MULTIDIMENSIONAL MODEL OF PRODUCTION SCHEDULING AND MONITORING

Drago Lisjak
Trade Departm, Faculty of Economics & Business, University of Zagreb, Croatia

Zvonko Sajfert
Technical Faculty “Mihajlo Pupin” Zrenjanin
sajfertz@tfzr.uns.ac.rs

Sanja Stanisavljev*
Technical Faculty “Mihajlo Pupin” Zrenjanin
sanjastanisavljev@live.co.uk

ABSTRACT

Abstract: Paper present multi-dimensional model of production scheduling and monitoring that should be useful to manufacturing and industrial engineers in metal industry. The model basically starts from the accepted assumption of the Modern Organization Theory that the company is a multi-dimensional system and that its elements are connected by stochastic links, therefore it is logical that for the planning process all relevant elements should be considered, meaning that the multidimensional model of operating planning shall provide better solutions than planning only into one dimension that usually is used in practice.

Key words: Production scheduling and monitoring, multidimensional model

1. INTRODUCTION

The substance of the conventional Gantt's chart which is still the basis for scheduling and operational monitoring of production in metal industry is that lengths of horizontally drawn lines to some scale mean the duration of works per items, and simultaneously the start and end of works. Fig. 1 is graphical presentation of one progress indicating board. It is in horizontal direction divided in days, and by vertical direction the work positions are lined-up (machines in some workshop). The board is so marked as to display the machines occupancy and cardboard's are used, cut in suitable scale (for instance 1 h = 10 cm). The cardboard's are ranged by the planned sequence of operations, at each work position. As a standby, due to possible standstill, between individual cardboard's some space has been left (for instance 4 hours/week). In addition to this the work shift is reported to 10 hours, so that the work, if necessary, could be extended without disturbance to the next process. There is a plum above the board, serving to monitor the operation course.

![Figure 1: Progress indicating board](image-url)
For monitoring the operation course a bar progress chart (or "critical path method") by elements has been prepared (Fig. 2) representing the base for the most modern systems of monitoring.

<table>
<thead>
<tr>
<th>Element</th>
<th>Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum 807/66-026</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14</td>
</tr>
<tr>
<td>Ring 807/66-914</td>
<td></td>
</tr>
<tr>
<td>Gear 807/66-700</td>
<td></td>
</tr>
<tr>
<td>Assembly</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 2: Gantt's chart by elements*

This monitoring method is suitable for production with linear machines arrangement, while the capacity problem is more or less solved: the main problem is the length of production cycle and the process interaction between the elements.

The principal problem in the group machines arrangement is how to reduce the transport routes under such conditions by maximum utilization of the machines capacities. By production planning, monitoring and control by this system, we can solve in first place the problems of machines capacities, and then all other problems in connection with them. Therefore in addition to the previous chart it will be necessary to apply progress monitoring chart per each machine.

### 2. MULTIDIMENSIONAL MODEL

The multidimensional model enables connection of operation time elements per different machines, products an, operators, which cannot be identified from the conventional Gantt's charts, being in one plane. The connection i obtained from geometrical projection in the section of two planes (on the model with three planes on Fig. 1 shown wit dashed lines) and so effects and techniques of critical path method with respect to presentation of structural connection between individual operations (operation time elements) are obtained. The sequence of operations and time elements is dictated by the process-operation list.

The Fig. 1 shows that in the plane "e-t" the planned work items are given: gear, ring and drum, whose sequence by the machines is dictated by the process. After completion of the processing on the turning lathe, the drum is transported (trt) and reaches the grinder or the boring machine. Likewise the ring and drum are operating according to the process.

In the "m-t" plane the machines occupation is presented. So on the lathe on Fig. 1 after the drum, the ring is placed an( between them is the time envisaged for preparatory-final works (tpz)(more precisely these are auxiliary-manual time elements). The starting time of ring execution is - in addition to preceding process machine time for the ring execution on the boring machine and drum on the lathe in plane "e-t" and process machine time for drum execution on the lathe in "m-t" plane is imposed by the relationship of the appurtenant time elements for transport trt and preparatory-final time tpz in plane ,"m-t". It is clear that the higher time of these two dictates the start of the following operation, in our case the ring on the lathe.

