



PRODUCTION PLANNING OF INDIVIDUAL MACHINE SYSTEMS: A RATE BASED APPROACH USING SIMILARITY

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Abstract. Production planning and scheduling is one of the most important technical activities of enterprises in the manufacturing and engineering industries. In this paper we define the concept of production rate at different hierarchy levels of production planning and scheduling. At the lowest level it appears as material removal rate (MRR). At the highest level it means the rate of activities of the current project. In the customer-oriented machine industry a project can be defined as a set of abstract engineering activities (e.g. mechanical design, part manufacturing, mechanical assembly, electrical and electronic design, electrical and electronic assembly, etc.) that must be completed by a specified due date. The main task of production planning is to distribute the necessary production load-fractions to the resources within the allowable time window in a quasi-optimal way. In project based production modeling the constrained optimum problems can be effectively solved by planning of the production rate as a function of time. In creating the planning models the similarity of projects can be advantageously utilized. The paper gives an overview of the theoretical background and summarizes the expectable benefits of the proposed approach. Some initial application experience obtained so far at a Hungarian factory will also be outlined.

Keywords: Aggregate production planning, project resource model, capacity model, constrained optimum problems, similarity, intensity/rate-based approach

1. INTRODUCTION

Production planning and scheduling is one of the most important activities for enterprises in the manufacturing and engineering industries. Production planning is carried out at several hierarchy levels in general. The task of *aggregate production planning* is to generate quantitative and scheduling data on production in the medium and long run (usually for three months and one year, respectively). The input data of production are: the orders based on market demands, specification of the products and technology processes, the internal and external (supply chain) capacities available, as well as stocks (V.D. Hunt, 1989). The output is the *aggregate production plan* and the *master schedule*.

In order to summarize the requirements for production planning we have to start from the goals of business policy of the firm in question. They can be as follows:

- **Improved customer service.** Nowadays this business goal is top priority. Keeping the market and attracting new customers is a precondition of realization of every other business goal. This goal can only be obtained by means of guaranteed quality of products, meeting deadlines and product specifications, as well as offering an advantageous price-level.
- **Increasing revenue.** This business goal, at the level of production planning and control, requires continuous improvement and control of the macro-parameters of the so-called *production triangle* (readiness for delivery, stocks level, capacity utilization: D.Kiss, 1988; T.Tóth, 1998; D.Kiss and T.Tóth, 1999).
- **Lowering working capital.** This goal can also be achieved by simultaneously and in a synchronized way improving the macro-parameters (production indices) of the production triangle mentioned previously. Meeting deadlines and minimizing the stocks level under reasonable constraints have a direct effect on working capital demand.
- **Managing fixed assets.** Utilization of the existing capacities invested in earlier is a fundamental condition to realize effective production capable of ensuring the profit expected. In case of well-proven products, successful accomplishment of the accepted external orders depends on, in most cases, the capacities available.
- **Reducing operation costs.** Under the conditions of the prices agreed and fixed in contracts the net profit can mainly be influenced by decreasing the operation costs and lead times, as well as by optimal utilization of the resources (machines, workers, materials).

It is easy to see that the concept of *competitive enterprise* can only be defined in a complex manner (J.G. Monks, 1987). The primary business goals can only be influenced through improving the secondary manager (or performance) indices. Effectiveness of production planning and control can only be ascertained after the results obtained in money, i.e. with a delay. Factual influence of the previously

made decisions related to scheduling of the production activities (i.e. concerning their quantitative and time-based distribution) can only be ensured by means of a smoothly operating activity-based controlling system.

2. AGGREGATE PRODUCTION PLANNING OF INDIVIDUAL MACHINES AND MACHINE SYSTEMS

The tasks of aggregate production planning are very different in mass production and in the one-of-a-kind production of complex individual machines and machine systems (e.g. production lines suitable for producing specialized products of large volume). In large series and mass production the most important viewpoint is to harmonize prediction of the market demand and utilization of the capacities available. In the case of production of the complex products mentioned above, production planning has to be subordinated to the interest of successful realization of the external orders obtained. Here the demand for flexibility of production is significantly greater than that of mass production and the deadlines are stricter. Production planning has to be dynamic and incremental. This means that aggregate production planning is controlled by not the start of planning periods but by the order-events appearing in changing dates. The new orders necessitate rearranging the work quantities previously allocated to production but this is also limited by the conditions determined by the works in progress.

