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Desing of Multi-Dimensional Model of Production Scheduling and Monitoring in Metal Industry

Paper present multi-dimensional model of production scheduling and monitoring 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 multi-dimensional model of operating planning shall provide better solutions than planning only into one dimension. The interaction and overlapping of production elements require the model which shall offer more connections to be previously planned.

Keywords: *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 1h =10 cm). The cardboard's are ranged by the planned sequence of operations, at each work position. As a stand-by, 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

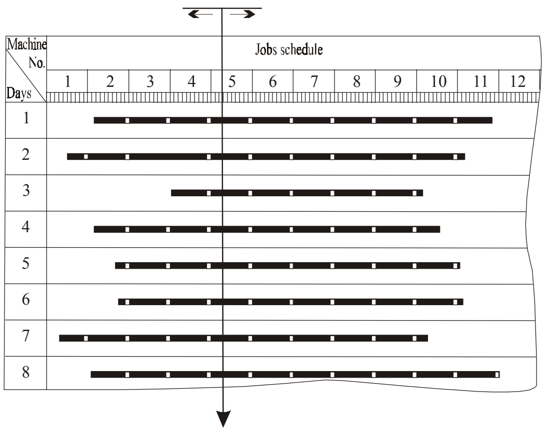

Figure 1. Progress indicating board

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.

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.

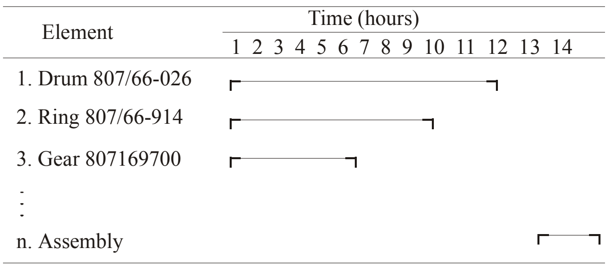

Figure 2. Gantt's chart by elements

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. The basis of such system is shown on Fig. 3.

The third dimension is by the achievement of the production quota of the operator and the time elements influencing the production quota, being located within the generally known mathematical equation (account), already provided in its developed form (formula 1).

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$$T_k = \frac{t_{pz}}{n} + t_{iz} + t_d \ .$$

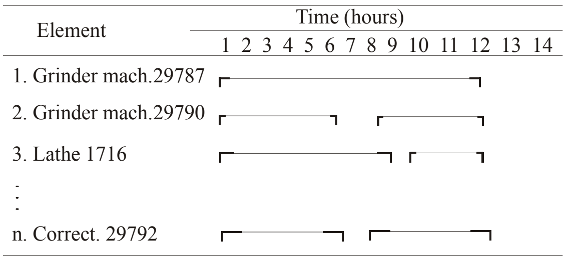

Figure 3. Gantt's chart by machines

The first two possibilities - bearing in mind that the enterprise is multi-dimensional system in which control of the production factor in all dimensions is the sole guarantee for safe production management - can be combined. It is achieved by the manner that in the chart elements for single elements the time is indicated when it is in specified machine, or is in transport between the machines or is at the control point (Fig. 4).

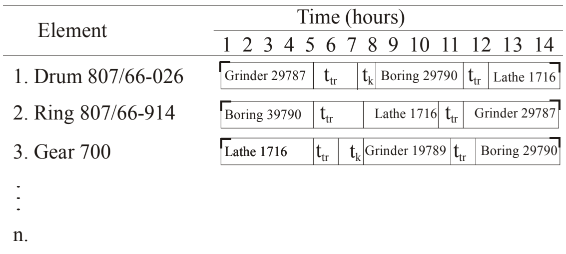

Figure 4. Combined Gantt's chart - "elements-machine"

The chart shows an example of three parts and three machines of operation production plan. Another possibility is to indicate the elements in the chart per machines (and conditions where it shall be applied) (Fig. 5).

In the first case, as it is obvious from Fig. 4 in addition to process mechanical and auxiliary-mechanical elements of operation time, the base time being limiting factor in time reduction for elements manufacture is (in addition to the process interaction) the transport and control time.

In the second case, except the machines time, the limitations are machines setting and other preparatory-final time elements, which in large series and in linear production have minor importance, consequently monitoring, planning and control of production is excluded (inadequate).

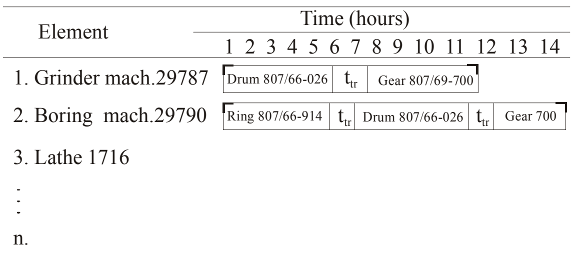

Figure 5. Combined Gantt's chart "machines-elements"

Another question is if these systems shall be semi-automatic, manual (as with Gantt's charts) or by means of Vidento boards, Centalograph, Kintzle, etc. Also there is no dilemma if the data shall be computer processed or not. The problem left is to improve the production organization to that level and also the documentation and the entire information system are so arranged as to reach implementation. Then by computer control (production adjustment) it shall be easier to monitor all three mentioned production dimensions, and the terminal screen in operation planning of production can provide even three-dimensional picture (Fig. 6).

