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THE IMPACT OF THE COST OF UNUSED CAPACITY ON PRODUCTION PLANNING OF FLEXIBLE MANUFACTURING SYSTEMS

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Abstract

Capacity is one of the most important measures of resources used in production. The conventional capacity measures do not include the value of the equipment in the production system and so their application can lead to erroneous operations management decisions. A new measure, the '*cost of unused capacity*', is more frequently used to characterize resource usage. Flexible manufacturing systems (FMS), where the machining methods, machine tools, handling equipment, control systems and computer systems are used in an integrated way, become rather complex. Under these circumstances the process of production planning turns into a more complicated one, and as a consequence of the high value of the resources the drive for decreased cost of unused capacity is significant. A linear programming model was formulated with the aim of taking into consideration the cost of unused capacity. The model makes it possible to take into account the unused capacities of various machines in different degrees, while increasing the contribution at the same time. If the cost of unused capacity is considered in capacity planning, the idle time of valuable resources can be exploited more efficiently.

Keywords: cost of unused capacity, linear programming model, Flexible Manufacturing System.

1. Cost of Unused Capacity

Capacity is one of the most important measures of resources used in production. Its definition and analysis is therefore one of the key areas of production management. The use of conventional parameters often leads to wrong decisions. There are three aspects of the problem of conventional capacity measures: the absence of economic content, quantity based approach, and the unduly high emphasis laid on technical processes. If capacity measures could side step the problems discussed above, i.e. if they could include the value of resources, and could refer to the costs of unused capacity, then better decisions could be made in a number of cases. Changes in the nature of production, and the enhanced significance of auxiliary processes made calculations necessary for production and service systems where processes are difficult to quantify. The appearance of activity-based costing (ABC) solved precisely these problems, because the main goal of the method is to analyse and differentiate the overhead costs associated with capacity maintenance and operation and support processes. When using ABC for the determination of cost data, the results are also appropriate for performing capacity usage calculations.

The ABC calculation attempts to approximate an ideal situation where the overhead is incorporated in the product only to the extent it actually exploits its resources. In the past, due to the small ratio of overheads, it was sufficient to use a single cost driver for overhead allocation. The presently observed growth of the ratio of overheads makes it important to allocate them accurately to different products. Different products use resources to a different extent, therefore, several cost drivers are used. The ideal case would be to use a separate cost driver for every cost, but this is impossible to realize. Costs must be collected in cost centers, and a characteristic cost driver must be assigned to each cost group in the center. The ABC method works on the basis of this principle [3].

To perform a capacity calculation, we have to know the ratio of the costs of the machine, equipment, plant or division depending on, and independent of the output. These costs are closely related to the resource where they appear. The operated resources can be divided into groups on the basis whether they are provided according to their usage needs or in advance, without the prior knowledge of these needs [1]. There is no capacity problem associated with *resources provided on the basis of direct needs*, because these are provided on the basis of known or estimated needs. *Resources provided in advance* are those that are made available independent of direct needs. Even though needs are forecasted by different methods to some degree, still there is the constraint of availability prior to the time when the need actually appears. There are three typical groups of resources provided in advance. One of them is *investment*. The company invests in machines, equipment, or buildings that present costs to be paid in advance and that are expected to operate for quite a number of years. Another cost type is the *contract* costs. In this case, the company signs a contract for the future use of a service. The third and last typical example is that of *workforce*. This includes those employees who are paid a fixed wage.

The *cost of unused capacity* can be calculated when the fix cost of the resource, the actual resource usage and the effective capacity are known. The determination of the group of resources allocated in advance, the collection of their fixed costs, and the measurement of the actual capacity usage require the development of the management information system [2]. The analysis of the cost of unused capacity is based on the following simple formula (1):

$$\text{Activity Availability} = \text{Activity Usage} + \text{Unused Capacity}. \tag{1}$$

The cost of capacity is the entire cost paid beforehand to obtain the resource under consideration. This consists of the costs of capacity rightfully used in operation – also called exploited – and the cost of unnecessarily allocated, that is, unused capacity, as shown in *Fig. 1* [1], [2], [8]. The separation into two parts of capacity costs can be appropriately done by linear approximation. There also exist theoretical models for the description of capacity utilization costs in terms of a non-linear function, but they are seldom used in practice. Dividing the costs of availability of

