dynamic classification,operational production plan, scheduling, unit and small batch production,

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OPTIMIZATION OF TASKS IN AN OPERATIONAL PRODUCTION PLAN IN CONDITIONS OF UNIT AND SMALL BATCH PRODUCTION

Abstract

In conditions of unit and small batch production a very important role is played by time of product availability for the customer. Despite using modern management techniques setup time still play an important role in the production cycle time. In the examined companies the relation between rearmament times to processing times is still high. The above researches inspired the author to prepare the method of setup times' reduction through proper arrangement of tasks in the operational production plan. Optimization of the daily production plans is based on two-level division of scheduling and arranging tasks. To counterbalance fluctuations and inaccuracy of operational planning it is necessary to introduce the positive feed-back into the system in a form of registering of operations implementation.

1. INTRODUCTION

In contemporary systems of the production very important role is played by time of product availability for the customer In principle this kind of production is more expensive than the mass one, therefore flexibility, short series, uniqueness of the product as well as shortening of the production cycle determine the competitiveness of this kind of production. The production cycle consists of, among others: the processing time and times of rearmament. Despite using modern management techniques e.g. SMED technique in the conditions of unit production in SME, times of rearmament still play an important role in the production cycle time. In the examined companies of the SME sector the relation between rearmament times to processing times is still high and amounts from a few to several per cent of the processing time.

The above researches inspired the author to prepare the method of rearmament times' reduction through proper arrangement of tasks in the operational production plan. In order to do that the notion of a classifier of a new kind was introduced – the classifier working at the level of task of production process operation. The task of the classifier is to aggregate tasks into organizationally similar groups which allow for implementation of tasks within the group: in sequences, without

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rearmament or by significantly shortening the above process. The above classification is based on features of tasks having influence on rearmament times and optimization of tasks arrangement. Using standardized classifiers for this purpose is not sufficient and in some cases can be harmful..

2. CURRENTLY USED METHODS OF CLASSIFICATION ACCORDING TO CONSTRUCTION FEATURES AND PRODUCTION PROCESS PARAMETERS

So far the subject of classification itself was the machines' elements. Widely used are symbols which serve two basis functions: *classification* and *identification.* After using unambiguous system of signs we can ensure identification of the marked element. *Classification* symbol is a symbol which is used to assign the given object to a certain group (class), created according to given criteria. On the other hand, an *identification* symbol is a symbol which is used to unequivocally and faultlessly recognize, define or name the given object. In majority of used symbols both segments appear simultaneously.

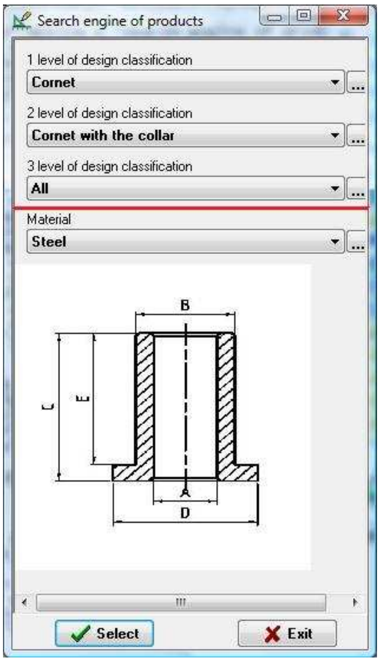

Fig. 1. Classification according to design features

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. One of them is the scheme proposed by Henry Opitz at the Technical University in Aachen. The system is based on nine-place, decimal hexagonal code. Positions from 1 to 5 describe the geometry of the element and constitutive solids creating its shape. Positions from 6 to 9 describe features concerning technology. This system also provides for possibility of expanding the code by four additional positions whose significance can be defined by the user.

Currently classification and coding of produced articles and elements is based on static systems of classification. Numerical plans are built in such a way that the code of the article depends on its unchangeable features, most often construction or technological features. Using this type of classification is useful at the stage of designing the construction and technology in order to find the elements similar in respect of construction and technology. It is also important at the stage of designing the group processing technology. Currently used are applications supporting the designing process based on the construction classification rules [Guni, 2006]. Their usefulness is however not extensive from the point of view of arranging tasks in the operational production plan.

The above methods of classification are applicable mainly in the construction and technology design phase. At the stage of production the criteria used in the design phase are insufficient. The most important reasons limiting the use of standard classification systems include:

1) the subject of classification,
2) stability of coding,
3) singleness of assigning a code to the element,
4) assumed features of classification,
5) existence of variants of the production process.

