

A new model for determining Production Capacity

TRAIAN ALEXANDRU BUDA, EMILIA CALEFARIU, FLAVIUS AURELIAN SARBU,
GARILA CALEFARIU

Faculty of Technological Engineering and Industrial Management
Transilvania University

Mihai Viteazul Street, no. 5, Brasov, 500174
ROMANIA

Abstract: This paper introduces a new model for computing the production capacity in a manufacturing system or in a supply chain. Solving the production capacity problem means to be able to answer the following question: how many parts, from each product, can be produced by a given manufacturing system in a given time span considering the product mix and a multi-stage Bill of Materials? The proposed model is able to determine the production capacity and the loading level per resource for a manufacturing system using as inputs the Bill of Materials, Routing file, time span and product mix. The novelty brought by this method consists in the adoption of the matrix calculus in order to manipulate the inputs to obtain the requested outputs. The opportunity of such a model is that it offers the complete view on the capacity problem with a full range of answers: the available and required capacity at resource and finished product level and the loading level for each resource. Also the facile implementation and integration in ERP systems is a vital point. The use of such a model is in the investment process, middle and long-term capacity planning and client order confirmation process. The model aims to solve any type of manufacturing system.

Key-Words: Capacity planning, Supply Chain, MRP systems, multi-stage BOM, Routing file, Matrix calculus

1 Introduction

The capacity planning is one of the most important topics, when speaking about businesses, manufacturing systems and supply chains. Defining the topic very briefly it can be said that the production capacity is the maximum volume of products that can be produced in a specific mix, in a given time span and considering the current available resources.

The topic appears always in connection with subjects as: production planning and control, master planning schedule, capacity investments, MRP environment, budgeting processes, market demand and fulfilling the customer requirements. The approached topic is separately framed in areas like Materials Management, Industrial Engineering, Supply Chain Management and Operations Management.

Based on the production capacity figures the long, mid and short term planning is made, the promises and the confirmations to the customers are made, new orders are accepted or rejected and the investments are orientated to eliminate the bottleneck processes and to increase the output. Hence is the purpose for mastering this topic.

Arnold and Chapman (2008) divide the capacity in two categories: capacity available and capacity required. The capacity available is the rate at which work can be withdrawn from the system. The capacity required is the capacity of the system needed to produce a desired output in a given period. Continuing to explain the capacity management process, in very simple words can be said that the capacity required is determined, based on the primary customer orders, for every resource of the system and then is compared with the capacity available. In order to be able to fulfill all the requirements, the available capacity has to be at any time higher than the required one.

Regarding the time horizon in which the capacity concept intervenes, it can be said that the concept is present all the time and at any level, the only difference is the level of the details. On the long range there are the production plan and the resource plan, on the medium range are the master production schedule and the rough-cut capacity plan and finally on the short range are the materials requirements plan and accordingly the capacity requirements plan (Arnold and Chapman 2008) The

main idea is to compare at any level and time the requirements with the available possibilities.

The problem is fully solved when a model is able to determine, based on the inputs, how many finished parts can be produced by the manufacturing system and the loading level per resource considering all the possible constraints (including here also supplier constraints), the product mix and the given period of time.

The usually inputs used to manage the capacity planning process are the customer orders (which lead to the product mix), the routing file, the bill of material file, the work center file and the time for which the capacity is considered.

For simple manufacturing systems with a narrow product spectrum and few manufacturing processes there is no challenge in managing and computing the production capacity and to monitor the bottlenecks. The real art is to establish these figures for systems that have a wide product spectrum and the production process is more complex by including the components production also and where the BOMs have multiple stages and the materials have multiple uses.

While the most models and theories are only able to test if some work-load or orders can be processed at some given time and offering a loading level, the purpose of this paper is to fix and manage the most complicated cases possible by saying how much can be done.

This paper is divided into 5 parts, as follows: the already presented introduction chapter, where is presented the approached problematic, a literature review part, which contains the current status of the topic, the proposed model, theory and applications, and conclusions.