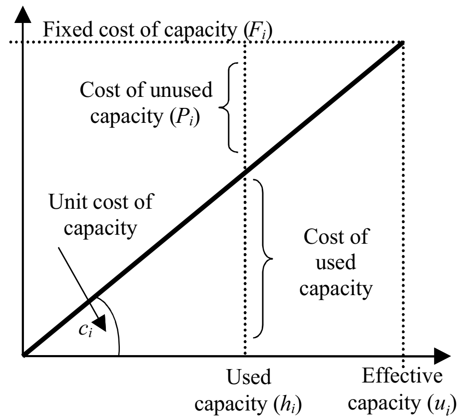

Fig. 1. Interpretation of the cost of unused capacity

the resource during a given period by the quantity of the resource available during the same period, we obtain the unit fix cost of the resource in question, which is just the slope of the linear function shown in *Fig. 1.* Knowing the quantity of the used resource and the unit cost it is easy to calculate the *cost of unused capacity* (2). If u_i is the capacity, h_i is the actual production, and F_i is the total fix cost of the resource, then the unused capacity is given, according to *Fig. 1*, as

$$P_i = F_i \left(1 - \frac{h_i}{u_i}\right). \tag{2}$$

2. Decisions in Flexible Manufacturing Systems (FMS)

This chapter examines the effect of production planning methods on the production planning of flexible manufacturing systems. In a complex flexible production system consisting of several machines and several products the production process is characterized by many parameters. As a result of planning the amount of products manufactured and the utilization of the machines has to be defined; it also has to be decided which manufacturing possibility is worth choosing from the available options. By comparing the calculated parameters it becomes possible to analyse the effect of the capacity indicator which has economic content. The significance of using the new capacity indicator in flexible manufacturing systems is that optimization can be carried out on several routes while taking into account the value of the machinery. The two fundamental goals of contributing as much to company contribution as possible and utilizing the machines as much as possible in the desired way, can be achieved on a complex system.

We present two models to prove our case. The aim of the first model is to create a product structure in manufacturing which chips in best to company contribution. The second model also takes the value of the machines and their under utilization into account in addition to the contribution realizable on the manufactured products. Therefore the first model is extended with a special function that takes into account the value of the machines. The use of the model is illustrated and analysed with the machines of a manufacturing plant.

2.1. Characteristics of Flexible Manufacturing Systems (a View of Cost Systems)

The increasing of the profit is an important goal of manufacturing companies; an effective way to achieve this is the rationalization of the production process by improving production planning. In a manufacturing plant several products often are manufactured simultaneously, which can be produced on the same assembly line due to the similarity of the ordered products. We require modern manufacturing systems to be flexible; manufacturing tools becoming universal is a key feature in achieving this. A primary aim of developing flexible production systems is the fast reaction to customer needs. If operations are performed by multifunctional, computer-controlled machines, usually connected to computer-controlled material-forwarding machines, then we have a flexible manufacturing system (FMS). Flexible manufacturing systems are an efficient and economical solution primarily in the case of products requiring different technologies and manufactured in medium numbers.If a product is manufactured in very large volume, the effective method is the use of specialized, high-productivity machines, whereas in the case of small volume, job-shop production is recommended.

The development of flexible manufacturing systems has been one of the most important developments of recent times in the field of industrial automation. Flexible manufacturing systems operated with proper manufacturing parameters and in a proper management environment are characterized by high flexibility, excellent utilization of machines and low work-in-process. The aim of developing FMS was to increase productivity, while flexibility had to be kept for quick response to customer needs. In the case of flexible manufacturing systems, like generally in the case of other modern tendencies, the most important aspects are quality, dependability, cost, and flexibility [6], [7].

Beside the above-mentioned goals, the effective management policy is also an important factor [11]. FMS demands an intelligent scheduling strategy to realize its potential advantages, that is, to increase productivity while retaining its flexibility at the same time. Various scheduling policies, heuristics and mixed integer linear programming models have been devised and researched by a number of experts recently [9].

Miltenbug and Krinsky defined flexibility in three different ways [10].

