PROTOTYPING ORGANISATIONAL VARIANTS OF REPETITIVE PRODUCTION*

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The paper deals with the problem of the prototyping of repetitive production. The problem results from the customer demand and competition on modern markets. The approach proposed in this paper consists in defining sufficient conditions to filter all solutions and providing a set of admissible solutions for both the customer and the producer. The methodology is the basis for creating a computer program called the "System of Order Validation". An example illustrating this approach is presented.

1. INTRODUCTION

Every manufacturer has access to (can buy) identical machines, tools and technologies. But the organisation of manufacturing and the management of operations are individual. The speed of estimating the market demand and its fast satisfaction decide the competitiveness on the modern market. The manufacturer should make the decision about the order acceptance, the moment the production order is placed. The decisions should guarantee the possibility of due time realisation. These trends are the reasons of a continuous development of manufacturing methods and techniques. The most significant are: computer integrated manufacturing, concurrent engineering, virtual manufacturing

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(Teixeire et al., 1997), biological manufacturing (Ueda, 1997) and holonic manufacturing (Valckenaers et al., 1998). Those concepts are client oriented.At the same time, the manufacturer aims to eliminate losses in all spheres of production. It is called lean manufacturing (LM) (Womack, Jones, 1996). Yet, none of the above mentioned methods poses an ultimate proposal. Automation assures efficient, but repetitive production of big quantity and small variety. Flexible automation enables a quick change in assortment and concurrent realisation of the processes involved. In the era of fast computers, we are witnesses of the emergence of a virtual enterprise, but, at the same time, the problem of geographical availability of resources appears.

The needs of the logistic approach to designing, planning and controlling the system must be addressed. Such is the consequence of the trend of the flow balance, assuring the shortening of the production cycle and order realisation in due time. The development of the production technology and computer science has influenced decision-making (Rudnicki, 1994). The control of this type of systems consists in decision rules allocation, which determines locally the way of the co-operation of subsystems.

Applications of manufacturing resource planning (MRPII) systems are observed in modern industry. Those systems realise the following tasks: material requirement planning (MRP), capacity resource planning (CRP), floor control (SFC) and management of work stage.

Based on the plan, the production schedule is generated, reflecting the potential of resources. The scheduling horizon in MRP is a few days. MRP systems implementations are observed mostly in large factories because of the costs and difficulties involved. They are usually adopted for series production with steady assortment. New MRP II systems and enterprise resource planning systems (ERP) are universal, but they do not consider the specific needs of individual factories, which are often organised on the basis of distributed control, where decisions are made locally. Those systems are not free from faults resulting from the simulation methods application. The simulation methods are highly work and time consuming. The MRP does not suggest any decisions, providing only the information about the constraints, making it possible to check the decision result by means of the simulation method. Local disturbances are not considered. As a result of that, the system does not react to disturbances. Simulation methods offer the most popular solutions. The phrase “re-do until right“ is characteristic for simulation (time consuming and expensive approach).

On the other hand, a modern manufacturer is interested in the method that would assure the fulfilment of the rule "do it right the first time". The complexity of tasks in simulation experiments and the necessity of prior planning and programming motivate the search for more effective alternatives.

Nowadays, two tendencies of manufacturing are observed in industry. The first one is the manufacturing of small quantity, but in great variety; the other one involves the manufacturing of little variety, but in different quantity. Both cases are characterised by small batches, which causes the shortening of the necessity-planning horizon.

In this paper, an approach differing from MRP is presented. The method uses the constraint propagation technique. This approach proposes the creation of sufficient conditions for filtering all possible solutions and it gives a set of admissible solutions for both the customer and the producer.

2. PROBLEM STATEMENT

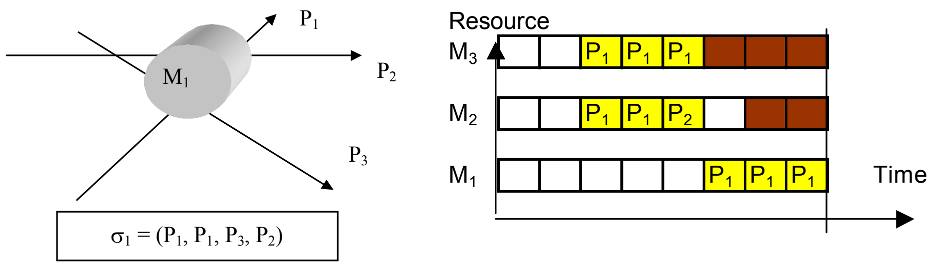
The satisfaction of the customer demands requires suitable process planning in view of the system capabilities. Production planning means a rapid determination of feasible variants of the production flow. The main objective of the presented approach is the integration of the stages of both production planning and control. Two decisions are made simultaneously:

- the acceptance of the production order for being processed in the system (planning stage),
- the control of the production, which guarantees the order realisation of this order while imposing the quality and quantity coefficient.

