DYNAMIC CLASSIFICATION OF TASKS IN CONDITION OF UNIT AND SMALL BATCH PRODUCTION

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Abstract
In the process of unit and small batch production a very important aspect is the amount of time from production setup to availability to the customer. In spite of applying modern management techniques, setup time still plays an important part in the production cycle time. In the examined companies the relationship between changeover time to processing time was significant. The above research inspired the author to prepare a method of setup time reduction through the appropriate arrangement of tasks in the operational production plan. The appropriate arrangement meant considering the similarity of parts from the point of view of carried out operation. The similarity of parts facilitates setup time reduction, which translate into smaller lot sizes, reduced in-process inventories, shorter lead time and higher throughput. The method was validated in conditions of the production practice for unit and small batch production. The presented method is one of the elements of a computer aided management system for small and medium enterprises (SME).

Keywords
dynamic classification, operational production plan, group technology, unit and small batch production, Theory of Constraints, heuristic algorithm.

Introduction

The manufacturing industry has evolved over the past several decades in response to changing customer needs. Previously the primary source of competitive advantage for manufacturing companies in many industries used to be related to price. Therefore, all manufacturing strategies were driven by attempts to reduce the cost of the product. Technological advances, in manufacturing as well as in information, have provided the impetus for changes in many paradigms, including customer expectations. Customers have become more demanding and want products that can meet their specific individual requirements. Thus customization is turning out to be essential to maintaining competitive advantage in many industries [1]. Producing customized products at a low cost, which seemingly is a paradox, is the purpose of many enterprises. This main purpose, which is considered as fulfilling customer needs, results in production in the unit and small batch process. The production cycle consists of, among others: the processing time and setup time. Despite using modern management techniques e.g. SMED (Single Minute Exchange of Die) technique, in the conditions of unit production in SME, setup time is significant. In the examined companies of the SME sector the relationship between setup time to processing time is still high and amounts from a few to several per cent of the processing time.

The above research inspired the author to prepare a method of setup time based on the similarity of the parts. In order to do this a classifier of
a new kind was introduced – the classifier works at the level of process in the operation production plan. The objective of the classifier is to aggregate process into organizationally similar groups. It allows production tasks inside groups: in sequences, without changeovers or by significantly shortening the setup process.

The above classification is based on features of tasks having influence on changeover times and optimization of tasks arrangement. Using the standard classifiers, used for Group Technology (GT), for this purpose is not sufficient and in some cases can be harmful.

The principled conception consists of applying a computer system consisting of three elements (see Fig. 1):

1. ERP class system – collecting primary data about the product and production plans (e.g. orders from customers, the database of machines and devices, routes of production process, the workers and their qualifications),
2. module of grouping and arranging tasks and operational controlling, working in an “on line” mode,
3. module of the simulation being an element of the digital factory – working in a periodic – “off line” mode. This module is destined for the periodic verification of the method.

The article is focused on the module of grouping and arranging tasks. Focusing on the work bottleneck and improving it is the essence of this approach. This approach corresponds with the assumptions of the theory of constraints (TOC) [2, 3]. Increasing the productivity of the bottleneck follows from the dynamic classification of tasks in the operational production plan.

A periodic simulation of the bottleneck is an additional element providing the effectiveness of the method. Using the tools of simulation in the “on line” mode demands the purchase, by enterprises, of such systems. At present costs of the license are too high for this approach. So, applying the periodic mode is a good enough solution. Automatic data preparation through the module of middleware is additionally improving the method.

Problem background

The review of solutions, applied so far, concern the following areas: recognizing part similarities, Group Technology (GT), setup time reduction and acquiring data from the container of the ERP class systems.

Manufacturing based classification began to evolve in the 1940s. It is based on the idea that parts do not have to look the same to be similar. Although they may appear to be different, they can be manufactured in the same way. It becomes possible to develop a classification system that groups parts according to their manufacturing characteristics [4, 5].

Analyzing literature it is possible to find a lot of methods of recognizing part similarities. The most important are: classification and grouping. Classification is a term from statistical sciences and it can be defined as a procedure in which individual items are placed into groups based on quantitative information on one or more characteristics inherent in the items (referred to as traits, variables, characters, etc) and based on a training set of previously labeled items [6, 7].

The main problem in initiating a group technology based manufacturing system is to group parts into families. Three methods for accomplishing this grouping are [8]: visual inspection, parts classification and coding, production flow analysis. As the first step, the development of manufacturing groups requires some measure of parts classification. There are a lot of coding and classification systems that are now in the public domain.
Machine-part grouping problems were also considered in many publications [9–12]. This issue is referred to as “part family & machine cell formation”, “machine part grouping”, “group technology manufacturing”. The problem arises when dividing the set of machines, into subsets and assigning operations to these subsets, in order to optimize a production organization quality criterion. In [12] the attempts to solve this problem with clustering methods were outlined.