Also it should be taken into account that waiting due to the differences of in duration of these two times are not shown on Fig.1. The model itself should comprise the intermediate spaces not included up to now in the presented activities occurring due to different standstills and cancellations.
In the "elements-time" plane ("e-t") it is possible to plan and follow-up the operator when he works on one or several machines. It is also possible to show the operators' time if in addition to the work on several machines transport between each operation is performed. So for instance on Fig. 2 in the "e-t" dimension the operator "XY" transports a part (ring) to the grinding machine, and upon completion he transports it to another machine lathe, from where it will be transported by another worker, which means that the operator is dealing with two machines. However, the most frequent case in industrial production is that one worker is serving one machine, and where the internal transport is by mechanical means, or it is performed by another worker, so planning and monitoring of time elements of the worker's operation can be equal with the planning and monitoring of the machines operation.

Tools and accessories are connected to the machine, their planning and monitoring is related to the "machine-time" plane ("m-t"), for the preparatory-final time (machine setting) respectively and it is possible to present them in this plane.

Nevertheless, it is possible even for planning and monitoring of transport time as well as preparatory-final one to introduce new planes in the model, and in this manner we can obtain a multi-dimensional model. It is clear that precise planning, monitoring and control of production requires more precise restriction of time elements by the three principal dimensions: item of work, machine and man. The restriction of time elements between the man and machine provided up to now the conventional chart "man-machine" but it was conceived for one man only - the operator, and for one machine. The required condition in our model is achieved in the three-dimensional model with the axes "machine-operator-time" (m-o-t). From the plane "operator-time" the connection is realized by the plane "machine-time" from the plane "work items-time" in the three-dimensional model with axes "machine-work itemoperators". Thus, the common plane of the two three-dimensional model is "m-t", which is obvious from Fig.3.

Figure 3: Elements of multidimensional models of operative planning

The plane "r-t" is combined with the plane "m-t" as it is assumed that in industrial production the working place is limited, i.e. the machine operator is not consuming his time on other elements of working time, being the obligation of other workers, such as internal transport, etc., which elements depend to the "e-t" dimension in the model. This model is shown on Fig.4.
By parallel planning by all four basic model axes "m-r-e-t" we obtain the final basic multidimensional model.

Simple computer program (adapted to the one for TMP) with the limitation that at the same time at one machine one work item is available, supervised by one operator by respecting the process and as shortest as possible production cycle, provides the solution and possibility of updated re-planning by the multidimensional model as shown on Fig.3.

Under conditions of industrial production, on the other hand, all these elements of work time (Fig. 3), machining time inclusive calculated in the technology and standardized times included in the production quota in individual, small series and series production are beyond less than the time elements of waiting time, standstill and cancellation.

The realistic planning model and production monitoring should include also these operation elements and their stochasticity with respect to time duration. The model from Fig. 1 is now modified for a case of waiting time, standstill and cancellation, so we obtain the model on Fig.6. The Fig. 6. displays that in the ring "channel" failure occurred during the operation in the boring machine resulting in shifting the later times; transport time and process time on the lathe. It is clearly reflected in the "m-t" plane and now the ring shall wait some time to reach the lathe, which is marked on the figure in the "lathe" channel with tc. Therefore, all times shall be indicated in the model, only waiting time, standstill and cancellation most probably shall have planned total time, but to be divided at random, which by the computer program under real conditions shall be recorded in the shortest period possible (re-planning process).

Figure 4: Planes in multidimensional model

Figure 5: Common "m-t" plane in multidimensional model
In the depicted real production conditions the elements of work time whose duration is subjected to stochastic laws of distribution can be overwhelming and tested at different production levels, whereas two are the basic ones:
- level of metal industry
- level of the enterprise (plant).

Having the knowledge of the work time elements, the ambiguity in planning and monitoring of production is reduced. According to Opitz (1971) from the total time (duration) of production cycle in German metal industry only 2% is process-machining time, and it is not realistic to plan (schedule) in our circumstances to be better, although this information should be taken with prudence.

For this purpose we have surveyed the elements of work time by machines and by items and the surveying methodology shall be described later.

The coefficients of work time and the total degree of machines utilization are given in Table 1. The sample included the period during 5 years of our largest metalwork industries with 74 plants (strata) and 3510 machines.