In the case of the production of individual complex machines and machine systems the project-like approach becomes more advantageous. Project-like production planning is a typical production planning function of the machine manufacturers that make very complex products according to special orders. A complex machine of great value, that has been made to order and is to be assembled of numerous parts, requires a great variety of expertise. Therefore such a complex product is usually made as a special version of another similar machine made and sold in a previous period, i.e. the new machine to be made to order can be considered as a further developed and more or less modified version of a similar one previously made and sold in a successful way. The activities and processes of a project are based on experience of previous similar production activities and processes on the one hand, as well as on the unchanged and standardized engineering documentation and specific data of the new project including the new technical documents attached, on the other hand.

Aggregate production planning uses a high-level resource model of hierarchical structure. This model is different from firm to firm and is adapted to the usual practice (see Figure 1).

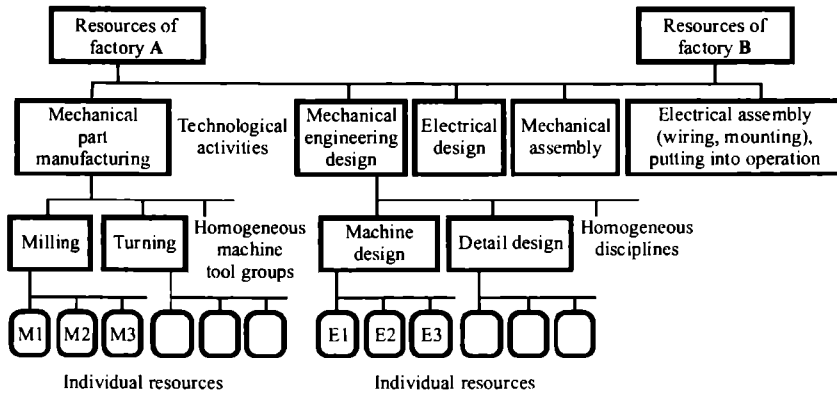


Figure 1: A characteristic resource model

A fundamental feature of the resource model is the available capacity of the given *resource class* depending on the *production calendar*. The resource model used by aggregate production planning is an abstract one and is connected with the high-level activities of production process. Every aggregate activity requires one or more resource(s) and this demand can be expressed in terms of generalized working hours required.

For example, let the list of aggregate production activities in a machine works be the following:

1. Mechanical engineering project work (engineering design)
2. Electrical project work (electrical design)
3. Part manufacturing
4. Component purchasing
5. Mechanical assembly (mounting)
6. Electrical assembly (wiring, mounting)
7. Putting into operation, testing and delivery.

To the activity type set $A = \{A_1, A_2, \dots, A_p, \dots, A_p\}$ a resource type set $R = \{R_1, R_2, \dots, R_k, \dots, R_K\}$ is allocated where $K \geq P$. The effective projecting models make it possible to utilize several resources by a given activity, too.

Available capacity is defined as the capability of resource class R_k for doing a certain work, available in the course of the given work-week (the unit of measurement is working hours/week) (A. Kusiak, 1984). In the aggregate planning models it is expedient to model the time by means of a series of discrete time intervals δt . In most cases the discrete time unit is one work-week. On the discrete time scale let t be the serial number of time interval, i.e.: $t = (1, 2, \dots, T)$. At the

planning time horizon the so-called *relative time* is $\tau = t \cdot \delta t$. At the end of the time horizon used in modelling we have $\tau_s = T \cdot \delta t$. Considering this time horizon there is an internal resource capacity for every time unit according to the calendar: $c_k(t)$, $k = 1, 2, \dots, K$. The production scheduling model treats the available capacity, after it has been fixed, as a constraint. In mechanical engineering not only the internal capacities should be taken into account but the external capacities based on suppliers as well, in order to fill the external orders obtained. The external capacity $s_k(t)$ is more expensive in general and it is also constrained (J.E. Buzacott, et.al., 1993).

From the point of view of content, project work can be classified into three different types. They are as follows:

(1) *Project work for tender*

This is the basic version of project work, which consists of the analysis of demand (or: interest) of the potential purchaser (or: customer), a feasibility study of the project and determination of the main data of the project. The deadline of the project previously accepted has to be determined on the basis of such a model, in which the activities and their work demand are only known at an estimated level.