- Different kinds of products can be manufactured on one machine, and one product can be manufactured on different machines.

- When the production of a new product starts, the existing machines can be used in the existing manufacturing system.
- When the form of a product is changed, it can still be manufactured in the system.

Production using flexible manufacturing systems have several advantages. In one manufacturing period, several operations can be performed by the same tool set on different products. In this way it requires fewer specialized machines to complete the tasks. Manufacturing similar products does not require the use of separate workshops and a separate series of machines. Unusedness can be more easily avoided by using FMS. When starting new products, we can put them in our already existing manufacturing system. Flexible manufacturing systems can therefore provide a competitive advantage by their adaptability. When flexible manufacturing systems are used, efficient management policy becomes very important because such systems are not only more costly than traditional manufacturing systems but the managing production is also more complicated.

2.2. Concepts and Definitions

A flexible manufacturing system is a group of machines capable of completing one or more operations and usually connected to an automatic material forwarding system, all controlled by a central computer [4]. A flexible manufacturing system is capable of manufacturing various products. The products can be produced by using different machines. The *route* shows which machines the product goes through technologically during the production process. In a flexible manufacturing system the products can usually be produced on several different routes. The routes are specified by the technologists of the manufacturing system based on the characteristics of the necessary operations to be carried out on the products and the properties of the available machines. The technologist identifies the operations required by the product and matches the operations to the capabilities of the machines. The route therefore shows which machines and to what extent are needed for a product with its given manufacturing variation. We identify as many manufacturing routes by product as many manufacturing possibilities the product has. When two different manufacturing routes use the same machines for the same amount of time, the two routes will be the same and appear as one route in the model. If the time spent on the machines is different, they appear as different routes. It is not necessary to consider every manufacturing route in the model, only those which are found viable by the production manager. In this way certain routes can be ignored according to the production policy of the firm. For example, if we wish to use a machine that can produce several products to manufacture only one product because of production policy, we do not include those routes in the model which the management has excluded, even if the application of the machine would be possible technologically. In the manufacturing system in question, a total of P different products must be manufactured. The products are denoted by index p. The number of the routes of product p is R_p $(p = 1, \ldots, P)$. The routes are denoted by index r. The manufacturing system contains M machines, indicated by index m. The planned capacity of the machine is indicated by k_m $(m = 1, \ldots, M)$. In the illustration, the unit of measure of the planned capacity is minute. The planned capacity indicates the capacity that the machine can reach under ideal conditions [12]. The operation time shows how many minutes spends the given product on the applied machine using the given manufacturing route. The operation time of product p on route r using machine m is indicated by t_{prm} $(p = 1, \ldots, P;\ r = 1, \ldots, R_p;\ m = 1, \ldots, M)$. If a product needs a machine in several different stages of the manufacturing process, the operation time will be the total of the times spent in the individual stages. The operation time also includes the time necessary to change the tools and the pieces. However, these times are significantly less than the working time, therefore they can be ignored. The order means the product quantity to be manufactured in the given manufacturing system. The order of the product p is indicated by x_p $(p = 1, \ldots, P)$. The amount of product p manufactured on route r is indicated by x_{pr} $(p = 1, \ldots, P;\ r = 1, \ldots, R_p)$. The primary result of the models set up with different purposes is the product quantity to be manufactured, indicated by x_p.

The notations can be found in *Table 1*

Table 1. The notation used

x_p	– the amount of p manufactured in the given period $(p = 1, \ldots, P)$,
x_{pr}	– the amount of p manufactured on route r in the period $(p = 1, \ldots, P)$, $(r = 1, \ldots, R_p)$,
k_m	– the capacity of resource m available in the given period $(m = 1, \ldots, M)$,
t_{prm}	– the time necessary to manufacture product p on route r on machine M $(p = 1, \ldots, P)$, $(r = 1, \ldots, R_p)$, $(m = 1, \ldots, M)$,
u_p	– the maximum amount of product p that can be sold on the market $(p = 1, \ldots, P)$,
l_p	– the minimal amount of product p to be manufactured $(p = 1, \ldots, P)$,
f_p	– the contribution realizable by selling product p $(p = 1, \ldots, P)$,
c_m	– the unit cost of resource m $(m = 1, \ldots, M)$.