Although, generally, the problem concerned the improvement of industrial engineering, the purpose of the optimization was situated elsewhere. This criterion reflects the “density” of operation within the machine groups established and the “sparseness” of operations outside these groups. Additional aspects, complicating the formulation and solution of the general problem are: timing, costs, sequencing of operations, the possibility of duplication and the cost of machines, as well as various limitations on groups.

Coding is connected with creating a code which consists of symbols reflecting features of the classified element. Currently many classification systems are used in practice [8], eg. Opitz code, CODE code, Miclass code, CADAM code. At present, advanced techniques for part classification are used e.g. neural networks [13] and the fuzzy logic [14].

The changing world economy has caused an increase in the use of just-in-time manufacturing, which results in a trend toward short-run, multiple-product manufacturing. The frequent product changeovers make it imperative to improve setup operations and shorten line changeover times. The simplest way reducing setup time is making a distinction between internal setup tasks, for which production equipment must be stopped, and external setup tasks that permit equipment to continue to run [15]. The target is a single setup, or reducing setup time to less than 10 minutes. The above named SMED principles are one of the standard techniques of Lean Manufacturing [16].

Problem formulation

Effective company management requires the right quality data which can be provided by the integrated information system. Therefore, a large number of SMEs have decided to introduce an ERP class system although they have recognized that the introduction process is difficult and expensive. However, an alternative solution cannot be easily found [17]. In the majority of companies the introduced ERP systems were not fulfilling expectations in the area of operational production control. Companies need efficient tools within the decision-making process which could work in an “on line” mode.

A given production system realizes “make to order” manufacturing. Due to the fact that the system resources are not wholly used, it is possible to accept additional orders. Prior to commencing the realization of these orders one should answer the following questions:

1. Do the resources possessed make it possible to realize the orders on time without exceeding the limitations?
2. If the demand for resources exceeds the availability, is it possible to increase the availability of resources (improve the bottleneck)?

Finding bottlenecks and seeking to upsize their availabilities answers the last question. In other words, one should find an answer to the following questions:

How to distribute production orders among alternative routes? What resources should be allocated to jobs to realize the orders on time and without exceeding constraints? This issue is related to following assumptions:

- orders must be realized on time,
- two or more operations cannot be performed at the same time on a given workstation,
- sequence of operations resulting from the technological route must be maintained,
- given operation cannot be started unless the set of their predecessors is completed,
- resources can be used in the defined time only,
- periods of availability of particular resources and their execution cost are known,
- a set of work orders is determined by their volume, duration and cost,
- operation times are known, these times consist of setup time and processing time,
- amount of change-overs is significant,
- production is carried out in conditions of unit and small batches,
- both the amount of resources as well as tasks is considerably large – above 20 × 20.

Such a formulation of the problem serves to emphasize its decision-making nature. So, a feasible variant of a given work order schedule following both the customer’s requirements and the manufacturing system capabilities is searched for.

Solution method

Optimization of the daily production plans is based on two-level division of scheduling and arranging tasks. The first step is scheduling backwards without balancing the resources (Fig. 2). It allows the
system to find bottlenecks. The next step is to focus on the bottlenecks. It is possible to reduce bottlenecks through the exchange of process’ alternatives (see in [18]).

The third step is scheduling backwards with balancing the resources. As a result of this action we receive our daily work plan. The further processing is applied to operation plans from the nearest period in the sets of tasks for the given workstation group – the machine group. The length of the period depends on the production type and on the articles produced. In the examined enterprises, in regard to the conditions of unit and small batch production, the period of processing assumes values from 1 to 5 working days. Tasks of the operational production plan were subject to grouping. As a criterion of grouping the most crucial features from the perspective of changeover time were assumed. After task grouping the group is manufactured without a division into fragmentary tasks. With such an arrangement the preparation-finishing times are shortened.

This results not in the effect of implementing tasks in the first day of the next day round but in the arranged groups round. As a limitation to the assignment to groups the organization parameters were assumed, such as the delivery time, the task priority, customer code and operation release. The assumption of limitation disturbs the schedule of tasks in a way which does not give side effects in the form of lengthening the cycle of some orders – while the effect of aggregation results in a reduction of work consumption mainly on the side of changeovers times. The fact of introducing the positive feed-back into the system leads to fast consideration of disturbance (in plus or minus) in the next day schedule.
The basic element of the above method is defining features of the article which have an impact on the changeover times. The above features are defined from the perspective of workstations and process production operations.