(2) *Detailed project work*

This is the principal version of project work including all the known phases of product design, technology process planning and production planning on the basis of the customer's order. The project must be included in the actual projects running in the same period. Scheduling of the project is to be carried out by taking into consideration the actual business goals and by fixing the constraints and the objective function.

(3) *Redesign, replanning and rescheduling of projects*

This is a correcting and modifying version of project work. It is used when certain modification is needed because of an unexpected reason that has arisen in the course of parallel project execution. There can be many kinds of reasons, including:

- a change in the business processes,
- a change in the production policy,
- changes in the engineering specification,
- unexpected business events,
- unexpected events in the technology process,
- changes in the constraints and objective functions,
- changes in the uncertainty factors, etc.

For project-like production planning, another key issue is what we consider to be the optimal production plan. As is known (see: *D.Kiss*, 1988, *T.Tóth*, 1998, *D.Kiss* and *T.Tóth*, 1999), in order to qualify as achieving the production goals three natural state variables (macro-parameters) are needed and they are also sufficient at the same time. These complex state variables can be considered the three nodes of an abstract triangle (the “Production Triangle” suggested by *D.Kiss*, 1988). They are as follows:

1. The *average utilization of resources*;
2. The *readiness for delivery*, i.e. the reciprocal value of the average lead time of the external orders;
3. The *average stock level* fixed in production.

These complex state variables, of course, are not independent of each other. Any of them can be improved to the detriment of the other two.

In the production planning of individual machine systems the alternative objective functions of a project scheduler suitable for optimisation appear as the special descriptions of the “Production Triangle” The objective functions are:

1. The weighted sum of the external capacities utilized;
2. The weighted sum of due-date tardiness of the projects;
3. The number of projects released at the same time.

In project-based production the successful realization of external orders is a very important and primary business goal that has to be supported by the utilization of external capacities as well. However, the maximal utilization of internal capacities is also expected. The most important characteristic of the *readiness for delivery* is to meet the due dates (terms of delivery) fixed in the contract. The deviation from the term of delivery either may be not allowed (hard constraint) or may be an objective to be minimized.

The task of the scheduler of project activities is to determine those production activities (both in quantity and in time) that meet all the constraints and minimize the objective function in the domain allowed. The first objective function of project work gives a good solution, typically, in the case of overloaded resources. If the works required by the actual order-book of the firm cannot load the resources in the planning period then the value of external capacity demand is equal to zero and there can be numerous scheduling solutions suitable for meeting the constraints. In many cases it is difficult to decide if improving the stocks level or improving the readiness for delivery should be the objective targeted at such a time. The conflict between the short term and long term goals makes the situation even more complicated. The philosophy of the schedulers used at present is, in general, that the constraints are the important ones; they have to be met by all means. There can also be several production plan solutions (schedules) meeting all the constraints. It is possible to select the most suitable of them on the basis of heuristic

considerations. Of course, an exact optimum is out of question here. The larger the number of permissible solutions, the more robust the optimum is, and the less sensitive it is to the changing circumstances.

3. THE PRODUCTION RATE AS A STATE VARIABLE

In the Department of Information Engineering at the University of Miskolc scientific investigations have been carried out for a long time related to the role of production rate type state variables at the different hierarchy levels of production management, from the well-known material removal rate (MRR) to the rates of the main production activities.

Production processes are typically integrating and cumulative processes, the output, i.e. the quantity of produced products, of which is continuously increasing in time. In the control of such processes the *process rate* (process intensity) is of great importance (G.L.Ravignani, 1977, I. Detzky, et al., 1989). If we consider production control as a closed control loop then the basic signal of control is the production rate. The rate of production processes can be measured in the measuring unit [working hours used/time unit] in the most general manner. At the level of operations the production rate depends on the *technological rate* that can be measured in measuring units [number of products/time unit] or [removed material volume/time unit]. In cutting technology processes where the finishing processes are of great importance, the measure of rate is [machined surface/time unit] and in case of chemical technology processes [processed mass (volume)/time unit].

For cutting the technological rate as a state variable in time can be defined as follows:

$$\int_0^t Q(\tau) d\tau = V(t), \quad (1)$$

or, in differential form:

$$Q(t) = dV(t) / dt, \quad (2)$$

where $Q(t)$ - the cutting rate changing in time;

$V(t)$ - the material volume removed until the time t .

Then

$$Q(t) = A(t) \cdot v_e(t), \quad (3)$$

where $A(t)$ - the momentary effective cross section of cutting

v_e - the feeding speed.

