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Design Methods that Work

COMPUTER- INTEGRATED PRODUCTION PLANNING AND CONTROL: THE OPT APPROACH

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Abstract: *A computer-aided method for production planning in a repetitive manufacturing system which allows for estimating the possibility of processing work orders in due time is presented. 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 client and the producer. Finally, an example illustrating our approach is presented.*

1. MODERN MARKET – CLIENT DEMANDS

The globalisation of economic activity has increased industrial competition. The production of customised products in response to short-time market changes and production at a low cost is observed. The intensification of competitiveness provokes the improvement of a new method of manufacturing management.
Production costs depend on both the implementation technology and production management.
Being competitive involves the organisation method of production flow, and, first and foremost, the time at which the method is chosen and applied. Such need is observed in most of small and middle batch production companies where the allocation of tasks to the resources is made according to local information.
In view of this situation in the market, manufacturing processes, and as a consequence, manufacturing planning and control have become increasingly complex during the last few decades. Market requirements tend towards more diversity, a higher quality and fast and accurate delivery performance. Shortening of lead-time, not only in manufacturing, but also in design and planning, has been addressed as a major competitive edge.
Capacities planning and scheduling have become multi-resource in nature and sternly complicated. The implementation of e.g. the group technology concept may offer an important advantage but such solution is only possible in relatively stable manufacturing environments. [8]
The production system is given and the set of production order as well.
Is there a possibility that analytical methods will answer the question, without simulation, if given production orders can be realised in the system satisfying given constraints?

2. MTO: THE TOC APPROACH

In the last decade client-oriented production dominates. Continuous search for competitive manufacturing methods does not allow elaborating a universal strategy suitable for every manufacturing condition. The producer's aim is to increase profits and not to assure the satisfaction of manufacturing as such. The ability of quick validation of market demands, meaning the ability to react to them, determines the competitive advantage, characteristic of the "Make To Order" (MTO) approach. The MTO companies are client- oriented. The MTO type manufacturing is characterised by short-term control of capacity and coupling customer order acceptance to the availability of critical capacity and materials [3].
For such production the Theory of Constraints (TOC) approach seems to be attractive. TOC define a system as a network of interdependent components, which work together to obtain a goal of the system. "If there is no goal there is no system"- [4]. Pursuits of TOC are: increase throughput, reduce

investment and inventory, and reduce operating expenses. The crucial elements of TOC are:

I. Establishing the goal

Improved customer service, by supplying close-to-100% customer's order in due time and assuring lower investment in material.

II. Understanding the system

How does the system work (is it hierarchical or distributed)? Design the processes making up make up our organisation in a way in line with the goal. Get a clear version of the processes of our system and determine how they interact.

III. Making the system stable

Stability means that the system must produce predictable results. The system interacts with the surrounding environment that changes continuously (for example when the same production order starts up or ceases).

The Optimal Production Technique (OPT) that is based on the TOC meets the main aim of any manufacturing organisation, which is to make a profit [1]. The basic idea which lies behind the OPT principles is the need to manage the organisational constraints (increasing throughput, reducing inventory and reducing operating expenditure). In the shop floor context, this means concentrating on controlling bottleneck resources. According to the OPT the maximum number of bottlenecks assure the maximisation of the resource utilisation and enhance the throughput.

Then, the key to synchronising manufacturing is to set up a control system that links constraint resources to the market demand and then ties the remaining resources responsible for producing the desired output. Synchronisation is achieved through the constraint resource that sets the rhythm of production like a drum for the rest of the facility [1].

3. PROBLEM FORMULATION

In the above context we face the following problem. The production system is given and the set of production order as well. Is there a possibility that analytical methods will answer the question: if given production orders can be realised in the system satisfying given constraints?

The production is characterised by cyclic behaviour. The repetitive production means that for every constant cycle T, the same sequence of operations is repeated for the resources. To guarantee a cyclic behaviour of the system, the conditions for starvation-free and deadlock-free system operation must be satisfied. To avoid the starvation problem the local dispatching rule (sequence of operations accessing to the shared resources) are allocated to each common resource. The arbitrary allocation of the dispatching rule to resources may provoke a deadlock. Only in case when both the balance of the processes flow in the system and sufficient buffers capacity are accomplished, the deadlock is not provoked in the system in the steady state [5,6].