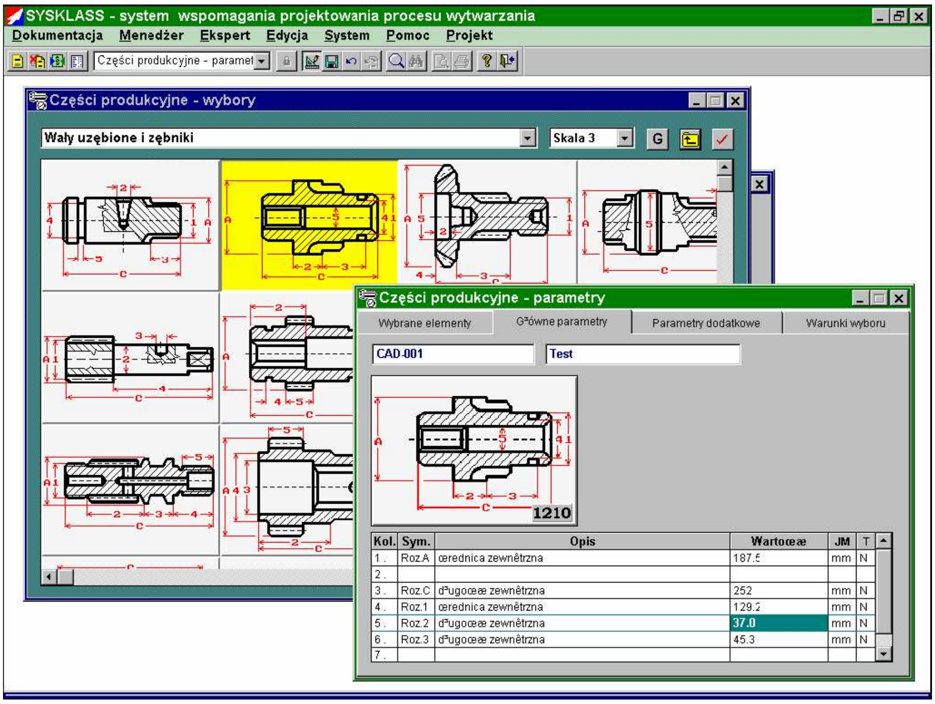

Fig. 2. Implementation of the classification according to design features in SYSKLASS software. [Guni,2006].

Ad.1. In each of the mentioned methods the subject of the classification itself is the element. The criterion of classification is mainly construction features and only later technological features. The subject of classification should be situated much lower – at the level of production process operations. At this level of classification criterion the organizational features play 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 parameters 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. In view of the above, what should the marking look like? Definitely, from the point of view of marking, these should not be two different elements. The solution is the proposed multiple assignment of one element to many groups.

Ad. 4. In static classifiers the organizational features do not play the key role but in the cases of tasks arrangement described below it is quite the reverse.

Ad. 5. Very rarely in contemporary production systems do we not use alternative routes and that is why using one code to mark technologies is not sufficient.

3. OPTIMIZATION OF REARMAMENT TIMES

Optimization of the daily production plans is based on two-level division of scheduling and arranging tasks (see fig. 3). The first step is scheduling backwards with balancing of resources. As a result of this action we receive our daily work plan. Using the 2^{nd} degree–optimization the daily work plan is further processed. The further processing is applied to operation plans from the nearest period in the round of tasks for the given workstation group – the production nest. The length of the period depends on the production type and on the articles produced. In conditions of unit and low-serial 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 rearmament times were assumed. After tasks grouping the group is manufactured without a division into fragmentary tasks. With such an arrangement the preparation-finishing times are shortened. This results 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, operation release. Assumption of limitation disturbs the schedule of tasks in a way which does not give(results in) side effects in the form of lengthening the cycle of some orders – while the effect of aggregation results in reduction of work consumption mainly on the side of rearmament times. The fact of introducing the positive feed-back into the system leads to fast consideration of disturbance (in plus or in minus) in the next day schedule.