The sum of the orders manufactured on the various routes is the order of the product (3).

$$\sum_r x_{\mathrm{pr}} = x_p, \qquad p = 1, \ldots, P,\ \ r = 1, \ldots, R_p \tag{3}$$

The lower limit of the product is the minimal amount the market demands. This product quantity must be produced in any case. The minimal amount of the product to be manufactured can come, for example, from a valid contract with a customer, or the mother company may have already ordered a given quantity from one of its own plants for the next period. The minimal amount of the product to be manufactured (lower limit) is indicated by l_p $(p = 1, \ldots, P)$. The upper limit of the product is the maximum amount that can be sold on the market and is indicated by u_p $(p = 1, \ldots, P)$.

2.3. Production Planning Models for Flexible Manufacturing Systems

The production planning of flexible manufacturing systems is made complex by the far larger number of manufacturing possibilities than in traditional systems. Several machines are capable of manufacturing the product and the machines are versatile, that is capable of performing several operations. In planning a goal can be for example the maximization of realizable contribution or the reduction of the machines unusedness. In flexible manufacturing systems there are usually CNC machines of different types, life spans, and levels of technological development. The differences are mostly in the value of the machines and in the support activities therefore fix costs are different [5]. In addition to the usual goals of management, a new goal emerged – the maximization of the cost of unused capacity.

Before setting up the model, the following steps are necessary:

- identification of the products to be manufactured
- identification of the machines and routes that can be applied in the manufacturing process
- identification of routes consistent with production policy
- definition of operation times valid for the machines used and products to be manufactured
- finding the planning objectives

Table 2 illustrates in a general layout the data that characterize the planning of a manufacturing system. The columns of the resource-product (machine-product) table show the resources, the rows show the products and routes while the cells show the operation times.

The following chapters present the traditional production planning model and its integrated, modified versions.

2.3.1. Increasing Contribution

In the case of the first production planning model the goal is to make a production plan that maximizes contribution while fulfilling manufacturing and market requirements. The objective function includes the contribution; therefore the unit of measure of the target equation is a currency, in this case thousand dollars.

$$z = \text{Max}\left[\sum_p f_p \sum_r x_{pr}\right] \tag{4a}$$

subject to

Table 2. Resource-product table

		Machine-1	Machine-2	…	Machine-m
Product-1	r_{11}	t_{111}	t_{112}	…	t_{11M}
	r_{12}	t_{121}	t_{122}		t_{12M}
	…				
	r_{1R1}	t_{1R11}	t_{1R12}		t_{1R1M}
Product-2	r_{21}	t_{211}	t_{212}	…	t_{21M}
	r_{21}	t_{221}	t_{222}		t_{22M}
	…				
	r_{2R2}	t_{2R21}	t_{2R22}		t_{2R2M}
…		…	…		…
Product-P	r_{p1}	t_{P11}	t_{P12}	…	t_{P1M}
	r_{p2}	t_{P21}	t_{P22}		t_{P2M}
	…				
	r_{pRP}	t_{PRP1}	t_{PRP2}		t_{PRPM}

$$\sum_p \sum_r t_{prm} x_{pr} \le k_m, \qquad p = 1, \dots, P, \quad r = 1, \dots, R_p, \quad m = 1, \dots, M \tag{4b}$$

$$l_p \le x_p \le u_p, \qquad p = 1, \dots, P, \tag{4c}$$

$$\sum_r x_{pr} = x_p, \qquad p = 1, \dots, P, \quad r = 1, \dots, R_p \tag{4d}$$

In the objective function (4a) there is contribution. In this model we try to find the maximum of the objective function. The first condition (4b) represents the limit stemming from the capacity of the machines. The second condition (4c) limits the minimal amount to be produced and the maximum marketable amount. The third condition (4d) defines the amount to be manufactured by product category, by adding up the amounts manufactured on the individual routes.

The result of the model is a product mix, which maximizes the contribution. The machines, however, represent different values and manufacturing characteristics. The result of the model does not take into account the fixed costs of the machines the products are manufactured on.