Because of the complexity of the discussed problem the approach based on checking the sequence of sufficient conditions is provided.

The sufficient conditions, (such as: batch size in relation to resources capacity, batch size in relation to free buffers space, possible realisation time in relation to the expected one) for filtering all solutions are proposed. It gives a set of admissible solutions for both the customer and for the producer.

It means that the limitation of the set of the solutions is taken into account, and it corresponds to checking if the conditions are satisfied.

However, in the situation when the production flow is changeable, the system transition from one known steady state (repetitiveness period) to another, expected one, has a crucial sense. The most important is that functioning of dispatching rules should cause self-synchronisation of the system according to expected cyclic behaviour (according to critical resource) and ending the whole production without the deadlock appearances.

From this reason the method of the system structure (closed loop) identification is applied as well. It is needed for decision making about dispatching rules construction that is used for starting-up and cease of production, or in the case of the transition between two different known production flows. The method of the system structure identification is based on the graph theory [2,6].

4. APPLICATION

The presented methodology constitutes the "System of Production Order Validation" (SWZ v.3) application [9]. The system aids an engineer in decision making about production order validation for manufacturing and allocation of dispatching rules which co-ordinates the production flow (integrates the levels of planning and control). Two ways are possible: one for an empty system (usually when the set of orders is waiting for acceptance) and the other one for a system where other processes are realised and a new process waiting for realisation (Fig.1).

The SWZ functions in an interactive mode. An operator inputs data on the production system and production orders expecting for realisation. An example of electronic specification is given in Fig.2.

Basing on the above data, the SWZ determines the parameters of the system operation, e.g. realisation time, efficiency, etc.

The system generates the control procedure (macro-rules) as well. The macro-rules consist of three parts. The first part of the macro-rule is the starting-up rule. It is executed one time and assures the synchronisation of the system with expected (desirable) cycle. The second part is the dispatching rule that is executed repetitively and guarantees steady-state

behaviour of the system. The last part is the cease-rule that assure ending of production.
The SWZ system integrates the production planning and control of its flow. First of all, in the scope of answering if the production order realisation is possible. Secondly, in the scope of control procedure generation.

