Earning Power Modelling for Manufacturing Operation

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Abstract: - One of the most important criteria to consider while analysing the MTO company's ability to make a profit in a competitive market is earning power. Specifically, this is defined by the Earning Power criterion. This means that the Earning Power modelling is a solid strategy for selecting and assessing which orders will bring profit to companies. As a result, a company manager must provide a model that can interact with the economic environment to make an offer and a price quotation to ensure the competitiveness of the company. In this article, we analyse this criterion for the processing operation.

Key-Words: - Control of manufacturing system, Order level of manufacturing system, Earning power

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1 Introduction

The criterion considered the most important when analysing the profit capacity of an MTO company, i.e., to be competitive in one segment of the market, this criterion it is called earning power, EP.

EP modelling is a solid strategy when selecting orders that bring profit to companies. Based on an EP determined for each order, one order can be accepted or rejected, [1].

Thus, there are going to be accepted just those orders that can bring significant profit to the company and increase market shares.

A selection takes place for each job, i.e. only the jobs that can have a favorable economical EP are kept, and the other ones are outsourced to some other processing companies, [2].

Regarding operations, optimal parameters for the processing system are determined depending on the maximum EP value. In this way, it can be achieved an integrated control of the manufacturing process.

By "Method for control of the make-to-order manufacturing system on the base of earning power assessment" the manager has the opportunity to organize all received orders in order to increase company competitiveness.

Managers can interact with the economic environment to make an offer and a price quotation so that the company is competitive, [3], [4].

The EP evaluation is made at the level of processing operations, job, and ultimately the order level.

2 Scheme of the Job Shop Manufacturing

In order to make feasible decisions on the arriving orders, all affected parties of the supply chain, which their decisions and performances have significant effects on prices and delivery times of the new arriving orders are considered in the structure. These parties consist of customers, the MTO company, suppliers, and subcontractors.

- *Order breakdown (jobs, operations)*

The order is a group of products structured by the customer for a product it solicits to manufacture, for example, 15 hydraulic cylinders. During order entry, all product components are analyzed. If some product components are related from a technological and commercial point of view forming a family, they will be manufactured simultaneously to several workstations, *M*. As a result, the number of copies that are released into production will increase and workstation adjustment suffers only minor changes when moving from one product to another in the same family. Each family is launched as a job in manufacturing. The operation is an operation cycle of a workstation when having a job.

For the 15 hydraulic cylinders, by the job we understand the execution of cylinder rod, piston, body, bearing, etc. to implement one of these jobs needed more operations such as cutting, drilling, boring, etc.