2.3.2. Increasing Contribution Considering the Cost of Unused Capacity

The aim of the second model is to create a production plan that not only helps to maximize the contribution but also helps to minimize the cost of unused capacity. The unit of the elements in the objective function is a currency, in this case thousand dollars.

$$z = \text{Max}\left[\sum_p f_p \sum_r x_{pr} + \sum_m c_m\left(k_m - \sum_p \sum_r t_{prm} x_{pr}\right)\right] \qquad \text{(5a)}$$

subject to

$$\sum_p \sum_r t_{prm} x_{pr} \le k_m, \quad p = 1, \dots, P, \;\; r = 1, \dots, R_p, \;\; m = 1, \dots, M \qquad \text{(5b)}$$

$$l_p \le x_p \le u_p, \qquad p = 1, \dots, P, \qquad \text{(5c)}$$

$$\sum_r x_{pr} = x_p, \qquad p = 1, \dots, P, \;\; r = 1, \dots, R_p \qquad \text{(5d)}$$

In objective function (5a) there is the contribution margin and the cost of unused capacity. With this model we try to maximize the value of the objective function. The conditions are the same as those of the previous models (5b)–(5d).

The result of the model is a production plan that not only yields company contribution but also influences the utilization of resources. The model takes into account the fact that contribution margin is different on different products and also where unused capacity occurs. Therefore, the aim is not only to increase contribution but also to manufacture those products that can be produced on different machines on such routes that do not use expensive resources. The rational use of expensive machinery is important because this way valuable resources are freed. If we can use less of high-value resources without significantly changing the product structure, the unused resources can be used freely, providing the management with new opportunities.

2.3.3. Illustration of the Application of the Model

We will illustrate the use of the capacity planning model presented earlier with an industry example. The data and the characteristics of the production environment are from a plant producing hydraulic and pneumatic parts. The products are manufactured on CNC machines. The machines are indicated by machine-*n* and products are indicated by product-*n*. The manufacturing system produces seven different products. In the production process five CNC machines can be used. The machines are versatile and can perform many operations necessary for production, and the products can be manufactured on several routes. In specifying the production routes, we can use the capacity of the machines flexibly.

The columns of the resource-product table contain the machines, and the rows contain the products and the product routes (*Table 3*). For the sake of data security we have changed and simplified the data used for the calculation. The production manager chooses the production routes of the products used in the manufacturing process based on the technology, his own experience, and the production policy. The routes chosen by the production manager can be found in the table below, broken down to products. For example product-1 can be manufactured on two routes. The first route of product-1 (r_{11}) means that manufacturing the product requires machine-1 and machine-4. The second route of the product (r_{12}) means that the product can be manufactured using machine-3 only. The cells of the resource-product table contain the operation times of the individual products, that is, the time the machines spend carrying out the given operation on the individual products. The production manager specifies the operation time of the products. For example, product-2 can be manufactured completely on the third machine in 1.6 minutes (1 minute 36 seconds).

Table 3. Routed resource-product table

Product	Route	Machine-1	Machine-2	Machine-3	Machine-4	Machine-5
Product-1	1	1.2	0	0	1.6	0
	2	0	0	1.2	0	0
Product-2	4	1.6	0	0	1.65	0
	5	0	0	1.6	0	0
Product-3	7	0	1.238	0.965	0	0
Product-4	10	0	0	0	0	1.4
	11	0	0	0	0.9	0.4
Product-5	13	0	0	0	0	1.2
	14	0	0	0	1.1	0.4
Product-6	16	1.73	0	1.3	0	0
Product-7	19	1.36	0	1.1	0	0

In order to apply the model the effective capacity of the machines has to be specified. The unit of capacity will be minute in this case. The test period of the model is one month, therefore every capacity figure and demand has to be given for one month. Each machine works in two shifts on weekdays. At weekends each machine works in one shift except machine-5. The capacity of the machines is 480 minutes per shift. The capacity (k_m) of the machines can be found in the table below (*Table 4*).

The lower and upper market limits of the products indicate the minimum amount to be manufactured and the maximum amount that can be sold. The system produces seven products, so seven lower and upper limits have to be specified. The lower market limits of the products are defined by the parts orders sent from the main headquarters of the company. The lower and upper limits of the products can be found in *Table 5*. In the case of product-1 for example, the ordered amount (therefore the minimal amount to be produced) is 500, and the maximum marketable amount is 1500. The upper market limits can be calculated based on various business policy, storage, market analysis, and marketing considerations.

