4 for the different product variants.

V1 is selected as reference variant followed by the definition of the priority restrictions for all variants: 1. Milling the spanner flat, 2. Milling the pocket, 3. Drilling the through boring, 4. Adding the Bezel, 5. Deburring and 6. Tapping the thread. The next step is the construction of the process-graph for the reference variant and the integration of the further variants by using the corresponding variant elements and connection types; the result is depicted in Figure 5. The individual variants are named above the connection lines, so the filtering of the process-graph is easily feasible. Processes are named with P and numbered consecutively, starting with the reference variant. The geometric characteristics are encircled by the dashed lines.

For simplification, not all necessary processes for a complete product machining have been taken into account, e.g. cleaning processes were excluded. The utilised processes can be seen in Table 3. Additionally, the resources connected to the processes are named and numbered.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Process description</th>
<th>Resource description</th>
<th>Nr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P01</td>
<td>Milling spanner flat</td>
<td>Miller 1</td>
<td>R01</td>
</tr>
<tr>
<td>P02</td>
<td>Center and spot drill through boring Face 1</td>
<td>Drill bit</td>
<td>R02</td>
</tr>
<tr>
<td>P03</td>
<td>Finish boring and bevel through boring V1</td>
<td>HM Borer with bevel</td>
<td>R03</td>
</tr>
<tr>
<td>P04</td>
<td>Bevel through boring Face 2</td>
<td>Miller 2</td>
<td>R04</td>
</tr>
<tr>
<td>P05</td>
<td>Cut outer bevel Face 1</td>
<td>Miller 2</td>
<td>R05</td>
</tr>
<tr>
<td>P06</td>
<td>Cut outer bevel Face 2</td>
<td>Miller 2</td>
<td>R06</td>
</tr>
<tr>
<td>P07</td>
<td>Deburring with brush through boring</td>
<td>Brush</td>
<td>R07</td>
</tr>
<tr>
<td>P08</td>
<td>Tapping outer thread Face 1</td>
<td>Thread cutter male thread</td>
<td>R08</td>
</tr>
<tr>
<td>P09</td>
<td>Tapping outer thread Face 2</td>
<td>Thread cutter male thread</td>
<td>R09</td>
</tr>
<tr>
<td>P10</td>
<td>Milling pocket Face 1</td>
<td>Miller 1</td>
<td>R10</td>
</tr>
<tr>
<td>P11</td>
<td>Milling pocket Face 2</td>
<td>Miller 1</td>
<td>R11</td>
</tr>
<tr>
<td>P12</td>
<td>Cut inner bevel Face 1</td>
<td>Miller 2</td>
<td>R12</td>
</tr>
<tr>
<td>P13</td>
<td>Cut inner bevel Face 2</td>
<td>Miller 2</td>
<td>R13</td>
</tr>
<tr>
<td>P14</td>
<td>Tapping inner thread Face 1</td>
<td>Thread cutter female thread</td>
<td>R14</td>
</tr>
<tr>
<td>P15</td>
<td>Tapping inner thread Face 2</td>
<td>Thread cutter female thread</td>
<td>R15</td>
</tr>
<tr>
<td>P16</td>
<td>Finish and bevel blind boring Face 1</td>
<td>HM Borer with bevel</td>
<td>R16</td>
</tr>
<tr>
<td>P17</td>
<td>Center and spot drill blind boring Face 2</td>
<td>Drill bit</td>
<td>R17</td>
</tr>
<tr>
<td>P18</td>
<td>Finish and bevel blind boring Face 2</td>
<td>HM Borer with bevel</td>
<td>R18</td>
</tr>
<tr>
<td>P19</td>
<td>Deburring boring corner</td>
<td>Water jet deburring tool</td>
<td>R19</td>
</tr>
</tbody>
</table>

Table 3 - Processes and Resources

4.2 Construction of the resource-graph

Figure 6 shows the derived resource-graph. The resources are numbered analogous to the processes. As can be seen, there are fewer resources then processes because different processes can use the same resource. Due to this fact multiple resources can be eliminated in accordance to the process-graph connection lines. This graph leads to a list with the required resources per geometric characteristic. By the definition of the resource-classes, which also represent the certain manufacturing modules (M), it can be determined which characteristic is machined by which module. Based on this, the preliminary order of the manufacturing modules and by combining multiple modules lying in a row, the final number and
arrangement of the manufacturing modules can be derived. In this example the module arrangement is found to be M1 – M2 – M1. The whole procedure can be seen in Figure 7. For every variant the last manufacturing module is M1 to machine the thread. Due to the fact that the deburring is performed either in M1 or M2 – depending on the variant with a brush which is implemented in M1 or the water jet deburring tool which is implemented in M2 – the order of the manufacturing modules must have the mentioned sequence to assure a linear piece flow.

If the thread cutting was planned to be performed in M1 at the beginning of the manufacturing resource, at least V3 would have to be transported backwards out of M2.

As mentioned in chapter 3.2 the modules are equipped with the needed resources only, so the first M1 is equipped with Miller 1, Miller 2, Pilotbit and HM Borer with bezel. M2 contains the water jet deburring tool and the second M1 contains brush (could also be placed in the first M1) and thread cutter for male and female threads.

Figure 5 - Process-graph.

Figure 6 - Resource-graph.

Figure 7 - Combination of the resources to the module order.
5 CONCLUSION AND OUTLOOK

In this paper a possibility for the planning of demand-oriented manufacturing resources is presented. The basic concept is a transparent and easily extendable process-graph and the derivation of the required resources. These resources are classified, and depending on defined priority restrictions for the machining of geometric characteristics, the final number and order of manufacturing modules is derived for the machining of the entire product portfolio taken into account.

The advantage of the presented approach is that it allows for the derivation of all currently needed resources while providing the basis for an easy extension towards further product variants and products. The process-graph offers the advantage that it can be changed and adapted in hindsight if needed. In addition, it is possible to estimate the changing demand of a manufacturing resource for a product change and to identify the location where the change has to take place. Process-graphs offer the possibility to consider different scenarios in a quick and easy way by a simple change of the processes or the allocated resources. The new approach leads to a concrete number of resources and to the knowledge about a potential module sequence to build up a demand-oriented manufacturing resource.

6 REFERENCES


7 ACKNOWLEDGEMENTS

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8 BIOGRAPHY

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