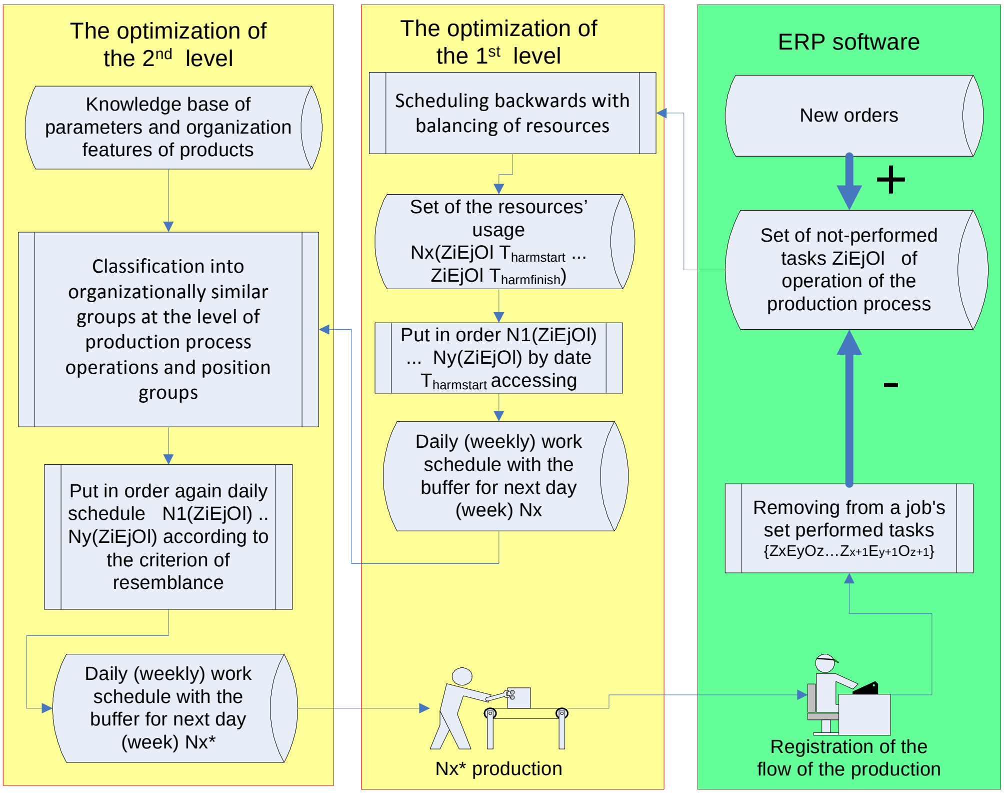

Fig. 3. Scheme of optimization of the daily production plans

The basic element of the above method is defining features of the article which have impact on the rearmament times. The above features are defined from the perspective of workstation of groups and process production operations. For example for the varnishing line the major influence on the rearmament times is the colour of the varnished elements. Regardless of shape (which does have influence on processing time) if in the round of tasks there are elements painted the same colour then the line will not be rearmed. Using 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 –while from the point of view of the painting operation the variety is more welcome. Thanks to variety you can place more elements, but painted the same colour, in the varnishing cabin. Instead of creating groups according to the completeness of the whole task (by steering the parameter of agreement of elements receiver) groups whose usefulness in arrangement would be insignificant or even harmful were created.

Another example can be work on laser cutter. In this case the preparation-finishing time is influenced by thickness of the sheet metal of which the elements are cut. If we arrange different elements of the same thickness on the sheet then regardless of the dimensions we will not exchange the input material and in this way we will not absorb the rearmament time. For the welding operation the preparation –finishing times will be influenced by instrumentation. Very often different elements are manufactured with the use of the same equipment and as a result the arrangement on the position taking into account the same equipment will shorten the work consumption. The next example can refer to the operation of thermo-forming. The rearmament time will be influenced by the temperature of the form. Keeping the form in non-heated warehouse the rearmament time is mainly influenced by the weather since the form has to be warmed before processing. By arranging the tasks properly we can get to know their terms and in this way shorten the time of the form warming.

Designing the production process we do not know in what sequence the elements will be made and as a result we assign the full time TPF (preparation-finishing time) in the technological preparation base, while if we arranged the tasks properly we could lower the times to a great extent. Preparation–finishing times cannot be lowered to zero but let us assume that we are able to asses the lowering of tpf for the remaining elements which constitute so prepared group.

Membership in the group is not limited. The basic limitation is the demanded production time. The group cannot be joined by too many elements because while performing the tasks for the whole group we perform them too fast than it 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 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 of such groups in a manual way would not be useful either, that is why it requires IT support. We could even risk assigning the attribute to the method: automatic.

Membership in the similar elements group is based on the criterion of similarity at the level of 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 have been presented below:

Step 1. Defining the workstation groups with high rearmament times.

Step 2. Defining parameters of tasks which have influence on rearmament times.

Step 3. Defining the influence of features on arrangement of tasks.

Step 4. Defining the set of tasks subject to arrangement and values for features from the set of tasks.

Step 5. Classification into organizational groups similar at the level of production process operation and workstations group.

Step 6. Arranging organizationally similar groups in the operational production plan.

Step 7. Calculating time of tasks with consideration of arrangement of the created groups.

Step 8. Assignment of tasks to workstations according to the membership in a group.

Step 9. Verification of the process with registration of the operation.