Eq. (3) can also be used in case of multiple-edged tools (see Figure 2).

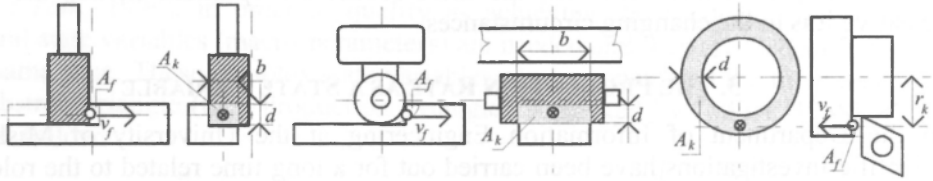


Figure 2: Interpretation of the momentary effective cross section in case of different machining methods.

In planning and production control the average rate $\bar{Q}$ is advantageously used for a given operation or operation element that makes it possible to estimate the primary time of cutting (the machining time) t_m

$$\bar{Q} = V / t_m. \quad (4)$$

Here V is the material volume removed in the given operation (or operation element: T. Tóth, 1997).

The rate of technological operations is the reciprocal value of the operation time; its measuring unit is [1/min]:

$$q_0 = \frac{1}{t_0} = \frac{1}{t_m + t_a}, \quad (5)$$

where q_0 - the rate of operation,

t_0 - the operation time,

t_a - the auxiliary time.

If in Eq. (5) $t_m \gg t_a$ then t_0 can be approximated by t_m and the following relationship is valid:

$$q_0 = \frac{\bar{Q}}{V}. \quad (6)$$

Part manufacturing demands a consecutive series of operations in general; therefore the average rate of part manufacturing, referring to work pieces or series, is an aggregate production characteristic.

$$\bar{q}_p = \frac{n_p}{t_c} \text{ [pieces/min]}, \quad (7)$$

where n_p is the lot size and the cumulated time t_c can be calculated as follows:

$$t_c = \sum t_{prep} + \sum t_0 + \sum t_w \quad (8)$$

Here t_{prep} is the preparation time and t_w is the time of the work piece spent in waiting. Summing has to be extended to all the operations of the series executed so far. The average rate of part manufacturing referring to work piece series plays a great role at shop floor level and in medium term scheduling where the equilibrium of demand rate and production rate is the condition of production stability.

The concept of production rate is the most abstract at high-level aggregate planning. At this level it is expedient to model the production rate by the rate of production activities. The rate of activities can change in the function of time not only from project to project but within any project as well.

Let the i -th activity of the actual running projects be A_i . Every activity has an earliest starting date and a latest completion due date (deadline). Let us denote these two dates with e_i and d_i , respectively. Both dates will be determined in the course of aggregate planning and they can be originated from the project deadline, as well as from the precedence of the activities. Any project means a defined product to be manufactured, the technology process planning of which gives that the project activity demands engagement $r_{i,k}$ [working hours] to the resource used by the activity, in a cumulated way. At preliminary planning for a bid this, of course, can only be based on engineering estimations, however after having carried out detailed process planning it can be calculated from the technology process plans in a well-established way. For a given activity one or more resource engagement(s) can also be allocated but this fact will have importance in the planning phase of the capacity-constrained production scheduling only.

We can give an implicit definition for *activity rate* in case of aggregate planning:

$$\sum_{t=e_i}^{d_i} q_{i,k}(t) \cdot \delta t = r_{i,k}, \quad i = 1, 2, \dots, n \quad (9)$$

Hence, the activity rate $q_{i,k}(t)$, changing in time discretely, is the activity concerning the time unit demanded by the i -th project, which loads the k -th resource. We name the “stepped” function $q_{i,k}(t)$ the *profile of activity* (see: Figure 3). For the profile numerous constraints can be defined which must be taken into consideration in the course of production planning and scheduling.

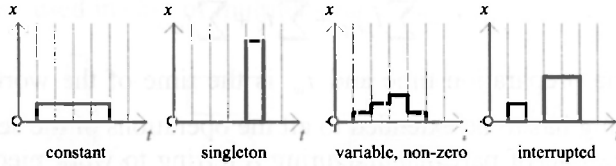


Figure 3. Characteristic activity profiles

The rate of a project activity can be constrained from below and from above:

$$q_{im} \leq q_i(t) < q_{iM} \quad (10)$$

The upper constraint depends on the type of activity, which expresses that the rate of the given activity cannot exceed the maximum denoted by q_{iM} even if there were free capacity available for this purpose. (It is not possible to design or to assemble a machine with optionally great rate; there should be an adequate human expertise and free capacities must be also available.) The lower constraint can express the fact that if we have already started with a certain activity then a minimum expenditure is needed for it in every time interval. If $q_{im} = 0$ then the activity in question can be interrupted; otherwise it cannot be done. A correct modelling of the rate constraints is of fundamental importance for scheduling of projects because the model of the scheduler is obviously sensitive to the right boundaries.