2 Literature review

The specialized literature offers, at a first look, a very good and complete theoretical image of the concept but which is mainly word-based presented.

Arnold, Chapman and Clive [1] present the analyzed concept in a tight correlation with the production planning subject in an MRP environment. As already presented in the introduction, there are actually two important concepts: the capacity required and the capacity available. These two concepts are handled by the capacity management process and with the purpose to balance them. Depending on the time span there are different plans for the capacity such as the

resource plan for the long term range, the rough-cut capacity plan for the medium range and the capacity requirements plan for the short range. As technical calculus approach is by using the classic MRP calculus and concepts. A similar approach is proposed by Zandin [11].

An interesting and originally approach is made by Harris and Lewis [5] who used the matrix formulation in order to complete describe the BOMs and use this information further for the calculus of the capacity which is also as a matrix expressed.

There is a special category of approaches, during Linear Programming. Billington[3] formulated a capacity-constrained MRP system as a mixed-integer program (MIP). The limitations of the proposed model are that there aren't any lot size constraints and there is the same lead time structure. Sum and Hill [8] described a method that adjusts lot-sizes to minimize set-ups and determines also the start and finish times of production orders while considering capacity constraints. The algorithm splits or combines production orders to minimize set-up and inventory cost. Tardif [10] proposed a computationally fast procedure, which is labeled MRP-C. It starts with a capacity aggregated LP formulation, which is then solved via a greedy heuristic. The resulting solution is then disaggregated via a second heuristic. Nagendra and Das [7] propose a model where the MRP progressive capacity analyzer (PCA) procedure in which finite capacity planning and lot sizing are performed concurrently with the MRP BOM explosion process is introduced. It models the lot size multiple restriction.

Taal and Wortmann[9] made a literature survey in the field of integrating MRP and the finite capacity planning. The highlights are presented below.

Drift [4] integrates a number of methods to solve capacity problems which are detected after a MRP run .A number of heuristic algorithms are described and tested. A weakness of this approach is that it solves capacity problems after MRP run.

Bakke and Hellebore [2] state that capacity problems should be prevented at the MRP/MPS level because the shop floor controllers are not able to solve capacity problems which come from the higher planning levels. They suggest that aggregating information over planning levels results in incorrect planning due to aggregation errors. The proposed solution is to integrate different planning horizons in one detailed plan over the whole

planning horizon. However this, this approach is only valid if the information concerning the long-term future is very reliable, and this is often not the case.

As a brief conclusion, there is difficult to find planning methods and tools that are fully considering, even with some limitations, the capacity constraints.

3 The proposed model

The formulation of the problem that the proposed model solves is: there are given “m” materials, of which “n” materials are finished goods, which are being produced over “k” resources; it is required to determine the capacity available and the capacity required, at material level, for a given period of time with the consideration of the production mix. The routing file, the single-stage BOM and the resource file are also considered to be known.

A holistic approach means to see the entire system as a whole without reducing it to the sum of its parts. This idea is the starting point in developing the current model. Transposing the holism concept in the capacity planning field means that the capacity has to be evaluated for the entire considered manufacturing system and not at work center or resource.

Going more deeply, the model proposes and sustains having a single point of view, which means to measure and compute the capacity only for the finished goods. This is the only thing that matters, because only these materials are sold further to the customers. Speaking in terms of MRP, it means to compute the capacity only for those materials that have the lowest level in BOMs and don't have any other parent materials. In order to consider in the model the capacity of the components or for the materials which have a higher index of BOM level (children materials), the connection between materials and resources will be used: the BOM files and the Routing files, which are considered to be known for every single case.

The following concept is used to obtain the desired model. A product “A” needs capacity directly from all the resources where it is processed but it also needs capacity indirectly from all the resources where its components are processed. To reduce the complexity, the product “A” is linked with all the resources from where it needs directly or indirectly capacity. The link and the proportionality are assured through the BOMs and

Routing files. The best mode to clarify the concept is via an example. Let be considered a simple BOM which consists of two products: A and B. A contains two of B. The cycle times are presented in the Routing file from Table. 1.