3.1. Defining workstations groups with long rearmament times

In contemporary systems of the production very important role is played by time of product availability for the customer In principle this kind of production is more expensive than the mass one, therefore flexibility, short series, uniqueness of the product as well as shortening of the production cycle determine the competitiveness of this kind of production. The production cycle consists of, among others: the processing time and times of rearmament. Despite using modern management techniques e.g. SMED technique in the conditions of unit production in SME, times of rearmament still play an important role in the production cycle time. In the examined companies of the SME sector the relation between rearmament times to processing times is still high and amounts from a few to several per cent of the processing time.

Generally it can be said that all workstation groups should be taken into account. There are two premises which resulted in lack of such conduct:

- effectivity of calculation process,
- division (separation) of tasks into different workstations.

Crucial role for the calculation process is played by the number of tasks taken into account. If we decrease the number of workstation groups taken into account and thus the number of tasks, then doubtlessly the effectiveness of calculation process will be bigger.

The second reason is more important than the first one. It touches upon the problem of tasks division. In majority of used methods of arrangement the principle of non-division of tasks is used. This method broke with this principle due to contemporary requirements concerning shortening of production cycles. One of the methods of shortening the length of the task cycle is the division of a task with high work consumption into several partial tasks and assignment of each of divided tasks to separate workstations. Usually the work consumption is lengthened by the sum of rearmament times of the divided tasks but the cycle is shortened. The method has limitations connected with availability at the same time of appropriate number of equipment and the number of workstations and organization of production documentation flow. The basic question concerned the border where the rearmament time is regarded as high? Should we define the border as deterministic value or as a relation of a sum of rearmament time to the sum of processing or the average rearmaments time falling on the production series? Answers to these questions were given by carrying out tests on real data. In order to give the answer to a question which of the above workstations have a high rearmament time a simple analysis of Pareto-Lorentz was carried out. According to the rule 20/80 groups of workstations having high deterministic rearmament values, high *setup time/processing time* as well as average rearmament time was split off into a separate group.

Let M = $\{m_1, m_2, \ldots m_n\}$,means a set of all machines,

M_x - means a set of machines with high rearmament times in timeperiod τ ,

M_{det} - means a set of machines with high deterministic rearmament times in time period τ,

M_{prop} - means a set of machines with high percentage rearmament times in time period τ ,

$\overline{M}$ - means a set of machines with average rearmament times in the time period τ.

Set M_x is defined as a sum of sets:

$$M_x = M_{det} \cup M_{prop} \cup \overline{M}$$

3.2. Defining parameters of tasks having influence on rearmament times

In the first step we are making a division of workstation groups into types homogenous in respect of parameters having influence on rearmaments. For each element of the set of machines $M_X = \{m_1, m_2, \dots m_n\}$ we will make a choice of parameters having influence on rearmament times so we will assign $m_1:\{p_{11},p_{12},..p_{1k}\}$, $m_2:\{p_{21},p_{22},..p_{2l}\}$, …, $m_n:\{p_{n1},p_{n2},..p_{nm}\}$. The assignment of parameters itself will not be sufficient; there should also be influence of the above parameter on reducing rearmament time given. The above influence will be hard to define in the zero-one logic thus principles of blurred logic were used. The above parameters will constitute the basic criterion in classification and creating 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 to membership in a group will be the time criterion. Tasks with the planned performance deadline distant from the first task performance deadline can be rejected from the membership in a group. In the above way a dynamic classifier is created according to task features at the level of production process operation which causes that depending on the classification moment the same element can be classified differently. In one case it can be assigned to a group and in the other it can be rejected.

For the purpose of illustration of the above rules an example was used. The above example is executed on real data of enterprise A.

Example.

In the example all 174 groups of machines participating in the realization of the operation production plan were analysed. Table 1 is demonstrating the set of machines included in a M_x .

Tab. 1. Set of machines included in a M_x .

Code of the group	**Determin. setup time**	**Proportion. setup time**	**Average setup time**	**Name**
ASSM	yes	yes	yes	Assembly
YENV	yes	yes	yes	Drill and milling CNC machine type 1