For example, for the varnishing line, the major influence on the changeover time is the colour of the varnished elements. Regardless of shape (which does have an influence on the processing time) if in the set of tasks there are elements painted the same colour...
then the line will not be rearmed. Using the standard construction classifier in this case – where the subject of classification is an element and not the operation can have unwanted effects. The groups would be created for elements of the same kind.

When designing the production process we do not know in what sequence the elements will be made and as a result we assign the full setup time in the base (in PDM or ERP class software). While, if we arranged the tasks properly we could lower the setup times to a greater extent. Preparation setup times cannot be lowered to zero but let us assume that we are able to assess the lowering of setup times for the remaining elements which constitute such a prepared group.

The assignment into the groups is not limited. The basic limitation is the demanded production time. The group cannot consist of too many elements because while performing the tasks for the whole group we perform them faster than is needed and we absorb the resources. Although we shorten work consumption we lengthen the unit production time. We are searching for an optimum in a multi-criterion optimization of the length of cycles, work consumption and production costs. In fact, the process of classification itself has a dynamic character which depends on the organizational conditions. Creating such groups in a manual way would not be useful either, which is why it requires IT support. This method could even be named as semi-automatic one.

Assignment to the similar elements group is based on the criterion of similarity at the level of the production process operation. The criteria are rather static but the given element – and in fact the task of the production process operation, can dynamically belong:

- to different groups in different operations of the production process,
- due to organizational limitations, to different groups fulfilling even the same statistical similarity criteria.

Taking into account the above assumptions a heuristic method of arranging was created and verified by tests in real conditions. The individual steps are presented below and on Fig. 3.

1. Bottleneck searching.
2. Bottleneck reduction (exchange alternatives of production process)
3. Defining parameters of tasks which have an influence on setup times.
4. Defining the influence of features on the arrangement of tasks.
5. Defining the set of tasks subject to arrangement and values for features from the set of tasks.
6. Classification into organizationally similar groups at the level of the production process.
7. Arranging organizationally similar groups in the operational production plan.
8. Calculating time of tasks with consideration given to the arrangement of the created groups.
9. Assignment of tasks to workstations according to the assignment to a group.
10. Verification of the process with registration of the operations.

Step 1 and step 2 were presented in [18] so in this paper the author focused on next steps.

**Methods of classification in GT**

Applied methods of classification so far are applicable mainly in the construction and technology design phase. At the stage of operational management the criteria used in the design phase are insufficient. The most important reasons limiting the use of a standard classification systems include:

1. The subject of classification.
3. Singleness of assigning a code to the element.
4. Assumed features of classification.
5. Existence of variants of the production process.

Ad.1. In each of the mentioned methods the subject of the classification is the element. The criterion of classification is mainly construction features or technological features. The subject of classification should be situated much lower, at the level of production process operations. At this level of classification the criterion of organizational features plays the basic role.

Ad.2. Built on the basis of construction and technological features the classifiers are of stable character, based on features which do not change their value. The change of the parameter value entails a change of construction-technology change and therefore practically a change of the classified object.

Ad.3. In the presented solutions the given element belongs to the group only once. In elements designed in recent years such a scheme is not sufficient. It is connected with using new materials and technologies. The example can be a washer made from plastic. From the designer – mechanic’s point of view it can be used for mechanical connections – as a screw washer. From the point of view of the constructor – electrician the same washer can be used as an insulator. From the above viewpoint, what should the marking look like?

Ad. 4. In static classifiers the organizational features do not play the key role but in the cases of tasks arrangement described it is quite the reverse.
Ad. 5. Very rarely in contemporary production systems are alternative courses created and that is why using one code to mark technologies is insufficient.

Given the potential advantages of the concept and the emergence of the interactive computer, there were described group technology efforts in the late 1970s and early 1980s. As the 1980s unfolded, many of them were abandoned [4]. The problem was that the design or engineering features were the requirements dictated to manufacturing standardization and vice versa. At present, methods of production cause a transference in the classification area from the design part to the area of operating management. A need for the optimization of the work of the bottleneck also exists, which in conditions of unit and small-batch is moving between machines. Only by increasing throughput at the bottleneck process can overall throughput be increased [2].

For this purpose it is possible to use methods of classification and grouping and through the optimization of sequencing tasks on the bottleneck to get reduction of setup times. Classification has automatic (software) and dynamic (organizational conditions are also taken into consideration) character, running in “on line” mode. The above method of classification doesn’t require encoding. The essence of this new approach is shown in Fig. 1., details in Fig. 2.