Table 4. Machine-product table

Machines	Capacity [min]
Machine-1	25000
Machine-2	25000
Machine-3	25000
Machine-4	25000
Machine-5	21100

Table 5. Market limits

Lower limit	Upper limit	
Product-1	500	1500
Product-2	600	2200
Product-3	8000	30000
Product-4	1000	4000
Product-5	1000	4000
Product-6	1100	4000
Product-7	800	1310

We have solved the large linear programming tasks that were required by the models with the LINGO mathematical program. For the sake of creating the algorithms and because of the properties of LINGO technical changes had to be made in specifying the LP tasks because the number of the routes of the products had to be the same. To fulfil this condition the $R_{\max}$ variable had to be introduced, which is the number of routes the product with the most routes has (6). In this case $R_{\max} = 2$.

$$R_{\max} = \text{Max}\,(R_p), \qquad p = 1, \ldots, 7 \tag{6}$$

Every product has $R_{\max}$ routes. In the case of products that originally had fewer routes, the operation times and amount of products to be manufactured are zero on the other routes, therefore the LP task has to be supplemented by the following condition (7).

$$x_{pr} = 0$$

if

$$\sum_m t_{prm} = 0, \qquad p = 1, \ldots, P, \;\; r = 1, \ldots, R_{\text{MAX}}, \;\; m = 1, \ldots, M. \tag{7}$$

The first model strives to maximize contribution. The solution provides the ordered amounts of the individual routes, that is, how many of the products have to be manufactured on the given route in the given period (1 month).

In the LP task of the second model, in addition to increasing the contribution, the unused capacities are weighted by the fixed cost of the machines. We aim at creating a product structure that uses less of our machines with high fixed costs. We maximize the cost of unused capacity. The weight numbers indicate the cost of unused capacity for unit capacity, and can be found in *Table 6*.

Table 6. Unit cost of resources

Machines	The cost of unused capacity [1000 dollar]
Machine-1	2
Machine-2	1
Machine-3	1
Machine-4	2
Machine-5	1

In the objective function the individual variables have to be multiplied by the degree of unused capacity. Unused capacity is the difference between the capacity and the load (used capacity) of the first machine. The limits and conditions of the LP task are identical with those of the previous model. The following contribution margin has to be realized on the products (*Table 7*).

Table 7. The unit contribution that can be realized on the products

Products	Unit contribution [1000 dollar]
Product-1	10
Product-2	5
Product-3	15
Product-4	5
Product-5	5
Product-6	10
Product-7	10

The optimal solutions of the LP tasks composed with the help of the models, the summarized orders can be found in *Table 8*.

The results can be analysed through the tables and graphs containing the solutions (*Table 8*, *9*, *Fig. 2*). From the results of the first task it can be seen that in an optimal scenario we have to manufacture as much as possible of product-1, product-2, product-4, product-5 and product-7, while the ordered amount of product-3 and

Table 8. Summarized results

Product	Route	Model 1		Model 2	
		Order	Total	Order	Total
Product-1	1 2	1500 0	1500	1500 0	1500
Product-2	1 2	2200 0	2200	600 0	600
Product-3	1	20193	20193	20193	20193
Product-4	1 2	0 4000	4000	4000 0	4000
Product-5	1 2	4000 0	4000	4000 0	4000
Product-6	1	3132	3132	3132	3132
Product-7	1	1310	1310	1310	1310

product-6 will be between the lower and upper market limits. By introducing the cost of unused capacity the product structure does not change significantly. The only change occurs in the demand of product-2. While the first model recommends producing the maximum amount of product-2 (2200), the second model recommends that only the minimal amount (600) should be manufactured. The minimal change in the product structure leads to a slight change in the contribution. Compared to the contribution of the first model the contribution of the second model is slightly lower but the utilization of the machines changes significantly.