	Work Center 1	Work Center 2	Work Center 3
A	-	-	CtA3
B	CtB1	CtB2	-

Table 1

By applying the presented concept it is obtained a new routing file which contains only the A part.

	Work Center 1	Work Center 2	Work Center 3
A	2 x CtB1	2 x CtB2	CtA3

Table 2

The great advantage is that now is being offered only one point of view.

3.1 Inputs

In this section are presented the inputs used by the model. The novelty is that all the inputs are expressed using the matrix concept. As it can be seen, the inputs are the single-stage BOMs, the Routing Files, the available time and the order book information.

- $R = \{R1, R2, \dots, Rn\}$ is the set of all the materials considered in the model;
- $U = \{U1, U2, \dots, Uk\}$ is the set of the resources considered to process the „n” materials;
- $M_{n \times n} = (rij)_{n \times n}$, where rij means that material „i” contains material „j” „r” times; when there isn't any link between the materials the value is 0; $M_{n \times n}$ is the adjacency matrix of the BOMs of all „n” materials;
- $T_{n \times k} = (tij)_{n \times k}$, where tij is the cycle time of material „i” on resource „j”; $T_{n \times k}$ is the adjacency matrix of the Routing file;
- $Q_s = (q1j)_{1 \times m}$ where $q1j$ is the required quantity, in units, for material j; Q_s contains the order book information for the „m” finished good materials;
- $C = (c1j)_{1 \times k}$ where $c1j$ is the available time for resource „j”; the matrix contains the available time of the „k” resources; the matrix is expressed in time units;
- $q = \sum_{i=1}^k q_{1i}$ Represents the sum of the total requirements, in units.

3.2 Step 1: Creating the multi-stage BOM

The first step is to obtain the multi-stage BOM, based on the single-stage BOM. To obtain it, it is used the concept named Transitive Closure from the Graph Theory. The concept states that having the adjacency matrix M of a directed graph G with vertex set $\{1, 2, 3, \dots, n\}$, the row i , column j entry of $M + M^2 + \dots + M^k$ counts the number of walks from node i to node j in the graph G of length k or less. Transposing the idea into MRP language, this means that the directed graph G is the reunion of all BOMs, the “ n ” vertex are the “ n ” materials, M is the adjacency matrix of the graph, which was already defined in the inputs section and “ k ” is the number of the BOMs levels. The sum matrix is then the matrix that contains the relationship between every two materials, considering the direct path (adjacent levels in the BOM) and also the indirect path (non-adjacent levels in the BOM, through other materials).

Let be considered the matrix M_1 the sum matrix.

$$M_1 = I + M + M^2 + M^3 + \dots + M^k \quad (1)$$

The next step is to eliminate from the M_1 matrix those lines which correspond to the non finished goods materials. The reason for doing this is that the capacity is considered only through the finished good materials. It is very easy to find those materials because the sum per column is different than zero. The result is considered in the matrix M_2 with m lines, corresponding to m finished good materials, and n columns, corresponding to the total number n of materials. It is obvious that $m \leq n$.

Further in this paper when referring to BOM, it will be consider the M_2 matrix. This matrix has to be interpreted as the way to see what and how many components a finish part needs to be realized. This information will be afterwards combined with the routing file in order to determine the capacity required per resource.

3.3 Step 2: Determining the weighted average cycle time

The objective of this section is to calculate the weighted average cycle time for each resource. The inputs are the Routing file, the multi-stage BOM and the order book file.

The first step is to find out how much time is needed to process one unit of each finished good item over each resource. To obtain this, it will be multiplied the multi stage BOM matrix with the

Routing file matrix, M_2T . For any finished good item $i, i \in [1, m]$, the total time needed to be processed on resource $j, j \in [1, k]$ is then:

$$\sum_{m=1}^n r_{im} \times t_{mj} = r_{i1} \times t_{1j} + r_{i2} \times t_{2j} + \dots + r_{in} \times t_{nj} \quad (2)$$

r_{im} - Material i contains r units from material m ;

t_{mj} - The cycle time for processing material m on resource j .