The following problem is discussed in the paper: what parameters, both for production orders and for the system as such, should be specified to obtain a feasible function? Feasibility is determined by assuring a qualitatively feasible behaviour of the system (deadlock-free and starvation-free) and such a solution that would meet a sufficient level of the quantitative indicators. The condition of quality enables the accomplishment of other parameters resulting from both the system limitations and the customer's demands.

The application of scheduling methods in manufacturing planning practices is not popular. The reason is that both scientific methods, as well as their mathematical representations, are not widespread. The most popular method is based on the application of priority rules. In this case, it is not possible to validate the efficiency of the system. Most cases of production planning and scheduling, in particular, belong to the class of NP-hard problems. A combinatorial explosion of possible variants makes it possible to use an optimal solution in practice. The algebraic approach presented in the paper guarantees meeting of the customer and producer demands. The application of this method is possible only if the system is characterised by a cyclical behaviour.

The reduction of the scheduling to one repetitive period simplifies matters, especially for a simple structure and cyclical behaviour. The repetitive concurrent processes are characteristic for FMS. Based on published research results (Skolud et al., 1998), one should say that the distributed control concept consists in selecting and allocating the local dispatching rules to resources, and in determining the storage capacity to accomplish these demands. For the considered repetitive systems, the distributed control is realised. The dispatching rules allocated to the resources for local decision-making are presented in Figure 1. The notation of the local dispatching rule is $\sigma_i = (p_1, p_2, ..., p_n)$, where the p_n is the number of the process waiting for access to the i-th resource. The rule is executed repetitively.



- σ_1 - dispatching rule allocated to the first resource,
- M1 – resource,
- P_1, P_2, P_3 –processes

Figure 1. The scheme and the Gantt's chart of the dispatching rule allocated to resource M1

3. PROTOTYPING THE PRODUCTION VARIANTS

The method of prototyping the organisational variants is based on the synthesis of the concurrent realised processes to the production systems. The following assumptions are taken into consideration:

- control is distributed,
- production flow is determined by the local priority rules.
- synthesis of the system structure (processes routing),

- buffers space allocation,
- critical resource allocation and the cycle of the system,
- checking the possibility of due time realisation.

The presented method is based on the sufficient condition that guarantees that a permissible solution is obtained. The procedure is presented in Fig.2.

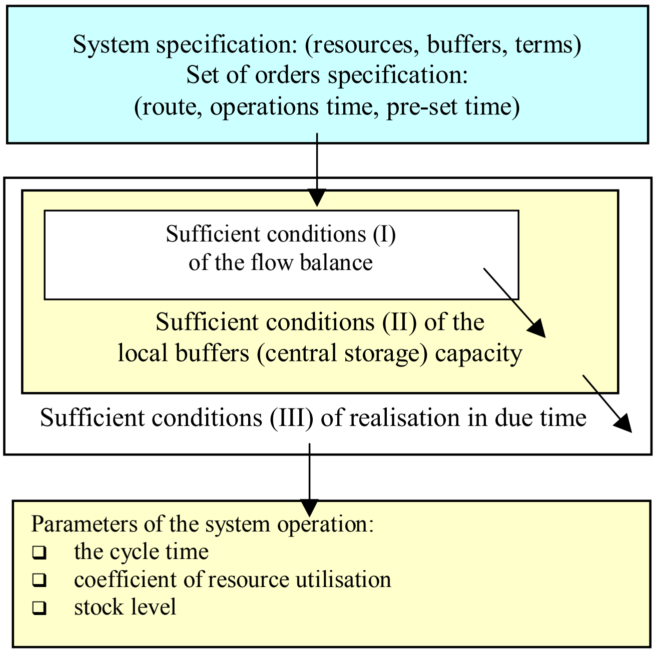


Figure 2. Procedure of the acceptance of the production orders set for realisation in the system

Condition I: The solution is qualitatively admissible when the balance of the system is assured. The balance of the system is accomplished when the number of entering processes is equal to the number of the processes leaving the system. Such is the case when equations (1) are satisfied (Kłos, et al., 1997):

$$\begin{aligned} &\chi_1 \cdot n_{11} = \chi_2 \cdot n_{21} = \ldots = \chi_m \cdot n_{m1}\,, \\ &\chi_1 \cdot n_{12} = \chi_2 \cdot n_{22} = \ldots = \chi_m \cdot n_{m2}\,, \\ &\ldots \\ &\chi_1 \cdot n_{1n} = \chi_2 \cdot n_{2n} = \ldots = \chi_m \cdot n_{mn}\,, \end{aligned} \tag{1}$$

where:

- n_{ij} - repetitiveness of the j-th process in the dispatching rule allocated to the i-th resource,
- χ_i - the repetitiveness of the rule allocated to the i-th resource in one cycle, element of the vector of the relative repetitiveness of the rules $\chi = (\chi_1, \chi_2, \ldots, \chi_m)$.