**Table 1. Level of capacity utilisation, the structure of the time machines spend in operation and out operation**

<table>
<thead>
<tr>
<th></th>
<th>$\eta_{lm}$</th>
<th>$\eta_{pe}$</th>
<th>$\eta_{im}$</th>
<th>$\eta_{k}$</th>
<th>$\eta_{a}$</th>
<th>$\eta_{c}$</th>
<th>$\eta_{o}$</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$n_i$</td>
<td>0.375</td>
<td>0.119</td>
<td>0.074</td>
<td>0.072</td>
<td>0.048</td>
<td>0.122</td>
<td>0.179</td>
</tr>
<tr>
<td></td>
<td>$N_i$</td>
<td>2026</td>
<td>2144</td>
<td>2555</td>
<td>2297</td>
<td>2250</td>
<td>2765</td>
<td>2508</td>
</tr>
<tr>
<td>II</td>
<td>$n_i$</td>
<td>0.192</td>
<td>0.080</td>
<td>0.058</td>
<td>0.056</td>
<td>0.008</td>
<td>0.052</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>$N_i$</td>
<td>994</td>
<td>1121</td>
<td>417</td>
<td>727</td>
<td>592</td>
<td>779</td>
<td>888</td>
</tr>
</tbody>
</table>

It is obvious from the table that the average capacity efficiency in the first shift is about 0.506, while the average standstill due to machine failure $\mu_k = 0.073$, due to operators' negligence $\mu_c = 0.122$, due to organization lack even 0.179. Calculations are done according to Richardson et al. (1982) and Klarin et.al. (2010).

If we have recorded data at the enterprise or plant level, it could be possible to make better planning, and the end result shall be shorter period of works elements for various waiting and standstills, thus resulting in shorter production cycle and better capacities use.

In operational planning and production monitoring particular attention deserve control elements of working time, internal transport and packing of goods, as they develop when the work items are not in the-machining process and there is no correlation or other direct links between these elements, for example the machine elements of work time. It is possible in practice that the capacity efficiency is very high, and yet the production cycle extremely long, as we have too many items in
the series and inadequate organization in the operation sequence (consecutive), so the item is waiting for machining. This dimension of the problem should be identified prior to the application of our multi-dimensional planning and monitoring model of the production cycle and process-machining time, the so-called flow coefficient, which according to investigations in our metal industries for small series production of 3-11 items amounts to 8-20 (k= tc/ttm ), and for series of several hundred items it is 3-10.

For the concrete plant surveyed in the preceding period we shall obtain more precise data for the case of internal transport time - ttr which shall be taken into account during its fitting in our model. The multi-dimensional model of operating planning is prepared manually and by man logic. During the monitoring phase it could be applied semi-automatic or automatic, but during the setting phase it depends on the production system (individual, mass, etc.)

Operational planning and monitoring is a complex system whose task is to the fastest possible way and with less funds accomplishes the market demands, all by eliminating the occurred problems. Undoubtedly, this is achieved by better utilization of the capacities and by removing the standstills but certainly by production effected with less transport and quality control, production that shall be executed in parallel with other activities (Hackstein et al., 1989). Shigeo Shingo (see Luczak, 2001), the President of the Japanese Association for Control (1986), calls such production "Just in time". Such production is without storage's and unnecessary transport, but it requires strict discipline and that all items are from own manufacture and suppliers reach exactly on time on the right place for processing or erection.

3. CONCLUSION

Multidimensional model for production scheduling and monitoring that we propose enables connection of operation time elements per different machines, products and operators, which cannot be identified from conventional Gantt's charts, being in one plane. That is the reason why we think so that multidimensional model is tool for effective production planning useful to manufacturing and industrial engineers and managers in metal industry today.

Proposed model for production scheduling and monitoring starts from the standpoint that the company is a multidimensional system and that its elements are connected by stochastic links, so that all relevant elements are considered. Indeed, the efficiency and effectiveness of the production process in a company, as a subject to considerable number of factors, their balance and way they operate together, requires the model which shall offer more connections to be previously planned.

REFERENCES

Hackstein R., Budenbender W., 1989, Flexible manufacturing systems as modules for the factory of the future, Symposium "Capacity utilisation in metal industry", (Faculty of Mech. Eng.; Belgrade)
Opitz, H., 1971, (v/odern Productionstechnik; Stand und Tendenzen, (Essen; UniVerlag).