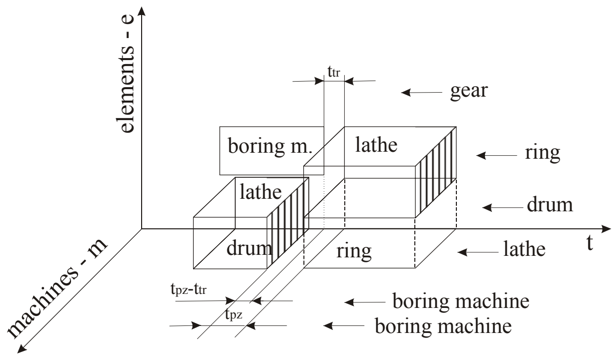

Figure 6. Elements of the multidimenzional planning model.

In practice, the planned time periods in these charts have been increased for a determined relatively high percentage, since, if production is planned by elements, we do not know exactly the preparatory-final time for the machine and if it influences or not the still stand time, for instance the drum on the grindstone on Fig. 4. Likewise, in cases we have a chart per machines, we do not explicitly know the time influence for transport and control when the drum shall be planned for grinding, as shown on fig. 5. These shortcomings can be eliminated by the application of multi-dimensional model.

2. MULTI-DIMENSIONAL MODEL

The multidimensional model enables connection of operation time elements per different machines, products and operators, which cannot be identified from the conventional Gantt's charts, being in one plane. The connection is obtained from geometrical projection in the section of two planes (on the model with three planes on Fig. 6 shown with 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 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 multi-dimensional model of operating planning shall provide better solutions than planning only into one dimension. The interaction and overlapping of production elements require the model which shall offer more connections to be previously planned.

In practice, the planned time periods in Gantt's charts were increased to some relatively high percentage, since, if production is planned by elements, we do not exactly know the preparatory-final time of the machine and if it affects the standstill or not. Also, if we have a chart per machine, we do not explicitly know the time necessary for transport and control at the time when the element shall be planned for the machine. Particularly this influenced the sequence and size of the standstill time and the failure which has been deleted for the time in the model.

The figure 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 (t_{tr}) 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. 6 after the drum, the ring is placed and between them is the time envisaged for preparatory-final works (t_{pz})(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 lath in "m-t" plane is imposed by the relationship of the appurtenant time elements for transport ot t_{tr} and preparatory-final time -t_{pz} in plane "m-t". Possible relationships are t_{pz} t_{tr}. 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. 6. 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. 7 in the "e-t" dimension the operator "XY" transports a part (ring) to the grinding machine, and upon work 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 item-operators". Thus, the common plane of the two three-dimensional model is "m-t", which is obvious from Fig. 8.

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. 7.

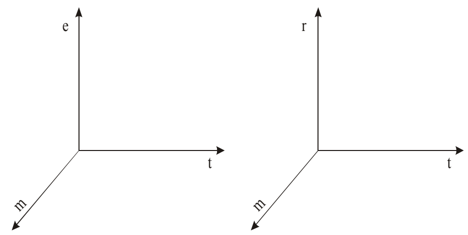

Figure 7. Planes.

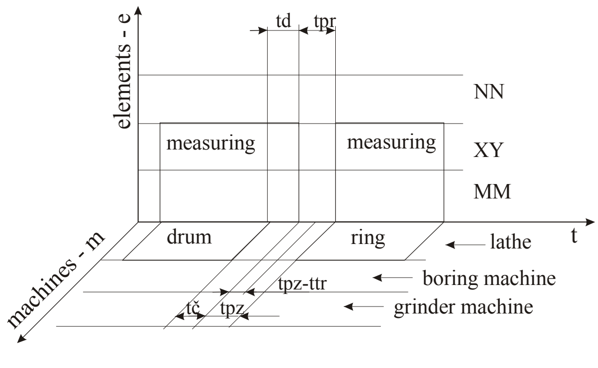

Figure 8. Multidimensional model.

By parallel planning by all four basic model axes "m-r-e-t" we obtain the final basic multi-dimensional 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 multi-dimensional model as shown on Fig. 6.

Under conditions of industrial production, on the other hand, all these elements of work time (Fig. 6), 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. 6 is now modified for a case of waiting time, standstill and cancellation, so we obtain the model on Fig. 9. The Fig. 9. 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 t_c. 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).