### Defining parameters of tasks having influence on changeovers times

In the third step we are making a division of position groups into types homogenous in respect of parameters having an influence on changeovers. For each element of the set of machines $M_X = \{m_1, m_2, \ldots, m_n\}$ we will make a choice of parameters having an influence on changeovers times so we will assign $m_1 : \{p_{11}, p_{12}, \ldots, p_{1k}\}$, $m_2 : \{p_{21}, p_{22}, \ldots, p_{22}\}$, $\ldots, m_n : \{p_{n1}, p_{n2}, \ldots, p_{nm}\}$. The assignment of parameters will be insufficient; there should also be taken into account the influence of the above parameter on reducing changeover time. The above parameters will constitute the basic criterion in classification and the creation of groups. The criterion itself can assume static values but membership of the given task to the group will take a dynamic character dependent on the organizational features or limitations used.

Apart from the choice of parameters, limitations should also be introduced in the division into groups. The major limitation in assignment to groups will be the time criterion. Tasks with the distant planned performance deadline can be rejected from a group. In the above way a dynamic classifier is created according to task features at the level of the production process operation which causes, depending on the classification moment, the same element to be classified differently. In one case it can be assigned to a group and in the other it can be rejected.

### Table 1

<table>
<thead>
<tr>
<th>Code of the feature</th>
<th>Kind of the feature</th>
<th>Name of the feature</th>
<th>Rule of receiving data</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>D, O</td>
<td>Identification code of the element</td>
<td>Code of the element from the workshop job</td>
</tr>
<tr>
<td>P2</td>
<td>T</td>
<td>Identification code of the raw material</td>
<td>Material demand (BOM) from ERP software</td>
</tr>
<tr>
<td>P3</td>
<td>T</td>
<td>Material of the same sort</td>
<td>Material demand (BOM) from ERP software</td>
</tr>
<tr>
<td>P4</td>
<td>T</td>
<td>Initial material of the same diameter (for pipes and profiles)</td>
<td>Material demand (BOM) from ERP software</td>
</tr>
<tr>
<td>P5</td>
<td>T</td>
<td>Initial material of the same thickness (for metal sheets)</td>
<td>Material demand (BOM) from ERP software</td>
</tr>
<tr>
<td>P6</td>
<td>U</td>
<td>Colour of painted elements</td>
<td>Configuration of features of the product (from ERP software)</td>
</tr>
<tr>
<td>P7</td>
<td>T</td>
<td>Compatible tools or instrumentations</td>
<td>Code of the tool from the operation of the process</td>
</tr>
<tr>
<td>P8</td>
<td>T</td>
<td>Compatible description of treatments</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P9</td>
<td>T</td>
<td>Temperature of the tool</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P10</td>
<td>D, T</td>
<td>Compatible weight</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P11</td>
<td>D</td>
<td>Compatible surface</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P12</td>
<td>D</td>
<td>Compatible dimensions</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P13</td>
<td>D</td>
<td>Compatible shapes of the surface</td>
<td>PDM or ERP software</td>
</tr>
<tr>
<td>P14</td>
<td>O</td>
<td>Customer to whom the product is addressed</td>
<td>Production order from ERP software</td>
</tr>
<tr>
<td>P15</td>
<td>O</td>
<td>Priority of superior order</td>
<td>Production order from ERP software</td>
</tr>
<tr>
<td>P16</td>
<td>O</td>
<td>Date of delivery</td>
<td>Production order from ERP software</td>
</tr>
<tr>
<td>P17</td>
<td>O</td>
<td>Release the operation (the previous operation was performed)</td>
<td>Registration of the operation from ERP software</td>
</tr>
<tr>
<td>P18</td>
<td>O</td>
<td>Delaying task in the production plan</td>
<td>Schedule from ERP software</td>
</tr>
</tbody>
</table>
The above features have positive, negative or neutral influence. They can be of the design (D), technological (T), organizational (O) and usable (U) kinds (see Table 1).

### Defining the influence of features on the arrangement of tasks

In order to define the influence of features on the tasks arrangement process the matrix of assignment to organizationally similar groups were created for each of these types. In order to do that for each of these groups the dependence on features as well as the kind of influence for this type of connection was defined. Influence means assignment to the organizational group and the method of calculation of changeover time. Kind of assignment from viewpoint of features from P set was defined as: very strongly positive (+++), strongly positive (++), positive (+), neutral (0), negative (-), strongly negative (--), very strongly negative (----), excluding assignment (----). In the above method the changeover time is practically calculated again.