Condition II: Sufficient buffer's space for the orders set realisation is $\Sigma Cs_{i,k}$, where $Cs_{i,k}$ is the buffers capacity allocated between *i*-th and *k*-th neighbouring resources. The minimum buffer's size for the pair of neighbouring resources is equal:

$$Cs_{i,k} = n_{ij} \cdot \chi_i \qquad (2)$$

Condition III: The sufficient condition for due time realisation possibility is the following:

$$tz_j (I_j \cdot T) / Q_j \geq 0 \qquad (3)$$

where:
- $Q_j = \chi_i . n_{ij}$, (4)
- T – cycle of the system, $T = MAX(\chi_i \cdot \tau_i)$, (5)
- τ_i - a realisation time of the rule execution allocated on the i-th resource,
- n_{ij} - repetitiveness of the j-th process in the dispatching rule allocated to the i-th resource,
- I - lot size of j-th process,
- tz_j - a given time limit determined by the customer.

Such an approach leads to a system assisting an engineer's work. The system is the System of the Order Validation (pol.: System Weryfikacji Zlecen – SWZ). The system allows for fast validation and prototyping the production order for realisation in the given system.

4. ILLUSTRATIVE EXAMPLE

SWZ was used for the execution of experiments. The sufficient condition was checked for determining the admissible solution (due time realisation possibility). Apart from checking for the admissible solution, SWZ makes it possible to create variants of permissible solutions (Fig. 3).

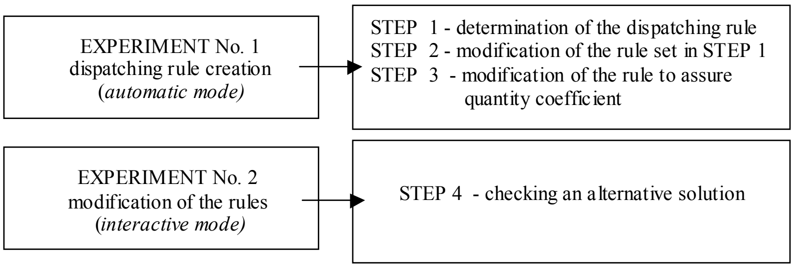


Figure 3. Plan of the experiment

4.1. Experiment preparation

To illustrate the functioning of SWZ, which is based on the presented methodology, the following assortment is considered. The assortment is produced in the "BEFARED" factory (Poland, Bielsko-Biała). The number of resources is 24. The number of production orders is 5. Table 1 and Fig.4 contain further data on the experiment.

Table 1. Production program for experiment

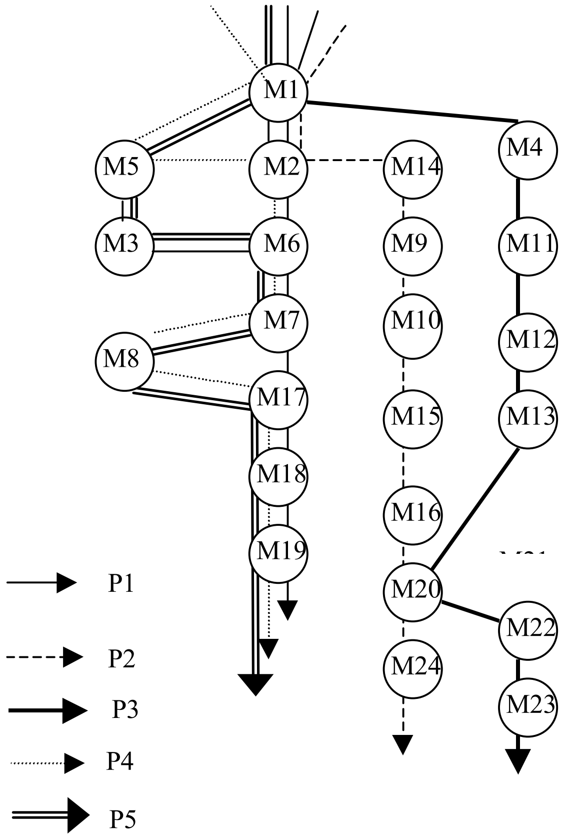
Production order 1	No. operation	1	2	3	4	5	6	7
Element: 3M01403	No. resource	1	2	6	7	17	18	19
number of batches: 72	Operation time	2	2	5	8	3	6	2