- *Manufacturing system configuration*

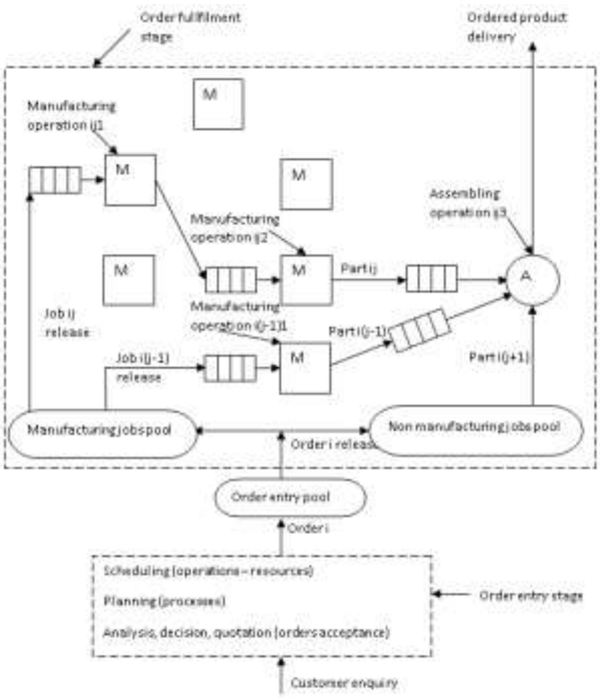

Fig. 1: Scheme of the job shop manufacturing

Each order has a manufacturing system specific, including all the workstations covered by the order.
Figure 1 presents the MTO manufacturing system configuration. Out of order entry pool, the *i* order is launched. This order is formed from manufacturing jobs, deposited in the manufacturing jobs pool, and non-manufacturing jobs, deposited in the non-manufacturing jobs pool. Manufacturing jobs are released into production from the manufacturing jobs pool to different workstations *M* (job *ij*, job *i(j-1)*). Supposed that *ij* job includes *ij1*, *ij2*, and *ij3* operations. For an *ij1* operation, the *ij* job will wait for its workstation *M*. After processing this *M* workstation goes ij_2 operation to another *M* workstation. *ij*3 operation is a *ij, i(j-1)* parts assembling operation and *i(j+1)* non-manufacturing part on *A* workstation. The *i(j-1)* job is made from the *i(j-1)1* operation performed on the *M* workstation. After processing, part *i(j-1)* will result. We supposed that a non-manufacturing jobs pool is a supply pool of parts unsuitable to be processed, as an example, the *i(j+1)* part.

- *Operation, job, and order characterization (features and parameters).*

The operation, job, and order have six specific features: earning power, cost, time, price, asset, and the number of samples.
At the operation level by *EP*, we understand the relation between the difference of price operation and cost of operation and product from product asset and operation time (relation 1). By operation asset, it is understood the capital invested in workstations necessary to process orders (machine tools, tools, devices, workers, buildings, land, etc).
At job level *EP* we understand the relation between price difference and cost for job processing and the number of products from job asset and operation time to accomplish the job. The costs necessary to accomplish the job are the sum of costs for the transactions that make the job. Thus, the cost for the *ij* job from Figure 1 is the sum of costs for *ij1, ij2,* and *ij3* operations.
At the order level, *EP* is the ratio between price difference and order cost and product from order asset and order time. Necessary costs to achieve the order are the sum of costs for carrying out jobs that form orders. Thus, the cost for order *i* from Figure 1 is the sum of costs *ij* jobs, *j=1…J*.
Operation, job, and order are characterized by the following parameters: part parameters (part length, part width, etc), process parameters (cutting speed *v*, advance *s*, cutting depth *t*), tooling parameters (tool material, devices, etc), and workstation parameters.

- *Manufacturing system integrated control*

In practice, decisions on the acceptance of orders and production planning are often considered separately. Sales Department is responsible for accepting orders, while the production department is occupied with production planning for the implementation of orders accepted. The sales department will tend to accept all orders in whatever capacity is available for the department because this department's target is turnover. The production department will try to maximize the use of workstations and minimize the number of late deliveries. Order acceptance decisions are often made without involving the production department or incomplete information based on available production capacity.
The method for integrated control of the job shop type manufacturing system proposed in this paper aims to facilitate the connection between the two departments and to achieve integrated control of the job shop type manufacturing system based on earning power evaluation.

3 Operation Modelling

From the analysis of the appropriate literature we can provide the following observations:

- Generally, cost-estimating approaches can be broadly classified as qualitative estimation methods (intuitive or analogical methods) and quantitative estimation methods (parametric or analytical methods).

- Method implementation consists of either the application of an algorithm or the development of a knowledge-based estimation system.
- Algorithm or knowledge-based systems are designed so that the field in which they can be used for cost estimation is either a class of processes or a class of geometrical shapes of product, but never a workstation (or group of workstations). It comes often in the situation to use several different models for calculating cost activity which a workstation makes on a semi-manufactured. Also frequently we can have a case when none of the models take into consideration the specific behaviour of that workstation. On the other hand, this field is extended to the level of processing operations of one part or of any stage of that operation, but never the entire batch processing. Therefore, the total manufacturing cost is estimated by adding the machining cost, material cost, set-up, and changeover costs, calculated for one part.
- The databases on which to build models or knowledge-based systems are collected from machining handbooks, from experts, or records about previously manufactured products. This last source contains only global data because currently there's no concern to record specific data.
- Finally, after being built, models or knowledge-based systems are not updated, not even periodically. Therefore, the evolution of workstation behaviour is not considered and recent experience is not used.

a) Model variables

The criterion that we consider to be the most important in analysing the MTO company ability to make a profit, that is, to be competitive in a market is the earning power, EP criterion. EP modelling is a solid strategy when selecting those orders that bring profit to companies. Thus, the company manager provides a model that can interact with the economic environment to make an offer and a price quotation so that the company is competitive.