For illustrating the method an example of an injection moulding machine and varnish operations were chosen. Findings were shown in Table 2.

<table>
<thead>
<tr>
<th>Type of the group</th>
<th>Code of the feature</th>
<th>Kind of the assignment</th>
<th>Method of calculating the setup time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>P1</td>
<td>+++</td>
<td>According to biggest setup time for 1st element. Setup = 0 for 2nd and next element from the group.</td>
<td>The full compatibility of coding the element always has a very strong positive influence. If the next task is identical i.e., an identical code of the element then setup for the next task will equal zero.</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>+++</td>
<td>If an exchange of material follows setup = setup + 2 hours, if not – setup time = 0. It is fundamental criterion of the assignment to the group.</td>
<td>Compatible initial material for the injection moulding machine means the lack of the need to empty the storage container. If a central delivery system for the raw material (of pellets) does not exist – the time of changeover is very long. Additional losses of material connected with cleaning the storage container appear.</td>
</tr>
<tr>
<td></td>
<td>P7</td>
<td>++</td>
<td>If an exchange of the form setup = setup + 0.5 h. If tool (form) was in an unheated room then we should add a time for heating the form from the temperature of the unheated room to the temperature of the surroundings (up to 0.5 h). It will be the second criteria of assignment into the group.</td>
<td>The exchange of the form is connected with a need to heat the form to a temperature of 40°C, and with making test series 3–10 pieces. Material and execution time of the test series losses occur.</td>
</tr>
<tr>
<td></td>
<td>P9</td>
<td>++</td>
<td>Setup = 0.5 h for the cold machine. If is appearing P7 then setup time equals setup time for P7.</td>
<td>The machine at the beginning of every shift requires heating. The time of heating the machine equals about 0.5 h. From this point of view it is more efficient to exchange forms at the beginning of every shift.</td>
</tr>
<tr>
<td></td>
<td>P12</td>
<td>+</td>
<td>0,1 h</td>
<td>Very divergent dimensions can have an influence on the additional equipment of a workstation which can require changeover time.</td>
</tr>
<tr>
<td></td>
<td>P20</td>
<td>--, ----</td>
<td>Parameters from P20 to P23 are limitations of the assignment to the group. P20 is suggesting not to arrange elements into groups with divergent priorities of orders. For P20 we will accept the divergence above 2 days as expulsion from the group.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P21</td>
<td>--, ----</td>
<td>The due date scheduled in the plan will be a basic parameter dividing organizationally similar groups – we will accept that if the due date of assignments to the group is above x working days, the next groups are created. In the computer program it will be an input parameter for forming a group e.g. for creating clusters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P22</td>
<td>–</td>
<td>Release of the operation is one of elements limiting the formation of a group. If the earlier operation wasn’t released in practical conditions then performing the task is impossible. On the basis of this parameter a conditional assignment to the group appears.</td>
<td></td>
</tr>
</tbody>
</table>
Recalculation of setup times

Complete time of task \( Id_i \) on machine \( j \)-\( F_{Id,j} \)

\[
F_{Id,j} = F_{setupId,j} + F_{workId,j},
\]

where \( F_{workId,j} \) – process time of task \( Id_i \) on \( j \) machine, \( F_{setupId,j} \) – setup time of task \( Id_i \) on \( j \) machine, \( F_{Id,j} \) – complete time of task \( Id_i \) on \( j \) machine.

If the tasks have not been arranged and the organizationally similar groups have not been created then total duration time on \( m \) machine:

\[
F_j = \sum_{i=1}^{n} F_{Id,i,j}.
\]

In the case of creating groups: If \( F_{Ok} \) means the total duration time of group

\[
O_k \quad \text{and} \quad O_k : \{Id_i, Id_{i+1},...Id_n\},
\]

then finally task duration time is:

\[
F_{Ok} < \sum_{i=1}^{n} F_{Id,i}, \quad (3)
\]

The \( F_{Ok} \) is calculated according to one of 3 equations:

In case of recalculating of setup times:

\[
F_{Ok} = f_{setupOk}(p_1,p_2,...p_l) + \sum_{i=1}^{n} F_{workId,i}, \quad (4)
\]

where \( f_{setupOk}(p_1,p_2,...p_l) \) is a function of the recalculation of setup times for the group \( O_k \), dependent on the set of parameters \( \{p_1,p_2,...p_l\} \) of the machines.