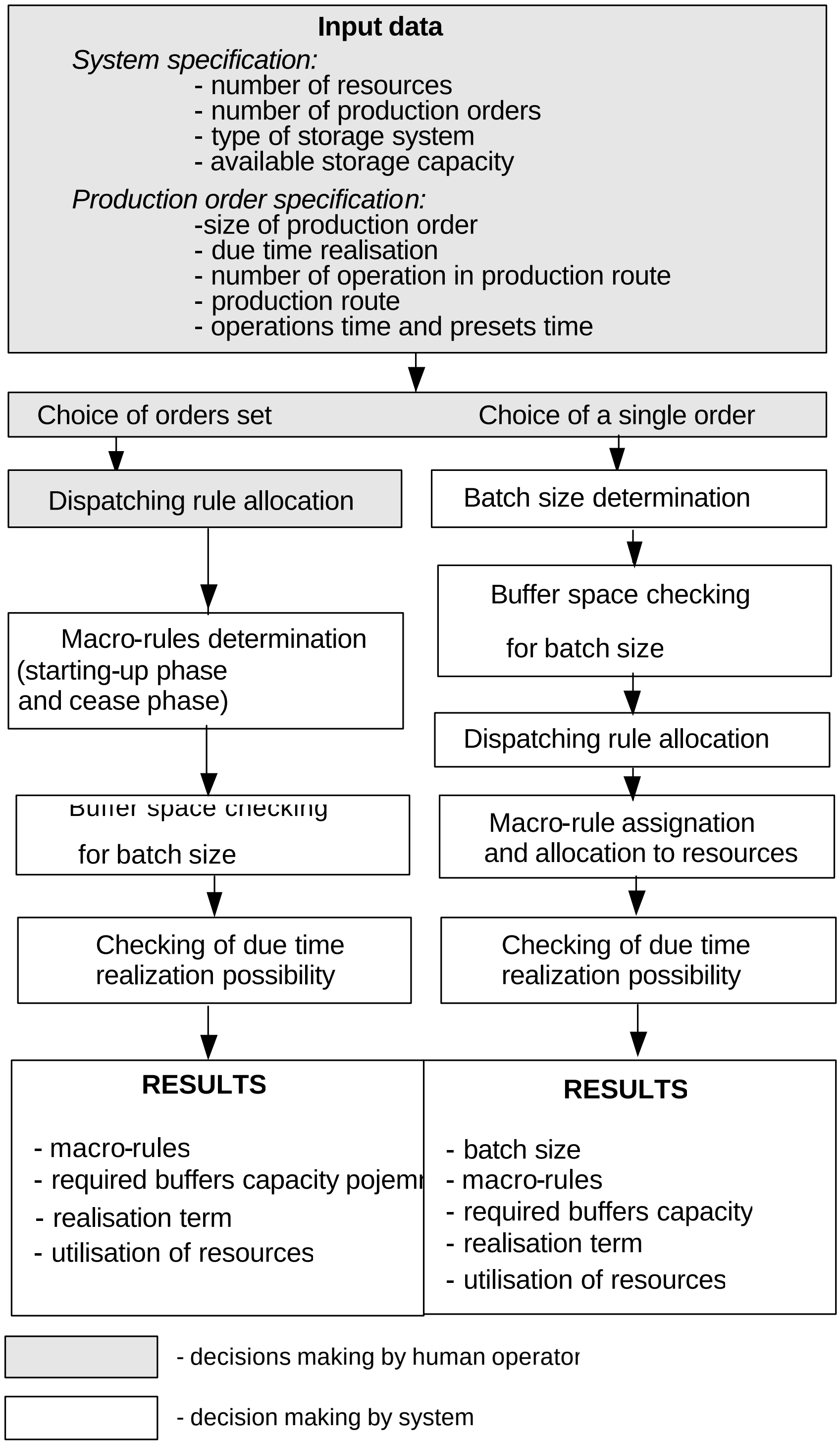

Fig.1. *Algorithm of SWZ operation [2]*

The system may be applied in sales offices for quick estimation of realisation time of new production order that waits for entering the system; in the planning department for production parameter determination (batch size, realisation period, etc.). The system generates the control procedure in the form of macro-rules allocated to the system resources.

5. ILLUSTRATIVE EXAMPLE

Let us consider a system of 4 resources (M_1, M_2, M_3, M_4). The following production orders Z_1, Z_2, Z_3. are waiting for realisation in the system.
Production orders correspond to processes P_1, P_2, P_3, respectively. Production routes of processes are presented in Fig.3, and described by matrix MP_1, MP_2 and MP_3. The first row of the matrix contains numbers of resources, the second one operation times, and the third one pre-set times.

$$MP_1 = \begin{bmatrix} 1 & 3 & 4 \\ 4 & 2 & 3 \\ 0 & 0 & 0 \end{bmatrix}, MP_2 = \begin{bmatrix} 4 & 3 & 1 & 2 \\ 5 & 7 & 5 & 4 \\ 0 & 0 & 0 & 0 \end{bmatrix},$$

$$MP_3 = \begin{bmatrix} 2 & 1 \\ 4 & 3 \\ 0 & 0 \end{bmatrix}.$$

Following dispatching rules that guarantee deadlock free system functioning in the steady state are allocated to resources: $R_1=(3,2,2,1)$, $R_2=(2,2,3)$, $R_3=(1,2,2)$, $R_4=(2,2,1)$.
For example, dispatching rule $R_1=(3,2,2,1)$ means that it is allocated to resource M_1 and that process P_3 is executed once, process P_2 twice and process P_1 once.
For these dispatching rules, the balance of the system is performed. It means that the number of elements entering the system during one cycle is equal to the number of elements leaving the system in this period. The repetitiveness of dispatching rules allocated to the resource takes the form of: $\chi_1=\chi_2=\chi_3=\chi_4= 1$.