Let the “time window” of the i -th activity be the following:

$$\Delta t_i = d_i - e_i \quad (11)$$

The minimum number of weeks during which the activity can be executed is as follows:

$$1 < \frac{r_i}{q_{iM}} < \Delta t_i, \quad (12)$$

from which we obtain:

$$\frac{r_i}{\Delta t_i} \leq q_{iM} \quad (13)$$

The inequality (13) means a lower constraint for the maximum of the activity rate, i.e. if (13) is not satisfied the project deadline cannot be met. Another constraint for q_{iM} can come about from technological features of the competent resource of the activity. For each activity a minimum time interval for completion of the activity can be determined according to experience. This can depend both on the project type and the utilized resources at the same time and it can be given for the project

planner in a two-dimensional table (p_{ik}). Obviously, the relation $p_{ik} \cdot \delta t \leq \Delta t_i$ has to be performed; otherwise the project deadline cannot be met.

On the basis of the aforementioned considerations, the constraint

$$\frac{r_i}{p_{ik} \cdot \delta t} \geq q_{iM} \quad (14)$$

is also to be satisfied. Therefore q_{iM} has to be kept within bounds:

$$\frac{r_i}{\Delta t_i} \leq q_{iM} \leq \frac{r_i}{p_{ik} \cdot \delta t}. \quad (15)$$

The relative value of the maximum rate allowed is as follows:

$$a_i = q_{iM} / r_i \quad (16)$$

Modelling of the loading profile of project activities is a problem treatable in a more complex way.

The profile can be modelled with a graph or a conventional *Gantt*-diagram in a rough way only, because these graphical tools only concentrate on the time conditions and partial deadlines. As regards the resource demand of the project, only a constant or periodically constant rate can be modelled.

Demonstration of the loading profiles with a set of time-functions is better but there exists the danger of not-easy-to-survey (see Figure 4).

For the rate-based modelling of activities the difficulties can be summarized in the following way:

The definition of activities is subjective; it depends on the opinion and experience of the experts (designers, planners).

- The characteristic profile of activities can be very different. Part manufacturing can be interrupted at a highly aggregate level if the time unit is a week. This means that the profile can be of zero rate value even if the execution phase has already started. Electrical design, however, cannot usually be interrupted. It is worth completing the smaller design works without interruption if we have already started to deal with them.
- Formulation of the requirements for the profile of activities can be neither complicated nor very rigid for a production planning expert. Every complication can disturb the planning manager. A more serious problem is that there are mathematical consequences of the constraints related to the profile form both for the model and for the solver software as well.

- Any experimental information can be useful but it can also be a useless constraint conserving a bad practice.

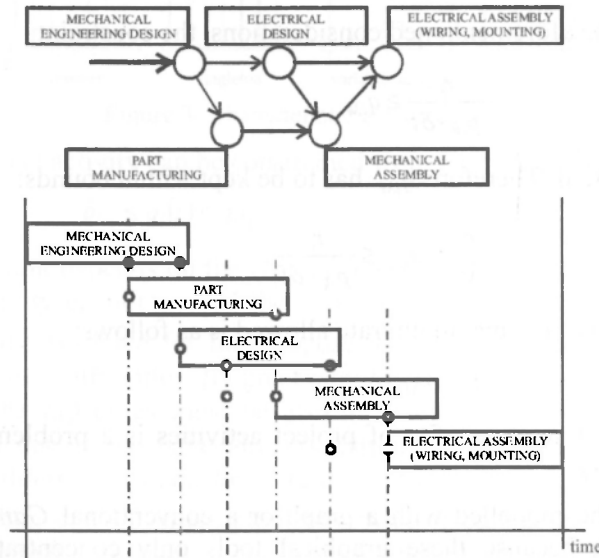


Figure 4: Demonstration of the loading profiles in graphical ways

There are precedence constraints between the activities. On the one hand, they originate from the technology process itself; on the other hand, they can be deduced from business goals, considerations between the projects. Precedence, for instance, can be described by a directed acyclic graph $D = (N, A)$. The simple or special precedence $A_i \rightarrow A_j$ means that activity A_j can only start if A_i has ended.