YENV1	yes	yes	yes	Drill and milling CNC machine type 2
YENV2	yes	yes	yes	Drill and milling CNC machine type 3 (5 axial)
YZSP	yes	yes	yes	Workstation for cleaning welds
UMUW	yes	yes	yes	Milling machine type 1
UMGW	yes	yes	yes	Milling machine type 2
ULUV	yes	yes	yes	Chain mortiser to grooves
WTRY	yes	yes	yes	Hydraulic injection moulding machine
UOJA	yes	yes	yes	Device for covering – type 1
UPMR	yes	yes	no	Sawing machine type 1
UPMRM	yes	yes	no	Sawing machine type 2
UPVAL	yes	yes	no	Circular saw to aluminium profiles
UPVS	yes	yes	no	Band sawdust
USGR	yes	yes	no	Planer type 1
USVS	yes	yes	no	Planer type 2
UWPZ	yes	yes	no	Horizontal drill
UWSPY	yes	yes	no	Special drill type 1
UWWW	yes	no	yes	Drill
MRNS	yes	no	yes	Gate milling machine CNC
GRAV	yes	no	yes	Device for blunting the edge in flat elements
GVRP	yes	no	yes	3 roller bender
GVRR	yes	no	yes	Tube bender
GVRR1	yes	no	yes	Tube bender CNC
HARV	yes	no	yes	Machines for the heat processing
KRU2	yes	no	yes	Parity drill
LLAK	no	yes	yes	Line for powder varnishing
LOSS	no	yes	yes	Stream-oriented cleaner line
LSRW2	no	yes	yes	Laser cutter for pipes and profiles
MJKY	no	yes	yes	Pressure flannel
PAUV	no	no	yes	Machine for the cut, blunting the edge and washing
PHU2	no	no	yes	Pneumatic press type 1
PHU3	no	no	yes	Pneumatic press type 2
PHU4	no	no	yes	Pneumatic press type 3
PLKY	no	no	yes	Workstations for varnish works
PMS2	no	no	yes	Eccentric press type 1
PMS3	no	no	yes	Eccentric press type 2
PVRY	no	no	yes	Eccentric press type 3
PUSP	no	no	yes	Workstation of foamed polyurethanes
SLUV	no	no	yes	Workstation for hard soldering
SMIA	no	no	yes	Workstation for the welding type 1
SMIG1	no	no	yes	Workstation for the welding type 2
SROB	no	no	yes	Welding robot type 1

SROB1	no	no	yes	Welding robot type 2
SROBU	no	no	yes	Welding robot type 3
SROBM	no	no	yes	Welding robot type 4
SVIG1	no	no	yes	Workstation for the welding type 3
SVIG2	no	no	yes	Workstation for the welding type 4
SZBZ	no	no	yes	Grinder type 1
SZPL	no	no	yes	Grinder type 2
VKNM2	no	no	yes	Lathe CNC (2-axial with the feeder)
VKNM3	no	no	yes	Lathe CNC (2-axial without the feeder)
VKP2	no	no	yes	Toolmaker's lathe
VPVS	no	no	yes	Band sawdust for the cut of foam
VRMM1	no	no	yes	Workstation for vacuum thermoforming
WANN	no	no	yes	Workstation for washing steel profiles
WAUV	no	no	yes	Machine for drilling with the feeder CNC
WIBK	no	no	yes	Cleaner
WNMR	no	no	yes	Numerically controlled drill
WVMR	no	no	yes	Machine for drilling and milling - horizontal
WVMR1	no	no	yes	Machine for drilling and milling - vertical
UPVR	no	no	yes	Circular saw
UWSV	no	no	yes	Bench drill
MRPN	no	no	yes	Vertical milling machine
MRPZ	no	no	yes	Horizontal milling machine

From the above group those groups of workstations were separated for which there occurred the condition of significant share of rearmaments time in the tasks duration time. As clearly can be seen in this example, there are certain groups of workstations homogenous from the point of view of dependence on parameters having influence on rearmaments. Each of the groups can be considered separately but it would be more convenient to create types of homogenous groups. The classification criterion for the types would be homogenous dependence of features having influence on rearmaments. On the other hand, a practical solution would be to build a set – matrices of features and assigning them to proper groups of workstations. After adding features of processing principles to the matrices (e.g. defining the way of acquiring data from the ERP class system, or rules of collecting data from other sources) the matrix of features would constitute some kind of universal advisory system. After aggregation of groups of machines into types and assigning matrices of features to them the principles of classification were defined which were the most difficult part in putting the method into practice.

3.3. Defining features on arrangement of tasks

Let $P=\{p_1,p_2,\dots p_n\}$ signifies the set of features important from the point of view of classification. What elements can belong to the above set ?. From examinations of production practice of the selected company A appropriate features were isolated. The above features have positive, negative or neutral influence. They can be of the construction (design) kind (D), technological kind (T), organizational (O) and usable (U) kind. (see tab. 2).