It can be seen from the formula above that by using the matrix product are considered not only the cycle time from material i on resource j , but also the cycle times of its components on resource j .

In order to introduce in the model the product mix information, the cycle time for all the resources has to be weighted. The weight factor, which is nothing else then the ratio between ones item demand and the total demand, comes from the order book file and are calculated with the following formula:

$$\frac{1}{q} Q_s \quad (3)$$

q - Total demand in units;

Q_s - Total demand for each material in units.

The weighted average cycle time for every resource is contained in $(T_m)_{1 \times k}$ matrix, which is obtained by using the formula:

$$\frac{1}{q} Q_s (M_2 T) = T_m \quad (4)$$

At this step was determined how much time needs, in average, a resource to produce one unit of a material, considering the production mix.

3.4 Step 3: Determining the capacity available

In this section will be determined the capacity available, in units, for each resource from the system and afterwards at material level. By knowing the total available time in a period and the weighted average cycle time based on the production mix, it can be then computed, at resource level, the capacity available in the analyzed period. The result is concentrated in the T_c matrix. The formula to obtain it is:

$$T_c = (tc_{1i})_{1 \times k} = \frac{c_{1i}}{tm_{1i}} \quad (5)$$

c_{1i} - is the available time, in time units, from resource i ;

tm_{1i} - is the weighted average cycle time for resource i .

The available time per resource can be split in brutto available time and netto available time. The brutto available time is equal with the considered period for which the capacity available is computed. When determining the capacity available over a period of 250 days, then the brutto available time period for each resource is 250 days. But from the brutto value it has to be considered following aspects like: the number of shifts, the percentage of setup-time from the total amount of time and others. One way to measure and determine the netto available time may be using of the Overall Equipment Effectiveness (OEE) indicator that can be applied to the brutto available time. Developing or presenting methods for netto available time calculus is out of the scope of this paper.

The next step is to develop the available capacity figures at the material level. To obtain it, the already obtained capacity available at resource level has to be combined with the production mixed that comes from the order book level. By multiplying the production mix with the available capacity per resource it can be known then the capacity available for every finished good material at every resource.

$$\frac{1}{q} Q_s^T T_c = Q_c \quad (6)$$

Q_c - Capacity available at material level per resource.

q - Total demand in units;

Q_s^T - The transpose matrix of Q_s ;

T_c - Capacity available at resource level.

The final step in calculating the available capacity for the entire system is to take the minimum available capacity for each material. The result is obtained by taking the minimum value from each line from matrix Q_c .

$$Q_k = k_{i1} = \min(q_{c_{ij}}) - \text{capacity} \quad (7)$$

available in units at material level

$$q_k = \sum_{i=1}^r k_{i1} - \text{capacity available in} \quad (8)$$

units for the entire manufacturing system

At this point the capacity available problem is fully solved.

3.5 Step 4: Determining the loading level

In this section is determined the loading level of the system at the resource level. The loading level is nothing else than the ration between the capacity required and the capacity available. There can be considered two types of the loading level, both of them with use in the practice. The first loading level

indicator is calculated considering the demand that has to be produced. The purpose of determining it is to see how the entire system is loaded and to see the potential bottlenecks. The second loading level indicator is based on the maximum quantity in units that the system can produce. The purpose of calculating it is to see the balance between the loadings of all the resources at 100% loading at the bottleneck.

Using the following relations the both indicators are obtained.

$$Q_s(M_2 T) = T_k - \text{the required capacity} \quad (9)$$

in time units to meet the demand level

$$K_i = \frac{tk_{1i}}{c_{1i}} - \text{the loading level} \quad (10)$$

$$Q_k^T(M_2 T) = T_k - \text{the required capacity} \quad (11)$$

in time units when bottleneck is 100% loaded

$$K_i = \frac{tk_{1i}}{c_{1i}} - \text{the loading level} \quad (12)$$

4 Application

In this section it will be presented a numerical application of the model. The requirement is to determine the capacity available, the capacity required and the loading level for a manufacturing system that produces 3 products A1, A2 and A3 over a period of 250 working days. The BOM for each material is represented in the Figure 1.