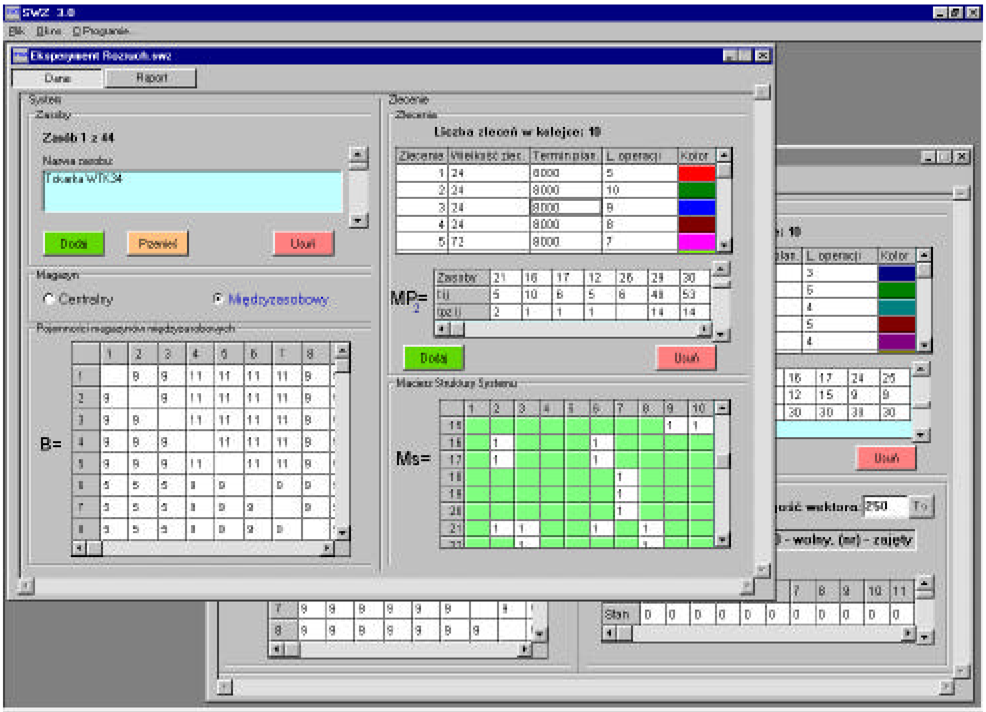

Fig.2. *Electronic specification of input data*

For such assignment of the dispatching rules, the following macro-rules with regard to starting-up phase and cease one are assigned:

$R_1^M=\{(1,1,2,2), (3,2,2,1), (2,2,2,2,3)\}$,

$R_2^M=\{(3), (2,2,3), (2,2,2,2,2,2)\}$,

$R_3^M=\{(1,2,2,2,2), (1,2,2), (1,2,2)\}$,

$R_4^M=\{(2,2,2,2,2,2), (2,2,1), (1,1)\}$.

The first data about the production system and data about expecting processes are introduces to SWZ (see Fig.4).