Total time for set of jobs on \( j \) machine \( F_j \) is calculated as:

\[
F_j = \sum_{k=1}^{l} F_{Ok} = \sum_{k=1}^{l} (f_{setupOk}(p_1,p_2,...p_l)) + \sum_{i=1}^{n} F_{workId,i,k}. \quad (5)
\]

1. In case of accepting of the largest time of setup from all tasks as the setup for the group:

\[
F_{Ok} = \max_{1\leq i \leq n} F_{setupId,i} + \sum_{i=1}^{n} F_{workId,i}. \quad (6)
\]

Total time for set of jobs on \( j \) machine \( (F_j) \) is calculated as:

\[
F_j = \sum_{k=1}^{l} F_{Ok} = \sum_{k=1}^{l} (\max_{1\leq i \leq n} F_{setupId,i,k} + \sum_{i=1}^{n} F_{workId,i,k}). \quad (7)
\]

2. In case of accepting of modified (increased) the largest time of setup from all tasks as the setup for the group:

\[
F_{Ok} = \max_{1\leq i \leq n} F_{setupId,i} + \sum_{i=1}^{n} F_{workId,i}, \quad (8)
\]

where \( \varepsilon_i \) is the rate of increasing the largest setup time for \( j \) machine. \( \varepsilon_i \) is calculated on the basis of data from the knowledge base of the expert system.

Total time for setup of jobs on \( j \) machine \( (F_j) \) is calculated as:

\[
F_j = \sum_{k=1}^{l} F_{Ok} = \sum_{k=1}^{l} \left( \max_{1\leq i \leq n} F_{setupId,k,i} \varepsilon_i + \sum_{i=1}^{n} F_{workId,k,i} \right). \quad (9)
\]

Defining the set of tasks for assignment purpose

For the definition of the set of tasks for assignment purposes a standard ERP system function was used – “backward scheduling” without limitations. After performing the scheduling function in the set of tasks the planned terms were defined and recorded on the list. Tasks were narrowed to groups of machines having bottlenecks. The most interesting groups were formed by tasks of the first week on the list. In conditions of changeable operational production plans the consideration of the subsequent weeks is pointless. In order to increase the productivity of calculations the task list has been narrowed to the few first weeks.

Classification into organizationally similar groups at the level of production process operations

This step is a key one in the whole method. There are possible different classification scenarios. For classification into organizationally similar groups the author applied a method consisting of three stages (see Fig. 4):

1. Pattern classification – according to the main criterion.
2. Cluster analysis – according to criterion of secondary importance.
3. Final grouping – according to additional constraints.
Pattern classification

Prototype classifiers are a type of pattern classifiers, whereby a number of prototypes are designed for each class so as they act as representatives of the class patterns. Prototype classifiers are considered among the simplest and best performers in classification problems. However, they need careful positioning to form groups [19]. Formally, the problem can be stated as follows: given training data \( \{(x_1, y_1), \ldots, (x_n, y_n)\} \), produce a classifier \( h : X \rightarrow Y \) that maps any object \( x \in X \) to its true classification label \( y \in Y \). Sets \( O_1, O_2, \ldots, O_m \) where \( O_i = \{Id_1, Id_2, \ldots, Id_z\} \) have separate character and \( O_i \subseteq O, U_iO_i = 0, \) for \( \forall i, k \in Id \) condition \( O_i \cap O_k = \emptyset \) is satisfied. The assignment of elements’ set \( Id_i \) to the set of groups \( O_k \) is a function dependent on parameters \( P: \{Id_i \in O_k : F(p)\} \).

Set \( O \) was divided into as many classes as many labels were \( y_i \in \{1, 2, \ldots, g\} \) created, where the label is unique value of parameter having the strong influence on setup time.

In the case of the laser cutter, the parameter \( P2 \) was the strongest influence on setup time. A number of created groups was equal to the distinct value of parameter \( P2 \) appearing in a set of tasks. In the case of the injection moulding machine two parameters appeared: \( P2 \) and \( P1 \). The number of created groups were equal to the unique and not empty value of cartesian set \( P1 \) and \( P2 \).

Example of classification for tasks of the laser cutter

For the laser cutter tasks were considered over a 3 period of time from 09.02.09 to 27.02.09. A set of tasks embraced 373 positions of the operation of cutting with the laser. Cutting took place in this quite wide period of time for 296 different products (parameter \( P1 \)). For the production products 56 different kinds of metal sheet were required (parameter \( P2 \)). The model for creating the classification was developed on the basis of the parameter \( P2 \). The label of classification was the unique value of parameter \( P2 \). 56 groups were created, assigning every task to it (see Fig. 5).