We analyse this criterion for processing operation, job, and finally, order.

In the processing operation, EP control can be obtained by changing the cutting regime parameters, i.e. cutting depth, feed rate, and cutting speed. The size of the feed rate is used to control roughness. Cutting depth of size cannot be changed only if it makes multiple passes through the judicious addition of processing division. We'll consider that the processing addition must be removed in a single pass. In this situation, one cannot change the cutting depth, because its size is dictated by the size of the process addition, which was established according to the method of obtaining the workpiece. Following this reason, the only parameter that can control the workstation is the cutting speed *v*.

Therefore, operation modelling has as input: price, process parameters, part features, tooling, job features, and workstation features, and as output, all service features: operation earning power (*EP*), operation cost (*c*), and operation processing time (*t*). The price for processing operation *P* is the model parameter.

Determining the function between features and operation parameters, job or order is the operating model for job or order.

Modelling technique used to evaluate earning power is the analytical technique.

We consider that we have to manufacture the part from Figure 2 and the manager must decide whether to accept this order. The technological process needed to process the part consists of the following operations: turning, drilling, and welding.

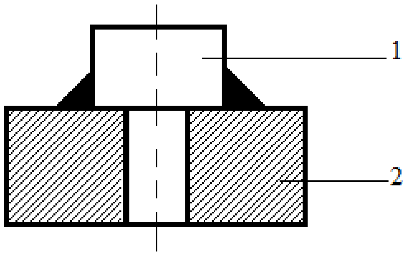

Fig. 2: Manufacturing part 1- rod, 2- plate

Taking the case of a cutting process for an order *i* with *j* jobs and *k* operations we can define EP_{ijk} as:

$$EP_{ijk} = \frac{P_{ijk} - c_{ijk}\left(p_{jkn}\right)}{A_{ijk} \cdot t_{ijk}\left(p_{jkn}\right)} \quad \left[\frac{Euro}{Euro \cdot min}\right] \tag{1}$$

where: P_{ijk} is the minimum market price for operation *k* and job *j* in order *i* [Euro];

The price for operation P_{ijk} can be calculated with the following relation:

$$P_{ijk} = (1+\alpha) \cdot c_{ijk}$$

(2)

where: α – is the share of profit which we seek to obtain and regulated during negotiations. α is it constant for a certain order, for all operations and jobs which form the order; $c_{ijk}(p_{jkn})$ expenses necessary to achieve job *j* depending on parameters *n* for operation *i* [Euro]; A_{ijk} – is the operation asset *k* from job *j* in order *i* [Euro]; $t_{ijk}(p_{jkn})$ – time for workstation's process when making the operation *k* from job *j* [min].

The operation of turning will be analytically modelled based on the fourth relation, [1]:

$$c_{ijk} = C_{amijk} + C_{pijk} + c \cdot S_{ijk} \cdot N_{ijk} \tag{3}$$

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where: C_{amijk} is cost for auxiliary labour for carrying out the operation *k* from job *j* [Euro]:

$$C_{am\,ijk} = \frac{C_{m\,ijk} \cdot N_{ijk}}{4} \quad (4)$$

C_{mijk} - cost for labour of operation *k* from job *j*.

For the turning operation that is part of job 1,
C_{mijk} = 2.75 Euro.