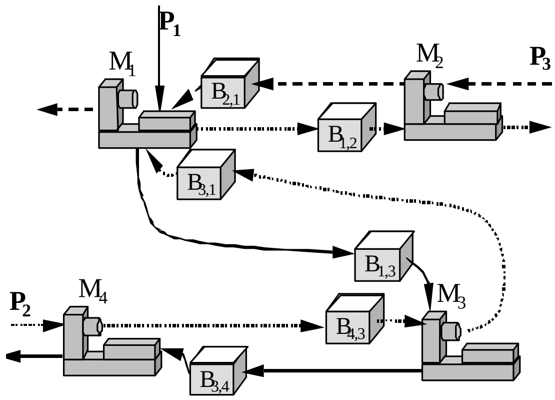

Fig.3. Flow of processes in the production system

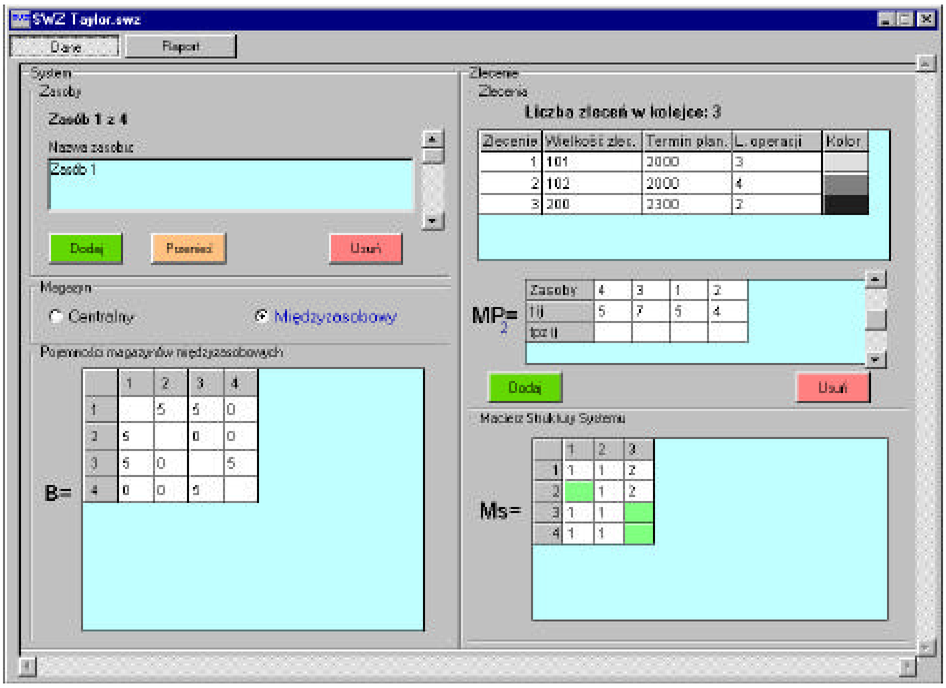

Fig.4. *Input data (for experiment)*

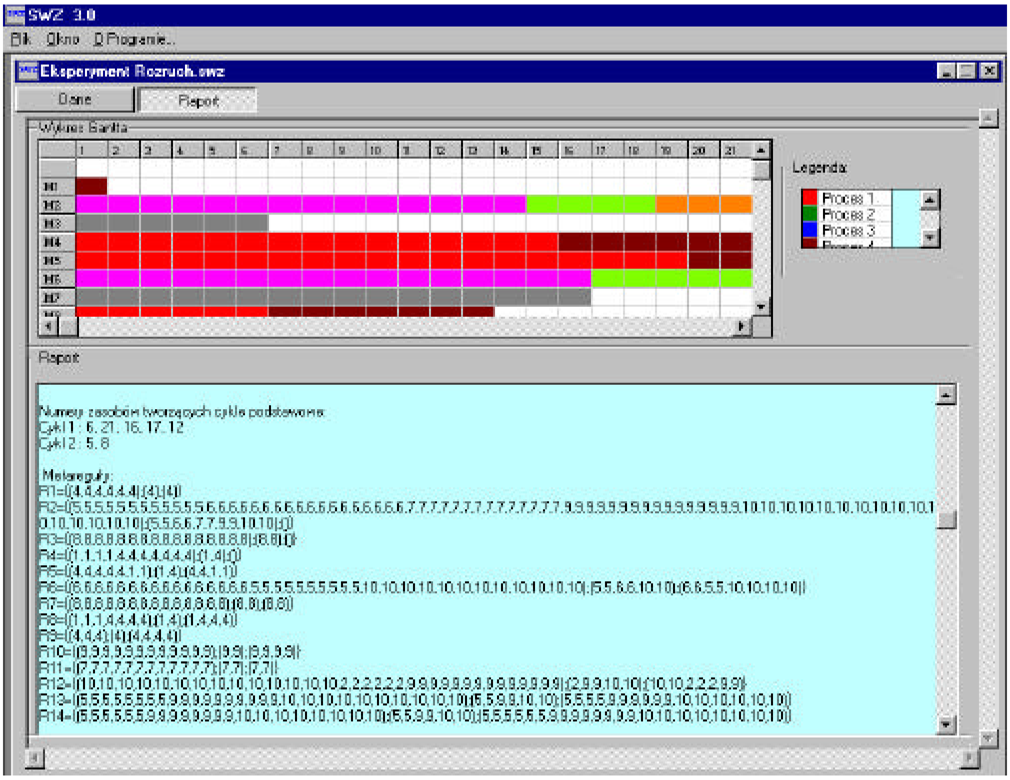

Fig.5. *Gantt chart and report*

Additionally introduced data are the following:

- the size of production order: for P_1 – 101 elements, for P_2 – 102, and for P_3 – 200,
- expected (by client) realisation time: $tz_1 = 2000$, $tz_2 = 2000$, $tz_3 = 2300$,
- capacity of inter-operation buffers: 5 for each buffer.

For this data, SWZ proposes changes of the dispatching rules to assure due time realisation of process P_3. Process P_3 should appear at least twice in dispatching rules that are allocated on the resources of its route. If an operator accepts this change, all processes can be accepted for realisation meeting customer demands (due time realisation). The raport is generated (Fig.5).

(REPORT)

```
Number of resources in the system:4
Number of waiting production orders: 3
```
Data about production orders:
```
Prod. order 1: Size: 101; Due time:
2000;  Number of operations:3
Prod. order 2: Size: 102; Due time:
2000;  Number of operations:4
Prod. order 3: Size: 200; Due time:
2300;  Number of operations:2
MP1
1      3      4
4      2      3
0      0      0
MP2
4      3      1      2
5      7      5      4
0      0      0      0
MP3
2      1
4      3
0      0
```
Local dispatching rules:

R_1=(1,2,3,3)
R_2=(2,3,3)
R_3=(1,2)
R_4=(1,2)

Number of resources that creates basic cycle:
```
Cykle 1 : 1, 2
Cykle 2 : 1, 3
Cykle 3 : 3, 4
```
Macro-rules:

R_1={(1,1,2);(1,2,3,3);(2,2,3,3)}
R_2={(3,3);(2,3,3);(2,2,2)}
R_3={(1,2,2);(1,2);(1,2)}
R_4={(2,2,2);(1,2);(1,1)}
```
Max. time of starting-up realisation
Trr = 52
Max. time of cease realisation Trw = 43