Demonstration group \( O_{11} \) marked with the bold line (Fig. 5) consisted of 18 objectives:

\[
O_{11} = \{Id_1, Id_3, Id_7, Id_{27}, Id_{39}, Id_{44}, Id_{46}, Id_{48}, Id_{73}, Id_{74}, Id_{79}, Id_{80}, Id_{85}, Id_{114}, Id_{199}, Id_{244}, Id_{297}, Id_{299}\}
\]
The second stage of classification
– cluster analysis

Cluster analysis includes a broad suite of techniques designed to find groups of similar items within a data set. Partitioning methods divide the data set into a number of groups predetermined by the user. Data clustering is used in several data applications, including among others, image classification, document retrieval and customer segmentation. Clustering algorithms generally follow hierarchical or partition approaches [20].

Hierarchical cluster methods produce a hierarchy of clusters from small clusters of very similar items to large clusters that include more dissimilar items. Hierarchical methods usually produce a graphical output known as a dendrogram or tree that shows this hierarchical clustering structure. Some hierarchical methods are divisive, that is progressively divide the one large cluster comprising all of the data into two smaller clusters and repeat this process until all clusters have been divided [7]. Other hierarchical methods are agglomerative and work in the opposite direction by first finding the clusters of the most similar items and progressively adding less similar items until all items have been included into a single large cluster [7]. For the partition approach the k-means and its variants, are the most popular algorithms [21].

Partition clustering algorithms require a large number of computations of distance or similarity measures among data records and clusters centers, which can be very time consuming for very large data bases. Moreover, partition clustering algorithms generally require the number of clusters as an input parameter. However, the number of clusters is usually an unknown priori, so the algorithm must be executed many times, each for a different number of clusters and it uses a validation index to define the
optimal number of clusters. In the case of forming organizationally similar groups calculating the amount of groups is possible.

At this stage of classification a subdivision of groups based on subgroups is shown:

The sets $O_{ix}$ were formed:

$$∀ i \in \{1, 2, \ldots, m\} \quad O_i = \{O_{i1}, O_{i2}, \ldots, O_{ip}\}$$

where $O_{ix} = \{Id_{x1}, Id_{x2}, \ldots, Id_{xz}\}$.

Groups have separate character:

$$O_{ix} \subseteq O_i, \quad O_i \subseteq O, \quad \text{and} \quad U_{ix}O_{ix} = O_i, \quad U_iO_i = O,$$

where $∀ i, k \in Id$ conditions are satisfied:

$$O_i \cap O_k = \emptyset, \quad ∀ i, k \in Id, \quad O_{ix} \cap O_{kx}.$$  

The assignment of elements’ set $Id_i$ to the set of groups $O_{ix}$ is a function dependent on parameters $P : \{Id_{ix} \in O_{ix} : F(p)\}$. At this stage of classification organizational parameters: $P20, P21, P22, P23$ played an important role (see Table 1).

Clustering aims to find useful groups of objects (clusters), where usefulness is defined by the goals of the data analysis.

An entire collection of clusters is commonly referred as a clustering. There are various types of clustering distinguished: hierarchical (nested) versus partition (unnested), exclusive versus overlapping versus fuzzy, and complete versus partial. For a solution to the problem of second stage of classification-a k-means technique was used. K-means is a prototype-based, partition clustering technique that attempts to find a user-specified number of clusters $(K)$, which are represented by their centroids. The K-means clustering technique is simple and this is why it is so useful. Its basic algorithm is presented on Fig. 6. The important factor for the quality of groups is in choosing $K$. The first initial centroid $(K)$ is a user specified parameter, namely, the number of clusters desired. Each point is then assigned to the closest centroid, and each collection of points assigned to the centroid is a cluster (see Fig. 6).

In the first step, points are assigned to the initial centroids. After points are assigned to a centroid, the centroid is then updated. In the second step, points are assigned to the updated centroid, and the centroids are updated again until centroids do not change or max iteration is achieved. Because most convergences occurs in the early steps, the condition at line 5 (see Fig. 6) is often replaced by a weak condition, e.g. repeat until only 1% of the points change clusters. Another way to avoid computing many of the similarities is using bisecting K-means algorithm. A third way for group forming is fuzzy logic [22].

**Basic algorithm K-means**

1: Select $K$ points of initial centroid, max_iterations.
2: repeat
3: Form $K$ clusters by assigning each point to its closest center.
4: Recompute the centroid of each cluster.
5: until Centroids do not change or iteration > max_iterations.

**Fig. 6. Basic algorithm K-means.**

**Example**

Considering further a set of tasks from Fig. 5, it means group with parameters $P20, P21, P22, P23$ we would received the data shown in Table 4.