Tab. 2. Set of features important from the point of view of classification

Code of the feature	**Kind of the feature**	**Name of the feature**	**Rule of receiving data**
P1	D, O	Identical code of the element	Code of the element from the workshop job
P2	T	Identical code of the raw material	Material demand (BOM) from ERP software
P3	T	Material of the same species	Material demand (BOM) from ERP software
P4	T	Initial material of the same diameter (for pipes and profiles)	Material demand (BOM) from ERP software
P5	T	Initial material of the same thickness (for metal sheets)	Material demand (BOM) from ERP software
P6	U	Colour of painted elements	Configurer of features of the product (from ERP software)
P7	T	Agreeable tools or instrumentations	Code of the tool from the operation of the process
P8	T	Unanimous description of treatments	PDM documentation (ERP software)
P9	T	Temperature of the tool	No measures in ERP software
P10	D, T	Weight moved close	PDM documentation (ERP software)
P11	D	Surface moved close	PDM documentation (ERP software)
P12	D	Dimensions moved close	PDM documentation (ERP software)
P13	D	Shapes of the surface moved close	PDM documentation (ERP software)
P14	O	Customer to whom the product is being addressed	Production order from ERP software
P20	O	Priority of superior order	Production order from ERP software
P21	O	Date of delivery	Schedule from ERP software
P22	O	Freeing the operation (the previous operation was performed)	Registration of the operation from ERP software
P23	O	Delaying task in the production plan	Schedule from ERP software

3.4. Defining the influence of features on arrangement of tasks

In order to define the influence of features on the tasks arrangement process the matrix of membership in organizationally similar groups were created for each of these kinds. In order to do that from each of these groups the dependence on features was defined and kind of influence for this type of connection was defined – influence meant assignment to the organizational group and the method of calculation of rearmament time for so created organizational group (organizationally similar).

Kinds of assignment with a view to features from P set was defined as:

- very strongly positive (+++),
- strongly positive (++),
- positive (+),
- neutral (0),
- negative (-)
- strongly negative (--),
- very strongly negative (---),
- excluding membership (----).

In the above method the rearmement time is practially calculated again. In order to calculate the rearmament time again the following kinds of methods were selected:

- declared directly for the organizationally similar group,
- according to the highest rearmament time from the group tasks set,
- percentage decrease by a given indicator of all elements

3.5. Defining homogeneous types of groups of machines

Since, many of groups of machines is similar depending on features it is possible to define homogeneous groups. So, next homogeneous types of groups of machines were determined. Table 3 is presenting results of above action.

Tab. 3. Homogeneous types of groups of machines (fragment).

Type of group	Code of group	Name of machines
1	UPVAL	Circular saw to aluminium profiles
1	GVRP	3 roller bender
1	GVRR	Tube bender
1	GVRRC	Tube bender CNC
2	HARV	Machines for the heat processing
3	LLAP	Line for powder varnishing
3	PLKY	Workstations for varnish works
4	UPMR	Sawing machine type 1
4	UPMRM	Sawing machine type 2
4	LCRW2	Laser cutter for pipes and profiles
5	PHU1	Pneumatic press type 1
5	PHU2	Pneumatic press type 2
5	PHU3	Pneumatic press type 3
5	PMS1	Eccentric press type 1
5	PMS2	Eccentric press type 1
5	SROB1	Welding robot type 1
5	SROB2	Welding robot type 2
5	SROB3	Welding robot type 3
5	SROB4	Welding robot type 4
5	SVIG1	Workstation for the welding type G1
5	SVIG2	Workstation for the welding type G2
6	PUSP	Workstation of foamed polyurethanes
7	WTRY	Hydraulic injection moulding machine

For illustrating the method an example of injections moulding machine was chosen (type 7 of homogeneous group from example 1 - see Table 3) and example of varnish operations (type 3 of homogeneous group from example 1 - see Table 3). Findings were shown in table 4 and table 5.

Tab. 4. The influence of features on the setup time and the membership in groups organizationally similar – group of injections moulding machine.

Type of the group	**Code of the feature.**	**Kind of the assignment**	**Method of calculating the setup time**	**Comments**
7	P1	+++	According to biggest setup time for 1st element. Setup = 0 for 2nd and next element from the group	The full agreement of coding the element always has the very strong positive influence. If the next task is identical i.e., an identical code of the element then setup for next task will be equal zero.
	P2	+++	If an exchange of material follows setup = setup + 2 hour, if not - setup time = 0. It is fundamental criterion of the membership into the group.	Compatible initial material for injections moulding machine means the lack of the need to empty the storage container. If not mums of central giving the raw material (of pellets) – the time of rearming is very long. Additionally when an exchange of material follows additional losses of material connected with cleaning the storage container appear.
	P7	++	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 of heating the form from temperature of unheated room to temperature of surroundings (till 0.5 h). It will be second of the criterion of the membership into the group.	The exchange of the form is connected with a need to heat the form to temperature 40^0 C, and with making test series 3 - 10 pieces – losses amount both from the side of the loss of material for test series as well as the execution time of test series.
	P9	++	Setup = 0.5 h for the cold machine. If is appearing P7 then setup time equal setup time for P7.	The machine at the beginning of every change requires heating. The time of heating the machine equal about 0.5 h. From this point of view it is comfortably to exchange forms at the beginning of every change.
	P12	+	0,1 h	Very divergent dimensions can have the influence on the additional equipment of a workstation with whom one should provide or rearm