Production order 2	No. operation	1	2	3	4	5	6	7	8	9	10
Element: 4M01002	No. resource	1	2	14	9	10	15	16	20	24	21
number of batches: 72	Operation time	1	1	2	1	2	1	1	2	1	15

Production order 3	No. operation	1	2	3	4	5	6	7	8
Element: 2M00704	No. resource	1	4	11	12	13	20	22	23
number of batches: 96	Operation time	1	1	2	2	1	2	1	1

Production order 4	No. operation	1	2	3	4	5	6	7	8	9
Element: 3M00806	No. resource	1	5	3	6	7	8	17	18	19
number of batches: 96	Operation time	1	3	1	2	3	1	4	1	1

Production order 5	No. operation	1	2	3	4	5	6	7	8	9
Element: 3M00802	No. resource	1	5	2	6	7	8	17	18	19
number of batches: 72	Operation time	2	8	3	4	3	2	3	7	1



Assumptions:

- the process is realised only one time on each resource;
- the protocol is exclusive (only one process can be realised on the resource at the same time);
- the steady-state behaviour is considered;
- the disposal time is 1200 time units;
- pre-set times are ignored because they are very short in comparison with operation times.

Figure 4. Scheme of the processes routes (machining department before heating treatment department)

4.2. Results

STEP 1. SWZ creates the dispatching rule automatically. Every process appears only one time in the rule. The cycle of the system is T=15. The realisation time for processes P1, P2 and P5 is 1080 time units, which is possible in due time. The realisation time for processes P3 and P4 is 1440 time units, which is not possible in due time. In this situation, SWZ presents the operator with three possibilities:

- the realisation of all processes in this way (but with delays in view of due time),
- the acceptance of only processes P1, P2 and P for realisation,

- the creation of a new dispatching rule (increasing the number of delayed processes in view of the rule) – go to STEP 2.

STEP 2. SWZ creates a new dispatching rule. The cycle of the system is T=15. The realisation time for processes P1, P2, P5 is 1224 time units, which is not possible in due time. The realisation time for P3 and P4 is 816 time units. SWZ proposes to execute another step (STEP 3).

STEP 3. The result of this step is obtaining permissible solutions because every process is possible to be realised in due time. Processes P1, P2 and P5 is 1116 time units and processes P3 i P4 is 992 units. The result of this approach is the set of dispatching rules (Table 2).

The central storage space capacity is 91. The operator can accept this solution (which is a permissible one), but can also check other alternatives (STEP 4).

Table 2. Dispatching rule for a permissible solution (STEP 3)

$\sigma_1 = (P_1\ P_1\ P_2\ P_2\ P_3\ P_3\ P_3\ P_4\ P_4\ P_4\ P_5\ P_5)$	$\sigma_{13} = (P_3\ P_3\ P_3)$
$\sigma_2 = (P_1\ P_1\ P_2\ P_2\ P_5 P_5)$	$\sigma_{14} = (P_2\ P_2\ )$
$\sigma_3 = (P_4\ P_4\ P_4\ )$	$\sigma_{15} = (P_2\ P_2\ )$
$\sigma_4 = (P_3\ P_3\ P_3\ )$	$\sigma_{16} = (P_2\ P_2\ )$
$\sigma_5 = (P_4\ P_4\ P_4\ P_5\ P_5)$	$\sigma_{17} = (P_1\ P_1\ P_4\ P_4\ P_4\ P_5\ P_5)$
$\sigma_6 = (P_1\ P_1\ P_4\ P_4\ P_4\ P_5\ P_5)$	$\sigma_{18} = (P_1\ P_1\ P_4\ P_4\ P_4\ P_5\ P_5)$
$\sigma_7 = (P_1\ P_1\ P_4\ P_4\ P_4\ P_5\ P_5)$	$\sigma_{19} = (P_1\ P_1\ P_4\ P_4\ P_4\ P_5\ P_5)$
$\sigma_8 = (P_4\ P_4\ P_4\ P_5\ P_5)$	$\sigma_{20} = (P_2\ P_2\ P_3\ P_3\ P_3)$
$\sigma_9 = (P_2\ P_2\ )$	$\sigma_{21} = (P_2\ P_2\ )$
$\sigma_{10} = (P_2\ P_2)$	$\sigma_{22} = (P_3\ P_3\ P_3\ )$
$\sigma_{11} = (P_3\ P_3\ P_3)$	$\sigma_{23} = (P_3\ P_3\ P_3\ )$
$\sigma_{12} = (P_3\ P_3\ P_3)$	$\sigma_{24} = (P_2\ P_2\ )$

STEP 4. In the discussed example, the operator tries to find an alternative solution. SWZ proposes to change the number of processes in the rule, for the processes that are realised longer than others. A result of this stage is time realisation, which is the same for all processes and is equal to 1080 time units.