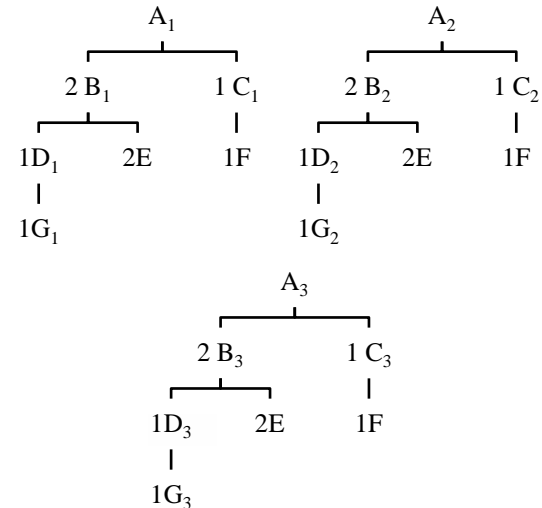


Fig. 1

The manufacturing system consists of 8 different work centers. The routing file is presented in the Table 3. The values represent the cycle time, in minutes per unit, of each material on each resource. When the value is 0 then the material doesn't require to be processed on that work center.

	W1	W2	W3	W4	W5	W6	W7	W8
A1	0	0	0	0	0	0	8.6	8.3
B1	0	0	0	4	0	7.8	0	0
C1	0	0	0	9.9	8.7	0	0	0
D1	0	0	9.2	0	0	0	0	0
E	8.5	9.5	0	0	0	0	0	0
F	7	0	0	0	0	0	0	0
G1	0	4.3	0	0	0	0	0	0
A2	0	0	0	0	0	0	9.5	7.7
B2	0	0	0	0	7.6	5.8	0	0
C2	0	0	0	4.2	0	6.6	0	0
D2	0	0	8.7	0	0	0	0	0
G2	6.7	0	0	0	0	0	0	0
A3	0	0	0	0	0	0	7.8	8.1
B3	0	0	0	9.6	9.3	0	0	0
C3	0	0	0	0	12	7.3	0	0
D3	0	0	9.4	0	0	0	0	0
G3	0	4.7	0	0	0	0	0	0

Table 3

The demand (matrix Qs) is presented in Table 4 and is expressed in units per considered period of 250 days. In table 5 is presented the netto available time for each resource (matrix C). The brutto available time for all work centers is 250 working days and by applying the worked number of shifts

per day is obtained the netto available time per period.

A1	A2	A3	Σ
1900	2200	2600	6700

Table 4

W1	W2	W3	W4	W5	W6	W7	W8
360,000	360,000	120,000	120,000	120,000	120,000	120,000	120,000

Table 5

In the following section is presented the calculation part.

Step 1: Determining the matrix M2 of the multi-stage BOM for the finished products

Based on the BOMs presented in Figure 1, it will be first represented, in Table 6, the single-stage BOM in the matrix M, which means to build the adjacency matrix. As it can be seen, there is

considered a 3 level BOM. In order to construct the multi-stage BOM matrix M1, it has to be performed the following sum:

$$M_1 = I + M + M^2 + M^3$$

The M1 matrix is presented in the Table 7. Afterwards, in order to obtain the structure of the finished parts A1, A2 and A3 will be constructed the matrix M2, represented in Table 8.