```
Dispatching rule repetitivenes:
```
Dispatching rule allocated to M1-1
Dispatching rule allocated to M2-1
Dispatching rule allocated to M3-1
Dispatching rule allocated to M4-1
```
Data about storage system :
```
Desired capacity of buffer between M2 i
M1 = 4. Real capacity = 5
Desired capacity of buffer between M3 i
M1 = 2. Real capacity = 5
Desired capacity of buffer between M1 i
M2 = 2. Real capacity = 5
Desired capacity of buffer between M1 i
M3 = 2. Real capacity = 5
Desired capacity of buffer between M4 i
M3 = 2. Real capacity = 5
Desired capacity of buffer between M3 i
M4 = 2. Real capacity = 5
```
Realisation time of dispatching rules:
```
Resource 1 = 15
Resource 2 = 12
Resource 3 = 9
Resource 4 = 8
```
Production cycle 15

Production order realisation time (for stedy-state):
```
Production order 1 = 1485
Production order 2 = 1485
Production order 3 = 1485
```
Resource utilisation 0,7333333

6. CONCLUDING REMARKS

In this paper, the bottleneck-like production flows control principle has been adopted within the framework of the constraint theory. The methodology based on the theoretical results has been implemented in a software package that permits the user to investigate the effects of a new work order execution on the performance of the manufacturing system at hand. The software system permits rapid production prototyping and serves as a computer–aided production management tool, enabling the production planning as well as the distributed control of concurrent production flows.

Apart from the above-presented approach, the problem of production flow synchronizing constraints and the integration of financial constraints will be developed in our further work.

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