N_{ijk} - number of pieces to be processed;

C_{pijk} - cost to prepare the operation *k* from job *j* [Euro];

For turning operation, C_{pijk} = 2.7 Euro.

$$c = \frac{c_\tau}{10vs} + \frac{\tau_{sr}c_\tau + c_s}{10Tvs} + \frac{t \cdot c_{mat}}{10} + \frac{K_e c_e}{10000vs} + \frac{C_M}{10K_M} v^{\alpha-1} s^{\beta-1} t^{\gamma}$$

[Euro/cm²], (5)

where: c_τ is the cost for one minute to use the job place; 0.45 Euro/min

τ_{sr} – time to change and sharpen the tool [min]; 10 min

c_s – tool cost between two consecutive re-sharpening processes; 20 Euro

c_{mat} – cost to remove one cm^3 of additional material; 0.008/cm^3

c_e – cost for one KWh of electric power; 0.23 Euro/KWh

K_e – energy coefficient [Wh/min]; 15 Wh/min

K_M – machine tool coefficient; $5.4 \cdot 10^6$

C_M – the cost of machine tool [Euro]; 100000 Euro

v – cutting speed [m/min];

s – feed rate [mm/rev]; 0.15 mm/rev

t – cutting depth[mm]; 3mm

$\alpha = \beta = \gamma = 0.5$;

T – tool durability

$$T = \left[\frac{470}{v}\right]^{2.5} \text{[min]}; \quad (6)$$

S_{ijk} – processed surface [cm^2]; 281.34 cm^2.

For the cutting process, loading time modelling for a workstation to perform operation *k* of job *j* of order *i* is:

$$t_{ijk} = t_{pijk} + t_{aijk} \cdot N_{ijk} + \tau \cdot S_{ijk} \cdot N_{ijk} \quad \text{[min]}$$

(7)

where: t_{pijk} – time to prepare the operation; 60 min

t_{aikj} – operation auxiliary time; 4.4 min

$$t_{a\,ijk} = 0{,}2 \cdot t_{u\,ijk} \text{ [min]} \quad (8)$$

t_{uijk} - unitary time to perform the operation; 22 min

τ - the specific time necessary to remove one *cm²* of material

$$\tau = \frac{T + \tau_{sr}}{10 \cdot T \cdot v \cdot s} \text{ [min/cm}^2\text{]} \quad (9)$$

Figure 3 presents the variation of the Earning Power depending on cutting speed. It can be noted that depending on the number of pieces of processed product *N*, choosing the optimal cutting speed can be obtained a maximum EP, i.e. can realize optimal control of the turning operation.

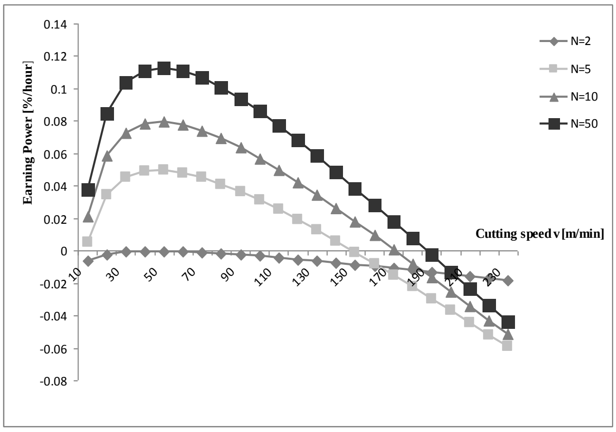

Fig. 3: The variation of the Earning Power depending on cutting speed

4 Conclusion

When graphically representing the EP of turning operation according to cutting speed (see Table 1), we showcase that there is a maximum value for EP for a specific optimal value of cutting speed (Figure 2). For example, for a number of pieces *N=2*, a maximum value of EP is -0.0002898 %/hour when *v=40* m/min*; N = 5*, a maximum value of *EP=0.0496663* %/hour for a cutting speed *v=50* m/min; for *N=10*, a maximum value of *EP* = 0.079419 %/hour for *v=50* m/min and when *N=50*, a maximum value of *EP*=0.112742971 %/hour for v= 50m/min.

In conclusion, based on our study, it is worth noticing that depending on the number of pieces of processed product *N*, choosing the optimal cutting speed can be obtained a maximum EP. This means that maximum EP may perform an important role to realize the optimal control of the turning operation.

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