It can also be interpreted as a more general precedence $A_i \xrightarrow{p} A_j$, which means the activity A_j can only start if A_i was completed to p %. In aggregate production planning the latter is typical. For modelling precedence a binary variable can be allocated to every activity fraction, $x_i(j) \Rightarrow z_i(j)$, which shows whether the rate is allowed in the given time interval. There is a “stepped” function $z_i(t)$ for activity A_i , which separates the interval $\Delta t_i = d_i - e_i$ into two sections. One of the sections is allowed for the activity, the other is not (T. Kiss, 2003).

4. RATE BASED MODEL FOR AGGREGATE PRODUCTION PLANNING

The first basic task of the aggregate production planning is to choose those production goals that are to be achieved in the planning period. Planning is carried

out on the basis of market predictions, the orders of customers and the capacities available, taking into consideration the specifications and quantitative data of the products to be manufactured. The second problem of production planning is to schedule the chosen high-level production activities in time and in a quantitative manner. In project-like production planning this can be done by choosing those specific production loads (i.e. discrete production rates) that appear on the resources in the chosen planning horizon. These tasks can also be solved in several ways and the task of computerized production planning applications is to support this solving process. Aggregate production planning models are conducive to constrained discrete optimum problems in general, the solving of which is supported by the results of Operations Research.

Considering the fact that there are effective computer solvers suitable for solving linear programming problems, it is worth investigating those models of the aggregate production planning which can be solved by these solvers. The problem has been investigated by a research consortium consisting of five Hungarian partners for the last two years, they are as follows: the Computer and Automation Research Institute of the Hungarian Academy of Sciences (CARI-HAS), Budapest University of Technology and Economics, the University of Miskolc and two firms from the competitive sphere. Several models of the joint research work show promising results (*F. Erdélyi, et al. 2002*).

Let us introduce the relative production rate changing on a discrete time scale:

$$x_i(t) = q_i(i)/r_i, \quad (17)$$

which means the loading fraction of the activity in the t -th time interval. It is obvious that

$$\sum_{t=e_i}^{d_i} x_i(t) = 1. \quad (18)$$

The relative production rate of project level can have a value between the limits 0 and 1. For the sake of simplifying the model let us assume that every activity can be interrupted therefore any value of $x_i(t)$ can also be equal to zero.

Let the goal of business policy be the maximal utilization of internal resources. In this case the rate of utilization of external capacities is to be minimized so that the objective function of the project scheduler is to minimize the utilization of external capacities. Hence, the objective function is:

$$\sum_k \left[w_k \sum_t y_k(t) \right] \Rightarrow \min, \quad (19)$$

where

$$y_k(t) = \max \left[0, \left(\sum_i q_{i,k}(t) \right) - c_k(t) \right] \quad (20)$$

In Eq. (20) $y_k(t)$ is the rate of external capacity used in the t -th time interval. In Eq. (19) w_i is the weighting factor expressing the properties of the resource in question.

The task of the project-based production scheduler is to determine those relative production rate fractions $x_i(t)$ and external demands $y_k(t)$ which meet all the constraints related to times, capacities and sequences, as well as to minimize the objective functions (N. Duffie, 2002).

The constraints are as follows:

$$x_i(t) = 0 \text{ if } 1 \leq t \leq e_i \text{ and } d_i \leq t \leq T \quad (21)$$

Constraint (21) means that the activity has to be completed in the given time window.

$$\sum_{t=e_i}^{d_i} x_i(t) = 1 \quad (22)$$

Constraint (22) expresses that every activity has to be carried out entirely (this is the same as equation (18)).

$$\sum_{i,k} r_{i,k} \cdot x_{i,k}(t) \leq c_k(t) + y_k(t) \quad 1 \leq t \leq T \quad (23)$$

Constraint (23) means that all the demands are covered by the internal and external capacities.

$$y_k(t) \leq b_k(t). \quad (24)$$

Constraint (24) shows that the external capacity is also limited.

$$x_i(t) \leq a_i \cdot z_i(t). \quad (25)$$

Constraint (25) expresses that the rate of activity cannot be greater than the allowed and it can only be different from zero in that interval where the precedence control condition allows.