The central storage space capacity is 129. The solution is an alternative one, and also permissible. The dispatching rules allocated to the resources are presented in Table 3.

Table 3. Dispatching rules for another solution (STEP 4)

$\sigma_1 = (P_1\ P_1\ P_1\ P_2\ P_2\ P_2\ P_3\ P_3\ P_3\ P_3\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$	$\sigma_{13} = (P_3\ P_3\ P_3\ P_3)$
$\sigma_2 = (P_1\ P_1\ P_1\ P_2\ P_2\ P_2\ P_5 P_5 P_5)$	$\sigma_{14} = (P_2\ P_2\ P_2)$
$\sigma_3 = (P_4\ P_4\ P_4\ P_4)$	$\sigma_{15} = (P_2\ P_2\ P_2)$
$\sigma_4 = (P_3\ P_3\ P_3\ P_3)$	$\sigma_{16} = (P_2\ P_2\ P_2)$
$\sigma_5 = (P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$	$\sigma_{17} = (P_1\ P_1\ P_1\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$
$\sigma_6 = (P_1\ P_1\ P_1\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$	$\sigma_{18} = (P_1\ P_1\ P_1\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$
$\sigma_7 = (P_1\ P_1\ P_1\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$	$\sigma_{19} = (P_1\ P_1\ P_1\ P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$
$\sigma_8 = (P_4\ P_4\ P_4\ P_4\ P_5\ P_5\ P_5)$	$\sigma_{20} = (P_2\ P_2\ P_2\ P_3\ P_3\ P_3\ P_3)$
$\sigma_9 = (P_2\ P_2\ P_2)$	$\sigma_{21} = (P_2\ P_2\ P_2)$
$\sigma_{10} = (P_2\ P_2\ P_2)$	$\sigma_{22} = (P_3\ P_3\ P_3\ P_3)$
$\sigma_{11} = (P_3\ P_3\ P_3\ P_3)$	$\sigma_{23} = (P_3\ P_3\ P_3\ P_3)$
$\sigma_{12} = (P_3\ P_3\ P_3\ P_3)$	$\sigma_{24} = (P_2\ P_2\ P_2)$

5. CONCLUSION

In the paper, the approach considering the integration of both the planning stage and the control is presented. The main objective of the presented method is the adaptation of the constraints to a feasible solution.

The method is based on the constraint propagation, which enables the synthesis of the system. Based on the method of the set filtering solutions (constraint propagation), the SWZ system was developed. The functioning of SWZ was illustrated using the data from a Polish factory.

The results can aid the planning process (batch sizing, due time realisation possibility), control (allocation of the dispatching rules) and strategic decision-making, in respect of the production order acceptance. The application of the method gives the following advantages:

1. Distributed control is less sensitive to disturbances and faults in the system.
2. Deadlock- free and starvation-free functioning is assured.
3. Analytical determination of parameters is possible.

Thus, an analysis of the production order validation may be carried out in view of its realisation possibility. SWZ can be adapted to the verification of the production order to a given production system. SWZ can be applied to solve problems of transport management. The role of SWZ is not only to determine if the production order can be accepted for realisation in the system. Simultaneously, it creates the dispatching rule and the size of storage, which are the parameters of the distributed control. The logistic (transport) problems, the start-up condition, as well as other problems involving the disturbance and cost validation are scheduled for discussion in further research works.

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IZGRADNJA PROTOTIPOVA ORGANIZACIJSKOG RJEŠENJA ZA MASOVNU PROIZVODNJU

Sažetak

U ovom se radu razmatra problem izgradnje prototipa masovne proizvodnje, koji proizlazi iz karakteristika zahtjeva kupaca, te konkurencije na suvremenim tržištima. Pristup predložen u okviru rada sastoji se u definiranju dovoljnih uvjeta za procjenu svih mogućih rješenja i stvaranju skupa rješenje otvorenih prema kupcu i proizvođaču. Ova je metodologija temelj za izradu računalnog programa "Sustav za provjeru narudžbi", koji se prezentira i na konkretnom primjeru.