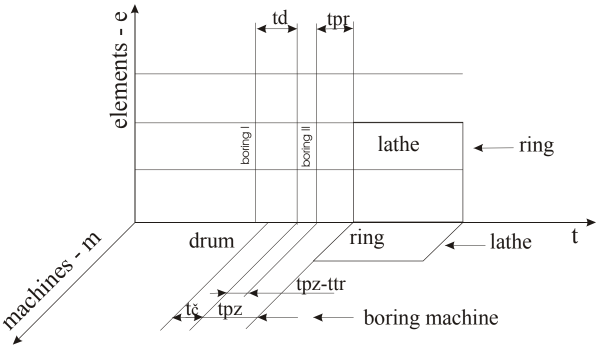

Figure 9. Multidimensional model.

In the depicted real production conditions the elements of work time whose duration is subjected to stochastic laws of distribution can be overwhelmed 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 Optiz 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 from 1982 up to 1987 of our largest metalwork industries with 74 plants (strata) and 3510 machines.

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 μ_k =0,073, due to operators' negligence μ_c =0,122, due to organization lack even 0,179.

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.

Table 1.

		η_{tm}	η_{pz}	η_m	η_k
I	η_i	0,37507	0,11925	0,07434	0,07285
	N_i	2026	2144	2555	2297
II	η_i	0,19156	0,08035	0,05754	0,05613
	N_i	991	1121	417	727

		η_a	$\eta_{č}$	η_o	η
I	η_i	0,04779	0,12190	0,17938	0,50558
	N_i	2250	2765	2508	3049
II	η_i	0,0076	0,05152	0,50029	0,26546
	N_i	592	779	888	1345

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 ($k=t_c/t_{tm}$), 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 - t_{tr} 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. Shigeo Shingo, 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.

On the other hand, the production cycle depends, as well as the degree of capacity utilization, from the organizational sequence of operations, as it is not unimportant if we have parallel type of operations or consecutive, and being limited at the same time by the production range: individual, series or mass. The last influences also indirectly the duration of production cycle by its impacts on the sequence of production organization. So shipbuilding blocks immense funds during longer period of time, while production is individual or in small series.

There are different definitions of start and end of production cycle in the literature, which depends in the first place of the task. In the event we observe only the production start, it could be defined by launching, and the cycle continues per phases, by requests, distribution, preparation of machine and tools, standstills in all phases from the start of the process itself, defined as t_{tm}- process machine time (Fig. 10).

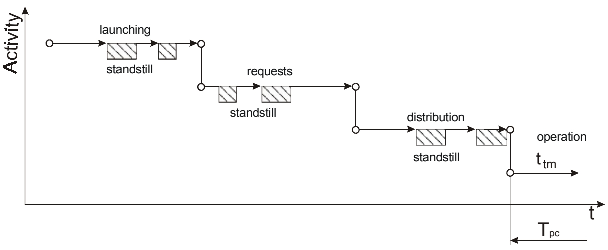

Figure 10. The start of the production cycle.

The end of the production cycle can be defined as end of the operation, waiting for transport, or control, transport, control, packing time and storage (Fig. 11).

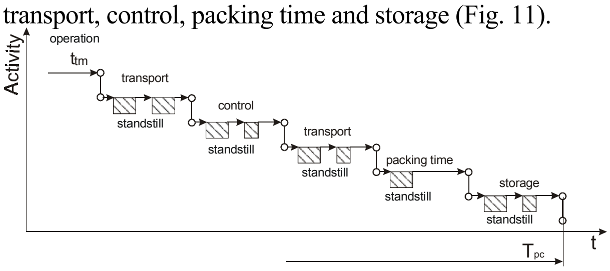

Figure 11. The end of the production cycle.

If we observe the flow of materials through the enterprise, we distinguish (Fig. 12):
- cycle of materials flow - T_{mp} time from the contact with the Purchaser to the dispatch of goods,
- supply-production cycle - T_{npr}
- production-selling cycle - T_{ppr}
- launching-selling cycle - T_{tp}
- manufacture cycle - T_{iz}

Figs.10 and 11 define the start and end of the launched cycle, clearly determining the manufacture cycle. It enables study of reproducible capability of the production system and consequently is the most important aspect of the system. It is also the most important observation aspect of the production cycle regardless to other important ones and which for example the other elements of work time which compared to process machine time are not proportional. Actually, only the launching-production cycle -T_{lp} contains elements of production, while the others include other elements of enterprise business operations.