	A1	B1	C1	D1	E	F	G1	A2	B2	C2	D2	G2	A3	B3	C3	D3	G3
A1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
B2	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0
C2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0

B3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0
C3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 6

	A1	B1	C1	D1	E	F	G1	A2	B2	C2	D2	G2	A3	B3	C3	D3	G3
A1	0	2	1	2	4	1	2	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A2	0	0	0	0	4	1	0	0	2	1	2	2	0	0	0	0	0
B2	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	0
C2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	0	0	0	0	4	1	0	0	0	0	0	0	0	2	1	2	2
B3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1
C3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7

	A1	B1	C1	D1	E	F	G1	A2	B2	C2	D2	G2	A3	B3	C3	D3	G3
A1	1	2	1	2	4	1	2	0	0	0	0	0	0	0	0	0	0
A2	0	0	0	0	4	1	0	1	2	1	2	2	0	0	0	0	0
A3	0	0	0	0	4	1	0	0	0	0	0	0	1	2	1	2	2

Table 8

Step 2: Determining the weighted average cycle time

Just to recall, the weighted average cycle time is a result of the product of three matrices and one scalar: the multi-stage BOM, the Routing file and

the demand matrix with the inverse of the total demand scalar. The relation (13):

$$\frac{1}{q} Q_s (M_2 T) = T_m \tag{13}$$

By doing the calculation, it is obtained then the weighted average cycle time in Table 9.

	W1	W2	W3	W4	W5	W6	W7	W8
	45.40	44.09	18.23	13.91	19.33	13.23	8.59	8.03

Table 9

Step 3: Determining the capacity available

Recalling the previous theory, by applying the relations (14) to (17) it is obtained the first result of the model.

$$T_c = (tc_{1i})_{1 \times k} = \frac{c_{1i}}{tm_{1i}} - \text{capacity} \tag{14}$$

available to at the resource level

$$\frac{1}{q} Q_s^T T_c = Q_c - \text{capacity available at} \tag{15}$$

material level at each work center

$$Q_k = k_{i1} = \min(q_{c_{ij}}) - \text{capacity} \tag{16}$$

available in units at material level

$$q_k = \sum_{i=1}^r k_{i1} - \text{capacity available in} \tag{17}$$

units for the entire manufacturing system

According to relation (14) it is determined the matrix T_c , represented in Table 10. The capacity available at resource level is nothing else then the ratio between the available time at resource and the weighted average cycle time per resource.

W1	W2	W3	W4	W5	W6	W7	W8
7,930	8,166	6,584	8,629	6,207	9,068	13,978	14,953

Table 10

According to relation (15) it is determined the matrix Q_c , represented in Table 11. By multiplying the available capacity at each work center with the

product mix it is obtained then the maximum quantity of each part that can be processed at each work center.

	W1	W2	W3	W4	W5	W6	W7	W8
A1	2,249	2,316	1,867	2,447	1,760	2,572	3,964	4,240
A2	2,604	2,681	2,162	2,834	2,038	2,978	4,590	4,910
A3	3,077	3,169	2,555	3,349	2,409	3,519	5,424	5,802

Table 11

To find the capacity available at material level, it has to be taken the minimum quantity per material that can be produced at each work center. In this example it can be seen that the work center number 5 is the bottleneck. After applying the relations (16) and (17) are obtained the capacity available in units at material level and for the entire system. The capacity for each material is presented in Table 12.

A1	1,760
A2	2,038
A3	2,409

Table 12

By summing all the values from the matrix Q_k it is obtained then the available capacity for the entire system, which in this case are 6207 units.

	W1	W2	W3	W4	W5	W6	W7	W8
Capacity Required	304,180	295,380	122,120	93,170	129,530	88,660	57,520	53,770
Capacity Available	360,000	360,000	120,000	120,000	120,000	120,000	120,000	120,000
Loading level	84%	82%	102%	78%	108%	74%	48%	45%

Table 13

Interpreting the results of this case, it can be said that the analyzed manufacturing system has an available capacity of 6207 units and cannot meet the demand of 6700 units. The bottleneck of the system is at the work center number 5, which has a loading

Step 4: Determining the loading level

The last step in the analysis is to assess the loading level for each work center. Basically this is obtained by dividing the required capacity by the available capacity, both of them expressed in time units. To obtain the indicator are used the relations (18) and (19):

$$Q_s(M_2T) = T_k - \text{the required capacity} \quad (18)$$

in time units to meet the demand level

$$K_i = \frac{tk_{1i}}{c_{1i}} - \text{the loading level} \quad (19)$$

The results are represented in Table 13:

level of 108%. The next bottleneck is the work center number 3, with a loading level of 102%. In order to meet the demand, the available capacity has to be risen with 9530 minutes.