**Table 4**

<table>
<thead>
<tr>
<th>TASK ID</th>
<th>GROUP ID</th>
<th>SUBGROUP ID</th>
<th>$P20$</th>
<th>$P21$</th>
<th>$P22$</th>
<th>$P23$</th>
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<td>0.667</td>
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<td>1.20</td>
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<td>1.000</td>
<td>1.70</td>
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<td>114.198</td>
<td>0.050</td>
<td>1.10</td>
</tr>
</tbody>
</table>
Amount of clusters (K-parameter)

The decision about the amount of clusters is being undertaken based on the following assumptions: the machine works in a one shift system. The working day consists of 8 hours. A parameter $P_{21}$ is a feature strongly influencing the formation of the groups. As the initial $K$ for creating the clusters a heuristic formula is accepted:

\[
\text{If } \max(P_{21}(I_{di})) - \min(P_{21}(I_{di})) > 1 \text{ then new clusters are formed.}
\]

Assuming, that for every of groups:

\[
\forall i \in \{1, 2, \ldots, m\} K_i = \text{int}(\max(P_{21}(I_{di})) - \min(P_{21}(I_{di}))),
\]

where the amount of clusters is indicating $K_i$ we receive the required initial amount of clusters. As the result of a calculation of the division we receive subgroups (see Fig. 7).

Assigning points to the closest centroid

To assign a point to the closest centroid, a proximity measure that quantifies the notion of closest similarity for the specific data under consideration is required. Euclidean distance is often used for this data point. Distance between two objects $D(i, j)$ or between centres of clusters $X_{ik}$ and $X_{jk}$ is calculated on the basis of the formula:

\[
D(i, j) = \sqrt{\frac{1}{M} \sum_{k=1}^{M} (X_{ik} - X_{jk})^2},
\]

where $M$ is a number of variables (space dimensions).

Final grouping

The first two stages consisted in creating groups and subgroups, for which classification took place according to the similarity of technological parameters $P2$-$P16$ strongly influencing grouping (e.g. in the case of the laser cutter – equal value of the index of the raw material $P2$) at preserving organizational limitations ($P20$-$P23$). The next phase of forming groups was final grouping.

Final grouping took place based on the results of the first phases. Additional conditions for the moving of elements between subgroups were taken into consideration. It wasn’t possible to carry the above task out in step 2 because the parameters limiting grouping were of an organizational nature.

In this phase, we moved tasks within neighboring subgroups verifying the results of grouping with additional limitations. For all groups, where these subgroups appeared at the front of the queues, where then analyzed, i.e. a decision on which tasks should be made first.

Subgroups which were in the previous phase were marked with initial numbers $O_k, O_{(k+1), 1}$. The final grouping was calculated according to the formula:

\[
\forall k \forall i \; Id_i \in O_{k, 2}:
\]

\[
\left\{
\begin{array}{ll}
\text{if } f(Pa) \text{ is true} & \text{then } Id_i \in O_{k, 1} \\
\text{if } f(Pa) \text{ is false} & \text{then } Id_i \in O_{k, 2}
\end{array}
\right.
\]

Not for all machines applying the 3rd stage is this necessary.

What’s more, a lack of underlying data in the classical structure given of an ERP package can cause additional problems for the classification. Often in order to make this stage extending the dataset for parameters is necessary for the above analysis to follow. As the result of a calculation of the above phase even entire clusters can disappear. Subgroups can be assimilated in the subgroup about the preceding index.
lowering the times of rearming connected with the positioning of the metal sheet. Findings were shown on Fig. 8.

As a result of the application of the algorithm all elements from $O_{11,2}$, $O_{11,3}$ subgroups and part of the elements from subgroup $O_{11,4}$ were moved to the $O_{11,1}$ subgroup.

Conclusions

The method which has been introduced in this paper gives more possibilities in the area of profitability of IT projects in the future. This approach seems to be an excellent tool for a decision making model for SMEs. In consequence, this method can be an alternative for expensive and hardly implemented scheduling methods. Constrained-based scheduling with dynamic classification are efficient tools for solving real-life scheduling problem in an “on line” mode.

The method is effective when the following conditions are met:

- preparation of the knowledge base with special attention to the availability of data from the point of view of features having influence on changeovers times and task parameter data bases,
- principles of dynamic creation of organizationally similar groups,
- cyclical (daily) classifications of tasks into organizationally similar groups,
- process support with the use of IT software.

The data from ERP systems and additional software applications allow the automatic creation of the groups in real production systems in SMEs.

References