If there is no solution of the planning task with the given data then it is the task of the production engineer to intervene interactively in the computer aided planning process. It can be expedient to slacken certain constraint(s) or to define a new production planning task by changing the demands of the project.

The aforementioned strategy of project work results in a solution most typically in resource-overloaded cases. If the task is not resource-overloaded then the value of the objective function is obviously zero and there can be numerous solutions for meeting the constraints. At that time the task of the project scheduler is to suggest those solutions from the possible and allowed solutions considering which profile of rate changing is the most suitable for meeting the requirements of the production goal.

5. Principles of Similarity Based Production Planning

Important tools of the aggregate production planning are those estimating procedures that estimate the probable structure of activities and the utilization of resources on the basis of the similarity of the products. Under such circumstances the modular structure of these products, the principles of Group Technology (GT) and the similarity-based estimations can have an important role.

Machine manufacturers meet the task of aggregate production planning in the period of tender when obtaining the order is an outstanding business goal. If the production plans of the product meeting the requirements of customer are not available then inserting the project into the running tasks requires careful aggregate planning that includes planning alternatives of "What would happen then if..." type as well. Here the most important things are a well-established delivery deadline and a reliable estimation of the probable capacity overloading (T. Tóth, 1999).

In the course of the realization of a project two different hierarchies have to be taken into consideration:

- the structural hierarchy of the product (complex machine) constituting the base of the project in question;
- the technological hierarchy realized in the manufacturing process.

Structural hierarchy reflects the physical reality of the product, as well as subordination of the main machine units adequate to the major functions. We assume that a product can be dissected into four hierarchy levels at the very most:

- (1) the complex (complete) machine
- (2) a machine unit
- (3) an assembly unit
- (4) a part group.

We hold natural that those projects can only be compared to each other that belong to the same structural hierarchy level.

In the hierarchy of the production process we allow two levels, namely

- (1) the level of aggregate activities of a complete project;
- (2) the level of operations of the production activities.

The first step of similarity-based production planning is to allocate the project to be planned to a product hierarchy level. After this, at the given hierarchy level, we select the similarity projects from the projects previously completed. This is an algorithm consisting of several steps. We make a list including the operations executed in the projects, the utilization of capacities, and the times for planning, manufacturing and assembly. The operation set obtained in this way can also be supplemented with several specific operations if needed for realization of the new project and if they have not appeared in any similar project so far. So we obtain a possible set of operations. We allocate the operation times occurring already in the completed projects to these operation sets in a primary table. The similarity based selection, after all, will be executed by means of a secondary table that qualifies the similar projects on the basis of the occurrence of operations and the operation times within defined tolerances. On the basis of activities of the projects selected in this way we can get a fairly good estimation for the production time requirements of the project activities planned.

6. CONCLUSIONS

Aggregate production planning is an important and difficult task of firms making individual machines and complex equipment. The concept of project-based production planning and scheduling makes it possible to treat the production activities and the engagement of capacities together. A production scheduling model can be based on the rate of project activities. The model of project activities is significantly different from the scheduling model of shop floor control. The high-level activities of the projects can be interrupted and can be planned at a changing rate. The activities can also use several different resources. The profile of rates in time can be influenced by additional constraints.

We have applied the rate-based model of aggregate production planning in R&D works carried out within the framework of a consortium. The model proved to be

successful in case of different products and production profiles as well. The experimental computerized applications are being tested at present. The advantages offered by the rate-based aggregate production scheduler are as follows:

- The number of occasions when the deadline is over-run decreases.
- The lead times of projects decreases.
- Utilization of capacities increases and will be more balanced.
- The use of overtime and external capacities decreases.
- The bottle-necks can be recognized and can be treated in a better way than earlier.
- The number of works in process decreases.

As a result of the advantageous effects listed above, the set of external orders can also change advantageously.

In addition, an important benefit is increasing the co-ordination of engineering functions and improving the integration of the chief engineer department and shop floor levels. Alternative solutions of modelling of the production processes increase efficiency of management decisions. On the basis of experience a reengineering process of greater scale can be realized for improving the working process of the production planning organization.