With the first model contribution is maximized. The application of the first model yielded the following results: the resources machine-2 and machine-3 are fully used, while resources machine-1, machine-4 and machine-5 are not fully used. The amounts of the products manufactured reach the upper limit with the exception of product-3 and product-4. The contribution of product-3 is high, while the contribution of product-2, product-4 and product-5 is low. In the objective function of the model we have maximized the contribution. The largest possible amount the production possibilities allowe has to be manufactured of product-3. The amount to be manufactured does not reach the upper market limit but only machine-2 and machine-3 can manufacture product-3. The two resources are fully exploited. The situation is similar in the case of product-6. The contribution is high but it still does not reach the upper market limit. In this case it is also the manufacturing possibilities which are responsible for this. Product-6 can only be manufactured on machine-1 and machine-3, but machine-3 is a fully exploited bottleneck, therefore product-6 cannot be manufactured in the upper limit amount, either. The above mentioned outcome is the result of the complexity of the system.

Beside contribution, the second model also takes into account unused capacity. This model uses more data than the previous model; unit resource costs are also taken into account. The unit resource costs of machine-1 and machine-4 are double of the unit resource cost of other resources. The aim is to increase unusedness on these machines at the expense of other machines. Using the model expanded by the capacity indicator with economic content our goal can be achieved. The results proved our theory. Machine-2 and machine-3 were already fully exploited in the production plan of the first model, therefore the load of machine-5 can be increased. The unusedness of the machines is illustrated by *Fig. 2*. At the expense of machine-5, the unusedness of the high-value machine-2 and machine-3 increases.

Table 9. Unused capacities of machines

	LP task 1	LP task 2
Machine-1	12480	15040
Machine-2	0	0
Machine-3	0	0
Machine-4	15370	21610
Machine-5	14700	10700

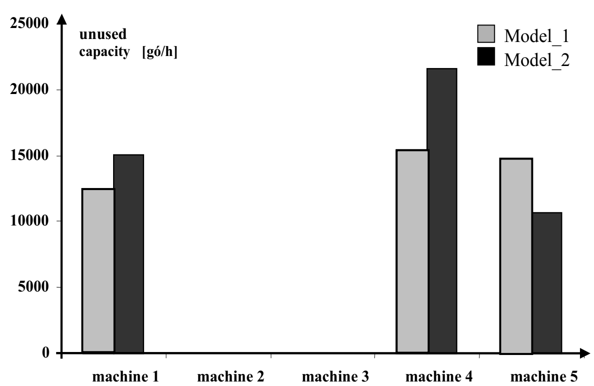

Fig. 2. The unusedness of machines

The calculations justify our assumptions. With a minimal change in the product structure and contribution, a significant amount of capacity is freed on the high-value resources machine-1 and machine-4. With the resources freed up, we do not have to bear the costs of renting, or if we own these resources, we can sell them. Assuming that the value of the machines correlate with the number of operations they can perform, they can be more easily assigned to other outsourced tasks.

The complexity of flexible manufacturing systems stem from the large number of operations they can perform and the large number of operations they have to perform on the products. Such complex and high-value systems also often have unused capacities. The part of sunk cost can be attributed to unused resources. That is why managers strive to use valuable resources as effectively as possible. If resources of higher value are less used while keeping the same product structure, they are freed and can be sold or rented out. It would be a lost opportunity if we did not exploit the concept of rationalizing unused capacities, therefore we try to maximize the cost of unused capacity. This is also true for the valuable machinery found in flexible manufacturing systems. The production management has to strive to use high-value machinery as rationally as possible. The introduction of the cost of unused capacity and its maximization is a good way of utilizing unused capacity and taking into account the values of the machines as well.

3. Conclusion

We have formulated an LP model with the aim of rationalizing unused capacity, using the capacity analysis principle (based on the resource-product database) of flexible manufacturing systems. The model presented made it possible to take into account the unused capacities of different machines in different degrees because the cost of unused capacity was introduced. In addition to maximizing contribution, the model also considered the cost of unused capacity of the individual resources. It can be seen that taking into account more aspects, different results will be achieved. With the expansion of the model the results of capacity analysis are in harmony with the more sophisticated system of aspects. The expansion of the model led to a new model where the goal of increasing contribution was supplemented by the reasonable utilization of unused capacities.

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