5 Conclusions

To sum up, the presented model offers a new perspective in production capacity calculation. Highlighting for the last time in this paper, the ease and the novelty of the model is the consideration that a finished good product needs capacity not only from the resources where it is processed directly, but it needs capacity also from resources where its components are processed. In this way there is only one point of view and the calculus is dramatically reduced and the results are improved. By using the model, can be observed certain advantages even when it is applied in complex cases: the possibility

of determining the capacity available for a manufacturing system at material and resource level, the possibility of determining easily the loading level for each resource and it offers a structured way to approach the considered problematic. The difference between existing approaches and this model is the ability to go into a very detailed level, the material level. The purpose of it is to be used in middle and long term planning, by offering answers and great input to the investment process. The model is also very responsive towards customers demand, because based on its output can be established which quantities can be promised and which contracts can be taken. The model has the property of going in

two directions: testing if a certain demand can be fulfilled and saying how much can be produced in a certain period of time. Another important feature is that the whole calculus is based on the cycle time of each material which gives precision.

The model was thought to be implementable very easy. To sustain this idea it can be seen that the used inputs are classical data structure from any MRP system. The processing of the inputs is nothing else then operations with matrices and scalar, feature that gives simplicity and scalability.

As limitations, the model is not considering any existing inventory in the system and it considers only one alternative for the routing file. In some particular cases this can be a limitation. But considering the middle and long term planning the inventory are anyway not considered and more alternatives for the routing file can be simulated by modifying the matrix T.

As future development of this current state of the model, will be solved the inventory problem in the system and it will be also proposed a model to solve the alternative Routing file problem.

References:

- [1] Arnold, T. J. R., Chapman, S. N. and Clive, L. M. 2008. *Introduction to Materials Management*. 6th ed. Pearson Prentice Hall.
- [2] Bakke, N. A. and Hellberg, R. 1993. *The challenges of capacity planning*. International Journal of Production Economics, 30-31, 243-264.
- [3] Billington, P. J., McClain, J. O. and Thomas, L. J. 1983. *Mathematical programming approaches to capacity-constrained MRP systems*. Management Science, 29, 1126-1141.
- [4] Drift, J. H. M. 1993. *Architecture of a Factory Controller*. PhD Thesis, Technical University of Delft, Delft, The Netherlands.
- [5] Harris, B., Lewis, F. and Cook, D. J. 2002. *A matrix formulation for integrating assembly trees and manufacturing resource planning with capacity constraints*. Journal of Intelligent Manufacturing, 13, 239-252.
- [6] Na, H.-b., Lee, H.-G. and Park, J. 2008. *A New Approach for Finite Capacity Planning in MRP Environment*. Lean Business Systems and Beyond, 257, 21-27.
- [7] Nagendra, P.B., Das, S. K. 2001. *Finite capacity scheduling method for MRP with lot-size restriction*. International Journal of Production Research, 39, 1603-1623
- [8] Sum, C. C. and Hill, A. V. 1993. *A new framework for manufacturing planning and control systems*. Decision Sciences, 24, 739-760.
- [9] Taal, M. and Wortmann, J. C. 1997. *Integrating MRP and finite capacity planning*. Production Planning and Control, 8, 245-254.
- [10] Tardif, V., Spearman, M., Coullard, C. and Hopp, W. 1993. *A framework for a capacitated MRP*. Working Paper, Northwestern University.
- [11] Zandin, K. B. 2001. *Maynard's Industrial Engineering Handbook*. 5th ed. McGraw-Hill.

Creative Commons Attribution License 4.0 (Attribution 4.0 International, CC BY 4.0)

This article is published under the terms of the Creative Commons Attribution License 4.0

https://creativecommons.org/licenses/by/4.0/deed.en_US