	P20	--,----		Parameters from P20 to P23 these are limitations of the membership in the group. P 20 is suggesting not to arrange elements into groups about really divergent priorities of the executing. As they have negative character they will be applied as ruling out. For P20 we will accept the divergence above 2 steps as expelling from the group.
	P21, P23	---,----		The due date scheduled plans will be a basic parameter dividing groups organizationally similar – we will accept, that if the due date of assignments on the group is above *x* working days next groups are being created. In the computer program it will be entrance parameter for forming a group.
	P22	--		Freeing the operation is one of elements limiting forming a group. If the operation earlier wasn't freed in practical conditions then performing the task is impossible. On the basis of this parameter a conditional membership in the group is appearing.
	P4, P5, P6	0	In this case it doesn't concern	In this case it isn't appearing
	P8, P10, P11, P13	0	Rearming the change of the time is missing	Rearming the influence on times is missing

3.6. Defining the set of tasks subject to arrangement and values for features from the tasks set

For the definition of set of tasks subject to arrangement a standard ERP system function was used – scheduling of tasks with a reverse method with limitations. After performing the scheduling function in the set of tasks subject to scheduling, optimization process tasks from the beginning of the list were chosen, arranged in a growing order according to the planned term. The above tasks were narrowed to the list of operations performed on groups of workstations having high rearmament times. The most interesting group will be formed by tasks of the first week on the list. In conditions of changeable operational production plans consideration of the subsequent weeks is pointless. In order to increase the productivity of calculations the task list has been narrowed to the first week. The method was illustrated with this example.

4. CLASSIFICATION INTO ORGANIZATIONALLY SIMILAR GROUPS AT THE LEVEL OF PRODUCTION PROCESS OPERATIONS AND WORKSTATION GROUPS.

The above step is the key one in the whole method. There are different classification scenarios possible. The below examples will help in practical implementation of different variants of classification.

There will be the following sets created: $O_1, O_2, \dots O_l$ while $O_n = \{Id_1, Id_2, \dots, Id_n\}$.

The membership of elements of task of set Id_i to the set of groups O_n is a function dependent on parameters p:

$$\{Id_i \in O_n : F(p)\}$$

As a result of software operation we have received the following organizationally similar groups. The subsequent groups are taken according to the strongest arrangement criterion:

$O_{11}=\{Id_{27}\}$, $O_{21}=\{Id_{25}\}$, $O_{22}=\{Id_{19}\}$, $O_{23}=\{Id_{20}\}$, $O_{31}=\{Id_{32},Id_{33}\}$, $O_{32}=\{Id_{28},Id_{29},Id_{40}\}$, $O_{33}=\{Id_{17}\}$, $O_{34}=\{Id_{30},Id_{31},Id_{41}\}$, $O_{35}=\{Id_{26},Id_{11},Id_{9},Id_{5},Id_{6}\}$, $O_{36}=\{Id_{24}\}$, $O_{37}=\{Id_{7},Id_{1},Id_{2}\}$, $O_{38}=\{Id_{10},Id_{18}\}$, $O_{41}=\{Id_{3},Id_{4},Id_{23}\}$, $O_{42}=\{Id_{8}\}$, $O_{51}=\{Id_{12},Id_{13},Id_{34}\}$, $O_{61}=\{Id_{14},Id_{15},Id_{16}\}$, $O_{71}=\{Id_{21},Id_{22}\}$, $O_{72}=\{Id_{42},Id_{43},Id_{35},Id_{36}\}$, $O_{73}=\{Id_{47}\}$, $O_{81}=\{Id_{38},Id_{39}\}$, $O_{91}=\{Id_{44},Id_{45},Id_{46},Id_{37}\}$.

4.1. Arrangement of organizationally similar groups in the operational production plan

As part of this step of the above method the criterion of division according to organizational feature P21– planned delivery time was used initially. We are limiting sets of organizationally similar groups from O_{11} to O_{nm} to sets fulfilling the condition of „*earlier*" planned execution term. After using the above condition we receive:

$O_{11}=\{Id_{27}\}$, $O_{21}=\{Id_{25}\}$, $O_{22}=\{Id_{19}\}$, $O_{23}=\{Id_{20}\}$, $O_{32}=\{Id_{28},Id_{29},Id_{40}\}$, $O_{34}=\{Id_{30},Id_{31},Id_{41}\}$, $O_{35}=\{Id_{26},Id_{11},Id_{9},Id_{5},Id_{6}\}$, $O_{41}=\{Id_{3},Id_{4},Id_{23}\}$, $O_{51}=\{Id_{12},Id_{13},Id_{34}\}$, $O_{71}=\{Id_{21},Id_{22}\}$, $O_{72}=\{Id_{42},Id_{43},Id_{35},Id_{36}\}$, $O_{91}=\{Id_{44},Id_{45},Id_{46},Id_{37}\}$,

Which constitutes the basic tasks set located on the resources. The rejected tasks will constitute the spare buffers. If due to liberations assignment of some tasks to the group is not possible or if they are performed faster than planned they can be performed as a substitute.