A disadvantage in application of the method is that the quantity of data required is greater than that of the standard approaches. Rate/intensity has a differential character and therefore it is fairly sensitive to errors of calculation and parameterization. The rate constraints allowable must be estimated on the basis of experience. Present engineering and management practice prefers the operations of constant rate as compared to the operations of variable rate. In the case of constant intensity the time of operation to be expected can be estimated in an easy way. During project planning the model allows zero rates, i.e. interrupting the activity. This fact can give trouble to the experts.

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REFERENCES

- [1] ASKIN, G. A., STANDRIDGE, C. R. (1993), *Modeling and Analysis of Manufacturing Systems*. John Wiley and Sons Inc., New York.
- [2] BUZACOTT, J. E., SHANTHIKUMAR, J. G. (1993), *Stochastic Models of Manufacturing Systems*. Prentice Hall Inc., New Jersey.
- [3] DETZKY, I. FRIDRIK, L., TÓTH, T. (1989), *On a New Approach to Computerized Optimization of Cutting Conditionns*. Proc. of the 2nd World Basque Congress. Bilbao, V.1. pp. 129-141.
- [4] DUFFIE, N. FALU, I. (2002), *Control Theoretic Analysis of a Closed Loop PPC System*. Annals of the CIRP V 51/1 2002. pp. 379-382.
- [5] ERDÉLYI, F. TÓTH, T., SOMLÓ, J., KOVÁCS, A., KÁDÁR, B., MÁRKUS, A. VÁNCZA, J. (2002), *Production management: taking up the challenge of integration*. 3rd Conference on Mechanical Engineering. Budapest, 2002. pp. 705-709.
- [6] GOLDRATT, E. M. (1994), *Theory of Constraints*. North River Press, New York.
- [7] HUNT, V. D. (1989), *Computer Integrated Manufacturing Handbook*. Chapman and Hall Ltd. New York.
- [8] KISS, D. (1988), *An Information Model for the Production Planning and Control of Enterprises*. Symposium of "Organization and Computational Technology Application", Nyiregyháza (in Hungarian).
- [9] KISS, D. AND TÓTH, T. (1999), *The methods of theoretical approach in Production Planning and Control*. In: Information Systems for Enterprise Management in Hungary (Heteyi, J., Ed.), ComputerBooks, Budapest, pp. 59-94. (in Hungarian).
- [10] KISS, T. (2003), *A Branch and Cut Approach for scheduling projects with variable intensity activities*. 6th Workshop on Models and Algorithms for Planning and Scheduling Problems. Aussois, France, 2003. pp. 160-172.
- [11] KRAJEWSKI J., RITZMAN B. (1996) *Operation Management*. (Strategy and analysis) Addison-Wesley Publishing Co.
- [12] KUSIAK, A., DORF, R. C. (1994), *Handbook of Design, Manufacturing and Automation*. John Wiley & Sons Inc., New York.
- [13] MONKS, J. G. (1987), *Operations Management: Theory and Problems*. McGraw Hill Book Company. New York.
- [14] PERKINS, J. R., KUMAR, P. R. (1989), *Stable, Distributed Real-Time Scheduling of Flexible Manufacturing Systems*. IEEE Trans.on Aut. Cont. V. 34, N.2, pp. 139-148.

- [15] RAVIGNANI, G. L., TIPNIS, V. A., FRIEDMAN, M. Y. (1977), *Cutting Rate Tool Life Function (R-T-F)*. General Theory and Application. Annals of the CIRP V. 25/1. pp. 295-301.
- [16] SOMLÓ, J. (2001), *Hybrid Dynamical Approach makes FMS Scheduling more effective*. Periodica Polytechnica. V. 45. No. 2. 2001. Budapest. pp. 175-200.
- [17] STARBEK, M., GRUM, J. (2000), *Operation lead time control*. Robotics and Computer Integrated Manufacturing. 2000. N. 16. pp. 443-450.
- [18] TÓTH, T. (1998), *Design and Planning Principles, Models and Methods in Computer Integrated Manufacturing*. University of Miskolc Press (in Hungarian).
- [19] TÓTH, T. (1999), *New Principles and Methods in the Computerized Integration of Process Planning and Production Control*. Publications of the University of Miskolc. Series C, Mechanical Engineering. Vol.49. pp.173-187.
- [20] TÓTH, T., ERDÉLYI, F. (1997), *The Role of Optimization and Robustness in Planning and Control of Discrete Manufacturing Processes*. Proc. of the 2nd World Congress on Intelligent Manufacturing Processes and Systems. Springer Verlag, Budapest, 1997. pp. 205-210.