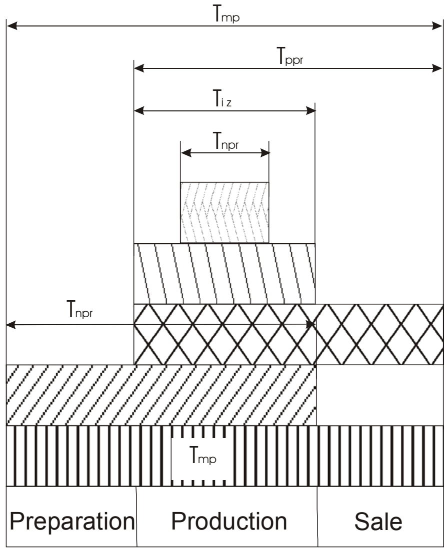

Figure 12. Production cycle.

It is obvious from Fig. 12 that the kinds of cycle are influenced by the phases of business process, preparation for production and sale, making the limits of all defined cycles except T_{iz}.

The basic production indicator of the cycle is the flow coefficient, whose forms the relationship between the total production time T_{pc} and the process machine time - t_{tm}

$$k = \frac{T_{pc}}{t_{tm}} \ .$$

It goes without saying that this coefficient is always higher than 1 and it depends of the production type and mass. So its value can be even up to 50 and the enterprise is having successful business operations. Under individual production it is the highest, while in mass production - the lowest.

In mass production again the increase of the pieces number the coefficient is reducing.

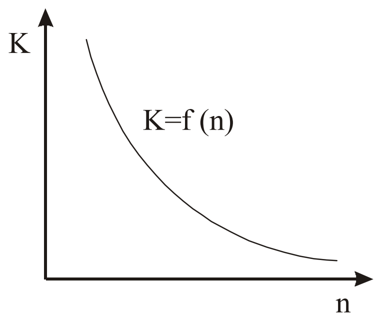

Figure 13. K factor coefficient relationship of pieces

number *n*.

In the ILR factory according to D. Koprivica for a series of 3 to 11 pieces, i.e. for individual production it is:

$$K_p = 2{,}76 + \frac{17{,}64}{t_{tm}} \ ,$$

while according to Lj. Ilic for series production in IMR factory, Belgrade for "production of crankshaft hub" it is:

$$K_s = 1{,}088 + \frac{9{,}7345}{t_{tm}} \ ,$$

while according to T. Kralev for Boris Kidric factory in Struga for mass production we have the following curve:

$$K_m = 0{,}46 + \frac{3821}{t_{tm}} \ .$$

Fig. 14 presents the flow coefficients relationship for the three factories and production types.

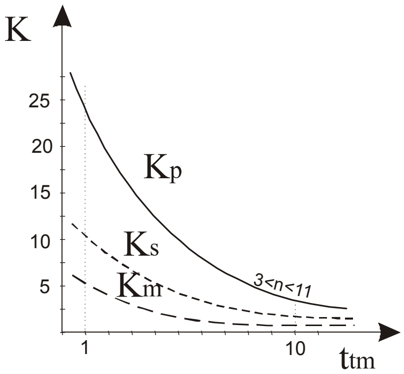

Figure 14. Flow coefficients relationship for the three factories and production types.

The flow coefficient in one factory is not constant, but variable, it should be monitored and make efforts to reduce it.

By reducing the process machine time - t_m which we also endeavor to realize, the flow coefficient is relatively increased, however this is by far more difficult to achieve under modern production conditions, particularly for the same machine equipment, and it could be stated that this influence is of second order, for less automatic production.

The flow coefficient should be monitored with respect to changes in production and in comparison of similar enterprises. Also all elements of work time and standstills in production cycle and optimize them. They serve not only to achieve the present financial effects due to "frozen" funds, but also for production realistic planning and monitoring in the following production cycle - next series and are input in our multi-dimensional model.

3. CONCLUSIONS

Presented paper shows multidimensional model for production scheduling and monitoring.

The multidimensional model enables connection of operation time elements per different machines, products and operators, which cannot be identified from the conventional Gantt's charts, being in one plane. Multidimensional model for production scheduling and monitoring is tool for effective production planning.

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ПРОЈЕКТОВАЊЕ ВИШЕДИМЕНЗИОНАЛНОГ МОДЕЛА ЗА ТЕРМИНИРАЊЕ И ПРАЋЕЊЕ ПРОИЗВОДЊЕ У МЕТАЛОПРЕРАЂИВАЧКОЈ ИНДУСТРИЈИ

М. Кларин, М. Мисита, В. Спасојевић-Бркић

У раду је приказано пројектовање вишедимензионалног модела за терминирање и праћење производње у металопрерадјивачкој индустрији. Модел у основи полази од доказане поставке Модерне теорије организације да је предузеће вишедимезионални систем и да су његови елементи везани стохастичким везама, па је логично да за процес планирања треба довести у везу све релевантне елементе и то значи да ће вишедимензионални модел оперативног планирања дати боља решења од планирања само у једној димензији. Међу-условљеност и испреплетеност елемената производње захтевају модел који ће дати много ви е веза које ће унапред бити планиране.