4.2. Calculating the time of tasks taking into account the arrangement

If $\mathcal{F}_{Id_i}$, means the summary task duration time Id_i on machine *m* then the above task duration time $\mathcal{F}_{Id_i}$ can be divided into two components $\mathcal{F}setup_{Id_i}$ - machine rearmament time and $\mathcal{F}work_{Id_i}$ - machine working time.

Task duration time:

$$\mathcal{F}_{Id_i} = \mathcal{F}setup_{Id_i} + \mathcal{F}work_{Id_i}.$$

(4.1)

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

$$\mathcal{F}_m = \sum_{i=1}^{m} \mathcal{F}_{Id_i}$$

(4.2)

In the case of creating groups:

If $\mathcal{F}_{O_k}$ means the summary duration time of group O_k and $O_1k{:}\{ [\![Id]\!]_1(i, \quad) \; [\![Id]\!]_1(i+1, \dots, \quad) \; [\![Id]\!]_1(n, \quad) \}$ then

$$\mathcal{F}_{O_k} < \sum_{i=1}^{n} \mathcal{F}_{Id_i}$$

(4.3)

and will be equal

$$\mathcal{F}_{O_k} \cong \max_{1 \le i \le n} \mathcal{F}setup_{Id_i} + \sum_{i=1}^{n} \mathcal{F}work_{Id_i}$$

(4.4)

Task duration time on *m* machine

$$\mathcal{F}_m < \sum_{i=1}^{m} \mathcal{F}_{Id_i},$$

(4.5)

$$\mathcal{F}_m = \sum_{k=1}^{l} \mathcal{F}_{O_k} \cong \sum_{k=1}^{l} \left(\max_{1 \le i \le n} \mathcal{F}setup_{Id_ik} + \sum_{i=1}^{n} \mathcal{F}work_{Id_ik} \right).$$

(4.6)

After creating organizationally similar groups there were new tasks created for which the rearmament time should be calculated. It was pessimistically received that group rearmament time equals the highest time of the individual rearmament of a task from the group. In the below case we will receive a new set of the following processing and rearmament times.

Tab. 5. Set of newly put in order tasks

Code of the group	Amount of original tasks	Setup time	Process time
11	1	2	1,25
21	1	2	0,67
22	1	2	0,47
23	1	2	0,47
32	3	2	3,00
34	3	2	6,00
35	5	2	8,13
41	3	2	2,67
51	3	2	3,00
71	2	2	5,00
72	4	2	35,33
91	4	2	67,00
Sum	31	26	132,98

4.3. Assignment of tasks to workstations according to membership in a group

After such a data preparation the positioning of tasks on resources is a classical problem of tasks arrangement, while the indivisible task is the whole group. The characteristics of tasks times points to quite big differences in work consumption of individual groups. In the above example there were 2 workstations of injection moulding machines working in the two-shift arrangement. One of the task solutions is a work plan for individual workstations presented below:

$M_1=\{O_{91}\}$, $M_2=\{O_{11,}\text{->} O_{21}\text{->} O_{22}\text{->} O_{23}\text{->} O_{32}\text{->} O_{34}\text{->} O_{35}\text{->} O_{41}\text{->} O_{51}\text{->} O_{71}\text{->} O_{72}\}$.

5. VERIFICATION OF THE PROCESS THROUGH REGISTRATION OF OPERATIONS

Number of disturbances in the conditions of unit and low-serial production is very high. Thus there are no ideal plans. The crucial condition of this method's usefulness is its verifiability in real conditions. To counterbalance fluctuations and inaccuracy of operational planning it is necessary to introduce the positive feed-back into the system in a form of registering of operations implementation. The above process is best to be carried out by self-registration of direct production employees.

6. CONCLUSIONS

For the method to be effective the following conditions should be met:

1. preparation of the knowledge base with a special attention to availability of the data from the point of view of features having influence on rearmament times,

    a. tasks parameters data bases,

    b. principles of processing of the process of dynamic creation of organizationally similar groups.

2. cyclical (daily) classifications of tasks into organizationally similar groups,

3. process support with the use of IT apparatus:

    a. ERP system,

    b. Additional APS class applications allowing for automatic creation of the groups.

4. operational planning process verification through production flow registration.

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